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MUON SPIN RELAXATION MEASUREMENTS OF SPIN-CORRELATION DECAY

IN SPIN-GLASS AgMn

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ABSTRACT

The field (H) dependence of the muon longitudinal spin-lattice relaxation rate well below the spin-glass temperature in AgMn is found to obey an algebraic form given by $(H)^{\nu-1}$, with $\nu = 0.54 \pm 0.05$. This suggests that Mn spin correlations decay with time as $t^{-\nu}$, in agreement with mean field theories of spin-glass dynamics which yield $\nu \lesssim 0.5$. Near the glass temperature the agreement between the data and theory is not as good.

There is considerable experimental and theoretical interest in the effects of random exchange interactions upon the static and dynamic properties of magnetic systems. In simple models of ordered magnetic systems, the spin autocorrelation function decays exponentially in time

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outside of the critical region.[1] Recently, Sompolinsky and Zippelius have reported[2] a mean-field calculation for a disordered (spin-glass) system in which the correlations decay algebraically in time as $t^{-\nu}$ for $\nu < 0.5$, in agreement with Monte-Carlo simulations of Ising spin glasses.[3] It is therefore of considerable interest to try to distinguish experimentally the effects of disorder upon spin dynamics.

This paper reports measurements, carried out at the Stopped Muon Channel of LAMPF, of the field dependence of the positive muon longitudinal spin-lattice relaxation rate in the spin-glass system AgMn. From these data the local-field correlation function is deduced. $Ag_{1-x}Mn_x$ alloys were studied with x = 1.6, 3, and 6 at. %, at temperatures $0.3 < T/T_g < 0.9$, where T_g is the glass temperature. Data were taken in applied fields ($H_\parallel$) between 0.15 kOe and 5.0 kOe on samples that were prepared and characterized as described in Ref. 4.

In obtaining the μ^+ spin-lattice relaxation rates, the experimental relaxation functions[4] $G_\parallel(t)$ were analyzed in the time regime $t \gtrsim 1/a_o$, where a_o/γ_μ is the width of the local dipolar field distribution (γ_μ is the muon gyromagnetic ratio). For rapid fluctuations of a random local field, one expects[4] $G_\parallel(t) \propto \exp[-(\lambda_\parallel t)^{1/2}]$. In fact, this root-exponential form was found to give better fits to the experimental $G_\parallel(t)$ than did a pure exponential form. Furthermore, expected scaling laws[5] of the form $\lambda_\parallel = x^2 f(T/T_g, H/T_g)/Tg$, where f(u,v) is a dimensionless function and H is an effective field (see below), were found to be better obeyed when the data were analyzed using the root-exponential form.

In addition to $H_\parallel$, the local dipolar fields contribute to the total field seen by the muon. When averaged over all μ^+ sites, the local field is Lorentzian[6] with a width $\Lambda = a_o/\gamma_\mu$ which is known[4] from zero-field μSR measurements ($\Delta \approx 230$ Oe for AgMn (1.6 at. %.) In order to approximate roughly the effects of Δ, we take the effective field H at the muon site to be $\sqrt{H_\parallel^2 + \Delta^2}$. We note that the measured Δ depends upon temperature.[4]

Figure 1 shows scaled isotherms $\lambda_\parallel(H)$ for a number of temperatures below T_g. Scaling behavior is quite well obeyed. These data were fit to two functional forms: a Lorentzian distribution (corresponding to an exponential autocorrelation function) and a power law, $\lambda_\parallel \propto (H)^{\nu-1}$. For each temperature the power law fit gave a significantly smaller value of reduced χ^2 than the Lorentzian form, as seen in Table I. The data for $0.3 \lesssim T/T_g \lesssim 0.7$ show a nearly temperature-independent value for ν: $\bar{\nu} = 0.54 \pm .05$. At $T \approx 0.9\ T_g$ we find a smaller value, $\nu = 0.24 \pm 0.02$.

On very general grounds[7] it can be shown that $\lambda_\parallel \propto J(\omega_\mu)$, where $J(\omega_\mu)$ is the noise power at the muon Larmor precession frequency ω_μ. Thus, measurement of the field dependence of $\lambda_\parallel(H)$ yields the functional form of $J(\omega_\mu)$, if the applied field does not significantly change $J(\omega_\mu)$.

We now address the question of the effect of $H_\parallel$ on $J(\omega_\mu)$. Zero-field NMR results[8] of Alloul <u>et al</u> in spin-glass <u>Cu</u>Mn are consistent with

$$1/T_2 \propto (\omega_{hf})^2\ J(\omega_{hf}) \propto \omega_{hf}^{\ \nu+1}, \tag{2}$$

where the last proportionality follows from the assumed form $J(\omega_{hf}) \propto \omega_{hf}^{\ \nu-1}$. Here ω_{hf} is the hyperfine field seen at two near-neighbor ^{63}Cu sites. A power law fit to these data yields $\nu = 0.4 \pm 0.2$. Although the NMR results are only for two local field values, they, together with our μSR data, are consistent with a field-independent $J(\omega)$, for $H_\parallel \lesssim 5$ kOe and $T/T_g \lesssim 0.9$. We note that muon data reported earlier[4] at $T \approx T_g$ show a relaxation rate inversely proportional to $H_{\parallel}$, yielding $\nu \approx 0$. As shown in a companion paper,[9] however, zero-field neutron scattering data from CuMn at $T/T_g = 1.1$ are consistent with the μSR results at $T/T_g \approx 0.9$, i.e., $\nu \approx 0.24$. These facts indicate that applied fields $\lesssim$ 5 kOe greatly effect the spin dynamics at $T \approx T_g$, but not at temperatures just below T_g. Thus the μSR data at the glass temperature cannot be compared either with the neutron scattering results or with zero-field dynamical theories.

The Fourier transform of $J(\omega_\mu) \propto \omega_\mu^{\nu-1}$ yields an algebraic decay of the local-field correlation function S(t): $S(t) \propto t^{-\nu}$. As stated above, we find $\nu = 0.54 \pm 0.05$ for $0.3 \lesssim T/T_g < 0.7$ and $\nu = 0.24 \pm 0.02$ for $T/T_g \approx 0.9$. In Ref. 9, neutron scattering data[10] are shown to be consistent with these results. The calculations of Sompolinsky and Zippelius[2] give the same functional form for the correlation function, with $\nu \sim 0.5$ at $T = T_g$ and $\nu \lesssim 0.5$ at $T << T_g$. Our data are thus quantitatively consistent with these calculations except for values of T very near T_g, where a value of ν significantly smaller than 0.5 is measured.

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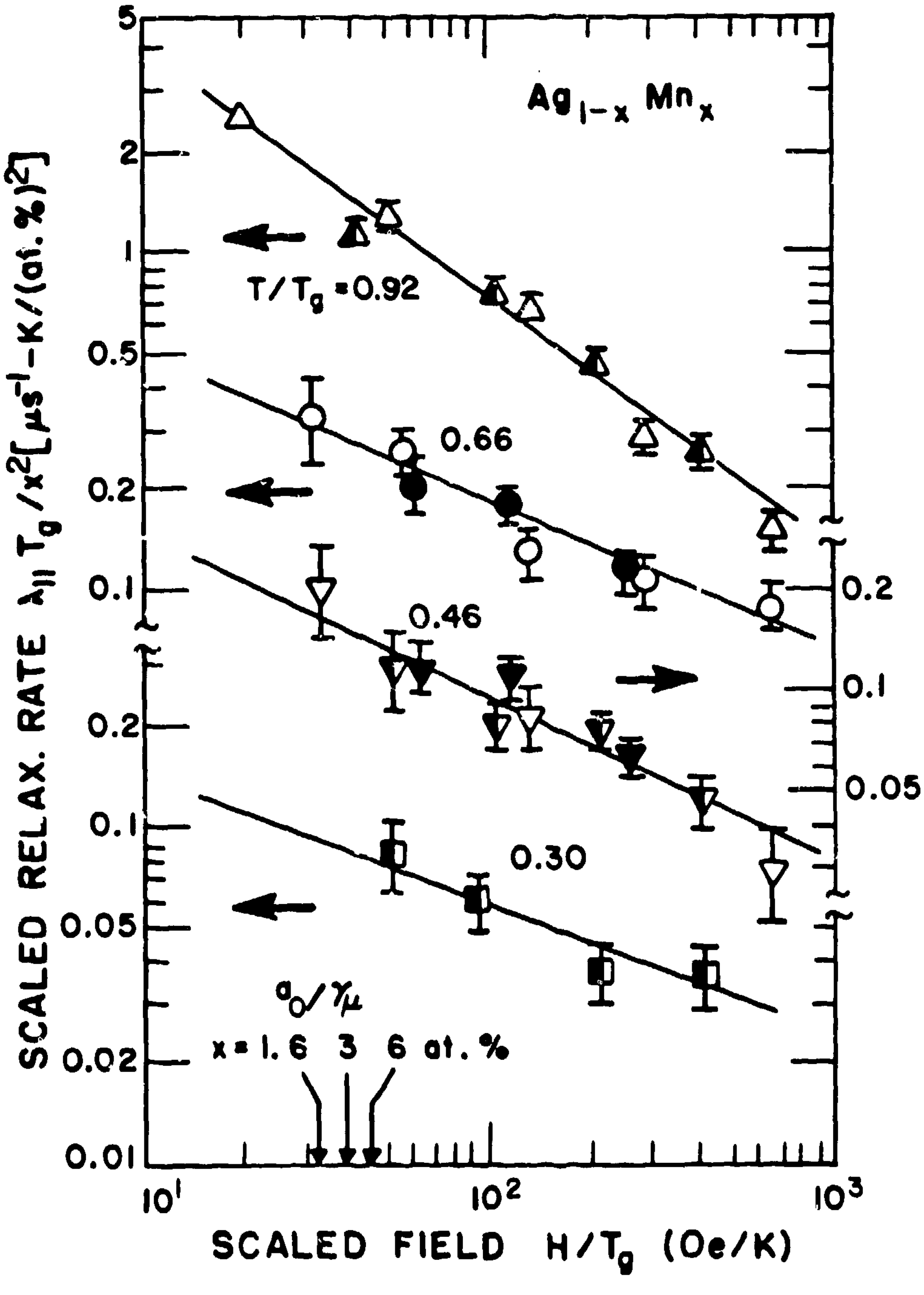
FIGURE CAPTION

Fig. 1. Scaled isotherms of μ^+ spin-lattice relaxation rate $\lambda_\parallel$ vs. effective longitudinal field H, for temperatures below T_g in $Ag_{1-x}Mn_x$ spin glasses. Open symbols: x = 1.6 at. %. Half-filled symbols: x = 3 at. %. Filled symbols: x = 6 at. %. Least-squares fits to a power law are shown for each scaled temperature T/T_g. Scaled widths $\Delta = a_o/\gamma_\mu$ of the μ^+ dipolar field distributions for the various Mn concentrations are shown by arrows on the horizontal axis.



Ag$_{1-x}$Mn$_x$
SCALED RELAX. RATE $\lambda_{\parallel} T_g/x^2$[$\mu s^{-1}$-K/(at.%)^2]
SCALED FIELD H/T_g (Oe/K)
T/T_g =0.92
0.66
0.46
0.30
a_0/γ_μ
x = 1.6 3 6 at.%

T/T_g	ν	$(\chi^2)_{pl}$	$(\chi^2)_{Lor}$
0.92	0.13 ± 0.02	2.62	24.1
0.66	0.55 ± 0.07	0.653	3.12
0.46	0.51 ± 0.07	0.808	1.06
0.30	0.59 ± 0.15	0.445	1.91

TABLE I. Values of the exponent ν obtained from power-law fits to the field dependence of $\lambda_{\parallel}$ (see Fig. 1). Values of reduced χ^2 for the power-law fits [$(\chi^2)_{pl}$] and for fits to a Lorentzian functional form [$(\chi^2)_{Lor}$] are also shown.