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TITLE: SPIN-GLASS DYNAMICS DETERMINED FROM MUON SPIN-RELAXATION AND NEUTRON SPIN-ECHO MEASURMENTS

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SPIN-GLASS DYNAMICS DETERMINED FROM MUON SPIN-RELAXATION AND NEUTRON SPIN-ECHO MEASUREMENTS

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ABSTRACT

Muon spin-relaxation (μSR) and neutron spin-echo (NSE) measurements of magnetic-ion correlation times and correlation functions in the spin-glass systems CuMn, AgMn, and AuFe are compared. It is found that the μSR and NSE measurements are in excellent agreement both above and below the spin-glass freezing temperatures. The experimental results are compared to recent theories of spin-glass dynamics.

I. INTRODUCTION

Two new experimental techniques have been developed which show great promise in elucidating the nature of the spin dynamics in magnetic systems: neutron spin echo (NSE)[1] and muon spin relaxation (μSR).[2,3] In this paper we compare measurements of the spin autocorrelation function in spin-glass systems CuMn and AgMn using the NSE and μSR techniques. Where applicable, the results of these measurements are compared with recent mean-field theories of spin-glass dynamics.[4]

NSE measurements can be used to derive the spin correlation function of a magnetic system $S(q,t)$,[1] where q and t are the momentum transfer and time variables, respectively. The μSR technique is sensitive to a broad average over all q, however, much like NMR. Moreover, neutron scattering is most effective in measuring correlation times (τ) $10^{-12} < \tau < 10^{-8}$s, whereas μSR is most effective for $10^{-11} < \tau < 10^{-4}$s. Thus, the techniques are complementary.

II. MEASUREMENTS BELOW THE SPIN-GLASS FREEZING TEMPERATURE T_g

Recent measurements[5] of the longitudinal-field dependence of the muon-spin-lattice relaxation rate $\lambda_\parallel$ in spin glass AgMn show an algebraic form $\lambda_\parallel = K\omega_\mu{}^{\nu-1}$, for $0.3 \lesssim T/T_g \lesssim 0.9$. Here ω_μ is the muon's Larmor frequency in the local plus applied field and K is a constant depending on temperature. Using very general arguments[6] one may show that $\lambda_\parallel \propto J(\omega_\mu)$, where $J(\omega)$ is the noise power of the fluctuating field, assuming that the applied field does not significantly affect the spin dynamics (this assumption is tested below). A simplified form of the total spectral density $\mathfrak{J}(\omega)$ for a q-independent probe can be written as

$$\mathfrak{J}(\omega) = A\,\delta(\omega) + K_1\,J(\omega) \qquad (1)$$

The first term gives the static, the second the dynamic mode density. Taking the Fourier transform of $\mathfrak{J}(\omega)$ yields the local-field autocorrelation function $S(t)$:

$$S(t) = \int_{-\infty}^{\infty} e^{i\omega t}\mathcal{J}(\omega)d\omega, \tag{2a}$$

$$= A + B\,F(t)\quad . \tag{2b}$$

The constants A and B are temperature dependent and their sum must equal one. For $\omega < \omega_e$, the exchange frequency, $J(\omega) \propto \omega^{\nu-1}$, and therefore F(t) is $\simeq (\omega_e t)^{-\nu}$ for $t \gg \omega_e^{-1}$; for $t \ll \omega_e^{-1}$ we require $F(t) \simeq 1$. The thrust of our comparison of the μSR and NSE data below T_g should now be clear: the μSR data can provide $J(\omega)$, from which S(t) can be derived for comparison* with the NSE results averaged over q.

The μSR results[5] for $Ag_{1-x}Mn_x$ with x = 1.6, 3, and 6 at. % at applied fields between 0.15 and 5.0 kOe yield $\nu = 0.54 \pm 0.05$, for $0.3 < T/T_g < 0.7$, and $\nu = 0.24 \pm 0.02$, for $T/T_g \simeq 0.9$. The coefficient B in Eq. (2b) can be roughly determined from fits to the μSR data ($\lambda_\parallel = K\omega_\mu{}^{\nu-1}$) if we take[3] $\lambda_\parallel \simeq 4\,a_0{}^2\,J(\omega_\mu)$. (This expression, strictly applicable only in zero applied field, relates $\lambda_\parallel$ to the known[3] dipolar-field distribution Δ, averaged over all muon sites. Here, $\Delta = a_0/\gamma_\mu$, where γ_μ is the muon gyromagnetic ratio.) Although this procedure yields quite reasonable values of B $(0 < B < 1)$ for $\nu < 1/2$ (see discussion below for theoretical constraints on ν), it is not precise enough to constrain B, which is therefore taken to be a free parameter in fitting the NSE data.

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*In this paper, we assume that the statistical properties of the magnetic-ion-spin fluctuations (which are measured by NSE) are approximately the same as the resulting fluctuations of the dipolar field at the μ^+ site.

Figure 1 shows the NSE results[1,7] of Mezei et al. in CuMn (5 at. %, $T_g = 27.5K$). The solid curves are plots of Eq. (2b) with $F(t) = (\omega_e t)^{-\nu}$. In the top curve at $T/T_g = 0.18$ we take $A = 0.95$ and $B = 0.05$, i.e., very little fluctuating amplitude. The next curve at $T/T_g = 0.73$ is for $A = 0.66$ and $B = 0.34$, and the bottom two curves at $T/T_g = 1.1$ are for $A = 0$ and $B = 1$, i.e., no static component at all. A reasonable mean-field estimate for ω_e is $\hbar\omega_e \approx kT_g$, yielding $\omega_e \approx 3.6 \times 10^{12}s^{-1}$. As seen in Fig. 1, we have obtained excellent fits to the NSE data using $\omega_e = 1.5 \times 10^{12}s^{-1}$, close to the expected value, and the same values of ν as found from the μSR data for $\lambda_\parallel$ in AgMn described above. Note in particular that both the NSE and μSR measurements show $\nu \approx 0.24$ at temperatures near T_g. The excellent agreement between the two probes indicates that: (1) the q-independent S(t) found in NSE for a small range of q ($0.045\mathring{A}^{-1}$ to $0.36\mathring{A}^{-1}$) evidently holds over the wider range to which μSR is sensitive, (2) the form of $J(\omega)$ determined from μSR is evidently unaffected by applied fields < 5 kOe up to $T/T_g \approx 0.9$, and (3) identical forms for S(t) are obtained for $\tau < 10^{-9}s$ (NSE) and $\tau > 10^{-9}s$ (μSR).

Recently, Sompolinsky and Zippelius have reported[4] a spin-glass correlation function which decays as $t^{-\nu}$, in agreement with both the μSR and NSE results. This theory predicts $\nu(T) < 1/2$ at $T < T_g$, but $\nu(T_g) = 1/2$. Thus theory and experiment agree below T_g, but not at $T \approx T_g$.

III. MEASUREMENTS ABOVE T_g

The spin-glass correlation function changes[1] above T_g, eventually tending to an exponential well above T_g ($T/T_g > 5$). For a resonance probe like μSR in a rapidly fluctuating environment which exhibits a nonexponential S(t), one may only define an effective correlation time τ_{eff} by[6]

$$\tau_{eff} = \int_0^\infty S(t)dt / \int_0^\infty S(o)dt. \tag{3}$$

The values of τ_{eff} in the AgMn, CuMn, and AuFe spin-glass systems have been obtained[2,3] from zero-field μSR measurements above T_g. A plot of these data is reproduced from Ref. 3 in Fig. 2.

Mezei[7] has fit the S(t) obtained from NSE above T_g to the following functional form:

$$S(t) = \frac{1}{E_m} \int_0^{E_m} e^{-t/\tau} dE, \tag{4}$$

where $\tau = \tau_o e^{E/T}$. For 5 at. % CuMn, Mezei finds $E_m \simeq 300K$ and $\tau_o = 6 \times 10^{-14}s$. Using these parameters and Eqs. (3) and (4) yields the solid curve in Fig. 2 for τ_{eff} vs. T. There is reasonable agreement between the μSR and NSE measurements, with no adjustable parameters. A similar comparison by Uemura[8] has been made independently.

IV. CONCLUSION

Muon spin relaxation and NSE techniques give consistent results both above and below the freezing temperature in simple spin glasses. These results tend to confirm recent theories[4] of spin-glass dynamics below the freezing temperature ($T/T_g < 0.7$), but indicate a contradiction at $T \simeq T_g$. This departure from theory should stimulate further experimental and theoretical work in this exciting area.

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REFERENCES

[1.] F. Mezei and A. P. Murani, J. Magn. Magn. Mat. 14 (1979) 211.

[2.] Y. J. Uemura, T. Yamazaki, R. S. Hayano, R. Nakai, and C. Y. Huang, Phys. Rev. Lett. 45 (1980) 583.

[3.] R. H. Heffner, M. Leon, M. E. Schillaci, D. E. MacLaughlin, and S. A. Dodds, J. Appl. Phys. 53 (1982) 2174.

[4.] H. Sompolinsky and Annette Zippelius, Phys. Rev. B25 (1982) 6860.

[5.] R. H. Heffner, D. W. Cooke, M. Leon, M. E. Schillaci, D. E. MacLaughlin, and L. C. Gupta, paper contributed to this conference.

[6.] A. Abragam, Principles of Nuclear Magnetism (Clarendon Press, Oxford, 1961).

[7.] F. Mezei, invited talk, 28th Conference on Magnetism and Magnetic Materials, Montreal, Canada, 1982, to be published in J. Appl. Phys.

[8.] Y. J. Uemura, Ph.D. thesis, University of Tokyo, 1981, unpublished.

FIGURE CAPTIONS

Fig. 1. Neutron spin echo spin-correlation function in CuMn (5 at.%) vs logarithm of time in seconds (Ref. 1). Three sets of data are shown (from top to bottom): $T/T_g = 0.18$, 0.73, and 1.10. Solid curves are from Eq. (2b) with $F(t) = (\omega_e t)^{-\nu}$, using values of ν obtained from μSR data (Ref. 5), and values of A and B as described in the text.

Fig. 2. Effective correlation time τ_{eff} vs temperature as determined from zero-field μSR data (Refs. 2 and 3). Solid curve is from Eqs. (3) and (4) using parameters determined by neutron spin echo measurements (Ref. 7).

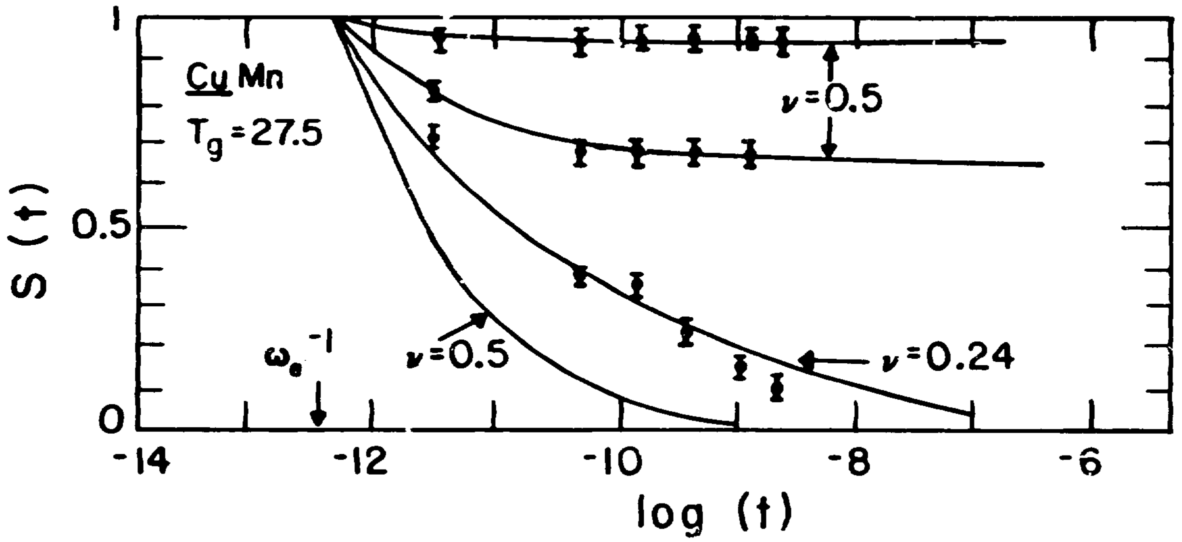
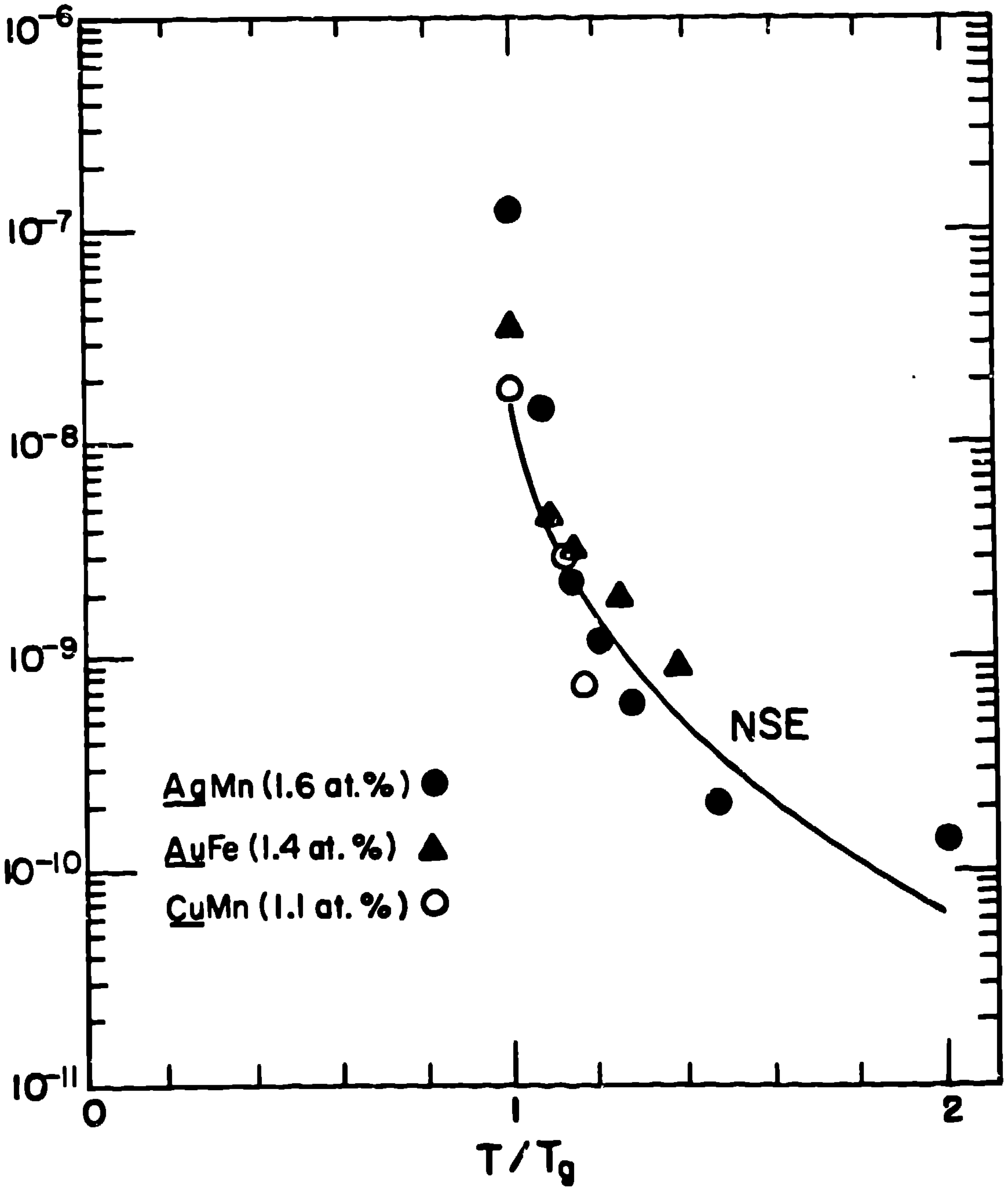


Figure 1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10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
$\tau \dot{T}_g$ (s-K)
0
1
2
T/T_g
NSE
AgMn (1.6 at.%) ●
AuFe (1.4 at.%) ▲
CuMn (1.1 at.%) ○

Figure 2