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Magnetic field–time-scaling relations and exotic spin correlations: a μSR study of spin glasses

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Abstract

In this work we analyze a longitudinal field [H] μSR experiment in the spin glass AgMn(0.5 at%) using a cut-off power-law dynamical field auto-correlation function $q(t) = 2ct^{-x}\exp[-(\nu t)^y]$. This function allows us to account for the data for more than 2.5 orders of magnitude in magnetic field and two orders in time. Our results suggest that spin glass freezing is associated with a dynamical transition from a cut-off power law to a pure cut-off.

Keywords: Spin glass; Scaling; Correlations

In a longitudinal field μSR (LF-μSR) experiment one measures the muon polarization along the applied field direction P_z, as a function of the field value H and time t. A recent set of experiments on the Heisenberg spin glass AgMn(0.5 at%) at $T > T_g$, demonstrated that $P(H,t)$ could be understood using a field–field dynamical auto-correlation function $q(t) \equiv \gamma_\mu^2 \langle \boldsymbol{B}_\perp(t) \cdot \boldsymbol{B}_\perp(0) \rangle$ ($\perp$ is perpendicular to H) of the form

$$q(t) = 2ct^{-x} f(t), \tag{1}$$

where $f(t)$ is a cut-off function [1].

This conclusion relied on a simple approach which was based on one theoretical assumption and two observations. The theoretical assumption is equivalent to writing $P_z(H,t) = \int \rho(c) \times \exp[-c\Gamma t]\,\mathrm{d}c$ where $\Gamma = (1/c)\int_0^\infty q(\tau)\cos(\omega\tau)\,\mathrm{d}\tau$, ρ is a distribution function, $\omega = \gamma_\mu H$, and γ_μ is the muon gyromagnetic ratio [2,1]. The observations are: (1) for magnetic fields higher than 125 G, the muon polarization shows magnetic-field time scaling relations of the form $P(H,t) = P(t/H^\gamma)$ with $\gamma < 1$, and (2) the muon relaxation rate at $H = 0$ is finite. The authors of Ref. [1] demonstrated that the exponent γ, derived from the LF-μSR experiment, is related to the exponent x of the correlation function via $\gamma = 1 - x$. They then went on to argue that the cut-off function f must be present in the correlation function in order for Γ to be finite at $H = 0$. However, the available data and the analysis tools were not sufficient to account quantitatively for $P(H,t)$ in low fields. In this paper we extend the previous analysis to low field, and show how the polarization could be understood using a cut-off correlation function.

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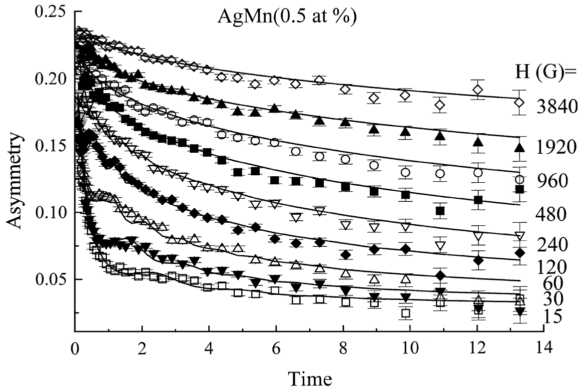

Fig. 1. Asymmetry [$\propto P_z$] data (symbols) in AgMn(0.5 at%) in a LF-μSR experiment. The solid lines are fits to Eq. (3) where $\Gamma(t)t$ is given by Eq. (2) and $q(t)=2ct^{-x}\exp[-(\nu t)^y]$. The best values are: $x=0$, $y=0.308(3)$, $\nu=2.01(1)$ MHz, $c_0=15.9(3)$ MHz^2, and $\beta=0.416(5)$.

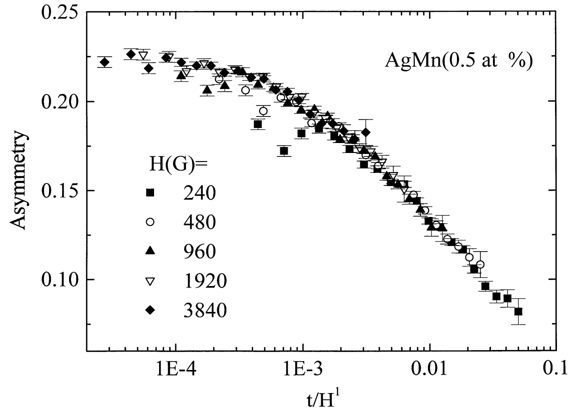

Fig. 2. The asymmetry in a LF-μSR plotted as a function of t/H^1 for fields higher than 240 G.

In Fig. 1 we present LF-μSR result for fields ranging from 15 to 3840 G. In fields $\leqslant 120$ G, wiggles are observed in the data. These wiggles could not be accounted for by the simple approach, and a more complete approach should be adopted. Here, we improve the analysis of Ref. [1] by using [3,4]

$$\Gamma(t)t=\frac{1}{c}\int_0^t (t-\tau)q(\tau)\cos(\omega\tau)\,\mathrm{d}\tau. \tag{2}$$

We normalize the integral by $1/c$ so as to make $\Gamma(t)t$ independent of the pre factor c.

In a related paper it is shown that expression (2) forecasts the wiggles seen in Fig. 1 [5]. In addition, if the wiggles survive for time t_w, then for $t>t_w$, and for fields $H>(\gamma_\mu t_w)^{-1}$, one expects $\Gamma(t)t\propto t/H^{1-x}$ and the scaling relation should hold. Since the wiggles in Fig. 1 prevail for $t_w\sim 2$ μs, all data sets should collapse into one function for fields higher than 100 G and at $t>2$ μs. In Fig. 2 we show the muon polarization as a function of t/H^γ, with $\gamma=1$, for high fields. Indeed, scaling holds at $t/H>0.02$ (and even earlier) meaning $x=0$.

In the scaling procedure some precautions should be taken since high fields alter the positron trajectories in an unknown way. As a result, the effective efficiency of the positron detectors is a function of the field. This effect, known as an α change, amounts to a shift in the base line of the polarization (when the α change is small as in here). While this phenomenon hinders the fits to particular models, its effect on scaling could be accounted for with the equation $P(H,t)=P(t/H^\gamma)+g(H)$ where $g(H)$ is a function of the field alone. As a result when one plots P, obtained at different fields, as a function of t/H^γ as in Fig. 2, the trajectories should run parallel to each other rather than fall on top of each other. That is indeed the case for the 3840 G data and a constant has been subtracted from the data set. Thus, using scaling for determining γ is not very sensitive to α changes. The tradeoff is the poor acuracy with which γ is determined ($\sim 10\%$).

In order to go further with the analysis we must either assume a particular function for ρ or assume a particular outcome of the integration in this equation. We choose the latter and use the phenomenological expression

$$P(H,t)=\exp(-[c_0\Gamma(t)t]^\beta). \tag{3}$$

This form was observed by many groups, in spin glasses at $H\to 0$ [1,6]. We can evaluate c_0 and β from the zero-field data. Since $f(0)=1$ one expects $\Gamma(t)t=2t^{2-x}/(2-x)(1-x)+\mathrm{O}(t^{3-x})$. Therefore, the early time behaviour of the polarization is given by $P(0,t)=\exp(-[\lambda t]^{(2-x)\beta})$ where $\lambda=[2c_0/(2-x)(1-x)]^{1/(2-x)}$. For the example presented here, we find $x=0$ (from scaling) and we expect $P(0,t)=\exp[-(c_0t^2)^\beta]$, at early time, from which c_0 and β could be obtained.

Finally, we assume a more explicit form for the cut-off function. Inspired by Ogielski's [7] dynamical simulations in a spin glass, we take

$$f(t) = \exp[-(\nu t)^{y}]. \tag{4}$$

In order to obtain ν and y from the experiment we developed a fitting procedure based on Eqs. (3) and (2) with Eqs. (1) and (4). The solid lines in Fig. 1 are obtained by such a fit. First, x, c_0, and β are kept fixed at the values previously determined, and the best values for ν and y are found. Then, all parameters are freed and a global fit is performed. In the global fit we allowed 30% freedom in H for fields $\leqslant 30$ G in order to account for the sample's susceptibility, and since the power supply is not designed to give accurate values in such small fields. The global fit with $x = 0$ yields $y = 0.308(3)$, $\nu = 2.01(1)$ MHz, $c_0 = 15.9(3)$ MHz^2 and $\beta = 0.416(5)$.

A similar experiment shows that at higher temperatures $x > 0$. Thus, in AgMn(0.5 at%) prior to the spin glass freezing there is a transition from a cut-off power to a pure cut-off correlation function.

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