Field Dependent Critical Fluctuations above \( T_g \) in the ESR Line Width of the Spin Glass \( \text{AgMn} \)

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The ESR of the spin glass \( \text{AgMn} \) (2.7 and 9.6 at \%) has been investigated below and above \( T_g \) \((0.1 T_g < T < 5 T_g)\) at various microwave frequencies. The analysis yields: 1) No explicit frequency dependence but strong magnetic field effects, inherent with ESR-experiments. 2) Part of the excess line width is identified as critical spin fluctuations, following a power law. However, because of the presence of the applied field, the reduced temperature \( t \) is not a good scaling variable. We choose the non-linear susceptibility \( \chi_s \) divided by \( H_E \), which scales as the order parameter susceptibility. The experiment yields \( W_{ex} \propto (\chi_s/H_E^2)^p \), \( p = 0.42 \). From this we deduce \( v \approx 3 \).

1. Introduction

ESR technique has been used for studying the dynamic behavior of spin glasses (SG). The appearance of an anomalous increase in the ESR linewidth \( W \) at temperatures above and below \( T_g \), has stimulated numerous experimental and theoretical work [1].

For canonical spin glasses as \( \text{AgMn} \) and \( \text{CuMn} \) one observes [2, 3, 4]: 1) \( W \) seems to be strongly frequency \( \omega \)-dependent in a plot of \( W \) vs. \( T \), for \( T < 2 T_g \). The increase in \( W \) becomes larger, the smaller \( \omega \). 2) At \( T \approx 1.5 T_g \) a shift of \( H_{res} \) appears, which looks \( \omega \)-dependent and increases with reducing \( T \).

There are macroscopic [5, 6] and microscopic [7] theories, stimulated by this \( \omega \)-dependent ESR line. The common feature of all these theories is that the response time of the system \( \tau \) is not negligible against \( 1/\omega \). None of these theories could however quantitatively explain the experimental results.

In increase of the ESR linewidth above \( T_g \) has been fitted to a power law of reduced temperature \( t = (T - T_g)/T_g \). If there is a phase transition at \( T_v \), one expects that the characteristic time of the transverse spin fluctuations behaves critically and follows a power law. However, for ESR, where large external fields are applied and where these fields vary with temperature, the reduced temperature may not be a good scaling variable. In the present work we use a more generalized scaling argument.

The study of the spin glass critical behavior is more complicated than that of simple magnetic systems. In spin glasses, the agreement between experiments and the predictions of the scaling theory is used in order to prove the existence of a phase transition, whereas in “usual” magnetic systems this agreement was a test for the validity of the scaling assumptions. Up to now, little is known about the critical behavior of spin glasses. The available results concern mainly the non-linear susceptibility \( \chi_s \), but a test of scaling on different measurable quantities of a given sample is lacking. Furthermore, the influence of anisotropy on the spin glass critical behavior and on the values of critical exponents is unclear.

The susceptibility \( \chi \) is the fundamental quantity concerning the spin relaxation rate [8, 9]. Often \( \chi \) is replaced by a Curie-Weiss law yielding a \( T \)-dependence only. This assumption, however, is disputable for SG’s in the vicinity of \( T_v \), where \( \chi \) does not follow a Curie-Weiss law.

In the present work we report ESR measurements between 1 and 9 GHz in the SG \( \text{AgMn} \) for two Mn concentrations of 2.7% and 9.6%. Following the ideas of the previous paragraph, we have measured the static magnetization \( M(H) \) with an applied magnetic field equal to the field for reso-
nance of the ESR. It is worthwhile to mention, that this produces a large set of $M(H, T)$ data, since the field for resonance depends on $T$ in the vicinity of $T_g$. From these data we deduce $M/H = \chi + \chi_{\text{Curie}}$. Sections 2 and 3 present the experimental details and the raw ESR results. In Sect. 4 we replace for the linewidth-data-plots the $T$-axis by an $H/M$-axis and show that all "$\omega$-dependence" disappears. At first glance all ESR linewidth data for one sample and different frequencies follow a universal curve.

Following the macroscopic ESR theories [5, 6], we show in Sect. 5 that $\omega \tau_{\text{eff}} \ll 1$. Finally, in Sect. 6, we analyse the width in the close vicinity of $T_g$ in the framework of dynamic critical scaling. Only part of the experimentally determined width shows critical behavior. Other contributions (i.e. at $\approx 2T_g$) are discussed. As far as we know the literature, we show for the first time a power law as function of the order parameter susceptibility $\chi_q$.

2. Experimental Details

The samples of AgMn were prepared by arc melting. The glowing buttons were quenched in the arc furnace down to room temperature. After etching, the samples were kept at 77 K, except for experimental runs. The concentration of the samples was determined by microprobe analysis and checked by comparing the values of $T_g$ (11.5 K and 31.2 K for the 2.7% and the 9.6% samples respectively) with those given in the literature. The samples are spheres with a diameter of about 3 mm. This almost spherical shape minimizes the demagnetizing field effects on the ESR results.

We performed ESR experiments at 9.50, 4.04, 3.44 and 1.12 GHz. The samples were cooled using a Heø gas-flow cryostat. The sample temperature was measured with an accuracy of 1% with a AuFe-Chromel thermocouple in contact with the sample.

In metallic systems, the ESR line is a mixture of $\chi'$ and $\chi''$. For systems with short mean free path compared to the skin depth, the mixture of $\chi'$ and $\chi''$ is equal to 1. For a Lorentzian line shape of $\chi''$, the derivative of the resulting ESR line (Dysonian) presents a ratio: $A/B = 2.53$ [12] (for the definition of $A$ and $B$ see Fig. 1).

We analysed the ESR spectra by fitting the experimental signal to a sum of $\partial \chi'(H)/\partial H$ and $\partial \chi''(H)/\partial H$. The fitting program permitted to vary the mixture fractions of $\chi'$ and $\chi''$ respectively and included the contribution of the negative fields to the dynamic susceptibility.

For both samples, at $T \geq T_g$, a Lorentzian line shape for $\chi''$ was observed. At $T \approx 1.1T_g$, we observed a pure Dysonian line with $A/B = 2.53$ for the 2.7% sample (Fig. 1a), and $A/B \approx 3.3$ in the case of AgMn 9.6%. Deviations of the high temperature experimental $A/B$ values from the ideal ones have already been reported in high concentrated samples of AgMn [2]. Below $\approx 1.1T_g$ for both samples $A/B$ decreases with temperature and the ESR spectra tend to obtain a more symmetrical shape.

Figure 1 shows two experimental spectra of AgMn 2.7% as well as the fitted curves, which give the values of the linewidth $W$ and resonance field $H_{\text{res}}$ (see Figure Caption). These spectra represent the best and worst signal-to-noise ratio of the experiments. Figure 1a shows the ESR signal, recorded at $\approx 2T_g$ and for the highest ESR frequency used, whereas the spectrum of Fig. 1b was measured at $T_g$ for the lowest ESR frequency. In the latter case, the ESR linewidth is almost equal to the resonance field and the analysis of the line is very inaccurate, even when the contribution from the negative fields is taken into account. We note that, under these conditions, the error of $H_{\text{res}}$ is significantly higher than that of $W$.  

![Fig. 1a and b. The ESR signal of AgMn 2.7 at% at two temperatures and two frequencies. a The fit curve coincides with the experimental one, so that the two curves cannot be distinguished from each other. The signal is pure Dysonian. The solid curve in b includes negative fields in the fit (dashed line without negative fields)](image-url)