EXPERIMENTS ON SPIN GLASS DYNAMICS

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INTRODUCTION

A spin glass is a disordered and 'frustrated' magnetic system. Experimental results on some hundred spin glasses imply that these two general ingredients are the only requirements for the 'universal' behaviour of the dynamics. In this article I will exemplify some key observations of the zero-field spin glass dynamics, where both the equilibrium as well as the non-equilibrium dynamics are considered. The experimental observations are found from measurements of the time dependent susceptibility on three-dimensional metallic and insulating spin glasses.

EXPERIMENTAL PROBES

In order to appreciate the nature of the spin glass dynamics a very wide time range has to be covered in experiments. Using neutron spin echo, susceptibility and noise measurements about 17 decades in observation time (tobs) can be covered. In ac-susceptibility measurements, where \( \chi(\omega) = \chi'(\omega) + i\chi''(\omega) \), \( t_{\text{obs}} \) equals \( 1/\omega \) and in zero-field-cooled (ZFC) susceptibility, \( (1/H)M_{\text{ZFC}}(t) \), the observation time is the time \( (t) \) after the field application. In the regime of linear response these experiments reflect the time dependence of the dynamic spin correlation function \( q(t) \). As inferred earlier the fundamental relations are:

\[
1 - q(t) = (1/H)M_{\text{ZFC}}(t) = \chi'(\omega) \quad (1)
\]

\[
S(t_{\text{obs}}) = (1/H) dM_{\text{ZFC}}/dt = -2/\pi \chi''(\omega) \quad t_{\text{obs}}t = 1/\omega \quad (2)
\]

S is generally denoted as the relaxation rate and is obtained from the logarithmic time derivative of the ZFC susceptibility or the imaginary part of the complex susceptibility. In the following I mostly present relaxation rate curves, which emphasize the significant features of the dynamics.
The spin glass phase is inherently a non-equilibrium phase. Below the spin glass temperature \((T_g)\) the system continuously ages\(^5\). In ZFC measurements the aging process is revealed as a wait-time \((t_w)\) dependence at the measurement temperature \((T_m)\), prior to the field application. Fig. 1 shows \((1/H)M_{ZFC}(t)\) and \(S(t)\) for a Cu(10\%Mn) sample at different \(t_w\). The salient features are the existence of an inflection point of the relaxation curves at \(\ln t = \ln t_w\) and that equilibrium dynamics are only found at \(\ln t << \ln t_w\). A physical picture for this remarkable behaviour is found from a phenomenological domain picture\(^6,7\) of the spin glass phase. In this picture aging involves the growth of domains \((R)\) within which equilibrium dynamics exist (spin glass order). \(R\) grows\(^7\) from a microscopic time \((t_0)\) with the age of the system \((t_0 = t + t_w)\) as shown in Fig. 2a. Associated with the application of a probing field in ZFC measurements is a probing length scale \((L)\), which grows with the observation time \((t)\) in a similar way as \(R\). Fig 2b shows \(L\) and \(R\) vs \(\ln t\). As seen in the figure, \(R\) remains almost constant for \(\ln t << \ln t_w\) and follows the path of \(L\) for \(\ln t >> \ln t_w\). When \(\ln t << \ln t_w\) \((L << R)\) quasi-equilibrium dynamics are probed, but when \(\ln t >> \ln t_w\) \((L = R)\) non-equilibrium dynamics are probed. The maximum in the relaxation rate at \(\ln t = \ln t_w\) signals a crossover between these relaxation regimes.

![Fig. 1](image1.png) \((1/H)M_{ZFC}(t)\) and \(S(t)\) vs logt for different \(t_w\). \(T_m=41\ \text{K},\ T_g=45\ \text{K}\). \(M_{FC}\) is the field-cooled magnetization.

![Fig. 2](image2.png) Growth with time of \(R\) and \(L\) and time dependence of \(S(t)\). \(\Psi\) is a barrier exponent.