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**DYNAMIC RESPONSE OF THE RE-ENTRANT INSULATING SPIN GLASS
 Eu_{0.54}Sr_{0.46}S**

Wei-Li Luo ⁽¹⁾, R. Hoogerbeets ⁽¹⁾, R. Orbach ⁽¹⁾ and N. Bontemps ⁽²⁾

⁽¹⁾ Department of Physics, University of California, Los Angeles, CA 90024, U.S.A.

⁽²⁾ Laboratoire d'Optique Physique, Ecole Supérieure de Physique et de Chimie Industrielles de la Ville de Paris, 10 rue Vauquelin, 75231 Paris Cedex 05, France

Abstract. - The time decay of the thermoremanent magnetization, $\sigma_{TRM}(t)$, of Eu_{0.54}Sr_{0.46}S was measured in the spin-glass phase. Two time responses were found, for short times: $\sigma_{TRM}(t)$ decays as a power law; for long times, $\sigma_{TRM}(t)$ decays as a stretched exponential. The time separating the two regimes increases with waiting time.

Eu_{0.54}Sr_{0.46}S has at least four different dynamic response regimes [1]: a paramagnetic regime; a ferromagnetic regime; a mixed regime with a ferromagnetic moment; and a spin-glass phase. For our sample T_c was found to be about 5.5 K from remanence measurements; the transition to the mixed regime takes place around 3.9 K; and $T_g \approx 2.3$ K. In the following we shall only report our results obtained in the spin-glass phase.

Our experimental procedure is the following: the sample is cooled in a magnetic field (6 G) from $T > T_c$ to T' , the temperature at which the time decay of $\sigma_{TRM}(t)$ is measured ($T' < T_g$). One waits a time t_w (20 min $\leq t_w \leq$ 60 min). After t_w the field is cut to zero, and $\sigma_{TRM}(t)$ is measured with a SQUID magnetometer for $2\text{ s} < t < 500\text{ s}$. As we have argued elsewhere [2] one can interpret our dynamic response measurements as a probe of the spin-glass dynamics due to a shift in applied magnetic field at a particular stage of the aging process because the inverse aging rate is found to be larger than our maximum observation time.

In figure 1 we have plotted $\sigma_{TRM}(t)$ vs. $\text{Log } t$ for $T = 2.25\text{ K}$. The solid line represents a fit of the stretched exponential form [3]:

$$\sigma_{TRM}(t) = \sigma_0 \exp \left[- (t/\tau_p)^{1-n} \right], \quad (1)$$

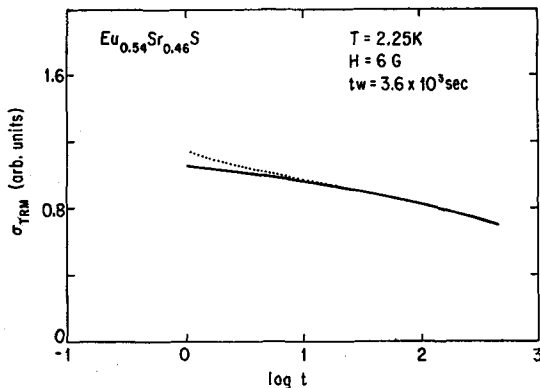


Fig. 1. - $\sigma_{TRM}(t)$ vs. $\text{Log } t$.

to the experimental data (the dots in Fig. 1) for $50\text{ s} < t < 500\text{ s}$. It is clear from figure 1 that equation (1) fits the data well at long times but deviates from the data for short times. In figure 2 we have re-plotted the data as $\text{Log} [\sigma_{TRM}(t)]$ vs. $\text{Log } t$. For $2\text{ s} \leq t \leq 25\text{ s}$ a straight line corresponding to a power law:

$$\sigma_{TRM}(t) = \sigma'_0 t^{-\alpha}, \quad (2)$$

fits the data well (we are unable to measure $\sigma_{TRM}(t)$ for times less than 2 s due to the reset time of our magnetometer after cutting off the field). However, at long times the power law clearly deviates from the experimental data. We denote the time at which the decay of $\sigma_{TRM}(t)$ changes from power law to stretched exponential as the crossover time, t_{c0} . In order to display the crossover most effectively, we plot [4]

$$F(t) = \text{Log} \left\{ -d [\text{Log } \sigma_{TRM}(t)] / d [\text{Log } t] \right\}$$

vs. $\text{Log } t$ in figure 3. For this function, a power law is a constant, while a stretched exponential is a straight line with finite slope. We denote t_{c0} as the time at which the two asymptotic behaviors cross.

This behavior, taken together with that observed by Bontemps and Orbach [4] on Eu_{0.4}Sr_{0.6}S, suggests that there are two time responses regimes in spin-glasses.

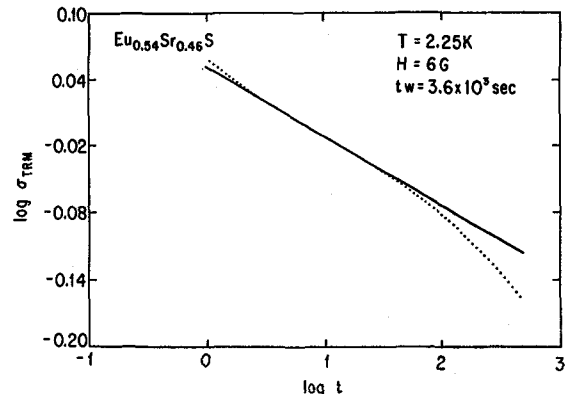


Fig. 2. - $\text{Log} [\sigma_{TRM}(t)]$ vs. $\text{Log } t$.

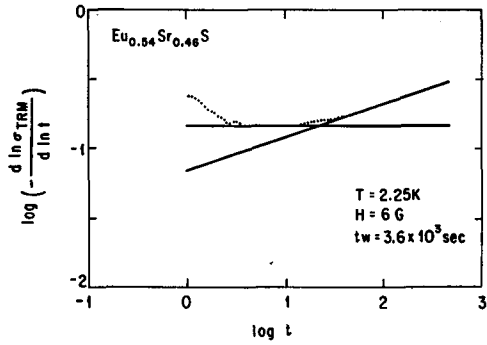


Fig. 3. - $F(t) = \text{Log} \left\{ -\frac{d[\text{Log } \sigma_{\text{TRM}}(t)]}{d[\text{Log } t]} \right\}$ vs. $\text{Log } t$.

Similar observations have been made by Alba *et al.* [5], but they fit their data by a *product* of a power law times a stretched exponential time response.

We interpret the time regimes in terms of transitions between nearby states in phase space with nearly equal magnetizations for the short time regime, while the long time regime is associated with highly improbable (but very effective for relaxation of the magnetization) transitions for reduction of the magnetization between states far away in phase space with large differences in magnetization.

A corroborating experiment is our observation that the crossover time t_{c0} *increases* with increasing waiting time t_w . This behavior is exhibited in figure 4. We ascribe this increase to a decrease in available states as the system energy decreases. This is consistent with the ultrametric density of states [6], and an assumption that the system energy diminishes with increasing t_w . The diminution in available states with nearly degenerate energies makes the improbable large changes in magnetization less likely relative to small changes, delaying the onset of stretched exponential decay relative to power law decay. This would show up as an increase in t_{c0} with increasing t_w , as observed.

The data in figure 4 are consistent with the observation of [5] that the temporal extent of the power law

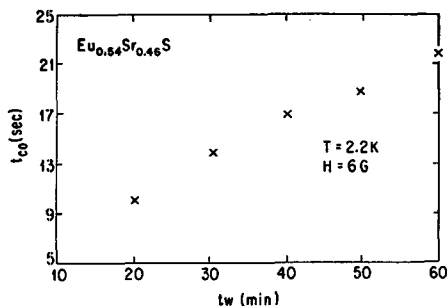


Fig. 4. - t_{c0} vs. t_w .

behavior of $\sigma_{\text{TRM}}(t)$ increases with increasing waiting time. For example, if we interpret their data in terms of two time regimes, t_{c0} would increase by an order of magnitude for a two order of magnitude increase in t_w .

However, as shown in [4] for $\text{Eu}_{0.4}\text{Sr}_{0.6}\text{S}$, a finite t_{c0} exists for a system with no detectable waiting time behavior. This leads us to suggest that, after a sufficient waiting time, t_{c0} will cease depending upon t_w . This leads us to a conclusion opposite to [5]. They state that, as $t_w \rightarrow \infty$, all curves tend towards a power law, and therefore that only the power law represents equilibrium response. Our conclusion would be that, as $t_w \rightarrow \infty$, t_{c0} would saturate at some finite value, and that the long time behavior ($t > t_{c0}$) would be a stretched exponential. We conclude, therefore, that both power law and stretched exponential time responses represent equilibrium dynamics.

In conclusion, the existence of two distinct time response regimes for $\sigma_{\text{TRM}}(t)$ suggests that two different decay routes are responsible in phase space. We suggest that these may be associated with diffusion amongst states with large overlap (close in magnetization - see [7]) for the short time regime, leading to a power law time decay, and transitions between states with small overlap (large differences in magnetization) for the long time regime, leading to a stretched exponential time decay.

Acknowledgments

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