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STATIC AND DYNAMIC CRITICAL BEHAVIOUR OF THE SPIN GLASS



J. Vetel ⁽¹⁾, M. Yahiaoui ⁽¹⁾, D. Bertrand ⁽¹⁾, A. R. Fert ⁽¹⁾, J. P. Redoules ⁽¹⁾ and J. Ferré ⁽²⁾

⁽¹⁾ Laboratoire de Physique des Solides, associé au CNRS, INSA, Avenue de Rangueil, 31077, Toulouse Cedex, France

⁽²⁾ Laboratoire de Physique des Solides, Bât. 510, Université de Paris-Sud, 91405 Orsay Cedex, France

Abstract. – We present results concerning the static and dynamic behaviour of the new Ising spin glass $\text{Fe}_{0.35}\text{Mg}_{0.65}\text{Br}_2$. The analysis of the static magnetisation leads to conclude to a transition at finite $T_c = 1.9$ K with $\gamma = 2$ and $\beta = 0.4$. Dynamics confirm this feature and we find critical exponent $z\nu \sim 10$.

We report hereafter an experimental study of the critical behaviour of the new Ising-type spin glass $\text{Fe}_{0.35}\text{Mg}_{0.65}\text{Br}_2$. Pure FeBr_2 is a layered compound which has an antiferromagnetic transition at $T_N = 14.2$ K. The main exchange parameters are $J_1 \sim 10$ K (in-plane next neighbours), $J_2 \sim -3$ K (in-plane next nearest neighbours) and $J'_1 \sim -3$ K (out-of-plane next neighbours). Contrary to the comparable compound FeCl_2 for which $J_1 / |J'_1| \sim 10$ giving it an important 2d character, a ratio $J_1 / |J'_1| \sim 3$ confers *a priori* to FeBr_2 a 3d character. A recent study of the phase diagram of the dilute system $\text{Fe}_x\text{Mg}_{1-x}\text{Br}_2$ by d.c. susceptibility measurements showed us that, for $x \leq 0.6$, the system exhibits the classical pathology of spin glasses. The aim of this paper is to check the effect of dimensionality on the nature of the phase transition by comparing the static and dynamic behaviour of $\text{Fe}_{0.35}\text{Mg}_{0.65}\text{Br}_2$ to those of $\text{Fe}_{0.3}\text{Mg}_{0.7}\text{Cl}_2$ which exhibits a transition at $T_c = 0$, as expected for 2d spin glasses [1].

The samples are issued from a single crystal grown by the Bridgman method. They are prepared in a glove box with an ^4He atmosphere to avoid their hydration. The disc shaped samples are obtained after cleavage parallel to the sheets. We have first measured, by the extraction method, the temperature dependence of the field cooled magnetisation under 24 different applied fields in the range 10-400 Oe. After demagnetising field correction, we obtained isothermal static magnetisation curves which allow to study the static critical behaviour. We have also performed a.c. susceptibility measurements over a wide frequency range 5×10^{-2} - 10^5 Hz by using different experimental methods to recover the characteristic $\tau(T)$ relaxation time temperature dependence. In the range 0.05-5000 Hz, we used a pick-up coil system: at the lowest frequencies ($\omega \leq 100$ Hz), the magnetic field modulated at the frequency ω and the corresponding pick-up coil voltage are both sampled at 20 kHz over a period by means of a 16 bit analog-digital converter associated with a PDP 11/73 computer. The real χ'_ω and the imaginary χ''_ω parts of the a.c. susceptibility are then calculated in real time. For higher frequencies, a double lock-in

amplifier gave directly the modulus and the phase of the signal. In the range 1.5 - 10^5 Hz, a magneto-optical method derived from the Faraday rotation arrangement was used [1]: in this experiment the Faraday rotation is modulated at the field frequency ω and its in-phase and out-of-phase components are proportional to χ'_ω and χ''_ω respectively.

The analysis of the static critical behaviour of spin glasses is founded upon the hypothesis that, in the expansion of the magnetisation in odd powers of the variable H/T :

$$M = a_1(H/T) - a_3(H/T)^3 + a_5(H/T)^5 - \dots \quad (1)$$

the non-linear coefficients diverge as powers of the reduced temperature defined by $t = 1 - T_c/T$, i.e. $a_3 \sim t^{-\gamma}$, $a_5 \sim t^{-2\gamma-\beta}$, ... while the first term has a regular behaviour [2]. We have deduced from our experimental data $a_3(T)$ and $a_5(T)$ by fitting M/H as a polynomial of H^2 at the temperature T . In the insert in figure 1, we show the linear correlation coefficient of the fit of the $a_3 \sim t^{-\gamma}$ law as a function of T_c : we observe a plain maximum at $T_c = 1.9$ K. We get an excellent linearity in the plot of $\log(a_3)$ vs. $\log(t)$ (Fig. 1) by using $T_c = 1.9$ K and we found

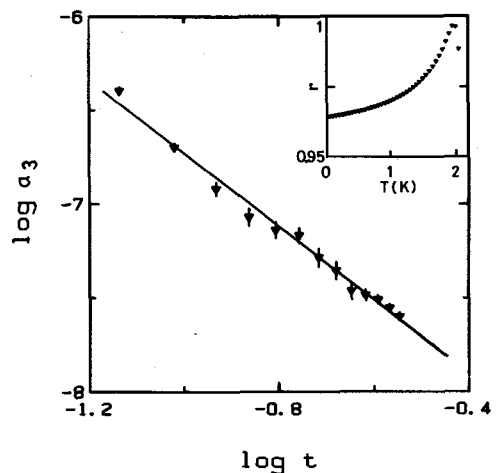


Fig. 1. – Plot of $\log(a_3)$ versus $\log(t)$ with $t = 1 - T/T_c$. The insert shows the usual linear correlation coefficient for different attempts values of T_c .

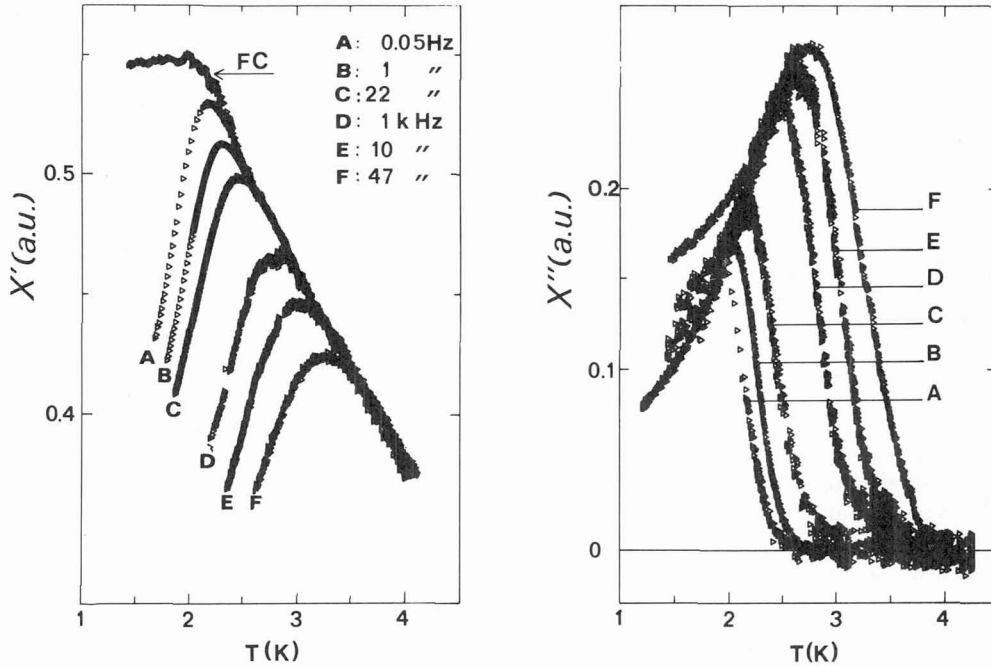


Fig. 2. - Plot of χ'_ω and χ''_ω vs. temperature for some frequencies. (The arbitrary unit for χ''_ω is 5 times lower than the unit for χ'_ω .)

as associated critical exponents $\gamma = 2$ and $\beta = 0.4$. The compound $\text{Fe}_{0.35}\text{Mg}_{0.65}\text{Br}_2$ shows unambiguously a phase transition at finite temperature, as usual for 3d spin glasses. This markedly differs from the 2d system $\text{Fe}_{0.3}\text{Mg}_{0.7}\text{Cl}_2$ for which $T_c = 0$.

We present in figure 2 some of our χ'_ω and χ''_ω data. We have chosen a criterium on χ''/χ' to determine T_f at a given frequency ω . We define T_f from the temperature corresponding to the onset of irreversibilities [3] (defined from a weak value of the phase $\varepsilon = \text{Arctg}(|\chi''|/\chi')$ for each value of ω). The dynamic scaling hypothesis assumes that the characteristic frequency is a power of the correlation length ξ , defining the exponent z , and therefore a power of $t = 1 - T_c/T$: we have thus

$$\omega = \omega_0 t^{z\nu} \tag{2}$$

In order to check this relation, we have plotted in figure 3a $\ln(\omega)$ vs. $\ln(t)$, assuming valid the value $T_c = 1.9$ K obtained from the above static scaling. We note a good linearity, with an exponent $z\nu \sim 12$, which can be however improved by a choice of a slightly different value of T_c ($T_c = 2.05$ K). The value of the exponent $z\nu$ is then about 10, therefore close to the classical ones 8-10 obtained for spin glasses. Contrary to what we observed for $\text{Fe}_{0.3}\text{Mg}_{0.7}\text{Cl}_2$, the Arrhenius law (Fig. 3b) is not convenient to explain critical dynamics in $\text{Fe}_{0.35}\text{Mg}_{0.65}\text{Br}_2$.

Static as dynamic critical behaviour analysis leads to conclude in favour of a transition a finite temperature in $\text{Fe}_{0.35}\text{Mg}_{0.65}\text{Br}_2$, showing therefore the importance of the dimensionality in the nature of the phase transition.

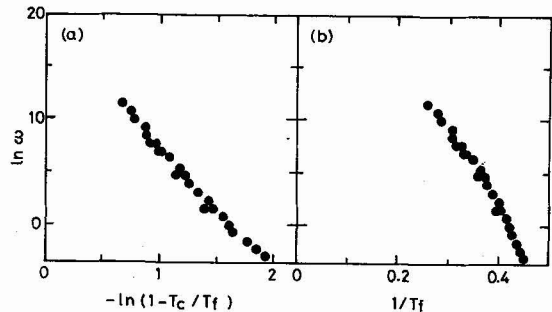


Fig. 3. - Plots of $\ln(\omega)$ vs. $\ln(1 - T_c/T_f)$ with $T_c = 1.9$ K (power law) and vs. $1/T_f$ (Arrhenius law).

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