

## EFFECTS OF DIMENSIONALITY ON CRITICAL SCALING IN TWO ISING-TYPE INSULATING SPIN GLASSES

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**Abstract.** — We show that the Ising-type spin glass  $\text{Fe}_{0.35}\text{Mg}_{0.65}\text{Br}_2$  behaves as a 3d spin glass with a transition at finite  $T_c = 1.9$  K. In contrast, we conclude for  $\text{Fe}_{0.3}\text{Mg}_{0.7}\text{Cl}_2$  to a transition at  $T_c = 0$  associated with an exponential divergence of the non-linear susceptibility  $\chi_{nl} \cdot T$  and of the relaxation time  $\tau$ .

$\text{FeCl}_2$  and  $\text{FeBr}_2$  are layered systems with Ising behaviour due to a strong anisotropy along the  $c$ -axis. The n.n. interaction  $J_1$  is ferromagnetic within a layer but adjacent layers tend to order antiferromagnetically due to the small interplane interaction  $J'_1$ . On substituting Mg to Fe, the disorder enhances the frustration as the in-plane n.n.n. interaction  $J_2$  is antiferromagnetic, as well as the interplane n.n. interaction  $J'_1$ . For large dilution both systems behave as Ising spin glasses [1].

From our field cooled (equilibrium) magnetisation measurements on a  $\text{Fe}_{0.35}\text{Mg}_{0.65}\text{Br}_2$  and a  $\text{Fe}_{0.3}\text{Mg}_{0.7}\text{Cl}_2$  sample, we have expanded the magnetisation in terms of  $H/T$ :

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

and deduced  $a_1$ ,  $a_3$  and  $a_5$  (Fig. 1). In a spin-glass  $a_3$  and  $a_5$  are powers of coherence length  $\xi$  [2], the latter

being an analytical function of  $K = J/T$  ( $J$  is related to the interactions) which tends to diverge when  $K$  approaches by lower values a convergence radius  $K_c$  which defines  $T_c$ . It is generally assumed that for finite  $T_c$ :

$$\xi / \xi_0 = (1 - K / K_c)^{-\nu} = (1 - T_c / T)^{-\nu} = t^{-\nu} \quad (2)$$

and  $a_3$  and  $a_5 \dots$  therefore are also powers of  $t$ :

$$a_{2n+1} = (1 - T_c / T)^{\beta - n(\beta + \gamma)} \quad \text{for } n > 0. \quad (3)$$

We have checked that, in our both systems,  $a_5 = a_3^{2+\beta/\gamma}$  with  $\beta/\gamma \sim 0.2$  and  $0.1$  in  $\text{Fe}_{0.35}\text{Mg}_{0.65}\text{Br}_2$  and in  $\text{Fe}_{0.3}\text{Mg}_{0.7}\text{Cl}_2$  respectively (see Fig. 1).

The dynamic scaling hypothesis states the relaxation time  $\tau$  also is a power of  $\xi$ :

$$\tau / \tau_0 = (\xi / \xi_0)^z = t^{-z\nu}. \quad (4)$$

From a.c. susceptibility measurements, we have deduced  $\tau(T)$  (Fig. 1) by setting that, at the frequency  $\omega$ ,  $2\pi\omega\tau \sim \varepsilon = \arctg(|\chi''_\omega|/|\chi'_\omega|)$  at the temperature  $T_f$  where  $\varepsilon = 10^{-2}$  [3].

For any quantity  $X$  which like  $\xi$ ,  $\tau$  or  $a_{2n+1}$  is a power of  $t$  of the form  $X = X_0 t^{-x}$  we can check that [4]:

$$\mathcal{P}_X(T) = -\frac{\partial \ln T}{\partial \ln X} = \frac{T - T_c}{xT_c} = \frac{T - T_c}{\theta_X} \quad (5)$$

$T_c$  and  $T_c + \theta_X$  are determined at the intercept of the  $\mathcal{P}_X(T)$  straight line with the  $y = 0$  and  $1$  axes respectively. The figure 2a shows that for  $\text{Fe}_{0.35}\text{Mg}_{0.65}\text{Br}_2$  the dynamic and the static data are consistent with this analysis for the same value of  $T_c \sim 2$  K. The exponents which we deduce from the slopes are  $\gamma \sim 2$ ,  $\beta \sim 0.4$  and  $z\nu \sim 10$  and thus consistent with what has been observed in many 3d systems and with what the theory predicts for Ising spin glasses at  $d = 3$  [5].

The figure 2b in contrast shows that  $\theta_\tau \sim 35$  K in  $\text{Fe}_{0.3}\text{Mg}_{0.7}\text{Cl}_2$  with  $T_c$  values within the range 0 to 1.4 K which includes  $T_c = 0$ . This implies a dy-

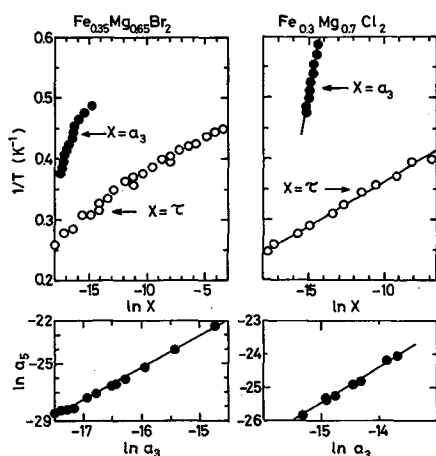


Fig. 1. — Arrhenius plot of the 3<sup>rd</sup> order Curie constant  $a_3$  and of the relaxation time  $\tau$  in  $\text{Fe}_{0.35}\text{Mg}_{0.65}\text{Br}_2$  (left hand side) and in  $\text{Fe}_{0.3}\text{Mg}_{0.7}\text{Cl}_2$  (right hand side). The lower part of the figure shows that the 5<sup>th</sup> order Curie constant is a power of the 3<sup>rd</sup> order Curie constant in both systems.

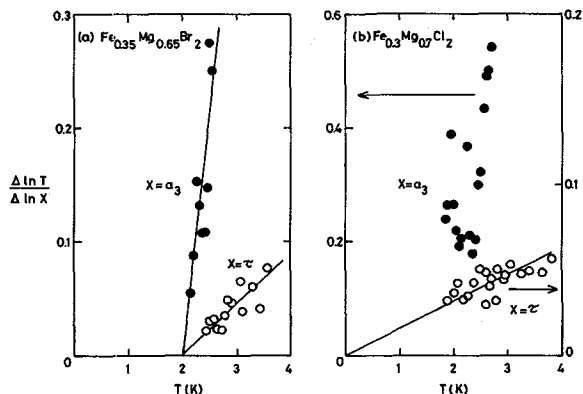


Fig. 2. - Plots of  $\partial \ln(T) / \partial \ln(a_3)$  and  $\partial \ln(T) / \partial \ln(\tau)$  vs.  $T$  for  $\text{Fe}_{0.35}\text{Mg}_{0.65}\text{Br}_2$  (a) and  $\text{Fe}_{0.3}\text{Mg}_{0.7}\text{Cl}_2$  (b). The straight lines are simple guides to the eye.

dynamic exponent  $z\nu \geq 25$  which may explain large relaxation time and therefore a strong dependence of the field cooled magnetisation on the cooling rate and an associated difficulty to reach reliable values of  $a_3$  and  $a_5$ . It may be argued that with  $J_1 \sim 10$  K and  $J'_1 \sim J_2 \sim -1$  K the 2d character is more marked in  $\text{Fe}_{0.3}\text{Mg}_{0.7}\text{Cl}_2$  than in  $\text{Fe}_{0.35}\text{Mg}_{0.65}\text{Br}_2$  where  $J'_1$  and  $J_2$  ( $\sim -3$  K) are comparably closer to  $J_1$  ( $\sim 10$  K).

Another possibility could be to decide that a different theory should be pertinent for  $\text{Fe}_{0.3}\text{Mg}_{0.7}\text{Cl}_2$ . For example the assumption of critical activated dynamics states that  $\tau / \tau_0 = \exp(W / kT)$  where  $W$ , and not  $\tau$ , is a power of the coherence length  $\xi$  [6, 7]:

$$W = kT \ln(\tau / \tau_0) \sim \xi^\psi \sim (1 - T_c / T)^{-\psi\nu}. \quad (6)$$

This generalises an argument that Binder and Young [8] first developed in the specific case where  $T_c = 0$  when they deduce "rapidly" from equation (2) that  $\xi \sim (T - T_c)^{-\nu} \rightarrow T^{-\nu}$  and find therefore with equation (6) that:

$$\tau / \tau_0 = \exp(A / T^\sigma). \quad (7)$$

We want to stress that there is no need for such an *ad hoc* argument to obtain essential singularities of the form (7) as the natural  $T_c = 0$  limit of the usual scaling theory (Eqs. (2-4)) is an exponential in all interesting cases where  $\theta_X$  remains finite. We have for example [4]:

$$\tau / \tau_0 = (1 - T_c / T)^{-\theta_\tau / T_c} \xrightarrow{T_c \rightarrow 0} \exp(+\theta_\tau / T). \quad (8)$$

Of course our accuracy would not permit to discard equation (6) or (7) to the benefit of equation (4) or (8). However we tend to resist the idea that two different theories are needed for such similar systems. If we use equations (6) and (7) in both systems we will also have to explain large differences in the exponents  $\psi$  and  $\sigma$ . Our position is to accept the results that exponents may be either large ( $z\nu \sim 25$  for  $T_c \sim 1.4$  K) or even infinite (if  $T_c \rightarrow 0$ ) in  $\text{Fe}_{0.3}\text{Mg}_{0.7}\text{Cl}_2$  and at the same time could present standard finite values in another similar system ( $\text{Fe}_{0.35}\text{Mg}_{0.65}\text{Br}_2$ ) or even the same ( $\text{Fe}_x\text{Mg}_{1-x}\text{Cl}_2$ ) with a different concentration. We believe that the idea of universality class changing discontinuously with space dimensionality should be reconsidered for spin glasses with short range interactions. Any such system presents at least two dimensionalities depending on whether the scale  $L$  at which it is considered is larger or smaller than a structural coherence length  $\xi_s \sim (p - p_c)^{-\nu'}$ . In a spin glass where there are simultaneously correlations at all scales smaller than the magnetic coherence length, we feel that the class of universality should rather be associated to a fractal dimension characteristic of the disorder which could vary continuously with the concentration and diverge at the percolation threshold.

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