Irreversibility onset in spin glasses from torque measurements

I.A. Campbell, N. de Courtenay, A. Fert

► To cite this version:

I.A. Campbell, N. de Courtenay, A. Fert. Irreversibility onset in spin glasses from torque measurements. *Journal de Physique Lettres*, 1984, 45 (11), pp.565-570. 10.1051/jphyslet:019840045011056500 . jpa-00232382

HAL Id: jpa-00232382

<https://hal.science/jpa-00232382>

Submitted on 1 Jan 1984

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Classification

Physics Abstracts

75.40F — 75.30K

Irreversibility onset in spin glasses from torque measurements

I. A. Campbell, N. de Courtenay and A. Fert

Physique des Solides, Université de Paris-Sud, Bâtiment 510,
Centre d'Orsay, 91405 Orsay Cedex, France

(Reçu le 8 février 1984, révisé le 23 mars, accepté le 30 mars 1984)

Résumé. — Des mesures de couple plus sensibles sur CuMn et AgMn donnent une température d'apparition du couple indépendante du champ pour H compris entre 0,5 kG et 9 kG. Ce résultat est compatible avec les prévisions de champ moyen concernant le gel transverse (ligne GT).

Abstract. — Improved torque measurements on CuMn and AgMn alloys show a field independent torque onset temperature for fields from 0.5 kG to 9 kG. This result is compatible with mean field transverse freezing (GT line) predictions.

It is now well established that for the canonical metallic spin glasses irreversibility sets in at a temperature very close to the ac susceptibility cusp temperature T_g for experiments performed in near zero applied field [1]. The onset temperature for irreversibility in stronger applied fields has been the subject of considerable controversy. Recently we reported small angle torque measurements on a CuMn sample which showed that the irreversibility onset temperature varied little with applied field; the experimental temperature dependence appeared to be compatible with the mean field model cross-over de Almeida-Thouless (AT) line [2]. We have now considerably improved the experimental set up, increasing the sensitivity by the order of 100 and improving the thermometry. New results on CuMn 2 %, AgMn 2.6 % and AgMn 0.8 % samples show that the irreversibility onset temperature as estimated by the torque criterion is essentially field *independent* in our experimental field range.

We use a capacitance bridge technique to measure torque at temperatures down to 1.5 K and fields up to 9 kG on samples of approximately 1 g. Our standard experimental procedure consists in cooling the sample in a field H_c at cooling angle $\theta = 0$ from well above T_g to a temperature T . We then turn the field to $\theta = + 5^\circ$, back to $\theta = 0$, to $\theta = - 5^\circ$ and finally back to $\theta = 0$ with a turn time of about 1 second and a pause time at each angle of about 1 minute. A signal proportional to the torque is exhibited as a function of time on an XY recorder. The sample is then warmed above T_g and the procedure is repeated for a different choice of T or H_c . As a complementary experiment torque was measured over the range of θ from 0 to 180° and back at $T = 1.5$ K.

As we have previously suggested [2] the existence of non-zero torque in experiments such as this is a criterion which can be used to establish the presence of irreversibility. For an isotropic paramagnetic sample $\mathbf{M}$ and $\mathbf{H}$ are parallel so there is no torque; if torque is observed in an

isotropic system the sample must necessarily be in an ordered state. It would probably be more correct to use the expression « non ergodic » rather than « irreversible » as irreversibility implies loss effects in the response to an external stimulus, while rigid spin torque can be lossless, but its existence is evidence that the system is not free to minimize free energy and hence is non ergodic.

The low temperature torque of fairly concentrated CuMn alloys has been studied in some detail [3]; it has been shown to arise from Dzyaloshinsky-Moriya coupling with the lattice. For our purpose it can be considered as leading to a unidirectional anisotropy which for a rigid spin system with remanent magnetization $\mathbf{M}_r$ induced by field cooling along z gives a total energy which can be written :

$$\frac{K}{|\mathbf{M}_r|} \mathbf{M}_r \cdot \mathbf{z} - \mathbf{H} \cdot \mathbf{M}_r.$$

We will be concerned principally with small angle properties — in the experimental protocol we have used turn angles are always small. The torque Γ is then given by :

$$\frac{\theta}{\Gamma} = \frac{1}{K} + \frac{1}{M_r H}.$$

If $M_r H \gg K$, then $\Gamma \cong K\theta$.

Typical torque curves at different temperatures are shown in figure 1. The initial torque after the field is turned is estimated by extrapolating back to time $t = 0$ and we can plot $\Gamma_0(T)$ for different values of H_c (Fig. 2). The results show for each field $\Gamma_0(T)$ which appears to tend to zero approximately as $(T^* - T)$ where T^* is a temperature which is field independent to the accuracy of the present experiment. As the curves for different fields coincide for $H \lesssim 1$ kG near T^* , we are in the limit $M_r H \gg K$ and $\Gamma \cong K\theta$ with K independent of H (only in this limit is the torque independent of M_r , H and hence of H). $K(T)$ thus varies approximately as $(T^* - T)$ near T^* .

Fig. 1. — Torque measurements on AgMn 2.6 % at different temperatures with $H_c = 2$ kG. Note scale change at $T = 8.6$ K. The arrows indicate times at which the field is rotated by $\pm 5^\circ$. In the 10.2 K measurement the weak residual signal is due to background eddy current and parasitic cell effects. This background signal is temperature independent.

Fig. 2. — Initial torque $\Gamma_0(T)$ for different applied fields H_c . The sample is AgMn 2.6 %. H_c values : (O) 0.58 kG ; (+) 1.13 kG ; (Δ) 5.5 kG ; ($\bullet$) 9.15 kG.

If the spin system is rigid then Γ will be independent of time, but the anisotropy $\tilde{K}$ is a remanent quantity which like the remanent magnetization can change with time. In fact we observe relaxation effects which are weak on the scale of one minute for T well below T^* but which accelerate as T approaches T^* . Torque relaxation has been discussed in terms of a reorientation of the anisotropy axis with time [4], and the data reported here are consistent with those of Pastora *et al.* [4] except that we find no limiting lower turn angle below which no relaxation occurs at any temperature.

Susceptibility measurements on the same samples as used in torque experiments [5] showed well defined cusp temperatures T_g which were not identical to the T^* values as defined above. For the three samples the values were :

<u>CuMn</u> 2 %	$T_g = 14.0$ K	$T^* = 12.1$ K
<u>AgMn</u> 2.6 %	$T_g = 10.85$ K	$T^* = 9.6$ K
<u>AgMn</u> 0.8 %	$T_g = 4.4$ K	$T^* = 3.8$ K.

In each case $T^*/T_g \cong 0.9$.

One might suspect that relaxation effects were the cause of the disappearance of the torque signal at $T < T_g$. However except for very close to T^* we can extrapolate back to $\Gamma_0(T)$ with some confidence so the points in figure 2 can be considered to be corrected for relaxation.

We can examine the results in terms of mean field model phase diagrams [6]. On this model, a $m = 3$ Heisenberg system should show onset of transverse irreversibility at a temperature T_{GT} which varies with field as :

$$T_{GT} = T_g(1 - \lambda(H/T_g)^2). \quad (1)$$

A second less well defined criterion suggests an Ising-like cross-over temperature for strong longitudinal and transverse irreversibility at :

$$T_{AT} = T_g(1 - \mu(H/T_g)^{2/3}). \quad (2)$$

The model GT coefficient λ is such that in our range of reduced fields T_{GT} would be virtually independent of field, so our results are compatible with an onset of non-ergodic behaviour below

a GT-like line with however the difference that our T_{GT} is not T_g but a temperature T^* slightly lower than T_g .

We can comment on the reasons which have led us to revise our previous conclusion [2] that the torque data was compatible with a T_{AT} limit for irreversibility. First, the experiments reported in reference [2] gave results which agree with the new measurements within their respective error bars (Fig. 3), although the new measurements are more reliable as the sensitivity has been

Fig. 3. — The temperature for onset of observable torque signal as a function of applied field. The temperature is normalized to T_g , the cusp temperature, and the field is normalized using $h = g\mu_B H \sqrt{\frac{S(S+1)}{3}}/kT_g$.

The lines labelled GT and AT are $T_{GT}(H) = T_g(1 - 0.23 h^2)$ and $T_{AT}(H) = T_g\left(1 - \left(\frac{5}{2}\right)^{1/3} h^{2/3}\right)$ respectively [6]. Experimental points correspond to : (●) AgMn 2.6 %, (○) CuMn 2 %, (+) AgMn 0.8 %, (◐) CuMn 2 % Ref. [2].

improved and small systematic temperature errors have been eliminated. Secondly we now have precise values of the cusp temperatures T_g for each sample, and we have worked with samples having lower T_g values which has enabled us to attain higher H/T_g ratios. Finally in comparing with the mean field model we have used the normalization :

$$h = g\mu_B H \sqrt{\frac{S(S+1)}{3}}/kT_g \quad (3)$$

rather than

$$h = g\mu_N H/kT_g \quad (4)$$

which we used in reference [2] following Chamberlin *et al.* [8]. The problem of the normalization was raised by K. Baberschke, and we chose this normalization (3) after discussion with him. It equates the high temperature paramagnetic susceptibilities of the classical model spins and the real quantum spins for $m = 3$. There is no perfectly satisfactory way of passing from a classical to a quantum system, but this seems to us the least unsatisfactory.

Thus we now conclude that for the range of reduced fields, we have worked with, the experimental results represented in figure 3 are not compatible with the model T_{AT} either as concerns the form of the H versus T relation or as concerns the order of magnitude.

The difference between our observed T^* and T_{GT} might be explained by recent theoretical work by Kotliar and Sompolinski [7] who have studied a mean field model of a Heisenberg spin glass with weak random anisotropy. They predict Ising-like behaviour (with an AT-like irreversibility temperature dropping as $H^{2/3}$) below a threshold field related to the anisotropy strength, and a Heisenberg-like behaviour (with a quasi-field-independent GT-like irreversibility temperature) above the threshold field. Our results are consistent with this picture if one assumes that the threshold field of our alloys is below our experimental field range (our lowest field was 0.5 kG). We can note that T^*/T_g at our lowest field coincides with the reduced « branch point » temperature of Chamberlin *et al.* [8] on AgMn 2.6 % at their highest experimental field which is 430 gauss. It is possible that there is a cross-over field from AT to GT behaviour in the region of 500 gauss for this sample. It would be interesting to investigate alloys with strong anisotropy.

We can compare the present results, with other types of experiment [8]. There is a considerable body of evidence that there is a rather well defined cross-over from viscous to non-viscous behaviour in longitudinal fields with a limiting field-temperature relation of the AT type (but with an experimental coefficient μ which is generally 10 to 100 times the model coefficient). In the longitudinal experiments, there does not seem to be any sign of the non ergodicity onset which we observe here. There are a number of possible explanations for this apparent disagreement. There may be a fundamental difference between the two types of measurement, with the longitudinal experiments sensitive only to the onset of *strong* irreversibility (AT line) while the torque measurements are sensitive to weak transverse irreversibility (GT line), as we are turning the spin system against local anisotropy fields. However it may be that if the anisotropy of each system plays an important rôle [7] we cannot compare directly the present experiments on low anisotropy systems in relatively strong fields with results on high anisotropy systems, or with measurements made in low fields. Experiments are needed in which magnetization and torque measurements are made on the same samples in the same range of fields.

Finally, it is possible that the observed viscosity onset in longitudinal fields is not associated with the AT line at all, but has a different physical origin. For instance if we think in terms of domain structure in a spin glass, there should be a limiting field for full domain alignment which would play the rôle of a cross-over field separating reversible and irreversible regimes at each temperature. This limit has no obvious analogy in a mean field model, for which there is no spatial dimension and for which the domain concept is inapplicable (cf. Malozemoff *et al.* [8]).

Specific heat measurements on CuMn have shown a small feature near T_g which only moves to appreciably lower temperatures in very strong fields [9]. This has also been taken to show GT behaviour.

In conclusion, torque measurements on canonical spin glasses have demonstrated that the systems show observable non ergodic behaviour below a temperature T^* which is essentially independent of applied field in the range of reduced fields

$$0.05 < H/T_g < 2 \text{ kG/K}.$$

T^* is about $0.9 T_g$ for the samples we have studied. This behaviour appears to be compatible with the mean field model transverse irreversibility (GT line) behaviour. Further work is needed to probe the region between T^* and T_g , and to investigate samples with strong anisotropy.

Acknowledgments.

We are very grateful to H. Bouchiat, J. P. Renard, K. Baberschke and H. Sompolinsky for samples, susceptibility measurements and for helpful discussions.

References

- [1] See references in MYDOSH, J. A., *J. Phys. Soc. Jpn* **52** (1983) S85.
 - [2] CAMPBELL, I. A., ARVANITIS, D. and FERT, A., *Phys. Rev. Lett.* **51** (1983) 57.
 - [3] IWATA, T., KOI, K., NAKAMICHI, T. and YAMAMOTO, M., *J. Phys. Soc. Jpn* **28** (1970) S82.
FERT, A. and HIPPERT, F., *Phys. Rev. Lett.* **49** (1982) 1508.
FERT, A., ARVANITIS, D. and HIPPERT, F., to be published in *J. Appl. Phys.* (MMM Conference 83).
 - [4] PASTORA, J. B., ADAIR, T. W. and LOVE, D. P., *J. Physique Lett.* **44** (1983) L-859.
 - [5] BOUCHIAT, H. and RENARD, J. P., private communications.
 - [6] GABAY, M. and TOULOUSE, G., *Phys. Rev. Lett.* **47** (1981) 201.
CRAGG, D. M., SHERRINGTON, D. and GABAY, M., *Phys. Rev. Lett.* **49** (1982) 158.
 - [7] KOTLIAR, G. and SOMPOLINSKY, H., to be published.
 - [8] MONOD, P. and BOUCHIAT, H., *J. Physique Lett.* **43** (1982) L-45.
CHAMBERLIN, R. V. *et al.*, *Phys. Rev. B* **25** (1982) 6720.
YESHRUN, Y. and SOMPOLINSKY, H., *Phys. Rev. B* **26** (1982) 1487.
THOLENCE, J. L. and SALAMON, M. B., *J. Magn. Magn. Mater.* **31-34** (1983) 1340.
SALAMON, M. B. and THOLENCE, J. L., *J. Appl. Phys.* **53** (1982) 7684.
YESHRUN, Y., KETELSEN, L. J. P. and SALAMON, M. B., *Phys. Rev. B* **26** (1982) 1491.
MALOZEMOFF, A. P., BARNES, S. E. and BARBARA, B., *Phys. Rev. Lett.* **51** (1983) 1704.
 - [9] FOGLE, W. E. *et al.*, *Phys. Rev. Lett.* **50** (1983) 1815.
-