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Anisotropy dynamics of CuMn spin glass through torque measurements

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Résumé. — La dynamique de l'énergie d'anisotropie, E_a , est étudiée sur un échantillon de verre de spin CuMn : 0,5 at. % par mesure de couple. Après réduction à zéro du champ de refroidissement dirigé suivant l'axe des $\hat{Z}$, et après un délai suffisant pour rendre négligeable l'effet du déclin temporel de l'aimantation, un champ de mesure H est appliqué à un angle de 90° par rapport à l'axe des $\hat{Z}$. Le couple d'anisotropie Γ décroît par suite de la redéfinition de la direction θ_N de l'axe d'anisotropie $\hat{N}$ par rapport à l'axe des $\hat{Z}$ pour $H \geq 70$ Oe et $T = 2,39$ K. L'angle θ_N croît avec H et T . E_a s'avère être unidirectionnelle seulement.

Abstract. — The dynamics of anisotropy energy, (E_a), in a CuMn 0.5 % spin glass sample is investigated by torque measurements. After reducing the cooling field along the $\hat{Z}$ axis to zero and delaying to allow the time decay of magnetization to diminish, a measuring field H is applied 90° from $\hat{Z}$. The anisotropy torque Γ decays due to redefinition of the direction θ_N of the anisotropy axis $\hat{N}$ with respect to $\hat{Z}$ for $H \geq 70$ Oe at $T = 2.39$ K. The angle θ_N increases with H and T . E_a is found to be unidirectional only.

The macroscopic anisotropy energy of metallic spin glasses has been investigated through magnetization [1, 2], susceptibility [3, 4], ESR [5, 6], NMR [7] and torque [4, 8, 9] measurements. The usual theoretical approach [3, 5, 10, 11] is to assume that the remanent magnetization σ undergoes rigid rotations about an anisotropy axis $\hat{N}$ which remains fixed, although Saslow has developed (following a suggestion of Monod) a theory which permits the anisotropy to be redefined by the measurement [12]. An anisotropy energy term, $E_a(\theta)$ is usually introduced into the macroscopic free energy E , such that with a measuring magnetic field $\mathbf{H}$,

$$E = E_a(\theta) - \sigma \cdot \mathbf{H} \quad (1)$$

where θ is the angle between σ and $\hat{N}$. It has been established [2] that for CuMn, $E_a(\theta)$ has a strong unidirectional (2π -periodic) component. Iwata *et al.* [8] also claimed to have measured a weak uniaxial (π -periodic) component. Since then, many experiments [3, 5, 13] have been analysed considering both types of contributions to $E_a(\theta)$, i.e. :

$$E_a(\theta) = -K_1 \cos \theta + K_2 \sin^2 \theta \quad (2)$$

where K_1 and K_2 are the unidirectional and uniaxial anisotropy constants respectively. Recent experimental evidence however [4, 9], points to the fact that for CuMn only the unidirectional component is present.

Under equilibrium conditions, equation 1 yields

$$\frac{\partial E}{\partial \theta} = 0 = \frac{dE_a(\theta)}{d\theta} - \sigma H \sin(\theta_H - \theta)$$

where θ_H is the angle between $\mathbf{H}$ and $\hat{N}$. That is, the anisotropy torque Γ_a (which is equal and opposite to the measured Zeeman torque) acting on σ is given by :

$$\Gamma_a = \frac{dE_a(\theta)}{d\theta} = K_1 \sin \theta + K_2 \sin 2\theta \quad (3)$$

assuming both types of contributions to $E_a(\theta)$ as in (2).

In this letter we report anisotropy torque decay measurements on a CuMn 0.5 % sample, which show a redefinition of the anisotropy axis $\hat{N}$ by the measuring field $\mathbf{H}$, even for relatively small values of $\mathbf{H}$ (≥ 70 Oe). Our results also indicate the presence of only an unidirectional component of the anisotropy energy.

Our measurements are made with a compensating torque magnetometer to be described elsewhere [14]. The experimental situation is shown in figure 1. The sample is cooled through the spin glass temperature, $T_0 = 8$ K, in the presence of a 7 kOe magnetizing field along the $\hat{Z}$ axis. This field causes a remanent magnetization σ_0 and establishes the initial direction $\hat{N}_0$ of the anisotropy axis, which coincides with $\hat{Z}$. It is a well known fact [15] that σ_0 decays with time, thus after reducing the cooling field to zero, a time delay of 85 ± 5 min. is allowed to prevent σ decay from being an important factor in our measurements. Then a small measuring field $\mathbf{H}$ is applied along $\hat{Z}$. Under these conditions, the torque on the sample is zero. Then $\mathbf{H}$ is rapidly rotated to a direction 90° from $\hat{Z}$. The torque Γ has a maximum value when $\mathbf{H}$ reaches the 90° position and then starts to decrease very rapidly. (Actually Γ was found to decay at all angles $\geq 10^\circ$ for $H = 700$ Oe but we decided to do the study by systematically rotating H to 90° from $\hat{Z}$ in order to maximize the effect for small fields). Typical measurements of the decay part of the cycle after Γ has reached

Fig. 1. — Experimental conditions for torque decay measurements. The sample is cooled through the spin glass temperature in a 7 kOe field H_c along $\hat{Z}$. This induces a remanent magnetization σ_0 and anisotropy axis $\hat{N}_0$. We delay for over an hour after reducing H_c to zero to allow σ to decay. Then a small $\mathbf{H}$ is set along $\hat{Z}$. $\mathbf{H}$ is rotated (~ 8 s) to 90° away from $\hat{Z}$, Γ increases to a maximum and then it starts to decay when H is at 90° . After a Γ decay curve is completed, $\mathbf{H}$ is decreased and rotated back toward $\hat{Z}$. A direction θ_N is found for which $\Gamma = 0$. Further rotation of the magnet toward $\hat{Z}$ yields a torque of opposite sign. θ_N is the direction $\hat{N}$ has been redefined to by the measurement. The dashed lines indicate the position of $\hat{N}$ and σ sometime during Γ decay.

a maximum value are shown in figure 2 as a function of measuring field and of temperature. After data for a decay curve has been obtained, H is reduced to a small value (~ 10 Oe) in order to prevent any further distortion of the system. Then the magnet is rotated back towards $\hat{Z}$ (Fig. 1), which causes Γ to decrease to zero at a new direction θ_N . Upon further rotation of the magnet toward $\hat{Z}$, a torque of the opposite sign will appear. The only possibility for Γ to be zero at θ_N is for σ to coincide with $\hat{N}$ at that angle. These results show that the anisotropy axis has been redefined by the measuring field to a new direction θ_N^0 away from $\hat{Z}$, a fact reported for the first time. Results of θ_N vs. H and θ_N vs. T are presented in figure 3. There it is seen that redefinition of θ_N is most easily obtained at high H and high T .

Redefinition of θ_N causes Γ to decay in time due to the fact that the angle $(\theta_H - \theta)$ between σ and H decreases. The dynamics of Γ decay itself will be discussed elsewhere [14]. Preliminary results indicate the value of the anisotropy constant remains approximately the same after redefinition of θ_N . This point will be more carefully investigated, but the redefinition of θ_N is the most important reason for the Γ decay.

Our results of redefinition of the direction of net anisotropy (θ_N) by the measuring field are contrary to the usual assumption of rigid rotations of the remanent magnetization σ around a fixed anisotropy axis, $\hat{N}$, frequently used to interpret most studies of anisotropy energy through different types of measurements. Also our results explain the irreversibility and time dependent effects found on previous ESR [13], torque [4, 9] and transverse susceptibility [3, 4] measurements at large values of θ_H and of measuring field H ; i.e., the net anisotropy direction is redefined by the measuring field, inducing irreversibility and time decay.

An extrapolation of the low field data of figure 3 shows (for the conditions of that figure) the existence of a threshold field $H_{th} \approx 50$ Oe for which θ_N is zero. That is at $T = 2.39$ K and $H \leq 50$ Oe there is no redefinition of the anisotropy axis' direction. This H_{th} should decrease as tempe-

Fig. 2. — Typical torque decay curves for (a) constant temperature and (b) constant measuring field H . At small values of H , Γ decays gradually while at larger H (700 Oe) about 90 % of the total decay occurs during the first four minutes. That means redefinition of anisotropy axis direction occurs very rapidly at large H . Similarly, at high T (4.4 K) most of the decay occurs in the first couple of minutes. Thus the anisotropy direction is most easily redefined at high H and high T . For this sample $T_0 \approx 8$ K.

Fig. 3. — Variation of redefinition of anisotropy direction, θ_N with measuring field H and temperature T . A given data point is taken after 45 min. of corresponding Γ decay. θ_N is most easily redefined at high T and large H . Extrapolation of θ_N vs. H indicates the existence of a threshold field $H_{th} \simeq 50$ Oe for which $\theta_N = 0$. Thus, for our sample at $T = 2.39$ K, torque curves (Γ vs. θ_H) should be measured with $H < 50$ Oe to avoid torque decay due to redefinition of θ_N .

rature increases, and *vice versa*, as indicated by the larger net decay of the 4.4 K curve in figure 2b. Thus any study of anisotropy energy through any type of measurement (ESR, χ_L , etc.) should be done with measuring fields lower than the threshold field corresponding to the given conditions of temperature and impurity concentration, in order to avoid redefinition of the anisotropy axis' direction.

We performed measurements of Γ vs. θ_H for $T = 2.39$ K and $H < 50$ Oe. The Γ vs. θ_H curves obtained are 2π -periodic. These results indicate that $E_a(\theta)$ is unidirectional only. Otherwise a uniaxial (π -periodic) shape contribution should have appeared at small H before redefinition of anisotropy direction occurs. The anisotropy energy also stays essentially unidirectional after θ_N has been redefined by a large measuring field.

We have reported here results for a CuMn 0.5 % spin glass sample which for the experimental conditions of figure 1 demonstrate that after removing the time decay of σ , for measuring fields > 50 Oe the anisotropy axis $\hat{N}$ is still in a dynamic state. A redefinition of the orientation θ_N with respect to $\hat{Z}$ by the measuring field H in time is demonstrated. This effect is contrary to the assumption of rigid rotations of σ around a fixed anisotropy axis commonly used to interpret most previous susceptibility, ESR, and torque measurements. This redefinition of θ_N together with Γ vs. θ_H measurements at $H < 50$ Oe show the anisotropy energy to be unidirectional only, in agreement with other workers [4, 9]. Our results demonstrate that whenever a large measuring field applied away from $\hat{Z}$ is used for any experiment on this type of material, the system is being forced into a perturbed state, namely one with a new direction of the net anisotropy axis. In this situation one would not measure the intrinsic properties of the system, but the properties of the state the system is forced into by the measuring field.

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