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DOMAIN-WALL RELAXATION NEAR THE CURIE TEMPERATURE OF UNIAXIAL GdCl₃

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Abstract. — The kinetic coefficient associated with the domain-wall motion exhibits a critical speeding up close to \( T_c \). Damping by longitudinal spin-spin-relaxation within "linear" walls is proposed to explain this intrinsic phenomenon.

The present understanding of structure, formation and dynamics of ferromagnetic domains is still incomplete. In essence, the difficulties arise from the nonlocal and anisotropic nature of the dipole-dipole-interaction [1]. Very recently, some dipolar effects on the magnetization-profile of a single domain [2], on domain-branching [3, 4] and wall dynamics [5] in thin slabs of uniaxial ferromagnets have been calculated.

Here we investigate the domain dynamics of the uniaxial, dipolar-dominated (Curie’s constant = 1.69 K \( \simeq \ T_c = 2.21 \) K) ferromagnet GdCl₃, including the critical region just below \( T_c \). We have measured the complex susceptibility \( \chi(\omega) \) along the easy (hexagonal) axis in the frequency range from 2 Hz to 10 MHz. The influence of shape and of impurities was studied on samples with different demagnetization-coefficients \((N = 0.056, 0.183 \text{ and } \approx 0.53)\) and \( \text{Nd}^{3+} \)-impurities. The effect of magnetic fields will be published separately [6]. The Argand-diagrams for GdCl₃, plotted for one sample in figure 1a, reveal a single relaxation process, which is well described by the following modified Debye-formula:

\[
\chi(\omega) = \chi_2 + \frac{\chi_1 - \chi_2}{1 + (i\omega\tau_d)^{1-\alpha}},
\]

where \( \alpha \) determines the width of a relaxation-time distribution around the mean \( \tau_d \) [7] increasing from 0.05 near \( T_c \) to 0.15 at \( T = 1.5 \) K. Since for all temperatures \( \chi(\omega \rightarrow 0) \) reaches the limit \( 1/N, \tau_d^{-1} \) is associated with the domain wall motion. \( \chi_2 \) can be identified with the adiabatic susceptibility \( \chi_a \) (i) via the thermodynamic relation \( \chi_a = \chi_T - (T/\chi_H)(\partial M_s/\partial T)^2 \) using data for \( \chi_H \) [8], \( M_s \) and \( \chi_T \) determined from static magnetization [9], and (ii) by comparison with the result of a renormalization group calculation by Bruce [10], \( \chi_a/\chi_T=1/4 \). This behaviour contrasts to that of the 3d-ferromagnets \( \text{CuRb}_2\text{Br}_4 \) [11] and \( \text{CrBr}_3 \) [12], for both of which \( \chi_a \) agreed with the isothermal susceptibility \( \chi_T \) due to faster spin-lattice-relaxation.

Figure 1b demonstrates the dramatic effect of 5 % Nd impurities. Even at 2.5 Hz, a new, extremely slow process prevents \( \chi_1 \) from reaching \( 1/N \), however, a residual domain-wall contribution to the magnetization dynamics still appears to be present. The mean relaxation rates, evaluated from the maxima of \( \chi''(\omega) \), are of the same order of magnitude as those of the pure system.

The \( \tau_d \)-values shown in figure 2 display three distinct features: (i) critical \((T \rightarrow T_c)\) speeding up of domain-wall relaxation in the pure samples, (ii) \( N \) decreases the relaxation times, and (iii) impurities cause a critical slowing down. To discuss these findings, we start with the second order continued fraction of the line...

Fig. 1. — Comparison of \( \chi(\omega) \)-data with fits to the modified Debye formula (Eq. (1)) in the Argand-diagram.

Fig. 2. — Temperature dependence of the average domain relaxation times of different GdCl₃ samples close to \( T_c \).
ear $\chi(\omega)$ [13], which generally relates $\tau_d^{-1}$ to a kinetic coefficient $L$,

$$L = \tau_d^{-1} \frac{\lambda^2}{(\chi_1 - \chi_2)}.$$  (2)

That $L$ can be considered as the intrinsic quantity associated with the domain-wall-motion is demonstrated by figure 3, proving that the kinetic coefficient really is the same for all samples. $L$ speeds up by a power-law in terms of $t = 1 - T/T_c$, $L = A t^{-z}$, with $z \approx 0.7$ and $A \approx 1.1$ MHz.

Often the relaxation rate $\tau_d^{-1}(T)$ is related to an Arrhenius law, $\tau_d^{-1} = \Gamma_0 \exp(-\Delta/T)$, associated with a thermally activated movement across an anisotropy barrier $\Delta$ [e.g., 11, 14]. Obviously, this does not hold for GdCl$_3$. Rado [15] described the dynamics of 180° Bloch-walls in ferrites at $T \ll T_c$, including the Landau- Lifshitz-damping. The motion becomes overdamped for strong spin-spin-relaxation, $\lambda > |\gamma| M_s (\delta/2\pi d x_1)^{1/2}$, where $\delta$ and $d$ denote the wall thickness and the average domain size, respectively. This limit is appropriate for GdCl$_3$ ($\gamma M_s = 24$ GHz, $\lambda = 10$ GHz [16]), so that we obtain for the kinetic coefficient from Rado's paper:

$$L_d^\text{rot} = \frac{\delta (\gamma M_s)^2}{\lambda}.$$  (3)

However, our experimental value $L_d \approx 1$ MHz implies $\delta/d \approx 10^{-4}$, which appears to be rather low as compared to an estimate by Dillon and Remeika [17] for a slab of a soft uniaxial ferromagnet, $\delta/d = (1.7 \pi M_s^2)/4 K \approx 10^{-2}$.

Alternatively, one may assume so-called "linear 180° walls" [18], which should be energetically favoured near $T_c$, where $\chi_\parallel > \chi_\perp$ is valid for all uniaxial ferromagnets. Supposing that now the longitudinal dipolar spin-spin-relaxation $\lambda_\parallel$ causes the spin damping of spins inside the walls, we replace equation (3) by

$$L_d \approx \frac{\delta}{d} \lambda_\parallel.$$  (4)

Insertion of $\delta = a t^{-\nu}$ [19] ($a$: lattice parameter) and $d = d_0 \nu^{3/2}$ [2] leads to $L_d \approx (a/d_0) t^{-z} \lambda_\parallel$ with $z = 3/2\nu \approx 0.79$, which is in substantial agreement with the observed speeding up. Furthermore, $\lambda_\parallel (T \approx T_c) = 20$ GHz [20] implies a domain width of $d_0 = 2 \times 10^4 a \approx 10 \mu$m, which roughly corresponds to direct measurements of $d$ in similar systems and so supports our equation (4).

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