Spin reversal in 180° domain walls of the spin-flip phase of easy-axis antiferromagnets

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A phase transition involving a change in the structure of the domain walls separating antiferromagnetic domains with different directions of the antiferromagnetism vector should occur in an easy-axis antiferromagnet in a magnetic field stronger than the field corresponding to the spin-flip transition. This effect has been observed experimentally in the orthorhombic antiferromagnet $CuCl_2 \cdot 2H_2O$.

The transition of an antiferromagnet from the paramagnetic phase to an ordered state causes the formation of regions with antiparallel directions of the antiferromagnetism vector $\mathbf{l} = (\mathbf{M}_1 - \mathbf{M}_2)/2M_0$ ($\mathbf{M}_i$ is the magnetization, i specifies the sublattice, and $M_0 = |\mathbf{M}_i|$). These regions are separated by 180° domain walls.[1]

For definiteness, we consider an orthorhombic antiferromagnet without a Dzyaloshinskiĭ interaction [the $t(-)$, $\bar{l}(-)$ structures in Turov's classification[2]] in a magnetic field parallel to the easy-magnetization axis (the OZ axis in the present study). As was shown in Ref. 3, at the transition through the intermediate state associated with the flipping of the magnetic moments of the sublattices in the spin-flip phase ($\mathbf{l} \| OX$), 180° domain walls form with a rotation of $\mathbf{l}$ in the plane that passes through the easy axis and the central axis (OX): domain wall I. In contrast with the antiferromagnetic phase, in which this structure of the domain wall is the only structure possible, in the spin-flip phase there may exist 180° domain walls in which the vector rotates in the plane perpendicular to the easy axis (in the XOY plane): domain wall II. While the rotation of $\mathbf{l}$ in domain wall I is accompanied by a substantial change in the resultant magnetization vector $\mathbf{m} = (\mathbf{M}_1 + \mathbf{M}_2)/2M_0$ (at the center of domain wall I, we have $\mathbf{m} = 0$), only $\mathbf{l}$ rotates in domain wall II, with $\mathbf{m}$ retaining its direction and essentially the same modulus.

How does an external magnetic field affect the energy of these types of domain walls? The energy density associated with the formation of domain walls (E_{wf}) is known to be determined by the energy of the inhomogeneous exchange interaction, $E_{\mathrm{ex}} = \alpha M_0^2$ (α is the constant of the inhomogeneous exchange interaction), and by the potential barrier ΔE separating the stable states of the system that occur in adjacent domains. Here we have $E_{\mathrm{wf}} \sim \sqrt{E_{\mathrm{exp}} \Delta E}$.

As $\mathbf{l}$ rotates in the XOZ plane (domain wall I), ΔE is equal to the difference between the energies of the antiferromagnetic phase ($\mathbf{l} \| OZ$) and the spin-flip phase ($\mathbf{l} \| OX$):

$$\Delta E = \frac{1}{2}\chi_{\perp}(H^2 - H_t^2), \tag{1}$$

where $\chi_\perp = 2M_0/H_e$ is the transverse susceptibility of the antiferromagnet, $H_e = 2\lambda M_0$ is the exchange field, λ is the magnitude of the intersublattice exchange interaction, $H_t = \sqrt{H_A^{XOZ} H_e}$ is the field of the spin-flip transition, and $H_A^{XOZ} = \beta M_0$ is the anisotropy field in the XOZ plane.[2]

If **l** rotates in the XOY plane (domain wall II), then ΔE is determined by the anisotropy field in this plane, H_A^{XOY}:

$$\Delta E^{\rm II} = H_A^{XOY} M_0 l = M_0 H_A^{XOY}\left[1 - \left(\frac{H}{H_e}\right)^2\right]. \tag{2}$$

It follows from (1) and (2) that $\Delta E^{\rm I}$ increases monotonically with increasing field, while $\Delta E^{\rm II}$ decreases, vanishing at $H = H_e$. Accordingly, in a certain field the 180° domain walls of type I formed during the spin-flip transition should convert into walls of type II. Most easy-axis antiferromagnets are systems with a slight anisotropy ($H_A^{XOY}, H_A^{XOZ} \ll H_e$). In this case the walls of type II become energetically favored even in fields far below the exchange fields. From the equality $\Delta E^{\rm I} = \Delta E^{\rm II}$, we find the following expression for the transition field H^*:

$$H^* = \sqrt{H_t^2 + H_e H_A^{XOY}} = \sqrt{H_e(H_A^{XOZ} + H_A^{XOY})}. \tag{3}$$

The same expression for H^* results from an exact calculation based on a comparison of the energy of a domain wall of type II,

$$E_{\rm wf}^{\rm II} = \sqrt{\alpha H_A^{XOY} M_0^3}\left[1 - \left(\frac{H}{H_e}\right)^2\right]^{1/2}, \tag{4}$$

with the energy of domain walls of type I, found in Ref. 3.

There is an important result to be noted here. The field at which the branches of the antiferromagnetic resonance intersect in the spin-flip phase of orthorhombic antiferromagnets (H'), calculated in Refs. 2 and 4, coincides in the case of a slight anisotro-

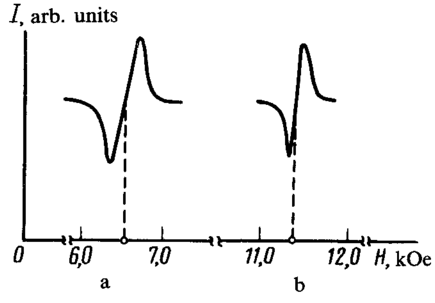

FIG. 1.

py ($H_A^{XOZ} \ll H_e$) with the field H^* given by expression (3). The spin reorientation in the domain wall of the spin-flip phase should therefore be expected at fields at which the antiferromagnetic-resonance lines intersect.

According to Ref. 4, in the orthorhombic antiferromagnet $CuCl_2{\cdot}2H_2O$ we have $H' = 11.2$ kOe at $T = 1.52$ K, and the resonant frequencies are 28.2 GHz.

In the present study of the single crystal $CuCl_2{\cdot}2H_2O$ at fields corresponding to the intersection of the antiferromagnetic-resonance frequencies, we observed an anomalous absorption of the rf field. The shape of the signal was similar to that observed during a spin-flip transition, while its intensity was two orders of magnitude lower. At $T = 1.52$ K, the signal was detected at a field $H^* = 11.662$ kOe ($H_t = 6.683$ kOe) and had a width of 80 Oe. Figure 1 shows the absorption lines in the field H^* (b) and in the field H_t (a) (reduced by a factor of 2×10^2). Over the frequency range studied (4.5–25 MHz) the absorption intensity increases monotonically with the frequency when the rf field is oriented along the hard axis of the crystal.

The nonresonant absorption that has been observed can be related in a natural way to an instability of the wall structure at $H \sim H^*$. The fact that the absorption is considerably lower than during the spin-flip transition is further evidence for this suggestion, since this lower absorption is related to a change in the structure of the insignificant part of the crystal occupied by the domain wall.

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