Temperature dependence of the magnetization in domain walls in ferromagnetic $CrBr_3$

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An NMR method has been used to study the magnetization in the domain walls of the easy-axis ferromagnet $CrBr_3$ at various temperatures. The magnetization varies in proportion to the square of the absolute temperature.

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One of the basic relations derived in the spin-wave theory is the temperature dependence of the magnetization (of the sublattices). If this dependence can be measured experimentally, it will be possible to test the spin-wave theory and to determine the nature of the magnon dispersion law.

Tsubokawa[1] discovered the ferromagnetic dielectric $CrBr_3$ in 1960. The magnetic system of this material is a good example of the Heisenberg model. Chromium tribromide is a hexagonal crystal with the BiI_3 structure. At 32.5 K it becomes a ferromagnet with an easy-axis anisotropy (a sixfold axis). The effective anisotropy field was determined by Dillon[2] ($H_A = 6.8$ kOe). The temperature dependence of the magnetization in $CrBr_3$ has been studied by the NMR method by Gossard, Jaccarino, and Remeika.[3–5] They interpreted the system of NMR lines observed by them as NMR signals from domains and from domain walls.

In our own study of the NMR in ferromagnetic $CrBr_3$ we have observed that in our samples the behavior of a line corresponding to a resonance in domain walls is different from that according to the data of Refs. 4 and 5. This behavior is the subject of the present letter.

The crystals of chromium tribromide studied in the present experiments were grown by L. A. Klinkova and her colleagues at the Institute of Solid State Physics, by a gas-transport reaction method.[6] The samples are wafers ~ 100 μm thick with an area on the order of 1 cm^2. Several of these crystals were placed in a channel in the frame of an inductance coil (inside the coil). This coil formed, along with a variable capacitor, a circuit with a resonant frequency that could be varied from 40 to 65 MHz. The frequency was tuned by varying the capacitance of the capacitor. The NMR was observed with a Bruker B-KR 322S pulse spectrometer. Measurements were taken over the temperature range from 2 to 20 K. The NMR frequency was determined by comparing the frequency of the free precession of the nuclear magnetization with a reference signal. The accuracy of these measurements was ±10 kHz at frequencies near 50 MHz.

Figure 1 shows the results found for the temperature dependence of the NMR frequency of the central component of the quadrupole-split triplet (Cobb *et al.*[5] interpret this triplet as corresponding to NMR in domains) and of a line corresponding to a resonance in domain walls. The position and temperature dependence of the NMR in the do-

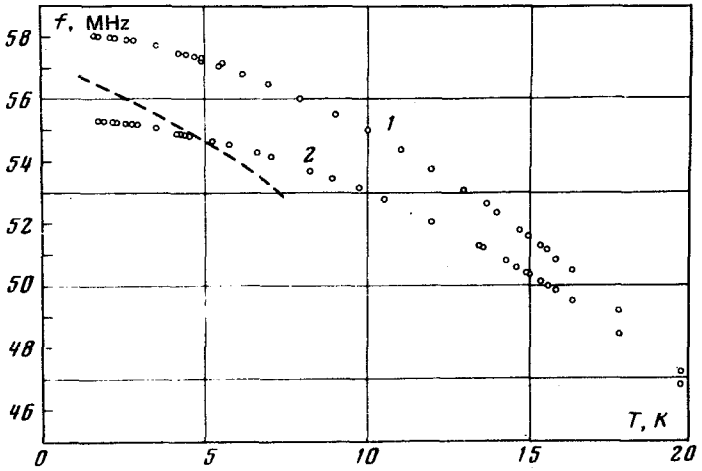

FIG. 1. Temperature dependence of the frequency of the central component of the NMR triplet. 1–NMR in domains; 2–in domain walls; dashed curve–data of Ref. 4.

mains agree well with the data of Ref. 3. The NMR in the domain walls behaves differently (the dashed curve corresponds to the data of Ref. 4). The temperature dependence of the NMR frequency is weaker in the domain walls, and there is a rather large difference between the effective hyperfine fields in the domains and the walls at $T=0$ ($\Delta H_{\text{eff}} = 11.7$ kOe).

In the region in which a domain structure exists, a ferromagnet simultaneously contains two magnetic systems of different sizes. The domains are three-dimensional entities, while the domain walls are approximately two-dimensional. The domain wall in $CrBr_3$ is quite thin, because of the comparatively weak effective exchange field and the large crystalline anisotropy. A comparative observation of the properties of these two systems in the same sample is of major interest here.

Figure 2 shows the dependence of the NMR frequency in the domain walls on T^2 and the dependence of the NMR frequency in the domains on $T^{3/2}$. In these coordinates,

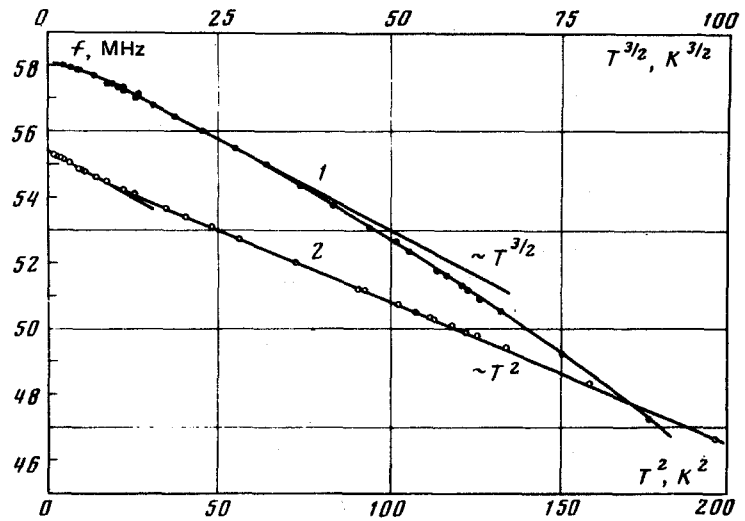

FIG. 2. 2–Dependence of the NMR frequency in the domain walls on the square of the temperature (lower abscissa scale); 1–dependence of the frequency of the central NMR component in the domains on $T^{3/2}$ (upper abscissa scale).

the experimental results can be described quite well by straight lines. The dependence $f_d(T^{3/2})$ was discussed in detail by Gossard *et al.*,[3] who found results in good agreement with our own.

From Fig. 2 we see that the behavior of the magnetization in the domain walls can be described by

$$M(T) = M(0)[1 - aT^2].$$

This behavior can be derived theoretically for a two-dimensional magnetic system with a linear spin-wave dispersion law. The experimental data reveal a slight change in the slope of $f_w(T^2)$ at 6 K.

There is a large difference between $f_d(0)$, the NMR frequency in the domains at $T=0$, and $f_w(0)$, the NMR frequency in the walls at $T=0$. Gossard *et al.*,[4] discussed this difference and suggested some possible causes, but their calculations showed that none of these suggestions was successful in explaining the difference. In our samples, this difference is even larger, as can be seen from Fig. 1: ~4.7% of $f_d(0)$. Perhaps the most likely reason is a difference between the magnetization in a domain wall and that in a domain, caused by zero-point magnetization vibrations. Unfortunately, we know of no calculations regarding a reduction of the magnetization in domain walls by zero-point vibrations.

An important circumstance here is that our results on the temperature dependence of the NMR frequency in the domain walls differ from those of Refs. 4 and 5. The apparent reason for this discrepancy is a difference in the wall structures, but at present we cannot offer anything approaching a satisfactory explanation. Klinkova and Bochkareva[6] compared the properties of $CrBr_3$ crystals by various workers and found that these properties (the density, for example) vary widely; consequently, reasons for the discrepancies among the results should be sought in a comparative study of the properties of the crystals from the various sources.

It follows from our own measurements that in the thin-wafer samples synthesized by the method of Ref. 6 the change in the magnetization in the domain walls is proportional to the square of the absolute temperature. At $T=0$ the magnetization in the walls is 4.7% less than that in the domains.

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