Direct experimental study of the elementary excitations of the Bloch lines

Yu. P. Kabanov, L. M. Dedukh, and V. I. Nikitenko
Institute of Solid State Physics, Academy of Sciences of the USSR

(Submitted 3 May 1988)
Pis'ma Zh. Eksp. Teor. Fiz. **47**, No. 12, 638–641 (25 June 1988)

Flexural standing waves caused by elliptically polarized vibrations of the various parts of the Bloch line have been detected. These vibrations are characteristic of the magnetic vortices.

Considerable progress has recently been achieved in research on the dynamic properties of 2D domain walls which contain Bloch (Néel) lines and whose spins change position not only in the direction perpendicular to the walls (as in the Landau-Lifshitz 1D domain-wall model[1]) but also along them. It was established that the Bloch lines, which distinguish the parts of the domain wall in which the spin is flipped, are characterized by an effective mass and mobility[2,3] which differ from those in the parts adjacent to the quasi-one-dimensional domain wall. The Bloch lines, which are topological[4,5] vortex-like solitons, are also characterized by a specific dynamics characteristic of vortices.[6] In an external uniform magnetic field these lines are affected by additional gyrotropic forces in the direction which does not coincide with the direction of their motion. As a result, the Bloch lines may execute free, elliptically polarized oscillations or uniform forced oscillations.

A general theory of elementary and nonlinear excitations in a magnetically ordered crystal cannot be developed without analyzing the total spectrum of the spin waves which are localized at a Bloch line. This important problem has so far, however, not been solved either experimentally or theoretically. In the present letter we show that a direct experimental study of elementary excitations is possible in a quasi-one-dimensional system of spins which form the Bloch lines.

We studied (112) plates of a 30-μm-thick yttrium garnet ferrite which contained

180° domains magnetized along the $[11\bar{1}]$ direction parallel to the surface of the sample. Figure 1a is a schematic representation of the part of the domain wall which contains two subdomains bounded by the Bloch lines (heavy curves). The shape of the surface of the domain wall parallel (on the average) to the xz plane was determined on the basis of studies using magnetooptical and powder methods.[7] The slight bending and deflection of the Bloch lines from the normal to the surface of the sample was determined by the effect produced on the spin distribution in the domain wall by the magnetic poles formed on the surface of the plate at the points where the domain wall emerged. When we observed the domain walls in a light polarized along the z axis (which coincided with the normal to the plate), we noticed that the subdomains which were adjacent to the Bloch line and which were identified because of the opposite-sign Faraday effect partially overlapped along the light propagation path. We therefore saw at the boundary of the two "light" subdomains in the field of view of the microscope with crossed Nicol prisms a "black" band, whose width was determined by the degree to which the Bloch line sloped in the direction of the x axis and whose length was determined by the slope of the domain wall. In Fig. 1b, which shows a

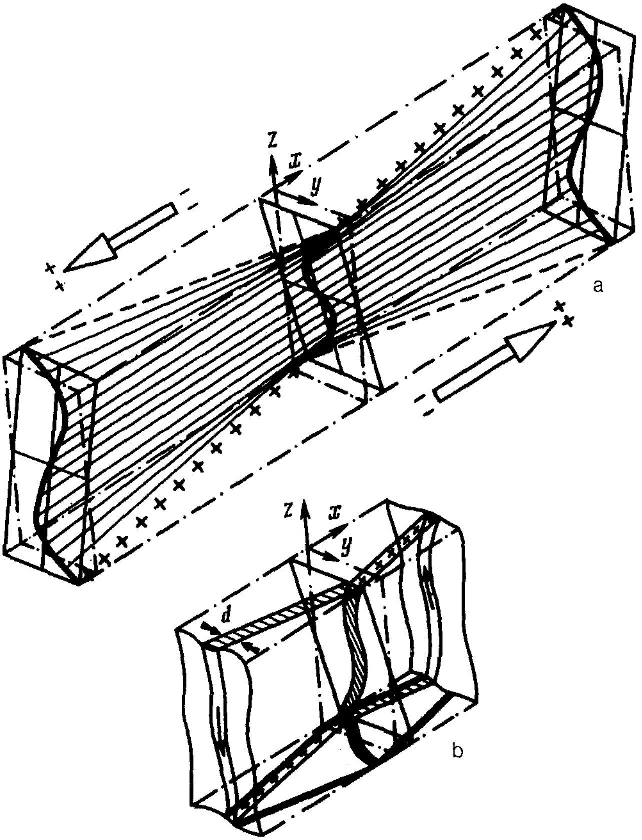

FIG. 1. (a) Shape of the surface of the 180° domain wall with a Bloch line; (b) the lower diagram shows the projection of the domain wall onto the sample's surface—the xy plane.

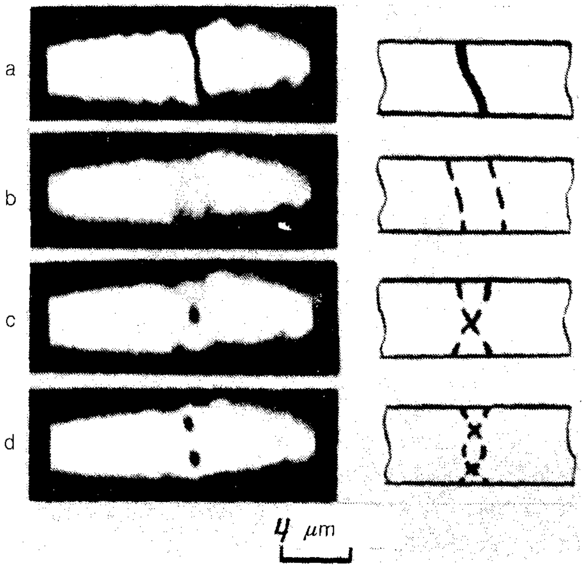

FIG. 2. Part of the domain wall with a single Bloch line in a polarized light (crossed Nicol prisms) with $H_z^2 = 0$ (a) and $H_z^0 = 225$ mOe, $\nu_p = 0.45$ MHz (b), 1.12 MHz (c), and 1.95 MHz (d). The maximum amplitudes and the shape of the fluctuating Bloch lines are indicated by the dashed lines in the diagrams.

fragment of the domain wall of finite width (*d*) with a single Bloch line, the corresponding magnetooptic image on the *xy* plane is bounded by a heavy line. A photograph of such a Bloch line in a polarized light is shown in Fig. 2a.

To record the displacement of the Bloch lines along the domain wall, we uncrossed the Nicol prisms of the microscope to the extent that one of the subdomains would be totally blacked out[3] and we limited the image of the subdomain's edge with the Bloch line (only its small segment, where necessary) by using a square diaphragm, as illustrated in Fig. 3, and projected it onto the photomultiplier. The signal from the photomultiplier was measured with a CK4-59 narrow-band spectrum analyzer.

Figure 3 shows traces of the magnetooptic signal (J), proportional to the displacement of the Bloch lines along the x axis, vs the frequency (ν) of the sinusoidal magnetic field (produced by the Helmholtz coils of 6 mm radius) applied along the z axis. Curve 1, plotted when the entire Bloch line was scanned photometrically (see the schematic diagram above this curve), has only one peak which corresponds to a resonant displacement of the Bloch line as a whole.[3] Curve 2, obtained when only a part of the Bloch line was scanned (the gap overlapped half the width of the image of the domain wall), exhibits additional peaks. The images of the Bloch line in crossed Nicol prisms at frequencies ν_p corresponding to these peaks are shown in Fig. 2, b and d.

These data, supplemented by the analysis of the phases of the oscillations of the magnetooptic signal from the various parts of the Bloch line, show that we have identified experimentally the bending vibrations of the Bloch line along the x axis and that the peaks on the $J(\nu)$ curves correspond to the formation of standing waves on the Bloch line, whose shape is shown schematically in Fig. 2, b and d, for a maximum

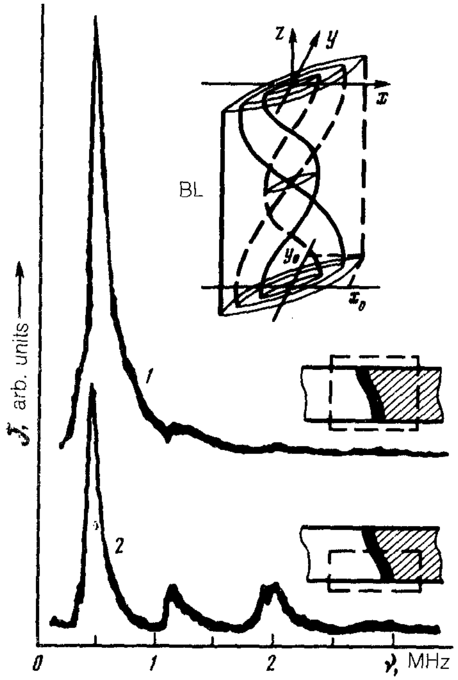

FIG. 3. Magnetooptic signal (J) proportional to the shift of the Bloch line along the x axis vs the frequency (ν) of the external field when the entire Bloch line is scanned photometrically (1) or when only a part of it is scanned (2). The upper inset shows the paths traced out by the Bloch line and its shape. The parts scanned photometrically are represented by rectangles in the insets above curves 1 and 2.

displacement in a projection onto the xy plane. The resonances of the displacements of this Bloch line were also recorded along the y axis at these frequencies ν_p. These resonances were measured when the Nicol prisms were crossed and when the gap overlapped half of the width of the image of the domain wall near the Bloch line. These resonances, along with the data presented above, show that the different segments of the Bloch line move along elliptical paths (see the upper inset in Fig. 3).

The elementary excitations which we have detected thus characterize a particular kind of bending vibrations of the magnetic vortex, at which the axis of the vortex bends through all the aximuthal angles in each period. The method which we have developed can be used to directly study the dispersion relation of the spin waves which are localized on the Bloch line. This dispersion relation can be reproduced from the plot of the frequency of the resonance peak vs its index number. In particular, we can infer from the experiment which we have described here that the magnon spectrum of the Bloch line extends into the region of frequencies lower than those of the elementary-excitation spectrum of a monopolar domain wall: The frequency of the first peak on the $J(\nu)$ curve in Fig. 3, which determines the gap of the spin-wave spectrum of the Bloch line, is lower than the normal modes of the translational and bending vibrations of the monopolar domain wall of the tested crystals.[3,8]

---

[1] L. D. Landau, Collected Papers, Nauka, Moscow, 1969, p. 128.
[2] A. Malozemov and J. C. Slonczewski, Domain Walls in Materials with Magnetic Bubbles, Mir, Moscow, 1982.

[3] V. S. Gornakov, L. M. Dedykh, V. I. Nikitenko, and V. T. Synogach, Zh. Eksp. Teor. Fiz. **90**, 2090 (1986) [Sov. Phys. JETP **63**, 1225 (1986)].

[4] M. Kleman, Points, Lines, and Walls in Liquid Crystals, Magnetic Systems and Various Ordered Media, Wiley and Sons, New York, 1983.

[5] G. E. Volovik and V. P. Mineev, Zh. Eksp. Teor. Fiz. **72**, 2256 (1977) [Sov. Phys. JETP **45**, 1186 (1977)].

[6] A. V. Nikiforov and É. B. Sonin, Pis'ma Zh. Eksp. Teor. Fiz. **40**, 325 (1984) [JETP Lett. **40**, 1119 (1984)].

[7] V. K. Vlasko-Vlasov, L. M. Dedukh, and V. I. Nikitenko, Zh. Eksp. Teor. Fiz. **71**, 2291 (1979) [Sov. Phys. JETP **44**, 1208 (1976)].

[8] L. M. Dedukh, V. I. Nikitenko, and V. T. Synogach, Pis'ma Zh. Eksp. Teor. Fiz. **45**, 386 (1987) [JETP Lett. **45**, 491 (1987)].

Translated by S. J. Amoretty