Partial restoration of clusters of vertical Bloch lines after a collision

M. V. Chetkin, I. V. Parygina, and L. L. Savchenko
M. V. Lomonosov Moscow State University, 119899B, Moscow

(Submitted 25 March 1991; resubmitted 11 April 1991)
Pis'ma Zh. Eksp. Teor. Fiz. **53**, No. 9, 477–480 (10 May 1991)

Experiments show that, at a certain velocity of a domain wall in an iron garnet film, there can be a partial restoration of clusters of vertical Bloch lines after these clusters undergo a head-on collision. This result agrees with predictions of a numerical simulation. For this reason, the situation described here is considerably more general than that in the classical theory of solitons or in experiments on the collision of Josephson vortices. An attempt is made to determine the topological charge of a cluster from the experimental profile of a solitary wave of a bending of a domain wall with the help of the Slonczewski equations.

Vertical Bloch lines separate regions of domain walls in ferromagnets which have magnetization rotations in opposite directions. They are topological solitons or kinks. Two facts have been established in experiments on the collisions of clusters of vertical Bloch [illegible] ular anisotropy. At low velocities of a domai [illegible] acting, clusters of vertical Bloch lines move [illegible] l in magnitude but opposite in sign. These [illegible] elocities of a domain wall, there are a mutual [illegible] of two clusters which are identical in the ma [illegible] r a head-on collision and a mutual penetra [illegible] in the same directions and with the same ve [illegible] vords, it has been demonstrated that clusters [illegible] -like behavior. Some similar experiments h [illegible] n of a kink and an antikink in a long Josephs [illegible] partial annihilation of two different clusters [illegible] sion. As a result of this annihilation, only a si [illegible] It moves in the same direction as the cluster h [illegible] gical charge before the collision.[3]

Nun [illegible] kov[4] and Chetverikov and Kotova[5] resulted i [illegible] velocities of the domain walls—greater than the velocity corresponding to complete annihilation but less than the velocity corresponding to a complete restoration of the colliding clusters—there should be a partial restoration of these clusters. That prediction has found experimental confirmation in the present study.

To detect clusters of vertical Bloch lines moving in opposite directions along a domain wall, we used a new procedure of triple high-speed photography. This procedure was a further development of a method of double high-speed photography which we had used previously. In the latter method, the region traversed by the domain wall with the cluster moving along it was recorded as a dark band on photographic film. The velocity of the domain wall was determined from the width of this band, and the velocity of the clusters along the domain wall was determined from the distance between the solitary waves of a bending of the domain wall.

In the new method, in the time interval between the two light pulses a dynamic domain wall with clusters of vertical Bloch lines is illuminated by yet another light pulse. This third pulse produces a phase-contrast image of the wall in the form of a narrow dark strip inside the band traversed by the wall during the time between the first and last light pulses (Fig. 1). From the distances between the first and second

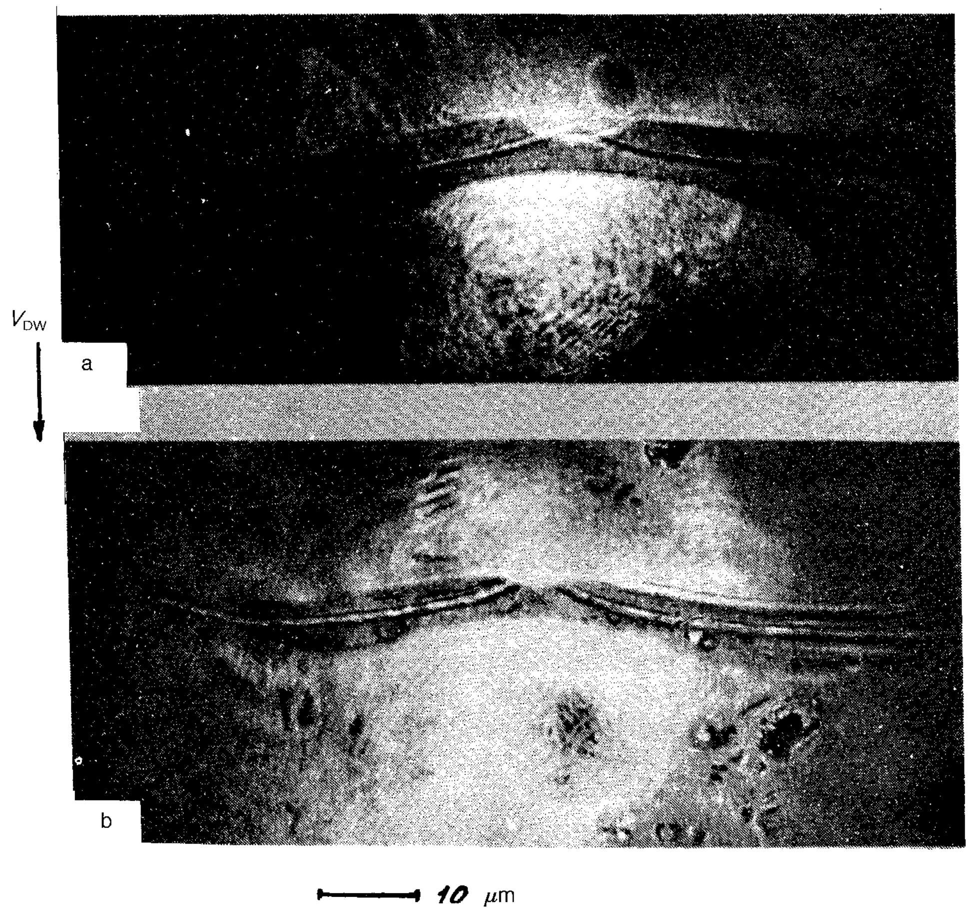

FIG. 1. Triple high-speed photographs of solitary bending waves on a dynamic domain wall which accompany clusters of vertical Bloch lines. Three positions of a domain wall are shown on the photographs: before the collisions of the clusters (the bright-dark transition at the top), immediately before (a) or after (b) the collision (the dark band in the middle), and after the collision, with a partial restoration of the clusters (the dark-bright transition at the bottom).

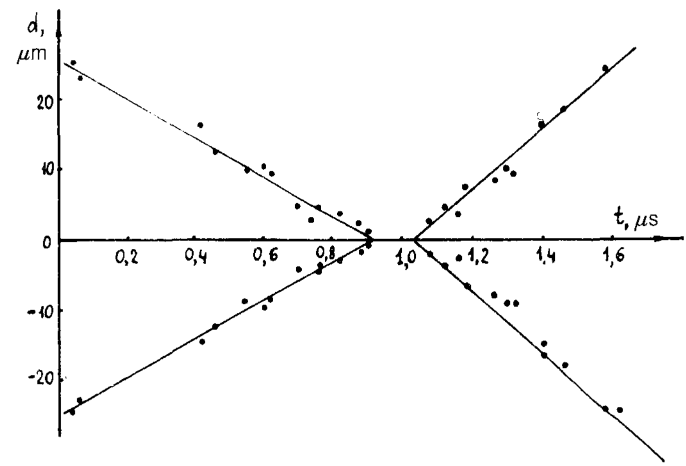

FIG. 2. Time evolution of the positions of the moving clusters of vertical Bloch lines on a domain wall before their collision (at the left) and after a partial restoration as a result of a collision (at the right).

positions of the clusters one can determine their velocity before the collision. From the distances between the second and third positions, one can determine the velocity of the clusters after the collision. Shown at the left in Fig. 1 are the positions of the colliding clusters at various times for a domain-wall velocity of 17 m/s. Shown at the right in the same figure are the positions of the clusters after the collision. From these results we can determine the velocities of the clusters before and after their collision. Before the collision, the velocity of each of the colliding clusters was 30 m/s, and that after the collision was 45 m/s. After the collision, the velocities were thus higher by a factor of 1.5. We observed a decrease in the amplitudes of the domain-wall bending waves accompanying both clusters which appeared after the collision. The photographs in Fig. 1 clearly demonstrate the increase in the velocities of the clusters after the collision and the partial restoration. The decrease in the amplitudes of the solitary bending waves are not as noticeable, because the two detected on the photograph before the collision are very close together. If the distance between them before the collision is large, the difference between the amplitudes of the solitary bending waves of the colliding and partially restored clusters is more noticeable.

Figure 2 shows the phase shift which arises in the course of the collision of clusters. We did not observe the difference in the velocities of the two colliding clusters which was predicted in the numerical simulation of Ref. 5, because of the incorporation of terms with first derivatives in the Slonczewski equation. The incorporation of these terms is not above question, but there is also a need for further work to improve the experimental accuracy. Experimentally, one thus observes a partial restoration or partial annihilation of colliding clusters of vertical Bloch lines in a domain wall in an iron garnet film with a large perpendicular anisotropy, as predicted theoretically (by numerical simulation).[4,5] At domain-wall velocities below 17 m/s one observes an annihilation; at higher velocities one observes a complete restoration of the clusters. On photographs of the type in Fig. 1, at an average wall velocity of 17 m/s, we also observed a small number of clusters which had passed through each other and which had been completely restored. On a small number of triple photographs we also see an annihilation of colliding clusters. Both of these facts seem to stem from the narrowness of the velocity interval, in which there is a partial restoration of the clusters after the collision, and from the presence of a gradient magnetic field, which stabilizes a rectilinear domain wall in an iron garnet film. This gradient causes a slight change in the magnetic field in which the wall is moving, so the velocity of the wall also changes. As a result, the wall may leave the region of partial restoration and go into regions of annihilation or complete restoration.

In connection with experiments carried out to detect clusters of vertical Bloch lines and collisions thereof, there is the problem of determining their topological charges. In the experiments described above, the only properties which were measured directly were the shape of the solitary domain-wall bending waves accompanying the moving clusters of vertical Bloch lines, their velocities, and the velocity of the domain wall. Using one of the Slonczewski equations (which relates the time derivative of the azimuthal angle of the magnetization at the center of the domain wall to the profile of the solitary bending wave), along with its derivatives,

$$-\frac{2M_s}{\gamma}\dot{\psi} = \frac{2M_s}{\mu}\dot{q} - \sigma\frac{\partial^2 q}{\partial x^2} + b^2 q \tag{1}$$

one can determine the spatial distribution of ψ and also the topological charge of the cluster of vertical Bloch lines. Here $\mu = \gamma\Delta/\alpha$ is the mobility of the domain wall, γ is the gyromagnetic ratio, M_s is the saturation magnetization, σ is the energy density of the domain wall, $b^2 = \mathrm{grad}H\Delta/4\pi M_s$, and Δ is the width of the domain wall. This can be done in the case in which the quantities q and ψ in (1) depend on only $x - ut$. Calculations carried out under these assumptions with $4\pi M_s = 100$ G, $\mathrm{grad}H = 5000$ Oe/cm, $A = 1.8\times10^{-7}$ erg/cm, $Q = 45$, $\alpha = 0.2$, and $\gamma = 1.7\times10^7$ $\mathrm{Oe}^{-1}\cdot\mathrm{s}^{-1}$ yield a topological charge close to $(6 \pm 2)\pi$ for the minimal clusters observable in our experiments after the partial restoration of the vertical Bloch lines and $(10 \pm 2)\pi$ before the collision. Since the amplitudes of the solitary bending waves observed experimentally and their derivatives along the coordinate at the leading edges of the solitary bending waves are large, the generalization of Eq. (1) to take account of the domain-wall curvature which was carried out in Ref. 6 is useful.

In summary, the experiments show that when two clusters of vertical Bloch lines which are identical in amplitude but which differ in the sign of the topological charge collide in a dissipative magnetic material, they can annihilate, and they can also undergo a partial or complete restoration. This circumstance makes the situation considerably more general than that in the classical theory of solitons, in experiments on the collision of Josephson vortices. It also means that colliding clusters of vertical Bloch lines could be utilized to carry out a large variety of algebraic operations. A method has been proposed for calculating the topological charges of clusters of vertical Bloch lines from the experimental profiles of the accompanying solitary waves and from the Slonczewski equations.

We wish to thank A. K. Zvezdin and A. F. Popkov for a useful discussion of these results.

[1]M. V. Chetkin, I. V. Parygina, V. B. Smirnov *et al.*, Phys. Lett. A **140**, 428 (1989).
[2]K. Nakajima, H. Misusawa, Y. Sawada *et al.*, Phys. Rev. Lett. **65**, 1667 (1990).
[3]M. V. Chetkin, I. V. Parygina, V. V. Smirnov, and S. N. Gadetskiĭ, Zh. Eksp. Teor. Fiz. **97**(1), 337 (1990) [Sov. Phys. JETP **70**, 191 (1990)].
[4]A. K. Zvezdin, A. F. Popkov, and I. P. Yarema, Zh. Eksp. Teor. Fiz. **98**, 1070 (1990) [Sov. Phys. JETP **71**, 597 (1990)].
[5]E. E. Kotova and V. N. Chetverikov, Zh. Eksp. Teor. Fiz. **98**, 2011 (1990) [Sov. Phys. JETP **71**, 1131 (1990)].
[6]M. V. Chetkin, V. B. Smirnov *et al.*, Zh. Eksp. Teor. Fiz. **94**, 164 (1988) [Sov. Phys. JETP **67**, 269 (1988)].

Translated by D. Parsons