Scientific session of the Division of General Physics and Astronomy of the Russian Academy of Sciences (29 April 1992)

Usp. Fiz. Nauk 162, 151–155 (December 1992)

A scientific session of the Division of General Physics and Astronomy of the Russian Academy of Sciences was held on 29 April 1992 in the P. L. Kapitsa Institute of Physics Problems. The following reports were presented at the session:

1. *A. K. Zvezdin, A. F. Popkov, and M. V. Chetkin.* Dynamics of solitons in a domain wall of a ferromagnet.

2. *S. N. Utochkin.* New magnetic structures and phase transitions in magnetic superlattices and multilayer films.

A brief summary of one report is given below.

A. K. Zvezdin, A. F. Popkov, and M. V. Chetkin. *Dynamics of solitons in a domain wall in a ferromagnet.* The study of Bloch lines (BLs) separating sections of a Bloch domain wall with different spin rotation directions, is of fundamental importance for understanding dynamical processes in magnets.[1] Bloch lines are also of interest for microelectronics in connection with the development of very-large-capacity memories.[2]

From the topological standpoint a Bloch line is a linear defect of the vector magnetization field—a magnetic vortex. The vortex properties of a Bloch line determine the gyrotropic interaction of the line with the domain wall (DW) in which it moves. The structure of a moving Bloch line is quite complicated. The line has a compact core, in which the orientation of the spins changes rapidly, and an extended "shell," which consists of a sagging of the domain wall at the location of the Bloch line.[3–5] The core of a moving Bloch line carries the topological charge of the line. This charge determines the degree of twisting of the spins in the domain wall. Sagging arises in the domain wall only when the Bloch line is moved by the gyroscopic force acting on the domain wall along the normal to its plane. Under static conditions there is virtually no sag and only a very small change in the thickness of the domain wall and a small cant at the location of the Bloch line are possible. Sagging is especially important experimentally for observing moving Bloch lines, though other possibilities for observing Bloch lines are now under development. The amplitude of sagging from a single moving Bloch line is small and it is experimentally easier to investigate clusters of N Bloch lines, where N is the topological charge of the cluster, equal to the total angle of twist of the spins divided by π.

In a uniaxial strongly anisotropic ferromagnet Bloch lines and clusters of Bloch lines can be described with the help of the Slonczewski equations,[1] which are essentially appropriately reduced Landau–Lifshitz equations, in which a moving isolated Bloch line is described by a solutuion of soliton type. It is natural to suppose that clusters of Bloch lines can be associated to multisoliton mathematical structures. Although the Slonczewski equations do not belong to any known classes of integrable systems, such an association is quite informative, especially since the Slonczewski equations have the important asymptotic property that asymptotically they transform into the generalized sine-Gordon equation.[3] Taking into account damping and external pumping, this asymptotic behavior is completely isomorphic to the equations of a distributed Josephson junction, in which soliton solutions have been well investigated both theoretically and experimentally. This means that the dynamics of Bloch lines and clusters of Bloch lines should also exhibit soliton properties, especially in collisions involving Bloch lines.

The results of experimental investigations of the dynamics of clusters of Bloch lines, which confirm these considerations, are presented in Refs. 6 and 7. In particular, it was shown that in head-on collisions of sufficiently rapidly moving clusters of Bloch lines the clusters pass through one another and their individual topological charges are conserved, while slow clusters annihilate one another. The classical theory of solitons provides only a guide for formulating and interpreting such experiments. It is necessary to investigate the real situation taking into account pumping, dissipation, the deformability of domain walls, etc. The results of this investigation are presented in this review.

We have shown that the dynamical properties of Bloch lines in a domain wall of a uniaxial ferromagnet resemble, to a certain extent, the properties of topological solitons. This is especially strikingly manifested in a head-on collision of individual Bloch lines and clusters. It should be noted that the system of dynamical equations describing Bloch lines does not belong to the known classes of integrable systems, even if dissipation and pumping are neglected. This behavior of Bloch lines is apparently associated with the fact that the Bloch lines have a compact core, where the spins change rapidly in space. A new effect is predicted: partial (stepwise) annihilation of clusters of Bloch lines near the critical velocity.[8] In numerical experiments on the collision of Bloch lines we recently discovered a new property of the solitons under discussion. For high translational velocities of domain walls, close to the peak velocity $v \sim v_p$, a collision of Bloch lines initiates continuous generation of new pairs of Bloch lines, as shown in Fig. 1. This process terminates only if the velocity of the domain wall drops below the critical velocity. This phenomenon was also recently observed experimentally.

There is a very close analogy between the behavior of Bloch lines and multisoliton excitations of a distributed Josephson junction. But there are also significant differences, associated, in particular, with the fact that in the case of the

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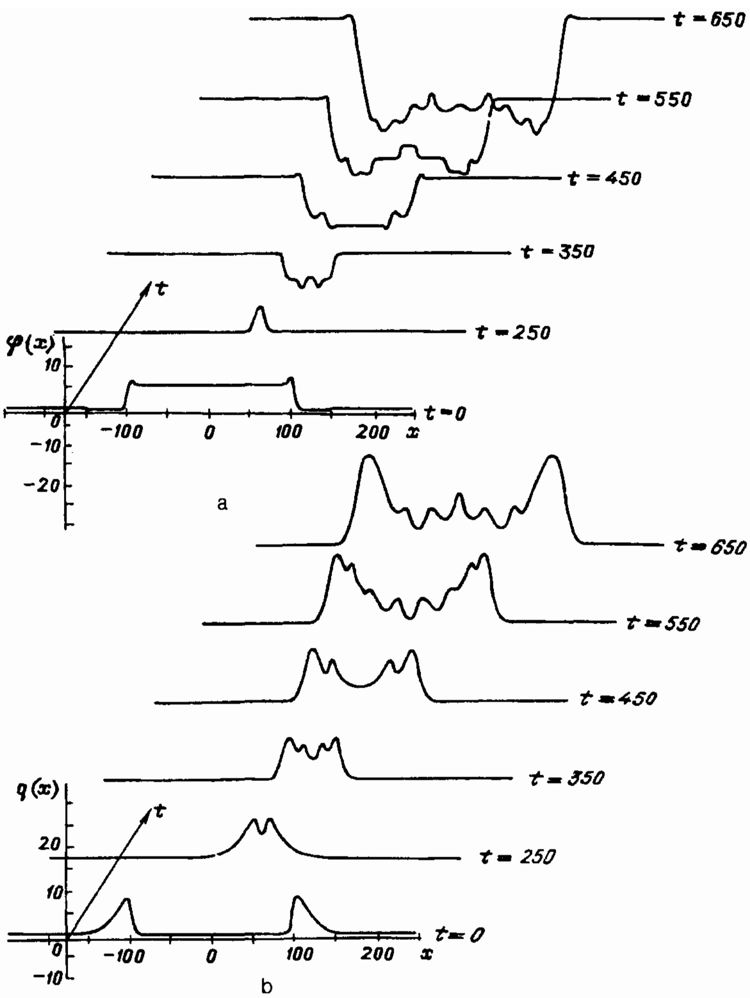

FIG. 1. Generation of Bloch lines in a moving domain wall after a collision of isolated Bloch lines. a—evolution of the cant angle $\varphi(x, t)$ of the magnetization out of the plane of the domain wall. b—Evolution of the profile $q(x, t)$ of a domain wall.

Bloch lines there appears an additional factor (besides pumping and dissipation) that destroys the integrability of the system and the soliton behavior, namely, the sagging of the domain wall due to the gyroscopic force accompanying the motion of Bloch lines, i.e., the vortex nature of Bloch lines. This factor opens up new possibilities for experimental investigation of the dynamical interaction of clusters of Bloch lines: collisions of clusters moving in the same direction ("overtaking" collisions)—a phenomenon that is apparently unknown in a distributed Josephson junction. This possibility appears becasue of the fact that due to the sagging of the domain wall the coefficient of viscous friction acting on a cluster (or in other words, the mobility of the cluster) depends on the velocity of the cluster and the topological charge. Therefore, in the presence of pumping several clusters with different topological charges and velocities can be created in a domain wall,[9] i.e., it is possible to produce conditions under which unidirectional collisions of the clusters occur. These considerations as well as the results of numerical calculations on incomplete passage of clusters of Bloch lines through one another in a collision and the experimental data of Ref. 10 on partial annihilation of clusters of Bloch lines make the situation under discussion more general than is implied by the classical theory of solitons.

The results of the theoretical analysis presented here are in good qualitative agreement with the experimental data.[6,7,9] In order to make a more detailed analysis of the dynamical interaction of Bloch lines and their clusters, especially in the region of critical velocities, where partial annihilation of clusters is possible, it is apparently necessary to take the magnetic-dipole interaction into account more accurately than is done in the approximation employed in the present work. It is also important to make a quantitative analysis of the role of the "degree of twisting" of the domain wall in collisions of Bloch lines, but this increases the scope of the problem.[11]

In films with perpendicular anisotropy with a twisted structure of the domain wall, the peak velocity u_p of vertical Bloch lines is determined by the formula $u_p \propto (sv_p)^{1/2} Q^{1/4} (\pi/2)^{1/2}$, where s is the velocity of the flexural oscillations of the domain wall (DW), v_p is the peak velocity of the domain wall, and Q is the figure of merit of the material. The mechanism which limits the velocity of a Bloch line is determined by the transformation of the line into a cluster consisting of five or more Bloch lines.[12] For extremely thin films $u_p \propto s = \gamma (8\pi A)^{1/2}$.[4,13]

Our calculations show that Bloch lines can interact with envelope solitons of low-amplitude spin waves, localized on the domain wall, similarly to the interaction of Josephson vortices with breather-type plasma solitons in a superconducting tunnel junction. This interaction is described by a two-particle Hamiltonian with an attractive single-cell potential. However, even in the absence of dissipation, there does not exist in a domain wall an analog of bound states of the breather type with large amplitude and low frequency, which can exist in a distributed Josephson junction. This is a consequence of the fact that the magnetodynamic equations describing the dynamics of spins in a pinned domain wall are not completely integrable. Low-amplitude soliton-like oscillations of a domain wall are metastable. They can be stabilized, however, with the help of an alternating magnetic field by means of direct or parametric pumping at a frequency matched with the frequency and amplitude of the stabilized soliton.[14]

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Translated by M. E. Alferieff