Domains and dislocations in antiferromagnets

I. E. Dzyaloshkinskiĭ

Institute of Theoretical Physics, USSR Academy of Sciences
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It is shown that dislocations in antiferromagnets are sources of magnetic domains and of singular lines—disclinations.

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It is well known that domains in antiferromagnets are not favored thermodynammically and can exist only because of some disequilibrium. One such disequilibrium is produced by dislocations, which of necessity lead to the appearance of magnetic domains. The mechanism of this phenomenon can be easily understood by examining the very simple Fig. 1 for an edge dislocation in a two-sublattice magnet.

From the mathematical point of view, the question of domains in magnets is closely connected with the general problems of vector-field singularities, and was discussed in connection with singular lines—disclinations—in liquid crystals (see, e.g., [1–3]) and with vortices and disgyrations in superfluid He^3. [4,5] We have carried out a similar analysis for dislocations in the simplest two-sublattice antiferromagnet.

The order parameter **l** is given in this case by (see Fig. 1)

$$\mathbf{l} = \mathbf{s}\cos\frac{\pi z}{c}, \tag{1}$$

where **s** is a vector that determines the moment of one of the sublattices, c is the distance between the planes, z is the coordinate of the magnetic ions (in an undeformed crystal we have $z = \ldots, -c, 0, c, 2c, \ldots$). On going around a dislocation[1)] we have $z \to z + B$, where $B = nc$ is the Burgers vector. Therefore $\mathbf{l} \to \mathbf{l}(-1)^n$. This means that the vector **s** can no longer remain constant and must depend on the coordinates in such a way as to compensate for the change of $\cos(\pi z/c)$ after making the circuit:

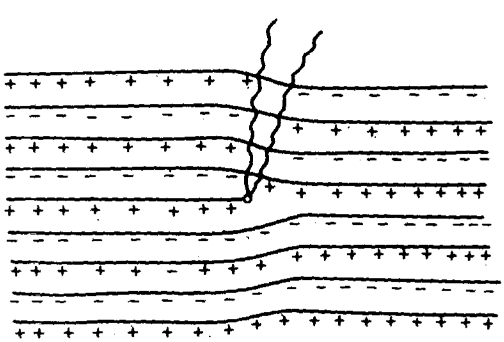

FIG. 1.

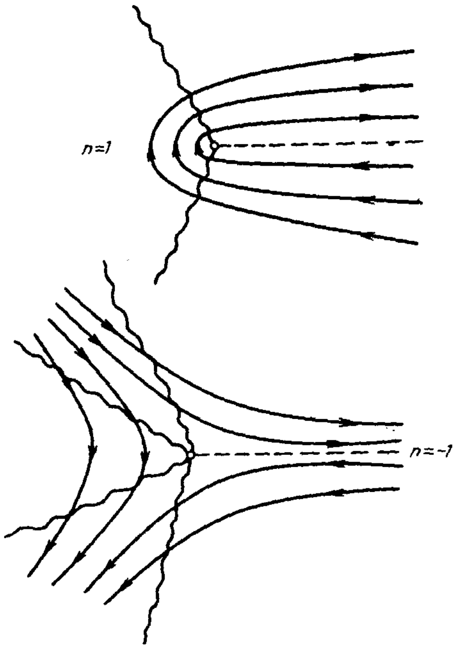

FIG. 2.

$$s \to (-1)^n s, \qquad l \to l. \qquad (2)$$

This singularity of the vector field **s** is called a disclination of the Frank index n (see[1,2]).

Far from the transition point, the vector **s** has a constant length and the energy connected with the inhomogeneity of its directions is of the form

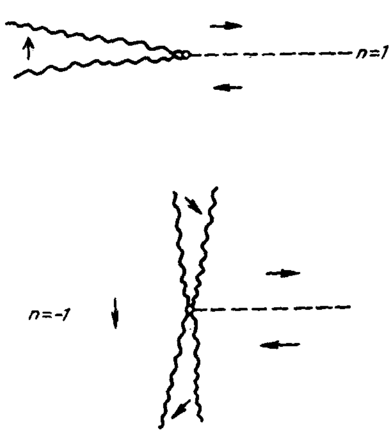

FIG. 3.

$$F = \frac{1}{2} \int dV \left\{ J \left[\left(\frac{\partial s}{\partial x}\right)^2 + \left(\frac{\partial s}{\partial y}\right)^2 + \left(\frac{\partial s}{\partial z}\right)^2 \right] + a s_z^2 \right\} , \quad (3)$$

where J is the exchange integral and a is the anisotropy energy. The disclinations are linear singularities of the corresponding Euler equations $\delta F/\delta \mathbf{s}(\mathbf{r}) = 0$. Anisimov and the author have previously shown[3] that for an energy in this form all the disclinations with even Frank indices n are absolutely unstable in the sense that they can be transformed by a continuous deformation, without any barrier whatever, into a homogeneous state. Disclinations of this kind correspond to saddle points of the functional (3), and not to stable or metastable minima. This conclusion agrees with the general topological analysis of the situation presented by Volovik and Mineev.[5] Therefore disclinations can not exist around dislocations with an "even" Burgers vectors, or not at all in the absence of dislocations.

From among the "odd" disclinations, the stable ones are only those with $n = \pm 1$. The remaining are again saddles.[3] The field of the directions of the vector $\mathbf{s}$ ("stream lines") at short distances $r < r_0 = (J/a)^{1/2}$ from the singular line is shown in Fig. 2. The finite character of the anisotropy makes the distribution of $\mathbf{s}$ mainly homogeneous at large distances $r > r_0$, and all "fast" rotations of $\mathbf{s}$ will occur only within the Bloch wall. The dashed lines in Figs. and 3, on which $\mathbf{s}$ reverses sign, is not a singular line, since the order parameter $\mathbf{l}$ is continuous on this line (see (2)).

The domain wall has the usual surface energy $\sigma(aJ)^{1/2}$. Therefore dislocations at which domain walls begin or end are acted upon by constant tension forces that tend to decrease the total surface of the walls. It would be of interest to observe the additional dislocation motion connected with the transitions to the antiferromagnetic state.

[1)]It does not matter whether we deal with an edge or a screw dislocation.

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