L. N. Bulaevskiĭ. *Magnetic superconductors*. The problem of coexistence of superconductivity and magnetism was stated by Ginzburg[1] in 1956 before the creation of the BCS microscopic theory of superconductivity. This problem is currently attracting a great deal of attention from theoreticians and experimentalists in connection with the synthesis of ternary compounds with regularly distributed magnetic rare-earth ions. These compounds have superconducting and magnetic properties.[2] It has been demonstrated experimentally and theoretically that antiferromagnetic ordering and superconductivity have practically no effect on one another. A more interesting situation arises in ferromagnetic superconductors $ErRh_4B_4$ and $HoMo_6S_8$, where superconducting and ferromagnetic ordering compete. When cooled, these compounds first go over into the superconducting state ($T_{c1} = 8.7$ and 1.8 K, respectively) and then this state is replaced by a normal ferromagnetic state at the point $T_{c2}$ (≈0.7 and 0.65 K), but in the intermediate phase from $T_M$ to $T_{c2}$ ($T_M \approx 1$ and 0.70 K) superconductivity coexists with nonuniform magnetic ordering with the period of the magnetic structure equal to 100 and 200 Å.

The appearance of nonuniform magnetic structure in the coexistence phase (instead of ferromagnetism in the absence of superconductivity) was predicted in 1959 by Anderson and Suhl,[3] and it has now been confirmed experimentally, but the problem of the type of nonuniform magnetic structure and the characteristics of the superconductivity in the coexistence phase has not been clarified experimentally.

Beginning with the basic work of Ginzburg and Anderson and Suhl, up to the present time, two theoretical approaches have been developed for describing the coexistence phase. The first approach, which is the most popular, is based on the use of the Ginzburg-Landau functional. This description takes into account both the electromagnetic interaction of superconducting electrons and localized moments (LM). In the second approach, the exchange interaction of electrons and LM are included within the framework of the microscopic BCS theory. Meanwhile, to describe real compounds, it was necessary to include both these interaction mechanisms within the framework of the microscopic theory, and it was necessary to include magnetic anisotropy as well in the calculation. This approach was developed in Ref. 4 and 5 and in a number of other papers, available in the literature, by the same authors.

The theoretical analysis shows that in real compounds the properties of the coexistence phase are determined primarily by the exchange mechanism of interaction of electrons and LM. Magnetic ordering in the coexistence phase must have the form of a one-dimensional transverse domain structure (see Fig. 1) with domain thickness $d \approx \sqrt{a\xi_0}$, where $a$ is the magnetic rigidity of the order of the atomic distance and $\xi_0$ is the superconducting correlation length. In dirty superconductors, a domain type magnetic structure acts on the superconductivity in a manner analogous to magnetic impurities in a state with a gap.[6] In clean crystals, in the region of strong exchange fields (at least near the temperature $T_{c2}$) superconductivity in the phase with the domain magnetic structure is gapless and, in addition, the gap is absent for those orientations of the electron velocity

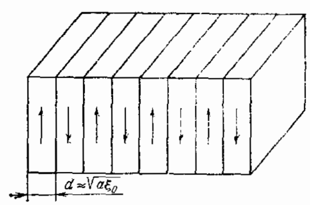


FIG. 1. Domain-type magnetic structure in the coexistence phase of ferromagnetic superconductors of the type $ErRh_4B_4$ and $HoMo_6S_8$ (theoretical prediction). The arrows show the direction of magnetization within the domains. The thickness of the domains $d$ is small compared to the superconducting correlation length $\xi_0$, but is large compared to the magnetic correlation length $a$.

on the Fermi surface that are approximately perpendicular to the wave vector of the domain structure.

The theoretical results obtained explain the existing experimental data for $ErRh_4B_4$ (Ref. 7) and $HoMo_6S_8$ (Ref. 8), including the peculiarities in neutron scattering in the coexistence phase and its transition into the normal ferromagnetic phase. However, the basic result of the theory of domain-type magnetic structure in the coexistence phase has not yet been confirmed experimentally due to the absence of perfect single crystals (as yet, only polycrystalline specimens of $HoMo_6S_8$ and two $ErRh_4B_4$ single crystals have been obtained, which, apparently, are nonuniform with respect to the parameters $T_M$ and $T_{c2}$ due to internal stresses).

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