Scientific session of the Division of General Physics and Astronomy of the Academy of Sciences of the USSR (27 February 1991)

Usp. Fiz. Nauk **161**, 193–197 (July 1991)

A scientific session of the Division of General Physics and Astronomy of the Academy of Sciences of the USSR was held on 27 February 1991 at the P. L. Kapitza Institute of Physics Problems of the Academy of Sciences of the USSR. The papers listed below were presented at this session:

1. V. L. Pokrovskiĭ. Vortex structures in laminated superconductors.

2. M. A. Teplov. Nuclear magnetic resonance, nuclear quadrupole resonance, and nuclear relaxation in high-temperature superconductors.

A brief summary of the papers is presented below.

V. L. Pokrovskiĭ. *Vortex structures in laminated superconductors.* According to a conventional point of view, in the majority of high-temperature superconductors, a superconducting order parameter is concentrated near the planes of CuO_2. This is traced clearly in superconductors Bi and Tl 2212, where the coherence length ξ_c along the normal to the layers, found by different methods, is less than interplanar distances d.[1] Laminated structure is also clearly expressed in some low-temperature superconductors, and in artificial laminated structures.[2]

Simplifying the situation we assume that a superconducting order parameter is concentrated on the planes and is absent in the intervals between them. In such a condition ($\xi_c \ll d$) a vortex line, which is parallel to the planes, is arranged so that the vortex center falls on the middle of an interplanar interval (Fig. 1). Such a vortex has no core where the superconducting order parameter is suppressed, as it happens in a homogeneous superconductor. Because of this, the energy barrier, which must be overcome in order to displace the vortex into a neighboring interplanar interval, is unusually great (of the order of Fermi energy). An exception is a small temperature range $T^* < T < T_0$ near the temperature T_c of a superconducting transition, where $\xi_c \geqslant d$, and the periodic potential, which acts on the vortex on the part of the lattice, is practically absent. For $T < T^*$, the vortices parallel to the planes may move only inside one interplanar interval. This circumstance results in a number of hysteresis phenomena. In the simplest experimental setup, suggested in Ref. 3, a magnetic field B_0 is fixed parallel to the layers and then the temperature is reduced gradually to $T < T^*$. In the interval $T^* < T < T_c$ a usual Abrikosov triangular lattice arises, which, with a decrease in temperature, becomes commensurate in direction (normal to the layers) with the crystal. We now fix T and begin to reduce B. A number of vortices leave the sample and the remaining ones form a triangular lattice, whose period z in the direction of c is the same as that at the initial value of the field B_0, and the period x, which is parallel to the layers, is inversely proportional to the field, so that $zx = \Phi_0/B$, where Φ_0 is the flux quantum and B is the induction (Fig. 2). For $B/B_0 \approx 0.26$, a spontaneous violation of symmetry must occur and a unit cell turns from a rhombus into a parrallelogram. This phenomenon is explained by the fact that with an increase in x the repulsive energies of the vortex pairs AB, AC, and BC become comparable (Fig. 2). With a further increase in x without changing z, the repulsive energy along BC becomes greater than the two others. This can be avoided by creating a small shear strain (Fig. 2b). This is a typical phase transition of the second kind described by the Landau theory. All parameters of the theory are found explicitly with the help of the London free energy.

A series of phase transitions of the first kind occurs with a further decrease in temperature. For small values of B/B_0, maxima of free energy $\sim (B_0/B)^2$, between which minima $\sim (B_0/B)^{1/2}$ lie, correspond to the rational values of $y = uz/x$. Apparently, if such states would be achieved, they will represent a two-dimensional polycrystal. A relation between the indicated phenomenon and phyllotaxis is shown by Levitov.[4]

With the field increasing, new vortices will enter the crystal not in the intervals where the old ones lie, forming, apparently, a fluid or glass. Here in the center of the sample a piece of an old, but strongly deformed, crystal remains. For great B/B_0 the shear modulus μ is about $\exp(-B_0/B)$. According to the usual Lindemann criterion melting should occur. However, Kolomeĭskiĭ and Mikheev[5] have shown that fluctuation repulsion of vortices as a result of their bending prevents melting.

Hysteresis vortex lattices might be discovered experimentally, using acoustic or electromagnetic wave scattering. A calculation of these processes will soon be published.

On the vortices in an inclined field there appear kinks, which can be considered as small sections of vortices in the C direction (Fig. 3). The appearance of kinks leads to a num-

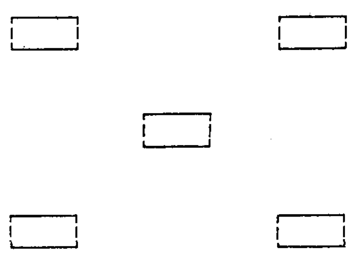

FIG. 1.

0038-5670/91/070626-04$01.00
© 1991 American Institute of Physics

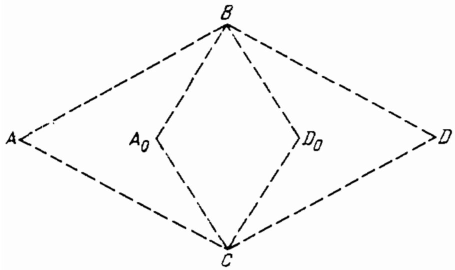

FIG. 2.

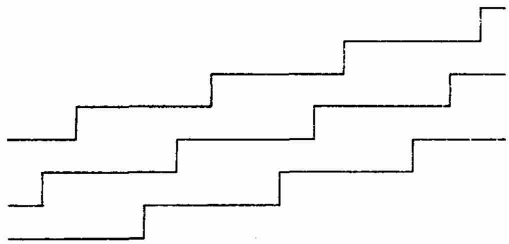

FIG. 3.

ber of interesting physical phenomena.[6] Periodicity of the system of vortices and kinks is already three-dimensional and not two-dimensional as in a homogeneous superconductor. Hysteresis phenomena are weakened and related with pinning of point singularities (kinks). In thin films the mechanical moment of a system as a function of the angle ϑ between the plane of the layers and the external magnetic field H undergoes a jump at $\vartheta = 0$.

In samples of a finite thickness, in addition to the usual lowest critical field $H_{c1}(\vartheta)$, which determines an upper boundary of the total Meissner effect, a field H_2 can be indicated such that for $H_2 < H^z_{c1} = H_2(1 - n_{zz})$ only the z-component of the magnetic field is pushed out from the sample[7] (the z-axis is directed along c and n_{zz} is the component of the tensor of demagnetizing factors). In the domain of Meissner's partial effect mechanical momentum depends linearly on $\sin\vartheta$ for a fixed $H > H_{c1} \sin\vartheta > H_{c1}/H$, and then undergoes a finite jump.

Magnetic moment projection on the magnetic field has jumps of derivatives for $H = H_{c1}$ and $H_z = H^z_{c1}$ and also a maximum at a greater value of the field $H = H_3$.[8] The first singularity and a maximum also arise in strongly anisotropic but homogeneous (nonlaminated) superconductors,[9] while the singularity at $H_z = H^z_{c1}$ is the manifestation of lamination. In the experiment of Ref. 10 the first singularity and maximum are seen distinctly, while the second singularity is masked by a small value of the jump of the derivative, but it is discovered after elementary data processing.

Kinks are the natural carriers of the normal component, which results in a sharp anisotropy of the critical current.[6,11] The experiment of Ref. 12 confirms the theoretical prediction.

The theory predicts[6,7] nonlinear torsional oscillations of the laminated superconductor samples.

The investigations presented in this summary were carried out in cooperation with B. I. Ivlev, N. B. Kopnin, S. S. Malov, and Yu. N. Ovchinnikov. Acknowledgment is made to my co-authors and also to V. N. Zavaritskiĭ, N. V. Zavaritskiĭ, I. F. Shchegolev, and V. A. Kopylov for discussing the experimental situation and making available experimental data.

[1] U. Welp, W. K. Kwok, G. W. Grabtree, K. G. Vandervoort, and J. Z. Liu, Phys. Rev. Lett. **62**, 1908 (1989). W. C. Lee, R. A. Klemm, and D. C. Johnston, *ibid.*, **63**, 1012.
[2] A. J. Vermeer *et al.*, Physica, Ser. C. **162–164**, 409 (1989).
[3] B. I. Ivlev, N. B. Kopnin, and V. L. Pokrovsky, J. Low Temp. Phys. **80**, 187 (1990).
[4] L. S. Levitov, Phys. Rev. Lett., **66**, 224 (1991).
[5] E. B. Kolomeiskii and L. V. Mikheev, Preprint, 1990.
[6] B. I. Ivlev, Yu. N. Ovchinnikov, and V. L. Pokrovsky, Europhys. Lett. **13**, 187 (1990); Mod. Phys. Lett. Ser. B, **5**, 73 (1991).
[7] S. S. Maslov and V. L. Pokrovskiĭ, Europhys. Lett. (in press).
[8] S. S. Maslov and V. L. Pokrovskiĭ, Pis'ma Zh. Eksp. Teor. Fiz. **53**, 614 (1991) [JETP Lett. **53** (12) 637 (1991)].
[9] A. I. Buzdin and A. Yu. Simonov, *ibid.*, **51**, 168 (1990) [JETP Lett. **51**, 191 (1990), Zh. Eksp. Teor. Fiz. **98**, 2074 (1990) [Sov. Phys. JETP] **71**, 1165 (1990).
[10] N. V. Zavaritskiĭ and V. N. Zavaritskiĭ, Pis'ma Zh. Eksp. Teor. Fiz. **53**, 212 (1991). [JETP Lett. **53**, 226 (1991)].
[11] M. Tachiki and S. Takahashi, Solid State Commun. **70**, 291 (1989).
[12] B. Roas, L. Schultz, and G. Saemann-Ischenko, Phys. Rev. Lett. **64**, 479 (1990).