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Abrikosov A A. On the magnetic properties of superconductors of the second group. *Sov. Phys. JETP* 5:1174-82, 1957. [Translated from: *Zh. Eksp. Teor. Fiz. SSSR* **32**:1442-52, 1957.]
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Magnetic properties of bulk superconductors of the second kind, whose existence I predicted in 1952,[1] are studied. Two critical fields are found limiting an interval where the superconductor is in a peculiar "mixed state" when the magnetic field penetrates the sample in the form of quantized fluxoids forming a regular structure. [The *SCI*® indicates that this paper has been cited in over 1,075 publications since 1957.]

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After graduation from Moscow University in 1948, I entered the Institute for Physical Problems. I started to work with L. Landau. At the same time my university-mate N. Zavaritskii began his work in the laboratory of the well-known experimentalist A.I. Shalnikov, who suggested that Zavaritskii study the critical magnetic fields of thin superconducting films. We often discussed Zavaritskii's work with him, and I also became interested in superconductivity.

In 1950, Landau and Ginsburg constructed their famous quasi-microscopic theory of superconductivity.[2] The application of this theory to the critical field of thin films showed brilliant agreement with the experimental data of Shalnikov and Zavaritskii. Zavaritskii decided to obtain more uniform films by evaporating the metal on a glass surface cooled down to helium temperature. By keeping the film permanently at helium temperature, recrystallization and formation of cracks was avoided. To our great surprise, the dependence of the critical field of the film on its effective thickness (thickness measured in units of the "penetration depth") showed disagreement with the Landau-Ginsburg theory.

Discussing the possible origin of this discrepancy with Zavaritskii, I thought about a theoretical possibility that had not been pursued. The theory contained a parameter (now called the Landau-Ginsburg parameter) that critically influenced the surface energy between the superconductivity and normal phases and that could be calculated from the observed structure of the so-called intermediate state.

Since the theory was not truly microscopic, it was not clear on which quantities the parameter x depended and what its variation limits were. Experimental data for pure superconductors always gave $x \ll 1$. Therefore, Landau and Ginsburg considered only this limit in detail, although they mentioned that at $x > 1/\sqrt{2}$ the surface energy becomes negative. We suspected that this had happened in the low-temperature films.

I calculated the critical field of a thin film on the basis of this idea.[1] The results fit Zavaritskii's data very well, which justified the conclusion that superconductors with $x \gtrsim 1/\sqrt{2}$ actually exist in nature.

It was natural to investigate the magnetic properties of bulk superconductors with $\delta_{ns} < 0$. The results showed that the superconductor can exist in a peculiar state that is not completely diamagnetic (partial Meissner effect), which I called "mixed state." It was interesting to find out what would be the fate of this state with a decreasing field and, particularly, whether a superconductor of the second kind becomes a true superconductor or not. Finally, I understood that the current distribution in the mixed state has a vortex structure and that the beginning of this state can be imagined as a system of current vortices or magnetic fluxoids located far away from each other. Inspired by this idea, I communicated it to Landau, but he did not approve it.

In 1956, Landau learned of Feynman's work on quantized vortices in rotating superfluid helium.[3] I told him that this idea corresponded exactly to my current vortices in superconductors of the second kind. After a careful examination of my calculations, he agreed. The work was finished shortly after. I found that the mixed state appears first at a certain field H_{c1}. At smaller fields ordinary superconductivity takes place. In the mixed state a lattice of quantized vortices or magnetic fluxoids is formed (now often called "Abrikosov vortices" or "Abrikosov structures"). I also calculated the magnetisation curve, whose shape resembled the magnetisation curves of the superconduction alloys Pb Tl measured by L. Shubnikov and his colleagues 20 years previously.[4] I tried a quantitative comparison. The agreement was excellent.

My article was published in 1957. But it was only in the early 1960s that it was "discovered" by physicists in connection with the creation of high critical field alloys.

I am not surprised by the frequent citation of my article. The superconductors of the second kind with high critical fields are the basis for the construction of superconducting magnets, which are at present the main technical application of superconductivity. I do feel a bit offended by the fact that some authors call the mixed state, which I predicted, the "Shubnikov phase." In his work Shubnikov never suspected a new phase and explained his results by inhomogeneity.

1. **Abrikosov A A.** The influence of dimensions on the critical field of the superconductors of the second group. *Dokl Akad Nauk SSSR* **86**:489-92, 1952.
2. **Ginsburg V L & Landau L D.** To the theory of superconductivity. *Zh Eksp Teor Fiz SSSR* **20**:1064-82, 1950. (Cited 80 times since 1955.)
3. **Feynman R P.** Application of quantum mechanics to liquid helium. (Gorter C J, ed.) *Progress in low temperature physics.* Amsterdam: North-Holland, 1955. Vol. I. p. 17-53.
4. **Shubnikov L V, Khotkievich V I, Shepeliov Y D & Riabinin Y N.** Magnetic properties of superconducting metals and alloys. *Zh Eksp Teor Fiz SSSR* **7**:220-37, 1937.

