Magnetic field dependence of the electrical conductivity in V_3Ge in the vicinity of H_{c2}

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The excess electrical conductivity of V_3Ge samples has been investigated experimentally in a perpendicular magnetic field near H_{c_2}. At fields $H > 0.97$ H_{c2} the experimental data agree with theoretical calculations for the fluctuational conductivity. At $H = 0.97\ H_{c_2}$ the conductivity increases sharply and the critical current appears; this is attributed to a transition to a mixed state.

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It is assumed[1] that in type-II superconductors a second-order phase transition from the normal state to a mixed state (the Abrikosov state) occurs at H_{c_2} (the second critical field); however, the immediate vicinity of the transition has not been studied sufficiently. Moreover, in measurements of the specific heat it was shown[2] that near H_{c_2} the experimental results are described well by a one-dimensional model; a λ anomaly characteristic of second-order phase transitions has not been observed. Since a phase transition cannot occur in one-dimensional systems, we might ask when does the normal state become an Abrikosov lattice which has been observed many times in fields lower than H_{c_2}.

We have measured the excess electrical conductivity $\Delta\sigma = (\sigma - \sigma_N)$ of V_3Ge samples as a function of the magnetic field H at a constant temperature of $T = 4.2$ K. The usual four-point method was used in the measurements. The magnetic field was directed perpendicularly to the long axis of the sample, along which the electric current flowed. The conductivity in the magnetic field H is defined as $\sigma = I/V(l/S)$, where I is the current flowing through the sample, V is the voltage between the potential contacts in the magnetic field H, l is the distance between the potential contacts ($\approx$ 3–5 mm), S is the cross-sectional area of the sample ($\approx 0.5\ \text{mm}^2$), and σ_N is the resistivity of the sample in the normal state (as $H \to \infty$). The other characteristics of the sample and the experimental conditions are given in Ref. 3.

The measurement results are shown in Fig. 1. The theoretical dependence is obtained in the Hartree approximation from the linear Ami-Maki theory,[4] which considers the increment to the conductivity of the normal state caused by fluctuational pairing of electrons by using Eq. (10) from Ref. 5, in which it was shown that a superconductor can be regarded as a one-dimensional system near H_{c_2}. In our case $N(0) = 9.73 \times 10^{41}\ \text{J}^{-1} \cdot \text{cm}^{-3}$ (Ref. 6), $\xi(0) = 48$ Å, $T_{c_0} = 6$ K, $T = 4.2$ K, $h = 0.293$, and H_{c_2}, which is not a singular point, play the role of an adjustment parameter. The graph can be divided into three regions $H/H_{c_2} > 0.973$, $0.969 < H/H_{c_2} < 0.973$, and $H/H_{c_2} < 0.969$. In the first region the critical current is equal to zero and the conductivity does not depend on the current, which is characteristic of the normal

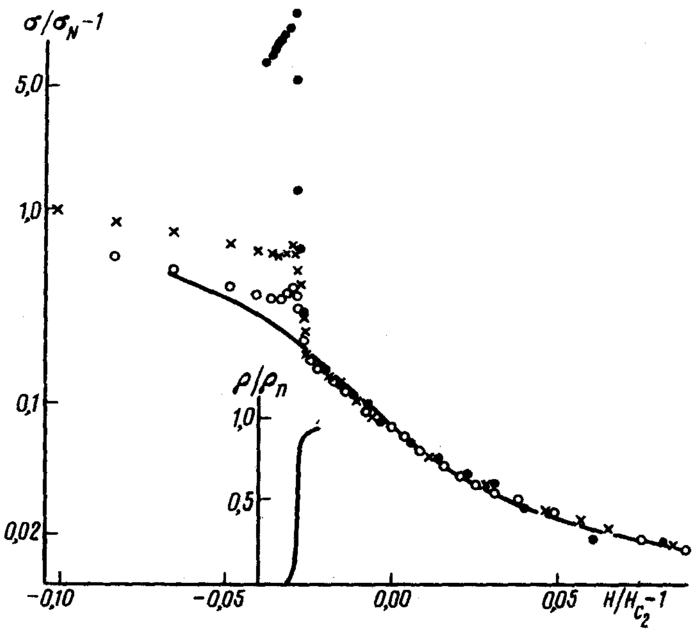

FIG. 1. Magnetic-field dependence of the excess conductivity for different currents flowing through the sample: •–$j = 0.5$ A/cm², ×–$j = 2$ A/cm², and ○–$j = 10$ A/cm²; is the theoretical dependence. The magnetic-field dependence of the resistance is shown at the bottom of the figure for $j = 0.05$ A/cm². $j = I/S$ is the density of the electric current flowing through the sample.

state; the experimental data agree with the Hartree approximation. In the second region there is a sharp increase of the excess conductivity, and the critical current appears. It is interesting to note that the observed sharp increase in the excess conductivity occurs against a background of a smooth variation due to fluctuational pairing of electrons. In the third region the critical current has a finite value and the conductivity depends on the current, which is characteristic of the mixed state; the experimental data do not agree with the Hartree approximation.

The above-described dependence of $\Delta\sigma$ on the magnetic field can be interpreted in the following manner: the agreement between the experimental and calculated values means that the superconductor is a one-dimensional system in the first region. In the second region, a transition occurs from the one-dimensional state to the Abrikosov state. We believe that the difference between the transition field ($0.97\,H_{c_2}$) and H_{c_2} is attributable to the fact that the entropy term in the Ginzburg-Landau "free energy" has not been completely taken into account, i.e., the Ginzburg-Landau "free energy" is essentially a block Hamiltonian.[7]

It is interesting to note that the width of the transition region ($0.004\,H_{c_2}$) is much narrower than that of the anomalous specific heat that has been observed in superconductors with similar $\xi(0)$ value under similar conditions (identical t).[5] It is possible that in the temperature dependence of the specific heat in the vicinity of H_{c_2} there is a narrow anomaly, in addition to the broad anomaly, which could not be observed in the experiment.

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