that our data agree with the results cited there.

MAGNETORESISTANCE OF BISMUTH IN FIELDS UP TO 450 kOe AT HELIUM TEMPERATURES

N. B. Brandt, E. A. Svistova, and G. Kh. Tabieva
Physics Department, Moscow State University
Submitted 3 May 1966
ZhETF Pis'ma 4, No. 1, 27-32, 1 July 1966

1. The study of galvanomagnetic phenomena in metals in the ultraquantum region, when the distances between the Landau levels become comparable and exceed the Fermi energy, affords a unique opportunity of investigating the structure of the energy spectrum of metals in a sufficiently broad energy interval near the Fermi boundary [1,2]. The structure of the spectrum changes in the ultraquantum region as a result of the change in the band boundaries, the Fermi energy in the bands, the carrier density, and the carrier distribution among the separate equal-energy surfaces. The character of this change is determined directly by the carrier dispersion, and therefore its investigation yields valuable information on the character of the dispersion law.

2. Effects connected with the transition into the ultraquantum region are easiest to observe in metals with low carrier density. In this paper we report results of an investigation of the electric resistance of single-crystal samples of bismuth in a transverse magnetic field H of intensity up to 450 kOe at liquid-helium temperature.

The magnetoresistance of bismuth in fields up to 300 Oe was first investigated in [3] at 77°K and it was observed that in strong fields the dependence of ρ on H is close to linear. As far as we know, the fields in which the electric resistance of bismuth was investigated at helium temperatures did not exceed 100 kOe [4,5].

3. To obtain the magnetic field we used a pulse installation with a period of 316 μsec. The main difficulty in the investigation of galvanomagnetic effects in pure metals at low temperatures by means of short-period magnetic-field pulses is that as the field is increased the small skin depth causes the samples to be destroyed by the interaction between the eddy currents and the field. This difficulty was eliminated by applying a primary constant magnetic field to increase the resistance of the sample by the required number of times.

Samples of different shapes (parallelepipeds, cylinders) and sizes (from 1 x 1 x 3.5 mm to 0.2 x 0.4 x 2.5 mm) were made of bismuth of two grades. Bi_1 with $\rho_{300}/\rho_{4.2} = 300 - 400$ and Bi_2 with $\rho_{300}/\rho_{4.2} = 150$. The nominal purity of both grades was higher than 99.9999%. The measurements were made on a large number of samples at all possible orientations of the magnetic field and of the current relative to the crystallographic axes. As a result of a thorough investigation of the influence of the geometry of the samples, the arrangement of the electrodes, the influence of the measuring-current strength, which determines the overheating of the sample during the pulse ("thermal shock"), and the method of fastening the sample, conditions were chosen under which the influence of the parasitic effects (especially those in [6]) could be neglected in practice. All the results given below are perfectly reversible and

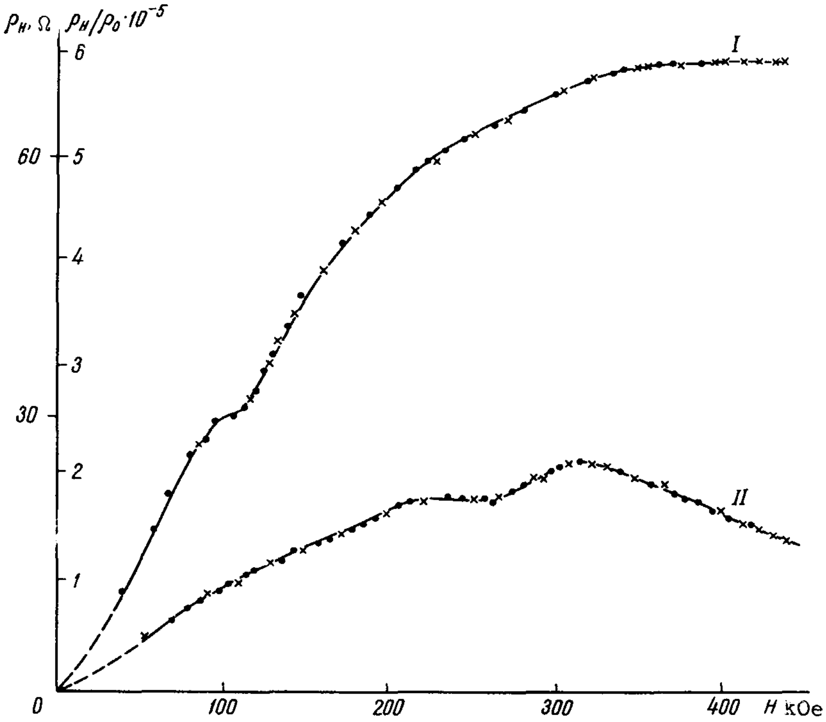

Fig. 1. Electric resistance of Bi in a magnetic field at liquid-helium temperature. I - H parallel to trigonal axis and i parallel to bisector axis, sample No. 4 (Bi_2). II - H parallel to binary axis and i parallel to bisector axis, sample No. 4 (Bi_2). ● - results of measurements in fields up to 410 kOe, × - up to 440 kOe.

reproducible at field pulses of different magnitude.

4. Figures 1 and 2 show by way of an example some plots of ρ against H at the three main orientations of the magnetic field relative to the crystallographic axes for several samples of Bi_1 and Bi_2 (No. 4).

A characteristic feature of these curves is the following form of the dependence of the monotonic component of ρ on the field: quadratic in the precritical magnetic field region ($H < 25 - 35$ kOe), nearly linear in the wide range of fields from 25 - 35 to 200 kOe, followed by saturation (when H is parallel to the trigonal axis in fields 200 - 400 kOe, curve I), and finally a section with negative derivative $\partial\rho/\partial H$ in fields exceeding 320 kOe (with H parallel to the binary and bisector axes, curve II).

Superimposed on the monotonic component of the $\rho(H)$ curve are clearly pronounced magnetoresistance oscillations (Shubnikov - deHaas effect). The strong dependence of the parameters of the spectrum on the field in the ultraquantum region causes the periodicity of the oscillations in the reciprocal field, which is usually observed in weak magnetic fields, to be violated. The pattern of the oscillations in fields up to 90 kOe are in good agreement with [4].

5. The results of [4] were interpreted by using a quadratic dispersion law for holes

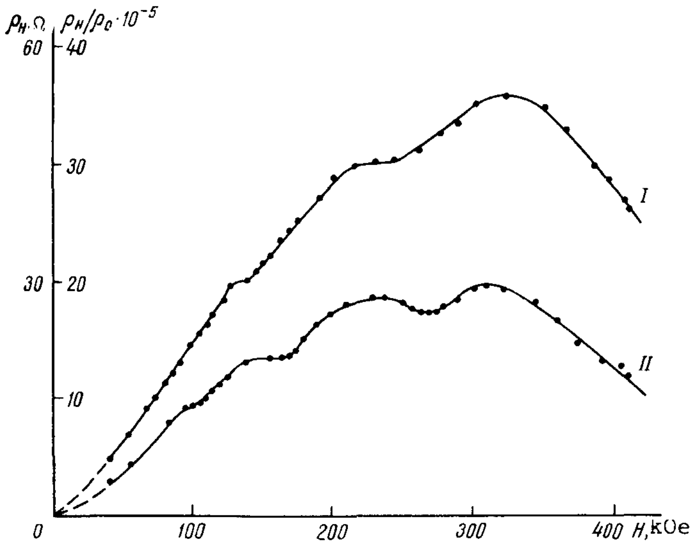

Fig. 2. Electric resistance of Bi in a magnetic field at liquid-helium temperature. I - H parallel to binary axis and i parallel to trigonal axis, sample No. 5 (Bi_1). II - H parallel to bisector axis and i parallel to trigonal axis, sample No. 6 (Bi_1).

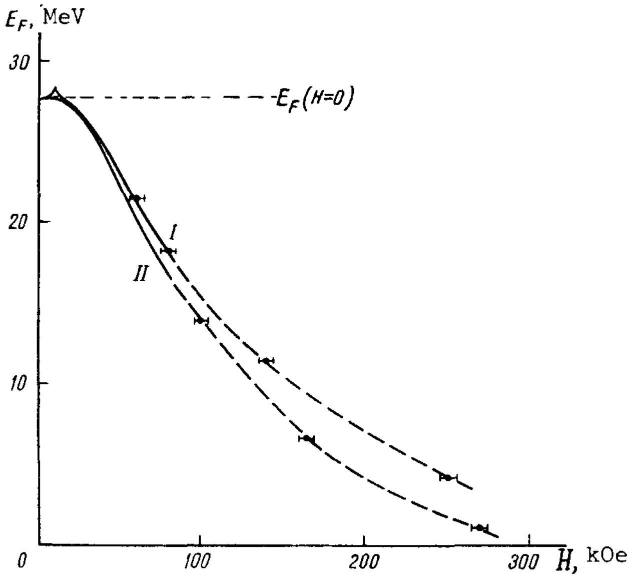

Fig. 3. Variation of Fermi energy in a magnetic field. I - H parallel to binary axis, II - H parallel to bisector axis. Solid curve - calculation using data of [4].

and Cohen's non-quadratic law [7] for electrons, with account taken of the strong spin splitting of the Landau levels.

Based on the results of this analysis, the minima of ρ on Fig. 1 must be ascribed to passage through the Fermi level of the hole levels n = ±4 (H = 80 kOe), n = ±3 (H = 140 kOe), and n = ±2 (H = 250 kOe) for H parallel to the binary axis, the levels n = ±4 (H = 100 kOe), n = ±3 (H = 165 kOe), and n = ±2 (H = 270 kOe) for H parallel to the bisector axis, and the level n = -1 (H = 100 kOe) for H parallel to the trigonal axis.

Figure 3 shows the dependence of the Fermi energy on the field, for field orientations parallel to the binary and bisector axes, calculated from the formula

$$(n + 1/2)\hbar\omega^h \cdot H_i = E_F(H_i).$$

When H is parallel to the trigonal axis E_F increases, but more slowly than it falls when H is parallel to the binary axis.

The non-quadratic dispersion of the electrons and the character of the spin splitting of the electric levels causes the carrier density n in bismuth to increase with the field approximately linearly for all magnetic-field orientations (when H is parallel to the binary axis and the field is approximately 400 kOe the carrier density increases by approximately 10 times).

The increase of the electron density in bismuth placed in a magnetic field is the cause of the linear section of the monotonic component of the $\rho(H)$ curves. It is easy to show that for constant n the resistance of bismuth in fields up to 200 kOe would increase approximately quadratically, as should be the case on the basis of the two-band theory [8,9].

The decrease of resistance in strong fields when H is parallel to the binary and bisector axes is apparently the result of the rearrangement of the energy spectrum and the appearance when $H > 320$ kOe of a new "three-ellipsoid" hole equal-energy surface, which greatly increases its electric conductivity.

For more data on this question, measurements in stronger fields are necessary.

We take this opportunity to thank M. Ya. Azbel' for a discussion of the results and valuable remarks, A. I. Shal'nikov for interest in the work, N. L. Shofman, T. V. Gorskaya, and A. N. Radionova for help with the measurements, and senior machinist A. P. Popov for the high grade mechanical work.

[1] M. Ya. Azbel' and N. B. Brandt, JETP 48, 1206 (1965), Soviet Phys. JETP 21, 804 (1965).
[2] I. I. Tsidil'kovskii, V. I. Sokolov, and M. M. Aksel'rod, FMM 16, 318 (1963).
[3] P. L. Kapitza, Proc. Roy. Soc. A119, 358 (1928).
[4] G. E. Smith, G. A. Baraff, and J. M. Rowell, Phys. Rev. 135A, 1118 (1964).
[5] J. Vuillemin, J. of Research and Development 8, No. 3 (1964).
[6] N. E. Alekseevskii, N. B. Brandt, and T. I. Kostina, JETP 34, 1339 (1958), Soviet Phys. JETP 7, 924 (1958).
[7] M. M. Cohen, Phys. Rev. 121, 387 (1961).
[8] E. H. Sondheimer, Proc. Roy. Soc. A193, 484 (1948).
[9] I. M. Lifshitz and M. I. Kaganov, UFN 69, 419 (1959) and 78, 411 (1962), Soviet Phys. Uspekhi 2, 831 (1960) and 5, 878 (1963).

STABILIZATION OF LOW-FREQUENCY PLASMA INSTABILITIES

Ya. B. Fainberg and V. D. Shapiro
Physico-technical Institute, Ukrainian Academy of Sciences
Submitted 8 May 1966
ZhETF Pis'ma 4, No. 1, 32-36, 1 July 1966

1. Several possible ways of stopping microscopic instabilities of a plasma were indicated earlier [1,2]. One of these methods is to modulate the beams of charged particles with external high-frequency fields. Theoretical and experimental research [3,4] has confirmed the efficacy of such a method for stabilization of two-stream instability. Stabilization of two-stream instability by means of a high-frequency electric field was considered by Aliev and Silin [5].

In this note we investigate the possibility of stabilizing drift instability of an inhomogeneous plasma by superimposing an external high-frequency electric field

$$E_0(t) = \mathcal{E}_0 \cos\Omega t,$$

parallel to the magnetic field. High-frequency stabilization of hydrodynamic instabilities of a plasma were considered earlier [6].