with an error of 1.7% was obtained.

For the resonance doublet of copper we have

$$f_{3248}/f_{3274}=1.98$$

with an error of the order of 1%.

The ratio of the f-numbers for the components of the doublet of copper was obtained also by King and Stockbarger[3]. Using the method of total absorption the authors of that paper obtained for this ratio

$$f_{3248}/f_{3274}=1.94,$$

with estimated error of 10%.

In the error-limits of the experiments the results obtained by the methods of hooks and the method of absorption are identical.

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The Effect of a Uniform Compression Upon the Galvanomagnetic Effects in Bismuth and Its Alloys

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A large number of studies have been devoted to the investigation of galvanomagnetic properties of metals. Recently, a broad and systematic investigation of the galvanomagnetic properties of pure metals was carried out by Borovik[1-4]. Utilizing the results of certain theoretical studies[5,6] Borovik obtained values for the density of conduction electrons, calculated on the basis of results of measurements of the Hall effect and the variation of the electrical resistance in the magnetic field.

In connection with our earlier considerations on the influence of the density of conduction electrons upon the nature of shift of the transition temperature of superconductors under elastic deformation[7,8], it was of interest to investigate the influence of uniform compression upon the electron concentration. For this purpose, measurements were undertaken of the Hall effect and of the variation of the electrical resistance in the magnetic field, for bismuth and for certain compounds of bismuth with other non-superconducting metals. We also investigated the temperature dependence of their electrical conductivity in a compressed as well as in a non-compressed state. The present communication presents the results obtained with bismuth.

The investigation of the influence of pressure upon galvanomagnetic properties in the region of low temperatures, as far as we know, has not been conducted by anyone and has therefore an intrinsic interest.

The study of galvanomagnetic phenomena was conducted on single crystal samples of bismuth having different purity and possessing in the most cases a spherical shape. This shape was convenient in that it assured a minimum of the irreversible processes connected with the possible deformation of the sample. Terminals were welded to the sample by the spark method.

For the investigation of samples under pressure we used a method which had been proposed by Lazarev and his collaborators[9], which we had already used sucessfully in our former studies. All temperature measurements were made in the broad range of temperatures from 1.5 to 300° K. The dependence of the electrical resistance upon temperature in zero magnetic field was measured during the heating-up of the apparatus, which had first been cooled down by liquid hydrogen or helium. The heating-up of the apparatus from 14 to 273° K lasted usually 5-6 hours, which permitted the measurement of the resistance with sufficient precision. The temperature was measured with the aid of a copper-constantan thermocouple, soldered to the external wall of the bomb opposite the center of the sample.

During the investigation of bismuth, 14 samples were investigated. The samples were prepared from Bi Hilger of a 99.9996% purity without preliminary recrystallization; and also from bismuth containing 0.02% of lead, some of the latter samples having been submitted to a purification process by recrystallization. Figure 1 shows the curves of the dependence of the ratio of the Hall field to the electrical field in the direction of the current, E_y/E_x, and the electrical resistance, r, upon the magnitude of the magnetic field, H, for a sample prepared from bismuth with 0.02 % lead, at a temperature of 20.4° K. Analogous results for the sample of bismuth No. 14, of the same purity, for a temperature of 4.2° K, and for two orientations in the field, are shown in Fig. 2. Uniform compression, as a rule, did not lead to a change in the

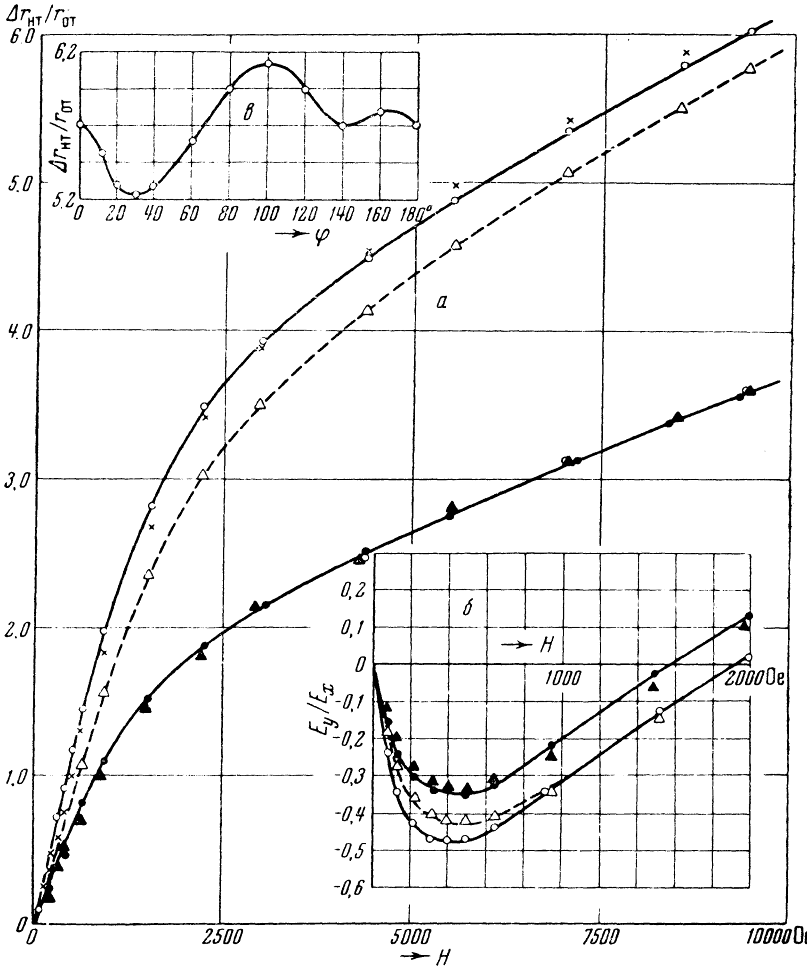

Fig. 1. Sample Bismuth No. 8_{II}, $T = 20.4°$ K, $\phi = 28°$.

a. dependence of resistance upon field,

b. dependence of E_y/E_x upon field,

c. diagram of rotation in the field H =7000 oersteds;

○ - points corresponding to the sample before pressure;

● - points with pressure of about 1500 atm. applied;

× - points for pressure removed;

▲ - repeated pressure of about 1500 atm.;

△ - after removal of the repeated pressure.

shape of the rotation diagram. In this, the sample anisotropy, characterized by the magnitude of the ratio of the minimum to the maximum resistance in a constant magnetic field, reversibly decreased 7 to 10% with the application of a uniform compression.

During measurement of the Hall effect in one of the samples of Hilger bismuth in the region of helium temperatures, a weak oscillation of the Hall electromotive force was discovered. An analogous phenomenon was noted in the work of references 10, 11 and 12. During uniform compression of this sample, the oscillation of the Hall electromotive force not only failed to subside but, to the contrary, increased somewhat and changed its period*.

During the investigation of temperature dependence of the electrical resistance of bismuth with a 0.02% lead content, it was found (on four samples) that a uniform compression to 1500 kg/cm^2 evokes the appearance of a maximum on the curve *r (T)* at temperatures near 30-40° K, (Fig. 3). Of the abovementioned four samples, Bi No. 7, No. 8 and No. 9

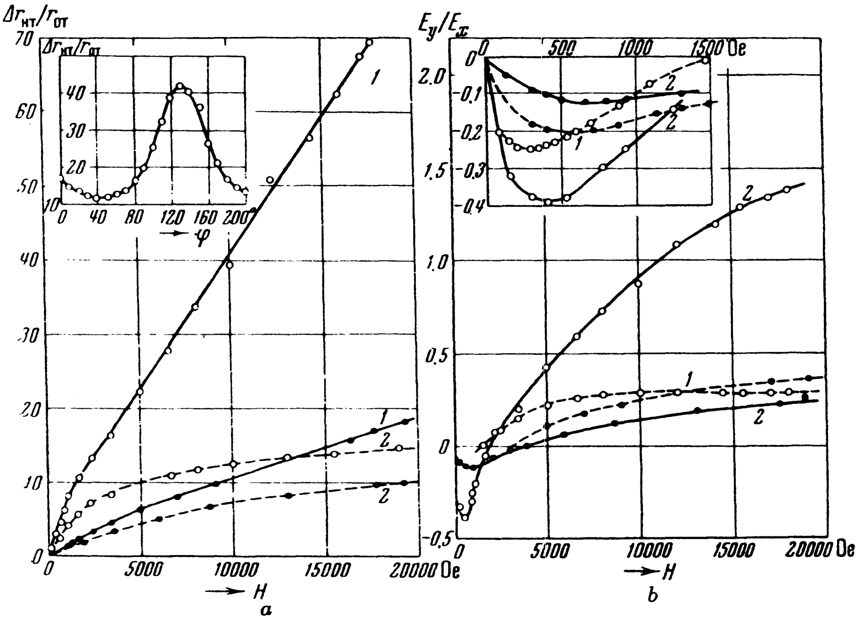

Fig. 2. Sample Bi No. 14, $T = 4.2°$ K

a. dependence of resistance upon the field and diagram of rotation in the field of H = 10,000 oersteds,

b. dependence of E_y/E_x upon the field;

1. for $\phi = 122°$, *2.* for $\phi = 320°$,

○- sample without pressure,

●- sample under pressure of 1500 atm.

were spherical in shape, while the sample Bi No. 8_{II} was a cylinder of a diameter of 3 mm and a length of 12 mm. The direction of current in all these four samples was approximately perpendicular to the main axis. For other orientations, this phenomenon is apparently absent. The dotted curve in Fig. 3 represents the dependence of electrical resistance upon temperature for a sample under a pressure of the order of 1500 kg/cm^2; the direction of current in the sample is parallel to the main axis.

In comparing the results obtained with pure bismuth, in our experiments as well as in the experiments of other workers[13,14], the following can be noted. While pure bismuth gives an almost quadratic dependence of electrical resistance upon the magnitude of the magnetic field, the corresponding curve for bismuth with a small admixture of lead shows a tendency for saturation. In this case, the dependence of E_y/E_x upon H changes its sign in the same region of fields in which the dependence $r(H)$ shows a bend.

The appearance of a maximum in the curve $r(T)$ upon compression is not observed with the purer samples of bismuth. It is not impossible, however, that such a maximum can be discovered in these samples, also, at considerably higher pressures. The presence of a maximum on the curve $r(T)$ was noted in reference 15, where the temperature dependence of samples of bismuth with a different content of lead was investigated. In comparing our results on the magnitude of the maximum with the results of reference 15, we conclude that uniform compression of a sample up to a pressure of 1500 kg/cm^2 is equivalent to a variation in the concentration of lead from 0.02% to 0.15%. One must note, however, that a maximum of the same magnitude, caused by admixtures, is situated in a region of higher temperatures (about 80° K).

It is possible that the appearance of a maximum caused by pressure in the curve of the dependence of the electrical resistance upon temperature is a consequence of a change in the concentration of conduction electrons due to compression. The utilization of the bi-zonal theory for the evaluation of the concentration and mobility of electrons taking part in the conduction, appears to be difficult for bismuth, because the prior presence of small admixtures, for instance, lead, leads to substantial deviations of the dependences E_y/E_x upon H and

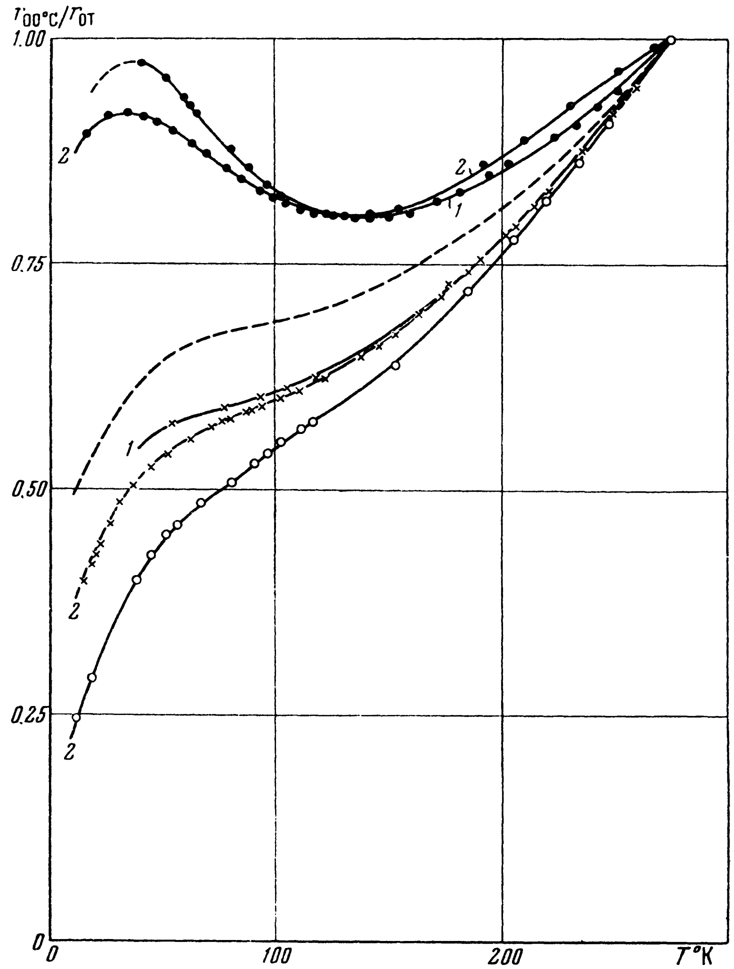

Fig. 3. Temperature dependence of electrical conductivity of bismuth with a 0.02% lead content.
1. Bi No. 14; 2. Bi No. 8;
○- samples without pressure;
●- samples under pressure of 1500 atm.;
×- after removal of pressure

$r(H)$ from those which are to to be expected from a model with an equal number of electrons and "holes", ($n_1 = n_2$). With the content of lead in bismuth reaching 0.02%, bismuth most likely corresponds to the case $n_1 \neq n_2$ and, although the variation of dependences of E_y/E_x upon H and $r(H)$ at uniform compression points toward a considerable change in the mobilities and in electronic concentration under the action of pressure, the determination of the magnitude of these changes requires experiments in considerably stronger magnetic fields. If, nevertheless, using the results with the purest bismuth, one evaluates the variation of electron concentration and mobility by regarding this as the case of a bi-zonal conductivity with an equal number of current carriers in each zone, it turns out that a uniform compression leads to a decrease in the concentration and mobility of current carriers. It is quite probable that one could thus explain the increase of electrical resistance of bismuth under a uniform compression at room temperatures, observed by Bridgman[16].

Mobility variations of conduction electrons and of their concentration under the influence of uniform compression, taking place evidently as a consequence of small variations of the lattice parameters, provides a basis for assuming that the temperature variations of the lattice parameters may lead to analogous results. Thus, in addition to the previously noted change[17] in the concentration of current carriers in bismuth at temperatures higher than the degeneracy temperature of the electron gas, i.e., higher than 70-140° K, one can expect, for bismuth, a variation of the electron concentration related to the decrease of the lattice parameters upon cooling. The validity of this hypothesis could explain the lack of agreement in the curves of the dependence of the resistance of bismuth upon the magnitude of the effective magnetic field $H(r_{0°C}/r_{0T})$ (see references 3, 4) obtained at different temperatures, because the Köhler scheme[18] does not take into account the variation in the number of current carriers with temperature.

On the basis of these same considerations, a comparison of galvanometric properties of bismuth having different purities is not possible, because, in addition to the changes in the mean free path caused by the admixtures, a very strong variation in the electron concentration can take place. Therefore, the considerable discrepancy between the curves of the dependence of the Hall constant upon the magnitude of the magnetic field, discovered by Gerritsen and de Haas[10], and the curves of $\Delta r_{HT}/r_{0T}$ is $H(r_{0°C}/r_{0T})$, obtained by Borovik[3] for different samples of bismuth, is not surprising.

It is quite possible that the dependence of electron concentration upon pressure and the related dependence of electron concentration upon temperature may take place not only in bismuth, but also in a number of other metals and alloys.

It should be remarked that the oscillations of the Hall effect, preserved during the uniform compression, suggest the possibility of studying the influence of a uniform compression on the De Haas-van Alphen effect. This supposition becomes more probable if one evaluates the results of studies in references 10, 11, 12, which point out the correlation of the oscillation of the Hall e.m.f. with the magnetic susceptibility in bismuth.

A major part of the present work was conducted at the Cryogenic Laboratory of the Moscow State Institute of Measures and Measuring Apparatus, in connection with which we consider it our pleasant duty to express appreciation to the Director of the Laboratory, Prof. P. G. Strelkov and to A. S. Borovik-Romanov. We also express thanks to T. I. Kostina, N. M. Kreynes and V. V. Evdokimova for their assistance in conducting experiments.

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* A detailed communication about the results of the investigation of the influence of a uniform compression on pure bismuth will be published in the near future.

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On the Observation of Cerenkov Radiation Accompanying Broad Atmospheric Showers of Cosmic Rays

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