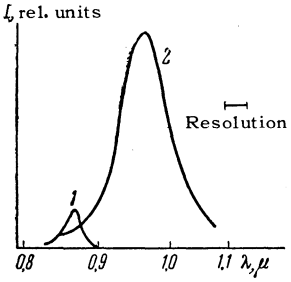
creased sharply on cooling from room temperature to that of liquid nitrogen. The radiation of germanium decayed exponentially with a time constant of ≈ 200 μsec. The duration of GaAs radiation was equal to the duration of the electron pulse.

The spectrum of the GaAs radiation was deduced from the amplitudes of the photomultiplier pulses on the screen of an oscillograph. The spectrum obtained in this way is shown in the figure. The width of the radiation line in this experiment was governed by the minimum width of the IKS-12 spectrometer slit, which was 0.3 mm.



Spectrum of recombination radiation of GaAs on excitation with fast electrons: 1) T = 300°K; 2) T = 77°K. I is the intensity in relative units.

The limited power of the accelerator used in the present work did not make it possible to reach a carrier density sufficient for a state with population inversion. In later work it is proposed to increase the accelerator current considerably in order to carry out experiments at higher excitation levels.

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[2] Basov, Krokhin, and Popov, Advances in Quantum Electronics, Columbia University Press, New York, 1961, p. 506.

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GALVANOMAGNETIC PROPERTIES OF RHENIUM

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Submitted to JETP editor December 26, 1962

J. Exptl. Theoret. Phys. (U.S.S.R.) **44**, 1116-1119 (March, 1963)

WE have already reported[1] that rhenium has an open Fermi surface. It was of interest to determine the topological nature of this surface. For this purpose we investigated single crystals of pure rhenium which had different orientations of the crystallographic axes with respect to the sample axes. The single crystals were obtained, as before, by melting and crystallization of rhenium rods (fired from a powder) in an electron-beam furnace.

From the prepared single crystals, plates mostly of dimensions 0.3 × 0.5 × 5 mm were cut by electro-spark machining. The electrical resistance of the samples changed between room temperature and 4.2°K [ρ(300°K)/ρ(4.2°K)] by a factor of between 1100 and 2100. Measurements were carried out both in a constant field and in pulse fields. During measurements in the constant field the field magnitude or its direction with respect to the crystal axes was varied linearly with time; this made it possible to record the dependence of the relative change in the resistance, $\Delta\rho/\rho = (\rho_H - \rho_0)/\rho_0$, on the magnitude and direction of

Sample No.	Orientation*		$\frac{\rho\ (300°\ K)}{\rho\ (4.2°\ K)}$	Sample No.	Orientation*		$\frac{\rho\ (300°\ K)}{\rho\ (4.2°\ K)}$
	θ	ξ			θ	ξ	
1	70	17	265	7	60	0	1740
2	0	0	1220	8	70	0	1550
3	0	0	1600	9	80	0	1100
4	90	0	1650	10	90	0	1650
5	40	0	1780	11	90	15	2000
6	50	0	1450	12	90	30	2100

*θ is the polar and ξ is the azimuthal angle of the sample axes with respect to the principal axes of the crystal (in degrees).

the field, using an automatic potentiometer. The method of making measurements on single crystals in pulse fields was similar to that used earlier.[1,2]

The properties of the samples are listed in the table.

Figure 1 shows the most typical angular dependences of $\Delta\rho/\rho$ in fields of 25 and 55 kOe, and Fig. 2 shows the dependence of $\Delta\rho/\rho$ on the magnetic field up to 150 kOe. From these curves it is clear that

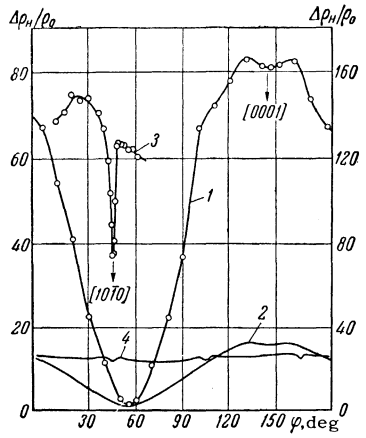

FIG. 1. Angular dependences of the relative change of the resistance in a transverse magnetic field (T = 4.2°K): 1) sample No. 4 in a field H = 55 kOe; 2) sample No. 4 in H = 25 kOe; 3) sample No. 3 in H = 55 kOe; 4) sample No. 2 in H = 25 kOe. The $\Delta\rho/\rho$ scale for curves 1 and 2 is given on the left and for curves 3 and 4 on the right; φ represents the angle of rotation of the magnetic field.

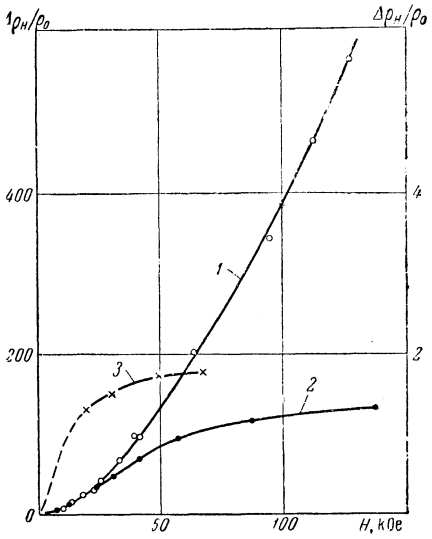

FIG. 2. Dependence of the relative change of the resistance on the magnetic field intensity (T = 4.2°K): 1) along the direction of the maximum in the angular dependence of sample No. 3; 2) along the direction of the minimum of sample No. 3; 3) along the direction of the minimum of sample No. 4. The $\Delta\rho/\rho$ scale for curves 1 and 2 is given on the left and for curve 3 on the right. The dependence of $\Delta\rho/\rho$ on H along the maximum for sample No. 4 is close to curve 1.

the angular dependence of "binary" samples is similar to that reported earlier[1] and differs from the earlier results only in that the ratio of the maximum and minimum resistances increased from 5 to 50 because of the higher value of the effective field[1)] (0.8×10^8 Oe, instead of 2.4×10^7 Oe).

The angular dependence of the resistance for the sample whose axis was parallel to the hexagonal axis of the crystal resembles somewhat a similar dependence obtained for Tl,[3] but, in contrast to Tl the resistance of Re at the maximum increases as $H^{1.7}$, while at the minimum it tends to saturate. If the angle θ between the hexagonal axis of the crystal and the sample axis in the [10$\bar{1}$0] plane is increased, then the hexagonal angular dependence is gradually deformed and finally transforms into the binary dependence; the two neighboring minima of the hexagonal angular dependence then approach gradually and decrease in magnitude. By recording the peak of the maximum of the binary angular dependence using a higher sensitivity of the circuit (Fig. 3) we could determine the angle θ_0 at which these minima vanish. This value of θ_0 was found to be 83°. The angular dependence of the resistance for a binary sample resembled similar dependences for Cd.[3] The

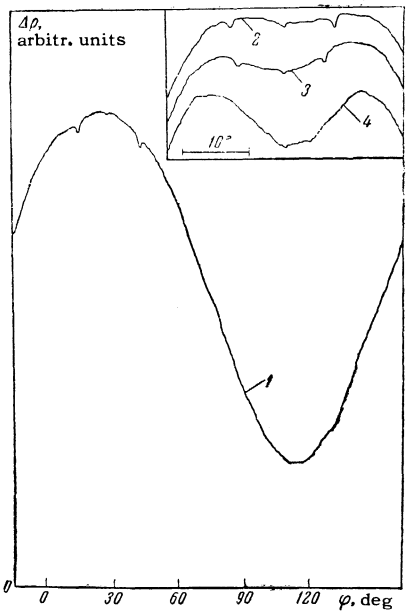

FIG. 3. Angular dependences of the relative change in the resistance in a transverse magnetic field (T = 4.2°K): 1) sample No. 7 in H = 25 kOe. The top right-hand corner shows the dependence $\Delta\rho(\varphi)$ in the region of the maximum for sample No. 9, recorded at high sensitivity. The sample was inclined to a field H = 25 kOe: 2) sample inclined by 6°, θ = 74°; 3) sample inclined by 4°, θ = 76°; 4) sample not inclined, θ = 80°.

maximum in the angular diagram of a binary sample always appears when the projection of the hexagonal axis on the plane of rotation of the magnetic field coincides with the direction of that field. The appearance of a minimum at which $\Delta\rho/\rho$ tends to saturation with increase of the field is in this case probably due to the fact that the current is perpendicular to an open direction of the Fermi surface. Consequently one of the open directions is parallel to the hexagonal axis. Therefore the quadratic rise of the resistance at the maximum should be considered as a result of the compensation of the hole and electron volumes of the Fermi surface. The minima in the hexagonal angular dependence indicate that, apart from the open directions parallel to the hexagonal axis, there should also be open directions in the hexagonal plane. However, it is possible that such directions appear only in strong fields, i.e., that they are due to so-called "magnetic breakdown." [4,5] Indeed, if we compare curves 2 and 3 in Fig. 2 we can easily see that while curve 3 even at $H \approx 20$ kOe shows a clear tendency to saturation, curve 2 in fields up to 25 kOe is practically indistinguishable from the quadratic dependence and the tendency to saturation appears in it only in fields exceeding 50 kOe.

Thus, we may assume that the Fermi surface of Re consists of two independent parts: hole and electron. From the data obtained by measurements of the Hall emf it follows that the electron surface is an open one. This open surface has open directions both along the hexagonal axis and in the hexagonal plane.

Concluding, we regard it as a pleasant duty to thank Academician P. L. Kapitza for his constant interest in this work and G. É. Karstens for determination of the crystallographic orientations of the samples.

[1)] The effective field is the quantity $H_{eff} = H\rho(300°K)/\rho(4.2°K)$. The maximum value of H_{eff} in our experiments was 2.5×10^8 Oe.

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[3] N. E. Alekseevskiĭ and Ye. P. Gaĭdukov, JETP **43**, 2094 (1962), Soviet Phys. JETP **16**, 1481 (1963).

[4] A. B. Pippard, Proc. Roy. Soc. (London) **270**, 1 (1962).

[5] M. H. Cohen and L. M. Falicov, Phys. Rev. Lett. **7**, 231 (1961).

Translated by A. Tybulewicz
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ON THE THEORY OF GREEN'S FUNCTIONS OF VECTOR FIELDS

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Submitted to JETP editor January 3, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) **44**, 1119-1121 (March, 1963)

A vector field with mass m and spin 1 is described by the equations

$$(\Box - m^2)\, A_n^{in} = 0, \tag{1a}$$

$$(g^{nn}\, \partial A_n^{in} / \partial x^n) = 0. \tag{1b}$$

The Lorentz condition (1b) excludes the quanta with zero spin. The quantization is usually carried out in terms of the three-dimensional operators $a_n^{\pm}(\mathbf{k})$, which are related to the four-dimensional operators $a_n(\pm k)$ in the usual way. [1] However, the whole procedure can also be carried through directly in terms of the covariant quantities $a_n(\pm k)$. In place of the usual expression for the commutator function we obtain then

$$D_{mn}^{\pm}(k) = \pm \frac{1}{(2\pi)^3 i} \left(g^{mn} - \frac{k_m k_n}{k^2} \right) 0\,(\pm k_0)\, \delta\,(k^2 - m^2). \tag{2}$$

Because of the factor $\delta(k^2 - m^2)$, this expression is not essentially different from the usual one. However, it is somewhat more general. In particular, it is adapted to the quantization of a field with vanishing mass.

The next step consists in defining the chronological product, i.e., the manner in which to go off the mass shell. The Green's function of different fields is, by definition, constructed in the following way: [1] the Green's function for an arbitrary field is obtained from the Green's function for a