Magnetic-breakdown oscillations of resistance in ruthenium

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The transverse magnetoresistance of the purest ruthenium single crystal presently available was measured at $T = 4.2°$ K in magnetic fields up to 100 kOe. Magnetic-breakdown oscillations of the resistance were observed for the first time in a nonferromagnetic transition metal.

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The results of investigations of the de Haas—van Alphen effect[1] and of the galvanomagnetic properties of ruthenium[2–4] have shown that the Fermi surface of this transition is such that magnetic breakdown is possible. It was established that a "neck-lens" magnetic breakdown between a multiply connected hole surface and a closed hole sheet ("lens"), centered at the L point of the Brillouin zone, leads to singularities of the magnetoresistance and to strong deviations from Kohler's rule. Direct proof of magnetic breakdown in ruthenium would be observation of the magnetoresistance oscillations at magnetic-field directions such that the magnetic breakdown transforms closed trajectories into open ones, i. e., the situation theoretically considered in[5] is realized. The present paper is devoted to searches for magnetic-breakdown oscillations in ruthenium.

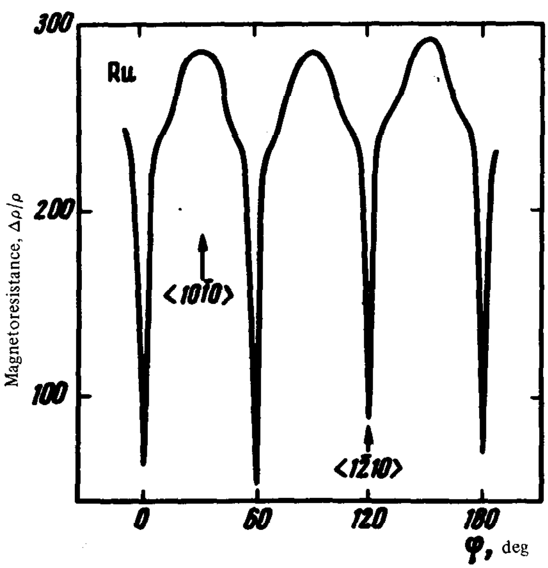

FIG. 1. Anisotropy of the magnetoresistance of ruthenium: $j \parallel \langle 0001 \rangle$; $T = 4.2$ °K; $H = 90$ kOe.

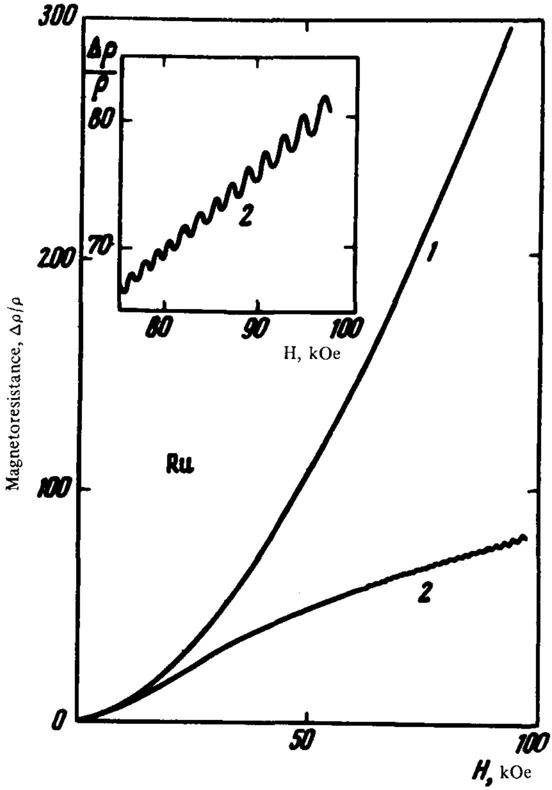

FIG. 2. Field dependences of the magnetoresistance of ruthenium: $T = 4.2\,^\circ K$; 1—$\mathbf{H} \parallel \langle 10\bar{1}0\rangle$, 2—$\mathbf{H} \parallel \langle 1\bar{2}10\rangle$.

We measured the transverse magnetoresistance $\Delta\rho/\rho$ of single-crystal samples measuring $0.5\times0.5\times10$ mm and having a ratio $\rho_{300\,^\circ K}/\rho_{4.2\,^\circ K} \approx 2000$ in fields up to 100 kOe at $T = 4.2\,^\circ K$. The results of the measurement of the mag-

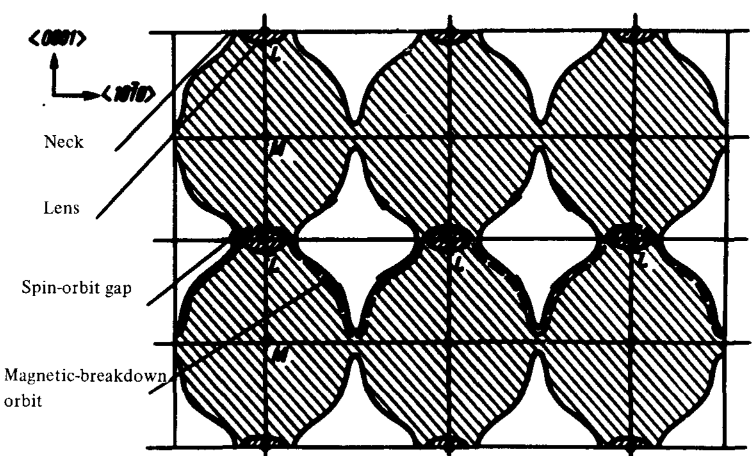

FIG. 3. Intersection of multiply-connected hole sheet and lens with the plane *LMML*.

netoresistance anisotropy of the samples with electric-current j oriented along the ⟨0001⟩ axis are shown in Fig. 1. In contrast to earlier studies,[2-4] sharp and deep minima of $\Delta\rho/\rho$ were observed at $\mathbf{H} \parallel \langle 12\bar{1}0\rangle$, pointing to the existence of open trajectories in the basal plane and perpendicular to j. This is also confirmed by the field dependences of $\Delta\rho/\rho$, which exhibit a tendency to saturation at $\mathbf{H} \parallel \langle 12\bar{1}0\rangle$ (Fig. 2). According to the model of the Fermi surface of ruthenium,[4] no open trajectories can occur in the basal plane at $\mathbf{H} \parallel \langle 12\bar{1}0\rangle$ because of the presence of "necks" on the multiply-connected hole surface along the line ML (Fig. 3), and the closed trajectories are transformed into open ones only because of the magnetic breakdown.

The strongest proof of magnetic breakdown, however, is the oscillating character of $\Delta\rho/\rho\,(H)$ precisely in the directions of the minima of the rotation diagram (Fig. 2). The magnetoresistance-oscillation frequency (4.2×10^6 Oe) agrees well with the frequency (4.0×10^6 Oe) measured in the de Haas-van Alphen effect and corresponds to the area of the extremal intersection of the lens with the plane $LMML$ ($\mathbf{H} \parallel \langle\bar{1}210\rangle$).[1] The agreement between the oscillation frequencies proves that the layer of open trajectories in the basal plane passes through the lens.

Thus, the sharp minima in the magnetoresistance anisotropy, the oscillatory character of the field dependence of the magnetoresistance, and the value of the oscillation frequency offer convincing evidence that a "neck-lens" magnetic breakdown takes place in ruthenium. We note in conclusion that insofar as we know ruthenium is the first nonferromagnetic transition metal in which magnetic-breakdown oscillations of resistance have been observed.

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[1]P. T. Coleridge, J. Low Temp. Phys. 1, 577 (1969).

[2]G. A. Bolotin, N. V. Volkenshteĭn, V. A. Novoselov, and V. E. Startsev, Fiz. Metal. Metalloved. 33, 740 (1972).

[3]N. E. Alekseevskiĭ, K.-H. Bertel, A. V. Dubrovin, V. I. Nikhankovskiĭ, and L. Urai, Pis'ma Zh. Eksp. Teor. Fiz. 18, 277 (1973) [JETP Lett. 18, 163 (1973)].

[4]N. V. Volkenshteĭn, V. P. Dyakina, V. E. Startsev, V. M. Azhazha, and G. P. Kovtun, Fiz. Metal. Metalloved. 38, 718 (1974).

[5]A. A. Slutskin, Zh. Eksp. Teor. Fiz. 53, 767 (1967) [Sov. Phys.-JETP 26, 474 (1968)].