Possibility of transition of hydrogen into the metallic state

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We investigated the resistivity of hydrogen at $T = 4.2\,^\circ\mathrm{K}$ in the pressure region $P \sim 1$ Mbar. A jump of the resistivity, amounting to six orders of magnitude, was observed. Observation of the "unfreezing" of the conducting state leads to the conclusion that the jump is connected with a phase transition.

The question of the transition of hydrogen into the metallic state has attracted much attention of late.[1–7] According to estimates,[1,3–7] this transition should occur at pressures of several megabars.

Observation of dielectric-metal transitions were previously reported[8–11] in diamond,[8,9] silica (SiO_2),[10] Al_2O_3, and other substances at pressures $P \sim 1$ Mbar.[11]

In the present study, using a procedure similar to that of[8–11], we have investigated the electric properties of hydrogen. To this end the hydrogen was precipitated on anvils cooled to $4.2\,^\circ\mathrm{K}$ and made of Carbonado-type diamond.[12] The thickness of the hydrogen layer is regulated by the amount of condensed gas. In the case of relatively large thicknesses of the solid-hydrogen layer, the resistance (R) does not depend on the force (F) applied to the anvils and remains constantly high.

The constancy of the resistance R at $F \approx \infty$ points to the important fact that no appreciable outflow of solid hydrogen takes place from the gap between the anvils at the given temperature.

When thinner hydrogen layers are deposited, a jump of the resistance by at least six orders of magnitude is observed (Fig. 1).

To verify that the jump of the resistance is connected with a phase transition, we used the method of "unfreezing" the metastable phase. This method was used earlier in[9–11].

Figure 2 shows a plot of the resistance in the case of repeated loading of the anvils. In this case the force was not dropped to a zero value, but to a value $F = F_b$, at which a conducting phase still existed, but symptoms of a transition to the dielectric state have already appeared. If the temperature is raised at a fixed force $F = F_b$, then the rate of the phase transition should increase, and the metastable metallic phase should "unfreeze."

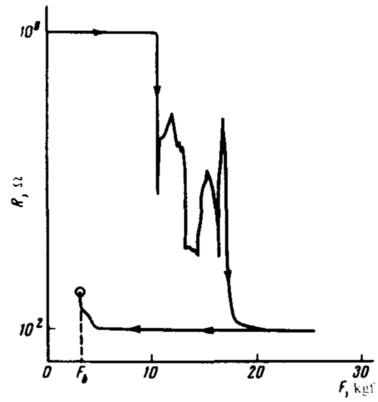

FIG. 2. Dependence of the resistance of hydrogen at $T = 4.2\,^\circ\mathrm{K}$ on the force following repeated loadings. The force was dropped to the value $F = F_b$.

Figure 3 shows the temperature dependence of the resistance at $F = F_b$.

Observation of the "unfreezing" effect leads to the conclusion that the jump of the resistance in hydrogen under pressure, under the conditions of our experiment, is due to a phase transition into the metallic state.

The pressure of the transition can presently be esti-

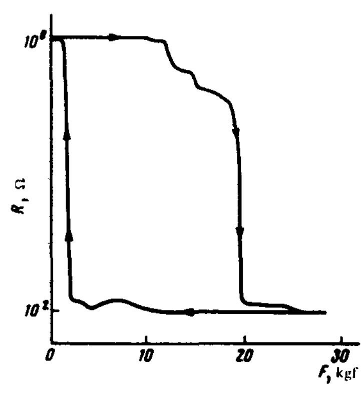

FIG. 1. Dependence of the resistance of hydrogen at $T = 4.2\,^\circ\mathrm{K}$ on the force applied to the anvils.

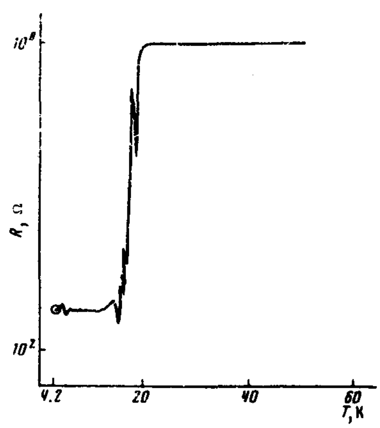

FIG. 3. Dependence of the resistance of hydrogen on the temperature at a fixed force F_b.

mated only approximately at $P \sim 1$ Mbar, which coincides in order of magnitude with the estimates given in[1,3-7].

We note in conclusion that the return of the hydrogen to the dielectric state after the removal of the pressure (Fig. 1) cannot be regarded as a demonstration that metallic hydrogen cannot exist at normal pressure. As is well known, it is necessary to employ special measures to conserve the "quenching" of the metastable modifications of substances.

[1] W. C. DeMarcus, Astron. J. **63**, 2 (1958).
[2] B. J. Alder, Progress on Very High Pressure Research, p. 152, New York—London, 1960.
[3] A. A. Abrikosov, Zh. Eksp. Teor. Fiz. **45**, 2038 (1963) [Sov. Phys.-JETP **18**, 1399 (1964)].
[4] V. P. Trubitsyn, Fiz. Tverd. Tela **7**, 3363 (1965) [Sov. Phys.-Solid State **7**, 2708 (1966)].
[5] V. P. Trubitsyn, Fiz. Tverd. Tela **8**, 3241 (1966) [Sov. Phys.-Solid State **8**, 2593 (1967)].
[6] V. N. Zharkov, V. P. Trubitsyn, and L. V. Samsonenko, Fizika zemli i planet. (Physics of the Earth and Planets), Moscow, Nauka, 1971.
[7] E. G. Brovman, Yu. Kagan, and A. Kholas, Zh. Eksp. Teor. Fiz. **62**, 1492 (1972) [Sov. Phys.-JETP **35**, 783 (1972)].
[8] L. F. Vereshchagin, E. N. Yakovlev, G. N. Stepanov, and B. V. Vinogradov, ZhETF Pis. Red. **16**, 382 (1972) [JETP Lett. **16**, 270 (1972)].
[9] L. F. Vereshchagin, E. N. Yakovlev, B. V. Vinogradov, V. I. Sakun, and G. N. Stepanov, ZhETF Pis. Red. **17**, 422 (1973) [JETP Lett. **17**, 301 (1973)].
[10] L. F. Vereshchagin, E. N. Yakovlev, B. V. Vinogradov, and V. I. Sakun, ZhETF Pis. Red. **20**, 472 (1974) [JETP Lett. **20**, 215 (1974)].
[11] L. F. Vereshchagin, E. N. Yakovlev, B. V. Vinogradov, and V. I. Sakun, ZhETF Pis. Red. **20**, 540 (1974) [JETP Lett. **20**, 246 (1974)].
[12] L. F. Vereshchagin, E. N. Yakovlev, T. D. Varfolomeeva, V. N. Slesarev, and L. E. Shterenberg, Dokl. Akad. Nauk SSSR **185**, 655 (1969).