Transitions of Al_2O_3, NaCl, and S into the conducting state

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Transitions of Al_2O_3, NaCl, and S into the conducting state under pressure were observed. The pressures were obtained in anvils of carbonado-type diamond.

The transition of an insulator into a metal is one of the fundamental problems of solid-state physics. From this point of view, it was of interest to investigate the possibility of transforming a number of typical insulators, such as corundum, sodium chloride, or sulfur.

We have previously developed a procedure for observing phase transitions into the conducting state at pressures $p \sim 10^6$ bar. Transitions in diamond and SiO_2 were observed by this procedure.[1,2]

Transitions under pressure from the dielectric state into the conducting state are characterized by the presence of metastable phases, namely, when the pressure is increased, the metastable phase prior to the transition into the conducting state is the dielectric phase; when the pressure is removed, the metastable phase prior to the transition to the dielectric is the conducting phase.

When the medium in the metastable state is heated the probability of transition to a stable state increases, and at sufficiently high temperature one can observe a transition to the stable modification. The "unfreezing" of metastable phases is a reliable test in the investigation of dielectric-metal transitions and is used in the present study.

Figure 1 shows a typical plot of the electric resistance of Al_2O_3 powder placed between anvils made of diamonds of the carbonado type. The abscissas represent the force, in kilograms, applied to the anvils. It is seen from the plot that when the anvil load is removed the resistance returns to its initial value. This favors the assumption that Al_2O_3 cannot be decomposed as it goes into the conducting state under pressure.

Figure 2a shows a plot of the electric resistance in an experiment in which the force on the anvil is reduced not to zero but to a value $F = F_b$. The sample was heated at the fixed force F_b. It is seen from Fig. 2b that a transition to the dielectric state takes place with rising temperature. To "unfreeze" the metastable conducting phase in this experiment it was necessary to raise the temperature only slightly (Fig. 2b).

The fact that the resistance returns to the initial value when the conducting phase is " unfrozen" also

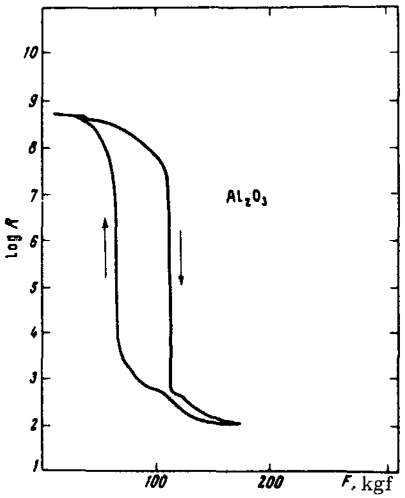

FIG. 1. Dependence of the electric resistance R on the anvil load F.

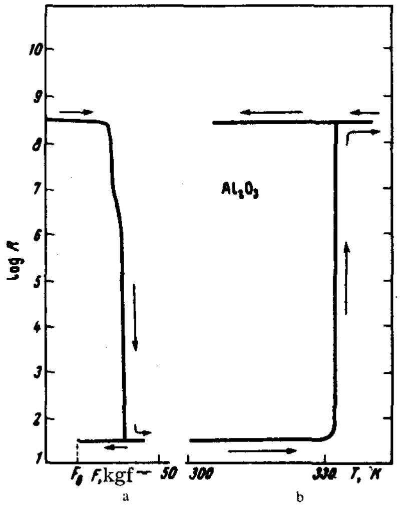

FIG. 2. a) Plot of $R(F)$. A force $F = F_b$ was maintained after reducing the load, and the sample was heated. b) Variation of the resistance during the heating.

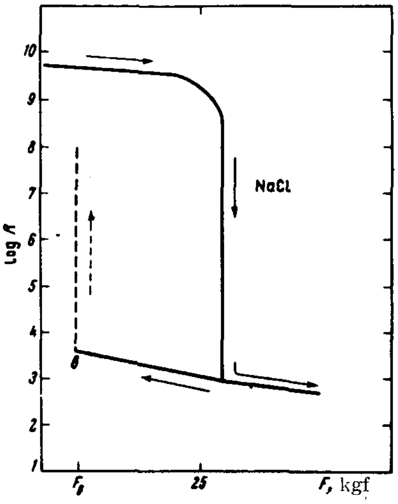

FIG. 3. Plot of $R(F)$ for NaCl.

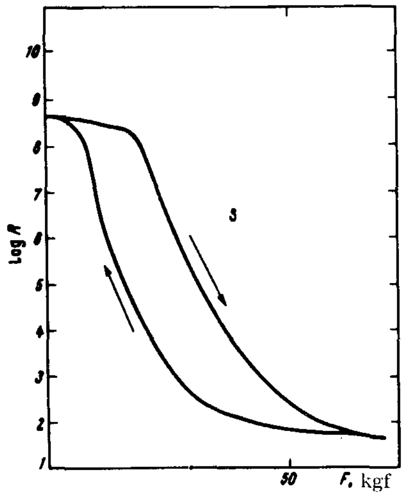

FIG. 4. Plot of $R(F)$ for sulfur.

favors the assumption that Al_2O_3 does not decompose under pressure. We observed no symptoms of decomposition after numerous loading and unloading and after heating the Al_2O_3 sample to 300 °C.

An investigation of the electric conductivity of NaCl under pressure shows that a conducting phase of this substance exists. Under definite conditions, the conducting phase becomes metastable and it can be changed to the dielectric state by heating. Figure 3 shows a plot of the resistivity of NaCl against the load; the dashed line shows the resistivity during the course of "unfreezing" of the metastable phase. We note that the experiments in NaCl were performed with dry powder. To this end, the NaCl was roasted directly in the anvils.

The transition in NaCl is discussed in a paper by Piermarini at the Gordon conference in the USA (June 1974). We consider it our duty to mention the fact that we have no exact data at present with which to compare the results.

The transition of sulfur (S) into the conducting state was observed earlier only under the influence of dynamic pressures ($P \sim 240$ kbar) and high temperatures (1000 °C).[3] There are references to tests under static pressures,[4] carried out at the Osaka University (Japan). This paper has, however, not yet been printed. In our experiments we observed diffuse transitions of S to the conducting state (Fig. 4).

We have discussed above transitions of Al_2O_3, NaCl, and S into the conducting state, this being a first stage in the investigation of new conducting substances obtained under high pressures. The next step would be to establish the sequence of these transitions under the influence of pressure. According to preliminary estimates, the transition pressure of sulfur is less than that of NaCl, which in turn is less than that of Al_2O_3. The transition pressure of Al_2O_3 agrees approximately with the pressure of the transition of diamond to the conducting state.

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[2]L. F. Vereshchagin, E. N. Yakovlev, B. V. Vinogradov, V. P. Sakun, and G. N. Stepanov (in press).
[3]N. Kawai and A, Nishiyama, Proc. Japan Acad. 50, 72 (1974) (1974).
[4]S. D. Hamann, Aust. J. Chem. 11, 391 (1951).