

characteristics become S-shaped, i.e., the switching effect. With increasing temperature, when the carrier relaxation from the shallower to the deeper wells is accelerated because of transitions over the barrier, the S-shape should become straighter. Temperature investigations have shown that in SDC Ge samples the S-shapes begin to straighten out at  $T > 5^\circ\text{K}$ , and there is no S-shape at all at  $T = 25^\circ\text{K}$ . This makes it possible to estimate the effective depth of the shallowest states, the overfilling of which is responsible for the switching, at several millielectron volts.

In weakly doped semiconductors, the presence of a compensating impurity raises the levels of certain ions of the main impurity considerably above the neutral-atom levels. After the breakdown, the electrons "freeze out" from the conduction band. This phenomenon can be particularly noticeable in the presence of correlation in the placements of the main and compensating impurity ions, when the energy of the Coulomb interaction of the impurities is much higher than at the average distance.

<sup>1)</sup>Breakdown with an S-shaped characteristic will henceforth be called "switching," for in this case two different values of the current can correspond to one value of the voltage.

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#### CONCERNING SUPERCONDUCTIVITY IN THE SODIUM-AMMONIA SYSTEM

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The resistivity of sodium-ammonia solutions with concentrations 1 - 12 at.% Na was investigated in the temperature interval 20 - 240°K. The results suggest that this system may be superconducting.

The possibility that a sodium-ammonia system may be superconducting has been frequently suggested [1, 2] because anomalously low resistivities have been observed in it [2 - 5], and from this point of view this is one of the most promising systems. However, owing to the lack of experimental facts, the question of superconductivity in sodium-ammonia solutions remains open.

We present here the results of an investigation of the resistivity of sodium-ammonia solutions with concentrations 1 - 12 at.% Na in the temperature intervals 20 - 80, 78 - 240, and 20 - 240°K. We measured about 300 samples with different geometries; the samples were either frozen in capillaries or frozen between cover glasses.

The temperature dependence of the resistance at 3.2% sodium concentration is shown in Fig. 1. Similar curves were obtained also for other compositions<sup>1)</sup>.

In the 20 - 80°K range, the resistance increases very slowly with temperature. Near the nitrogen point, a sharp increase of the resistance is observed (by approximately two orders of magnitude) followed by a flattening into a plateau. With further temperature rise, the samples go over into the dielectric phase, which spans the interval 120 - 160°K (II). A new transition to the conducting state occurs above 160°K (III). The resistance maximum at 195°K is connected with the transition of the sample to the liquid phase.

We note that in temperature regions I and III the temperature dependence of the resistance is described by a single function

$$R(T) \sim A \exp[-aT_0/T], \quad (1)$$

where A is a pre-exponential factor approximately equal to  $10^4$ ,  $a$  is a constant approximately equal to 3, and  $T_0$  is  $\sim 190^\circ\text{K}$  in our case. This suggests that states I and III are identical and if there is no dielectric phase in interval II we can expect the resistance to behave in the manner shown dashed in Fig. 1.

In slow cooling from  $165^\circ\text{K}$ , the temperature dependence of the resistance is irreversible, namely, a certain supercooling (triangles in Fig. 1) produces a dielectric phase that remains in existence down to nitrogen temperatures<sup>2</sup>).

It is typical that all the phase transitions noted in our experiments are caused by very slight additions of sodium ( $\sim 2 - 3\%$ ). There is no transition whatever in pure ammonia.

In some experiments, when the samples were frozen in nitrogen, the absolute resistivity  $\rho^*$  referred to the amount of the sodium participating in the sample, i.e., assuming that all the sodium is precipitated in the form of a single metallic filament, turns out to be very small (see the table).

Composition % Na		1	2	2.5	3.2	7.5	12
$\rho^*$ , $\Omega\text{-cm}$	Samples from plates	$10^{-4}$	$2 \cdot 10^{-5}$	$10^{-7} - 10^{-8}$	$10^{-8}$	$5 \cdot 10^{-6}$	$10^{-5}$
	Samples from capillaries	$10^{-4}$	$2 \cdot 10^{-5}$	$10^{-7}$	$2 \cdot 10^{-8}$	$4 \cdot 10^{-6}$	$10^{-5}$

Anomalously low ( $10^{-7} - 10^{-8}$ ) resistivities that are independent of the sample geometry were observed at 2.5 - 3.2% Na concentrations. We indicate for comparison that in the case of such first-grade conductors as copper and sodium the resistivity at  $100^\circ\text{K}$  is  $\sim 10^{-5} - 10^{-6}$  ohm-cm. The observed resistivities can therefore not be attributed to precipitation of all the sodium in the form of a single metallic filament (a process which is difficult to imagine in any case), as in the framework of the usual conductivity mechanisms [5].

Additional information that casts light on the cause of the low resistance was obtained from experiments performed at nitrogen temperatures. It was noted that when the sample was rapidly frozen in nitrogen, its resistance could not be measured with our apparatus (R-348 potentiometers) at the initial instant. After some time the resistance of the sample kept at the same temperature increased strongly and reached saturation after 20 - 25 minutes (Fig. 2). The experimental points fit quite well in a straight line, indicating that the time dependence of the resistance is exponential

$$R(t) = B \exp[-bt_0/t], \quad (2)$$

where  $B \sim 10^2$ ,  $b \sim 1.2$ , and  $t_0$  (the time to saturation) is  $\sim 25$  min. Extrapolation of the  $R(t)$  to the time  $t = 0$  yields  $R(0) = 0$ . Indeed, even a rather crude graphic extrapolation of the curve of Fig. 2 yields a resistivity  $\rho^* < 10^{-3}$  ohm-cm.

In our opinion, such low resistances can be explained by assuming the existence of superconductivity in the Na-NH<sub>3</sub> system. It follows from one-dimensional superconductivity [2] that the fluctuations that destroy the long-range order can produce in such systems a certain resistance.

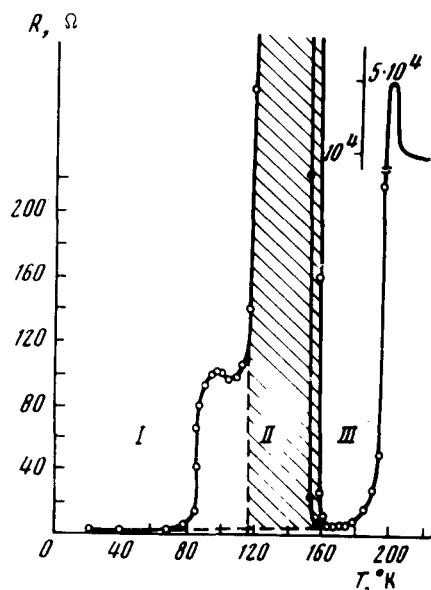


Fig. 1. The temperature dependence of the resistance of a solution with 3.2 at.% sodium concentration: circles - measurements at rising temperature, triangles - at slowly decreasing temperature.

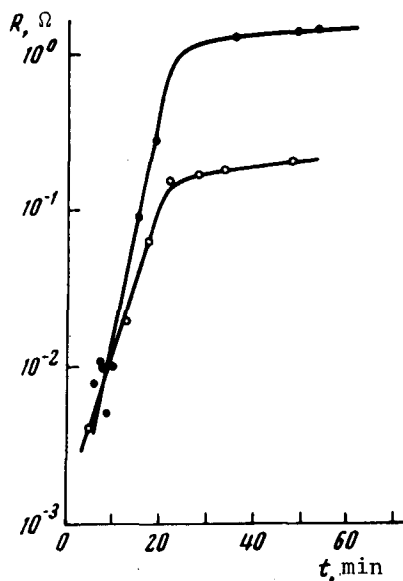


Fig. 2. Time dependence of resistance of Na-NH<sub>3</sub> with concentration 3.2 at.% Na. The two curves correspond to two different experiments.

The time dependence can be explained on the basis of the imbalance of the investigated system. The superconductivity produced at the initial period of time is destroyed as the system relaxes. Such a situation was considered in [6]. Estimates [6] yield a relaxation time  $\tau \sim 10^{-5}$  sec, whereas in our experiments  $t_0 \sim 20$  min.

The exponential growth of the resistance with time explains why the data obtained by others are contradictory, namely, the experimenters obtained different values of the physical quantities, depending on the instant of time when the measurements were started. Therefore, low values of the resistance were obtained at best in one or two out of a hundred experiments, for example, and only in two studies [3, 4] were "undamped" currents with lifetimes 1 - 2 min observed. The relatively short lifetimes of the persisting currents follow also from (2). If we use the estimated resistivities obtained in these experiments,  $\rho \sim 10^{-12} - 10^{-13}$  ohm-cm, and our values of B, b, and  $t_0$ , then the lifetime of the persisting currents is about 1 minute. We see thus how easy it is to miss the effect by delaying the start of the measurement. This explains in turn why there is no unequivocal answer to the question of superconductivity in sodium-ammonia solutions.

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1) The present paper deals mainly with the Na concentration interval 2.5 - 3.2 at.%. Details of the experiments and descriptions of the other compositions will be reported elsewhere.

2) The transformation at 165°K is accompanied by release of the latent heat of transition.

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#### THE REACTION $\text{Li}^7(e, e'p)$ AT 1200 MeV

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The cross section of the reaction  $\text{Li}^7(e, e'p)\text{He}^6$  as a function of the detachment energy was measured at seven proton-emission angles at 4-momentum squared  $0.16 (\text{GeV}/c)^2$ . The angular distributions were plotted for the protons knocked out of the 1p and 1s shells of  $\text{Li}^7$ . The results are compared with shell-model calculations with an oscillator potential. A  $\chi^2$  fit yields a wavefunction parameter  $100 \pm 9 \text{ MeV}/c$  for the 1s shell of  $\text{Li}^7$  and  $70 \pm 5 \text{ MeV}/c$  for the 1p shell; the suppression coefficients are 0.30 and 0.47, respectively.

In the plane-wave impulse approximation, the cross section of the  $(e, e'p)$  reaction is proportional to the cross section for elastic scattering of an electron by a proton moving with momentum  $q$ , and to the square of the wave function of this proton in the target nucleus. Since