Voltage-current characteristics of a regular system of weakly coupled superconducting particles

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The voltage-current characteristic of a regular system of identical, weakly coupled superconducting particles has been studied for a sample covered by a metal film. Near T_c, an inverse hysteresis is found, i.e., the current corresponding to the return to the superconducting state is higher than the critical current for the disruption of superconductivity. When samples with clean surfaces are used as both source and detector, they influence each other; i.e., there is a stimulation of superconductivity.

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Systems consisting of large numbers of identical Josephson junctions are interesting because of the possible synchronization of these junctions.[1–3]
We have used a high-pressure matrix method to produce a regular system of identical metal particles with scale dimensions ~2000 Å connected by microbridges ~600 Å in diameter (the filling of the matrix with the metal was ~25%).

We studied the voltage-current characteristics of the system in its superconducting state. Near the transition temperature the characteristics exhibit an anomalous behavior. Figure 1(a) shows a family of characteristics for a sample with indium particles (the sample dimensions were 0.5×1.3×3 mm) at 3.50 K. The transition from the

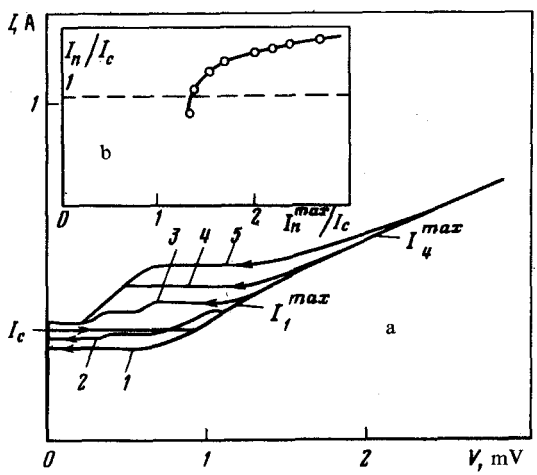

FIG. 1. a—Voltage-current characteristics of a regular system of superconducting indium particles with a metal coating ($T = 3.50$ K); (b)—dependence of the current at the transition to the superconducting state (I_n) on the maximum current (I_n^{max}) passed through the sample ($T = 3.50$ K).

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normal state to the superconducting state occurs at a current (I_n, $n = 3, 4$) higher than the current which disrupts the superconducting state (I_c). The magnitude of this "inverse hysteresis" depends on the maximum current (I_n^{max}) which has been passed through the sample, increasing with increasing I_n^{max} (Fig. 1b). This inverse hysteresis occurs only near the critical temperature T_c, which in our case is slightly above the critical temperature of bulk indium. As the temperature is lowered, the hysteresis vanishes (the characteristic at $T \sim 3.4$ K has the usual shape). It turns out that this hysteresis stems from the existence of an indium film which was deposited on the surface of the sample in the course of its mechanical treatment. When the metal was removed from the surface, the inverse hysteresis vanished, and the voltage-current characteristic took the form in Fig. 2a (curve 1).

We attempted to use the systems from which the surface metal film had been removed as a Josephson source and a Josephson detector. As the detector we used a sample with indium particles, while the source was a sample with particles of Wood's metal (50% Bi, 25% Pb, 12.5% Cd, 12.5% Sn) with $T_c \sim 6$ K (the sample dimensions were $0.6 \times 2 \times 4$ mm). The samples were placed 0.2 cm from each other in liquid helium. It was found that one sample affected the other in a manner reminiscent of the stimulation of superconductivity by an rf field.[4,5] Figure 2a shows a family of voltage-current characteristics of the detector, with the voltage across the source as parameter (Fig. 2b). When there is a voltage across the source, the critical current of the detector becomes higher (curves 2–7 in Fig. 2a) than the critical current with the source turned off (I_1). Curves 4 and 8 show that in this case the magnetic field of the source has

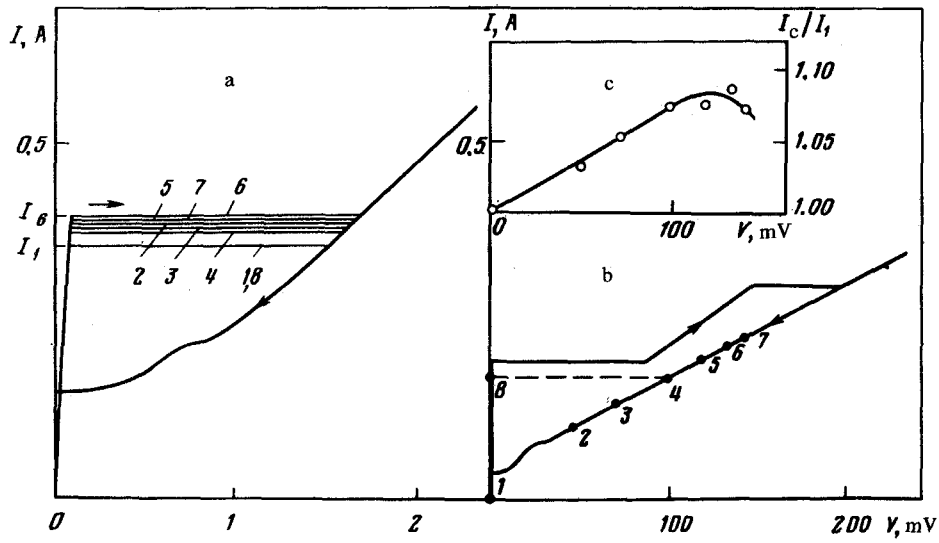

FIG. 2. Results for a system consisting of a source and a detector which are samples with regular arrays of superconducting particles (without a surface metal film). a—Voltage-current characteristic of a detector of indium particles ($T = 3.51$ K) (I_1–I_8 correspond to various voltages across the source); (b)—voltage-current characteristic of a Wood's-metal source ($T = 3.51$ K); (c)—dependence of the critical current of the detector on the voltage across the source ($T = 3.51$ K).

nothing approaching a significant effect, since the currents (and thus the magnetic fields) are the same in the two cases, but the stimulation of superconductivity occurs only when there is a voltage across the source (i.e., only when it is in a nonsuperconducting state). Figure 2c shows the stimulation effect (the current I_n) vs the voltage across the source. When the sample surfaces were again covered with a metal film, the stimulation effect disappeared, and the inverse hysteresis reappeared near T_c on the voltage-current characteristics.

In summary, systems of this type with a regular array of weakly coupled superconducting particles exhibit properties analogous to those of Josephson sources and detectors. When the surfaces of these systems are covered with metal films, they exhibit anomalous voltage-current characteristics near T_c, whose nature is not clear. It is possible that the anomalous behavior results from an rf field for which the film acts as a shield; another possibility is an involvement of vortices which penetrate into the multiply connected sample when the superconductivity is disrupted by the current.

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