V. P. Galaĭko and V. M. Dmitriev. *Nonequilibrium superconductivity in specimens with small transverse dimensions.* Nonequilibrium superconductivity is interesting for the fact that new and unusual properties may be expected under nonequilibrium conditions in superconductors by virtue of their special sensitivity to external disturbances. These conditions can be set up most easily throughout the entire volume of the superconductor by using specimens with small transverse dimensions and, for example, passing a current higher than the critical value through the specimen or exposing it to electromagnetic radiation. It is possible as a result to observe certain new physical aspects of superconductivity, which are the subject of the present note. They concern the nature of resistive (i.e., dissipative but not normal) current states in narrow superconductive channels and stimulation of superconductivity in these channels by external electromagnetic radiation. From the standpoint of superconductor kinetics, both of these phenomena are determined by the properties of the essentially nonequilibrium electron distribution over microstates in the presence of the superconducting condensate.

1. *Resistive current states.* When a supercritical current is passed through a narrow semiconducting

specimen (film or whisker), a number of singularities that cannot be explained in the generally accepted models are observed near the critical temperature T_c of the superconductor.[1-3] The most important ones are as follows: 1) a broad resistive range on the volt-ampere characteristic (VAC) between the critical depairing point I_c and the depairing point I_{c2}, above which the specimen goes over into the normal state; 2) a nonzero value of the reactive component of the specimen's admittance in measurements in the microwave range; 3) in some cases, generation of low-frequency ($f=30-250$ MHz) electromagnetic vibrations. These experiments indicate the simultaneous existence of superconductive ordering ($\Delta \neq 0$) and a constant longitudinal electric field in the specimen. Because of the specimen's small transverse dimensions, it cannot be a result of a mixed or intermediate state, and the possible contribution of the fluctuations of Δ to resistance is found to be too small. The hypothesis has therefore been advanced[4] that the transition from the normal current state to the resistive state in the channel is accompanied, because of the Cooper instability, by a nonequilibrium microscopic, "phase" separation into superconductive and quasinormal regions that alternate along the specimen. Subsequent theoretical[5-8] and experimental[3,9] studies have clarified the physical mechanisms by which this structure forms, the nature of its singularities, and details of principle.

It was found that the phase of the superconductive-ordering parameter is important in the formation of structure, as is the fact that the condensate can adjust itself quickly to the spatial distribution of the longitudinal field, so that the field potential enters into the local excitation spectrum. The resulting imbalance of electron- and hole-like excitations relaxes slowly, giving rise to normal diffusion fluxes that penetrate to a depth δ_E into the superconductive regions. Parallel flow of superconductive and normal currents becomes possible as a result. Here the quasinormal segments of the structure are associated with singular centers at which there are discontinuities of the rate of change of the phase with time. This results in small Josephson oscillations in the neighborhood of these centers.

The relaxation processes that determine the depth δ_E may be related both to elastic and to inelastic electron collisions, producing different temperature dependences in the extreme cases: $\delta_E^{(e)} \sim (1-t)^{-1}$, $\delta_E^{(i)} \sim (1-t)^{-1/4}$. The structure is manifested experimentally in the form of voltage discontinuities on the VAC, separated by segments with dynamic resistance $R_N = 2\delta_E N/\sigma_n S$ (N is the step number, σ_n is the normal conductivity, and S is the cross section of the specimen. Measurements of R_N enable us to determine the temperature dependence of δ_E, which conforms to theory, changing from $(1-t)^{-1}$ to $(1-t)^{-1/4}$ with the approach to the critical temperature.

The details of the VAC and those of the electrical-potential oscillations in the case of moving structure are generally in agreement with the implications of the theory and point to the conclusion that in addition to the previously known resistive states of large superconductors there is also a kind of nonequilibrium resistive current state of microscopic "phase" separation in small specimens.

2. *Stimulation of superconductivity by an electromagnetic field.* Any external disturbance, including electromagnetic radiation, usually suppresses superconductivity. However, it has been found[10] that there is a nonequilibrium superconducting state in an external microwave field, in which its superconductive properties are amplified for $T < T_c$ or arise out of the normal state for $T > T_c$. It has been shown theoretically[11] and confirmed experimentally[12] that this results from a change in the energy distribution of the electronic excitations in the microwave field, which, under certain conditions, can contribute effectively to superconductive electron pairing, raising the critical parameters I_c, H_c, and T_c of the superconductor. The conditions are: the presence of external radiation with frequency $\omega_1 > \omega > \omega_2$ and not too high amplitude, a specimen temperature relatively close to the equilibrium critical temperature, and a zero magnetic field or one that is not too large compared to critical. The numerical values of these quantities depend on the material of the specimen. Without these conditions, the stimulating effect of the radiation gives way to its usual depairing effect or to disruption of superconductivity by Joule heat.

An interesting aspect of this type of nonequilibrium superconductivity is the fact that as the temperature of the specimen in the radiation field is lowered, the superconductive-ordering parameter appears abruptly at the transition point $T_m > T_c$, as in a phase transition of the first kind. At the same time, analysis of the nonequilibrium depairing curves $j_s(\Delta)$ indicates that the nonequilibrium critical current, which is usually the quantity measured in experiments, is a continuous function of temperature, even though it increases rapidly from zero as the temperature is lowered ($T < T_m$). Thus, we encounter the case in which the superconductor cannot be loaded with any constant current at a nonzero superconductive-ordering parameter, since this causes it to transfer to the dissipative state.

These nonequilibrium-superconductivity effects are interesting in themselves, but their interrelationships, which have yet to be studied, will be even more interesting.

[1] G. E. Churilov, V. M. Dmitriev, and A. P. Beskorsyǐ, Pis'ma Zh. Eksp. Teor. Fiz. **10**, 231 (1969) [JETP Lett. **10**, 146 (1969)].

[2] G. E. Churilov, V. M. Dmitriev, and V. N. Svetlov, Fiz. Kond. Sost. (Physico-technical Institute Ukr. Acad. Sci.), No. 28, 65 (1973).

[3] V. P. Galaǐko, V. M. Dmitriev, and G. E. Churilov, Fiz. Nizk. Temp. **2**, 299 (1976) [Sov. J. Low Temp. Phys. **2**, 148 (1976)].

[4] V. P. Galaǐko, V. M. Dmitriev, and G. E. Churilov, Pis'ma Zh. Eksp. Teor. Fiz. **18**, 362 (1973) [JETP Lett. **18**, 213 (1973)].

[5] V. P. Galaǐko, Zh. Eksp. Teor. Fiz. **66**, 379 (1974); **68**, 223 (1975); **71**, 273 (1976) [Sov. Phys. JETP **39**, 181 (1974); **41**, 108 (1975); **41**, 141 (1976)].

[6]V. P. Galaǐko and V. S. Shumeǐko, *ibid.* **71**, 671 (1976) [**44**, 353 (1976)].

[7]V. P. Galaǐko, J. Low Temp. Phys. **26**, 483 (1977).

[8]E. V. Bezuglyǐ, E. N. Bratus', and V. P. Galaǐko, Fiz. Nizk. Temp. **3**, 1010 (1977) [Sov. J. Low Temp. Phys. **3**, 491 (1977)].

[9]V. M. Dmitriev and E. V. Khristenko, *ibid.* **3**, 1210 (1977) [**3**, 587 (1977)].

[10]A. F. G. Wyatt, V. M. Dmitriev, W. S. Moore, and F. W. Sheard, Phys. Rev. Lett. **16**, 1166 (1966).

[11]G. M. Éliashberg, Pis'ma Zh. Eksp. Teor. Fiz. **11**, 186 (1970) [JETP Lett. **11**, 114 (1970)].

[12]V. M. Dmitriev and E. V. Khristenko, Fiz. Nizk. Temp. **4**, 821 (1978) [Sov. J. Low Temp. Phys. **4**, 387 (1978)].