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NONLINEAR PHENOMENA IN COMPLEX SYSTEMS

Fractals, Chaos, Attractors, Bifurcations, Phase Transition, Self-organization

On the Appearance of Space Temperature Electric Structures in Hyperconductors under High Magnetic Fields

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As part of the study of low temperature galvanomagnetic properties of high purity **Al** in the Corbino geometry the voltage-current characteristics (IV) under external transverse magnetic field in the regime of given current revealed the effects of voltage stabilization [1]. Here we attempt to ascribe these phenomena to appearance in the sample of bulk temperature structures characteristic of highly nonequilibrium systems. Joule's heat of flowing electric current gives rise to disk warming. We also discuss the problems of the influence of warming in disks on the phenomena of electric transport with allowance for own magnetic fields being generated in disk.

The Corbino disk is a circular conductor with a current contacts in the center of sample and around outward perimeter. Both current contacts are the equipotential surfaces including the situation under applied external magnetic field B_z which is perpendicular to disk surface.

The radial component of current density j_r will stay constant when external magnetic field increasing. In such sample the current lines acquires a spiral shape under Lorentz forces. The number of turns is determined by the relaxation time of carriers τ and the magnitude of external magnetic field B_z. In plane of disk the radial electric current is produced and the density of this current is not constant along the radius: $j_\varphi \sim 1/r$. One may judge about radial current proceeding from own magnetic field B_z that interacts constructively or destructively with the applied field depending upon whether the carriers spiral inward or outward, respectively. For ordinary conductors and light currents the effect of the self-field of the current is very small. But the effect should be large in materials of high mobility such as hyperconductive **Al**.

The experiments were performed on the Corbino disk (fig.1, insert) prepared from high-purity polycrystalline **Al** with resistance ratio $\rho_{293K}/\rho_{4.2K} \simeq 20000$. The disk had outward diameter $\simeq$ 35 mm and thickness $\simeq$ 2 mm. Conventional four-probe measurements of magnetoresistance were performed under direct current. Potential contacts were set on the sample along radial direction with due account of Corbino measurement distinctions. The magnetic field up to 8.5 T were realized by superconductive solenoid. Magnetic field parameters were determined by miniature Hall detector. The regime of given current was in working order and maximal current density was $2 \cdot 10^6$ A/m^2. Disk behaviour in medium with the given temperature was investigated at the same time with experiments in liquid helium. The experiments in liquid helium where the disk warming is conditioned by Joule's heat of flowing electric current were investigated at the same time with the experiments in medium with given temperature. This temperature was changed by electric heating-up of oven over a range from 4.2 to 50 K. Temperature parameters were determined by thermal element TSAD and thermocouple **Au** + 0.07% **Fe-Cu**. The temperature dependences were investigated under detector current 70 A.

Fig.1 presents temperature dependences of magnetoresistance ρ_B (in terms of voltage U_B) for aluminium disk. Minimum on the dependences $U_B = f(T)$ for various external magnetic fields are observed. It is assumed that for disk in τ-approximation

$$\rho_B = \rho_0(\omega\tau)^2,$$

where ρ_0 - resistance value at $B = 0$, ω - cyclotronic frequency. The minimum corresponds to the range of transition from strong ($\omega\tau \gg 1$) to weak ($\omega\tau \ll 1$) magnetic fields. Transition range is displaced along temperature scale under the condition

$$B^2(1/T^n) = const; \qquad \rho_B \sim \rho_{xx} \sim (\tau^2(B)/\tau_0)$$

For more strong fields the minimum is observed at more great temperatures. High sensitivity of resistive properties of medium relative to the temperature fluctuations occurs. Static current-voltage characteristics of disks, fig.2, is of great interest. $I - V$ shows monotonous character in current range from 0 to 1600 A in absence of external magnetic field. The application of magnetic field variates $I - V$ form. Linear rise of voltage occurs only on the initial part. Then the shape of curve depends on current direction and therefore on interaction pheuomena of the own and external magnetic fields at the same time with another possible reasons. In case of constructive current direction maximum is observed on curves. The maximum is displaced to more small currents when magnetic field increasing. In case of destructive current direction the monotonous rise of voltage is replaced abruptly by saturation and then the curve slopes go down.

We have an example of dynamic system in which aggregate of degrees of freedom is associated with the temperature field in disk-like sample. This form may be represented as a hollow cylinder with small height. As it was pointed the system is warmed up by joule's heat of flowing electric current in conditions of contact with cryogenic liquid. Then the equation described the evolution of temperature field in conditions of radial heat flow along sample which is warmed up by electric current under presence of strong magnetic field and helium temperature has the following form

$$c\frac{dT}{dt} = \rho(\omega\tau)^2 j^2 - q_- + \lambda\left(\frac{1}{r}\frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial r^2}\right),$$

where c - heat capacity, q_- - power of heat removal, λ - heat conductivity.

In this case τ is determined by the sum of electron-impurity (τ_{im}) and electron-phonon (τ_{ph}) interactions. Just as τ_{im} is unchanged over the whole temperature range τ_{ph} is the temperature dependent function that is indefinitive over a wide temperature range. For helium temperature the characteristic phonon impulse is

$$p_{ph} = (T/\vartheta)p_F,$$

where θ - Debye temperature, p_F - Fermi impulse, and p_{ph} is more less than p_F.

Effective scattering of electrons on phonons occurs during process of diffusion of electrons along the Fermi surface afterwards repeated acts of collisions with phonons. The number of phonons is proportional to T^3. Account to the diffusion mechanism of electron relaxation processes follows to $p_{ph} \sim T^{-5}$. In helium region of temperature

$$\tau = (\tau_{ph}\tau_{im})/(\tau_{ph} + \tau_{im}).$$

That follows to strong dependence of heat generating function upon temperature. Point out peculiars of function of heat removal q_-. We may say that q_- is the control parameter of dynamic system. Heat exchange of system with cryogenic liquids is very specific. There are several regimes and mechanisms of heat removal: heat conductivity, convection, film and bubble boiling, and transition region with definite values of heat flows. The heat removal function increases with temperature in the main. But it is nomonotonic in region of transition from film to bubble boiling. This circumstance stipulates the strong nonequilibrium of thermodynamic open system in a sence of nonlinearity, violation of conditions of reason-consequence bonding and principle of symmetry of kinetic coefficients. The system is no linear both far from equilibrium and near by it.

Calculations with use of experimental data testifies that maximum on $I - V$ corresponds to heat generating $\sim 5 \cdot 10^3\ W/m^2$. Such value of heat flow is limiting for bubble boiling [2]. Burn-out is accompanied the abrupt decrease of heat transfer as a result of high heat resistance of vapour film. Therefore the conditions for sample warming up is created. High sensitivity of resistive properties of a system relatively temperature fluctuations maintain $I - V$ gives rise to $I - V$-stabilization over a wide dynamic range of exciting currents. In this case the thermodynamic nonlinearity of system is due to boundary conditions of bonding of sample with external continuum when the function of heat removal in the time of crisis of cryogenic liquid boiling (in our case there is a helium) has nonmonotonous form.

Temperature parameters were determined by thermocouple placed in the center of disk. Observable warming up as a function of flowing current is shown in fig.3. One can see under high fields to neglect warming is impossible already for the very small currents.

Heat character of peculiarities of $I - V$ behaviour is confirmed by investigations of own magnetic field B_c depending on current I. The maximum on $I - V$(fig.2) and maximum on "own magnetic field - current" dependence (fig.4) corresponds to one and the same current. Here $B = (B_c/B_z) \cdot 100\%$. Further decreasing of own magnetic field is associated with decreasing of relaxation time of carriers.

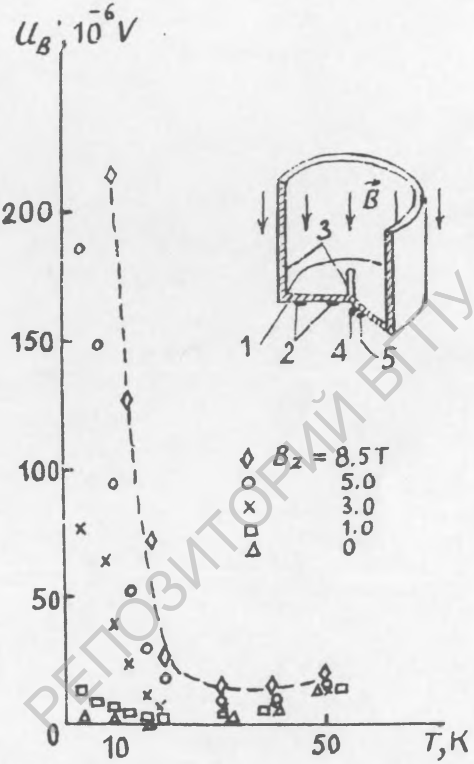

Fig.1. The temperature dependences of voltage in disk under various magnetic field inductions;
on insert: 1 - disk, 2 - potential contacts, 3 - current contacts, 4 - magnetic field detector, 5 - temperature detector.

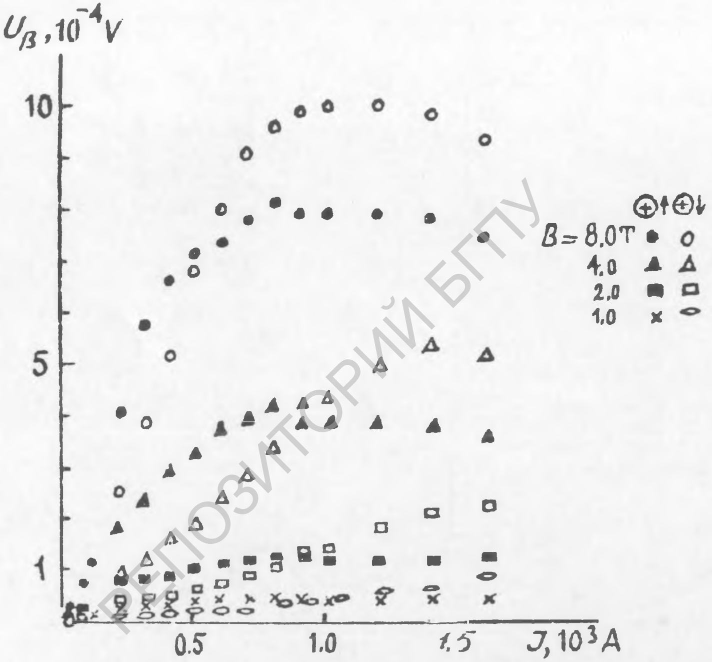

Fig.2.Static $I - V$ for constructive ⊕↓ and destructive ⊕↑ directions of current.

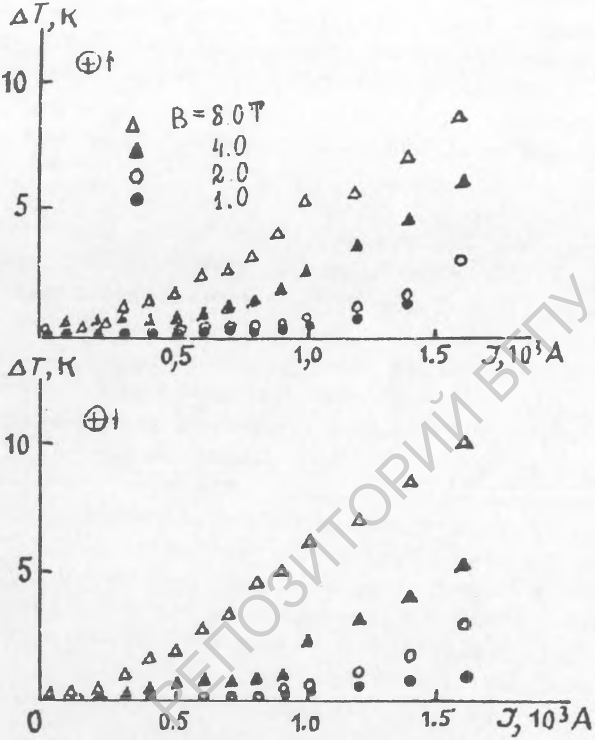

Fig.3. Heating of disk depending on current.

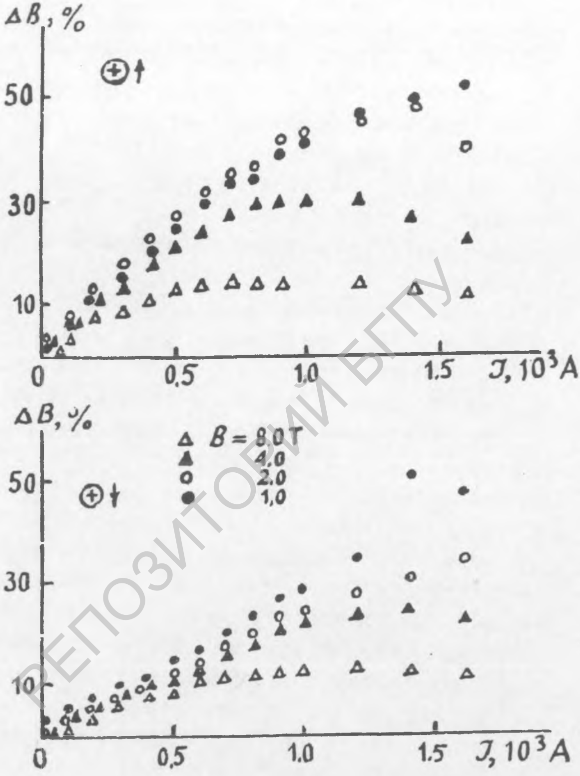

Fig.4 Own magnetic field in the center of disk depending on current.

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