in the adopted logarithmic approximation if we assume that $\lambda = \omega_0$. Such a calculation gives $T_p \approx 78$ °K for $\ln B = 0.4$ and $T_p \approx 33$ °K for $\ln B = 1.9$. Allowance for the internal disorder suggests that at temperatures 33–78 °K there should be no phase transition in KCP but the compounds should exhibit maximum (antiphase) correlation between charge density waves in different chains. These estimates are in good agreement with the experimental results. The selected model is inapplicable to compounds of the TTF-TCNQ type which also exhibit a structural instability because these compounds have a complex structure: there are two kinds of conducting chain and the transverse directions are inequivalent.[13]

We can thus assume that the properties of systems of this kind are related to a structural transition which is affected (as is true of KCP) by other factors such as the internal disorder, etc.

The author is grateful to L.N. Lipatov for valuable discussions of a number of topics and to Yu. A. Firsov for comments on the work reported above, and also to G.I. Podol'skaya for her help in numerical calculations.

[1)] It should be noted that in the earlier investigation[8] the contribution of the diagram 1c was not doubled. The second coefficient of the function $\beta$ in the normalization Ref. 8 should be 16.

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Translated by A. Tybulewicz

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# Study of phase transitions in $(TSeT)_2Cl$ under pressure at low temperatures

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The effect of high hydrostatic pressure on the phase transitions in the $(TSeT)_2Cl$ complex is studied at temperatures ranging from room to helium. The first-order phase transition which occurs under a pressure of 5 kbar at room temperature continues to exist at all temperatures down to helium temperature. The temperature of the metal-semimetal phase transition decreases with pressure. However it is not possible to suppress this transition completely since the initial metallic phase goes over either to the semimetal state (at $P < 4$ kbar) or to the high-pressure phase (at $P > 4$ kbar). The $T$-$P$ state diagram of the complex is plotted.

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Among all the presently known organic compounds of the quasi-one-dimensional type which are metallic at high temperatures, perhaps one of the most interesting is the tetraselenotetracene chloride complex $(TSeT)_2Cl$, the structure and basic properties of which were described earlier.[1,2] This complex, having metallic conductivity at high temperatures, undergoes in the region of 19 K a second order phase transition from the metallic state to a semimetal state whose conductivity is close to the room-temperature conductivity of the high-temperature phase.[3] Furthermore, under a pressure of 5 kbar and at room temperature, this compound undergoes a first-order phase transition to a new metallic state, which remains stable down to helium temperatures. The residual resistivity of the new metallic phase at temperatures below 10 K is $1.1 \times 10^{-5}$ ohm-cm (Ref. 4).

To clarify the nature of this transformation the authors studied its characteristics at low temperatures. We were particularly interested by the possibility of maintaining the high-pressure phase in a metastable state at normal pressure. Moreover, it was of independent interest to investigate the possibility of suppressing the metal-semimetal phase transition and maintain the initial low-pressure metallic phase at

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helium temperatures. With this aim, the effect of high hydrostatic pressure on the phase transitions in the $(TSeT)_2Cl$ compound was studied in the entire temperature interval from room temperature to helium temperatures. An attempt was made to construct the T-P state diagram of this complex.

## EXPERIMENTAL PROCEDURE

Single crystals of $(TSeT)_2Cl$ 20–40 $\mu$m in diameter and 2–3 mm long were used for the experiments. These crystals were produced by oxidation of TSeT by anhydrous $CaCl_2$ in dimethylformamide.[5] The pressure was generated in a "piston-cylinder" chamber using a specially prepared low temperature press, the construction of which permits one to vary the force on the piston at all temperatures right down to helium temperatures. As the pressure-transmitting medium we used an organo-silicon liquid, GKZh-94, which solidifies when cooled to $T \lesssim 180$ K but does not crystalize. To prevent the liquid from freezing to the walls of the chamber channel, which could lead to undesirable pressure gradients in the active volume, a teflon cell analogous to that described in Ref. 6 was used. This permitted us to obtain a relatively high degree of pressure uniformity right down to helium temperatures.

The specimen was secured with a graphite paste to the ends of platinum or copper leads 30 $\mu$m in diameter lying in a plane perpendicular to the axis of the chamber (Fig. 1). In the majority of cases, this mounting scheme and the use of GKZh-94 with the teflon cell guaranteed the preservation of the specimen even with pressure changes in the region of helium temperatures, i.e., under conditions when the pressure-transmitting medium had already solidified. Near the specimen, a miniature cylindrical shell was fastened, on which manganin and tin pressure sensors were wound. The pressure in the channel of the chamber was measured by the manganin sensor at all temperatures. In addition, at helium temperatures, the pressure was determined also by the temperature change of the superconducting transition of the tin sensor.[7] The unavoidable pressure decrease during the cooling the apparatus was compensated for by the press as required.

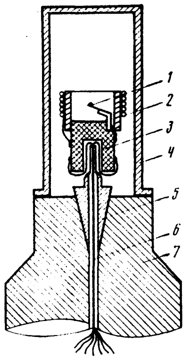

FIG. 1. Mounting of the specimen, pressure sensors and electric leads in the high-pressure cell: 1—specimen, 2—manganin and tin pressure sensors, 3—ebonite prism for mounting the crystal and sensors, 4—teflon cell, 5—cone with small tube, 6—leads, 7—obturator.

The electric leads to the high-pressure chamber were installed in the following way. Through a cone terminating in a small tube, were passed the required number (up to 12 and more) of copper leads 0.1 mm in diameter, and the opening was filled with an epoxy resin. Then the tip of the tube was crimped over a length of 2–3 mm so that all the leads lay in one plane and were tightly pressed to one another and to the walls. After this, the resin was polymerized and the cone with the resulting "beard" was pressed into an obturator whose conic opening was smeared with BF-2 adhesive mixed with powdered $Fe_2O_3$ (Fig. 1).

It was possible to detect the phase transitions of the specimens by the behavior of their electric conductivity. This was measured with direct current along the crystallographic axis by the 4-contact method. A Cu-Au + 0.07 at.% Fe thermocouple was used to measure the temperature.

## EXPERIMENTAL RESULTS AND DISCUSSION

The presence of an internal (manganin) pressure sensor enabled us to determine more precisely that the phase transition in the studied complex takes place at room temperature under a pressure of $5 \pm 0.2$ kbar[1)] with a 0.3–0.4 kbar hysteresis that depends weakly on temperature (Fig. 2). With a decrease in temperature, the pressure at the start of the transition is somewhat lowered. At $T \gtrsim 180$ K, both the forward (with an increase in pressure), and the reverse (with a decrease in pressure), transitions take place rather abruptly. At lower temperatures both transitions are somewhat blurred. This is probably due not so much to the nature of the transitions as to the fact that at $T < 180$ K the liquid which transmits the pressure solidifies, and distinct pressure gradients nevertheless arise in the channel when the load changes.

The experimental data which we obtained confirms

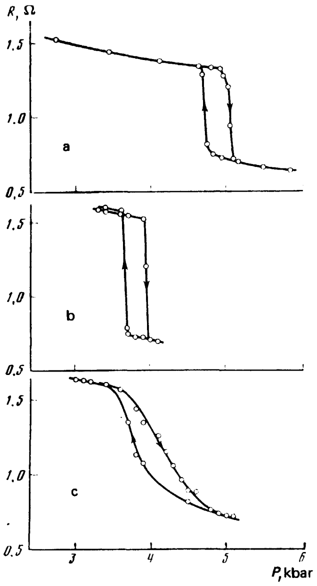

FIG. 2. Pressure dependence of the resistance of the $(TSeT)_2Cl$ complex at temperatures: a—293 K, b—200 K, c—165 K.

that the studied transition exists (in both directions) at all temperatures down to 4.2 K. The weak temperature dependence of the hysteresis indicates that this transition can probably take place at still lower temperatures. All of these features and, primarily, the mere existence of the transition at temperatures close to absolute zero, where there is extremely low pressure transfer that depends little on the temperature, indicate that this transition is not the usual thermally activated polymorphic transition. The latter, as a rule, take place with a significant hysteresis between the start of the forward and reverse transitions. This hysteresis rapidly increases with decreasing temperature. As a consequence, at temperatures close to absolute zero, the transition either does not occur at all, or an extremely large pressure transfer is required for it to take place.[8]

The studied transition has, apparently, an athermal, cooperative character, and the rearrangement of the crystal lattice takes place probably by way of a slight rotation of the plane of the TSeT molecule in the entire volume of the specimen at the same time. Evidently, this rotation becomes energetically advantageous with a decrease in the volume of the specimen, and cooling merely assists its realization. Unfortunately, this feature of the transition leaves extremely little hope of the possibility of stabilizing the high pressure phase at normal pressure.

To ultimately resolve the question whether a restructuring of the crystal lattice actually occurs, it is obviously necessary to perform x-ray structural studies at all temperatures and pressures.

Using the experimental results of this work, we tried to qualitatively construct the T-P phase diagram of the $(TSeT)_2Cl$ compound (Fig. 3). For the temperature and pressure of the transitions, the averages of the corresponding transitions on the $R(T)$ and $T(P)$ curves were assumed. Shown on the diagram are: the region of the initial metallic low pressure phase, I, which when cooled goes over into the semimetal state[3]; the region of existence of this low-temperature semimetal phase, $S$; and finally, the region of existence of the high pressure phase, II, which remains metallic down to the lowest temperatures. From this diagram it is evident that although the temperature of the metal-semimetal phase transition decreases, it is not possible to completely suppress this transition ($I - S$), i.e., to preserve phase I at arbtirarily low temperatures by increasing the external pressure, since it goes over either into the $S$-phase (at $P \leqslant 4$ kbar) or to phase II (at $P > 4$ kbar).

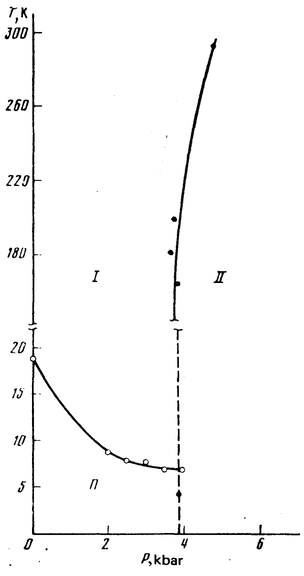

FIG. 3. $T-P$ phase diagram of the $(TSeT)_2Cl$ compound. The transitions are registered in the course of changes in: ●—pressure ($T$ = const.), ○—temperature ($P$ = const).

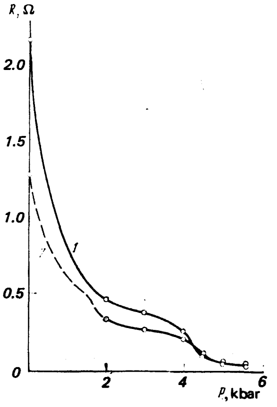

FIG. 4. Semiemperical pressure dependence of the resistance of the $(TSeT)_2Cl$ complex at temperatures: 1—4.2 K, 2—10 K.

The strong pressure dependence of the resistance of the $S$-phase is noteworthy (Fig. 4). Such a behavior of this phase is due to the suppression of the $I \rightarrow S$ phase transition with increasing pressure; this was investigated in a previous work.[4] At the present time, the physical cause of this behavior is not clear. In the region of 4 kbar and at temperatures $\leq 7$ K, the $S$ phase changes directly into the high pressure phase II, and the result is a jump in resistance (curve 1 on Fig. 4).

In this pressure region the jump is observed on the loading curves at temperatures $> 7$ K (curve 2 on Fig. 4), but here it is due to the transition of phase I into phase II; this follows from the phase diagram in Fig. 3. From this diagram it is evident that at temperatures between 7 K and 17 K and at pressures below 4 kbar, there should be one more jump observed on the loading curves, due to the transition from phase $S$ to phase I, the resistance of which is markedly lower.

Unfortunately, due to methodological difficulties, we were unable to prevent the crystals from cracking in this temperature region at pressures below 2 kbar. Therefore direct experimental data in this region is lacking. The assumed form of curve 2 in this interval is shown dashed on Fig. 4.

In conclusion, the authors express their gratitude to É. B. Yagubskiĭ for preparing the specimens.

1) In a previous work[4], an internal pressure sensor was not used, and this led to a somewhat exaggerated value of the transition pressure.

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# Kinetics of formation of Abrikosov vortices in type-II superconductors

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Data obtained by mechanically vibrating a superconductor sample in a magnetic field indicate that the Abrikosov fluxoids penetrate the sample in jumps. The number of vortices entering the sample in each jump is so high that even if they were distributed over the entire sample surface prior to penetration they would fill several surface layers with total thickness on the order of the penetration depth, and so densely that the distance between them would be of the order of the coherence length. This suggests that a surface barrier of such an assembly of "protovortices" is small compared with the insurmountably high barrier for a single vortex.

PACS numbers: 74.30.Ci, 74.60. — w

This communication is devoted to an experimental investigation of the kinetics of the penetration of Abrikosov vortices into a type-II superconductor and to their departure from the sample when the external magnetic field is increased and decreased.

A mechanical procedure was used for the investigation—we observed the vibrations of a superconductor suspended on a thin elastic filament in a vortex-producing magnetic field perpendicular to the sample axis.[1] By measuring the frequency of the oscillations of the suspension system we could asses the number of fluxoids that penetrate through the superconducting sample, since their tendency to become oriented along the magnetic field contributes a definite increment to the torsional momentum of the suspension.

A diagram of the setup used by us to observe the kinetics of vortex creation and destruction is shown in Fig. 1. The superconducting sample *1* (2.4 mm dia, $l = 1.5$ mm) was secured to a straightened glass rod *2* that carried on its upper end a light disk *3* of duraluminum with a moment of inertial $I = 2.25\ \mathrm{g \cdot cm^2}$. The rod *2* was suspended on a thin elastic phosphor-bronze filament *4* (40 μm dia, $l = 100$ mm) and executed axial-torsional oscillations that were registered with the aid of a light beam reflected from mirror *5* and a scale *6*. The entire low-temperature part of the setup was filled with liquid helium and placed between Helmholtz coils *7* that produced a magnetic field up to 400 Oe directed perpendicular to the sample axis. This system is light enough for precise registration of the dependence of the frequency $\Omega$ on the field intensity $H$ produced when Abrikosov vortices appear in the superconductor.

We used cylindrical samples of thermodynamically reversible single-crystal $Ta_{70}Nb_{30}$.[2] The samples were spark-cut from the original single crystal, and then carefully polished electrically to obtain crystals with mirror-finish surfaces (roughness dimension < 1 μm).

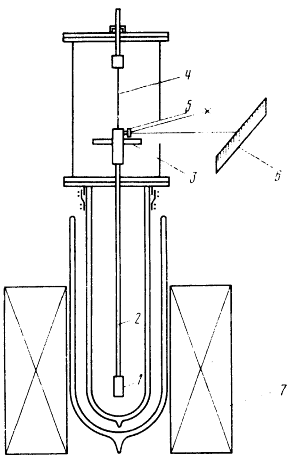

FIG. 1. Diagram of setup: 1—sample, 2—sample-holding rod, 3—disk, 4—suspension filament, 6—scale, 7—Helmholtz coils.