surements on single crystals of terbium and the Tb-Y
alloys and the thermodynamic analysis of the experi-
mental data have shown that, in a magnetic field applied
in the basal plane, the helical antiferromagnetic-ferro-
magnetic transition is a first-order phase transition.
In this transition, the abrupt liberation or absorption of
heat occurs mainly as a result of changes in the inter-
layer exchange interaction and the magnetoelastic en-
ergy.

In the case when the magnetic field is applied along the
hexagonal axis c, the character of the magnetic phase
transformations changes significantly. To wit, a helical
antiferromagnetic-helical ferromagnetic transition oc-
curs. This transition is accomplished without stepwise
increases in the entropy and the magnetization.

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[1]K. P. Belov, M. A. Belyanchikova, R. Z. Levitin, and S. A.
Nikitin, Redkozemel'nye ferromagnetiki i antiferromagnetiki
(Rare-Earth Ferromagnets and Antiferromagnets), Nauka,
1965.
[2]S. A. Nikitin, E. V. Talalaeva, L. A. Chernikova, and A. S.
Andreenko, Fiz. Met. Metalloved. 40, 967 (1975).

[3]A. C. Hudgins and A. C. Pavlovic, J. Appl. Phys. 36, 3628
(1965).
[4]K. P. Belov, S. A. Nikitin, V. P. Posyado, and G. E. Chup-
rikov, Zh. Eksp. Teor. Fiz. 71, 2204 (1976) [Sov. Phys.
JETP 44, 1162 (1976)].
[5]H. R. Child, W. C. Koehler, E. O. Wollan, and J. W. Cable,
Phys. Rev. 138, A1655 (1965).
[6]M. A. Krivoglaz and V. D. Sadovskiĭ, Fiz. Met. Metalloved.
18, 502 (1964).
[7]B. Cooper, Phys. Lett. 19, 900 (1967).
[8]W. Evenson and S. Liu, Phys. Rev. 178, 783 (1969).
[9]S. A. Nikitin and L. I. Solntseva, Zh. Eksp. Teor. Fiz. 59,
351 (1970) [Sov. Phys. JETP 32, 189 (1971)].
[10]S. A. Nikitin, A. S. Andreenko and V. P. Posyado, Fiz.
Tverd. Tela (Leningrad) 19, 855 (1977) [Sov. Phys. Solid
State 19, 496 (1977)].
[11]D. Jennings, R. M. Stanton, and F. H. Spedding, J. Chem.
27, 909 (1957).
[12]V. S. Belovol, V. A. Finkel', and V. E. Sivokon', Zh. Eksp.
Teor. Fiz. 69, 1734 (1975) [Sov. Phys. JETP 42, 880 (1975)]. ·
[13]I. E. Dzyaloshinskiĭ, Zh. Eksp. Teor. Fiz. 47, 336 (1964)
[Sov. Phys. JETP 20, 223 (1965)].
[14]V. V. Druzhinin, S. P. Zapasskiĭ, and V. M. Povyshev, Fiz.
Tverd. Tela (Leningrad) 17, 2034 (1975) [Sov. Phys. Solid
State 17, 1328 (1975)].
[15]L. D. Filatova and V. M. Tsukernik, Zh. Eksp. Teor. Fiz.
53, 2203 (1967) [Sov. Phys. JETP 26, 1243 (1968)].
[16]R. Jordan and E. Lee, Proc. Phys. Soc. London 92, 1074
(1967).

Translated by A. K. Agyei

Resistivity of shock-compressed ytterbium

M. N. Pavlovskiĭ

Results are reported of an experimental investigation of the electric conductivity of shock-compressed
ytterbium in the pressure range up to 220 kbar. It is shown that up to ~30 kbar the resistivity of
ytterbium increases with pressure, and the ytterbium acquires semiconducting properties. At pressures on
the order of 20 to 30 kbar the ytterbium undergoes a phase transition and becomes metallic again.
Further increase of the shock-loading amplitude leads, at 80–150 kbar, to a sharp increase of the
ytterbium resistivity, thus attesting to still another transition due to a realignment of the electron
structure, a transition not heretofore observed under static compression conditions. The temporal
characteristics of the aforementioned transitions were measured under actual shock-loading conditions. It
is shown that raising the temperature and increasing the intensity of the shear deformations accelerates
the transitions and decreases the values of the corresponding critical pressures.

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The investigated shock-compressed ytterbium was
99.9% pure, had an initial resistivity $\sim 2.8 \times 10^{-5}$ Ω-cm
at room temperature and atmospheric pressure, and a
density 6.97 g/cm^3. The dependence of the relative
change of the resistance of the ytterbium on the shock-
loading pressure, $R/R_0 = f(P)$, where R_0 and R are the
ytterbium resistances prior to and during the compres-
sion and P is the shock-loading pressure, was obtained
by performing a series of experiments (see Fig. 1) in
which the loading pressure of a standard material with
an inlayed ytterbium sample was known beforehand.

The ytterbium sample was a sinusoid of ytterbium foil
0.05 mm thick glued with epoxy resin between the layers
of the standard material. The leads for the ytterbium
sample were strips of copper foil. When necessary, the
ytterbium sample was insulated from (metallic) the
standard material with a film of ftoroplast-4 (Teflon)
0.02 mm thick. The sample was compressed by a plane
shock wave produced by exploding a cylindrical explo-
sive whose strength was varied. Shock waves of differ-
ent intensity were applied to the standard substances
with the inserted ytterbium samples through copper and

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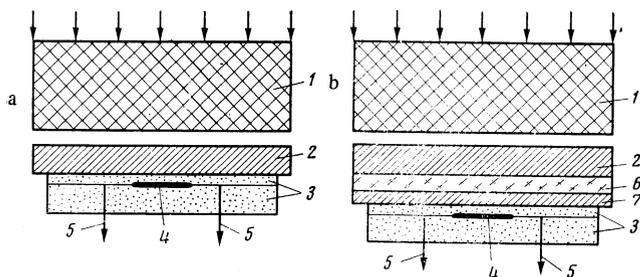
FIG. 1. Variant of experimental setup for the determination of the resistivity of shock-compressed ytterbium: 1—explosive charge, 2—copper or aluminum screen 10 mm thick, 3—standard material, 4—ytterbium sample, 5—copper leads from ytterbium sample to oscilloscope, 6—Plexiglas liner 6 mm thick, 7—copper screen 4 mm thick.

aluminum screens that covered the samples. The gap between the explosive charge and the screen was 5 mm, thus ensuring production of a shock wave with a square-wave profile in the screen.

The explosive systems used for the shock loading of the samples were described before.[1] To apply a voltage pulse on the ytterbium sample and to register the resultant signal we used the electric measurement circuit employed successfully for a number of years for an analogous purpose when operating with a manganin pressure pickup,[2] and also in measurements of the electric conductivity of shock-compressed dielectrics.[3] Its operating principle is shown schematically in Fig. 2. At 5–10 μsec prior to the arrival of the loading shock wave at the ytterbium sample, whose initial resistance R_0 was ~1.5 Ω, a voltage pulse was applied to the sample through a ballast resistor R_b from a 4-μF capacitor. Since $R_b \gg R_0$, the current in the circuit remained practically constant during the entire registration time.

The voltages z_0 and z before and after compression of the ytterbium sample were transmitted from the sample leads through a cable line Cab without preamplification directly to the deflecting plates of the cathode-ray tube of an S1-24 oscilloscope. A typical oscillogram of one such calibration experiment is shown in Fig. 3a. The resistance R of the shock-compressed ytterbium sample was determined by its initial resistance R_0, the combined resistance of the copper leads $R_l \approx 0.02$ Ω, and by the ratio of the amplitudes of the spikes z/z_0 on the
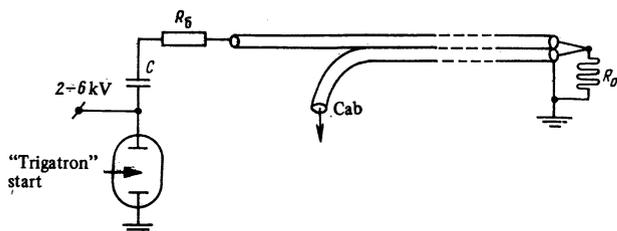
FIG. 2. Electric circuit used to measure the conductance of shock-compressed ytterbium: R_0 initial resistance of the ytterbium, R_b—ballast resistor, C – 4–μ F capacitor, Cab—cable through which the voltage is applied to the deflection plates of the oscilloscope.
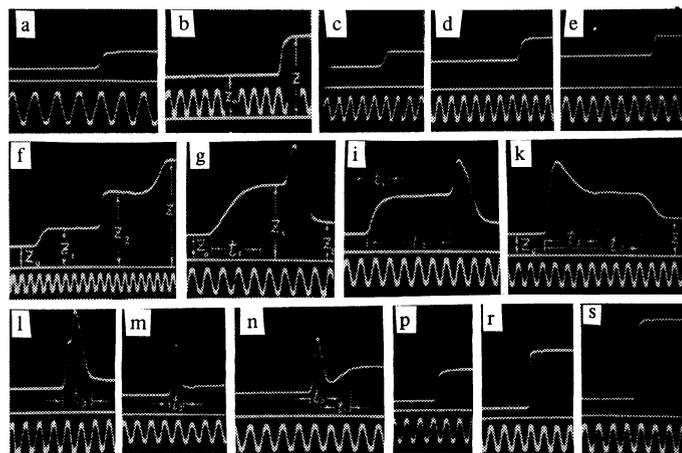
FIG. 3. Oscillograms showing the variation of the resistivity of ytterbium under shock loading. The standard materials in which the ytterbium samples were inserted were the following: a—KCl (20.4 kbar, $\Delta T \approx 13°$), b—polyethylene (22.5 kbar, $\Delta T \approx 35$), c,d,e—Plexiglas (28.5 kbar, $\Delta T \approx 46°$; 30 kbar, $\Delta T \approx 50°$; 35 kbar $\Delta T \approx 70°$), f—Plexiglas ($P_1 = 13$ kbar, $\Delta T \approx 6°$; $P_2 = 22$ kbar, $\Delta T \approx 11°$; $P_3 = 26.5$ kbar, $\Delta T \approx 14°$), g,1—copper (24 kbar, $\Delta T \approx 4°$; 64 kbar, $\Delta T \approx 50°$), i,m,n,s—lead glass (20 kbar, $\Delta T \approx 7°$; 75 kbar, 115 kbar at $\Delta T \approx 1500°$); k—lead glass (24.5 kbar, $\Delta T \approx 30°$), p—CsI (101 kbar, $\Delta T \approx 440°$), r—KCl (132 kbar, $\Delta T \approx 1200°$). The timing sine wave on all oscillograms corresponds to 5 MHz frequency.

oscillogram (see Fig. 3):

$$R = (R_0 + R_l)z/z_0 - R_s.$$

The linear dependence of the oscilloscope beam deflection on the registered voltage was quite accurate. The rms error in the measurements of R/R_0 was 2–4%. The measurement error due to the effect of the pressure on the resistance of the copper leads R_l under shock compression is estimated at not more than 0.05%.

The standard materials were both light (paraffin, polyethylene, Plexiglas) and relatively heavy (single-crystal CsI, lead glass of density 4.78 g/cm³, copper, and lead). Use was made also of magnesium, ftoroplast-4 (Teflon), and single-crystals of LiF, NaCl, and KCl, i.e., substances that differ strongly from one another in the initial density and dynamic impedance. In some of the experiments, a liner of lead, nickel, sodium chloride, aluminum, paraffin, Plexiglas, or Teflon was placed between the screen and the standard substance, for the purpose of varying somewhat the loading pressure on the standard material, and hence on the ytterbium, in a desired direction. The pressure realized in the standard material and in the ytterbium were determined in this case by constructions on the $P–U$ diagram (P and U are the pressure and mass velocity, respectively), starting from the known mass velocity in the screen of the measurement setup and from the shock adiabats of the materials of the screens, the standard materials, the ytterbium, and the liners.[1,4-7] In the calculation of the parameters of the compression behind the front of the shock wave, the expansion isentropes of the employed materials were identified with the mirror reflections of their shock adiabats.
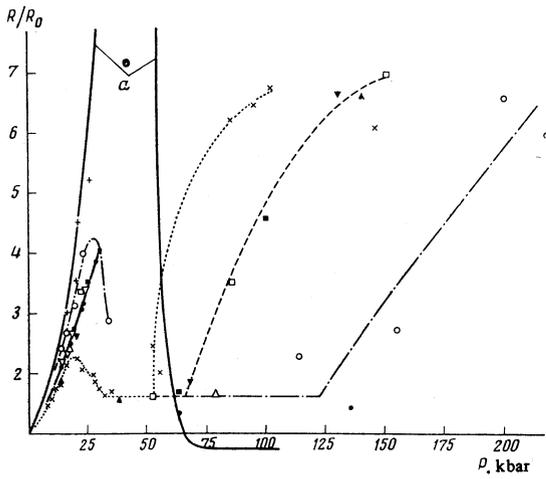
FIG. 4. Dependence of the relative resistance of shock-compressed ytterbium on the pressure. The experimental points were obtained by placing the ytterbium in the following standard materials: X—in paraffin, polyethylene, and Plexiglas, ●—in copper and lead, o—in lead glass, ■—in CsI, $\triangle$—in LiF, ∇—in magnesium, ▲—in Teflon, □—in NaCl, ▼—in KCl; +—experimental points obtained after multiple shock compression of ytterbium; a—plot obtained by Bridgman[11] for ytterbium under static compression.

All the experimental points obtained for the dependence of the relative increase of the resistivity of ytterbium on the pressure of a single shock loading are shown graphically in the form $R/R_0 = f(P)$ in Fig. 4.

Figure 3f shows one of the oscillograms of the variation of the resistivity of ytterbium following repeated compression by successive shock waves propagating in the standard material. The measurement setup used in these experiments is shown schematically in Fig. 1b. The use of Plexiglas liners in the copper screen of this setup has made it possible to load the standard materials (in this case paraffin, Plexiglas, and Teflon), and hence also the ytterbium sample, by a series of successively propagating shock waves. The parameters of the multiple compression of the standard material and of the ytterbium were determined with the aid of constructions on the P-U diagram, starting from the known mass velocity in the copper screen ($U_{Cu} = 0.17$ km/sec) of this device, and using the known shock adiabats of copper, paraffin, Teflon, and ytterbium.[4-7] The results of the measurements of the electric conductivity of ytterbium, obtained by multiple shock compression, are shown graphically in the form $R/R_0 = f(P)$ in Fig. 4.

To estimate the ytterbium temperature rise $\Delta T = T_*$ $- T_0$ (T_0 is the initial temperature of the ytterbium prior to the shock compression, $\pm 10°$ in most experiments; T_* is the temperature established in the ytterbium after the shock compression) due to the shock compression, the dynamic adiabat of ytterbium given in[7] was used, as well as the known values of the specific heat ($C_v = 6.03$ cal/g-atom-deg) and of the Grüneisen coefficient γ.[8] The experimental data on the dynamic compressibility of the ytterbium were described, just as in[7], with the aid of the following expressions for the shock adiabat and the "zeroth" isotherm[9]:

$$P_H = \frac{\rho_0 C_0^2}{n(h-k\sigma)}\left[\left(h - \frac{n+1}{n-1}\right)\sigma^n + \frac{2n}{n+1}\sigma - (h+1)\right],$$

$$P_c = \rho_0 C_0^2(\sigma^n - 1)/n,$$

where P_H and P_c are the respective pressures on the Hugoniot adiabat and the "zeroth" (0 K) isotherm, $h = 1 + 2/\gamma$ is the maximum degree of compression, C_0 is the initial speed of sound, k is the porosity coefficient, and ρ_0 is the initial density of the ytterbium. The best description of the experimental data given in[7] was obtained at $h = 4$, $n = 2, 3$, $C_0 = 1.587$ km/sec, $\rho_0 = 7$ g/cm³, and $k = 1.01$. The temperatures on the Hugoniot adiabat were calculated from the formula

$$T = T_0 + \frac{{}^{1}/_{2}P_H(V_0 - V) - E_x}{C_v},$$

where V_0 and V are the specific volumes of the ytterbium before and during the shock compression, and E_c is the "cold" (0 K) component of the energy.

The change of the ytterbium temperature as it relaxed in the rare-faction wave was measured with the aid of the adiabatic relation between the temperature and the volume:

$$T = T_H(V_H/V)^\gamma.$$

The temperatures estimated from the Gust and Royce data[10] on the dynamic compressibility are somewhat lower in the pressure region of interest to us, inasmuch in the pressure range up to ~200 kbar the shock adiabat of ytterbium, as given in[10] in the coordinates P and V, is much lower than the dynamic adiabat given in[7]. An exact calculation of the temperatures of the shock-compressed ytterbium is therefore impossible at present. It should be noted in particular that owing to the difference between the dynamic impedances of the ytterbium and the standard materials in which it is placed, the ytterbium final temperature T_* established after a series of compression and relaxation waves circulate through the ytterbium may differ substantially, at equal values of the pressures P_* and when different standard materials are used—an ytterbium sample placed in a material with a larger dynamic impedance will accordingly have a lower final temperature T_*.

It is clearly seen from the plot in Fig. 4 that the relation $R/R_0 = f(P)$ obtained for shock-compressed ytterbium has three characteristic sections. The first lies at pressures ~30 kbar, the second in the range 30–80 kbar, and the third above ~80 kbar. The shock-loaded ytterbium, in analogy with the earlier observations[11,15] under static-compression conditions, becomes semiconducting at pressures higher than ~10 kbar (at constant pressure, the resistivity of the ytterbium decreases exponentially with increasing temperature). Registration of the duration of the front on the oscillograms of the time dependence of the resistivity of ytterbium shock-loaded at pressures 14–30 kbar, has made it possible to assess in a number of cases the time of the transition of the ytterbium from the initial to the semiconducting state. Thus, when the ytterbium sample was placed in copper (see Fig. 3g) and in lead glass

(see Fig. 3i), at pressures 24 and 20 kbar, the times t_1 of the transition into the semiconducting state were respectively ~0.5 and 0.3 μsec. The time t_2 in Figs. 3g and 3i is the interval between the arrivals of the first and second (amplitude ~60 kbar) loading waves at the ytterbium sample (see Fig. 1b). The temperature rise $\Delta T = T_* - T_0$ of the ytterbium as a result of its shock compression amounts in this pressure range to 3–20°, depending on the degree of compression and on the standard material used. It should be noted that in the pressure range up to ~30 kbar the increase of the resistivity of ytterbium under shock loading is less than observed under static-compression conditions,[11–17] apparently as a result of the increase of the ytterbium temperature and the more intense shear deformations due to shock compression. Accordingly, when ytterbium is repeatedly compressed (see Fig. 4) its resistivity approaches the values recorded under static compression.[11–17] The total increase of the ytterbium temperature, $\Delta T = T_* - T_0$ after the passage of three loading waves through the sample was approximately 10–15°, depending on the standard material in which the ytterbium sample was placed.

At pressures close to 30 kbar, the ytterbium again acquired metallic properties, and underwent under shock-loading conditions a phase transition analogous to that observed earlier[11–17] under static-compression conditions. However, the value of the critical pressure of the phase transitions under the conditions of the dynamic loading decreased somewhat (from 40–50 to 20–30 kbar). The resistivity of shock-compressed ytterbium at pressures up to ~30 kbar and the value of the critical pressure of the phase transition decrease with increasing temperature, a fact noted also under conditions of static compression[14,15] and decrease also with increasing intensity of the shear deformations.

At pressures above the phase transitions ($P > 30$ kbar), a difference was noted between the values of the resistivity of ytterbium compressed in different manners, viz., under dynamic loading the resistivity of ytterbium at pressures 35–80 kbar is approximately 1.6 times larger than the initial value (at $P = 1$ atm), whereas under conditions of static compression the resistivity of the ytterbium, measured at pressures above the aforementioned phase transition, is lower than the initial value and amounts, according to Bridgman's data,[11] to only 70% of the initial value (see Fig. 4). The relative constancy of the resistance of ytterbium in the pressure range 35–80 kbar (see Fig. 4) is apparently due to the mutual cancellation of the decrease of the mobility $\mu \sim T^{-3/2}$ and the increase in the number of carriers $N \sim T^{3/2}$ [15] in this region in the case of ytterbium that is shock compressed only once.

The most substantial difference between the results obtained under conditions of static and dynamic compression was registered at pressures exceeding 50–100 kbar. Whereas under static compression the resistance of ytterbium at these pressures, according to the data of a number of workers[12,13,15], is practically independent of pressure, a strong increase (by approximately 6.5 times) of the resistance was registered for dynamic loading at pressures 80–200 kbar. As seen from the data of Fig. 4, the critical pressure at which the increase of the resistivity of ytterbium is observed, depends strongly on the standard material–the increase of the resistivity sets in at lower pressures if the ytterbium sample is placed in a light material (polyethylene, Plexiglas, etc.) It appears that in this case, too, as in the phase transition at pressures ~30 kbar, the higher temperatures and more intense shear deformation facilitate, at pressures close to kbar, the transition of the ytterbium into a state with higher resistivity. The increase $\Delta T = T_* - T_0$ of the ytterbium temperature when the standard material is polyethylene, KCl, NaCl, CsI, Teflon, and lead glass amounted to about 700–1700° in the pressure range 80–200 kbar, depending on the degree of compression and the employed standard material. The change ΔU of the ytterbium mass velocity was 1.5–2 km/sec in this case.

No increase was observed in the resistivity of shock-compressed ytterbium in copper ($P = 136$ kbar, $\Delta T \approx 350°$, $\Delta U \approx 0.7$ km/sec) (see Fig. 4), apparently because the necessary conditions were not provided for the transition of the ytterbium to the state with higher resistivity. This seems also to be the reason why V. N. German and I were unable to record the formation of a new phase of ytterbium by the procedure described in in[18] of preserving the shock-compressed samples and subjecting them subsequently to an x-ray structure analysis. Ytterbium sample having a temperature 20 °C prior to the shock compression and showing no traces of melting whatever after the removal of shock loads of 120, 200, 350, and 500 kbar, were all similar in structure. The same result was obtained also when the ytterbium samples were first cooled to liquid-nitrogen temperature before the shock compression.

Interesting results were obtained in the study of the conductance of shock-compressed ytterbium in the pressure range 35–100 kbar. As seen from the oscillogram of Fig. 3k (the experimental setup is shown in Fig. 1b and the ytterbium sample was placed in lead glass, with the pressure behind the front of the first loading wave equal to 34.5 kbar), the resistivity of the ytterbium at the first instant after the shock loading increases strong strongly, by approximately 4.35 times, becoming patently semiconducting (see Fig. 4). Subsequently the relative resistance of the ytterbium decreases gradually to a value $R/R_0 \approx 2.9$, apparently as a result of a phase transition from the semiconducting to the metallic state, which occurs in this particular case after a time interval $t_3 \approx 0.85$ μsec. Thus, when ytterbium placed in lead glass, as well as in copper, lead and similar materials, is subjected to shock waves whose amplitudes exceed the critical pressure (~30 kbar) of the semiconductor—metal phase transition of ytterbium, the oscillograms show clearly the transition period t_3 during which the ytterbium re-acquired the metallic properties.

The subsequent strong decrease of the relative resistance of the ytterbium to $R/R_0 \approx 1.7$, which takes place after a time interval t_2 (see Fig. 3k) after the shock compression of the ytterbium, correspond to the instant when the ytterbium sample is hit by a second loading

shock wave of amplitude ~ 60 kbar. The most probably explanation of the decrease of the resistivity of the ytterbium, registered behind the second loading wave, is apparently the increase of the overlap of the energy bands a situation that is perfectly feasible according to[15] (in the case of mutual deformation of the conduction and valence bands as a result of the shock compression of the ytterbium). This increase causes a substantial increase in the number of carriers, but raises the ytterbium temperature insignficantly. With increasing amplitude of the shock loading, the duration t_3 of the aforementioned transition period decreases (see Figs. 3l and 3m, where the load pressures were 64 and 75 kbar, and the time intervals t_3 were 0.4 and 0.2 μsec, respectively). Analogous phenomena were observed earlier in the study of the evolution of polymorphic transitions in shock-compressed KCl and KBr.[19]

Application of a shock wave of amplitude 115 kbar to ytterbium in lead glass (see Fig. 3n, the experimental setup is shown in Fig. 1a) led to registration of three successive stages in the variation of the resistivity of the ytterbium. At first the ytterbium resistivity increased abruptly because it acquired the properties of a semiconductor. After the lapse of a transition period $t_3 \approx 0.15$ sec, the ytterbium returned to the metallic state. Further realignment of the electron structure under pressure caused the resistance of the ytterbium to increase again. At 115 kbar, the time of this realignment, under the described compression conditions, was $t_4 \approx 0.2$ μsec. When the amplitude of the shock loading increased to ~ 130 kbar and above, the picture represented by Figs. 3p, r, and s was registered—the resistivity of the ytterbium increased by 4–6.5 times within times shorter than 0.1 μsec. The realignment processes are of nanosecond durations, much shorter than the time resolution of the employed recording apparatus. A similar decrease of the times of the metal—semiconductor—metal transitions was registered also at pressures lower than 100 kbar (see Figs. 3c, d, e) when the ytterbium samples were placed in materials having a relatively large dynamic compressibility (poly-ethylene, Plexiglas, KCl, NaCl, etc.). Thus, the experiments have shown that higher temperatures and more intense shear deformations, which are realized when the ytterbium samples are placed in these materials, accelerate the completion of the realignment of the electron structure of the ytterbium.

[1]L. V. Al'tshuler, M. N. Pavlovskiǐ, L. V. Kuleshova, and G. V. Simakov, Fiz. Tverd. Tela (Leningrad) 5, 279 (1963) [Sov. Phys. Solid State 5, 203 (1963)].
[2]G. V. Simakov, M. N. Pavlovskiǐ, N. G. Kalashnikov, and R. F. Trunin, Izv. Akad. Nauk SSSR Ser. Fiz. Zemli No. 8, 11 (1974).
[3]L. V. Kuleshova, Fiz. Tverd. Tela (Leningrad) 11, 1085 (1969) [Sov. Phys. Solid State 11, 886 (1969)].
[4]L. V. Al'tshuler and M. N. Pavlovskiǐ, Zh. Prikl. Mekh. Tekh. Fiz. No. 2, 110 (1971).
[5]N. G. Kalashnikov, L. V. Kuleshova, and M. N. Pavlovskiǐ, Zh. Prikl. Mekh. Tekh. Fiz. No. 4, 187 (1972).
[6]A. A. Bakanova, I. P. Dudoladov, and Yu. N. Sutulov, Zh. Prikl. Mekh. Tekh. Fiz. No. 2, 117 (1974).
[7]A. A. Bakanova, I. P. Dudoladov, and Yu. N. Sutulov, Fiz. Tverd. Tela (Leningrad) 11, 1881 (1969) [Sov. Phys. Solid State 11, 1515 (1970)].
[8]K. A. Gschneider, Solid State Phys. 16, 275 (1964).
[9]I. P. Dudoladov, V. I. Rakitin, Yu. N. Sutulov, and G. S. Telegin, Zh. Prikl. Mekh. Tekh. Fiz. No. 4, 148 (1969).
[10]W. H. Gust and E. B. Royce, Phys. Rev. B 8, 3595 (1973).
[11]P. W. Bridgman, Proc. of the American Academy of Arts and Sciences 83, 1 (1954).
[12]L. F. Vereshchagin, A. A. Semerchan, and S. V. Popova, Dokl. Akad. Nauk SSSR 139, 585 (1961) [Sov. Phys. Dokl. 6, 609 (1962)].
[13]R. A. Stager and H. G. Drickamer, Science 139, 1284 (1963).
[14]P. C. Souers and G. Jura, Science 140, 481 (1963).
[15]D. B. McWhan, T. M. Rice, and P. H. Schmidt, Phys. Rev. 177, 1063 (1969).
[16]H. T. Hall, J. D. Barnett, and L. Merrill, Science 139, 111 (1963).
[17]D. R. Stephens, J. Phys. Chem. Solids 25, 423 (1964).
[18]I. N. Dulin, L. V. Al'tshuler, V. Ya. Vashchenko, and V. N. Zubarev, Fiz. Tverd. Tela (Leningrad) 11, 1252 (1969) [Sov. Phys. Solid State 11, 1016 (1969)].
[19]L. V. Al'tshuler, M. N. Pavlovskiǐ, and V. P. Drakin, Zh. Eksp. Teor. Fiz. 52, 400 (1967) [Sov. Phys. JETP 25, 260 (1967)].

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