

Superconductivity of the compounds PbTe and PbSe under high pressure

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Superconductivity was observed in the high-pressure phases of the compounds PbTe and PbSe at pressure $p \approx 175$ and ≈ 300 kbar, with superconducting-transition temperatures 8 and 6.5°K, respectively.

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The lead chalcogenides PbTe and PbSe are, under normal conditions, typical semiconductors, in which the thermal gaps at low temperatures amount to 0.190 and 0.165 eV. Both compounds crystallize into an NaCl structure with lattice constants $a = 6.46$ and 6.12 \AA .^[1] Insofar as we know, PbTe and PbSe were investigated heretofore only at pressures p up to 100 kbar. In this pressure region, the indicated compounds undergo polymorphic transformations and their structure changes from the NaCl type (low-pressure β phase) into an SnS type structure (γ phase).^[2]

We have investigated the electric conductivity of PbTe and PbSe up to pressures $p \approx 350$ kbar in the temperature range 2–300 °K.

Single crystals of PbTe and PbSe were prepared by the Bridgman method and had p -type conductivity with carrier density $\sim 10^{19} \text{ cm}^{-3}$ at room temperature. A pressure up to 350 kbar was produced in a modified high-pressure chamber^[3] placed between anvils of ultra-hard polycrystalline material based on type CB synthetic diamond. For the construction of the high-pressure chamber, we used finely dispersed Fe_2O_3 powder compressed at an average pressure $p \approx 20$ kbar. A feature

of the chambers was the use of elements 1 (Fig. 1) with prescribed distribution of the powder density. The central part of the chamber was denser than the peripheral one by 2–2.5 times, so that the optimal distribution of the stresses in the anvils could be chosen and the limit of the attainable pressure could be raised by approximately 20% (in comparison with the chambers of^[3]).

The pressure-transmitting medium was steatite in the form of pellets (Fig. 1) compressed from powder at a

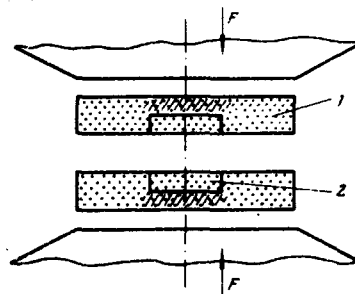


FIG. 1. High-pressure chamber: the increased-density region in the elements 1 is shown shaded, 2—steatite washers.

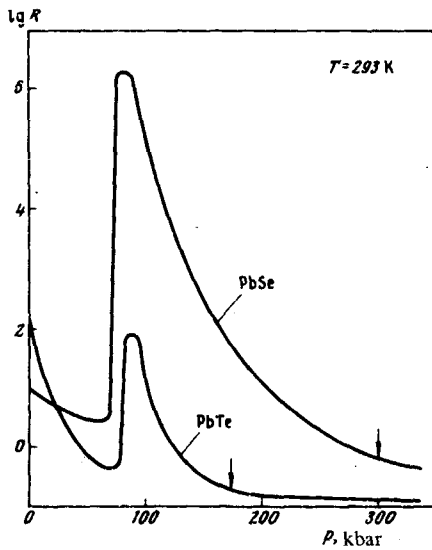


FIG. 2. Dependence of the resistance of PbTe and PbSe on the pressure (obtained with automatic recorder). The arrows indicate the pressures corresponding to the onset of superconductivity.

pressure $p \approx 3$ kbar.

Particular attention was paid to the procedure used to measure the high pressures. At helium temperatures, the pressure was determined with a superconducting lead manometer, which was placed together with the investigated sample at the center of the high-pressure chamber. The variation of the superconducting-transition temperature T_c of lead compressed up to 200 kbar has been studied quite well.^[4] In the present investigation, the lead manometer was used at higher pressures. To this end, an attempt was made to calibrate it in the region $p > 200$ kbar. It was found that at $p \approx 250$ kbar, corresponding to the reference point of the transition to the metallic phase of GaAs, the superconducting transition in lead is observed at $T_c \approx 2.4$ °K. With further increase of pressure, T_c continues to decrease monotonically, reaches a value 1.96 °K at the maximum pres-

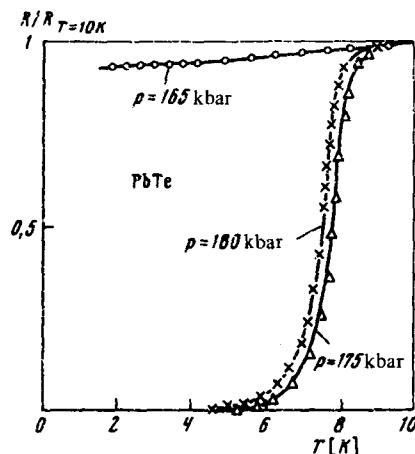


FIG. 3. Dependence of the relative electric resistivity of PbTe on the temperature at various pressures.

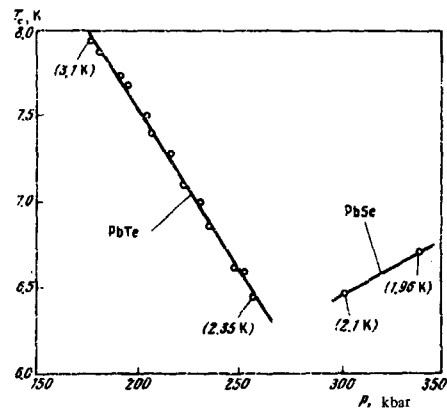


FIG. 4. Dependence of the temperature of the superconducting transition of PbTe and PbSe on the pressure.

sure. By extrapolating into the pressure region $p > 250$ kbar on the basis of the dependence of the pressure in the chamber on the force applied to the anvils, it was established that $T_c = 2.1$ and 1.96 °K correspond to pressures $p \approx 300$ and 340 kbar, respectively.

The measurements of the temperature dependence of the electric conductivity have shown that the γ phase of PbTe is metallic, and that of PbSe is semiconducting. After going over to the γ phase, the resistance R of PbTe or PbSe at room temperature decreases monotonically with increasing pressure and has no singularities (Fig. 2).

The energy gap of the semiconducting phase of PbSe decreases under pressure and vanishes at $p \approx 250$ kbar. At higher pressure, the conductivity of PbSe becomes metallic. It can be assumed that I. M. Lifshitz's electronic phase transition of order 2.5, of the semiconductor-metal type,^[5] takes place in PbSe at $p \approx 250$ kbar.

It was observed that superconductivity with transition temperatures $T_c \approx 8$ and 6.5 °K occurs in the metallic phases of PbTe and PbSe at pressure $p \approx 175$ and 300 kbar, respectively. It is interesting to note that the transitions of PbTe and PbSe into the superconducting modifications are apparently not accompanied by noticeable jumps of the resistance on the $R(p)$ curves at $T > T_c$. Therefore the question of whether a restructuring of the lattice takes place at these pressures remains open (Fig. 2, the arrows show the pressures corresponding to the onset of superconductivity). It can only be stated that the superconductivity sets in quite sharply (Fig. 3). At pressures 10–15 kbar lower than the indicated values, no superconductivity is observed at $T > 2$ °K. Figure 4 shows plots of T_c against the pressure for PbTe and PbSe. The numbers in the parentheses on this figure show that corresponding superconducting-transition temperatures of the lead manometer. In the pressure interval 175–260 kbar, the value of T_c of PbTe decreases practically linearly, with a baric coefficient $dT_c/dp \approx -2 \times 10^{-6}$ deg/bar. In the pressure region 300–340 kbar, T_c of PbSe increases at a rate $dT_c/dp \approx 0.5 \times 10^{-6}$ deg/bar.

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