New superconducting modifications of yttrium

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The resistivity of Y was investigated in the range of pressures P up to 160 kbar and at temperatures 0.1–4.2 °K. At P up to 110 kbar, Y is not superconducting down to 0.1 °K. It appears that three different crystalline modifications of Y are stable in the pressure range 110–160 kbar.

1. The element Y of the third group of the periodic system has a hexagonal close-packed structure of type A3 at the temperature $T = 300$ °K and at normal pressure.[1] The details of the P—T diagram of Y are unknown. At the maximum attainable purity, Y samples exhibit no superconductivity above 0.02 °K.

An investigation of the resistivity of Y at pressures up to 170 kbar and temperatures $1.2 = 4.2$ °K[2] has revealed that at $P \sim 110$ kbar yttrium becomes superconducting at the transition temperature $T_c \sim 1.3$ °K. With increasing pressure, T_c rises to 2.7 °K. Wittig[2] advances the hypothesis that the appearance of superconductivity in Y is not connected with a polymorphic transition but is the consequence of the continuous increase of the d-electron concentration by the compression. This point of view agrees with the results of measurements of the resistivity of Y and Ba at pressures up to 140 kbar.[3] In[3] the superconductivity of compressed Y or Ba is also attributed to an increase in the d-electron concentration.

2. It was of interest to determine whether the conductivity of Y sets in jumpwise or, in accord with the

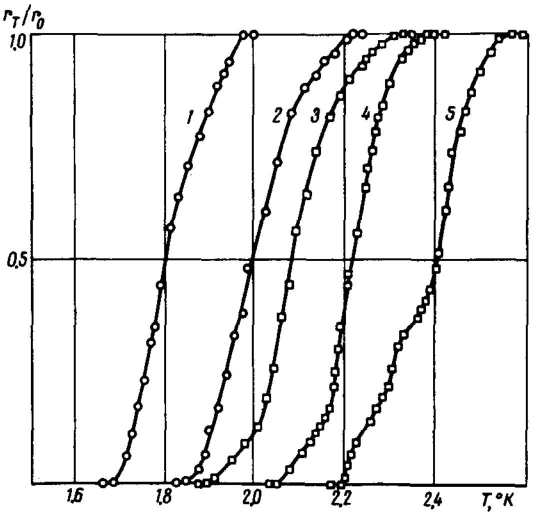

FIG. 1. Superconducting transitions of Y at various pressures: 1 - 118 kbar, 2 - 114 kbar (sample No. 1); 3 -140 kbar, 4 - 146 kbar, 5 - 152 kbar (sample No. 2).

point of view advanced in[2,3], T_c increases monotonically upon compression at infralow temperatures.

We have investigated the resistivity of Y at pressures up to 160 kbar and temperatures 0.1—4.2°K. The purity of the Y samples was 99.9%. The ratio $R(300\,°\mathrm{K})/R(4.2\,°\mathrm{K}) \approx 8$ remained practically constant during the compression.

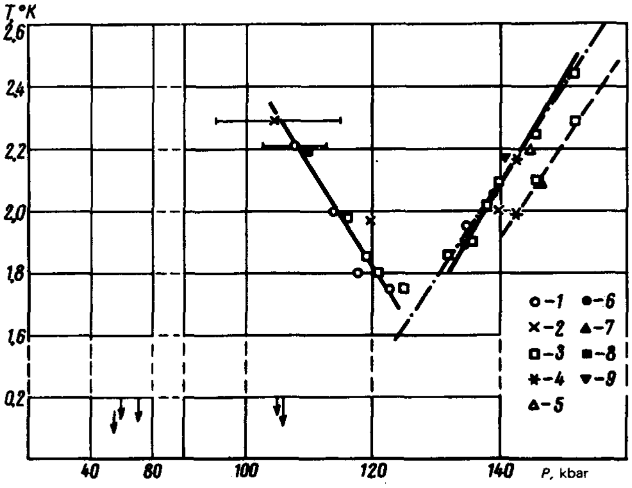

FIG. 2. Pressure dependence of the superconducting transition of Y. The measurements on samples 1—5 were performed in a press (sample No. 1 + Pb), and the measurements on samples 6—9 were made with a booster (sample No. 6 + Pb). The arrows mark the values of P and T at which there was no superconductivity (all these measurements were made in a booster with Pb). The dash-dot line shows the results of[2].

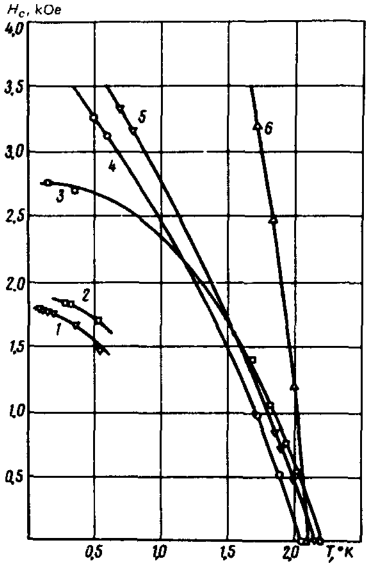

FIG. 3. Critical magnetic fields of Y at different pressures (P in kbar): 1 - 125, 2- 123, 3 - 110, 4 - 139, 5 - 141, 6 - 147.

The pressure was produced at room temperature in the high-pressure chamber described in[4]. The force was produced either with a mechanical low-temperature press or with a booster. The use of a mechanical press has made it possible to perform the measurements on one sample at consecutively increasing pressure. The absolute value of the pressure was determined from a calibration curve drawn through reference points, with accuracy ± 10%[4] (the pressure-measurement accuracy is much higher when consecutive compression of the chamber is used). In some experiments the pressure was determined, accurate to 5%, from the values of T_c of Pb samples installed together with the investigated sample.[5,6] Temperatures down to 0.1°K were obtained by the adiabatic demagnetization method.[7] The transition of the sample to the superconducting state was revealed by the change of the resistivity.

In the pressure region up to 105—110 kbar, yttrium is not superconducting down to ~0.1°K. At ~110 kbar, the superconducting modification Y II is produced jumpwise (Fig. 1, curves 1 and 2), with $dT_c/dP = -(3.2 \pm 1) \times 10^{-5}\,°\mathrm{K\,kbar}^{-1}$ (Fig. 2).

Starting with ~125 kbar, the character of the dependence of T_c on P is radically altered, viz., T_c increases with $dT_c/dP = (3.5 \pm 1) \times 10^{-5}\,°\mathrm{K\,kbar}^{-1}$. This section of the curve agrees well with Wittig's data[2] and can be ascribed to the modification Y III. At ~140 kbar, it appears that a new superconducting modification Y IV is produced, with dT_c/dP close to that of Y III. This is indicated, first, by the two-step character of the superconducting-transition curves near the Y III → Y IV transition pressure (regardless of the method whereby the pressure is produced - Fig. 1, curves 4 and 5), and second, by the jumpwise change of the slope of the critical magnetic field curves $H_c(T)$ on going from the pressure region 125—140 kbar to the region above 140 kbar (Fig. 3, curves 4, 5, and 6). A similar abrupt change of dH_c/dT on going from $P < 125$ kbar to $P \sim 125$—140 kbar [Fig. 3, curves (1, 2, 3) and (4, 5)] indicates apparently that there are two different modifications of Y in this region.

It appears thus that at pressures up to 160 kbar there exist three modifications of Y, and the onset of the superconductivity of Y at $P = 110$ kbar is not monotonic and is probably not connected with an increase in the d-electron concentration by compression.

Measurements of the resistivity of Ba at pressures up

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to 60 kbar and temperatures down to 0.1 °K have shown that in Ba, just as in Y, the superconductivity appears jumpwise (at $P \sim 60$ kbar).

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