ON THE SUPERCONDUCTIVITY OF TIN AND INDIUM UNDER PRESSURE

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The shift in the critical temperature due to pressure was measured over the pressure range 0 — 1730 kg/cm² for tin and indium. A linear dependence $T_c(p)$ is observed for indium over the entire pressure range, while tin shows an appreciable deviation from linearity at pressures of 400 — 800 atm. The linearity of the function $T_c(p)$ for indium, which has a simple Fermi surface, is compared with the complicated variation of $T_c(p)$ in thallium and tin, which have complicated Fermi surfaces.

THE shifts in the critical temperatures of tin and indium have previously[1,2] been determined at pressures of 1730 and 1370 kg/cm². The values of ΔT_c obtained at these pressures were, respectively, 0.097° ± 0.002° and 0.080° ± 0.002° for tin, and 0.080° ± 0.002° and 0.063° ± 0.002° for indium.

If we assume that the effect is linear, dT_c/dp for tin amounts to $(-5.7 \pm 0.2) \times 10^{-5}$ deg/atm while for indium it amounts to $(-4.6 \pm 0.2) \times 10^{-5}$ deg/atm.

The linear dependence of $T_c(p)$ has not been questioned, and until now it has been assumed, in particular, for tin and indium. However, the completely different behavior of thallium[3,4] has forced us to consider this view with great caution. In fact, even the sign of the effect for thallium changes at pressures above 2500 atm.

A number of investigators[4,6] have studied the effect of pressure in recent years. They have obtained appreciably discrepant results for the very same metals (e.g., for tin and indium). We may find a satisfactory explanation for certain of the widely varying data. For example, the obviously low value $dT_c/dp = -3.8 \times 10^{-5}$ deg/atm given by Hatton for indium is probably associated with a considerable deformation of the metal (owing to the method of applying pressure). As is known, this leads to a rise in the transition temperature.[5] From these considerations, we should consider the highest values of the shift in T_c as being the most reliable. It is relevant that for indium the value of dT_c/dp shows only a small spread of values over the entire pressure range up to 10 000 atm [from $(-4.0 \pm 0.3) \times 10^{-5}$ to $(-4.6 \pm 0.2) \times 10^{-5}$ deg/atm]. At the same time, tin shows an appreciable discrepancy between the values of dT_c/dp at high pressures [from $(-4.3 \pm 0.4) \times 10^{-5}$ to $(-4.6 \pm 0.5) \times 10^{-5}$ deg/atm] and at pressures of 1370 and 1730 kg/cm² [$(-5.7 \pm 0.2) \times 10^{-5}$ deg/atm]. The latter values have been checked repeatedly, and it would be difficult to find a reason for the increase in the value of dT_c/dp.

It seemed essential to perform precision measurements in the pressure range 0 — 2000 atm.

The shift in T_c for tin and indium was measured using two methods for applying pressure. Pressures up to 100 atm were applied by liquid helium. A differential method was used: one sample was placed in a bomb, and the other outside. The method permitted the application and reduction of pressure at liquid-helium temperature, so that we could verify that T_c was the same before and after the application of pressure.

The results of such measurements for indium are shown in Fig. 1. The value

$$dT_c/dp = -4.4 \pm 0.3 \cdot 10^{-5} \text{ deg/atm}$$

for this pressure range agrees well within the limits of accuracy with the value in the pressure range obtained by the ice method[1,2] [$(-4.6 \pm 0.2) \times 10^{-5}$ deg/atm]. Thus, indium retains a linear dependence of $T_c(p)$ in the pressure range up to

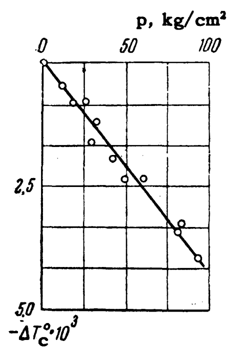

FIG. 1. The dependence of ΔT_c on p for indium in the pressure range 0–100 kg/cm².

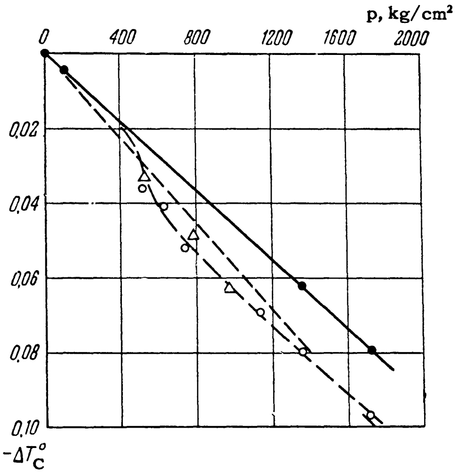

FIG. 2. The dependence of ΔT_c on p for indium (solid curve) and for tin (dotted curves). Δ and o indicate different samples of tin.

2000 atm (Fig. 2), as it does according to the data of other authors[4] at higher pressures.

Tin behaves differently. In the pressure range 0 — 100 atm, $dT_c/dp = (-4.4 \pm 0.2) \times 10^{-5}$ deg/atm, in good agreement with the results of other authors.[7] However, this value of dT_c/dp does not agree with the shift in T_c at pressures of 1730 and 1370 kg/cm². In Fig. 2, the dotted straight line corresponds to a linear variation of T_c with pressure, as was assumed in previous studies[1,2] with a value $dT_c/dp = (-5.7 \pm 0.2) \times 10^{-5}$ deg/atm.

Thus, we must conclude that for tin the curves for $T_c(p)$ have a different slope in the pressure ranges 0 — 100 and 0 — 1730 atm, i.e., the T_c of tin shows a nonlinear pressure dependence in the range 100 — 2000 atm.

In order to check this fact, measurements of T_c were made in the pressure range 500 — 1200 atm by means of the ice method using water-alcohol solutions.[8] In order to determine the pressure developed in the bomb, a sample of indium serving as a manometer was always placed in the bomb in addition to the tin sample. Supplementary measurements were made with two indium samples to establish the absence of pressure differentials between the sites of the samples (the pressure differential $\Delta p < 20$ atm).

The results of the measurements on tin are also given in Fig. 2. We see from the diagram that the curve for tin is parallel to that for indium in the pressure range 1730 — 800 atm (with a displacement $\Delta T = -0.017°$, i.e., with a value $dT_c/dp = (-4.6 \pm 0.2) \times 10^{-5}$ deg/atm).

We must consider that a transition from the one curve to the other occurs between the pressures 800 and 100 atm.

Such a variation in the curve may formally be represented as a superposition of a linear variation with $dT_c/dp = (-4.6 \pm 0.2) \times 10^{-5}$ deg/atm, and a variation appearing above 100 atm, and attaining a saturation value of $-0.017°$ at about 800 atm.

We must note that something similar takes place in thallium, for which also the dependence $T_c(p)$ may be represented in the form of a linear portion of the curve having $dT_c/dp = -0.56 \times 10^{-5}$ deg/atm, superimposed on a variation showing a saturation value of $+0.03°$ above ~ 2000 atm.[4]

In spite of the fact that the behavior of thallium is a convincing example of deviation from linearity even at such low pressures as $\gtrsim 10^3$ atm, the strange behavior of tin does not become more understandable.

In general, we must note that the effect of pressure on superconductors has not yet been explained. The new theory of superconductivity gives the following relation between the critical temperature T_c and the Debye temperature Θ and the electronic parameters (the electron-phonon interaction constant g and the electron density ν): $T_c \sim \Theta \exp(-2/g\nu)$. Uniform compression of a metal leads to an increase in the Debye temperature, and thereby to a linear increase in T_c. Apparently, we must seek an explanation for the pressure-variation of T_c in the effect of pressure on the electronic properties of the metal. In this regard, it is interesting to note that indium, which shows a linear variation of $T_c(p)$, has the simplest form of Fermi surface (closed, and almost spherical). It may be pertinent to relate the complicated variation of $T_c(p)$ for thallium to its very anisotropic Fermi surface (a system of corrugated planes). For tin, the form of the Fermi surface is also complicated (by the presence of open sections).

In order to understand the mechanism of the effect of pressure on superconductivity in general and the peculiarities of this effect in various metals, it is apparently essential to extend the studies to metals having varying electronic spectra, together with parallel studies on them of the effect of pressure on the galvanomagnetic properties. Such measurements are being carried out at present.

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