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DIFFERENT EFFECTS OF IMPURITIES AND PLASTIC DEFORMATIONS ON THE SUPERCONDUCTING TRANSITION TEMPERATURE OF A METAL

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Submitted to JETP editor September 12, 1962

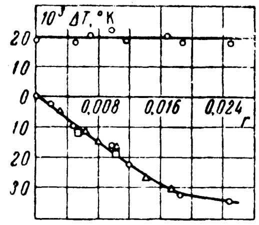
J. Exptl. Theoret. Phys. (U.S.S.R.) **43**, 2311-2312 (December, 1962)

RECENTLY a number of papers have been published concerned with the effect of impurities on the temperature T_K of the superconducting transition in tin, indium, aluminum and thallium.[1-3] For these metals, apart from thallium, there is observed for small impurity concentrations a decrease of the transition temperature with increasing concentration, which, as shown by Pippard,[4] is possibly related to the change in the mean free path of conduction electrons. From this point of view, diminishing the mean free path of electrons by another mechanism—lattice distortion—should also reduce T_K. However, deformation (strong, it is true) of tin, thallium and indium at liquid helium temperature increases T_K in these metals.[5]

It appeared important to study on the same specimens the effect on the transition temperature of lattice distortions caused by impurities and deformation. The variation of T_K with antimony concentration c was measured in tin for concentrations up to 0.5%.

The transition temperatures of specimens made in the usual way from a melt agreed well with the known variation of T_K with impurity concentration (see the figure, lower curve). The residual resistance ($r = R_{4.2°K}/R_{20°C}$) served as a measure of concentration.

The dependence of the transition temperature shift on residual resistance for tin: lower curve – our data for annealed (o) specimens and for specimens obtained from a melt (Δ); □ – data from [1]; upper curve – for deformed specimens



To make deformed specimens with equal degrees of deformation, pieces of the alloys (and pure tin with $r = 2 \times 10^{-5}$) were pressed at room temperature through a die of 0.18 mm dia. After measuring in the deformed state, the specimens were annealed at t = 80°C for ~ 20 hours to remove the distortions. The transition temperature of the specimens after the anneal also agreed well with the lower curve of the figure, which proves the complete removal of distortion due to deformation by the anneal.

There was a completely different variation of T_K with impurity concentration in the deformed specimens—the transition temperature at all concentrations increased by a constant amount, $\Delta T_K = 0.020°K$, relative to T_K for pure undeformed tin (upper curve). Meanwhile the deformation contribution to the electrical resistance amounts for pure tin to practically the entire residual resistance (0.3×10^{-3}). This contribution changes little in the range of concentrations corresponding to the linear portion of the lower curve (from 0.4×10^{-3} for c = 0.18% Sb to 1.4×10^{-3} for c = 0.38% Sb).

The results obtained show that, at least for tin,[1)] the changes in electron mean free path due to impurities and to lattice deformation distortions affect T_K by completely different mechanisms. Further, the deformation mechanism (as is seen from the figure) completely eliminates the impurity effect.

The observed increase of temperature may be related to the fact that plastic deformation of a metal reduces the Debye temperature,[7] i.e., weakens the elastic properties of a metal. The latter in its turn increases the electron-phonon interaction,[8] i.e., increases T_K.

The authors thank B. G. Bar'yakhtar for discussion and T. A. Ignat'eva for help in the experiments.

[1)] It is interesting that for aluminum filings T_K is lower than for annealed metal.[6].

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DISCONTINUITY OF THE THERMAL EXPANSION COEFFICIENT OF Nb_3Sn AT THE SUPERCONDUCTING TRANSITION

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Submitted to JETP editor September 12, 1962

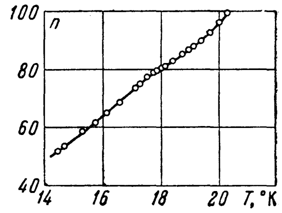
J. Exptl. Theoret. Phys. (U.S.S.R.) **43**, 2312-2313 (December, 1962)

To study the jump in the expansion coefficient of tin and lead during transition through the superconducting transition temperature (T_K) and the volume change during the transition in a magnetic field, a sensitive method was developed which allowed measurements of these quantities to be made with sufficient accuracy (for example, volume changes $\Delta V/V \leq 10^{-8}$ were measured[1,2]).

1. This method allowed us to measure the discontinuity in the thermal expansion coefficient of Nb_3Sn at the transition. It was important to obtain this data in connection with a number of peculiarities in the properties of superconductors of this type, for example, the large magnetic field destroying superconductivity and the small field at which field penetration into the volume of the superconductor starts.

As in the previous measurements, the sensitive element of the apparatus was a long bimetallic strip, twisted into a spiral, one end of which was fixed, whilst the other could rotate when there were volume changes of one metal with respect to the other. This rotation is the measured quantity. In the present case one of the metals was niobium (99.5% purity) on which a layer of Nb_3Sn was deposited (from the outer side of the spiral) by the method of diffusive growth.[3] The dimensions of the spiral (length of strip 55 cm, niobium thickness ~ 0.26 mm, thickness of Nb_3Sn layer ~ 0.05 mm) ensured adequate sensitivity to changes of length of one component of the strip relative to the other (7×10^{-8} deg^{-1} for one division of the scale when reading with a mirror system).

The curve shown in the figure gives the rotation of the spiral (in scale divisions) as a function of



temperature in the neighborhood of the superconducting transition of Nb_3Sn. It is seen that, superposed on a monotonic behavior due to the difference in the coefficients of expansion of the components of the spiral, there is a singularity at the superconducting transition temperature, i.e., 18°K. In fact, the slope of the curve (i.e., the difference in expansion coefficients) above T_K (range 19–20°K) is greater than the slope of the curve below this temperature (17–14°K). The jump in the expansion coefficient of Nb_3Sn measured thus is 1.5×10^{-7} ($\pm 10\%$) deg^{-1}. It is interesting that this value of the jump in expansion for Nb_3Sn is close to the values of this quantity during the superconducting transitions in tin (1×10^{-7})[2] and lead (4×10^{-7}).[2] The value is three orders smaller than that ($\sim 5 \times 10^{-4}$ deg^{-1}) calculated using well-known thermodynamic formulae and the values of the quantities $\partial T_K/\partial p$ and $\partial H_K/\partial T$ for Nb_3Sn.[3] This means that in this superconductor probably only an insignificant part of the volume has the property that high field values are needed to destroy superconductivity,—a deduction which agrees with measurements of other properties of Nb_3Sn.[4,5] Otherwise one has to assume that in Nb_3Sn (and similar superconductors) the penetration depth of the magnetic field is extremely large.

2. Apart from measurements in the neighborhood of T_K, measurements were made in the same apparatus of the behavior of the differences in expansion coefficients and in compressibilities of Nb_3Sn and Nb in the temperature range 300–2°K.