Isotope Effect in Nb_3Sn

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(Received August 11, 1960)

The isotope effect on the superconducting transition of Nb_3Sn has been measured. The value of -0.08 for the exponential factor is only $\frac{1}{5}$ of that of the elemental superconductors which have been reported.

THE isotope effect for superconductors has been measured for Hg, Sn, Pb, and Tl.[1–5] It has not, to our knowledge, been measured for any intermetallic compounds or for any of the transition metals. Indeed those transition metal superconductors which have stable isotope pairs have T_c's below 1°K.

As we were unable to determine the isotope effect in transition elements, we have measured a pair of compounds of a transition metal with two isotopes of Sn. We are aware that this may not be directly comparable to a measurement of the transition elements. It is, however, the best approximation available to us at this time and may alternatively shed some light on any difference in the superconductivity phenomenon in intermetallic compounds as opposed to pure elements.

We have measured the isotope effect on the superconducting transition of Nb_3Sn using Sn^{116} and Sn^{124}. The results for the original Sn isotopes are shown in Fig. 1 and are in good agreement with previous measurements. In the well-known relationship $T_c \sim M^p$, $p = -0.46$. The measurements were made by a method, pre-

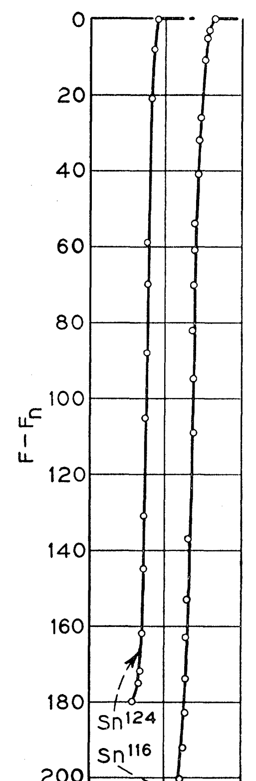

FIG. 1. Plot of the superconducting transitions of Sn^{116} and Sn^{124}.

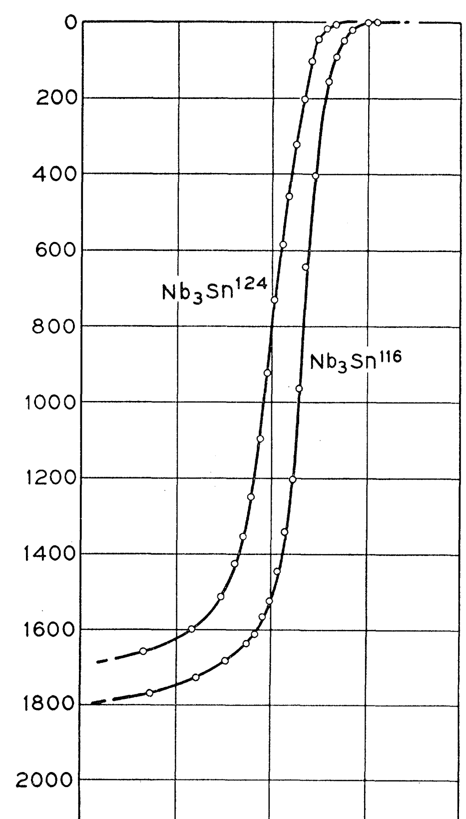

FIG. 2. Plot of the superconducting transitions of Nb_3Sn^{116} and Nb_3Sn^{124}.

[1] C. A. Reynolds, B. Serin, and L. B. Nesbitt, Phys. Rev. **84**, 691 (1951).
[2] E. Maxwell, Phys. Rev. **86**, 235 (1952).
[3] E. Maxwell and O. S. Lutes, Phys. Rev. **86**, 649 (1952).
[4] R. W. Shaw, D. E. Mapother, and D. C. Hopkins, Bull. Am. Phys. Soc. **5**, 163 (1960).
[5] R. R. Hake, D. E. Mapother, and D. L. Decker, Phys. Rev. **104**, 549 (1956).

viously described in detail,[6] in which the sample serves as the core of an inductance in the tank circuit of an oscillator. Figures 1 and 2 show the change in oscillator frequency on the ordinate, plotted against temperature, as the susceptibility of the sample changes at the superconducting transition.

If one takes the Nb_3Sn compounds to be of mass 394.73 and 402.73, respectively, the value of p for $Nb_3Sn = -0.08 \pm 0.02$. This compares with values in the neighborhood of -0.5 reported for the soft superconducting metals. The difference in magnitude between the observed value of p for the compounds and that of the elemental tin isotopes is far outside any limits of error. Additional experiments are called for before any final conclusions as to the isotope effect in the transition elements can be drawn. It is hoped that in the near future this will be done.

[6] A. L. Schawlow and G. E. Devlin, Phys. Rev. **113**, 120 (1959).

ACKNOWLEDGMENTS

We take this opportunity to thank Dr. B. T. Matthias and Dr. A. L. Schawlow for much helpful discussion.

PHYSICAL REVIEW VOLUME 120, NUMBER 6 DECEMBER 15, 1960

Effective Mass in Gray Tin from Knight Shift Measurements

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(Received July 25, 1960)

The nuclear magnetic resonance of Sn^{119} in gray tin was measured between 200°K and 300°K and the effective g factor was found to increase by about 4 parts in 10^5 over this temperature range. This increase in Knight shift is thought to arise from an increase in the number of conduction electrons. By combining this result with Busch and Mooser's measurements of the magnetic susceptibility over the same temperature range m_l, the single-valley effective mass of the lighter of the charge carriers, is found to be $(0.3\pm0.05)m$ if the electron g factor is 2. The experiment also allows one to determine the Knight shift without making a comparison with a diamagnetic substance. The Knight shift of intrinsic gray tin is found to be 6×10^{-5} at 300°K. The fact that the Knight shift is positive shows that the electron g factor is not negative as would be expected if the band structure of gray tin were similar to that of InSb.

SHIFTS in the nuclear magnetic resonance fields which arise from the hyperfine interaction between the nuclei and conduction electrons are generally known as Knight shifts (k) and have been observed in many metals.[1] Semiconductors are also expected to have Knight shifts but because of the greatly reduced number of conduction electrons at convenient temperatures, the shifts are small and have not previously been observed. In gray tin the forbidden gap is very narrow so that the Knight shift though still small compared to chemical shifts, is made observable by virtue of its temperature dependence. In this way we were able to measure k in gray tin and to use the result in gaining some information about its band structure.

I. THEORY

In intrinsic semiconductors the total number of charge carriers is given by

$$N=(1/2\pi^2)(2kTm/\hbar^2)^{\frac{3}{2}}(\bar{m}_e^*\bar{m}_h^*)^{\frac{3}{4}}F_{\frac{1}{2}}[(E_F-E_c)/kT], \quad (1)$$

where $\bar{m}_e^*$ and $\bar{m}_h^*$ are the average density of state masses for the electrons and holes divided by the free electron mass m and $F_{\frac{1}{2}}(\eta)$ is the Fermi-Dirac function $\int_0^\infty z^{\frac{1}{2}}[1+\exp(z-\eta)]^{-1}dz$. Values for $F_{\frac{1}{2}}(\eta)$ and its derivatives have been computed by McDougall and Stoner.[2] E_F and E_c are the Fermi level and the lower edge of the conduction band, respectively. For an intrinsic semiconductor E_F is completely determined by the gap, temperature, and $\bar{m}_e^*/\bar{m}_h^*$.

Among the experimental quantities which depend on the number of carriers are the magnetic susceptibility χ, the conductivity σ, and the Hall coefficient R. Since these parameters are proportional to $(\bar{m}_e^*\bar{m}_h^*)^{\frac{3}{4}}$ it might be thought that their measurement would yield information about the effective masses. However, one cannot hope to separate either mass from the product $\bar{m}_e^*\bar{m}_h^*$ by such experiments, and one is moreover dealing with an *average* density of state mass whose relation to the effective masses appropriate to each individual conduction band minimum (m_e^*, m_h^*) is complicated and unknown unless the band structure is well understood. The value of N and hence of χ, σ, and R at a particular temperature depends on the value of the energy gap ΔE at this temperature and the position of Fermi level in relation to the gap. For intrinsic semiconductors, $E_F=\Delta E/2-\frac{3}{4}kT\ln(\bar{m}_e^*/\bar{m}_h^*)$ if E_F is measured from the top of the valence band. Therefore, if the temperature dependence of ΔE is

[1] W. D. Knight, *Solid-State Physics*, edited by F. Seitz and D. Turnbull (Academic Press, New York, 1956), Vol. 2, p. 93.

[2] J. McDougall and E. C. Stoner, Phil. Trans. Roy. Soc. (London) **A237**, 67 (1938).