energies, $\sim 6kT_c$, and to lower reduced temperatures, $t\sim 0.3$.

We wish to thank J. D. Wells for assistance with the microwave components and T. Holstein and A. T. Forrester for helpful discussions of the work.

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[1] Corak, Goodman, Satterthwaite, and Wexler, Phys. Rev. **102**, 656 (1956); W. S. Corak and C. B. Satterthwaite, Phys. Rev. **102**, 662 (1956); B. B. Goodman, Compt. rend. **244**, 2899 (1957).

[2] Blevins, Gordy, and Fairbank, Phys. Rev. **100**, 1215 (1955).

[3] Biondi, Garfunkel, and McCoubrey, Phys. Rev. **101**, 1427 (1956). In these measurements the experimental error was $\pm 3\%$. Because of this scatter, the form of the curves was not uniquely determined; in fact, the particular form used has now been shown to be incorrect. In addition, the aluminum wave-guide sample, Al 1, was poorly designed, leading to extraneous absorption. The present measurements are much more accurate ($\pm 0.3\%$ error) and have been obtained with better samples.

[4] R. E. Glover and M. Tinkham, Phys. Rev. **104**, 844 (1956); **108**, 243 (1957). M. Tinkham, Phys. Rev. **104**, 845 (1956).

[5] Bardeen, Cooper, and Schrieffer, Phys. Rev. **106**, 162 (1957), and to be published.

[6] Since the rounding of the curve at $0.65kT_c$ extends only over a range of a few thousandths of a degree and since the curve extrapolates well to $r=0$ at $t=0$, we conclude that the surface of the Al 3 sample was near-ideal.

[7] We are greatly indebted to T. Holstein for carrying out this calculation. He used an expression for the surface impedance given by R. B. Dingle [Physica **29**, 311 (1953)] and added the effect of the superconducting electrons.

[8] D. Shoenberg, *Superconductivity* (Cambridge University Press, Cambridge, 1952), pp. 164 ff.

[9] Biondi, Forrester, and Garfunkel, Phys. Rev. **108**, 497 (1957), following letter.

Millimeter Wave Studies of Superconducting Tin

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THERE is now a considerable body of experimental[1–4] and theoretical[5] evidence associating the superconducting state with an energy gap of the order of kT_c, where T_c is the superconducting transition temperature. The absorption by superconductors of electromagnetic radiation with photon energies in this range provides a particularly direct approach to the study of such a gap. Tin, with a transition temperature of 3.72°K, is well suited to a study of this sort. It is easy to reach temperatures which are sufficiently low that absorption by normal electrons is very small, and that the superconducting energy gap, according to the latest ideas, has reached its limiting value. The interesting wavelength range, for a transition temperature of 3.72°K, is 1 to 4 mm, a difficult but accessible microwave region.

For these wavelengths it is necessary to use crystal harmonic generators; therefore a technique is needed which is capable of operating with very small power levels. Accordingly, the experiment which has been undertaken is one in which measurements are made on the temperature variation of the power transmitted by a length of superconducting tin wave guide—for the present work a piece of extruded tin of inside dimensions 0.008 in.×0.122 in. and 12 in. long, with an average attenuation at the transition temperature of about 1.5 db. In this work, direct measurements were made of the *difference* between the transmitted power levels at two temperatures. This was accomplished by having the crystal detector feed a receiver synchronized with periodic temperature variations in the sample. This technique gives a very accurate indication of the shape of the curves in the vicinity of T_c.

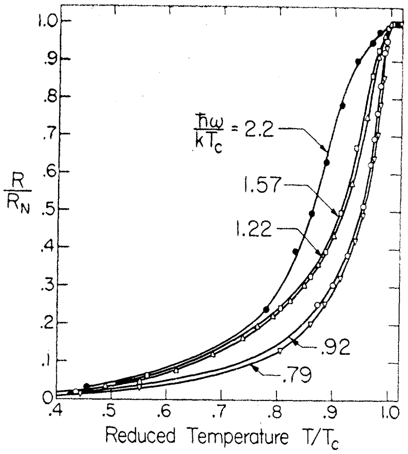

FIG. 1. Surface resistance ratio of superconducting tin as a function of reduced temperature.

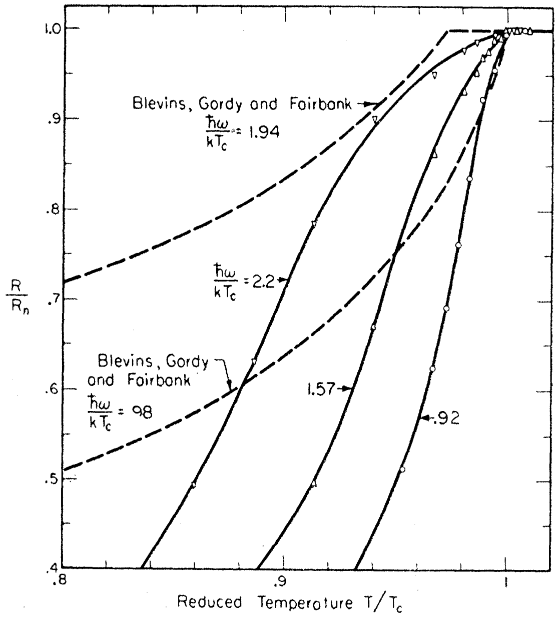

FIG. 2. A comparison between the surface resistance measurements for tin by Blevins, Gordy, and Fairbank (dashed curves) and our measurements (solid curves and experimental points), in the vicinity of the superconducting transition temperature.

The deduction of the surface resistance R from data on the transmitted power requires a knowledge of one additional parameter; for example, the generated power reduced by the losses in the lines to and from the tin sample; measurements of this have been made by using two different length samples. Our choice of this parameter to make $R\to 0$ as $T\to 0$ is justified (a) by the measurements which lead to $R/R_n=0\pm 0.25$ at $T=0$; (b) by the work of Biondi, Garfunkel, and McCoubrey,[6] who find for aluminum that $R\to 0$ as $T\to 0$ whenever $\hbar\omega/kT_c<2.5$; and (c) by the expectation (which is consistent with our results) that the energy gap at $T=0$ is larger than any of the photon energies used in this work.

Using appropriate dimensionless quantities, surface resistance is shown in Fig. 1 as a function of temperature, for several frequencies. Independent of the choice of the value of R/R_n at $T=0$, our curves do not show the outstanding characteristic found in similar studies on tin by Blevins, Gordy, and Fairbank,[2] i.e., a marked decrease in the "temperature for the onset of superconductivity" with increasing frequency, as shown in two of their curves reproduced in Fig. 2. All of our curves are seen to drop away from $R/R_n=1$ at a single temperature. The differences between our curves and those of Blevins *et al.* lie outside the indicated scatter of either experiment.

It is apparent that the values of R/R_n, for temperatures just below T_c, are greater for $\hbar\omega/kT_c>1$ than could be expected from the nature of the low-frequency curves. The appearance suggests that an absorption process not active at lower frequencies has become important. Following the analysis for aluminum,[6] differences have been taken between the actual R/R_n curves and those scaled up from low-frequency data on the basis of a two-fluid model. If it is assumed that these differences are due to an absorption by the superconducting electrons, it is possible to make an estimate of the temperature for which the energy gap is equal to the photon energy for each curve. Values so obtained are compared with the theoretical curve of Bardeen *et al.*[5] in Fig. 3. Because absorption per unit volume and penetration depth are intimately tied together in determining the surface resistance, the proper evaluation of the errors made in our determination of the gap requires a much more involved analysis. While the agreement in Fig. 3 is gratifying, a more rigorous comparison of theory and experiment will be obtained when calculations of the absorptivity from the theory of Bardeen, Cooper, and Schrieffer become available.

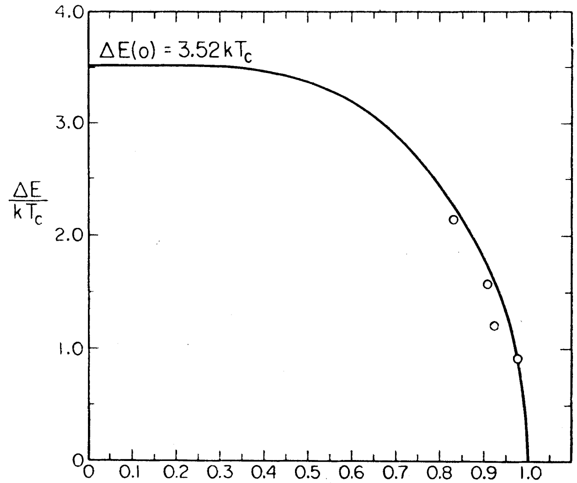

FIG. 3. A comparison between the energy gaps inferred from our measurements and the theoretical curve of Bardeen, Cooper, and Schrieffer.

We would like to thank T. Holstein for numerous discussions of this work. We are very grateful to R. S. Ohl of Bell Telephone Laboratories, who supplied the silicon crystals used in our harmonic generators, and who gave us some valuable suggestions concerning their use.

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[1] Corak, Goodman, Satterthwaite, and Wexler, Phys. Rev. **102**, 656 (1956); W. S. Corak and C. B. Satterthwaite, Phys. Rev. **102**, 662 (1956); B. B. Goodman, Compt. rend. **244**, 2899 (1957).

[2] Blevins, Gordy, and Fairbank, Phys. Rev. **100**, 1215 (1955).

[3] Biondi, Garfunkel, and McCoubrey, Phys. Rev. **101**, 1427 (1956).

[4] R. E. Glover and M. Tinkham, Phys. Rev. **104**, 844 (1956), and to be published. M. Tinkham, Phys. Rev. **104**, 845 (1956).

[5] Bardeen, Cooper, and Schrieffer, Phys. Rev. **106**, 162 (1957), and to be published.

[6] Biondi, Garfunkel, and McCoubrey, Phys. Rev. **108**, 495 (1957), preceding Letter.

Dislocations in Whiskers

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THE discovery of the exceptional strength of thin filamentary crystals or "whiskers" of tin[1] has prompted development of detailed theories[2,3] of the growth and defect structure of whiskers, all of which are based on the operation of screw dislocations in the whiskers. However, no conclusive experimental evidence for these screw dislocations has yet been reported. We have studied a variety of whiskers using an x-ray technique and have observed screw dislocations in some of them.

Earlier attempts to detect screw dislocations in whiskers using x-ray diffraction methods have been made[4-6] by exploiting a calculation by Eshelby[7] showing that a screw dislocation parallel to the axis of a cylindrical whisker produces a lattice twist about the axis given by $\alpha=(b/\pi R^2)/(1-\xi^2/R^2)$, where b is the Burgers vector of the screw dislocation, R is the whisker radius, and ξ is the displacement of the dislocation from the