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 $R\rightarrow 0$ as $T\rightarrow 0$ 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 $R\rightarrow 0$ as $T\rightarrow 0$ 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.

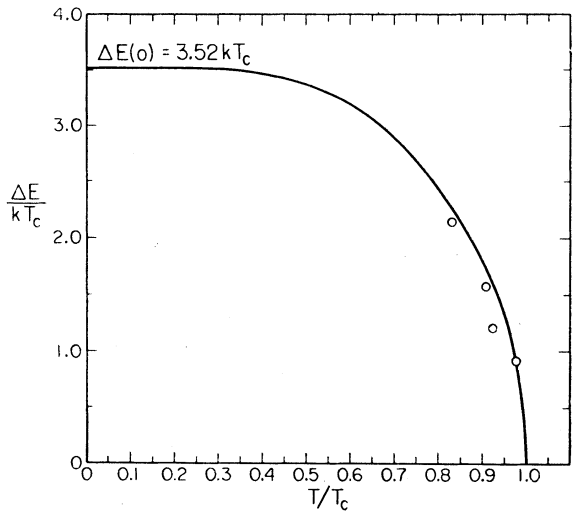

FIG. 3. A comparison between the energy gaps inferred from our measurements and the theoretical curve of Bardeen, Cooper, and Schrieffer.

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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

whisker axis.[8] We have used an improved technique[9] in which the lattice twists are determined from the tilt of equatorial Laue spots obtained by utilizing x-rays from a microfocus tube, and recorded on a cylindrical camera coaxial with the whisker. The twist is given by $\alpha = k \tan\rho$, where ρ is the tilt angle of the Laue diffraction image of the whisker and k is a constant determined by camera geometry which is so arranged that the Laue spots are distorted only by twisting of the diffraction planes in the whisker. Effective precautions are taken to avoid any deformation during handling, and motion, misalignment, or strain during exposure.

Our most common observation with whiskers of zinc, copper, iron nickel, manganese, and sometimes silver and palladium grown by chemical reaction[3] is the lack of any detectable lattice twist. Any twist more than 0.01 that expected of a prime axial screw dislocation would have been observed. This does not eliminate a dislocation mechanism for growth of these whiskers because there may be (1) an even number of parallel cooperating screw dislocations with equal magnitudes of Burgers vectors of each sign, or (2) a screw dislocation that climbs or is forced out through the lateral surface of the whiskers.

On the other hand, nine sapphire (α-Al_2O_3) whiskers[9,10] with $\langle 00\cdot 1\rangle$ growth axes were each found without exception to contain an axial screw dislocation with a Burgers vector equal to an integral multiple of the prime Burgers vector in the $\langle 00\cdot 1\rangle$ direction. These dislocations are clearly shown by axial pores about 0.1 to 1.0 μ in diameter as predicted by Frank.[11] The x-ray measurement of the lattice twist used to compute b was confirmed by optical observation of the twist of the $(10\cdot 0)$ facets on the lateral surfaces of the whiskers.

Numerous whiskers of silver, palladium, and copper grown by chemical reaction appeared as single crystals in the form of both helices and nominally straight but twisted prisms. A nominally straight silver whisker and a helical palladium whisker,[12] both with low-index growth axes, showed large axial twists corresponding to screw dislocations with large Burgers vectors. The observed lattice twists could be accounted for by an axial dislocation (or group of dislocations) with a net Burgers vector equal to an integral multiple of atom periodicities in the direction of the growth axis. A single-crystal helical copper whisker showed no lattice twist. Several straight palladium whiskers in the form of tightly twisted prisms showed high-index growth directions close to the $\langle 211\rangle$ direction and lattice twists corresponding to Burgers vectors from zero to unmeasurably large values.

We conjecture that the contortions of these whiskers are due to climb of the dislocation inside the tip of the whisker during growth due to condensation of $<0.1\%$ vacancies that are trapped in the lattice at the tip of the whisker during growth. This forces the point of intersection of the dislocation with the surface to prescribe a helical path which successively crosses the several facets comprising the growing whisker tip, thus periodically changing the effective growth direction. The observed growth forms can be accounted for by variations of the ratio of the radius of gyration of the dislocation terminus to the radius of the whisker, the ratio of the rate of gyration to the rate of growth, and the orientation of the net Burgers vector.

In most of our tin whiskers grown by stress activation no lattice twist was detected, but two had uniform twists corresponding to calculated Burgers vectors for axial dislocations of about 0.2 and 0.4 A. Previously, Treuting[4] reported small lattice twists in tin whiskers that may have been plastically deformed, while Hirsch[5] reported that no twists were detectable.

The hypothesized presence of screw dislocations in some whiskers has been unequivocally confirmed, and some complexities of their behavior have been noted. Further details of our observations will be published later.

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High Negative Nuclear Polarizations in a Liquid*,†

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UPON partially saturating the electron spin resonance (ESR) in a solution of sodium and naphthalene in 1,2-dimethoxyethane, we have observed by means of a simultaneous nuclear magnetic resonance (NMR) experiment, negative nuclear polarizations of the proton spins of up to sixty-five times the equilibrium value. We call this an inverted Overhauser effect.[1,2]

The naphthalene in the solution is ionized by the addition of an electron forming an ionic free radical.[3]