Superconducting Transitions in Tin Whiskers

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Superconducting Transitions in Tin Whiskers*

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MEASUREMENTS have been undertaken to determine the form of the superconducting resistance transition in tin whiskers.[1] These small filaments are of interest in the study of size effects in superconductors because they are an order of magnitude smaller than used in previous such studies.[2] Our preliminary results differ markedly from those for larger wires.

Transitions were obtained at several temperatures using a transverse magnetic field; i.e., the restoration of resistance at a given temperature was studied by increasing a magnetic field applied perpendicularly to the specimen axis. The whisker, of diameter 1.2×10^{-4} cm, was mounted on a Pyrex plate using silver paste contacts. The effective sample length was approximately 50×10^{-4} cm. The temperature was controlled by a liquid helium bath and the resistance measured with a Mueller bridge. The sample current was less than 5 μa.

Results at three different temperatures are shown in Fig. 1. The data are plotted on a reduced basis, H_c being

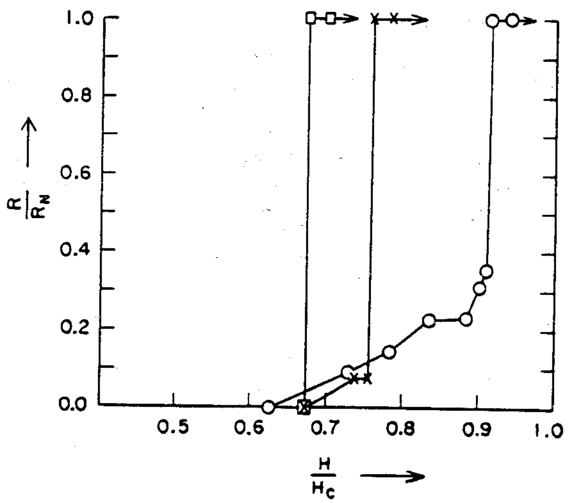

FIG. 1. Plot of whisker transition showing fraction of normal resistance restored as a function of the reduced field variable. o—3.65°K, ×—3.60°K, □—1.69°K.

the critical field for a bulk specimen of natural tin[3] in a longitudinal field. The unusual behavior of the transition is most pronounced at 1.69°K, where an abrupt (less than 0.02 percent of H_c in width) transition occurs at $H=0.67H_c$. At this temperature there is no apparent evidence of the intermediate state. As the temperature is increased towards the transition temperature of bulk tin (3.73°K), the intermediate state appears and occupies an increasingly wide range of field. It should be remarked that a residual resistance was measured in the superconducting region. This was attributed to the contacts and was subtracted from the total.

For purposes of comparison the results obtained by Andrew[2] for his largest and smallest wires at 1.66° are shown in Fig. 2, together with our result at 1.69°. The intermediate state is observed for all of Andrew's wires. The value of H/H_c at which intermediate resistance first appears is designated as ρ. For Andrew's larger wires ρ is nearly $\frac{1}{2}$, in keeping with the demagnetizing coefficient of a transverse cylinder. As the wire diameter is reduced ρ increases, becoming 0.64 for a diameter of 27×10^{-4} cm.

Approximate theories for the intermediate state in transverse wires have been developed by Andrew[4] and Kuper,[5] using concepts originally stated by Landau.[6] The intermediate state, *when it exists*, consists of alternating superconducting and normal domains, so shaped that the overall free energy is lower than for either the normal or the superconducting state. The delayed onset of the intermediate state, in the thinner wires, is attributed to the positive surface energy of the interphase boundaries. As the wire diameter is reduced, the domain segmentation, hence the relative contribution of the surface energy, increases and the intermediate state is characterized by a higher free energy. Consequently the free energies of superconducting and intermediate states become equal at greater H/H_c. Thus ρ increases. Kuper's theory gives $\rho=\frac{1}{2}+0.42(\Delta/r)^{\frac{1}{2}}$, where r is the cylinder radius and Δ the surface energy parameter, having the dimension of length.

We now offer a possible explanation for the observed transition of the whisker. With reduction of wire diameter, ρ does not increase indefinitely but approaches a limiting value. This follows since at some field, between $H_c/2$ and H_c, the free energies of normal and superconducting states must be equal. Thus, as Andrew[4] has pointed out, if the intermediate state has not appeared when this field is reached, the specimen will prefer a direct transition from the superconducting to the normal

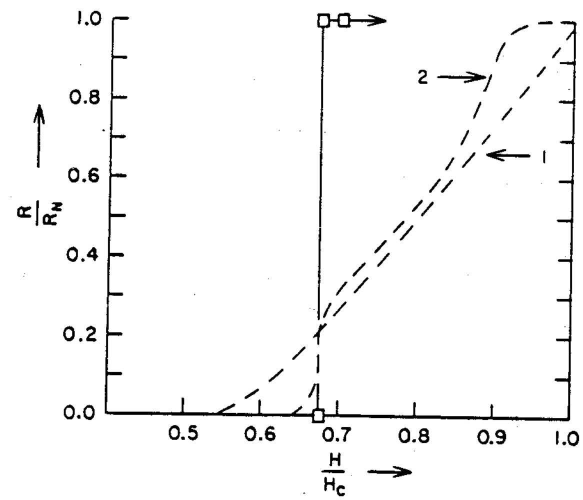

FIG. 2. Comparison of whisker transition with results of Andrew for larger wires. 1—Andrew, 1.05×10^{-1} cm diameter, 1.66°K. 2—Andrew, 27×10^{-4} cm diameter, 1.66°K. □—whisker, 1.2×10^{-4} cm diameter, 1.69°K.

state. Hence no intermediate resistance will be observed. In the general case of an ellipsoid the limiting value of ρ is easily shown to be $(1-n)^{\frac{1}{2}}$, where n is the demagnetizing coefficient. Applying this to the transverse cylinder ($n=\frac{1}{2}$), one would not expect to observe transitions from the superconducting to the intermediate state at values of $H/H_c>0.71$. Kuper's result gives $\rho\geq0.71$ for $r\leq16\Delta$. Thus, for $r<16\Delta$, restoration of normal resistance should be abrupt, and should occur at $H/H_c=0.71$. Since $\Delta\sim10^{-5}$ cm,[7] the discontinuous transition of the whisker appears reasonable. The occurrence of the transition at $H/H_c<0.71$ might be explained by a somewhat noncircular cross section. The appearance of the intermediate state at the higher temperatures could be due to a decrease of Δ. Such a temperature dependence would, however, be contrary to the usual interpretations of other experiments.[7] Further investigations are in progress.

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