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Temperature Dependence of the Surface-Sheath Nucleation Field in Strong-Coupling Superconductors

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In an earlier paper the temperature dependence of H_{c3} in a strong-coupling type-I superconductor was determined and compared with the theory of Eilenberger and Ambegaokar (EA). An error in the EA theory is now taken into account. The dc resistivity appropriate to the surface-sheath region has been obtained by a more consistent method. When these new factors are considered, the results suggest that the discrepancy between theory and experiment is due to a more fundamental reason than just experimental inaccuracy.

Recently[1] we have presented data on the temperature variation of the surface-sheath nucleation field (H_{c3}), in a strong-coupling type-I superconductor (0.25 at.% Bi in Pb). In that paper we compared our experimentally determined value for the slope $(dH_{c3}/dT)|_{T_c}$ (-234 G/°K) with a prediction for that quantity based on the theory developed by Eilenberger and Ambegaokar[2] (EA) for this material (-188 G/°K). The latter is a phenomenological theory in which the Landau-Ginzburg equations have been generalized to include strong-coupling effects. We attributed most of the discrepancy between theory and experiment to possible uncertainty in several experimental parameters which must be put into the EA equations in order to extract a value for the slope. In particular, we noted that since we had no direct means for determining a value for the dc conductivity in the surface sheath, of necessity we used the conductivity of the bulk material, which is easily measurable. Since the presence of surface scattering processes would make the resistivity in the surface larger than that of the bulk, we were aware that our calculated slope could be expected to be too small, as was the case.

It is the purpose of this paper to point out several subsequent developments which relate to the results and discussion in the above-mentioned paper. We find that, when these new factors are considered, the disagreement between theory and experiment is somewhat increased, and we now believe that the discrepancy is of a more fundamental nature than had previously been supposed.

Of primary significance is a recent paper[3] by EA in which they pointed out an error in their original work. As a result, each of their predicted values for $(dH_{c3}/dT)|_{T_c}$ should be decreased by the factor 0.68. The authors pointed out that the fairly good agreement which had been demonstrated between the theory and data taken on pure lead, must now be considered as being spurious. The same correction factor would apply to our material.

We have also managed to make progress toward obtaining a value for the dc conductivity in the surface of our alloy. We have used the following result by Goodman[4] which relates the Ginzburg-Landau parameter κ in dilute alloys to that of the pure material through the dc resistivity:

$$\kappa = \kappa_0 + 7.5\times 10^3 \rho\gamma^{1/2}. \qquad (1)$$

Here, the subscript refers to pure lead, ρ is the dc resistivity, and γ is the coefficient of the electronic specific heat. We have determined κ from our data by plotting $\kappa(T) = H_{c3}(T)/2.4H_c(T)$ vs T, and extrapolating to T_c. Several authors have measured $H_{c3}(T)$ in pure lead,[5-10] so that it should be possible to determine κ_0 from their data by the same method. However, these measurements disagree somewhat with each other. This disagreement is presumably due to differences in the surface conditions of the samples used. To obtain a value relevant to our work we have measured $\kappa(T)$ in a pure single-crystal lead sample which had been carefully prepared in a manner identical to that used in the case of our alloy. Thus, the sur-

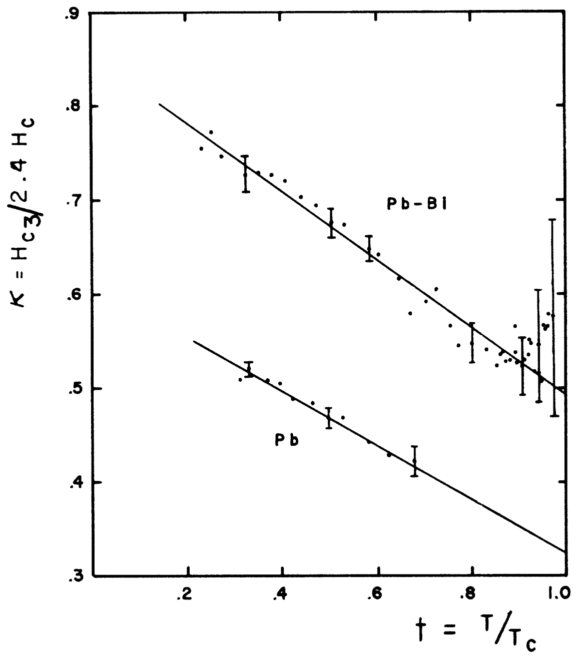

FIG. 1. Temperature variation of the Ginzburg-Landau parameter κ obtained from $H_{c3}/2^{1/2}\,(1.695H_c)$.

face conditions should be comparable. The measuring procedure has been described in Ref. 1. In Fig. 1 we have plotted our values for $\kappa(T)$ and $\kappa_0(T)$. The points have been linearly extrapolated to T_c with the results $\kappa = 0.49 \pm 0.04$ and $\kappa_0 = 0.32 \pm 0.02$. When these values, and the value for the coefficient of the electronic specific heat reported in the literature,[2] are substituted into (1), we obtain $\rho = 0.55 \times 10^{-6}\ \Omega$ cm. Since both κ and κ_0 have been determined from sheath measurements, this resistivity should be appropriate to the surface. We note that it is about three times the bulk value.[1] With this resistivity, we find that our previously calculated value for $(dH_{c3}/dT)|_{T_c}$ should be increased by a factor of 1.27. The net result, if both of the correction factors mentioned above are considered, is that the theoretical slope is now $(dH_{c3}/dT)|_{T_c} = -162$ G/°K.

As a final point we would like to report a small change in the measured slope for our alloy. We have reanalyzed our data for $H_{c3}(T)$ and found that the value $(dH_{c3}/dT)|_{T_c} = -256 \pm 14$ G/°K fits the data somewhat better than our previously reported result.

Having accounted for the difference between the bulk and surface conductivities, we do not feel that possible uncertainties in experimental quantities could account for all the discrepancy between theory and experiment which remains. The disagreement with our data and that obtained for pure Pb would indicate that this theory should be extended to include additional factors which could affect H_{c3}. Possibly an inclusion of the effects of Fermi-surface anisotropy and the details of the surface scattering processes would be the next logical step.

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