CONF-890718--31

LBL-27541

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Materials & Chemical Sciences Division

Presented at the Conference on Materials and Mechanisms of Superconductivity, High-Temperature Superconductors, Stanford, CA, July 23–28, 1989, and to be published in Physica C

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July 1989

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

LBL--27541

DE90 000166

ORIGIN OF THE "LINEAR" TERM IN THE SPECIFIC HEAT OF $YBa_2Cu_3O_7$*

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We report measurements of the specific heat, C, of a number of samples of YBCO, and interpret the results as showing the existence of localized magnetic moments on the YBCO lattice that suppress the transition to the superconducting state. Both the extent of the transition [as measured, for example, by the "jump" in C at T_c, $\Delta C(T_c)$] and the magnitude of the low-temperature "linear" term in C, $\gamma(0)T$, are correlated with the concentration of these moments in the way expected for pair-breaking centers: $\gamma(0)$ increases and $\Delta C(T_c)/T_c$ decreases, both linearly, with increasing moment concentration. The contribution to $\gamma(0)$ associated with these pair-breaking centers, together with that previously recognized as arising from impurity phases, accounts completely for the observed $\gamma(0)$. We are not aware of other results that are inconsistent with these correlations, and conclude that there is no contribution to $\gamma(0)$ that is an intrinsic property of the superconducting state in YBCO.

There is reliable evidence that impurity phases which contain Cu^{2+} moments that order near 10K, most notably $BaCuO_2$, contribute both to the high temperature susceptibility, χ, and to the zero field "linear" term, $\gamma(0)T$, in the low temperature specific heat of YBCO.[1] However, the experimental correlation between $\gamma(0)$ and χ, when combined with the fact that $\gamma(0)$ is rarely found to be $< \sim 4 mJ/mole \cdot K^2$, suggests there is a contribution to $\gamma(0)$ which is intrinsic to the superconducting state.

Most YBCO samples show an upturn in C/T at low temperatures which is converted to a Schottky-like anomaly by the application of a magnetic field.[2] These effects are evidence for Cu^{2+} moments which order below 1K in zero field. In the following we show evidence that these moments are located in the YBCO lattice and provide a pair-breaking mechanism that suppresses the superconducting transition, simultaneously reducing $\Delta C(T_c)$ and increasing $\gamma(0)$. The sum of this contribution to $\gamma(0)$ and that from impurity phases accounts completely for the observed value of $\gamma(0)$ and leads to the conclusion that there is no contribution intrinsic to the superconducting state. Nevertheless, allowing for the possibility of such an intrinsic contribution, γ_o, we write, $\gamma(0)=\gamma_o+n_1\gamma_1+n_2\gamma_2$, γ_1 and γ_2 are the molal contributions to $\gamma(0)$ due to the impurity phase and to the Cu^{2+} moments in the YBCO lattice, and n_1 and n_2 are the number of moles of impurity phase and lattice moments, respectively. n_2 can be determined from the Schottky peak, and $n=n_1+n_2$ from the high temperature

*Supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Sciences Division of the U.S. Dept. of Energy under Contract DE-AC03-76SF00098, and by an EXXON Education Grant from the Research Corporation.

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measurements. A statistical analysis of the data on a number of YBCO samples gives $\gamma_o = 0.1 \pm 0.8$ mJ/K^2•mole, thereby indicating that superconducting YBCO has no intrinsic linear term. The analysis also gives $\gamma_1 = 106$ and $\gamma_2 = 1370$ mJ/K^2•mole. Fig. 1 shows plots of $\gamma(0)$ and its components, $n_1\gamma_1$ and $n_2\gamma_2$ versus n, n_1, and n_2, respectively. The $\gamma(0)$ points have an rms deviation of 34% from the straight-line fit with non-zero intercept, while the other two plots have rms deviations of 14% from lines which pass through the origin.

The fraction of superconducting material can be inferred from the specific heat in various ways. Fig. 2 demonstrates the consistency of $\Delta C(T_c)/T_c$ with two other such measures, ΔS and $d\gamma/dH$. Fig. 3 shows the dependence of $\Delta C(T_c)/T_c$ and $n_2\gamma_2$ on n_2. The decrease of $\Delta C(T_c)$ and the increase of $\gamma(0)$ (as manifested in the change of $n_2\gamma_2$ with n_2) are signatures of the operation of a pair-breaking mechanism, which provides a physical basis for understanding the n_2-dependent contribution to $\gamma(0)$. Extrapolation of $\gamma_2 n_2$ to the value of n_2 at which $\Delta C(T_c)$ goes to zero provides an estimate of the normal-state value of γ, $\gamma = 14$mJ/K^2•mole. Together with the maximum value of $\Delta C(T_c)/T_c$, its value at $n_2 = 0$, this gives $\Delta C(T_c)/\gamma T_c = 6$ for the fully superconducting state. That ratio is substantially larger than the BCS weak-coupling limit, 1.43, and provides a measure of strong-coupling effects.

REFERENCES

1. A.P. Ramirez, et al. Mater. Res. Soc. Symp. 99 (1987) 459. R. Kuentzler, et al., Solid State Commun. 65 (1988) 1529. D. Eckert, et al., J. Low Temp. Phys. 73 (1988) 241.

2. R.A. Fisher et al., J. Superconductivity 1 (1988) 231.

3. C.-S. Jee, J. Superconductivity 1 (1988) 63.

FIGURE CAPTIONS

Fig. 1. $\gamma(0)$, $n_1\gamma_1$, and $n_2\gamma_2$ [$\gamma(0) = n_1\gamma_1 + n_2\gamma_2$] vs. $n = n_1 + n_2$, n_1, and n_2, respectively. The straight lines represent least-squares fits.

Fig. 2. Intercomparison of three measures of the fraction of superconducting material: ΔS, $d\gamma/dH$, and $\Delta C(T_c)/T_c$. $\Delta S = \int_{T'}^{T_c} [C(H=0) - C(7T)]/T \, dT$, where T′ is the temperature at which C(H=0) = C(7T). $d\gamma/dH$ is the field derivative of $\gamma(H)$ in the mixed state. The straight lines represent least-squares fits.

Fig. 3. $\Delta C(T_c)/T_c$ and $n_2\gamma_2$ vs. n_2. The straight lines represent least-squares fits. $\Delta C(T_c)/T_c = 84(1-59n_2)$, $\gamma_2 = 1370$, $\gamma_1 = 106$ mJ/K^2•mole.

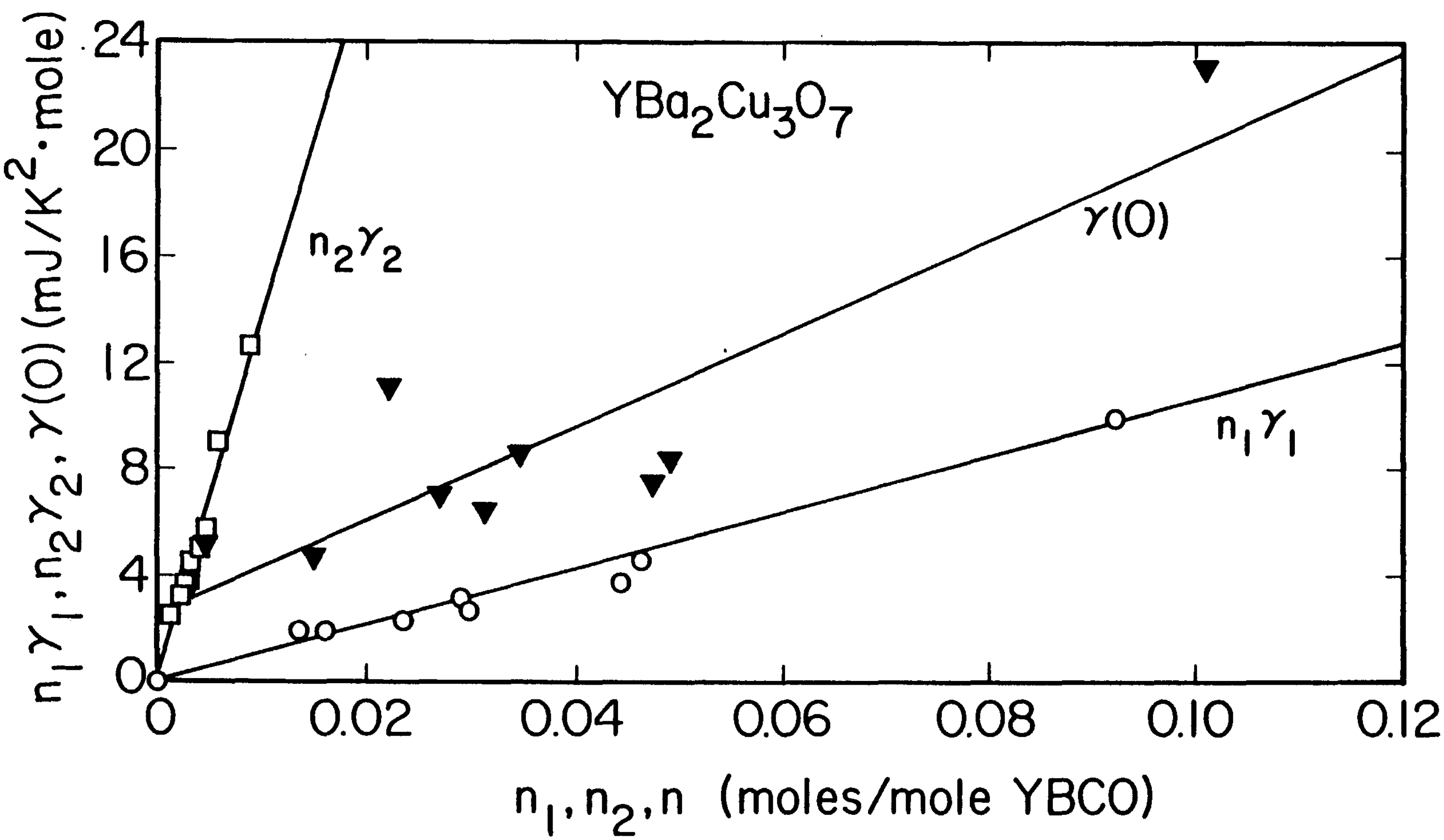

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FIG 1

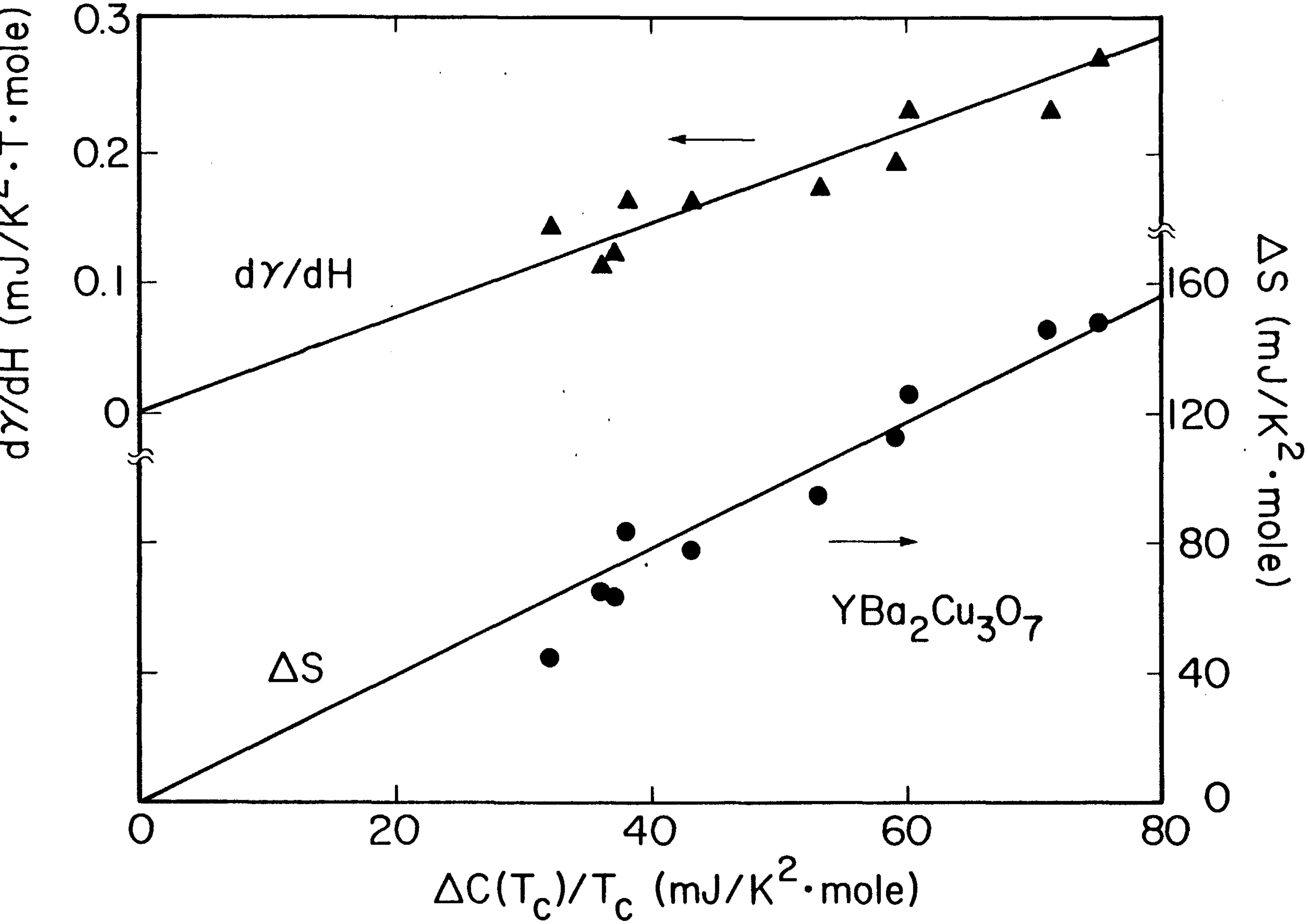

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FIG 2

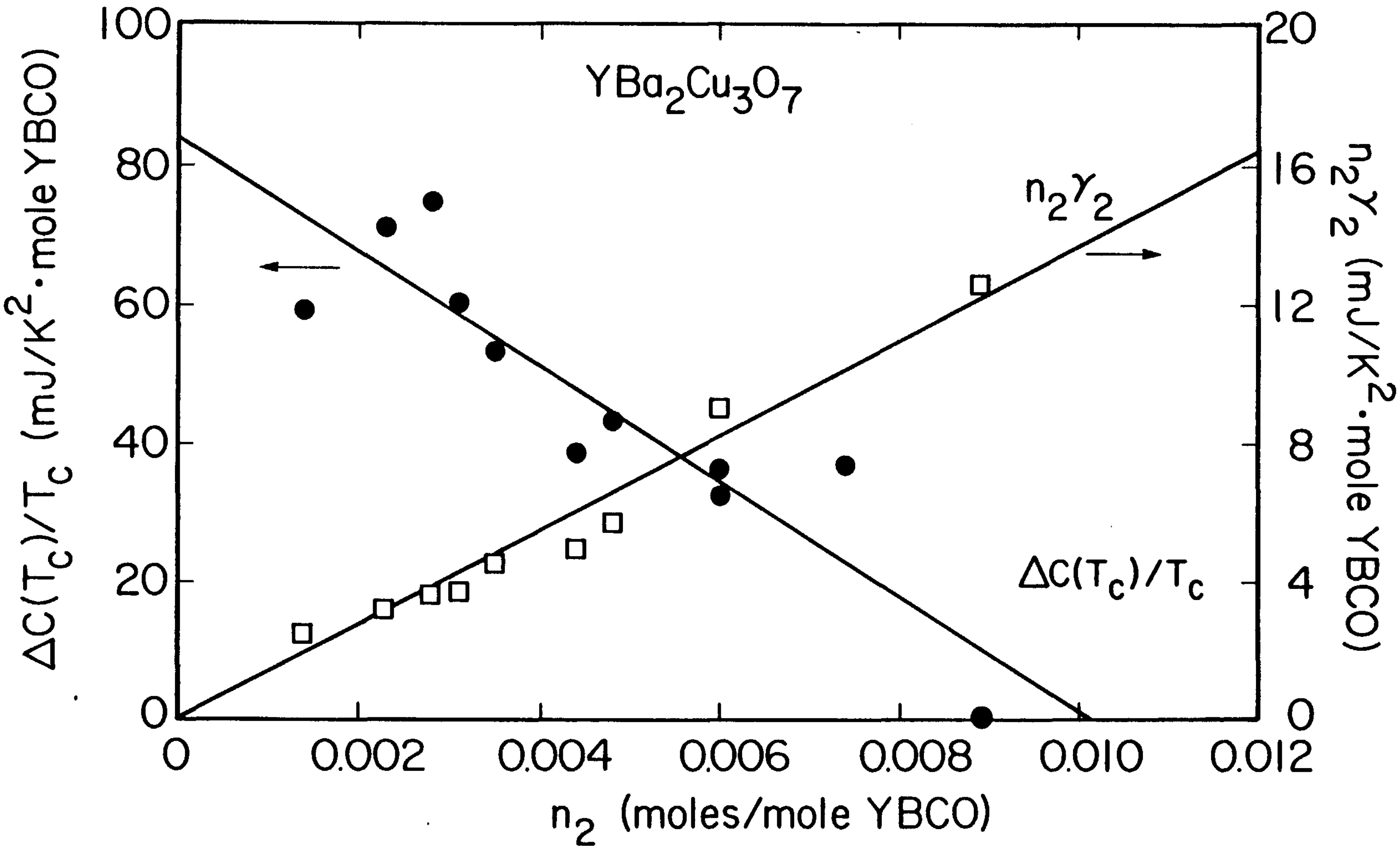

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FIG 3