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**SPECIFIC HEAT EVIDENCE FOR STRONG
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Specific Heat Evidence for Strong Coupling in $\text{YBa}_2\text{Cu}_3\text{O}_7$

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Specific heat data for $\text{YBa}_2\text{Cu}_3\text{O}_7$ are consistent with $\gamma = 15 \pm 3 \text{ mJ/mole}\cdot\text{K}^2$ and $2\Delta_0/kT_c = 6.8 \pm 0.6$. These results indicate that strong-coupling effects are present but that the coupling is unlikely to be predominantly a conventional electron-phonon interaction.

In this note an interpretation of specific heat, C , measurements on $\text{YBa}_2\text{Cu}_3\text{O}_7$ is applied to an analysis of data in the vicinity of T_c to obtain information about the strength of the coupling responsible for the superconductivity. Correlations among several sample-dependent parameters have been interpreted (Phillips et al 1990) as showing that typical samples are only 30-90% superconducting; that the volume fraction of superconductivity, f_s , can be determined from the discontinuity, $\Delta C(T_c)$, at the critical temperature, T_c ; and that the Sommerfeld constant for the fully normal state, γ , is $16 \text{ mJ/mole}\cdot\text{K}^2$, a value close to that calculated (Massidda et al 1987; Krakauer et al 1988) for the bare density of states, γ_{bs} , indicating that electron-phonon enhancement effects are not significant. Thus, if electron-phonon coupling is responsible for the superconductivity, $\text{YBa}_2\text{Cu}_3\text{O}_7$ should be a weakly-coupled BCS superconductor with $\beta = \Delta C(T_c)/\gamma T_c = 1.43$. However, such a conclusion is clearly at odds with $\gamma \sim 16 \text{ mJ/mole}\cdot\text{K}^2$ and the measured values of $\Delta C(T_c)$.

Figure 1 shows C/T vs T for a $\text{YBa}_2\text{Cu}_3\text{O}_7$ sample made by the citrate pyrolysis technique. An entropy-conserving construction gives $\Delta C(T_c)/T_c = 64 \text{ mJ/mole}\cdot\text{K}^2$, -83% of the value expected for a fully superconducting sample (Phillips et al 1990; see also Junod et al 1990), i.e., $f_s = 0.83$. With $\gamma = 16 \text{ mJ/mole}\cdot\text{K}^2$ and $\beta = \Delta C(T_c)/f_s \gamma T_c = 5.5$ -- almost 4 times the BCS weak-coupling value and clearly indicative of strong-coupling. The dotted and solid curves in Fig. 1 represent, respectively, approximations to C_n and C_s , the normal- and the 83%-superconducting-state values of C . $C_n = C_l + \gamma T$, where C_l , the lattice contribution, is assumed to consist of dilatation and harmonic terms. C_n was obtained by interpolation between the data above 96K and the data in the region 62-65K, the region expected to include the temperature, T_x , at which $C_s = C_n$. Over this interpolation interval the

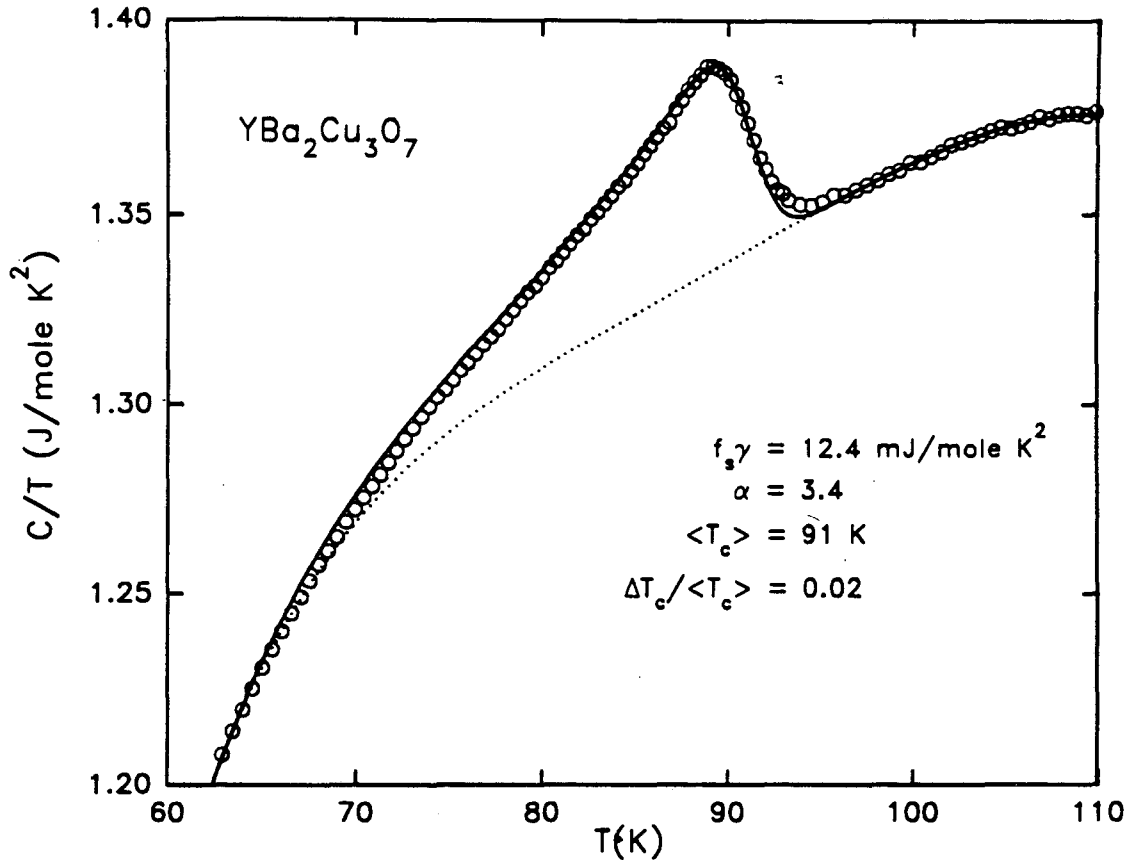


Figure 1. C/T vs T . See text for discussion.

harmonic lattice term can be adequately represented by a polynomial in T , by an expansion of the form described by Gordon et al (1989), or by a superposition of Einstein terms. The solid curve is given by $C_s = C_l + f_s C_{es} + (1-f_s)\gamma T$, where C_{es} is the fully-superconducting-state electronic C , and has been calculated by assuming a Gaussian distribution of transition temperatures centered on $\langle T_c \rangle$ with a width ΔT_c . It is also assumed that the superconducting state can be described by the " α model" (Padamsee et al 1973) in which the gap in the density of states is related to the BCS gap by the factor $\alpha/1.764$. Application of this model involves two adjustable parameters: α which determines the shape of the anomaly, and $f_s \gamma$ which determines the amplitude. The solid curve corresponds to $\langle T_c \rangle = 91\text{K}$, $\Delta T_c / \langle T_c \rangle = 0.02$, $\alpha = 3.4$, and $f_s \gamma = 12.4 \text{ mJ/mole}\cdot\text{K}^2$, and results in $\Delta C(T_c) / \gamma T_c = 5.3$ and $T_x = 63\text{K}$. The inclusion of a small fluctuation contribution that lowers $f_s \gamma$ to $12 \text{ mJ/mole}\cdot\text{K}^2$ would slightly improve the fit in the region near 93K , but is not essential. As required by thermodynamics, the area between the data and the dotted curve in the temperature region $63 \leq T \leq 96\text{K}$ is equal to the entropy difference between the normal and superconducting states at T_x . (For this comparison, the normal-state value was taken as γT_x and the superconducting-state value was

calculated using the α model.) The results of the fitting procedure are not unique. Reasonably good fits to the data can be obtained with other choices for $f_s \gamma$ and α (but $\langle T_c \rangle$ and ΔT_c remain essentially the same). We conclude that the data are consistent with the values $f_s \gamma = 12.4 \pm 3$ mJ/mole $\cdot K^2$ and $\alpha = 3.4 \pm 0.3$. With $f_s = 0.83$, this range in $f_s \gamma$ corresponds to $\gamma = 15 \pm 3$ mJ/mole $\cdot K^2$, in agreement with the value 16 mJ/mole $\cdot K^2$ obtained on the basis of other considerations (Phillips et al 1990). The values of α consistent with the data are twice the weak-coupled BCS value. They correspond to a gap ratio $2\Delta_0/kT_c = 6.8 \pm 0.6$, in agreement with other measurements (see, eg., Batlogg 1990) and, when combined with the result $\gamma - \gamma_{bs}$, imply that the conventional electron-phonon interaction cannot be solely responsible for the superconductivity.

The principal uncertainty in the conclusions derives from uncertainty in C_n , the "background" C on which the analysis is based. Loram and Mirza (1988) have also used the α model to obtain similar values for γ and α . They made differential C measurements with quenched non-superconducting $YBa_2Cu_3O_7$ as the reference. In that case there are uncertainties in the correction to C_l (comparable to those in C_n in this work), and there are also uncertainties in the interpretation of the several linear terms that occur in the data.

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References

- Batlogg B 1990 Proc. Los Alamos Symp. on HTSC -1989 eds K S Bedell et al (Redwood City: Addison-Wesley) pp 37-93
 Gordon J E et al 1989 Solid State Commun 69 625 and erratum Solid State Commun, to be published
 Junod A et al 1989 Physica C162 1401
 Krakauer H et al 1988 J. Superconductivity 1 111
 Loram J W and K A Mirza 1988 Physica C153-155 1020
 Massidda A et al 1987 Phys. Lett. A122 198
 Padamsee H et al 1973 J. Low Temp. Phys. 12 387
 Phillips N E et al 1990 Phys. Rev. Lett. 65 357

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