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### Title

SPECIFIC HEAT OF THE HIGH-T<sub>C</sub> YBA<sub>2</sub> (CU<sub>3-X</sub> M<sub>X</sub>)O<sub>7</sub> WITH M = CR OR ZN

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To be 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

### Specific Heat of the High- $T_c$ $\text{YBa}_2(\text{Cu}_{3-x}\text{M}_x)\text{O}_7$ with $M = \text{Cr}$ or $\text{Zn}$

S. Kim, R.A. Fisher, N.E. Phillips, and J.E. Gordon

June 1989

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SPECIFIC HEAT OF HIGH- $T_c$   $\text{YBa}_2(\text{Cu}_{3-x}\text{M}_x)\text{O}_7$  WITH M=Cr OR Zn

S. KIM\*, R. A. FISHER\*, N. E. PHILLIPS\* and J. E. GORDON\*<sup>†</sup>

\*Materials and Chemical Sciences Division, LBL, University of California, Berkeley, CA 94720, USA; <sup>†</sup>Physics Department, Amherst College, Amherst, MA 01002, USA

The effects of substitution of Cr and Zn for Cu in YBCO have been studied calorimetrically and by magnetic measurements. There is a qualitative correlation between the suppression of the superconducting transition and an increase in the concentration of localized moments in both cases.

$T_c$  for  $\text{YBa}_2\text{Cu}_3\text{O}_7$  (YBCO) decreases when 3-d elements are substituted for Cu. Zn probably randomly occupies both chain and plane sites,<sup>1</sup> while Cr probably substitutes only in chain sites.<sup>2</sup> Table 1 lists derived properties, and Ref. 3 gives references to previous measurements of specific heat (C) on doped YBCO.

Figure 1 shows  $T_c$  (onset),  $\Delta T_c$  and  $-4\pi\chi_v$  determined from field-cooled susceptibility ( $\chi$ ) measurements. The localized moment fraction [ $n_1(\chi)$ ] was determined from a fit of  $\chi$  above  $T_c$  by a Curie-Weiss law with  $S=1/2$  and  $g=2$ . C data for  $H=0$  are plotted in Fig. 2, and fitted by:  $C=A_{-2}T^{-2}+\gamma(0)T+B_3T^3+B_5T^5$ . The  $H=0$  C/T upturns (probably caused by the onset of magnetic ordering of localized moments) become Schottky anomalies in 7T as shown in Fig. 3. The localized moment fraction [ $n_1(C)$ ] was evaluated from the entropy associated with the anomaly, with  $S=1/2$ .  $n_1(\chi)$  is always greater than  $n_1(C)$  which implies some entropy loss for  $T>30\text{K}$ . C/T near  $T_c$  is displayed in Fig. 4, where the solid line represents the normal state C from a harmonic lattice fit<sup>4</sup> to C data above  $T_c$ .

As  $x$  increases, for both Cr- and Zn-doping,  $T_c$ ,  $-4\pi\chi_v$ ,  $\Delta C(T_c)/T_c$ ,  $\gamma$  and  $d\gamma/dH$  decrease;  $\Delta T_c$ ,  $n_1(C)$ ,  $\gamma(0)$  and  $B_5$  increase; and  $n_1(\chi)$  and  $A_{-2}(H=0)$  increase, but not monotonically in the case of Zn-doping. (Any simple relation between  $n_1(C)$ ,  $n_1(\chi)$  and the superconducting transition is presumably obscured by variations in the amounts of magnetic impurity phases.)  $B_3$  increases for Cr-doping and decreases for Zn-doping. The  $A_{-2}(7\text{T})$  term is from hyperfine interactions for Cu, which for increasing  $x$  approach the theoretical 0.47, perhaps because of decreasing relaxation times associated with increasing localized moments induced by doping.

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of Basic Energy Sciences, Division of Materials Sciences of the U.S.  
Department of Energy under Contract DE-AC03-76SF00098. J.E.G. thanks the  
Research Corporation for an EXXON Education Grant.

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2. G. Xiao et al., Phys. Rev. B35 (1987) 8782.
3. R. A. Fisher et al., J. Superconductivity 1 (1988) 272.
4. J. E. Gordon et al., Solid State Commun. 69 (1988) 625.

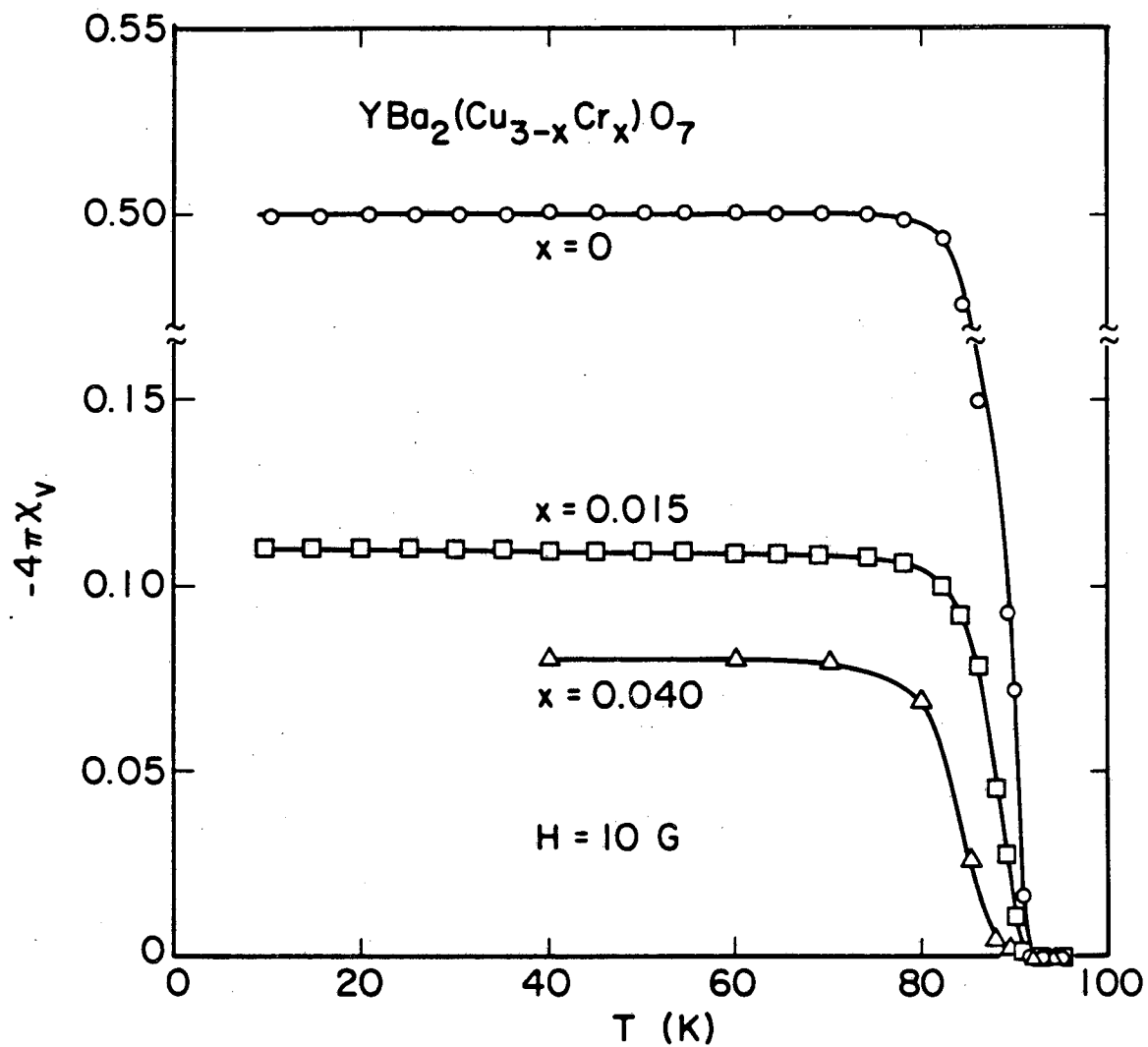
TABLE 1. Properties of  $\text{YBa}_2(\text{Cu}_{3-x}\text{M}_x)\text{O}_7$  for  $\text{M}=\text{Cr}$  or  $\text{Zn}$ . Units are mJ, K, mole and  $T_c$ , and % is mole% referred to a formula unit.

	Cr: $dT_c/dx\% = -0.5$			Zn: $dT_c/dx\% = -1.1$		
x%	0	1.5	4.0	0	3.0	15
$T_c$ (onset)	92	91	90	91	89	75
$\Delta T_c$	5	6	13	3	4	17
$-4\pi\chi_V$	0.50	0.11	0.08	0.17	0.17	0.05
$n_i(\chi)\%$	2.7	7.6	7.8	3.7	2.2	10.1
$n_i(\text{C})\%$	0.35	0.75	1.4	0.48	0.60	0.89
$A_{-2}(\text{H}=0)$	45	97	207	58	34	109
$A_{-2}(7\text{T})$	0.20	0.25	0.32	0.25	0.36	0.45
$B_3 \times 10^1$	2.64	3.10	3.11	2.68	2.10	2.01
$B_5 \times 10^3$	1.1	1.2	1.4	1.1	1.6	1.9
$\theta_0$	457	434	433	455	494	500
$\gamma(0)$	7.0	8.8	9.5	8.6	11	23
$\Delta C(T_c)/T_c$	47	27	0	39	26	0
$\gamma(\beta=1.43)$	33	19	0	27	18	0
$d\gamma/dH$	0.17	0.17	0.16	0.16	0.14	0

FIGURE CAPTIONS

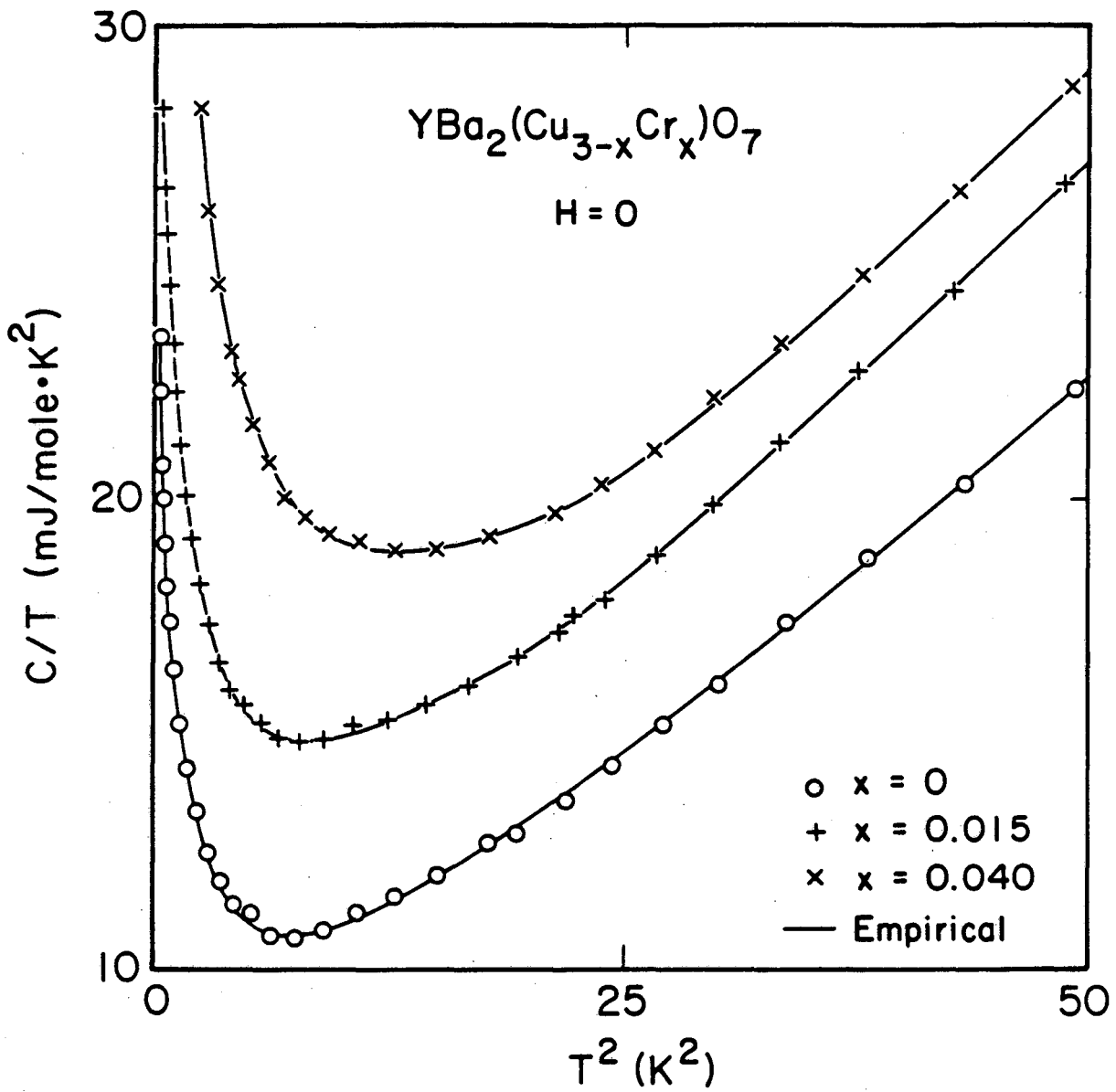
1. Meissner fraction vs T for  $\text{YBa}_2(\text{Cu}_{3-x}\text{Cr}_x)\text{O}_7$ .
2.  $C/T$  vs  $T^2$  in the low-temperature region.
3. C minus hyperfine, electronic and lattice terms.
4. Effect of Cr-doping on  $\Delta C(T_c)/T_c$ .





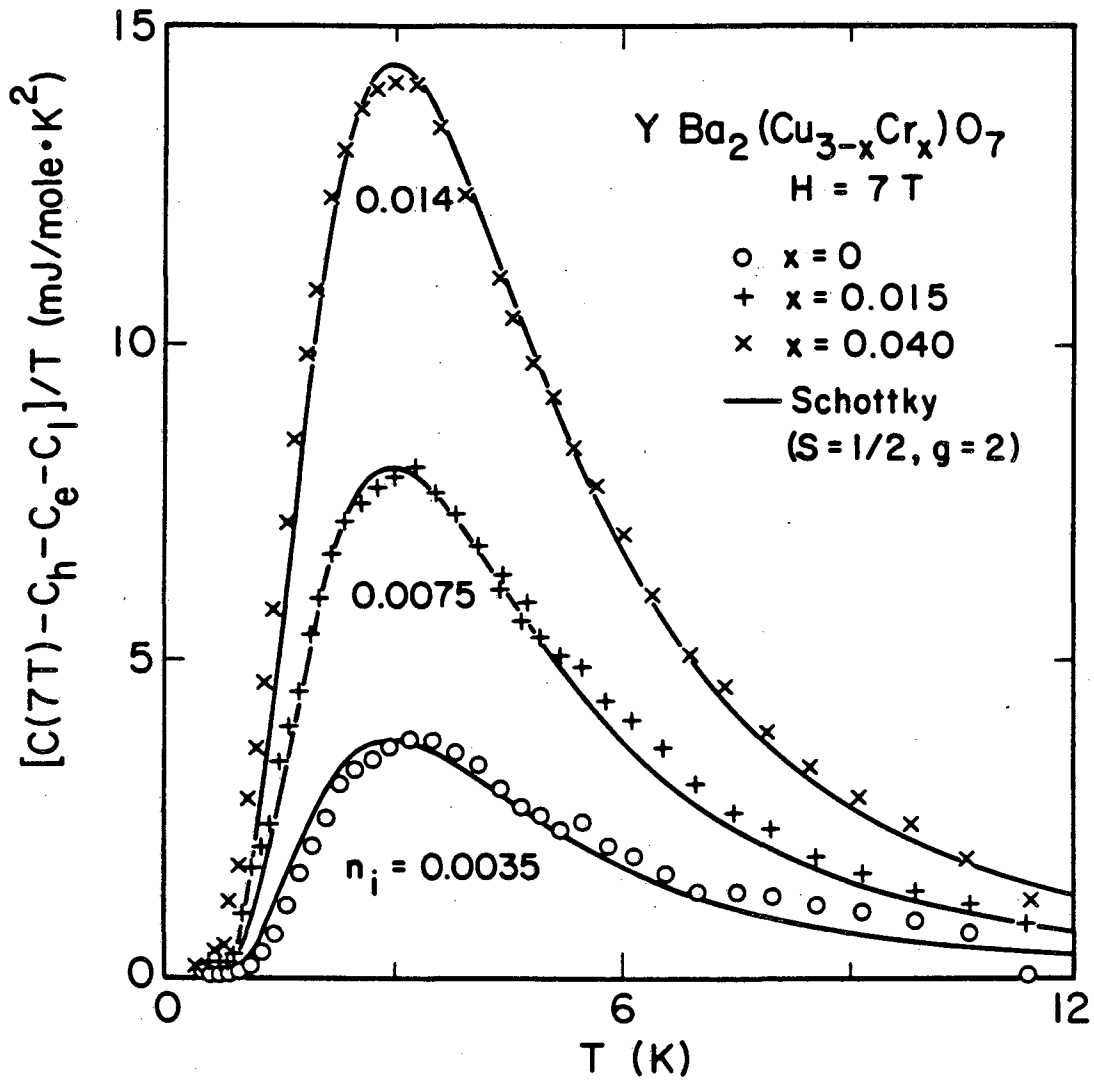
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Fig. 1



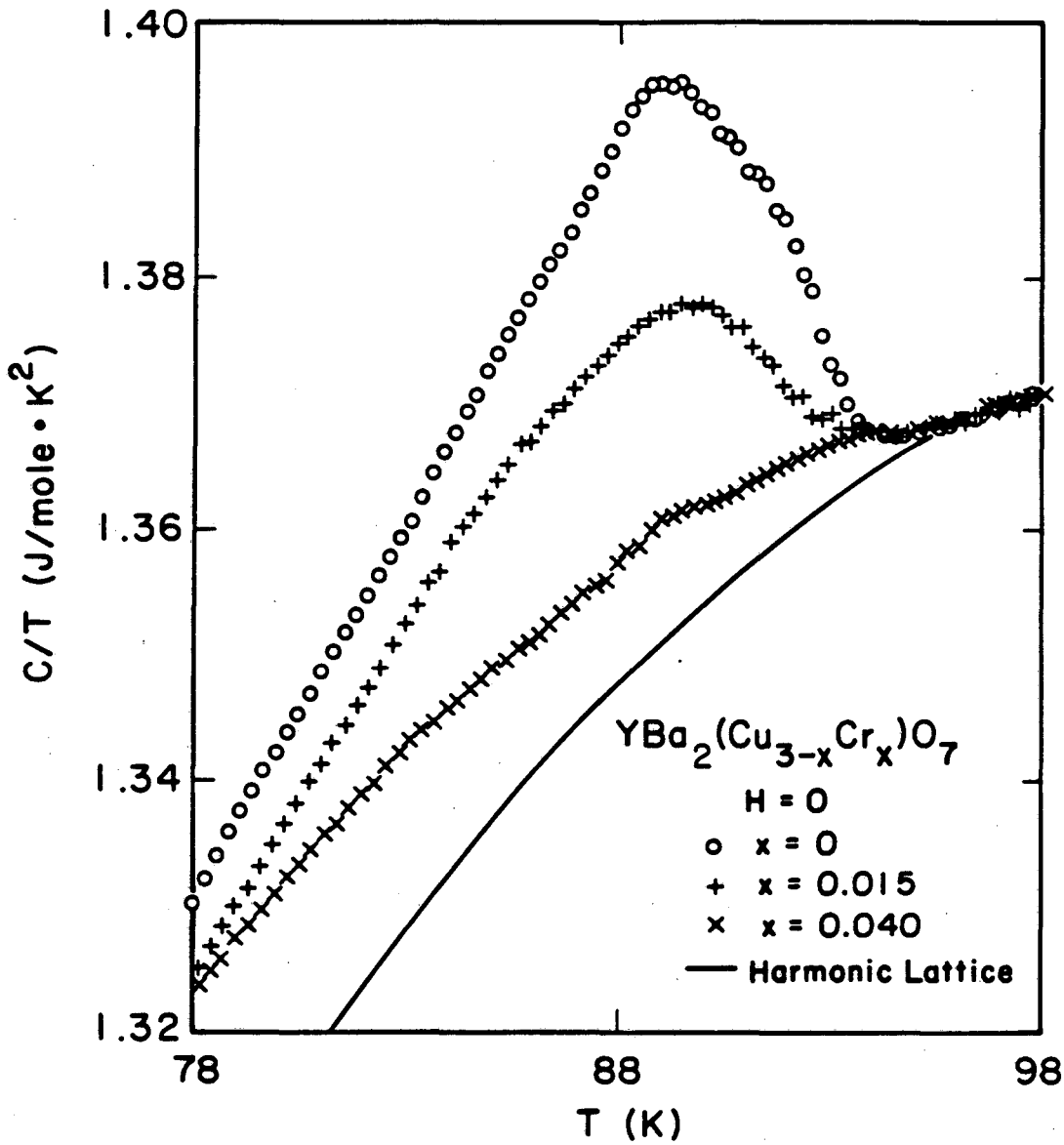
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Fig. 2



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Fig. 3



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Fig. 4

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Dear Mr. [Name],  
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I am sorry that I cannot give you a more definite answer at this time.  
The matter is still under consideration and I will write you again as soon as I have a final decision.  
I am sure you will understand my position.  
Very truly yours,  
[Signature]

Very truly yours,  
[Signature]

Very truly yours,  
[Signature]

The first part of the document discusses the importance of maintaining accurate records of all transactions. It emphasizes that every entry should be supported by a valid receipt or invoice. This ensures transparency and allows for easy verification of the data.

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The final section provides a summary of the key findings and recommendations. It reiterates the importance of a well-structured and transparent system for long-term success. The document concludes by expressing confidence in the proposed solution and its potential to improve the overall operational efficiency.



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### Lattice and Electronic Specific Heat of $YBa_2Cu_3O_7$

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June 1989

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LATTICE AND ELECTRONIC SPECIFIC HEAT OF  $\text{YBa}_2\text{Cu}_3\text{O}_7^*$

J.E. GORDON<sup>†</sup>, R.A. FISHER, S. KIM, and N.E. PHILLIPS

Materials and Chemical Sciences Division, Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720, USA.

We report specific heat measurements on  $\text{YBa}_2\text{Cu}_3\text{O}_7$  (YBCO) from 78 to 284K. The higher temperature data are well-represented as the sum of a term proportional to  $T$  and a harmonic lattice contribution. These data show no evidence of an anomaly in the temperature region 200-230K. The data near  $T_c$  are consistent with the specific heat of a BCS superconductor that has a contribution from 3-dimensional Gaussian fluctuations.

Specific heat ( $C$ ) measurements on a 1.9g YBCO sample prepared by the citrate pyrolysis method have been made from 78 to 284K both by conventional heat pulse (HP) techniques and by a continuous heating (CH) method. Fig. 1a shows a plot of every other HP point as well as a curve that represents a fit to all of the data above 110K by the sum of a term proportional to temperature and a harmonic lattice contribution.<sup>1</sup>

A partial motivation for making these measurements was to seek evidence for a specific heat anomaly reported at  $\sim 215\text{K}$ .<sup>2</sup> In Fig. 1b the HP data between 200 and 230K are shown along with a fit to the data obtained by including all points above 110K except for those between 200 and 230K. As Fig. 1b indicates, the results show that any anomaly in the specific heat of this sample is substantially smaller than that reported earlier. The CH data have less scatter but slightly larger systematic uncertainties, and also fail to show anomalous behavior in this temperature region.

Fig. 2a shows both the HP and some of the CH data in the vicinity of  $T_c$  (89.4K). Well away from the peak, the two sets of measurements agree to  $\sim 0.1\%$ . However, near the peak the CH data (heating rate  $\sim 6.5$  mK/sec) show a marked rounding. It is possible that this rounding is evidence of long relaxation

effects near  $T_c$ , but further experimental work is necessary before such a conclusion can be made with confidence. Fig. 2b shows the HP data along with an extrapolation of the fit made to the data above 110K. This fitted curve, when extended to 60K, and when corrected by a BCS electronic specific heat contribution<sup>1</sup>, passes through specific heat data obtained on a 20 g sample made from the same batch of material as the 1.9 g sample.

Figure 3 is a plot of  $C/T$  vs.  $T$ , where  $\Delta C = C(\text{measured}) - C(\text{fit})$ . The continuous curve in Fig. 3 represents a BCS superconductor with  $T_c = 89.38\text{K}$ ;  $\gamma = 41 \text{ mJ/mole K}^2$ ; and with an added 3D Gaussian fluctuation contribution  $C(\text{fluctuation}) = A^\pm / |T/T_c - 1|^{1/2}$ . The values of  $A^+$  ( $T > T_c$ ) and  $A^-$  ( $T < T_c$ ) are 0.51 and 0.24 J/mole K, respectively. The ratio  $A^+/A^-$  is similar to that reported<sup>3</sup> for a YBCO single crystal, but the values of  $A^+$  and  $A^-$  are larger, corresponding approximately to the difference in the values of  $\Delta C(T_c)$  and, presumably, to differences in the fractions of the samples that are superconducting.

It is interesting to note that the width of the transition in this polycrystalline sample can be accounted for entirely by fluctuation effects -- sample inhomogeneity does not appear to make a significant contribution.

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\*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, by an EXXON Education Grant from the Research Corporation, and by an Amherst College Research Award.

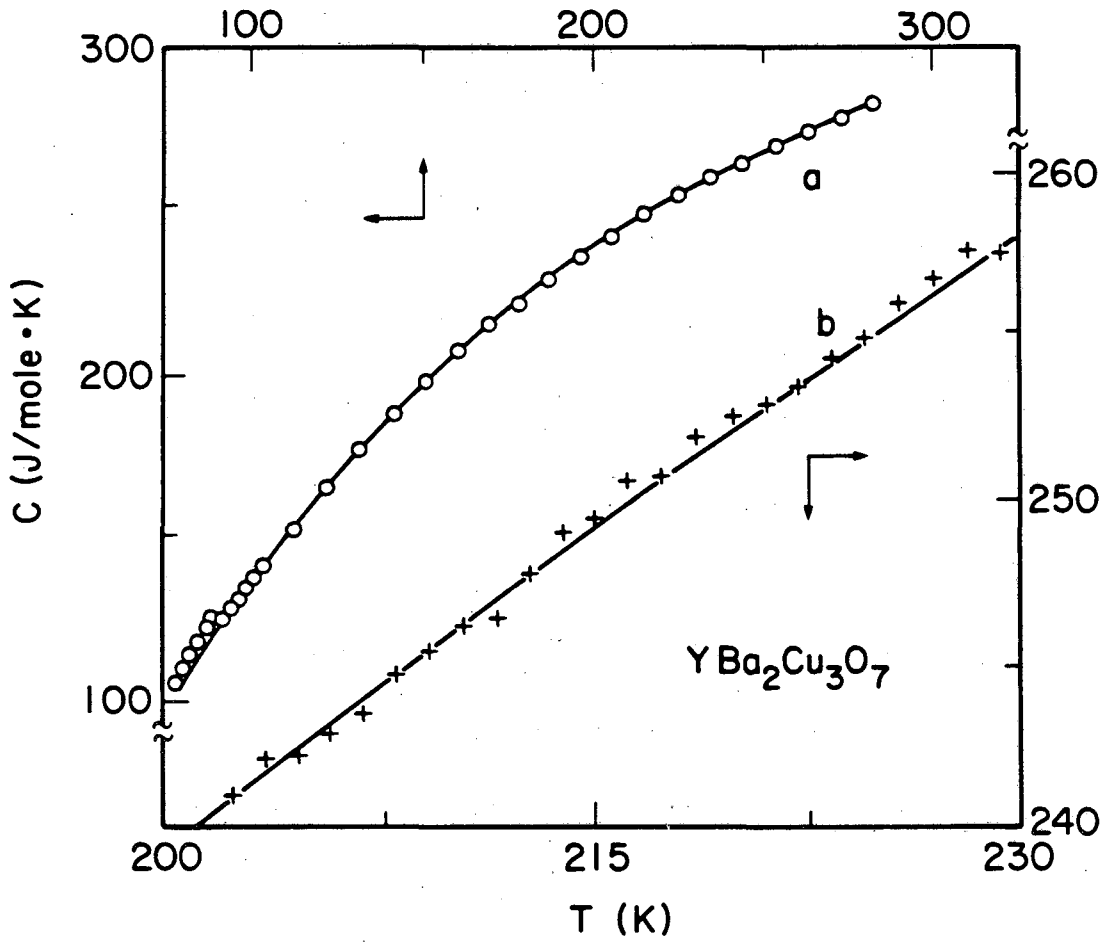
+Permanent address: Physics Dept., Amherst College, Amherst, MA 01002, USA.

## FIGURE CAPTIONS

FIGURE 1. a) Molar specific heat of YBCO between 78 and 284K. The smooth curve is a fit to the data. b) Enlarged view of the data between 200-230K. See text for discussion.

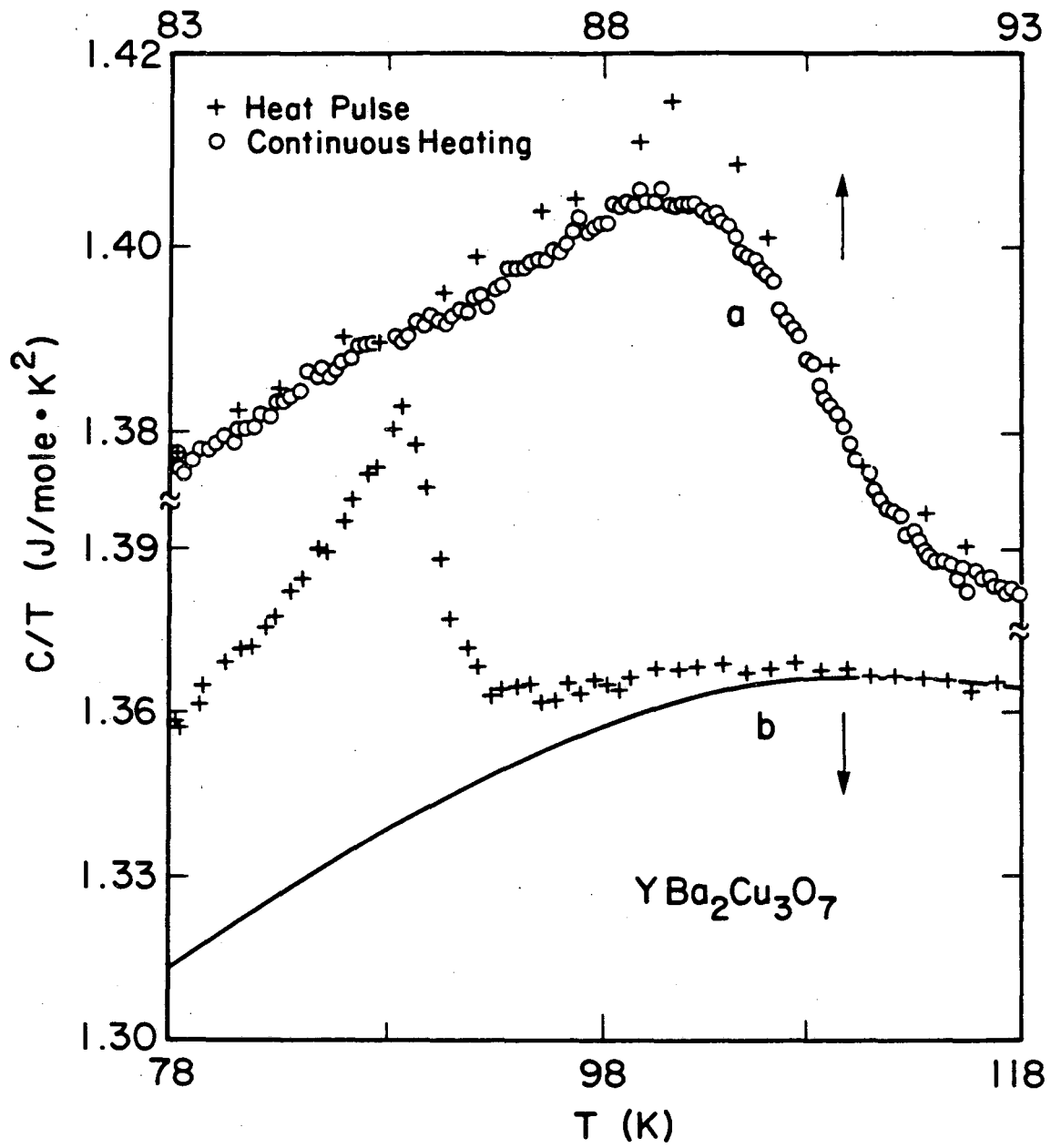
FIGURE 2. a)  $C/T$  vs.  $T$  near  $T_c$  for both heat pulse (+) and continuous heating (0) data. b) Heat pulse data and extrapolation of the fit to the higher temperature data.

FIGURE 3.  $\{C(\text{measured}) - C(\text{fit})\}/T$  near  $T_c$ . The curve represents the sum of BCS and 3D Gaussian fluctuation contributions.



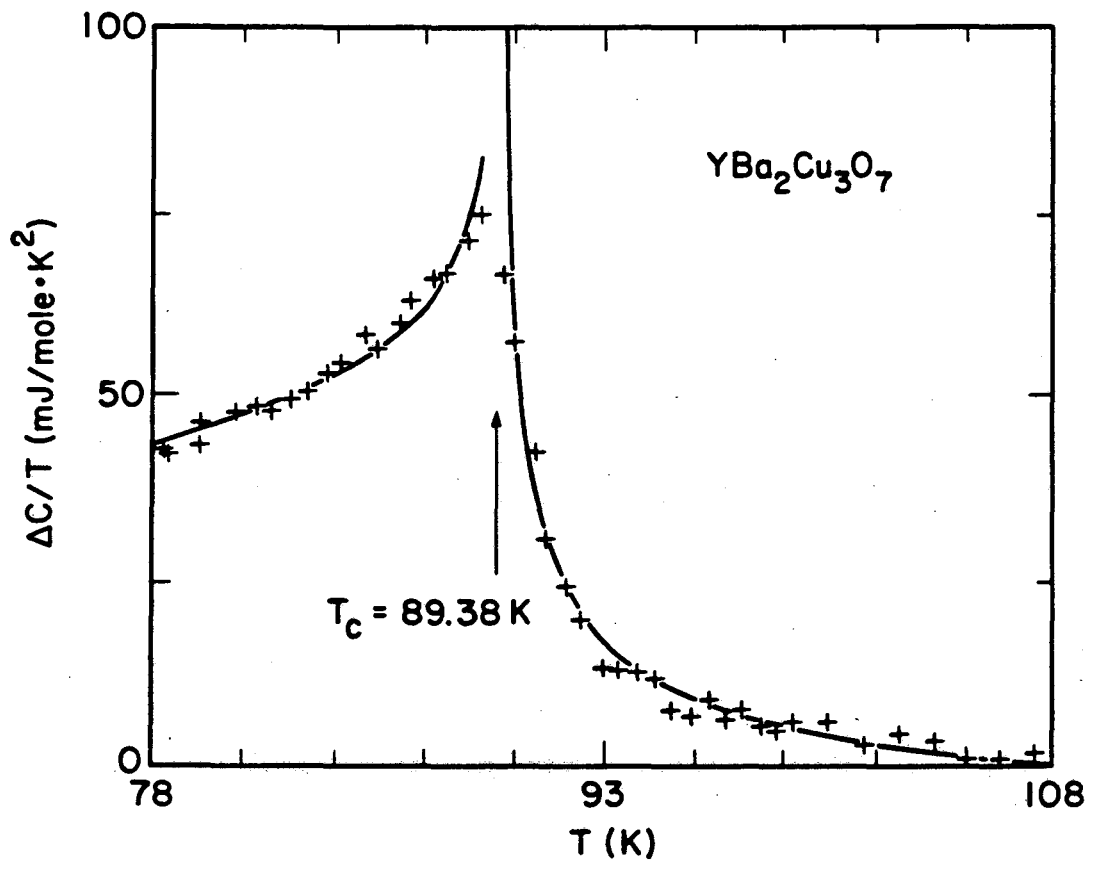
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Fig. 1



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Fig. 2



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Fig. 3





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