Heat capacity of high-temperature superconductor $YBa_2Cu_3O_{7-x}$

N. E. Alekseevskiĭ,[1)] A. V. Gusev, G. G. Devyatykh, A. V. Kabanov, A. V. Mitin, V. I. Nizhankovskiĭ,[1)] and E. P. Khlybov
Institute of Chemistry, Academy of Sciences of the USSR

(Submitted 16 November 1987)
Pis'ma Zh. Eksp. Teor. Fiz. **47**, No. 3, 139–141 (10 February 1988)

The heat capacity of the superconductor $YBa_2Cu_3O_{7-x}$ has been measured. Two anomalies have been observed on the temperature dependence of the heat capacity. One of these anomalies, which occurs at $T < 9$ K, is characteristic for the Schottky-type heat capacity and the other one corresponds to the superconducting transition.

In this letter we present data on the study of the heat capacity of an oxide superconductor $YBa_2Cu_3O_{7-x}$. The samples were prepared through solid-state reaction.[1,2] The measurements were carried out over a broad temperature range using a $YBa_2Cu_3O_{7-x}$ sample 14 mm long, 8.6 mm in diameter, and 4.6 g in mass. We used two setups for the measurements. In the temperature interval 2–15 K we used a calorimeter with a mechanical thermal switch. The basic design of the calorimeter and the measurement procedure are similar to those used in Ref. 3. A setup described in Ref. 4 was used for the measurements at higher temperatures. Platinum and germanium resistance thermometers were used as temperature sensors. The measurement error, determined from the measurement of the heat capacity of the standard copper samples, was less than 1.5% in the temperature interval 2–15 K and no greater than 0.2% at higher temperatures.

It is pertinent to note that the plot of the heat capacity versus the temperature of the system $YBa_2Cu_3O_{7-x}$ exhibits two characteristic features, one of which manifests itself at $T < 9$ K and the other is seen near the superconducting transition temperature. At $T < 9$ K (Fig. 1) the temperature dependence of the heat capacity $d(C/T)/dT$ decreases markedly as the temperature is lowered and at $T < 4.2$ K it becomes negative. If the temperature dependence of the heat capacity is analyzed in the usual manner,[2)] it can then be described quite accurately ($\delta < 4\%$) in the temperature region $T < 9$ K by the equation

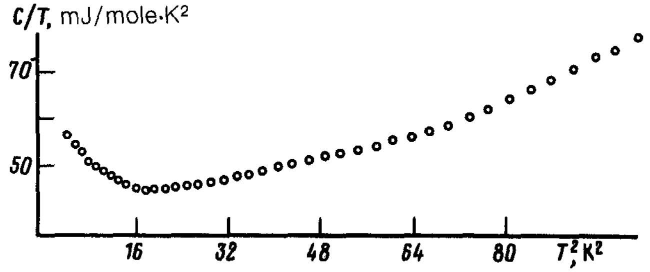

FIG. 1. The dependence C/T plotted as a function of T^2 in the temperature interval 2–15 K.

$$C = \frac{A}{T^2} + \gamma T + aT^3 + bT^5,$$

where

$$A = 245\ \frac{\text{mJ}\cdot\text{K}}{\text{mole}}, \qquad \gamma = 36,7\ \frac{\text{mJ}}{\text{mole}\cdot\text{K}^2}, \quad a = 0{,}268\ \frac{\text{mJ}}{\text{mole}\cdot\text{K}^4}$$

$$b = 0{,}274\ \frac{\mu\text{J}}{\text{mole}\cdot\text{K}^6}$$

The temperature dependence of the first term is characteristic of the high-temperature limit of the Schottky-type heat capacity. The presence of the term A/T^2 in the heat capacity may be attributable to the magnetic impurities or to the hyperfine splitting of the Y nuclei. It is also quite conceivable that magnetic ordering of the system occurs at lower temperatures. Such anomalous behavior, but on a lower scale, was observed in the system $La_{1.8}Ba_2CuO_y$ (Ref. 7). Assuming that each molecule has 13 atoms, the coefficient of the cubic term of the heat capacity can be used to calculate the Debye temperature $\Theta_0 = 455$ K.

The electronic component and the value of γ in this case are difficult to estimate from the data on the heat capacity. Thus, for example, if the linear dependence $(C/T \propto T^2)$ is extrapolated from the region above T_c, the value γ of will be anomalously large ($\gamma = 1.3$ J/mole$\cdot$K^2). Such a large value of γ may stem either from the fact that the extrapolation from a very high temperature region produces a large error or from the large linear lattice contribution to the heat capacity due to the "quasi-amorphous" state of the sample. The use of the dependence $C/T \propto T^2$ in the superconducting region is not entirely correct. If it is assumed, however, that at T below T_c not

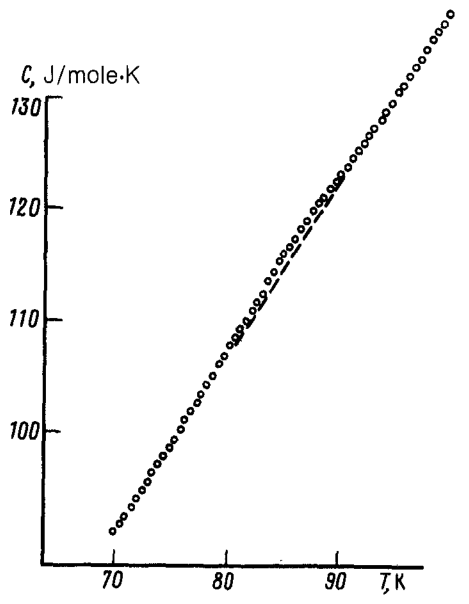

FIG. 2. Temperature dependence of the heat capacity near the transition to the superconducting state.

all electrons undergo a transition to the superconducting state, then γ can be estimated from the relation $C/T \propto T^2$ at $T < T_{C_0}$. The value of γ estimated in this manner is 37 mJ/mole·K^2. This value can be reconciled with the value $\gamma = 40$ mJ/mole·K^2, calculated from the magnetic susceptibility, if it is assumed that the temperature-independent component χ is the Pauli contribution. It should not be ruled out, however, that this value of γ may also be the consequence of the linear lattice component of the specific heat caused, as was indicated above, by the quasi-amorphous state of the system.

We did not observe an abrupt change in the heat capacity, characteristic of superconductors, at $T = T_C$. Near T_C, however, the temperature dependence of the heat capacity exhibits an inflection point (see Fig. 2). This inflection point may stem from a diffuse superconducting phase transition which apparently is caused by the inhomogeneity of the sample.[3)] A similar diffuse phase transition was observed in $YBa_2Cu_3O_7$ by Kitazawa *et al.*,[8] although the heat capacity in their experiment did not behave anomalously at $T < 9$ K, possibly because their measurements were not carried out to sufficiently low temperatures. Extrapolation of the functional dependence of the heat capacity above and below the phase transition has made it possible to estimate the magnitude of the jump $\Delta C \gtrsim 2$ J/mole·K, in agreement with the data of Ref. 8.

[1)]Institute of Physics Problems, Academy of Sciences of the USSR.
[2)]It should be noted that the compound $YBa_2Cu_3O_{7-x}$, a cluster compound, can have a rather complex phonon spectrum which is not described, in principle, by the Debye approximation but can have auxiliary Einstein-type terms.[5] The characteristic Einstein temperatures in this case can be ~600 K, as was reported, in particular, for $La_{2x}(BaSr)_xCuO_4$, by Tranguada and Heald.[6]
[3)]A homogenizing annealing of the sample was not carried out.

[1]J. G. Bednorz and K. A. Muller, Z. Phys. **B64**, 189 (1986).
[2]M. K. Wu, J. R. Ashburn, C. J. Tonrng *et al.*, Phys. Rev. Lett. **58**, 908 (1987).
[3]K. D. Von Siegel, G. Wolf, K. Bohmhammel, and M. G. Schmidt, Exper. Techn. der Physik **25**, 299 (1977).
[4]G. G. Devyatykh, A. V. Gusev *et al.*, Zh. Neorg. Khim. **30**, 1368 (1985).
[5]N. E. Alekseevskiĭ, N. M. Dobrovol'skiĭ, G. Wolf, and H. Holfeld, Zh. Eksp. Teor. Fiz. **83**, 1500 (1982) [Sov. Phys. JETP **56**, 865 (1982)].
[6]J. M. Tranguada. and S. M. Heald, Phys. Rev. **B35**, 7187 (1987).
[7]L. E. Wenger, J. T. Chen, and G. W. Hunter, Phys. Rev. **B35**, 7213 (1987).
[8]K. Kitazawa, T. Atake *et al.*, Appl. Phys. Jpn. **26**, 1748 (1987).

Translated by S. J. Amoretty