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TITLE: RESISTIVITY OF $EuBa_2(Cu_{1-y}Zn_y)_3O_x$ AS A FUNCTION OF TEMPERATURE, MAGNETIC FIELD, PRESSURE AND Zn CONCENTRATION

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RESISTIVITY OF $EuBa_2(Cu_{1-y}Zn_y)_3O_x$ AS A FUNCTION OF TEMPERATURE, MAGNETIC FIELD, PRESSURE AND Zn CONCENTRATION

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Abstract

We report electrical resistance and magnetoresistance measurements on $EuBa_2(Cu_{1-y}Zn_y)_3O_x$ under pressures to 17 kbar. With Zn substitution, T_c is depressed rapidly (~19 K/at.% Zn) and there are qualitative changes in the temperature and field response of the resistance. Pressure drives the Zn-substituted samples toward undoped $EuBa_2Cu_3O_x$ behavior. Analysis of the temperature dependent resistance for y = 0.05 and P = 0, together with Hall effect and thermopower data, suggests that the suppression of superconductivity may arise from weak three-dimensional localization promoted by Coulomb interactions.

Running title: Resistivity of $EuBa_2(Cu_{1-y}Zn_y)_3O_x$

Key words: $EuBa_2(Cu_{1-y}Zn_y)_3O_x$, resistivity, pressure, localization

Understanding the mechanism for high superconducting transition temperatures T_c in the oxide compounds $RBa_2Cu_3O_x$ is among topics most actively pursued currently. The observation [1] of virtual independence of T_c when R is a rare earth highlighted the importance of the Cu-O planes/chains for superconductivity. Recent studies of the oxygen content [2] and 3d element substitution for Cu [3] have reinforced this viewpoint. However, there is still no consensus on the actual processes leading to superconducting pair formation and condensation.

We have studied the influence of small amounts of Zn in $EuBa_2(Cu_{1-y}Zn_y)_3O_x$, where y = 1, 3.5 and 5 at%, through electrical resistivity and magnetoresistance under pressures P < 17 kbar and Hall effect and thermopower measurements using conventional ac and/or dc techniques. As shown in Fig. 1 the superconducting transition temperature is depressed by Zn substitution at a rate dT_c/dy = -19 K/at%, which is over five times larger than for Cr and Mn doping [4] and nearly three times larger than for Ni [5]. Because Zn has a full 3d shell, this depression clearly is not related to magnetic pair-breaking effects.

In Fig. 2 we show the resistance R of $EuBa_2(Cu_{0.99}Zn_{0.01})_3O_x$ at four different pressures as a function of temperature. In contrast to R(T) for $EuBa_2Cu_3O_x$, which is linear in T from above T_c to room temperature, the resistance for x = 0.01 varies non-monotonically with decreasing temperature, reaching a maximum near 80 K before dropping to zero at ~45 K. With increasing pressure, the region of linear resistance extends to lower temperatures, T_c increases, ΔT_c (10-90%) sharpens, and at the highest pressures the maximum in R disappears. The inset of Fig. 2 shows that dT_c/dP is almost ten times larger for x = 0.01 than for x = 0 and for other $RBa_2Cu_3O_x$ samples previously studied [6].

For $x = 0.05$ (Fig. 3), the zero pressure resistance increases monotonically with decreasing temperature, and there is no sign of superconductivity above 4 K. (Results for $x = 0.035$, not shown, are intermediate between $x = 0.01$ and 0.05 both at ambient and elevated pressures.) With pressure the low temperature resistance upturn is suppressed and a maximum appears near 10 K under 16.1 kbar, possibly signaling the appearance of a superconducting transition. The application of an 8 T magnetic field H (see Fig. 4) restores the resistance to its temperature dependence in zero field for $P \leq 11.6$ kbar. The sequence of curves in Fig. 4 shows that the large magnetic field effect on the resistance depends on the magnetic and thermal history of the sample. Magnetoresistance curves obtained in a similar manner for $P = 11.6$ kbar resemble those in Fig. 4 for $H > 0.05$ T, while for $P = 0$ the resistance changes by less than 0.5% under an 8 T field at all temperatures $T < 300$ K, as is also the case for undoped $EuBa_2Cu_3O_x$.

In an earlier study of 3d element substitutions for Cu in $YBa_2(Cu_{0.9}A_{0.1})_3O_{6+\delta}$, Xiao [3] noted, on the basis of a moderate resistance upturn for $T > T_c$, that the conduction electrons appeared to become weakly localized before superconductivity sat in and that this was most pronounced for Zn. The inset of Fig. 3 shows a plot of electrical conductance versus $T^{2/3}$. The linear variation, $1/R \propto T^{2/3}$, found for $4 < T < 120$ K, is consistent with the power law dependence expected [7] for weak three-dimensional localization. If the observed behavior is due to localization, it arises from more than simple disorder because 5% Cr or Mn substitutions, while causing a resistance upturn at low temperatures before the onset of superconductivity, do not have such a dramatic effect.

Both the thermopower and Hall coefficient, positive for $y = 0$, remain positive but change substantially, by factors of nine and three respectively, upon substituting 5 at% Zn, indicative of strong modifications to the Fermi surface character. Previously we have argued [8] for the presence of strong Coulomb correlations in $YBa_2Cu_3O_x$. The data of Figs. 1-4 might suggest that Coulomb effects become increasingly important with Zn doping. Reasoning for a plausible argument is as follows: Because Zn has a full d-band, substitution of Zn reduces the d-density-of-states at E_F, believed to be important for superconductivity [9], and consequently inhibits conduction screening of Coulomb interactions. The enhanced Coulomb effects in turn promote localization at the expense of superconductivity. On the other hand, pressure favors superconductivity as shown in Fig. 2. These arguments are consistent with a large body of data, in addition to those presented here, on the Cu-O superconductors.

In summary, Zn substitution for Cu in $EuBa_2(Cu_{1-y}Zn_y)_3O_x$ results in a strong depression of superconductivity that may arise from Coulomb-correlation assisted localization. The application of pressure tends to drive $y > 0$ samples towards behaviors found in undoped $EuBa_2Cu_3O_x$.

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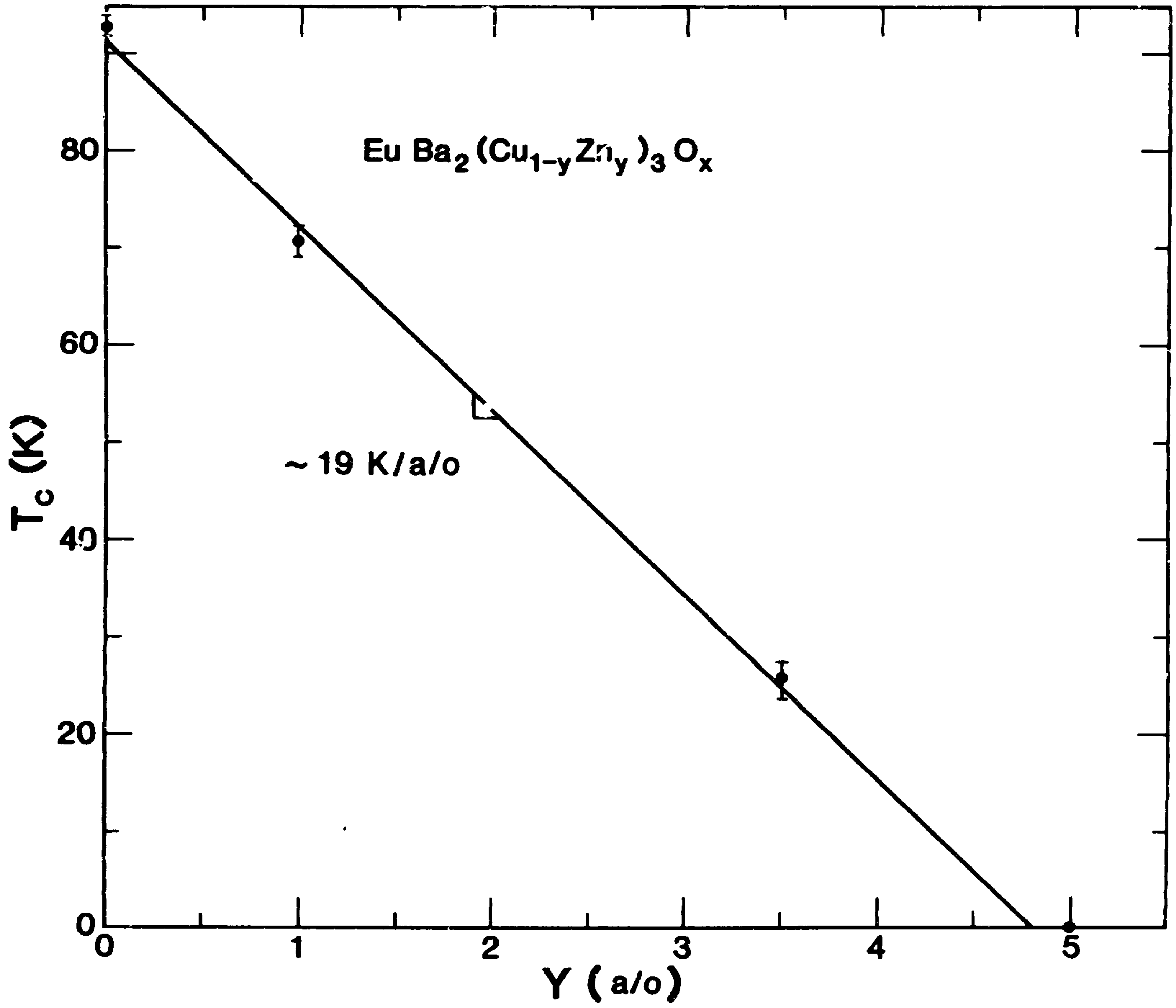
Figure Captions

Fig. 1 Superconducting transition of $EuBa_2(Cu_{1-y}Zn_y)_3O_x$ as a function of Zn concentration. T_c was determined from the onset of diamagnetic response sensed by dc susceptibility measurements.

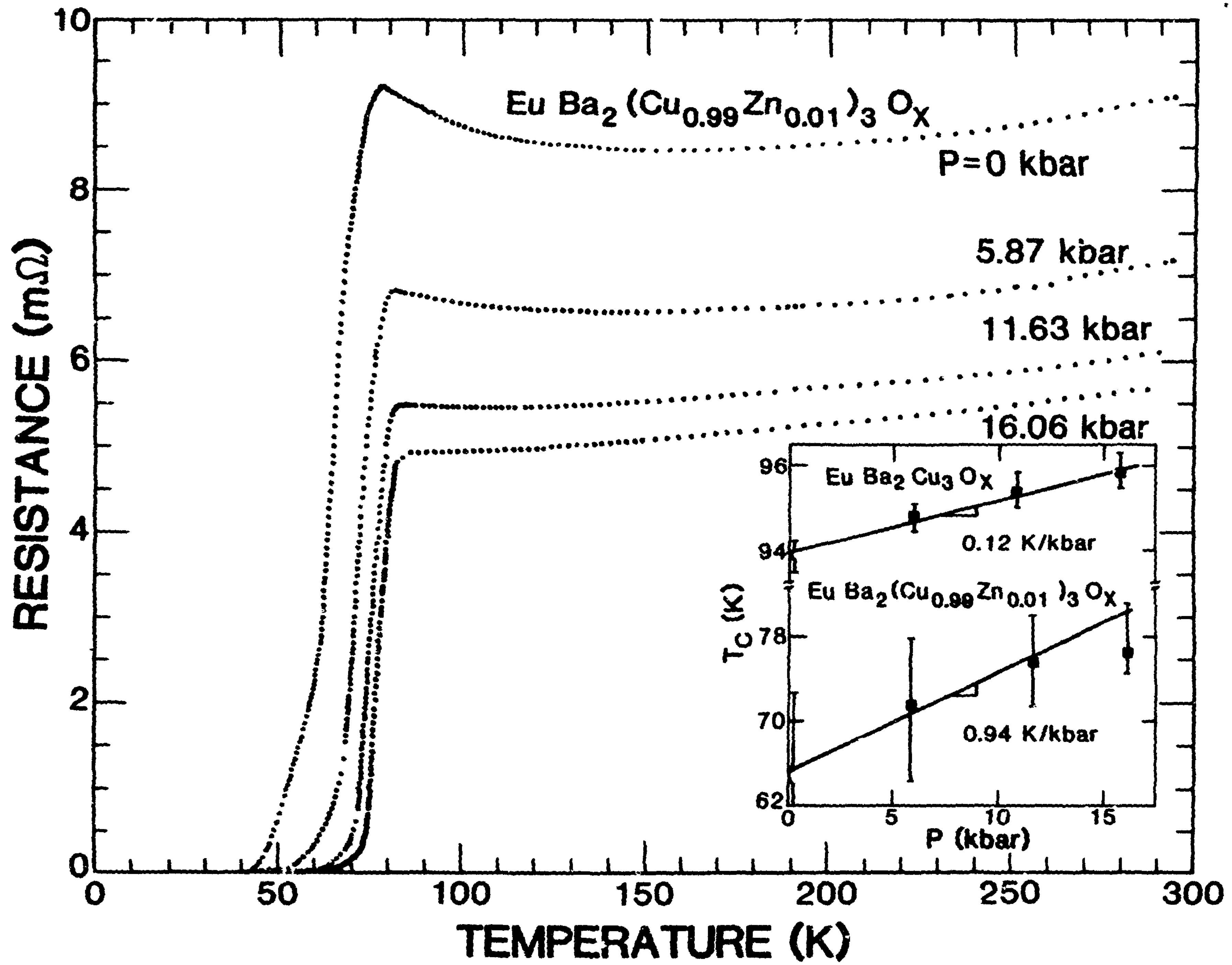
Fig. 2 Resistance of $EuBa_2(Cu_{0.99}Zn_{0.01})_3O_x$ at four pressures as a function of temperature. The inset compares the pressure dependence of the mid-point transition temperature of $EuBa_2Cu_3O_x$ and $EuBa_2(Cu_{0.99}Zn_{0.01})_3O_x$.

Fig. 3 Resistance R of $EuBa_2(Cu_{0.95}Zn_{0.05})_3O_x$ at three pressures versus temperature T. The inset is a plot of 1/R versus $T^{2/3}$ for this sample at P = 0 kbar.

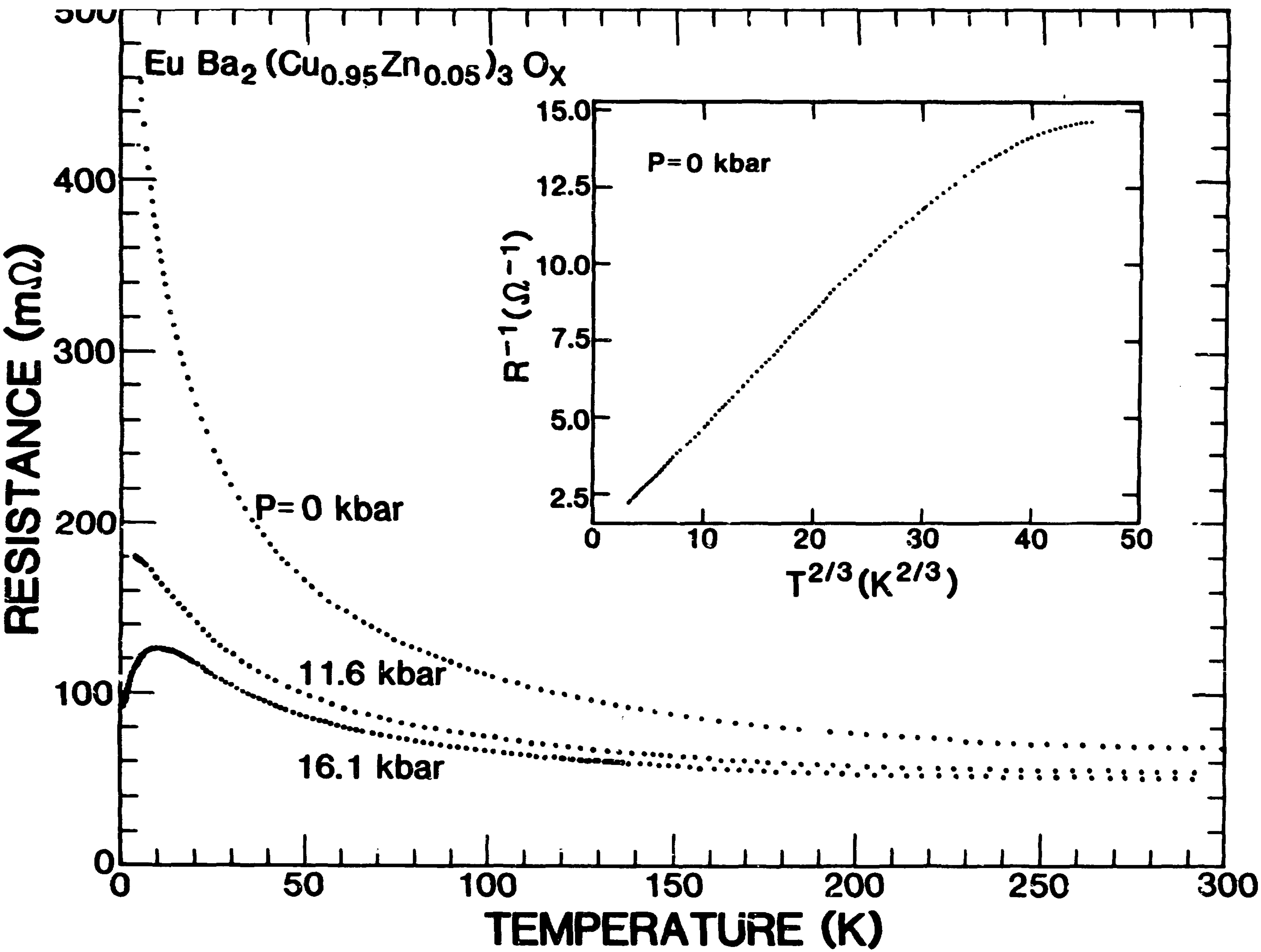
Fig. 4 Resistance versus temperature for $EuBa_2(Cu_{0.99}Zn_{0.05})_3O_x$ at P = 16.1 kbar in various applied magnetic fields H. After cooling the sample in zero field, measurements upon warming to 20 K were taken in the sequence: 0 (open circles), 8, 7, 6, 5, 0.5, 0.05, and 0 T. After the last H = 0 run, the sample was warmed to 40 K, then cooled and rerun in zero field (squares).



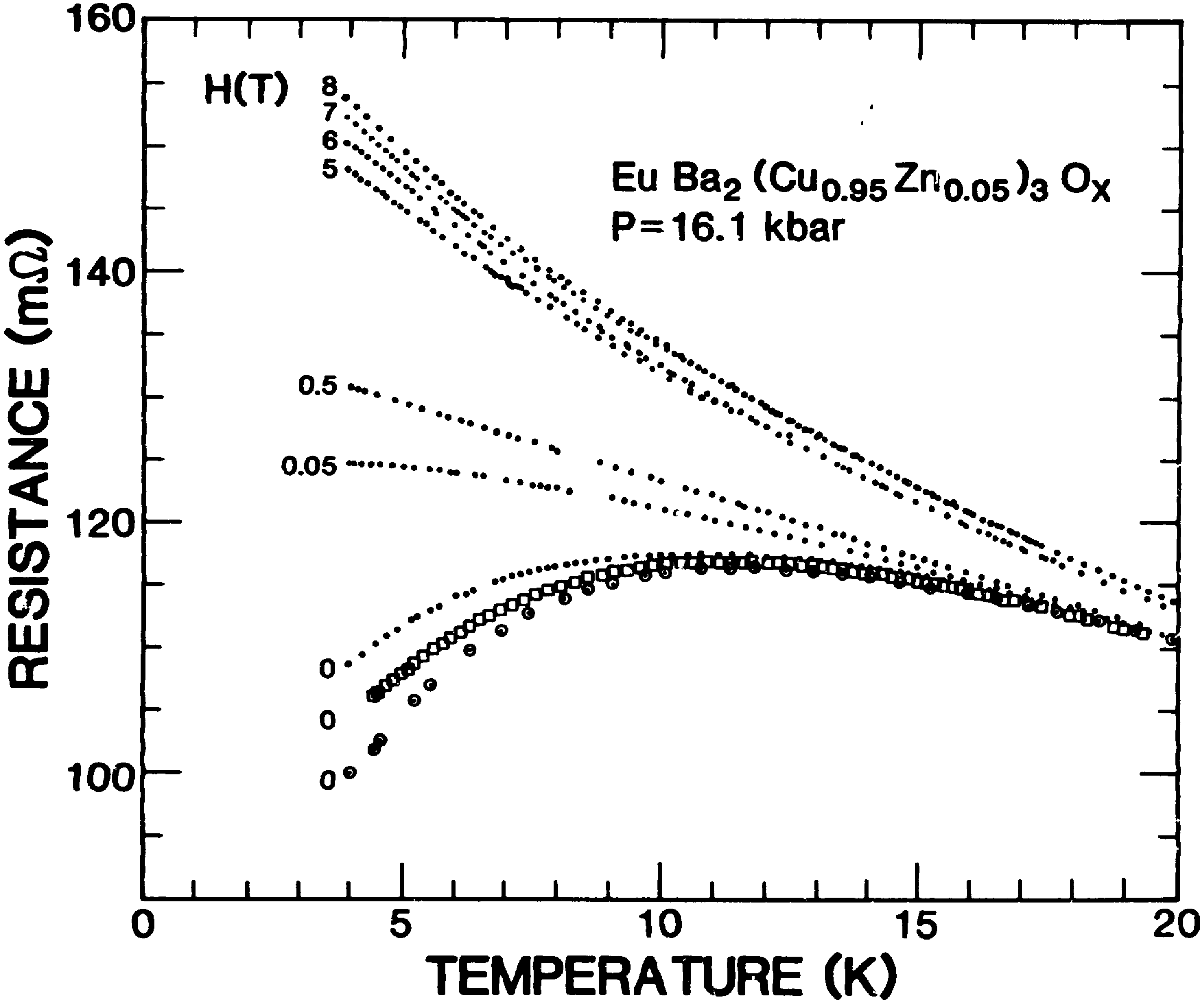
Eu Ba2 (Cu1-y Zny)3 Ox
~ 19 K/a/o
Tc (K)
Y (a/o)
0
20
40
60
80
0
1
2
3
4
5



Eu Ba2 (Cu0.99 Zn0.01)3 Ox
P=0 kbar
5.87 kbar
11.63 kbar
16.06 kbar
RESISTANCE (mΩ)
TEMPERATURE (K)
0
2
4
6
8
10
0
50
100
150
200
250
300
Eu Ba2 Cu3 Ox
0.12 K/kbar
Eu Ba2 (Cu0.99 Zn0.01)3 Ox
0.94 K/kbar
Tc (K)
P (kbar)
96
94
78
70
62
0
5
10
15



Eu Ba2 (Cu0.95Zn0.05)3 Ox
P= 0 kbar
11.6 kbar
16.1 kbar
RESISTANCE (mΩ)
TEMPERATURE (K)
0
100
200
300
400
500
0
50
100
150
200
250
300
P= 0 kbar
R−1 (Ω−1)
T2/3 (K2/3)
2.5
5.0
7.5
10.0
12.5
15.0
0
10
20
30
40
50



RESISTANCE (mΩ)
TEMPERATURE (K)
160
140
120
100
0
5
10
15
20
H(T)
8
7
6
5
0.5
0.05
0
0
0
Eu Ba2 (Cu0.95 Zn0.05)3 Ox
P=16.1 kbar