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1992 J. Phys.: Condens. Matter 4 4273

(http://iopscience.iop.org/0953-8984/4/17/006)

J. Phys.: Condens. Matter 4 (1992) 4273–4281. Printed in the UK

Electrical resistivity and magnetic susceptibility rounding above the superconducting transition and pairing state in $Bi_{1.5}Pb_{0.5}Sr_2Ca_2Cu_3O_y$

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Received 4 October 1991

Abstract. The rounding effects above the superconducting transition of the electrical resistivity and of the magnetic susceptibility have been measured in the same $Bi_{1.5}Pb_{0.5}Sr_2Ca_2Cu_3O_y$ polycrystalline compounds. Our results for the reduced temperature (ϵ) behaviour of both observables confirm the absence of appreciable non-universal Maki–Thompson and structural inhomogeneity effects. The results for the ϵ behaviour and for the intrinsic amplitude of both observables can be explained simultaneously and consistently in terms of two-dimensional order-parameter fluctuations in pair-breaking layered superconductors with a two-real-component order parameter, but assuming also the presence, only in the paraconductivity, of a non-universal contribution having a Lawrence–Doniach-like ϵ dependence. These last conclusions apply also to our previous experimental results for $YBa_2Cu_3O_{7-\delta}$ samples, where order-parameter fluctuations in the mean-field region are three dimensional.

1. Introduction

A key question about copper oxide superconductors is whether the superconducting pairing state is 'conventional' ($^1s_0$-wave pairing) or 'unconventional' ('extended' or non-$^1s_0$-wave pairing) [1–3]. In a recent letter [4] (hereafter referred to as I), we have presented experimental data on the intrinsic fluctuation-induced diamagnetism $\Delta\chi_{ab}$ and on the intrinsic paraconductivity $\Delta\sigma_{ab}$ in the a–b plane obtained in the same $YBa_2Cu_3O_{7-\delta}$ (YBCO) samples. The reduced-temperature ϵ behaviour of both observables is very similar, suggesting then that the possible *non-universal* effects contributing differently to the measured $\Delta\sigma(\epsilon)$ and $\Delta\chi(\epsilon)$ may probably be discarded, at least in the mean-field region (MFR). This concerns, in particular, the Maki–Thompson [5, 6] contributions (which will affect only $\Delta\sigma_{ab}(\epsilon)$) and the inhomogeneity effects in single-phase samples [7] (which will affect $\Delta\sigma(\epsilon)$ and $\Delta\chi(\epsilon)$ differently). These findings, which confirm our previous paraconductivity results [8, 9], simplify considerably the analysis of the superconducting order-parameter fluctuation (OPF) effects in these materials which otherwise may not lead, mainly when analysing only one cuprate oxide family, to unambiguous conclusions [5, 6, 10]. Furthermore, our analysis in I suggested that the *absolute amplitudes* of both observables, which in contrast with their ϵ-behaviour will depend on the type of superconducting pairing state [11–14], cannot be explained simultaneously and consistently only in terms of universal OPF effects in conventional ($^1s_0$-wave pairing) layered superconductors. However, an erroneous interpretation of the existing theory [11–14] invalidates our conclusions for unconventional (non-s-wave pairing) impure superconductors (see corrigendum to I). It seems therefore, suitable to check whether the above indicated results for YBCO compounds apply also to other copper oxide systems. Among the existing copper oxide families, the Bi–Pb–Sr–Ca–Cu–O superconductors should probably be very good candidates owing, in particular, to the pronounced two-dimensional (2D) behaviour of their paraconductivity in the MFR [9, 15, 16], which is in contrast with the 3D behaviour of the YBCO compounds.

In this paper, we present high-resolution measurements of the rounding, above the superconducting transition, of the magnetic susceptibility in the low-magnetic-field limit $\chi(T)$, and of the electrical resistivity $\rho(T)$ in the *same* $Bi_{1.5}Pb_{0.5}Sr_2Ca_2Cu_3O_y$ (BSCCO) polycrystalline samples. Although the rounding of $\rho(T)$ [9, 15, 16] and the rounding of $\chi(T)$ [17, 18] in Bi-based superconductors have been measured in detail by various groups, to our knowledge it is now the first time that *high resolution* data of $\Delta\sigma_{ab}(\epsilon)$ and $\Delta\chi_{ab}(\epsilon)$ are obtained in the same samples [19], a central condition necessary to compare quantitatively and consistently both observables with each other and with the theoretical approaches. In particular, we shall see here that the absolute amplitudes of both observables again provide, as was the case for (3D) YBCO materials, a basic test to check the type of pairing in (2D) BSCCO compounds. Also, we shall briefly reanalyse here our previous data for YBCO samples in terms, in particular, of the existing approaches for unconventional pairing superconductors.

2. Experimental details

Three polycrystalline samples of nominal composition $Bi_{1.5}Pb_{0.5}Sr_2Ca_2Cu_3O_y$ have been studied. Their preparation and details of their general properties have been reported in [20] and in references therein. X-ray diffraction analysis indicates the presence of various distinct phases, although the phase with $T_C \approx 108$ K is predominant. The main effect on the $\rho(T)$ and $\chi(T)$ rounding behaviours of these relatively small stoichiometric inhomogeneities is the enlargement of the transition widths. For instance, the *upper* half-width ΔT_{CI} of the resistive transition may be defined by [8]

$$[\mathrm{d}\rho(T)/\mathrm{d}T]_{T_{CI}+\Delta T_{CI}} = \tfrac{1}{2}[\mathrm{d}\rho(T)/\mathrm{d}T]_{T_{CI}} \qquad (1)$$

where T_{CI} is the temperature where $\rho(T)$ around the transition has its inflection point $(\mathrm{d}^2\rho(T_{CI})/\mathrm{d}T^2 = 0)$. In the case of the BSCCO samples studied now, 1 K $\lesssim \Delta T_{CI} \lesssim 2$ K whereas, for the YBCO samples studied in I, $\Delta T_{CI} \lesssim 0.25$ K, a width close to the expected intrinsic value. Although the marked 2D character of the OPF in the BSCCO compounds will enlarge the transition, [9, 15, 16], an appreciable part of this width will be due to the presence of the stoichiometric inhomogeneities noted above. Thus, to avoid any complication associated with these spurious effects, our analysis will be done for $T - T_{CI} > \Delta T_{CI}$. In this case we cannot, therefore, probe the possible 2D–3D and mean field–full critical regime crossovers which may appear beyond the MFR, closer to the superconducting transition.

Optical microscopy measurements and SEM show that the typical grain and crystallite sizes of our polycrystal samples are 10–50 μm. The samples show pores on the same scale as the grains and crystallites, the latter also showing a high density of twin boundaries on a length scale larger than 1000 Å. The porosity of the samples decreases the average density to between 80% and 90% of the ideal value. The length scales of these different *structural* inhomogeneities are, in all cases, much larger than any characteristic length relevant for OPF, e.g. the superconducting order-parameter correlation length, $\xi(T)$, in all directions or the effective interplane (CuO_2) distances d_e (see later). Above T_{CI}, each crystalline behaves then as a (randomly oriented) single crystal. The influence on the measured $\rho(T)$ and $\chi(T)$ roundings of these long-scale structural inhomogeneities may be accounted for by the empirical approaches that have been described in I and in references therein. The experimental systems to measure $\rho(T)$ and the magnetization $M(T)$ in the low-magnetic-field limit ($H < 0.3$ T $\ll H_{c2}(0)$), and the corresponding resolutions, were the same as those indicated also in I.

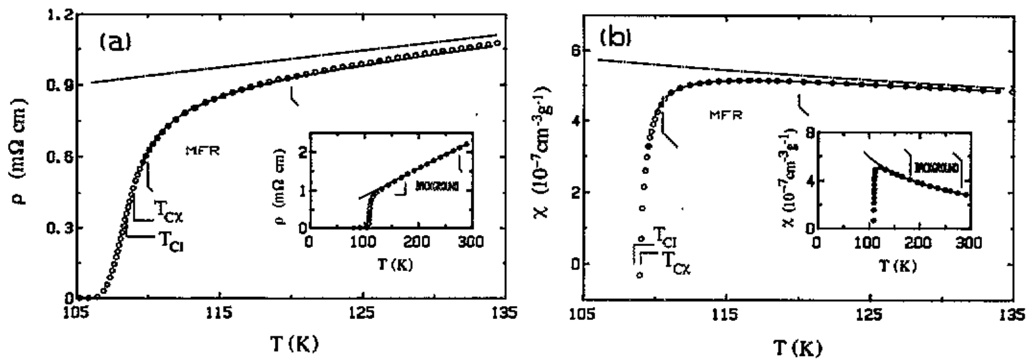

Figure 1. An example of the temperature behaviour of (*a*) the measured resistivity and (*b*) the magnetic susceptibility. The chain lines are the corresponding backgrounds, and the full lines have been obtained using a Lawrence–Doniach temperature dependence for the intrinsic rounding effects.

3. Experimental results

As example of our results on $\rho(T)$ and $\chi(T)$ for the *same* sample is shown in figures 1(*a*) and 1(*b*). These $\chi(T)$ data were obtained with H = 50 mT. As was the case for our data on the polycrystalline YBCO samples described in I, the granular nature of the BSCCO samples measured now is clearly reflected in the results presented in figure 1. For instance, the absolute values of both $\rho(T)$ and its slope are affected by the reduction in the effective cross section in polycrystalline samples. Also, probably owing to the presence of some paramagnetic impurities and to localized moments originated by oxygen defects, $\chi(T)$ in the normal region increases somewhat as T decreases. However, these non-intrinsic effects, always present to some extent when analysing critical phenomena in any real (or even single-crystal) material, may be easily overcome by the same data analysis as was used in I for the YBCO system. Let us just note that the normal (background) resistivity $\rho_{ab\mathrm{B}}(T)$ in the a–b plane, of good BSCCO single-crystal samples has not yet been measured. So, to extract the intrinsic paraconductivity $\Delta\sigma_{ab}(T)$ from $\rho(T)$, we use as the slope of the intrinsic background resistivity $\mathrm{d}\rho_{ab\mathrm{B}}(T)/\mathrm{d}T \simeq 0.5\mu\Omega$ cm K^{-1}, a value suggested by extensive study of

$\rho_{ab\text{B}}(T)$ in several superconducting families [21]. Other details of the extraction of $\Delta\sigma_{ab}(T)$ and $\Delta\chi_{ab}(T)$ may be seen in I and in references therein.

As can be seen in figures 1(*a*) and (*b*), here again T_{CI} agrees to within $\pm\Delta T_{\text{CI}}$ with $T_{\text{C}\chi}$, latter defined as the temperature where $\chi(T)$ goes through zero. In this example, T_{CI} = 108.5 K and $T_{\text{C}\chi}$ = 109 K, whereas ΔT_{CI} = 1.3 K. The T-location of the MFR is also, as it was for YBCO samples, bounded through

$$0.1 \lesssim \Delta\sigma_{ab}(T)/\sigma_{ab\text{B}}(T) \lesssim 0.6 \tag{2}$$

and

$$0.1 \lesssim \Delta\chi_{ab}(T)/\chi_{ab\text{B}}(T) \lesssim 0.6 \tag{3}$$

which correspond, *in both cases*, to $1.5 \times 10^{-2} \lesssim \epsilon \lesssim 10^{-1}$, where $\epsilon \equiv \ln(T/T_{\text{CI}})$, or $\epsilon \equiv \ln(T/T_{\text{C}\chi})$ is the reduced temperature for $\Delta\sigma_{ab}$ and $\Delta\chi_{ab}$, respectively. The lower ϵ-limit will correspond to the Ginzburg reduced temperature ϵ_{G} which in 2D is given by [22]

$$\epsilon_{\text{G}} = k_{\text{B}}/\left(4\pi\xi_{ab}^2(0)d_e\,\Delta C\right) \tag{4}$$

where k_{B} is the Boltzmann constant, $\xi_{ab}(0)$ is the superconducting correlation length in the *a*–*b* plane, d_e is the *effective* interlayer distance (which takes into account the existence in these compounds of inequivalent conducting layers at different distances [13, 23]), and ΔC is the heat capacity jump at the transition. We shall see later that this last expression leads to an ϵ_{G}-value close to the above-indicated lower ϵ-limit. Above the high-temperature limit the conventional Ginzburg–Landau-like theories will fail (for instance, the transverse superconducting correlation length becomes smaller than the distance between the closest adjacent CuO_2 planes or even smaller than the interatomic distances).

The intrinsic $\Delta\sigma_{ab}(\epsilon)$ and $\Delta\chi_{ab}(\epsilon)/T$ for the BSCCO superconductors, extracted from the $\rho(T)$ and $\chi(T)$ data obtained in the three samples studied here, are represented in figures 2(*a*) and 2(*b*), respectively. A first important result of figure 2 is the very similar temperature behaviour, over all the MFR, of both observables. This result was also found, as noted in the introduction, in the YBCO samples studied in I and, therefore, strongly suggests that all the rounding effects in copper oxide superconductors not common to both observables may probably be discarded, at least in the MFR where the relative influence of these non-universal effects could be, if they exist, probably more important. The above conclusion concerns the Maki–Thompson contribution [5, 6] (for the currently accepted pair breaking time values [9], $\tau_0 \lesssim 10^{-12}$s), which will affect only $\Delta\sigma$. The absence of anomalous paraconductivity confirms our previous proposals based on the analysis of $\Delta\sigma$ in different copper oxide families [9] in contrast with other paraconductivity analyses [5, 10]. The structural inhomogeneity effects on the *reduced-temperature* behaviour of $\Delta\sigma$ and $\Delta\chi$, which will affect differently both magnitudes, will be, if they exist, to within the 30% dispersion of our data, confirming our previous paraconductivity analysis [8, 9, 24]. This last result is also in contrast with other proposals on the structural inhomogeneity influence on the resistivity rounding in copper oxide materials [7]. Moreover, these results seem to confirm that our choices of the backgrounds, of T_{CI} and $T_{\text{C}\chi}$ as the mean-field critical temperature T_{C0}, and of the ϵ-location of the MFR, are reasonable approximations. This contrasts with other proposals where T_{C0} is assumed to differ from T_{CI} or $T_{\text{C}\chi}$ by almost 10 K, or where the MFR is extended even above $2T_{\text{CI}}$, a region where $\xi_c(\epsilon)$ will be shorter than the interatomic distances [5, 10, 18].

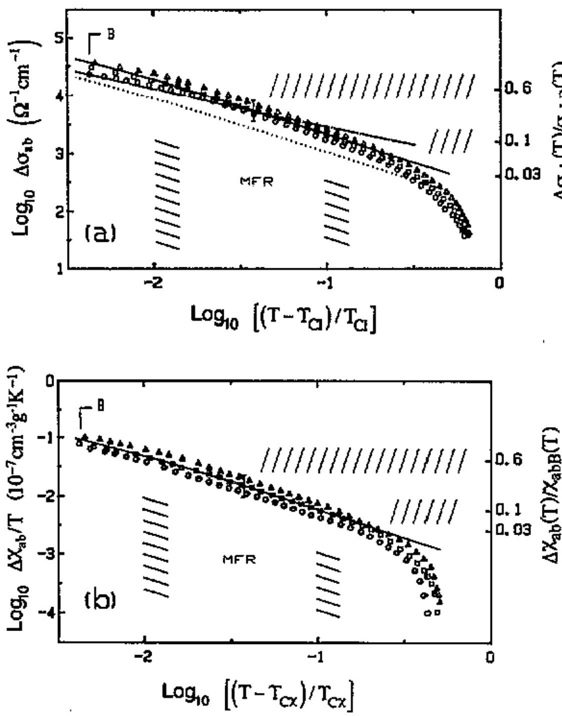

Figure 2. (*a*) Intrinsic paraconductivity and (*b*) paradiamagnetism in the *a–b* plane of BSCCO compounds. The error bars apply in the indicated MFR and they have been estimated by taking into account the uncertainties of both the experimental $\rho(T)$ and the experimental $\chi(T)$ data and also those introduced in extracting $\Delta\sigma_{ab}(\epsilon)$ and $\Delta\chi_{ab}(\epsilon)$ from these data. The curves correspond to the different mean-field approaches for OPFs, as explained in the main text.

4. Comparison with the theoretical approaches

As noted in I, the existing approaches for direct OPF effects in layered superconductors lead to the same ϵ-dependence for both $\Delta\sigma_{ab}(\epsilon)$ and $\Delta\chi_{ab}(\epsilon)/T$. In the MFR, and independently of the type of pairing state or of the number n of real components of the order parameter [11–14],

$$\Delta\sigma_{ab}(\epsilon) = (A_\sigma/\epsilon)(1 + B/\epsilon)^{-1/2} \tag{5}$$

and

$$\Delta\chi_{ab}(\epsilon)/T = (A_\chi/\epsilon)(1 + B/\epsilon)^{-1/2} \tag{6}$$

where $B \equiv [2\xi_c(0)/d_e]^2$, and where we have neglected the possible small terms proportional to $[\xi_c(0)/\xi_{ab}(0)]^2$. Here $\xi_c(0)$ is the superconducting correlation length amplitude in the c direction (normal to the a–b planes). As also noted in I, a crucial feature is that A_σ and A_χ in the above equations depend on the type of pairing and on n. For conventional ($^1s_0$-wave) pairing and $n = 2$ (denoted here by the superscript s), $A_\sigma^s = e^2/16\hbar d_e$, and $A_\chi^s = \pi k_B \phi_0^{-2} \xi_{ab}^2(0)/3d_e$. For unconventional (non-$^1s_0$-wave) pairing (denoted by the superscript ns), only some partial results are at present available [12–14]. For the $g = 1$ complex component order parameter, i.e. $n = 2$, in a square lattice, $A_\sigma^{ns} = A_\sigma^{s}$, and $A_\chi^{ns} = A_\chi^{s}$, where we have assumed an impurity pair-breaking factor r of the order of unity [12]. For two-complex-component ($g = 2$) order parameters, and assuming also $r = 1$ and a square lattice [12], $A_\sigma^{ns} = A_\sigma^{s}(g + I_1 + I_2)$, where I_1 and I_2 are non-universal contributions, and [14] $A_\chi^{ns} = gA_\chi^{s}$. Note that A_σ^{ns} has been explicitly calculated for only $g = 1$ or $g = 2$, but the proportionality of A_σ^{ns} or A_χ^{ns} with g agrees with the fact that different components of the order parameter will have independent fluctuations contributing to the amplitudes of both rounding effects. In the above expressions, e is the electron charge, $\hbar$ is the reduced Planck constant, k_B is the Boltzmann constant and ϕ_0 is the flux quantum. Note that A_χ/A_σ is independent of d_e, and for conventional pairing or for one-complex-component ($g = 1$) unconventional pairing, one gets the ratio (in cgs units) $A_\chi/A_\sigma = 2.47 \times 10^{-10}\xi_{ab}^2(0)$.

The full lines in figures 2(*a*) and 2(*b*) correspond to the best fit of equations (5) and (6), respectively, in the indicated MFR and with A_σ, A_χ and B (in the two curves) as free parameters. The resulting values are (in cgs units)

$$A_\sigma = (2 \pm 0.5) \times 10^{14}\mathrm{s}^{-1} \qquad A_\chi = (4 \pm 1.2) \times 10^{-10}\mathrm{K}^{-1}$$

and

$$B \lesssim 4 \times 10^{-3}. \tag{7}$$

Two complementary results must be stressed already. First, the ϵ-behaviour of equations (5) and (6) agrees, on a quantitative level, with our data in the MFR for both observables, the RMS fit deviation being in all the cases better than 5%. Then, whereas in the YBCO samples B was found in I to be close to the upper ϵ-limit of the MFR, for the BSCCO samples studied now B is much less than the lower ϵ-limit. These results fully confirm, therefore, our early results [15] suggesting that OPFs are 2D ($\xi_c(\epsilon) \ll d_e$) in Bi-based HTSCs, whereas they are 3D ($\xi_c(\epsilon) > d_e$) in the MFR of YBCO samples.

We are now able to compare the above-indicated theoretical results with the measured amplitudes. For conventional superconductors, or for one-complex-component ($g = 1$, i.e. $n = 2$) unconventional pairing, by using A_χ/A_σ we obtain $\xi_{ab}(0) = 9 \pm 4$ Å. Although the order parameter correlation lengths in Bi-based HTSCs have been studied relatively little, it is expected that $\xi_{ab}(0)$ for these compounds will take similar values as for YBCO samples [21, 25]: $\xi_{ab}(0) \simeq$ 14 Å, which is appreciably larger than that extracted from A_χ/A_σ. We must check, then, each quantity separately. Using A_χ^s and the above-indicated accepted $\xi_{ab}(0)$-value, we obtain $d_e = 17 \pm 5$ Å, which is reasonably close to 15.4 Å, the half-unit-cell length of the BSCCO compounds. So, the theoretical results for s-wave pairing or for unconventional pairing with $g = 1$ explain, on a quantitative level and consistently with the accepted characteristic lengths, our experimental result for $\Delta\chi_{ab}(\epsilon)$. Unconventional pairing with $g > 1$ is unambiguously excluded. By using now in A_σ^s again $\xi_{ab}(0)$ = 14 Å and for d_e the characteristic length extracted before from A_χ, we obtain $A_\sigma^s = (0.9 \pm 0.3) \times 10^{14}$ s^{-1}. This value is appreciably shorter than the measured amplitude and leads to the dotted line in figure 2(*a*). The chain line in this figure was obtained by adding a Maki–Thompson contribution $\Delta\sigma_{MT}^s(\epsilon)$ for conventional layered superconductors [6], to the dotted line, with the phase relaxation time τ_ϕ as a free parameter. The resulting best-fit value is $\tau_\phi = 2 \times 10^{-13}$ s at 115 K. The evident disagreement is not mitigated by using for $\Delta\sigma^{s}_{\rm MT}(\epsilon)$ a modified expression for two different Josephson-coupling parameters [6]. This result fully confirms thus our earlier proposal on the absence of Maki–Thompson effects [9, 15] in spite of the fact that the copper oxide materials are in the clean limit [5, 6], and in agreement with optical measurements [26]. Magnetic pair breaking or unconventional pairing in impure superconductors could explain the failure of these $\Delta\sigma^{s}_{\rm MT}(\epsilon)$ expressions [12, 27]. Note that $A^{\rm ns}_{\sigma}$, with $g = 2$, could explain, with reasonable characteristic lengths, the observed $\Delta\sigma_{ab}(\epsilon)$-amplitude, if the non-universal terms, including Yip's contributions I_1 and I_2, are absent but then the disagreement with $\Delta\chi_{ab}(\epsilon)$ will become unacceptable. Note also that by using in equation (4) the value of ΔC proposed in [28], namely $\Delta C = 2.6 \times 10^4$ J m^{-3} K^{-1}, the above characteristic length for conventional or unconventional pairing with $g = 1$ leads to $\epsilon_{\rm G} = 1.3 \times 10^{-2}$, in excellent agreement with that observed in the $\Delta\sigma_{ab}(\epsilon)$ and $\Delta\chi_{ab}(\epsilon)/T$ curves (about 1.5×10^{-2}). It seems, therefore, that our data for $\Delta\sigma_{ab}(\epsilon)$ and $\Delta\chi_{ab}(\epsilon)$ in BSCCO compounds could be explained in terms of universal OPF effects in strong pair-breaking layered superconductors having a two-real-component order parameter ($n = 2$, as in s-wave pairing or, in one-complex-component unconventional pairing, $g = 1$), but assuming also the presence, only in the paraconductivity, of non-universal contributions having a Lawrence–Doniach-like temperature dependence. It is likely that a 2D non-square lattice can generate, even for $g = 1$, these non-universal contributions [12].

As noted before, the conclusions for unconventional pairing presented in I for the YBCO samples were erroneous, because they were based on an inconsistent use of Yip's results for $\Delta\sigma_{ab}(\epsilon)$ in that unconventional case. Because of this, it will be useful to summarize here our correct conclusions in that case. In cgs units, $A_\sigma = (3.2 \pm 0.9) \times 10^{14}$ s^{-1}, $A_\chi = (6 \pm 2) \times 10^{-10}$ K^{-1} and (for both observables) $B = 0.15 \pm 0.08$. For conventional superconductors, or for one-complex-component ($g = 1$, i.e. $n = 2$) unconventional pairing, by using A_χ/A_σ we obtain $\xi_{ab}(0) = 9 \pm 3$ Å, which is appreciably shorter than the value proposed in the literature [21]: $\xi_{ab}(0) = 14 \pm 2$ Å. In this case, we must check also, as for BSCCO samples, each quantity separately. Imposing on A^{s}_{χ} the above-indicated accepted $\xi_{ab}(0)$-value, we obtain $d_e = 11 \pm 3$ Å, in excellent agreement with the unit-cell length for YBCO samples (11.7 Å). In addition, in this 3D case we have access through B to $\xi_c(0)$. With $B = 0.15 \pm 0.08$, and using $d_e \simeq 11 \pm 3$ Å, we obtain $\xi_c = 2 \pm 1$ Å, in good agreement with 1.5 Å $\lesssim \xi_c(0) \lesssim 3$ Å proposed in the literature [21]. So, the theoretical predictions for s-wave pairing or for unconventional pairing with $g = 1$ also explain, as was the case for BSCCO samples, our results for $\Delta\chi_{ab}(\epsilon)$ in YBCO samples, at a quantitative level and consistently with the accepted characteristic lengths. Unconventional pairing with $g > 1$ is unambiguously excluded. By using now in A^{s}_{σ} the characteristic lengths extracted before from A_χ, we obtain $A^{s}_{\sigma} = (1.3 \pm 0.4) \times 10^{14}$ s^{-1}, which is appreciably shorter than the measured amplitude. The disagreement cannot be overcome, as was also the case for BSCCO samples, by adding to A^{s}_{σ} a Maki–Thompson contribution. Note, finally, that for YBCO samples the lower ϵ-limit, the one corresponding to $\Delta\sigma_{ab}(\epsilon)/\sigma_{ab\rm B}(\epsilon) \simeq 0.6$, or $\Delta\chi_{ab}(\epsilon)/\chi_{ab\rm B}(\epsilon) \simeq 0.6$, was around 7×10^{-3}. In this 3D case, $\epsilon_{\rm G}$ is given by [22]

$$\epsilon_{\rm G} = (1/32\pi^2)\left[k_{\rm B}/(\xi^2_{ab}(0)\xi_c(0)\ \Delta C)\right]^2. \tag{8}$$

By using the measured ΔC jump [29], i.e. $\Delta C = 4.7 \times 10^4$ J m^{-3} K^{-1}, and the above-indicated characteristic lengths, equation (8) yields $\epsilon_G = 6 \times 10^{-3}$, in excellent agreement with our findings in I.

5. Conclusions

In conclusion, we have reported high-resolution data of the electrical resistivity and of the magnetic susceptibility rounding effects above the superconducting transition obtained in the same polycrystalline BSCCO samples. The intrinsic paraconductivity $\Delta\sigma_{ab}$ and paradiamagnetism $\Delta\chi_{ab}$ in the *a*–*b* plane have been extracted from these data following similar systematics for both observables. As was the case for YBCO samples, $\Delta\sigma_{ab}(\epsilon)$ and $\Delta\chi_{ab}(\epsilon)/T$ have very similar reduced-temperature behaviours, over all the MFR. This result found with the three samples studied here, which have different long-scale structural inhomogeneities, again suggests that all the rounding effects not common to both observables may probably be discarded in the MFR. This concerns, in particular, the Maki–Thompson [5, 6] contribution (which will affect only $\Delta\sigma$), at least with the ϵ-dependence that has been proposed [6], and the structural inhomogeneity effects [7] (which will affect $\Delta\sigma$ and $\Delta\chi$ differently). Also, these results seem to confirm the validity of our extraction procedure of $\Delta\sigma_{ab}(\epsilon)$ and $\Delta\chi_{ab}(\epsilon)$, in contrast with other analyses [10, 18]. Concerning the pairing state and the number of components of the order parameter, it seems that our data for both observables in both HTSC systems could be explained in terms of universal OPF effects in impure (pair-breaking) layered superconductors having a two-real-component order parameter ($n = 2$, as in s-wave pairing or in one-complex-component unconventional wave pairing), but by assuming also the presence, only in the paraconductivity, of non-universal contributions having a Lawrence–Doniach-like temperature dependence, as for two-complex-component ($g = 2$) unconventional pairing [12]. The theoretical analysis of these unconventional contributions, and also of the pair-breaking effects in 'extended' s-wave superconductors [1–3, 30], will provide a useful test of such a pairing state for copper oxide materials. From the experimental point of view, it will be important to do new measurements in the same good single-crystal samples of both rounding effects, mainly to check their intrinsic *amplitudes*. As stressed before, these amplitudes depend, in particular, almost linearly on various not always well settled geometrical parameters (through the effective magnetic field in the case of $\Delta\chi_{ab}$, and through $\mathrm{d}\rho_{ab\mathrm{B}}(T)/\mathrm{d}T$ in the case of $\Delta\sigma_{ab}$, and we cannot exclude the failure of our estimates of the uncertainties on these parameters.

Acknowledgments

We acknowledge E Morán and co-workers and I Rasines and co-workers for the samples and J F Annett and co-workers for making available to us their unpublished results. This work has been supported by CICYT, grant MAT 88-0769, the Programa MIDAS, grant 89-3800, and the Fundación Ramón Areces, Spain.

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