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High temperature superconductivity in $\text{SmBa}_2\text{Cu}_3\text{O}_{7-x}$: transport properties and effect of pressure

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Résumé. — Les propriétés physiques, température de transition supraconductrice, susceptibilité magnétique, résistivité électrique et pouvoir thermoélectrique de poudres frittées de $\text{SmBa}_2\text{Cu}_3\text{O}_{7-x}$, ont été étudiées en fonction des conditions de préparation et donc de la stoechiométrie en oxygène. Le champ critique B_{c2} a été estimé à partir de mesures de résistivité en champ maximum de 8 T et la pente $(dB_{c2}/dT)_{T_c}$ a été trouvée voisine de 4 T K^{-1} dans les échantillons à plus haut T_c . Une étude de la résistivité sous pression hydrostatique (0-18 kbar) montre que T_c augmente avec la pression ($dT_c/dp = 0,5 \text{ K kbar}^{-1}$). Enfin des mesures de caractéristique courant-tension indiquent que des jonctions de type Josephson ou de type S-I-N (Supraconducteur-isolant-métal normal) existent à l'intérieur des échantillons, par suite de l'inhomogénéité de composition.

Abstract. — Sintered powders of $\text{SmBa}_2\text{Cu}_3\text{O}_{7-x}$ have been prepared and characterized. The physical properties, superconducting temperature transition, up to 92 K, magnetic susceptibility, electrical resistivity and thermopower have been studied as a function of the preparation conditions and therefore of oxygen stoichiometry. The upper critical field has been estimated from resistivity measurements in fields up to 8 T and the slope $(dB_{c2}/dT)_{T_c}$ found to be close to 4 T K^{-1} for the highest T_c samples. Studies of the electrical resistivity under hydrostatic pressures up to 18 kbar show an increase of T_c under pressure with $dT_c/dp \sim 0.5 \text{ K kbar}^{-1}$. Finally measurements of voltage-current characteristics indicate that either Josephson junctions or superconductor-insulator-normal metal junctions can be found inside the samples, as expected in inhomogeneous materials.

1. Introduction.

Since the pioneering work of Bednorz¹ and Müller establishing superconductivity above 30 K in $\text{Ba}_x\text{La}_{2-x}\text{CuO}_4$ [1] and successively of Chu *et al.* [2] opening the way to superconductivity above liquid nitrogen temperature in $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$, a considerable amount of work has been performed all over the world on both families of materials. It is now also well-known that, not only $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$, but most of the compounds of the rare earth series, $\text{LnBa}_2\text{Cu}_3\text{O}_{7-x}$, show high temperature supercon-

ductivity [3-8]. It seems that neither the change of ionic radii of the trivalent rare earth ion through the Lanthanide series, nor the presence of a magnetic moment on Ln^{3+} affect considerably the value of the superconducting transition temperature T_c . However, as far as we know, important properties, such as the critical field, the critical current, tunnelling properties, have not yet been reported for the rare earth compounds. It is not clear at the moment whether they depend on the nature of the A ion in $\text{ABa}_2\text{Cu}_3\text{O}_{7-x}$.

Among the rare earth series, the Samarium may be interesting because the Sm^{3+} ionic radii (0.964 Å) is quite different from that of Y^{3+} (0.893 Å). Therefore, one may expect some lattice

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distortion compared to the case of $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ and possibly different values for the electron-phonon coupling. Moreover, Sm^{3+} has peculiar paramagnetic properties since its first excited level is close to the ground state $^6\text{H}_{5/2}$ (separation between levels $\sim 1\,500\text{ K}$), so that a simple Curie law is not obeyed.

We have reported preliminary results on several $\text{LnBa}_2\text{Cu}_3\text{O}_{7-x}$ compounds, including $\text{SmBa}_2\text{Cu}_3\text{O}_{7-x}$, in reference [7]. Meantime, other groups have reported some properties of the Sm compound with the highest possible T_c [9]. Our purpose was to study samples with different oxygen stoichiometries and to get some insight into the transition from semiconducting-like to metallic and superconducting behaviour. We have therefore prepared samples by varying the synthesis conditions and characterized them by electrical resistivity and magnetic susceptibility measurements. Since electrical resistivity alone does not give enough information on the carriers and transport mechanism, we also report thermopower data. Electrical resistivity has also been studied in magnetic fields up to 8 T , in order to obtain preliminary information on the dependence of the critical field B_{c2} on the preparation conditions. Along the same line, pressure measurements up to 20 kbar have been performed on samples with different properties. Finally a preliminary report of tunnelling experiments is given.

2. Sample preparation and experimental techniques.

The compounds have been prepared by solid reaction of mixed oxide powders (CuO , BaO and Sm_2O_3) in proper amounts. Successive cycles of heating, cooling and grinding were performed. For the final treatment, they were pressed into pellets (at 4 Tons/cm^2) and sintered at 950°C or $1\,050^\circ\text{C}$.

Table I gives the details of the preparation conditions, annealing temperatures and times and cooling procedure for the samples reported here.

Characterization by X-ray powder pattern show that the samples are principally single phase, with the same structure as $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ [10]. The superconducting samples were found orthorhombic with lattice parameters, in the case of the highest T_c , $a = 3.85\text{ \AA}$, $b = 3.91\text{ \AA}$, $c = 11.72\text{ \AA}$, in excellent agreement with the values reported in reference [9]. The samples either non-superconducting or with a low T_c were generally found tetragonal ($a = 3.88\text{ \AA}$, $c = 11.66\text{ \AA}$), as reported for $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ [11]. Magnetic susceptibility measurements have been performed with a vibrating sample magnetometer. Electrical resistivity measurements have been made with the four-point technique, using pressed indium as electrical contacts. For critical fields measurements, magnetic fields up to 8 T were available. Thermopower has been measured with a differential method using a dynamical technique. Electrical resistivity has also been measured with hydrostatic pressures up to 18 kbar . Pressure was generated in a hydrostatic type beryllium copper self-clamped vessel. The sample was pressurised inside a teflon capsule by a $50 : 50$ pentane isoamyl alcohol mixture. The value of the pressure was obtained from the superconductive transition of lead. Current-voltage as well as conductivity voltage characteristics have also been measured at 4.2 K on some samples. The experimental details are given in section 5.

3. Magnetic properties.

The magnetic susceptibility has been measured in small fields ($B \sim 10\text{ G}$) after cooling in zero field. Figure 1a shows typical data obtained either after cooling in zero field or after cooling in a field of

Table I. — *Preparation conditions and related superconducting transition temperatures in $\text{SmBa}_2\text{Cu}_3\text{O}_{7-x}$.*

Sample	Annealing temperature ($^\circ\text{C}$)	Annealing time (hours)	Cooling procedure	T_c^{onset} (K)	T_c^{midpoint} (K)
2	950	1 (in air)	— quenched (200°C/min) from 760 to 30°C	—	—
7	1 050	16 (in air)	— quenched (200°C/min) from 550 to 30°C	85	80
25	950	5 (in air)	— slow cooling (100°C/hour) down to 30°C	70	45
31	1 050	12 (in air)	—	70	60
33	1 050	1 (in air)	—	40	20
47	950	72 (in air)	—	87	79
48-3	950	3 (in air)	—	87	74
52-4	1 050	8 (in air)	—	84	75
73	500	50 (in oxygen)	—	92	91

Fig. 1. — (a) Magnetic susceptibility measured in a field of 17 G vs. temperature — zero cooling field ----- cooling field 17 G (sample 7). (b) Magnetic susceptibility measured in a field of 17 G after cooling in zero field (samples ----- 7, — 25, — 31, — 47, —▲— 73). Note that a complete diamagnetic screening ($|\chi| = 1/4 \pi \text{ cm}^{-3}$) corresponds roughly to $|\chi| = 1.3 \times 10^{-2} \text{ emu g}^{-1}$.

17 G. Results obtained for samples with different T_c are shown in figure 1b. The superconducting transition temperatures are found to be in the range 60-90 K. No correction for the diamagnetizing field has been made: it is expected to be less than 5 %, since the samples were in shape of rectangular rods, typically $5 \times 2 \times 1 \text{ mm}^3$. The diamagnetic shielding factors $-4 \pi \chi$ were evaluated by assuming a specific mass of 6 g cm^{-3} , smaller than the theoretical value of 6.9 g cm^{-3} , to take into account the compacity factor of the powder. Orders of magnitude of 65 % to 75 % were found in the highest T_c samples. This factor was generally found to decrease with T_c . Figure 2 shows the magnetic susceptibility measured in a field of 2 T both for a semiconducting-like (see Sect. 4) and a superconducting sample. These data show that sample 2 obtained by quenching from 1 050 °C down to room temperature is non superconducting. It has now been well established that

Fig. 2. — Magnetic susceptibility measured in a field of 2 T vs. temperature (sample — 2, ----- 7). The susceptibility expected from the Sm^{3+} ions is shown by the continuous line.

samples of $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ obtained in a similar way have a stoichiometry far from $x = 0$ and are non superconducting [14]. Obviously, the same is true for the Sm compound.

One should mention that preliminary XANES studies performed with the synchrotron radiation provided by LURE (Orsay) have corroborated that the valence state of Sm is 3+ in these compounds [12]. We have therefore shown in figure 2, for comparison, the values of the susceptibility expected for paramagnetic Sm^{3+} ions only [13].

4. Transport properties.

The electrical resistivity is shown as a function of temperature in figure 3 for several samples. Sample 2 is semiconducting-like while samples 25, 7, 31 and 73 are superconducting. Sample 33 shows a complex behaviour, probably due to the coexistence of several phases. The highest onset temperature for superconductivity is found to be 92 K and the transition width (10 %-90 %) of the order of one degree in this case.

The thermopower S measured for superconducting and non superconducting samples is plotted vs. temperature on figure 4 [15]. In all cases, it is positive, therefore hole-type. Preliminary Hall effect measurements performed between 120 K and 150 K show that the Hall constant is positive. For the superconducting samples, S goes to zero as $T \rightarrow T_c$, as expected. Above T_c , the values of S are in the range 10 to $40 \mu\text{V K}^{-1}$, values quite large for metals. A maximum in $S(T)$ above T_c appears as a precursor to the superconducting transition. The non superconducting sample shows an anomalous temperature dependence, neither characteristic of a simple metal nor of a semiconductor. Figure 5 shows for comparison the temperature dependance of the electrical resistivity and of the thermopower for a superconducting sample.

Fig. 3. — Electrical resistivity vs. temperature (a) samples ----- 7, ——— 31 ——— 25 — Δ — 73. (Note the change of scale for samples 31 and 25.) (b) Non superconducting samples ——— 2, ----- 33.

Fig. 4. — Thermopower vs. temperature for samples 2 (○), 31 ($\blacktriangle$), 47 ($\bullet$), 7 (+), 73 ($\triangle$).

In order to gain some insight into the nature of the transport in these materials and the relation with the superconducting transition, we have plotted in figure 6 both the value of the resistivity measured just above T_c and of the thermopower at 300 K vs. T_c for several samples. It is clear that T_c is larger for smaller values of both $\rho(T_c^+)$ and $S(300 \text{ K})$.

Preliminary information on the upper critical field has been obtained by measuring the resistivity at temperatures close to T_c as a function of the magnetic field. Figure 7a shows typical results. In figure 7b, we have represented the thermal dependence of the critical field B_{c2} , defined as the value

Fig. 5. — Thermopower and resistivity vs. temperature for sample 7.

Fig. 6. — Resistivity measured just above T_c vs. T_c and Thermopower at 300 K vs. T_c .

corresponding to $\rho(T_c^+)/2$ (midpoint of the resistive transition), for several samples. One can estimate that the slope dB_{c2}/dT in the interval 2-8 K is close to 4 K K^{-1} in the highest T_c samples.

5. Effect of pressure on the transition temperature.

The resistance has been measured as a function of temperature for several pressures, ranging between 0 and 19 kbar. Figure 8a shows the results obtained for two samples with different T_c . The resistivity is found to be smaller above T_c under pressure while T_c is increasing with pressure. The values of T_c are plotted vs. pressure in figure 8b for the two samples of $\text{SmBa}_2\text{Cu}_3\text{O}_{7-x}$ and for La_2CuO_4 as obtained in reference [17]: values of 0.4 to 0.5 K/kbar are found for dT_c/dP . They are in the same range as in the case of La_2CuO_4 . Figure 8c shows that the pressure effect seems to decrease with increasing T_c .

6. Tunnelling experiments.

We describe measurements of the current-voltage (I - V), the conductivity-voltage (σ - V) and the

Fig. 7. — (a) Resistivity vs. magnetic field at temperatures below and close to T_c (sample 47). (b) Critical field estimated from the mid-point of the curve $\rho(B)$ vs. temperature for several samples (7 ($\blacktriangle$), 47 ($\diamond$), 52-1 ($\blacklozenge$), 48-3 ($\square$), 73 ($\circ$)).

characteristics of $d \ln \sigma / dV - V$. In similar investigations on the new high- T_c oxides, point contacts are generally prepared by pressing a metal tip on the sample [18] or by pressing two pieces of the new superconductor together [19, 20]. It should be noted that Esteve *et al.* [18] observed Josephson junction characteristics, even when the metal tip was not superconducting. The authors concluded that the junction is inside the material rather than between the tip and the sample as in « classical » point contact-Josephson junctions (4 V) [20]. Using point contacts with the high T_c oxide, the Josephson junction is thought to be under the point-contact, where the current density is highest, and results from grain boundaries, cracks or other defects [18].

In this work, $\text{SmBa}_2\text{Cu}_3\text{O}_{7-x}$ samples, with $T_c^{\text{onset}} = 85$ K, were mounted in a brass holder providing one electrical contact of a large area (some mm^2). For this contact, indium was pressed on the sample. For the opposite point contact a *non*-superconducting tip, gold plated and spring-loaded, was used. The tip had a diameter of about 50 μm .

The electric measurement always included the series resistance of the tip. This resistance was less than 0.1 Ω . High frequency π -filters were used to

reduce the effect of noise. The brass holder with the sample and the point contact was mounted in an arrangement which could be filled with helium gas and immersed into liquid helium.

Two different types of non-linear I - V curves were obtained. The first type displayed the structure of Josephson point contacts. The critical current varied from sample to sample between 0.5 and 20 μA . The d.c. supercurrent mostly had a finite slope corresponding to a series resistance of several Ohms (Fig. 9a). Near the critical current the I - V characteristic showed thermal rounding as known from Josephson junctions with low critical currents. Noise rounding made it difficult to measure critical currents at temperatures considerably higher than 4 K.

For some contacts we found a series array of two or even three Josephson junctions. A series array of two junctions with higher critical currents, little series resistance and noise rounding is shown in figure 9b. The curve also shows hysteretic jumps characteristic of Josephson junctions with not too small parallel capacitance C . (Stewart-McCumber parameter $\beta_c = 2e(\hbar)J_c R^2 C \geq 0.8$ [21]). One should note that I - V curves as in figure 9b are obtained apparently randomly. Once the contact gets open a resetting never led to a similar I - V curve so far.

Our measurements with non superconducting tips confirm previous suggestions that the junction is in the bulk of the superconductor, probably under the tip [18, 20a]. The superconductor consists then of a random network of Josephson junctions. Some point contacts yield (by chance) access not only to one but to a series array of junctions. The finite slope of several Ohms in the d.c. supercurrent could be due to boundary resistance between grains and (or) to the presence of non superconducting phases in the samples.

The second type of I - V curves we found displayed a shape distinctly different from that of Josephson point contacts. Such an I - V curve and the corresponding σ - V curve are shown in figure 10a. This type was generally found by applying less pressure to the contact and could be obtained much easier than curves with a clear d.c. Josephson current. Three features are noted in figure 10a : 1) a broad conductance minimum with a small offset of about 2 mV from zero voltage bias. 2) Small conductance minima at finite voltages which are marked by asterisks. 3) A small conductance peak centred at zero voltage bias. The small conductance peak at zero voltage can be a remainder of a d.c. Josephson current. It did not appear in all curves displaying the broad conductance minimum.

The small conductance minima at finite bias did not occur in all curves displaying the broad conductance minimum but were also seen without the conductance peak at zero bias. They could be due to

Fig. 8. — (a) Resistivity vs. temperature at different pressures. Samples : 31 ; ($\times$) 0 kbar, ($+$) 16.8 kbar ; 47 ($\diamond$) 0 kbar, ($\emptyset$) 18.9 kbar. (b) T_c vs. pressure for SmBaCuO_{7-x} (samples 47 and 31) and La₂CuO₄ (from Ref. [17]). dT_c/dp is found to be 0.41, 0.49, 0.42 K kbar⁻¹ for samples 47, 31 and La₂CuO₄ respectively. (c) Relative variation of T_c with pressure ($\sim d \log T_c / dp$) vs. T_c for samples of SmBaCuO_{7-x} and La₂CuO₄.

Fig. 9. — (a) Example of current-voltage characteristic obtained with sample 52-4 of $\text{SmBa}_2\text{Cu}_3\text{O}_{7-x}$. (b) Other type of characteristic showing the existence of two Josephson junctions in series.

the existence of a network of Josephson junctions, among which one becomes normal when its particular critical current is exceeded [20b]. The problem of this interpretation is, however, that we could not see a clear change of the conductance of the sample when passing through a small conductance minimum.

A broad conductance minimum similar to the curve of figure 10 has been reported for some contact settings on $\text{Y}_{0.35}\text{Ba}_{0.65}\text{Cu}_3\text{O}_{7-x}$ ($x \sim 0.7$) by Cantor *et al.* [19]. In these experiments two pieces of the high T_c material were pressed together. The authors point out that the conductance minimum can be expected for tunnelling through granular barriers. Zeller and Giaever [22] have shown that tunnel junctions containing small metallic particles in the oxide display a broad conductance minimum and

Fig. 10. — (a) Current-voltage and conductivity (dI/dV)-voltage characteristics. Note the peak at zero voltage and the spikes on the σ - V curve. (b) $d(\ln \sigma)/dV$ as a function of applied voltage V . The locations of the broad maxima indicate a superconducting energy gap Δ in the range 5-10 meV.

explained this in terms of an activation energy which reduces current flow at small voltages.

An interesting result of this work is that the σ - V curves can display the structure of the superconductive energy gap (of the small particles), just as the I - V curve of a superconductor-insulator-normalconductor junction displays the energy gap Δ of the superconducting electrode. The σ - V characteristic in figure 10a has (except for the peaks at zero and finite biases) a shape like the I - V curve of a SIN junction of low quality. It seems that there is a gap structure around ± 10 mV, but it is very round.

Another way of analysing current-voltage measurements is to plot the logarithmic derivative $d/dV(\ln \sigma)$ as a function of applied voltage [23]. Such a curve is shown in figure 10b for the same sample as in figure 9. Peaks occur at about ± 7 mV. Such peaks indicate the onset of new conductance channels which can be due to e.g. localized states in a tunnel barrier or to the presence of an energy gap in tunnelling through granular structures. If there would be a single gap Δ a very sharp peak at $V \sim \Delta/e$ should occur. Broad peaks as in figure 10b

indicate the presence of a distribution of different values of the energy gap, corresponding gap values are in the range 5-10 meV, which is consistent with figure 10a.

7. Discussion.

In spite of the fact that the oxygen stoichiometry has not been measured on our samples of $\text{SmBa}_2\text{Cu}_3\text{O}_{7-x}$, it is clear that the variation of the preparation conditions induce different stoichiometries and therefore different T_c . Preliminary thermogravimetric studies [24] show that the temperature and annealing time dependences of the oxygen content in our samples are similar to those found in $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ [14]. The results reported here therefore correspond to values of x close to 0 for the highest T_c samples and to values larger than 0.5 for the semiconducting-like samples.

The results obtained for the diamagnetic shielding factors ($\sim 75\%$) and for the Meissner effect ($\sim 35\%$) (see Fig. 1a) are similar to what has been found on $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ [25]. One should note that the magnetic measurements in low field (Fig. 1b) show that the decrease of χ below T_c seems to be less steep for lower T_c . This indicates that the low T_c samples are probably more inhomogeneous and contain regions with different values of T_c .

The magnetic measurements in high fields corroborate that the valence state of Sm is $3+$, with a temperature dependent effective magnetic moment. However, the data cannot be accounted for only by the Sm^{3+} magnetic properties. Figure 2 shows clearly that, in the case of the superconducting sample, the susceptibility includes a term varying slowly with temperature, of the order of $1 \times 10^{-6} \text{ emu g}^{-1}$. This term could be due mainly to Pauli paramagnetism, if the orbital Van Vleck paramagnetism is negligible. It would correspond to a density of states at the Fermi level of roughly 8 eV^{-1} per Cu ion. This is a rather large density of states. However, one cannot exclude that the susceptibility includes a Curie-type contribution due to localized paramagnetic Cu ions in some non superconducting fraction of the sample.

The magnetic susceptibility of the non superconducting sample cannot be due at low temperature to Sm^{3+} ions only. The Curie-like behaviour below 100 K may also correspond to the presence of some localized paramagnetic Cu ions. The electrical resistivity of these samples is increasing with decreasing temperatures, therefore semiconducting-like, although the order of magnitude of ρ ($10^{-1} \Omega \text{ cm}$ at room temperature) could be that of a « bad » metal.

Figure 3a shows that it is possible to prepare samples with various intermediate properties between a « good » superconducting sample and a semiconducting-like one. However, one should

point out that while the magnetic susceptibility corresponds to a real bulk property, the electrical resistivity data are determined by the percolation between the most conducting or superconducting regions in inhomogeneous samples. This results, in the case of « intermediate » samples, in discrepancies between the values of T_c obtained by susceptibility and by resistivity measurements.

The thermopower data indicate that the transport properties are hole type. This is consistent with results obtained on $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ [26] (except those of Ref. [27]). The Hall effect has also been found p-type in the Y compound [28], either in sintered powder or in epitaxial thin films, for magnetic field parallel to the c -axis [29]. However, single crystal data show a negative Hall effect for current and magnetic field parallel to the Cu-O layers [30]. The physical properties of these oxides are highly anisotropic [31-32] and one should not forget that powder data give only an average behaviour. Furthermore, these data are, in this case, complicated by the presence of several phases in the powder, as shown by the tunnelling studies: the samples contain both superconductor-insulator-superconductor Josephson type and normal metal-insulator-superconductor junctions. In other words, the sintered powder oxides are inhomogeneous materials containing insulating or semiconducting, metallic, superconducting or not, regions. These inhomogeneities might be related to grain boundaries. The physical properties therefore result from a combination of these different types of regions. Especially the measured thermopower reflects the presence of both semiconducting and metallic domains. Therefore, the comparatively large value of the thermopower above T_c may be due to the presence of semiconducting regions. It is tempting to attribute the maximum found above T_c to superconducting precursor (fluctuations) effects or to a strong electron-phonon coupling as in phonon drag phenomena: only single crystal data can corroborate this picture. The behaviour of the thermopower in the semiconducting-like sample is rather peculiar: it is also probably due to the coexistence of several phases in the sample.

There is however a correlation between the values of T_c and the transport properties in the normal state: T_c is larger for smaller values of the resistivity or for smaller values of the thermopower. This is related to the band structure and to the filling of the relevant conduction bands: the « best » metallic properties, therefore the largest density of states at the Fermi level, correspond to the highest T_c , as expected in the BCS theory. The situation in these oxides is in fact rather complicated since the deviation from stoichiometry (from $x = 0$) corresponds not only to a change of electron concentration, but also to an increased disorder resulting from oxygen vacancies and to a change of crystal symmetry (from

orthorhombic to tetragonal) [33]. Band structure calculations taking into account these properties have now been performed for $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ [34, 35]. They are consistent with an increase of T_c with the oxygen content as well as with the degree of oxygen vacancy ordering [35].

The magnetoresistance has been found positive in the normal state of all samples: this is consistent with a normal metal and indicates that the paramagnetism of the Sm^{3+} ions has no effect.

The value of the slope $(d\mathcal{B}c_2/dT)_{T_c}$, found close to 4 T K^{-1} for the highest T_c sample, is comparable to or larger than that obtained in the Y or other rare earth compounds: values of 2.8 T K^{-1} are reported in reference [36]. However, data obtained in fields higher than 8 T would be required for a real comparison. One should also note that $(d\mathcal{B}c_2/dT)_{T_c}$ seems to decrease steeply with T_c (see Fig. 7b).

Pressure both decreases the resistivity in the normal state and increases the superconducting temperature, as has been found in the Y compound as well as in other Ln (Gd, Er, Yb) compounds [37, 38]. However, the values of dT_c/dP obtained in the Sm compound of 0.4 to 0.5 K kbar^{-1} are larger than those reported for other materials (0.09 to 0.19 K kbar^{-1}) in Ref. [32]). Our results together with those of Borges *et al.* [32] seem to indicate that the effect of pressure on T_c is larger in the rare earth compounds than in the Y one. This is possibly due to the size of the Ln^{3+} ion larger than that of the Y^{3+} , which may result in a higher compressibility coefficient. One should note that pressure does not seem to change the slope of the curve $\rho(T)$. This may indicate that this slope is due to electron-phonon coupling involving phonons weakly modified

by the pressure and possibly internal to the (001) plane of the layers. On the contrary, the comparatively large effect of the pressure on T_c may be due to an increased three dimensional character under pressure.

Figure 8b and c show also the results obtained previously for the effect of pressure on La_2CuO_4 [17]. Although superconductivity in La_2CuO_4 may be due to filaments of a minor phase [39], it is interesting to note that there is a correlation between the relative change of T_c under pressure and the superconducting transition temperature (Fig. 8c) in this class of materials.

8. Conclusion.

Our result corroborate that the properties of the $\text{SmBa}_2\text{Cu}_3\text{O}_{7-x}$ superconducting oxides are generally similar to those of $\text{YBa}_2\text{Cu}_3\text{O}_7$. A detailed comparison is presently made difficult by the powder nature of the samples, associated with considerable inhomogeneity in both types of materials. The upper critical field may be comparable or larger in the Sm than in the Y compound. The effect of pressure on T_c may also be larger. However, single crystal data would be necessary to decide whether the size of the rare earth ion plays really some role in the values of important parameters, such as the critical current and critical field.

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