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ARE THE NEEL TEMPERATURE \((T_N)\) AND THE SUPERCONDUCTING TRANSITION TEMPERATURE \((T_C)\) SIMPLY RELATED IN \(La_2Cu_xO_4-y\) UNDER PRESSURE?

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Abstract. - We have investigated under high pressure a sintered \(La_2Cu_{1.02}O_{4-y}\) sample which exhibits bulk superconductivity below \(T_C \approx 37\) K and antiferromagnetic ordering below \(T_N \approx 240\) K. \(dT_N/dp\) has been determined using d.c. susceptibility and resistivity measurements under pressure. \(dT_c/dp\) and \(dT_N/dp\) are found to have opposite signs. This experimental result is confronted to the theory.

It is well known that \(La_{2-x}A_xCuO_4-y\) compounds \((A = Sr, Ba or Ca)\) are high \(T_C\) superconductors for \(x > 0.06\) with a maximum superconducting transition temperature \((T_C)\) of \(37\) K for \(x \approx 0.15\) \([1, 2]\). Moreover \(La_2Cu_xO_{4-y}\) \((0.98 \leq x \leq 1.04)\) annealed under oxygen have been found to be superconductors with \(T_C \approx 37\) K \([3]\).

On the other hand, antiferromagnetic order has been evidenced by neutron diffraction experiments in \(La_2CuO_{4-y}\) compounds \([4]\) in which values of the Néel temperature \((T_N)\) between 0 and \(\approx 300\) K have been reported to depend on the values of \(y\) \([5]\). \(T_N\) is found to decrease towards 0 for \(y\) approaching 0.

For the Ba-La-Cu-O compounds, it has been reported a large pressure effect on \(T_C\) which cannot be accounted for by phonon mediated B.C.S. theory. However less conventional models such as those based on charge and spin fluctuations could explain large \(dT_c/dp\) values \([6]\). In such models, the pressure effects on \(T_C\) and \(T_N\) are expected to be correlated. The knowledge of \(dT_N/dp\) can thus help to confirm or confirm the validity of these different models. In this work we report the first measurement of \(dT_N/dp\) in the high \(T_C\)'s superconductors.

This study was made on a \(La_2Cu_{1.02}O_{4-y}\) sintered sample from the same series than in \([3]\), exhibiting a superconducting transition temperature \(T_C = 37\) K.

Very low values of \(H_C\) are anticipated for our sample \([3]\). In a d.c. field of 1 Oe, the Meissner effect is 25%. In a low a.c. field of 2 \(\times 10^{-3}\) Oe, the diamagnetic susceptibility is 90% of \(-1/4\pi\) which shows the bulk nature of the superconductivity.

In figure 1 we show the temperature dependence of the magnetic susceptibility under fields of 1, 30 and 60 kOe respectively. The results are in agreement with a previous study \([7]\). The presence of a maximum in the \(\chi(T)\) curve is characteristic of the antiferromagnetic ordering. \(T_N\), defined as the inflexion point below the maximum, decreases under field. It takes the value of 240 K, 227 K and 124 K under 1, 30 and 60 kOe respectively, in agreement with a recent work \([8]\).

The magnetic susceptibility does not follow a well defined Curie-Weiss law above \(T_N\). The susceptibility under a 1 kOe field can be fitted by \(\chi(T) = x_0 + C / (T - \theta_p)\) with \(x_0 \approx 4.7 \times 10^{-5}\) e.m.u./mole/Oe in limited ranges of temperature. Depending on the temperature range, different values can be derived for the paramagnetic Curie temperature \(\theta_p\) and for the magnetic moment \(\mu\) per Cu ion, leading to \(\theta_p \approx 51\) K and \(\mu \approx 0.27 \mu_B\) for 300 K < \(T < 320\) K and to \(\theta_p \approx 240\) K and \(\mu \approx 0.12 \mu_B\) for 270 K < \(T < 290\) K, in agreement with previous works \([5, 8]\). Such a very rapid decreasing of the measured effective moment when the temperature decreases can be partly due to some 3D antiferromagnetic short range order. Those features imply a complicated nature of the antiferromagnetic order including ferromagnetic correlations and a temperature dependence of the magnetic moments.

We measured the d.c. field magnetic susceptibility of the sample under hydrostatic pressure (H.P.) up to...
Fig. 2. – Isobaric curves of (a) d.c. magnetic susceptibility, \( X \); (b) temperature derivative of the resistance, \( dR / dT \) (with vertical shifts for clearness); lower part: pressure variation of \( T_c \), \( T_m \) and \( T_1 \) (see text) for \( \text{La}_{2}\text{Cu}_{1.02}\text{O}_{4-\nu} \).

7.6 kbar in a self clamped little cell (of \( \approx 40 \) g weight) using a SQUID magnetometer. All parts of the cell are in non magnetic ST 125 Beryllium-Copper (Be-Cu). We used light hydrocarbon as pressure medium and lead as manometer. In the experimental range the cell contribution is diamagnetic. The maximum signal of the sample is only about 5/100 of the overall susceptibility. Curves of \( \chi (T) \) under different pressures are given in figure 2a. They exhibit a well-defined kink for a temperature \( T_m \), taken as characteristic of the magnetic ordering. \( T_m \) is found to decrease at a rate: \( dT_m / dp = -0.5 \) K/kbar.

For resistivity measurements under H.P. up to 18.7 kbar we used another self-clamped Be-Cu cell with the same pressure medium and manometer. On the resistivity curves, a large bump is associated to the magnetic ordering. The curves of \( dR/dT \) (Fig. 2b) exhibit a well defined minimum for a temperature \( T_1 \), taken as characteristic of the magnetic ordering. \( T_1 \) decreases under pressure at a rate: \( dT_1 / dp = -1 \) K/kbar.

On the other hand, we found that the superconducting transition temperature \( T_c \) (midpoint resistive transition) increases under pressure at a rate: \( dT_c / dp = +0.23 \) K/kbar, in agreement with a previous work [3].

Pressure effects on \( T_c \), \( T_m \) and \( T_1 \) are plotted in figure 2 (lower part). The Néel temperature \( T_N \) (average of \( T_m \) and \( T_1 \)) is estimated to decrease with pressure at a rate lying between -0.5 and -1 K/kbar.

In the resonating-valence-bond (R.V.B.)-like models based on strong short range interelectronic repulsions, the superconducting transition as well as the antiferromagnetic ordering are based on the same physical mechanism. In these models \( T_N \) and \( T_c \) depend on the hopping integral \( t \), leading to:

\[
\frac{d \ln T_N}{dp} \approx 2 \frac{d \ln t}{dp} \quad \text{and} \quad \frac{d \ln T_c}{dp} = \frac{d \ln t}{dp} \cdot f(p)
\]

where \( f(p) \) is a positive function of the pressure, depending on the exact nature of the R.V.B. model [6]. This is in apparent contradiction with our experimental results.

However, pressure effects on \( T_N \) may originate in considerations which are not taken into account by these models. Pressure may play a preponderant role on the correlation length as does doping [4]. This is in agreement with the suppression of \( T_N \) by quasihydrostatic pressure as we observed on the same sample [9]. Sensitivity of \( T_N \) on doping or pressure could originate from modifications of the balance between antiferro and ferromagnetic interactions. From references [10, 4] such ferromagnetic interactions come from Cu\(^{2+}\) spins pairs ferromagnetically coupled via an oxygen hole O\(^-\).

The presence of such competing exchange interactions leading to frustration might be responsible for the non trivial pressure variations observed. Therefore our results cannot constitute a definitive argument against the R.V.B.-like models, but they have to be taken into account.

[9] Beille, J. et al., to be published.