FIELD TRANSITION FROM 3D TO 2D ANTIFERROMAGNETIC CORRELATIONS IN NON-STOICHIOMETRIC La2CuO4-δ

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FIELD TRANSITION FROM 3D TO 2D ANTIFERROMAGNETIC CORRELATIONS IN NON-STOICHIOMETRIC $La_2CuO_{4-\delta}$

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Abstract. – SQUID magnetization experiments performed up to 70 kOe show the existence of a metamagnetic-like transition in $La_2Cu_{1.02}O_{4-\delta}$ from which one derives the inter and intraplanar coupling constants as well as the 2D correlation length. The results indicate either a strong field dependence of the correlation length or a drecrease of the local moment with the Néel temperature ($M \propto \sqrt{T_N}$ above 50 K and $M \simeq$ constant below this temperature).

It is surprising to see the lack of field experiments in Cu-based superconducting systems. In this paper we give the first evidence for a metamagnetic-like transition in a non-stoichiometric $La_2CuO_{4-\delta}$, and we interpret this result in terms of a simple model of competing interplanar coupling, applied magnetic field and athermal fluctuations (presumably 2D quantum fluctuations).

The magnetization curves are all similar to the one given figure 1. The transition field H_c is defined by the equality of hatched areas. The deduced field-temperature phase diagram is given figure 2 in reduced coordinates. Note that the data points coming from $M(H)$ curves and those corresponding to the maximum or inflexion point of the susceptibility fall on the same curve, proving that this line corresponds effectively to a metamagnetic transition and not to a simple rotation of the Néel vector.

Physically the metamagnetism of $La_2Cu_{1.02}O_{4-\delta}$ must be associated with interplanar coupling field breaking leading to more or less extented 2D correlations ξ. Equating field and thermal energies for a cluster of size $(\xi / a)^2$, we get:

$$\chi^l_{T_N} H_c^2 = 3k \left(J_0 M^2_{(T_N)} \left(\xi_{(T_N)} / a \right)^2 - T_N \right) \quad (1)$$

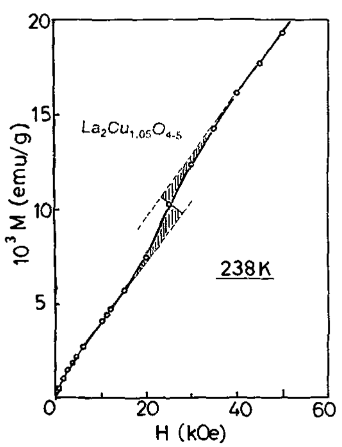

Fig. 1. – Magnetization curves of $La_2Cu_{1.02}O_{4-\delta}$ at 238 K.

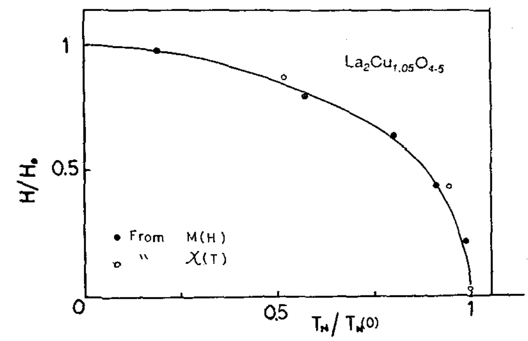

Fig. 2. – Variation of the metamagnetic-like transition field with the Néel temperature.

where $\chi^l_{T_N} = \chi_m (\xi / a)^2 / N$ is the quasi 2D cluster susceptibility. The measured susceptibility χ_M can be described by a Curie-Weiss like (χ_m) plus a temperature independant (χ_0) susceptibility. Putting $h = H_c(T) / H_c(0)$, $t = T_N(H) / T_N(0)$, $m = M(T_N) / M(0)$ and $s = \chi(T_N) / \chi(0)$ expression (1) writes:

$$h^2 = \frac{m^2}{s} - \frac{t}{s} \frac{T_N(0)}{J_0 M^2_{(0)}} \left(\frac{\xi}{a} \right)^{-2}, \quad (2)$$

$$H_0^2(0) = 3RJ_0 M^2(0) / \chi_m(0). \quad (3)$$

The unknown quantities are i) $\chi_m(T)$ below 50 K where our samples become superconducting, ii) $M(T)$ (we only know $M(310) \simeq 0.27\ \mu_B$ from the Curie-Weiss like behaviour between 300 and 310 K iii) J_0 and $\xi(T)$. We have done, at the moment, two different fits of the measured $H_c(T_N)$ to expression (2) according to the following different hypotheses:

1) $s = m = 1$, 2) $s = 1$ and m variable.

$m = s = 1$: expression (2) reduces to

$$h^2 = 1 - 1.95 \times 10^5 \left(\frac{\xi}{a} \right)^{-2} t \quad (4)$$

for the measured $T_N(0) = 260$ K, $H_c(0) = 60$ kOe, and the self consistant values $\chi_m(0) = 9 \times 10^{-5}$ emu/mole Oe, $M(0) \simeq 0.25\ \mu_B$; $J_0 = 2.16 \times$

$10^{-2}\text{K}/\mu_B^2$ has been obtained from (3). The correlation length $\xi(T_N)$ deduced from the fit is given figure 3a; it certainly does not fit the relation [1]:

$$\frac{\xi}{a}(T_N) = \frac{J_1 M^2}{T_N} e^{4\pi J_1 M^2 / T_N}. \quad (5)$$

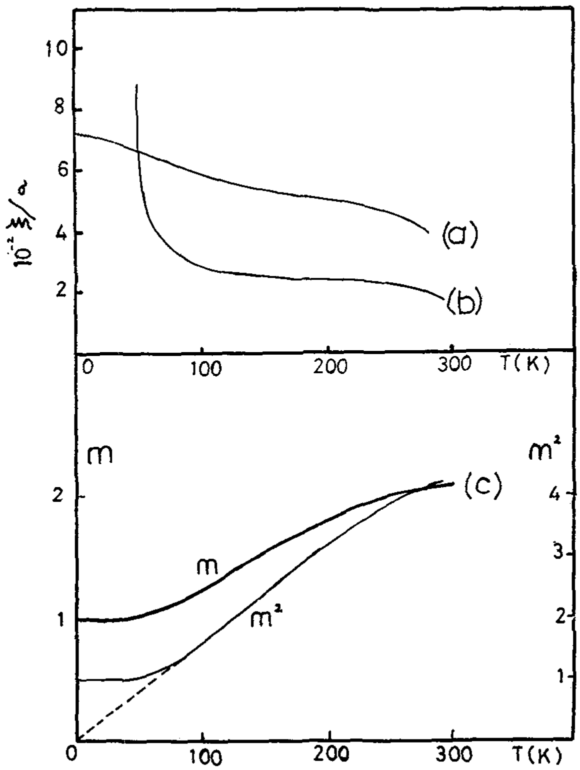

Fig. 3. – Evolution of the 2D correlation length deduced from the fit of $H_c(T_N)$ to equation (2). Case (a): $s = 1$, $m = 1$. Case (b): $s = 1$, $m(T_N)$; the variations of $m(T_N)$ and $m^2(T_N)$ are given in (c).

The moment M being supposed independant of T in this case $(s = m = 1)$, this result is consistant with a strong field induced decrease of ξ (roughtly $\xi(H_c, T_N) \propto \xi^{-1}_{(T_N)}$ although $\chi H_c^2 \ll J_1 M^2$). Using (5) in zero field, we get, for $\xi(T_N(0))/a \simeq 440$, $J_1 = 2\,250\ \text{K}/\mu_B^2$ and hence $J_0/J_1 = 9.6 \times 10^{-5}$.

$s = 1$ and $m(T_N)$: expression (2) becomes:

$$h^2 = m^2 - 1.95 \times 10^5 \left(\frac{\xi}{a}\right)^{-2} \cdot t. \quad (6)$$

Using the experimental values given above we get from (3), $J_0 M^2(0) = 1.33 \times 10^{-3}$ K. Assuming that $\xi(T_N)/a \simeq 220$ [2], we deduce from $260 = T_N(0) = J_0 M^2_{(0)}\ m^2 \left(\xi_{(T_N)}/a\right)^2$, the value $m \simeq 2$, giving $M(0) \simeq 0.13\mu_B$. On the other hand (5) gives $J_1 M^2_{(0)} \simeq 31.7$ K. Finally we get $J_0 \simeq 7.9 \times 10^{-2}\ \text{K}/\mu_B^2$, $J_1 \simeq 1\,880\ \text{K}/\mu_B^2$ (i.e. $J_0/J_1 \simeq 4.2 \times 10^{-5}$) and the variations of $m(T_N)$ and $\xi(T_N)$ given figure 3c and 3b. Between 260 and 80 K, $m(T_N) \simeq 0.13\sqrt{T_N}\left(\text{K}^{1/2}\right)$, and $\xi(T)$ is almost constant; below 80 K, $m(T_N) \simeq 1$ and $\xi(T_N)$ diverges. This behaviour is quantitatively compatible with (5) and therefore we have not to invoke here the field dependance $\xi(H)$. 2D quantum fluctuations and/or disorder of impurities with large diffusion cross section should limit $\xi(T_N \to 0) \to \xi_0$, with no effect on the metamagnetic curve. a possible interpretation for the observed $m(T_N)$ variation (Fig. 3c) is the competition between fast athermal fluctuations (with $M(0) \simeq 0.13\ \mu_B$ due to J_0, $J_1 \neq 0$) and thermal fluctuations (with $M_{max} \simeq 1\mu_B$), leading to a crossover near 50 K. Such a value gives a characteristic frequency $\omega_q \simeq 10^{13}$ Hz for the athermal fluctuations (2D quantum fluctuations, breathing modes of $Cu^{2+/3+}$, role diffusion). Neutron scattering experiments as well as other magnetization measurements (in progress) should allow to determine the function $\xi(T_N, H_c(T_N))$.

[1] Chakravarty, S., Halperin, B. I. and Nelson, D. R., *Phys. Rev. Lett.* **60** (1988) 1057.

[2] Endoh, Y., Yamada, K., Birgeneau, R. J., Gabbe, D. R., Jenssen, H. P., Kastner, M. A., Peters, C. J., Picone, P. J., Thurtson, T. R., Tranquada, J. M., Shirane, G., Hikada, Y., Oda, M., Enomoto, Y., Suzuki, M. and Muraakami, T., *Phys. Rev. B* **37** (1988) 7443.