Comment on "Observation of Magnetic Ordering in Superconducting $La_{2-x}Sr_xCuO_4$ by Muon Spin Rotation"

In a recent Letter describing muon spin relaxation (μSR) experiments on $La_{2-x}Sr_xCuO_4$ Weidinger *et al.*[1] suggested that magnetism coexists with bulk superconductivity for $0.07 \leq x \leq 0.15$. Furthermore, the authors argue that the observed decrease in the effective internal field seen by the muon as x increases is due either to fluctuating moments or to a reduction in the moments themselves with Sr doping. We argue that these data are best explained by muon coupling to a dilute inhomogeneous concentration of copper magnetic moments, which arise from local Sr or O deficiency, and that the decreasing relaxation rate as x changes from 0.07 to 0.15 is due to an increased dilution of magnetic sites, not to decreased moments or to dynamic relaxation. Thus a discussion of the data "in the context of a magnetic pairing mechanism"[1] is not relevant. We base our conclusions on a simple analysis of the μSR line shapes and relaxation rates.

Apart from very low temperatures (35 mK) for $x=0.07$, the relaxation functions in Ref. 1 are all exponentials for short times (≤ 2 μs) with a decay rate $1/T_e$ which grows rapidly for $T<4$ K. We first argue that dynamic broadening, although expected to give rise to an exponential time-decay function, is unlikely for the following reasons. (1) If the relaxation arises from coupling to local moments which order below 4 K, one would expect a divergent temperature dependence for $1/T_e$ at low temperatures, which is not seen. (2) If the relaxation arises from coupling to uncorrelated paramagnetic impurities, a $1/T$ temperature dependence would be expected for $1/T_e$ due to Korringa[2] relaxation of the paramagnetic ions. This is also not seen. (3) Muon relaxation by conduction electrons is almost always far too weak to be observed in most metals.[3] Thus we conclude that the observed relaxation arises from an inhomogeneous distribution of quasistatic internal fields.

The key to understanding the experimental results of Ref. 1 is in the observed exponential relaxation functions. Weidinger *et al.* argue that the assumed magnetic state arises as a smooth continuation of the long-ranged antiferromagnetic order observed for $x \rightarrow 0$ (see Fig. 4 of Ref. 1). However, such a configuration (with moments on each Cu site) must lead to a Gaussian distribution of internal fields, and therefore an initial Gaussian time decay of the μSR relaxation function.[4]

Alternatively, an exponential decay is expected if the muons are coupled to randomly located, dilute concentrations of magnetic moments.[5,6] Such a situation would arise naturally if there were significant Sr or O deficient regions in the samples. Furthermore, if the Sr or O deficient regions were reasonably well dispersed then all muons stopping in the sample would be affected by the magnetic sites.

A rough estimate of the expected exponential relaxation rate $1/T_e$ for dipolar coupling can be made:[7] $1/T_e = Kpc\gamma_\mu \gamma_e \hbar \langle |m| \rangle$, where p is the copper-site concentration, γ_μ and γ_e are the muon and electron gyromagnetic ratios, and c is the percent of copper sites possessing a moment of magnitude $\langle |m| \rangle$. The constant K results from an orientational average of the moment m, and depends weakly on the nature of the assumed ordering ($K \simeq 4.5$ within 10%). Assuming that 10% of the copper sites possess moments of about $0.6\mu_B$ (observed in La_2CuO_4) we estimate $1/T_e \simeq 1.0$ μs^{-1}. This is close to the value observed by Weidinger *et al.* for $x=0.15$. (Note that a strictly linear concentration dependence is not expected here because of suspected metallurgical clustering.) We believe that the Sr or O deficient regions become significantly concentrated to yield the observed Gaussian relaxation function for $x=0.07$, where we suggest that only a small fraction of the sample contains superconducting regions. This is consistent with the decreasingly small values of the measured Meissner fractions as the Sr content is reduced. Additional support for our picture comes from recent mixed-state μSR data.[8]

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[1] A. Weidinger *et al.*, Phys. Rev. Lett. **62**, 102 (1989).
[2] J. Korringa, Physica (Utrecht) **16**, 601 (1950).
[3] R. H. Heffner *et al.*, Phys. Rev. B **39**, 11 345 (1989).
[4] R. S. Hayano *et al.*, Phys. Rev. B **20**, 850 (1979).
[5] R. E. Walstedt and L. R. Walker, Phys. Rev. B **9**, 4857 (1974).
[6] Y. J. Uemura and T. Yamazaki, Physica (Amsterdam) **109-110B**, 1915 (1982); S. A. Dodds *et al.*, Phys. Rev. B **28**, 6209 (1983).
[7] G. A. Gist and S. A. Dodds, Phys. Rev. B **30**, 2340 (1984).
[8] D. R. Harshman *et al.*, Phys. Rev. Lett. **63**, 1187 (1989).

