

Ishida, Kitaoka, and Asayama Reply: In the Comment by Alloul *et al.* [1], there is a large difference of appreciation between our group and the Orsay group. We stress that the conclusion from our Cu NMR/NQR [2] in Zn:YBCO₇ which is the optimum doped compound is *not analogous* to that from the Y NMR in Zn:YBCO_{6+x} reported by the Orsay group [3], although we admit that nonmagnetic impurities induce appreciable localized moments on the nearest neighbor Cu sites (hereafter denoted as Cu_{nn}) *in the underdoped compound*. In our Cu NMR measurement, we also observed a slight broadening of the Cu NMR resonance line in Zn:YBCO₇ following the Curie law. However, from our Cu NMR/NQR studies, we cannot conclude whether this Curie term is intrinsic or not at the present. Our Cu NQR measurement strongly suggests the suppression of the antiferromagnetic spin fluctuation (AFSF) at the Cu site close to Zn except for Cu_{nn}. We found shorter and longer components of T_1 in Zn:YBCO₇ above T_c . The value of the former is almost the same as that in the pure YBCO₇, and the fraction of longer component increases with Zn content, so that we can conclude that the longer T_1 corresponds to the Cu site close to Zn. And then, $1/T_1$ of this Cu site follows $(T_1 T)^{-1} = \text{const}$ relation with the suppressed value. This suppression of the AFSF was also seen even in the underdoped YBa₂Cu₄O₈ doped by Zn in which the induced moments are confirmed by our Cu NQR/NMR [4]. Therefore, it is concluded that the *induced spins on Cu_{nn} are not correlated* with the host AFSF, since there exists a region near the induced spin, where the AFSF is suppressed significantly. From the Y NMR experiment, this suppression around Zn cannot be observed, since the AFSF is filtered at the Y site due to the form factor of the hyperfine interaction.

On the contrary, Alloul *et al.* [1] suggest that the appearance of local magnetism on the Cu near Zn or Al impurities is the consequence of the *enhancement* of the AF correlation in the vicinity of the impurity. In order to investigate the character of the induced spin around the impurity, we have carried out the Al NMR in Al:LSCO. The Al NMR was shown to probe the induced spins on Cu_{nn} from the transferred hyperfine interaction through the Cu_{nn}(3d)-O(2p_σ)-Al(3s) covalent bonds. A remarkable finding was that the Cu_{nn}- $1/T_1$ deduced from the Al- $1/T_1$ exhibited an appreciable *decrease* upon heating which is in opposition to the behavior of the host Cu- $1/T_1$. From this novel T dependence of the Cu_{nn}- $1/T_1$, it became clear, for the first time, that magnetic fluctuations of the induced spins on Cu_{nn} were *isolated* from the correlated AFSF in the host. This isolation seems to occur in association with the collapse of the AFSF at the Cu sites over a distance of $\sim 2a-3a$ surrounding Cu_{nn}. The relaxation rate of the induced spins, $1/\tau$ described as $1/\tau = aT + b$ within experimental errors, is understood by following two relaxation channels, i.e., the T dependent one (aT term) from the sd -exchange coupling between the induced spins and the conducting holes and the T -

dependent one (b term) arising from the exchange coupling among the induced spins. Here we note that the evaluation of aT and b from the Al- $1/T_1$ is independent of whether the *induced spins are independently fluctuating* or the induced spins behave as *a single local moment* around Al like a spin cluster. This is checked by changing the number of sites from four to one and a magnitude of effective moments from $g\sqrt{S(S+1)} = 0.74$ to 1.47 in Eqs. (1)–(5) in Ref. [2]. Thus the values of J_{sd} and ΔT_c are almost the same in both the cases. As Alloul *et al.* pointed out, it might be considered that the conventional Abrikosov-Gor'kov (A-G) theory was so simplified that the actual impurity effect in the high- T_c superconductors could not be dealt with by this theory. However, since the actual theoretical treatment has not been developed yet, it is natural to analyze the experimental results within the A-G theory to understand the impurity effect. It is obvious that the experimental estimation of ΔT_c by Al doping on the basis of the A-G theory is smaller by more than 1 order of magnitude than the experimental value. We consider that this result is similar to the Y NMR done by Mahajan *et al.* [3]; however, Alloul *et al.* [1] conclude that the influence of induced local moments should not be considered as negligible, although the estimation of ΔT_c from the A-G theory is quite smaller than the actual ΔT_c . On the contrary, we conclude that the large reduction of T_c by nonmagnetic impurities is not due to the magnetic pair-breaking effect by induced local moments but due to other mechanisms, e.g., a strong potential scattering from nonmagnetic impurity sites on the d -wave model, which easily brings the residual density of states (RDOS) at the Fermi level. The RDOS in the superconducting state is clearly seen not only in Zn:YBCO₇ [1,5], but also in Bi2212, Tl2223, Hg1223, and Tl1212 [6] due to a crystal imperfection.

Apparently, a set of the Cu and Al T_1 results in Al:LSCO evolved new insights into novel changes of the electronic state on the Cu sites near the nonmagnetic impurities, and provided an important clue to address the symmetry of the order parameter to be d wave.

K. Ishida, Y. Kitaoka, and K. Asayama
Department of Material Physics
Osaka University
Osaka 560, Japan

Received 24 May 1996 [S0031-9007(97)02722-1]

PACS numbers: 76.60.-k, 74.20.Mn, 74.25.Nf, 75.40.Cx

- [1] H. Alloul, J. Bobroff, and P. Mendels, preceding Comment, Phys. Rev. Lett. **78**, 2494 (1997).
- [2] K. Ishida *et al.*, J. Phys. Soc. Jpn. **62**, 2803 (1993); Phys. Rev. Lett. **76**, 531 (1996).
- [3] H. Alloul *et al.*, Phys. Rev. Lett. **67**, 3140 (1991); A. V. Mahajan *et al.*, Phys. Rev. Lett. **72**, 3100 (1994).
- [4] G.-q. Zheng *et al.*, J. Phys. Soc. Jpn. **62**, 2593 (1993).
- [5] D. A. Bonn *et al.*, Phys. Rev. B **50**, 4051 (1994).
- [6] K. Asayama *et al.*, Czech. J. Phys. **46**, 3187 (1996).