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Scalar and Dipolar Coupling Studies of Organocuprates

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The structures of organocuprate reagents have been intensively studied[1] by solution molecular weight determinations,[2] X-ray structural[3,4] studies, and numerous spectroscopic[5,6] measurements. In addition, theoretical chemists have in the past five years made extensive investigations[3a,7] to predict the energies and geometries of organocuprate structures suggested by the experimental data collected on the compounds in solution. This interest in the structural composition of organocuprate reagents stems from the pervasive use and high utility of these reagents in synthetic organic chemistry. Specifically, the reactive properties (yields, selectivities) of these reagents depend greatly upon the stoichiometric composition of the reagents in solution. Extensive correlations between this chemical reactivity and the structures of organocuprates have been suggested in the literature, and the numerous structural studies have been aimed at examining these correlations.

One issue that has been the subject of considerable study is the difference between lower-order and higher-order cuprates. Lower-order (LO) cuprates are defined in the literature as cuprates consisting of two negatively charged organic moieties bound directly to a Cu(I) metal center. Higher-order (HO) cuprates, however, consist of three such organic moieties bound directly to a Cu (I) center. In the absence of counterions, these structures result in a monoanionic cuprate (LO) and a dianionic cuprate (HO).[8] Many structural studies have examined various organocuprate compositions which have been thought to consist of HO cuprates,[2a,3,5,6a,b,d,f,i,l] and a few of these studies have brought into question the idea that the ground-state structures for some of these cuprates are actually higher order.[3,5b,6c,h,j] A second issue, discussed quite recently in the context of the effect of structure on organocuprate reactivity, is the role of the lithium ion in organocuprates.[9,6i] We report our investigations on organocuprates relevant to these two issues.

Three synthetically important organocuprate reagents are dimethylcuprate, Me_2CuLi (**1**), trimethylcuprate, Me_3CuLi_2, (**2**), and dimethylcyanocuprate, $Me_2Cu(CN)Li_2$ (**3**). Compounds **2** and **3** have been depicted initially as HO cuprates and were the subject of many of the studies mentioned above. The synthesis of these compounds and their isotopically labeled versions is based upon the syntheses previously described in the literature[6b,f,k] and is outlined in the Supporting Information. Our initial studies of **1**−**3** utilized fully ^{13}C-labeled material which allows examination of scalar coupling between magnetically inequivalent methyl carbon atoms and methyl hydrogen atoms in the molecules as well as the possible examination in **3** of scalar coupling to the cyano carbon. A structure for the copper core such as that shown for **1** in Figure 1 results in an $A_3XX'A_3'$ spin system. If the actual solution structure of the copper core is similar to that shown in Figure 1 (two methyl groups covalently bound to the copper), then a corresponding coupling pattern in the ^{13}C and ^1H NMR spectra should be obtained. As can be seen from the ^{13}C NMR spectrum of **1** (Figure 2a), the expected pattern is observed experimentally. Simulation[10] results in the spectra depicted in Figure 2b with the coupling constants $^1J_{CH} = 109.5$ Hz, $^2J_{CC} = 21$ Hz, $^3J_{CH} = -0.8$ Hz, and $^4J_{HH} = 0$ Hz. Thus, by careful examination of the coupling pattern, one can determine the number of methyl groups bound to the copper center.

With this in mind, we generated compound **2** by treatment of $^{13}CH_3Cu$ with 2 equiv of $(^{13}CH_3)^6Li$ in THF-d_8. The ^{13}C NMR spectrum of **2** (Figure 3a) shows resonances for two major types of methyl groups. The coupling pattern for the methyl group centered at −9.2 ppm exactly matches that of compound **1**, indicative of two methyl groups bound to a common copper center. The methyl group at −15.1 ppm has a chemical shift and coupling pattern quite similar to that obtained for a THF-d_8 solution of methyllithium, the broadness of the peaks being due to $^6Li-^{13}C$ scalar coupling. In addition, smaller resonances upfield from MeLi are also observed which are currently not identified. The most economical explanation for the resonances observed for the major components in solution[6b] is that compound **2** is actually a mixture of dimethylcuprate (**1**) and methyllithium.

Bertz has previously reported the $^{13}C\{^1H\}$ NMR spectra taken of a THF-d_8 solution of **3** generated from the treatment of $Cu^{13}CN$ with 2 equiv of $^{13}CH_3Li$. In these spectra the signals due to the methyl group and the cyano group showed no coupling to each other down to −105 °C even in the presence of hexamethylphosphorictriamide (HMPA).[6f] This stood in stark contrast to lithium methylcyanocuprate ($^{13}CH_3Cu(CN)Li$, **4**), which showed $^2J_{CC} = 21$ Hz at −105 °C (or at −80 °C in the presence of 10 vol. % HMPA). We have found that this two bond carbon−carbon coupling in **4** is also evident at −80 °C (and higher temperatures) in the absence of HMPA when in highly dilute concentration (0.02 mM). In contrast to this result and in agreement with Bertz's previous work, the methyl resonance of $(^{13}CH_3)_2Cu(^{13}CN)Li_2$ (**3**) in the ^{13}C NMR spectrum of a dilute solution of a mixture of **3** and **4** (Figure 3b) shows no coupling to the cyano group at −80 °C while the coupling in **4** is evident. This lack of coupling indicates that the cyano group is not directly bound to the copper center. As Bertz pointed out, this absence of coupling in **3** could also be explained by a rapid exchange of

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(1) For a review, see: Krause, N.; Gerold, A. *Angew. Chem.* **1997**, *109*, 194.

(2) (a) Ashby, E. C.; Watkins, J. J. *J. Am. Chem. Soc.* **1977**, *99*, 5312. (b) Gerold, A.; Jastrzebski, J. T. B. H.; Kronenburg, C. M. P.; Krause, N.; van Koten, G. *Angew. Chem.* **1997**, *109*, 778.

(3) (a) Stemmler, T. L.; Barnhart, T. M.; Penner-Hahn, J. E.; Tucker, C. E.; Knochel, P.; Böhme, M.; Frenking, G. *J. Am. Chem. Soc.* **1995**, *117*, 12489. (b) Barnhart, T. M.; Huang, H.; Penner-Hahn, J. E. *J. Org. Chem.* **1995**, *60*, 4310.

(4) (a) van Koten, G.; Jastryebski, J. T. B. H.; Muller, F.; Stam, C. H. *J. Am. Chem. Soc.* **1985**, *107*, 697. (b) Lorenyen, N. P.; Weiss, E. *Angew. Chem., Int. Ed. Engl.* **1990**, *29*, 300. (c) Olmstead, M. M.; Power, P. P. *Organometallics* **1990**, *9*, 1720.

(5) (a) Lipshutz, B. H.; Kozlowski, J. A.; Wilhelm, R. W. *J. Org. Chem.* **1984**, *49*, 3943. (b) Huang, H.; Alvarez, K.; Cui, Q.; Barnhart, T. M.; Snyder, J. P.; Penner-Hahn, J. E. *J. Am. Chem. Soc.* **1996**, *118*, 8808. (c) Singer, R. D.; Oehlschlager, A. C. *J. Org. Chem.* **1992**, *57*, 2192.

(6) (a) Ashby, E. C.; Watkins, J. J. *J. Chem. Soc., Chem. Commun.* **1976**, 784. (b) Lipshutz, B. H.; Kozlowski, J. A.; Breneman, C. M. *J. Am. Chem. Soc.* **1985**, *107*, 3197. (c) Dieter, R. K.; Hanks, T. W.; Lagu, B. *Organometallics* **1992**, *11*, 3549. (d) Lipshutz, B. H.; James, B. *J. Org. Chem.* **1994**, *59*, 7585. (e) Lipshutz, B. H.; Sharma, S.; Ellsworth, E. L. *J. Am. Chem. Soc.* **1990**, *112*, 4032. (f) Bertz, S. H. *J. Am. Chem. Soc.* **1991**, *113*, 5471. (g) Bertz, S. H.; Dabbagh, G.; He, X.; Power, P. P. *J. Am. Chem. Soc.* **1993**, *115*, 11640. (h) Bertz, S. H. *J. Am. Chem. Soc.* **1990**, *112*, 4031. (i) Bertz, S. H.; Dabbagh, G. *J. Am. Chem. Soc.* **1988**, *110*, 3668. (j) Cabezas, J. A.; Oehlschlager, A. C. *J. Am. Chem. Soc.* **1997**, *119*, 3878. (k) Bertz, S. H.; Vellekoop, A. S.; Smith, R. A. J.; Snyder, J. P. *Organometallics* **1995**, *14*, 1213. (l) Power, P. P.; Olmstead, M. M. *J. Am. Chem. Soc.* **1989**, *111*, 4135.

(7) (a) Snyder, J. P.; Bertz, S. H. *J. Org. Chem.* **1995**, *60*, 4312. (b) Snyder, J. P.; Spangler, D. P.; Behling, J. R.; Rossiter, B. E. *J. Org. Chem.* **1994**, *59*, 2665.

(8) Lipshutz, B. H.; Wilhelm, R. S.; Kozlowski, J. A. *Tetrahedron* **1984**, *40*, 5005.

(9) (a) Nakamura, E.; Mori, S.; Nakamura, M.; Morokuma, K. *J. Am. Chem. Soc.* **1997**, *119*, 4887. (b) Nakamura, E.; Mori, S.; Morokuma, K. *J. Am. Chem. Soc.* **1997**, *119*, 4900.

(10) Spin systems were simulated using the Bruker XSim96 package.

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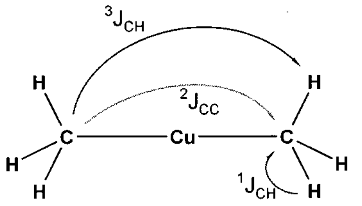

1

Figure 1. Dimethylcuprate core with observed scalar couplings.

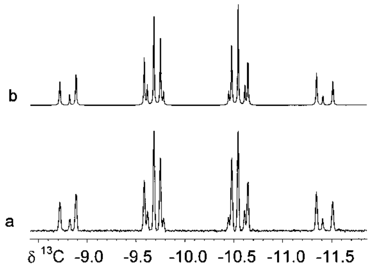

Figure 2. (a) Experimental and (b) simulated ^{13}C NMR spectra of **1**.

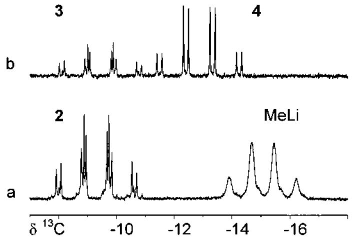

Figure 3. ^{13}C NMR spectra of (a) **2** and (b) a mixture of **3** and **4**.

cyanide ligand leading to loss of coupling. However, as can be seen from the identical coupling pattern and constants for the ^{13}C of the methyl group, the geometry and bonding of the dimethylcuprate core in **3** has not changed from that in compound **1**. This strong similarity to **1**, in addition to the absence of cyano ^{13}C coupling, strongly indicates that the cyano group is not bound to the copper center in the ground-state structure of **3**.

When **1** is generated using doubly ^{6}Li- and ^{13}C-labeled MeLi and ^{6}Li$-$^{1}H and ^{6}Li$-$^{13}C heteronuclear Overhauser effect spectroscopy (HOESY) spectra are recorded, a cross-peak between the lithium and the protons is observed but no cross-peak between the lithium and the carbons is observed. In contrast, when **1·LiI** is generated by direct treatment of CuI with 2 equiv of doubly labeled MeLi, cross-peaks are observable in both the lithium$-$proton and lithium$-$carbon HOESY spectra. Furthermore, when HOESY spectra are acquired for doubly labeled samples of **2**, no cross-peaks are observed between lithium and the protons (or carbons) of the methyl groups of the dimethylcuprate core. Instead, strong cross-peaks (spectrum given in the Supporting Information) are observed between the protons (and carbons) of the methyl groups of methyllithium and all of the types of lithium in solution, both the lithium assigned to the methyllithium tetramer[11] by the 5.7 Hz $^{1}J_{^{6}\mathrm{Li}^{13}\mathrm{C}}$ coupling and the lithium stoichiometrically assignable to the dimethylcuprate. Thus, in the presence of methyllithium the methyl groups of the dimethylcuprate core appear to have little influence on the relaxation of the lithium nuclei. The fact that the methyllithium carbons and protons "see" all of the lithium nuclei in solution indicated to us that there must be a fast chemical exchange between the lithium nuclei in solution. To test this hypothesis we acquired a ^{6}Li$-$^{6}Li exchange spectroscopy (EXSY) spectrum. This spectrum (included in the Supporting Information) shows that the lithium nuclei in solution do indeed exchange on a time scale which is comparable to that of the magnetization transfer of the HOESY experiments.

We have interpreted these results in the following way: although the lithium nuclei of the dimethylcuprate do indeed have an interaction with the methyl groups, this interaction is rather weak as observed by the ease of rapid chemical exchange of the lithium nuclei and the disappearance of an observable interaction in the presence of methyllithium. This may indicate that although structures such as those previously discussed in the literature exist in solution, the lithium cations may spend a substantial amount of time away from the dimethylcuprate core as isolated solvated ions or in solvent-separated ion pairs. In addition, as there is a difference between **1** and **1·LiI**, a change in structure to a monomer as suggested by Van Koten, Krause, and co-workers on the basis of solution molecular weight data is supported.[2b]

In summary, the coupling patterns which are available in the ^{1}H and proton coupled ^{13}C NMR spectra of fully ^{13}C-labeled organocuprates allow the differentiation between the ground-state structures of lower- and higher-order organocuprates. By applying this technique, we have shown that the predominant THF solution structures of organocuprates **2** and **3** are lower-order in nature and the dimethylcuprate core resembles that found for **1**. In addition, by labeling organocuprates with ^{6}Li, we have gained information of the dipolar coupling in these complexes which can be related to their structures. Our studies of **1**$-$**3** indicate that the lithium atoms of these complexes are very weakly associated to the rest of the cuprate complex and likely spend a substantial amount of time dissociated from the anionic core structure.

Due to the absence of an observable NMR interaction between the chemically important cyanide moiety and the rest of the molecule, our studies have not revealed its position. Our ongoing research on this topic includes efforts to examine the position of the cyanide group through use of ^{15}N labeling and solvent effect studies. Recently, Oehlschlager and co-workers[6j] have reported that THF solutions containing high concentrations of HMPA may contain tricoordinate copper species.[12] We are currently extending our ^{13}C-labeling techniques to **3** generated in THF/HMPA to compare data to these recent interesting results.

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Supporting Information Available: Synthesis of ^{13}C- and ^{6}Li-labeled compounds **1**$-$**3** and selected HOESY and EXSY spectra (5 pages). See any current masthead page for ordering information and Web access instructions.

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[11] Compared to the literature value of 5.5 Hz calculated from the ^{7}Li$-$^{13}C coupling constant of 14.5 Hz found by McKeever, L. D.; Waack, R.; Doran, M. A.; Baker, E. B. *J. Am. Chem. Soc.* **1968**, *90*, 3244.

[12] Bertz, S. H.; Nilsson, K.; Davidsson, Ö.; Synder, J. P. *Angew. Chem.* **1998**. In press.