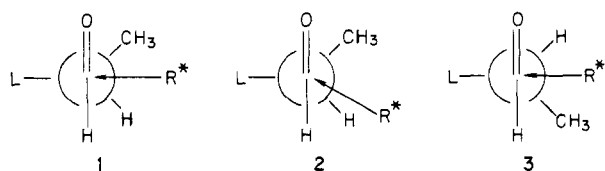


15-C-5 gave the best result. (iii) For RMgX, kryptofixes such as K-21, K-22, K-211, K-221, and K-222 were effective. (iv) The selectivity inversion was observed with cuprate-crown reagents, and both kryptofixes and simple crown ethers were effective for achieving the anti-Cram selectivity.

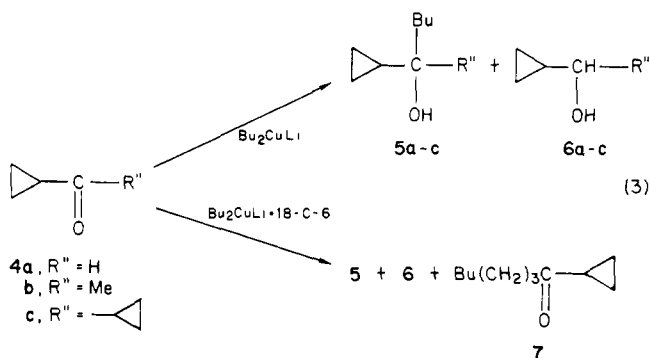
To make sure that the isomer ratio is based on kinetic control, the reactions were quenched (i) immediately after addition of 2-phenylpropionaldehyde at  $-78^{\circ}\text{C}$ , (ii) at  $-20^{\circ}\text{C}$ , and (iii) after 2 days at room temperature. With BuLi-15-C-5, the conversion was low at  $-78^{\circ}\text{C}$ , but the ratio was essentially identical under three different conditions (ii, iii, and entry 1). Although 2 equiv of BuLi-crown reagents were used in Table I, use of an equivalent amount of the reagent produced the alcohol in high yield under a prolonged reaction period, normally 18 h, at room temperature. The reaction of Bu<sub>2</sub>CuLi-18-C-6 was also quenched under the three different conditions. The reaction was more rapid than that of BuLi-15-C-5. Here again, the same isomer ratio was obtained at the four different conditions (i-iii and entry 18).

The enhanced Cram selectivity with RLi-crown and Grignard-crown reagents is in good agreement with a prediction made by Anh.<sup>5</sup> The complexation of M<sup>+</sup> by crown-type compounds must diminish the electrophilic assistance of M<sup>+</sup> toward carbonyl group, leading to an increased Cram selectivity irrespective of perpendicular (1)<sup>6</sup> or nonperpendicular (2) attack. In fact, the



enhanced Cram selectivity (8:1) of Et<sub>2</sub>Mg in comparison with the selectivity (4:1) of EtMgBr clearly indicates an important role of the complexation; it can be easily presumed from the Lewis acidity that the electrophilic assistance of RMgX is greater than that of R<sub>2</sub>Mg. Besides, the crown presumably assists in increasing the state of aggregation.<sup>7</sup> This hypothesis is supported by an observation that the reactivity of the organometallic-crown reagents decreased markedly in comparison with the uncomplexed reagents. Consequently, both loss of the complexation and increase of the state of aggregation operate to enhance the Cram selectivity.

The anti-Cram selectivity with cuprate-crown reagents suggests the intervention of a radical mechanism.<sup>8</sup> Accordingly, we examined the reaction of Bu<sub>2</sub>CuLi-18-C-6 with cyclopropylcarbonyl compounds (4) (eq 3). With 4a, both Bu<sub>2</sub>CuLi and



(5) (a) Anh, N. T. *Top. Curr. Chem.* **1980**, *88*, 145. (b) Anh, N. T.; Eisenstein, O. *Nouv. J. Chim.* **1977**, *1*, 61.

(6) Cherest, M.; Felkin, H.; Prudent, N. *Tetrahedron Lett.* **1968**, 2199, 2205.

(7) In fact, such a phenomenon is known in Grignard reagents.<sup>1k</sup>

(8) A radical mechanism has been suggested for the anti-Cram selectivity in certain ketone reactions. Argona, O.; P-Ossorio, R.; P-Rubalcaba, A.; Quiroga, M. L. *J. Chem. Soc., Chem. Commun.* **1982**, 452. A-Ibarra, C.; Arjona, O.; P-Ossorio, R.; P-Rubalcaba, A.; Quiroga, M. L.; Santestanes, M. J. *J. Chem. Soc., Perkin Trans. 2* **1983**, 1645. **Note Added in Proof:** In a communication that appeared subsequent to submission of this manuscript, Professor H. Yamamoto and co-workers report the anti-Cram selectivity via certain aluminum reagents: Maruoka, K.; Itoh, T.; Yamamoto, H. *J. Am. Chem. Soc.* **1985**, *107*, 4573.

Bu<sub>2</sub>CuLi-18-C-6 gave the butylated alcohol 5a in an essentially quantitative yield. With 4b, both reagents afforded 5b in 75–82% yield along with 6b (1%) and the self-condensed aldol product (8–15%). A marked difference between both the reagents was not observed. However, the ring-opening product 7 was obtained in the reaction of 4c with Bu<sub>2</sub>CuLi-18-C-6: 7 (39%), 6c (39%), 5c (10%), and the recovered 4c (12%). With Bu<sub>2</sub>CuLi, 7 was not produced: 5c (89%), 6c (1%), and the recovered 4c (10%).

Formation of 7 evidently indicates the intervention of an electron-transfer process. Increase of the reduction product 6c also supports the participation of a radical mechanism. With 4a and 4b, the transfer of the Bu group to an intermediate (anion radical) must be rapid, preventing the ring cleavage. Taken together, R<sub>2</sub>CuLi-crown (presumably R<sub>2</sub>Cu<sup>•</sup>-Li<sup>+</sup>-crown) possesses greater ability to transfer electrons than R<sub>2</sub>CuLi itself.<sup>9</sup>

The anti-Cram selectivity can be explained as follows, though it is highly speculative. If an electron-transfer mechanism is involved, 1–3 put more negative charge on oxygen than the normal transition state for a nucleophilic addition. It is therefore felt that the oxygen is, in effect, made larger, destabilizing the conformation 1 (and 2) by increasing the CH<sub>3</sub>-O<sup>•</sup> interaction. Further, the directionality of R<sup>•</sup> attack must change in the radical mechanism. In fact, a perpendicular attack is proposed for a radical reaction of propene.<sup>10</sup> If the perpendicular attack is involved in the present reaction, 3 is more stable than 1 owing to the CH<sub>3</sub>-O<sup>•</sup> interaction, leading to the predominant formation of the anti-Cram isomer. We are now studying the related reactions of various organometallic-crown and enolate-crown reagents and will report these works shortly.

**Acknowledgment.** Thanks are given to Ryuichi Imamura for <sup>1</sup>H and <sup>13</sup>C NMR measurements.

(9) Our preliminary investigation on ate complexes-crown reagents, such as R<sub>2</sub>BM-crown and R<sub>2</sub>AlM-crown, revealed the radical reactivity of these complexed organometallics.

(10) Padden-Row, M. N.; Rondan, N. G.; Houk, K. N. *J. Am. Chem. Soc.* **1982**, *104*, 7162.

## <sup>113</sup>Cd Chemical Shifts of Cadmium-Iodide Complexes in Supercooled Aqueous Solution

Marilyn J. B. Ackerman and Joseph J. H. Ackerman\*

Department of Chemistry, Washington University  
St. Louis, Missouri 63130

Received July 15, 1985

It has been suggested that metal nuclide chemical shifts will vary in a linear progression in cation-solvent systems where a single species first solvation sphere is replaced in a stepwise manner by a different solvent, i.e., MX<sub>4</sub> → MX<sub>3</sub>Y → MX<sub>2</sub>Y<sub>2</sub> → MX<sub>1</sub>Y<sub>3</sub> → MY<sub>4</sub>.<sup>1,2</sup> Assumption of the generality of such trends has led to the development of powerful metal nuclide NMR chemical shift methods for evaluation of solvation sphere composition (e.g., preferential solvation) in mixed-solvent systems.<sup>3–5</sup> Here, under conditions of rapid chemical exchange, the single observed chemical shift is taken to be the average of the chemical shifts in the pure solvents weighted according to the mole fraction of each solvent in the contact solvation shell.<sup>1</sup>

The competitive or preferential solvation problem is equivalent to the ligand displacement problem<sup>4</sup> and some precedent for such

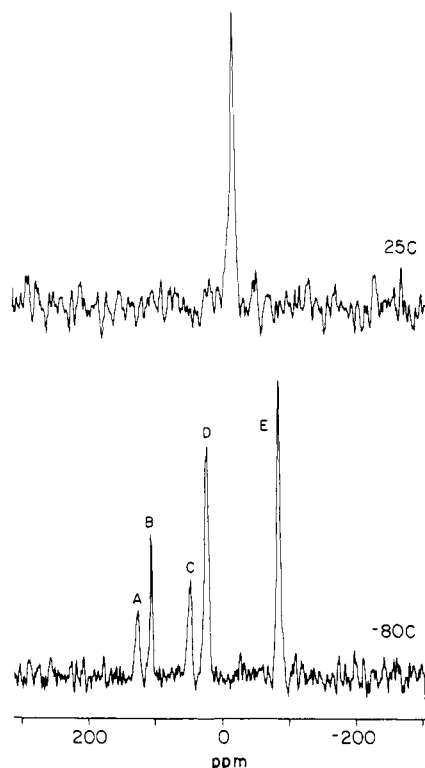
(1) Frankel, L. S.; Stengle, T. R.; Langford, C. H. *Chem. Commun.* **1965**, 393.

(2) Frankel, L. S.; Langford, C. H.; Stengle, T. R. *J. Phys. Chem.* **1970**, 1376.

(3) Langford, C. H.; Tong, J. P. K. *Acc. Chem. Res.* **1977**, *10*, 258.

(4) Bryant, R. G. In "NMR of Newly Accessible Nuclei"; Laszlo, P., Ed.; Academic Press: New York, 1983; Vol. 1, p 135.

(5) Lindman, B.; Forsen, S. In "NMR and the Periodic Table"; Harris, R. K.; Mann, B. E., Eds.; Academic Press: New York, 1978; p 129.



**Figure 1.**  $^{113}\text{Cd}$  NMR spectra taken at 25 (top panel) and  $-80^\circ\text{C}$  (bottom panel) of a water-in-oil emulsion whose aqueous component contained 0.01 M  $^{113}\text{Cd}(\text{NO}_3)_2$ , 0.018 M NaI, and 8 M  $\text{LiNO}_3$ . Spectra were obtained on a Bruker WH-360 NMR spectrometer operating at 79.89 MHz with a 20-mm probe. Acquisition parameters: 50-KHz bandwidth; 8192 data points; 10- $\mu\text{s}$  pulse width ( $\sim 10^\circ$  flip angle); 0.3-s pulse repetition period. The top spectrum represents 70 min of data collection while the bottom spectrum represents 8 h 40 min.  $^{113}\text{Cd}$  chemical shifts are referenced to a room temperature aqueous solution of 5 mM  $\text{Cd}(\text{ClO}_4)_2$  as 0.0 ppm using the IUPAC convention,<sup>16</sup> shifts to increasing frequency are more positive chemical shifts. Minor susceptibility and static field corrections were made by referencing to the  $\text{H}_2\text{O}$   $^1\text{H}$  chemical shift.<sup>17</sup> Chemical shifts were assigned as follows through  $\text{I}^-$  titration:<sup>12</sup> (A)  $\text{CdI}_3^-$ , 122 ppm; (B)  $\text{CdI}_4^{2-}$ , 101 ppm; (C)  $\text{CdI}_2$ , 43 ppm; (D)  $\text{CdI}^+$ , 20 ppm; E,  $\text{Cd}^{2+}$ , -86 ppm (although the role of  $\text{H}_2\text{O}$  and  $\text{NO}_3^-$  is not specified, resonance E is likely representative of a cadmium nitrate ion pair).

chemical shift behavior can be found in the  $^{13}\text{C}$ ,  $^{119}\text{Sn}$ , and  $^{195}\text{Pt}$  chemical shift progressions of carbon, tin, and platinum halide complexes.<sup>6-8</sup> However, because of the often rapid chemical exchange present among different coexisting metal-ligand complexes, such assumed linear trends of metal nuclide chemical shifts are generally difficult to document. Furthermore, in instances where ion-pair formation or changes in symmetry and/or coordination number (e.g., octahedral  $\text{MX}_6 \rightarrow$  tetrahedral  $\text{MY}_4$ ) are unavoidable, chemical shift trends predicted in the absence of such potentially significant shielding perturbations may be markedly altered. For example, because of ion-pair interactions and effects of heteroselective solvation in the  $\text{AgNO}_3/\text{H}_2\text{O}/\text{CH}_3\text{CN}$  system the stepwise variation of solvent composition from pure  $\text{H}_2\text{O}$  to pure  $\text{CH}_3\text{CN}$  does not lead to a monotonic change in  $^{109}\text{Ag}$  chemical shift,<sup>9</sup> which would be expected for a shift progression that was linear in solvent coordination sphere composition.

We have previously demonstrated that the use of supercooled aqueous solutions can be employed to markedly reduce chemical

exchange rates, thus imposing the NMR slow exchange regime on normally rapidly exchanging species.<sup>10</sup> Supercooling is facilitated by preparation of the aqueous solution in the form of noncommunicating microdroplets (diameter ca. 1–10  $\mu\text{m}$ ) as a water-in-oil emulsion.<sup>11</sup> Depending on aqueous solution composition, solution-state temperatures in the range ca.  $-40$  to  $-100^\circ\text{C}$  are obtainable. This approach has been used herein to directly delineate the species specific  $^{113}\text{Cd}$  chemical shifts of the cadmium-iodide system. Figure 1 illustrates the effect of supercooling an aqueous solution of 0.01 M  $\text{Cd}^{2+}/0.018$  M  $\text{I}^-/8$  M  $\text{LiNO}_3$  upon the  $^{113}\text{Cd}$  NMR spectrum (experimental details are given in the figure caption). The top panel shows a room temperature spectrum where rapid chemical exchange results in a single  $^{113}\text{Cd}$  resonance despite the presence of five  $\text{Cd}^{2+}$  species ( $\text{Cd}^{2+}$ ,  $\text{CdI}^+$ ,  $\text{CdI}_2$ ,  $\text{CdI}_3^-$ ,  $\text{CdI}_4^{2-}$ ; role of  $\text{H}_2\text{O}$  and  $\text{NO}_3^-$  not specified). Supercooling the same solution to  $-80^\circ\text{C}$  imposes the slow exchange regime and results in chemical shift resolution of all  $\text{Cd}^{2+}$  species as shown in the lower panel. To our knowledge this is the first time an entire cadmium-halide system has been chemical shift resolved in the solution state. Taken together with our earlier study of the cadmium-glycine system<sup>10</sup> this suggests that such a supercooling approach toward imposition of the slow exchange regime has considerable generality of applicability.

$^{113}\text{Cd}$  chemical shift assignments can be made by  $\text{I}^-$  titration of the various cadmium-iodide species. Completion of such a titration (data not shown<sup>12</sup>) clearly demonstrates that the cadmium species can be listed in order of increased shielding (decreasing chemical shift) as  $\text{CdI}_3^- < \text{CdI}_4^{2-} < \text{CdI}_2 < \text{CdI}^+ < \text{Cd}^{2+}$ . This nonmonotonic shielding progression is the same as that predicted earlier by Drakenberg et al.<sup>13</sup> and Ackerman et al.<sup>14</sup> from room temperature NMR studies in which the solution composition was modeled based on known equilibrium constants and the species specific  $^{113}\text{Cd}$  chemical shifts determined indirectly through least-squares analysis of data obtained under rapid-exchange conditions. However, because of the indirect nature of such chemical shift determinations, the findings are equivocal (e.g., it was not possible to accurately determine the chemical shift of  $\text{CdI}_2$  because of its very small mole fraction relative to the other cadmium-iodide complexes). Our directly measured (low temperature) shifts provide support for these earlier  $^{113}\text{Cd}$  room temperature chemical shift assignments.<sup>13,14</sup> Based on thermodynamic analysis of the stepwise formation of metal-ion complexes in aqueous solution, Åhrland has suggested that the change from octahedral to tetrahedral geometry occurs upon formation of the  $\text{CdI}_3^-$  species (where  $\text{H}_2\text{O}$  occupies the fourth coordination site).<sup>15</sup> This substantial symmetry change may, in fact, be reflected in the "unexpected" jump to lowest shielding of the  $\text{CdI}_3^-$  resonance.

These results argue for caution in the use of NMR methodologies that examine solvent or ligand displacement predicted on presumed but unsubstantiated linear chemical shift trends. A complete description of this work is in preparation.

**Acknowledgment.** This project was supported by Washington University intramural funds and NSF Grants CHE-8200230 and CHE-8100211. A preliminary report of this work was presented at the 26th Experimental NMR Conference, Asilomar, CA, April 21–25 (1985). Helpful discussions with Dr. James Fry (Colorado State University) are gratefully acknowledged.

(10) Ackerman, M. J. B.; Ackerman, J. J. H. *J. Phys. Chem.* **1980**, *84*, 3151. [Also see: Jakobsen, H. J.; Ellis, P. D. *J. Phys. Chem.* **1981**, *85*, 3367.]

(11) Rasmussen, D. H.; Mackenzie, A. P. In "Water Structure at the Water-Polymer Interface"; Jellinek, H. H. G., Ed.; Plenum Press: New York, 1972; p 126.

(12) Extensive manuscripts presenting both the methodology behind this work and the detailed results for the cadmium-iodide system are currently in preparation.

(13) Drakenberg, T.; Björk, N.-O.; Portanova, R. *J. Phys. Chem.* **1978**, *82*, 2423.

(14) Ackerman, J. J. H.; Orr, T. V.; Bartuska, V. J.; Maciel, G. E. *J. Am. Chem. Soc.* **1979**, *101*, 341.

(15) Åhrland, S. *Struct. Bonding* **1973**, *15*, 167.

(16) *Pure Appl. Chem.* **1976**, *45*, 219.

(17) Ackerman, J. J. H.; Gadian, D. G.; Radda, G. K.; Wong, G. G. *J. Magn. Reson.* **1981**, *42*, 498.

(6) Raynes, W. T. In "Nuclear Magnetic Resonance"; Harris, R. K., Ed.; The Chemical Society: London, 1972; Vol. 1, p 1.

(7) Kidd, R. G.; Goodfellow, R. J. In "NMR and the Periodic Table"; Harris, R. K.; Mann, B. E., Eds.; Academic Press: New York, 1978; p 195.

(8) Harris, R. K.; Kennedy, J. D.; McFarlane, W. In "NMR and the Periodic Table"; Harris, R. K.; Mann, B. E., Eds.; Academic Press: New York, 1978; p 309.

(9) Henrichs, P. M. In "NMR of Newly Accessible Nuclei"; Laszlo, P., Ed.; Academic Press: New York, 1983; Vol. 2, p 319.