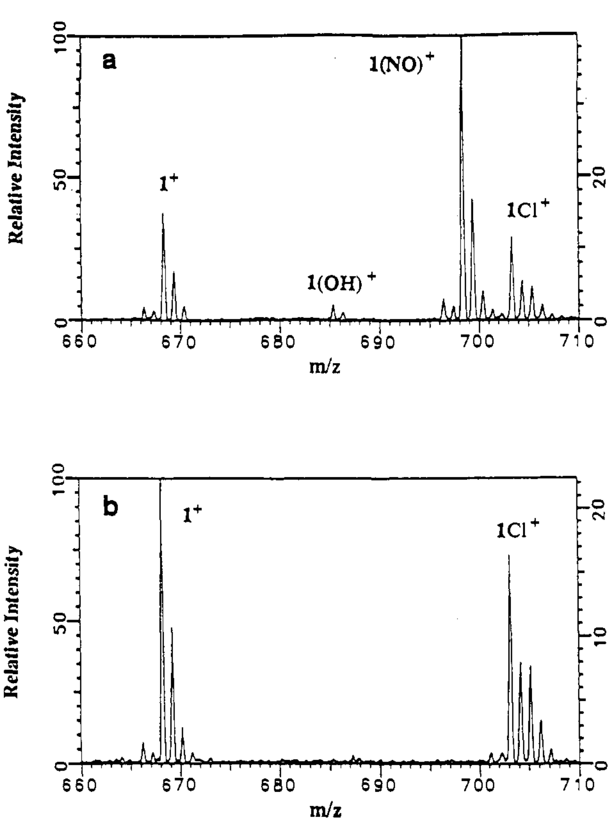

Figure 1. (a) Spectrum of ions formed by laser desorption of **1**Cl after exposure to NO_2. Naturally occurring isotopes (^{13}C, ^{37}Cl, ^{54}Fe, etc.) give each chemical species several isotopic variants. The right-side axis is absolute intensity in arbitrary units. (b) Spectrum identical with a except that ions of the mass of **1**O^+ ejected continuously during the exposure to NO_2.

4. Consequently, $[\mathbf{2}O]^{\bullet+}$ is not directly observed. The intermediacy of $[\mathbf{2}O]^{\bullet+}$, however, is implied both by the kinetics of the reactions and by the results of ion ejection experiments. Such an experiment is illustrated in Figure 1 for the reaction of $\mathbf{1}^{\bullet+}$ with $NO_2^{\bullet}$, which is analogous to the $\mathbf{2}^{\bullet+}$ reaction with $NO_2^{\bullet}$. The reactant ion is produced by pulsed laser desorption and stored in the ion trap. A pulsed valve[12] then opens and admits a burst of $NO_2^{\bullet}$ following which spectrum 1a is obtained revealing a substantial $[\mathbf{1}NO]^+$ product. Spectrum 1b is obtained under identical conditions except that an rf voltage is applied to the cell to eject ions of the mass of $[\mathbf{1}O]^{\bullet+}$ continuously during the $NO_2^{\bullet}$ burst.[13] Even though $[\mathbf{1}O]^{\bullet+}$ cannot be detected, it can be ejected.[14] Obviously from spectrum 1b, eliminating $[\mathbf{1}O]^{\bullet+}$ eliminates $[\mathbf{1}NO]^+$, supporting the intermediacy of the former in producing the latter.

The reactions of $\mathbf{3}^{\bullet+}$ with $NO_2^{\bullet}$ are analogous to those of $\mathbf{1}^{\bullet+}$ and $\mathbf{2}^{\bullet+}$. On the other hand, $\mathbf{4}^{\bullet+}$ does not react with $NO_2^{\bullet}$. We have previously shown that the "tethered" imidazole base in $\mathbf{4}^{\bullet+}$ is coordinated with the metal.[8] The failure of $\mathbf{4}^{\bullet+}$ to react thus suggests that the efficiency of O atom transfer from $NO_2^{\bullet}$ is sensitive to the nature of any axial ligand in the complex and that the O atom adds to the metal.

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Pinched-Cone Conformers of Calix[4]arenes[1]

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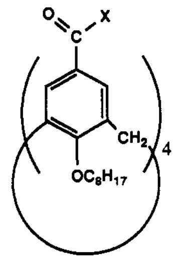
Calix[4]arenes are cyclic tetramers of phenol that exist as cone, partial cone, 1,2-alternate, and/or 1,3-alternate conformational isomers.[3-6] Currently, it is the *cone* isomer that is receiving the greatest attention as a framework for constructing molecular hosts, templates, and pores.[3-9] Although the ^1H NMR spectra that have been reported for all homo-tetrasubstituted calix[4]arene cones are consistent with C_{4v} symmetry, recent theoretical calculations predict that such a conformation can represent a saddle-point structure, where the corresponding C_{2v} isomers ("pinched cones") are thermodynamically favored (Figure 1).[6] The fact that pinched-cone conformers have not yet been detected *in solution*[9] has been rationalized in terms of a rapid interconversion between two equivalent C_{2v} isomers.[6] Experimental support for this hypothesis, however, is lacking.

During the course of our studies dealing with the construction of perforated monolayers,[7,8] we had need for the tetrasubstituted calix[4]arenes **I** and **II**. While the synthesis of these compounds proved to be straightforward, it soon became apparent that both compounds showed unusual spectral properties. Our principal findings, which are reported herein, provide the first direct evidence that pinched-cone conformers can play a major role in the overall structure and dynamics of the calix[4]arene framework.



I, X=OH
II, X=NH_2
III, X=OCH_3

Alkylation of 25,26,27,28-tetrahydroxycalix[4]arene[10] with 1-bromooctane afforded the corresponding tetra-*n*-octyloxytetraether, which was readily isolated as a mixture of cone and noncone isomers. Subsequent Friedel–Crafts acylation (CH_3COCl) or reaction with NBS afforded a stereoisomeric mixture of acetylated and brominated derivatives, respectively, from which

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(2) On leave from the Institute of Macromolecular Chemistry, Czechoslovak Academy of Sciences, Prague, Czechoslovakia.

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J. Am. Chem. Soc. **1991**, *113*, 9671–9673

Figure 1. Stylized illustration of cone and pinched-cone conformational isomers of a calix[4]arene, showing the relative orientation of the aromatic moieties.

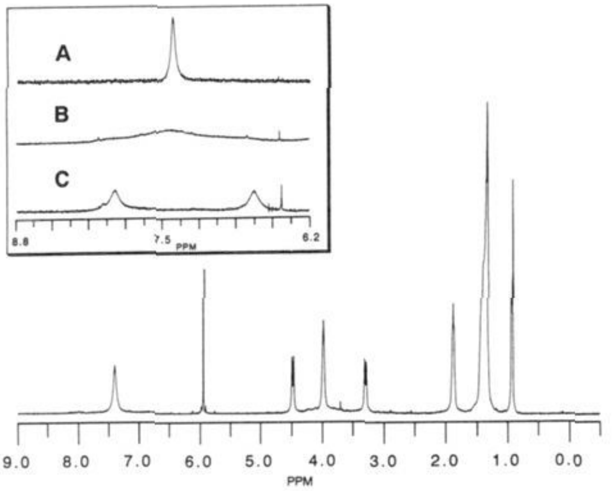

Figure 2. *^{1}H NMR (500 MHz) spectra of* **I** *in $CDCl_2CDCl_2$ at 100 °C;* insert shows aromatic protons at (A) 115 °C, (B) 45 °C, and (C) −4 °C. Residual solvent protons (δ 5.95) were used as an internal reference.

were isolated cone structures. Haloform oxidation of the former resulted in the formation of **I**; cyanation of the latter followed by hydrolysis yielded **II**.[11]

The ^{1}H NMR spectrum (500 MHz) of **I** that was observed in DMSO-d_6 at 23 °C gave a splitting pattern that was consistent with a cone (and also a rapidly equilibrating pinched cone) structure; i.e., a well-defined pair of doublets was observed for the bridging methylenes at δ 4.32 and 3.37 (J_{AB} = 13.0 Hz), and the aromatic protons appeared as a singlet at δ 7.30. In contrast, the ^{1}H NMR spectrum of **I** in $CDCl_2CDCl_2$ (23 °C) exhibited broadened resonances for the bridging methylenes (δ 3.3 and 4.4) and two broad signals for the aromatic protons of equal intensity (δ 6.7 and 8.0). The latter sharpened at lower temperatures, coalesced at 45 °C, and became a sharp singlet at higher temperatures (Figure 2). In addition, the oxymethylene protons, which appeared as a sharp absorption at higher temperatures (δ 4.0), were seen as two broad signals of equal intensity as the temperature was lowered (δ 4.1 and 3.7). The observed shielding of half of the aromatic and oxymethylene protons (and deshielding of the remaining half) at lower temperatures, together with this coalescence behavior, provides compelling evidence for pinched-cone conformers that are in dynamic equilibrium. On the basis of a coalescence temperature, T_c, of 45 °C and $\Delta\nu$ = 610 Hz, we calculate a barrier for interconvesion of $\Delta G^{\ddagger}$ = 14.1 kcal mol^{-1}.[12,13] Replacement of the carboxylic acid protons of **I** with deuterium afforded a T_c of 70 °C, $\Delta\nu$ = 660 Hz, and $\Delta G^{\ddagger}$ = 15.2 kcal mol^{-1}. Similar results were obtained with **II**; here, T_c = −4 °C, $\Delta\nu$ = 475 Hz, and $\Delta G^{\ddagger}$ = 13.3 kcal mol^{-1}; for deuterium-exchanged **II**, T_c = 15 °C, $\Delta\nu$ = 500 Hz, and $\Delta G^{\ddagger}$ = 14.2 kcal mol^{-1}. Finally, an analogous calix[4]arene, **III**, formed from **I** via CH_2N_2, "appeared" as a C_{4v} structure from −28 to 100 °C in $CDCl_2CDCl_2$.

The ability to observe C_{2v} symmetry for **I** and **II** by ^{1}H NMR spectroscopy clearly reflects the relatively high barrier for interconversion between the two pinched-cone conformers. On the basis of the *appearance* of **I** and **II** as cone structures in DMSO-d_6, the significant deuterium isotope effect on T_c, and the appearance of **III** as a C_{4v} structure in $CDCl_2CDCl_2$, we conclude that internal hydrogen bonding contributes, considerably, to this barrier. Previous molecular mechanics calculations have indicated that the C_{2v} conformer of 5,11,17,23-tetramethyl-25,26,27,28-tetramethoxycalix[4]arene is 3.2 kcal mol^{-1} lower in energy than the corresponding C_{4v} structure.[6] If a similar difference exists for the calix[4]arene framework in **I** and **II**, then the observed free energies of activation can be accounted for by assuming that *two* internal hydrogen bonds are formed between alternate pendant groups (contributing a total of ~10–11 kcal mol^{-1}) and that the C_{4v} structure represents a transition state for the interconversion.

As the level of sophistication in the design and synthesis of calix[4]arene-based hosts, templates, and pores increases, greater attention will have to be paid to the details of molecular structure and dynamics. Pinched-cone conformers will certainly require careful scrutiny in this regard.

Registry No. I, 137233-49-9; II, 137233-50-2; D_2, 7782-39-0.

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[11] All new compounds showed the expected ^{1}H NMR (500 MHz) spectra and elemental analysis or HRMS.

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Structural Characterization of Mixed-Alkali-Metal Bis(trimethylsilyl)amide Bases

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The enhanced deprotonating (or metalating) power of mixed organoalkali bases containing lithium and potassium or sodium over those containing only lithium was first observed by Wittig.[1] In the middle 1960s, Lochmann[2] and Schlosser[3] showed that very strong deprotonating reagents could be formed by combining equimolar mixtures of a potassium alkoxide with an alkyllithium compound. Despite an increasing number of syntheses which have utilized these "superbasic reagents",[4] relatively few physical organic studies[5] have been reported that have directly addressed the structure of the species responsible for their enhanced deprotonating ability. In recent years, however, solid-state structures of various mixed organoalkali compounds have been reported[6] in addition to the *n*-butyllithium–lithium *tert*-butoxide complex.[7]

In a related area, the addition of alkali-metal alkoxides to lithium amides also increases the deprotonating ability of the amide bases.[8,9] In our attempts to study mixed-alkali amide/alkoxide

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