Unusual conformational control of mobile mono- and diionizable calix[4]arene ligands by alkali metal cations†‡

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Conformations adopted in $CDCl_3$ solution by alkali metal salts of mobile calix[4]arene ligands with one and two pendent proton-ionizable groups have been studied by NMR spectroscopy. For a series of the ligands with two *N*-(R-sulfonyl)carbamoylmethoxy substituents, there is no significant change in the conformational preferences of the calix[4]arene unit upon variation of the NSO_2R substituents. Systematic changes of the preferred conformation(s) for the calix[4]arene moiety from cone to partial cone to 1,3-alternate are observed for all five of the ligands as the alkali metal cation is varied from Li^+ to Na^+ to K^+ to Rb^+ to Cs^+. For ligands with one proton-ionizable group [carboxylic acid or *N*-(trifluoromethylsulfonyl)carboxamide] the conformational preferences of the calix[4]arene unit are also controlled by the identity of the complexed metal ion. The Li^+ salts prefer the cone conformation, while for the Na^+ and K^+ salts more than two significantly populated conformations are evident. Remarkably, Cs^+ and Rb^+ salts prefer a partial cone conformation, which provides the possibility for the metal ion to have three π-interactions with the arene units of the calix[4]arene moiety and a coulombic interaction with the ionized group.

Introduction

Substituted calix[4]arenes are used extensively as ligands for the recognition of a wide range of metal ions.[2] The conformation of the calix[4]arene moiety plays an important role in selective metal ion complexation.[3,4] Not only does the conformation determine the spatial orientation of the substituents bearing potential ligating groups, it also controls the ability of the arene units of the calixarene to participate in complexation *via* cation–π interaction.[5,6]

Recently we reported[7,8] that calix[4]arene ligands **L1**H_2–**L4**H_2 provide selective complexation of Pb^{2+} and, particularly, Hg^{2+} among a variety of divalent metal cations. These mobile ligands were found to extract Hg^{2+} better than analogues that were fixed in the cone conformation.

Although there are several reports in the literature[6,9–19] on the effect of metal ion complexation on the conformations of mobile calix[4]arene ligands, no systematic study of this phenomenon has appeared to date. Knowledge of conformational preferences upon metal ion complexation is essential for the design of new ligands with improved selectivities. There have been earlier reports[6,12] of a mobile calix[4]crown-6 ligand adopting a 1,3-alternate conformation in a complex with caesium picrate, but a cone conformation in a complex with sodium picrate. Subsequently, a calix[4]crown-6 rigidified in the 1,3-alternate conformation was prepared and found to be a highly selective complexing agent for Cs^+ over Na^+.

Herein we report conformational studies of alkali metal salts that are formed from mobile calix[4]arene ligands with one and two pendent proton-ionizable groups.

Results and discussion

Conformational studies of alkali metal salts of diionizable calix[4]arene ligands

Attachment of groups larger than ethyl to the oxygens on the lower rim of calix[4]arenes restricts oxygen-through-the-annulus rotation of the arene units.[20] Therefore, ligands **L1**H_2–**L5**H_2 are expected to be conformationally mobile with three possible limiting conformations: cone; partial cone (paco); and 1,3-alternate (1,3-alt) (Fig. 1). The broad signals observed in the ^{1}H NMR spectra for ligands **L1**H_2–**L5**H_2 in $CDCl_3$ solution at room temperature indicate that conformational interconversions indeed take place.

When the alkali metal salts of ligands **L1**H_2–**L5**H_2 were prepared by reaction with an excess of alkali metal carbonate, the signals in the ^{1}H NMR spectra of those salts became much sharper than those in the spectra of the ligands themselves. (Fig. 2 shows the *tert*-butyl region of the ^{1}H NMR spectra for **L1**H_2 and the five **L1**M_2 salts.†) The absence of an NH resonance confirmed complete proton replacement by the metal ions. It is important to note in Fig. 2 that each salt exhibits a distinct spectrum, indicating that the calix[4]arene conformation is different for each salt.

The conformational preferences of the alkali metal salts of ligand **L1**H_2 in $CDCl_3$ were assessed by NMR spectroscopy. The spectra of the Li^+, K^+ and Cs^+ salts, which exhibited fewer signals due to the dominance of one conformation, were analyzed first.

The ^{1}H NMR spectrum of the **L1**Li_2 (Table 1) features a pair of well-separated doublets for the methylene groups that bridge the arene units (ArCH_2Ar groups) (this is connected to a 29.70 ppm ^{13}C NMR signal) along with two singlets of equal intensity in both the aromatic and *tert*-butyl regions. From this we can deduce that a cone structure is the major conformation of **L1**Li_2. The ^{1}H NMR spectrum observed for **L1**Cs_2 is similar to that of **L1**Li_2 with two singlets of equal intensity in both the aromatic and *tert*-butyl regions. However, the doublets for the ArCH_2Ar protons are now very close (3.714 and 3.722 ppm) and are connected to a 37.62 ppm signal in the ^{13}C NMR spectrum. This is consistent with a dominant 1,3-alternate conformation for **L1**Cs_2.

For **L1**K_2, three signals in the *tert*-butyl region with an intensity ratio of 1 : 1 : 2, two pairs of doublets for the ArCH_2Ar protons, two nonequivalent methoxy groups, a single type of CH_3SO_2 proton, and a pair of doublets for the diastereotopic protons in the equivalent $OCH_2C(O)$ groups are all consistent with a partial cone structure as the major conformation. When

† Electronic supplementary information (ESI) available: spectra of the aromatic and lower-rim substituent protons. See http://www.rsc.org/suppdata/p2/b1/b101232k/
‡ See reference 1.

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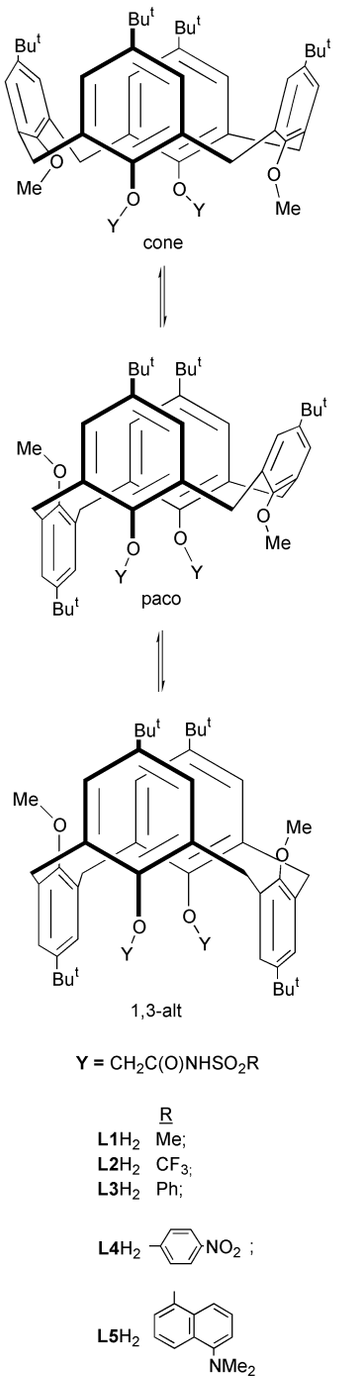


Fig. 1 Three possible limiting conformations of the calix[4]arene unit in $\mathbf{L1}H_2$–$\mathbf{L5}H_2$.

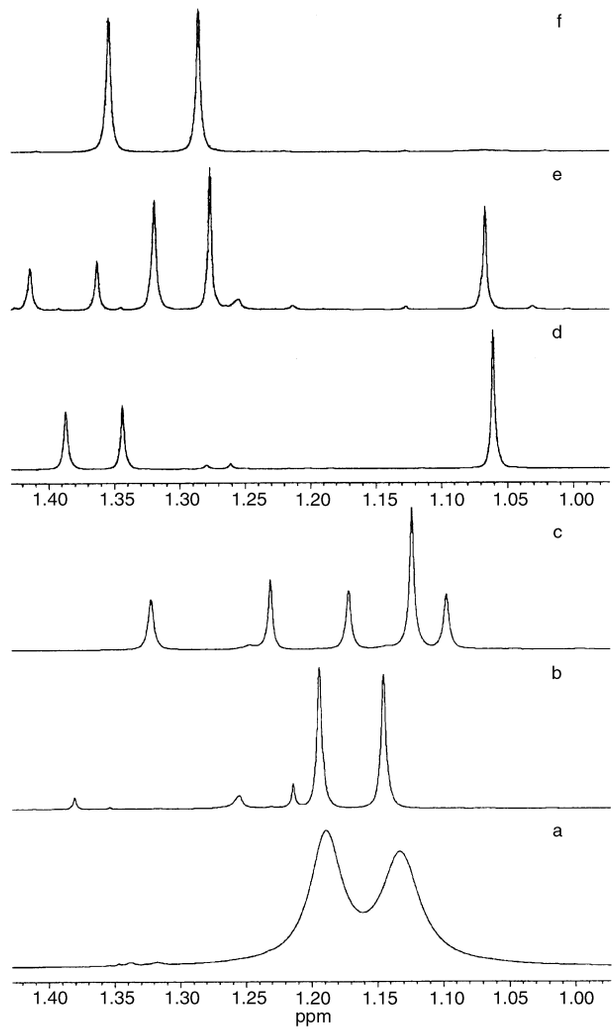


Fig. 2 ^{1}H NMR spectra (*tert*-butyl region) for (a) $\mathbf{L1}H_2$; (b) $\mathbf{L1}Li_2$; (c) $\mathbf{L1}Na_2$; (d) $\mathbf{L1}K_2$; (e) $\mathbf{L1}Rb_2$; (f) $\mathbf{L1}Cs_2$ (499.7 MHz, $CDCl_3$, 296 K).

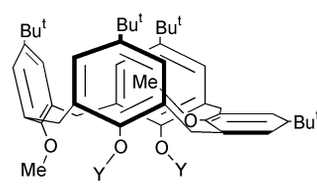


Fig. 3 Flattened partial cone structure of the calix[4]arene unit in $\mathbf{L1}Na_2$ as suggested by the NMR data.

the ^{1}H NMR spectrum of $\mathbf{L1}Rb_2$ is compared with those for the K^+ and Cs^+ salts (Fig. 2), it appears to consist of two sets of signals, one similar to that of the K^+ salt and another to that of the Cs^+ salt. We therefore conclude that in $\mathbf{L1}Rb_2$ the calix[4]arene moiety exists in both partial cone and 1,3-alternate conformations, in a ratio 43 : 57.

Similarly, the ^{1}H NMR spectrum for $\mathbf{L1}Na_2$ reveals the presence of cone and partial cone conformations with a ratio 31 : 69. However, there are some differences between the ^{1}H NMR spectra observed for the partial cone conformations of the Na^+ salt and those of the K^+ and Rb^+ salts. In the ^{13}C NMR spectrum of $\mathbf{L1}Na_2$, one signal for the $ArCH_2Ar$ groups was observed at 34.75 ppm. This chemical shift value is intermediate between those typical for the methylene group bridging *syn*- and *anti*-oriented arene units (30–33 and 36–38 ppm, respectively) in calixarenes.[21] A second signal for the $ArCH_2Ar$ groups was observed at 29.95 ppm. This indicates the presence of a structure rarely observed in solution, a flattened partial cone structure for the calix[4]arene moiety for $\mathbf{L1}Na_2$ (Fig. 3). Another interesting feature of the partial cone conformation of $\mathbf{L1}Na_2$ is the signal, shifted significantly upfield (to δ 0.21), for the inverted (*endo*) OCH_3 group protons. This unusual position for the methoxy group proton resonance has been observed previously in some calixarene derivatives[9] in which the *endo* methoxy group is located inside the calix[4]arene cavity in close proximity to the arene units. It is thought that in such a position, the oxygen atom of the methoxy group could participate in coordination of a metal ion at the lower rim of the calix[4]arene unit. Also, this indicates that the two Na^+ must be located outside the calix[4]arene cavity, since it is occupied by the methoxy group. Conversely, in the partial cone conformation structures for $\mathbf{L1}K_2$ and $\mathbf{L1}Rb_2$, the ^{1}H NMR spectra indicate that the *endo* methoxy group is not located inside the calix[4]arene cavities (δ 2.85 and 2.98, respectively). Therefore, at least one alkali metal cation may be located inside the hydrophobic calix[4]arene cavity.

Table 1 Selected ^{1}H NMR data for the alkali metal salts **L1**M_2[a]

	tert-Butyl protons[b]	ArCH_2Ar	Lower rim substituents	Aromatic protons
Cone **L1**Li_2	1.14 s (2)	3.34 d (*J* 12.2)	3.04 s (CH_3SO$_2$)	7.05 s
	1.19 s (2)	4.19 d (*J* 12.2)	3.92 s (CH_3O)	7.10 s
		{29.70}[c]	4.44 s (OCH_2CO)	
Cone **L1**Na_2	1.10 s (2)	3.35 d (*J* 12.3)	2.95 s (CH_3SO$_2$)	7.04 s
	1.17 s (2)	4.22 d (*J* 12.3)	3.88 s (CH_3O)	7.10 s
		{29.97}[c]	4.43 s (OCH_2CO)	
Paco **L1**Na_2	1.12 s (2)	3.46 d (*J* 12.7)	0.21 s (*endo* CH_3O)	7.02 d (*J* 2.2)
	1.23 s (1)	4.36 d (*J* 12.7)	2.58 br s (CH_3SO$_2$)	7.11 s
	1.32 s (1)	{29.95}[c]	3.94 s (*exo* CH_3O)	7.21 d (*J* 2.2)
		3.44 d (*J* 15.3)	4.27 d (*J* 15.1)	7.26 s
		4.33 d (*J* 15.3)	4.39 d (*J* 15.1)	
		{34.75}[c]	(OCH_2CO)	
Paco **L1**K_2	1.06 s (2)	3.17 d (*J* 12.4)	2.85 s (*endo* CH_3O)	6.92 br s (4 H)
	1.34 s (1)	4.07 d (*J* 12.4)	2.99 s (CH_3SO$_2$)	7.21 br s (2 H)
	1.39 s (1)	{29.40}[c]	3.67 s (*exo* CH_3O)	7.27 br s (2 H)
		3.70 d (*J* 15.3)	4.05 d (*J* 15.0)	
		3.84 d (*J* 15.3)	4.36 d (*J* 15.0)	
		{37.95}[c]	(OCH_2CO)	
Paco **L1**Rb_2	1.07 s (2)	3.19 d (*J* 12.6)	2.98 s (*endo* CH_3O)	6.92 br d
	1.36 s (1)	4.11 d (*J* 12.6)	3.01 s (CH_3SO$_2$)	6.93 br d
	1.41 s (1)	{29.71}[c]	3.67 s (*exo* CH_3O)	7.23 s
		3.73 d (*J* 15.0)	4.07 d (*J* 14.7)	7.28 s
		3.86 d (*J* 15.0)	4.33 d (*J* 14.7)	
		{37.99}[c]	(OCH_2CO)	
1,3-Alt**L1**Rb_2	1.28 s (2)	3.71 br s	2.97 s (CH_3SO$_2$)	7.116 s
	1.32 s (2)	{37.65}[c]	3.34 s (CH_3O)	7.125 s
			4.21 s (OCH_2CO)	
1,3-Alt**L1**Cs_2	1.28 s (2)	3.714 d (*J* 16.2)	2.97 s (CH_3SO$_2$)	7.13 s
	1.35 s (2)	3.722 d (*J* 16.2)	3.37 s (CH_3O)	7.14 s
		{37.62}[c]	4.22 s (OCH_2CO)	

[a] At 499.7 MHz in $CDCl_3$ at 296 K, δ are in ppm, *J* are in Hz. [b] Number of *tert*-butyl groups in parentheses. [c] The ^{13}C signal which is connected to the pair of proton doublets in the HSQC spectrum.

Table 2 Conformational preferences (%) for the calix[4]arene unit in $CDCl_3$ for the alkali metal salts of mobile diionizable ligands **L1**M_2–**L5**M_2

	Li		Na		K		Rb		Cs
	Cone	Paco	Cone	Paco	Paco	1,3-Alt	Paco	1,3-Alt	1,3-Alt
L1M_2[a]	88	12	31	69	96	4	43	57	>97
L2M_2[b]	>95		40	60	>85		50	50	>95[c]
L3M_2[b]	>95		25	75	>95		67	33	92[d]
L4M_2[b]	>90		30	70	>90		45	55	>95
L5M_2[b]	>90		60	40	>95		70	30	>95

[a] ^{1}H NMR at 499.7 MHz, 296 K. [b] ^{1}H NMR at 300.1 MHz, 297 K. [c] In acetone-d_6. [d] ^{1}H NMR at 499.7 MHz, 308 K.

Analysis of the NMR spectra for the alkali metal salts **L2**M_2–**L5**M_2 was performed in a similar fashion. Data for the preferred conformations of the calix[4]arene units are presented in Table 2. It is readily apparent that there is no significant change of the conformational preference upon variation of the NSO_2R substituent (*i.e.*, from **L1** to **L5**). There is, however, a systematic change in the preferred conformation(s) of the calix[4]arene moiety from cone to partial cone to 1,3-alternate for all five of the ligands as the alkali metal cation is varied from Li^+ to Na^+ to K^+ to Rb^+ to Cs^+. The number of inverted arene units in the calix[4]arene increases in this order. To the best of our knowledge, this is the first demonstration of such conformational control of calix[4]arenes by variation in the size and softness of the complexed metal cations. Never before have three different preferred conformations been observed for complexes of a particular mobile calix[4]arene ligand only upon variation of the complexed metal cation.[22]

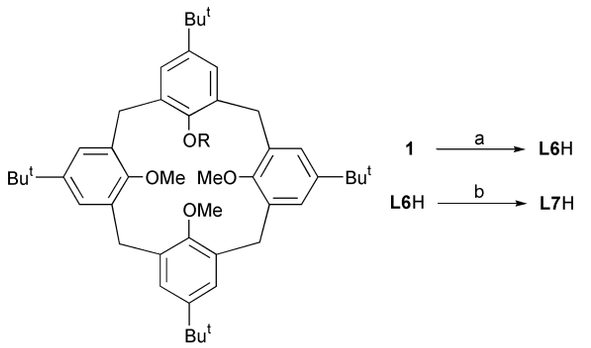
The ^{1}H NMR spectra for **L1**M_2–**L5**M_2 are broadened when the temperature is lowered, indicating that on the NMR time scale rapid conformational interconversion takes place at 296 K. Therefore, the observed conformational preferences reflect the relative thermodynamic stabilities of the complexes. The conformer with the greatest population has the lowest energy and the highest stability. It seems reasonable that rigidifying a ligand in a conformation preferred by the complex of a mobile ligand with a particular metal cation would form the most stable complex among other rigid conformational isomers with this cation.

Conformational studies of alkali metal salts of monoionizable calix[4]arene ligands

The alkali metal salts for the diionizable ligands **L1**H_2–**L5**H_2 have two metal ions per calix[4]arene unit. To extend our conformational studies to 1 : 1 complexes, mobile ligands **L6**H and **L7**H (with a single proton-ionizable group) were prepared. As shown in Scheme 1, the carboxylic acid **L6**H was obtained first and converted[7] into the *N*-(trifluoromethylsulfonyl)carboxamide **L7**H.

In contrast to **L1**H_2–**L5**H_2, there are three mobile arene units in **L6**H and **L7**H. Accordingly, there are six different limiting conformations (**A**–**F**, Fig. 4) possible for the calix[4]arene moiety in these compounds.

Alkali metal salts of **L6**H and **L7**H were prepared in a similar fashion to those for the ligands **L1**H_2–**L5**H_2. Substantial changes in the ^{1}H NMR spectra of the salts **L6**M and **L7**M in



	R
1	H
L6H	CH_2CO_2H
L7H	$CH_2C(O)NHSO_2CF_3$

Scheme 1 Synthetic route for the preparation of **L6**H and **L7**H. *Reagents and conditions*: a) i) $BrCH_2CO_2Me$, NaH, THF, reflux, 20 h; ii) NMe_4OH, THF–H_2O, reflux, 36 h; b) i) $(COCl)_2$, C_6H_6, 60 °C, 14 h; ii) $CF_3SO_2NH_2$, NaH, THF, rt, 16 h.

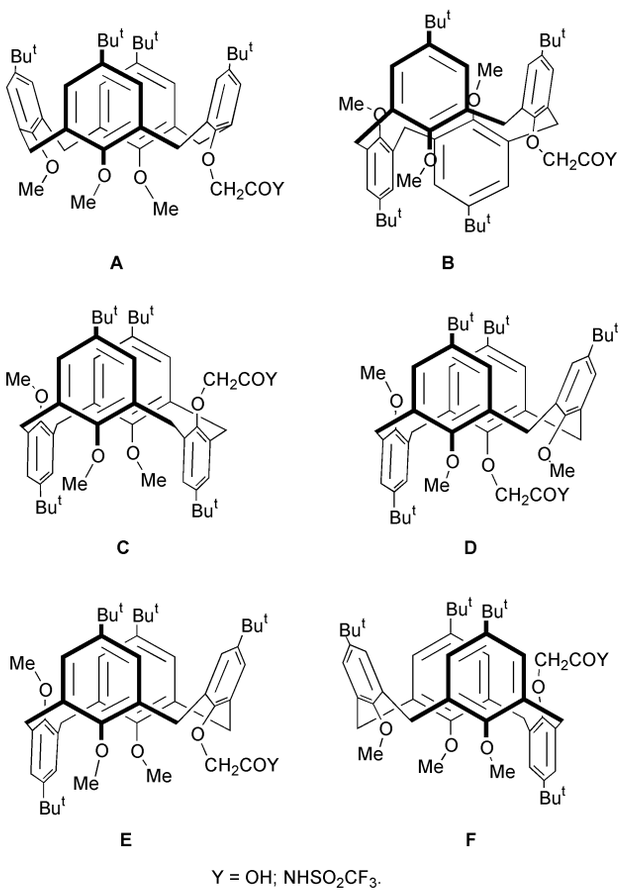


Fig. 4 Six possible limiting conformations of the calix[4]arene unit in **L6**H and **L7**H.

$CDCl_3$, compared to the ligands themselves, were observed (see Fig. 5). We used analysis of the NMR spectra to assess the conformational preferences of the calix[4]arene moieties in these salts.

Consistent with a cone conformation for the calix[4]arene moiety, the ^{1}H NMR spectrum for **L6**Li exhibits two pairs of well-separated doublets for the bridging methylene group protons (Fig. 5). For **L6**Cs, the signals for the $ArCH_2Ar$ group protons reveal the presence of both the *syn*- and *anti*-oriented arene units. A singlet for the $OCH_2C(O)$ group protons shows that the two anisolic units flanking the arene unit with the ionized group are oriented in the same direction. Therefore, a paco conformation (**E** or **F**, Fig. 4) is indicated. For the final assignment we used a NOESY spectrum. The singlet for the $OCH_2C(O)$ group protons has a NOE connection with the signal for the methylene group bridging the two *anti*-oriented arene units. The signal for the lesser populated methoxy group has a NOE connection with a downfield doublet from protons of the methylene groups that bridge the two *syn*-oriented arene units. Therefore, we deduce that paco conformation **F** is the preferred conformation for **L6**Cs. The same paco conformation is preferred by the calix[4]arene unit in **L6**Rb, although its population is lower than in the **L6**Cs. The ^{1}H NMR spectra for **L6**Na and **L6**K are very complicated. As judged by the number of *tert*-butyl group singlets, more than two significantly populated conformations are present. Due to this complexity, it was impossible to determine the preferred conformations for these two salts.

Table 3 Conformational preferences (%) for the calix[4]arene unit in $CDCl_3$ for the alkali metal salts of mobile monoionizable ligands **L6**M and **L7**M[a]

	Li			Rb	Cs
	Cone	Na	K	Paco **F**	Paco **F**
L6M	>95	[b]	[b]	65	>95
L7M	92	[b]	[b]	60	88

[a] ^{1}H NMR at 499.7 MHz, 296 K. [b] Mixture of conformations.

The conformational preferences for salts **L7**M in $CDCl_3$ solution were determined in a similar fashion. The data are presented in Table 3.

It can be seen that the conformational preferences of the calix[4]arene moieties in the alkali metal salts of the monoionizable ligands are also determined by the identity of the complexed metal ion rather than the nature of the ionizable side arm. A preferred cone conformation for the Li^+ salts is consistent with literature data [17] and the results described earlier in this paper for the diionizable ligands.

The results for the Cs^+ salts are noteworthy. For the first time, mobile calix[4]arene ligands are found to prefer a paco conformation, in a complex with Cs^+. Both **L6**Cs and **L7**Cs prefer the paco conformation, which has the potential for three cation–π interactions of Cs^+ with the arene units of the calix[4]arene moiety, over the 1,3-alternate conformation, for which only two such interactions are possible. In a nonpolar solvent, the cation and anion remain in close proximity due to coulombic interaction. It is envisioned that in **L6**Cs and **L7**Cs (paco conformation **F**) the metal ion is located inside the calix[4]arene cavity where it can interact effectively with both the ionized side arm and with three arene units. The design and synthesis of rigidified monoionizable calix[4]arenes with an analogous paco conformation should provide ligands with high binding propensity for Cs^+.

Concluding remarks

This study of conformational preferences for metal ion complexes of mobile calix[4]arene ligands in solution provides important information for the design of new ligands with high selectivity for desired metal ions. We are currently exploring this strategy in the search for new, highly selective calix[4]arene ligands.

Experimental

General

NMR spectra were measured with a Varian Unity INOVA spectrometer (499.7 MHz for ^{1}H, 125.7 MHz for ^{13}C) and an IBM AF-300 spectrometer (300.1 MHz for ^{1}H, 50.3 MHz for ^{13}C). Chemical shifts (δ) are expressed in ppm downfield from TMS and coupling constant (J) values are given in Hz. HSQC

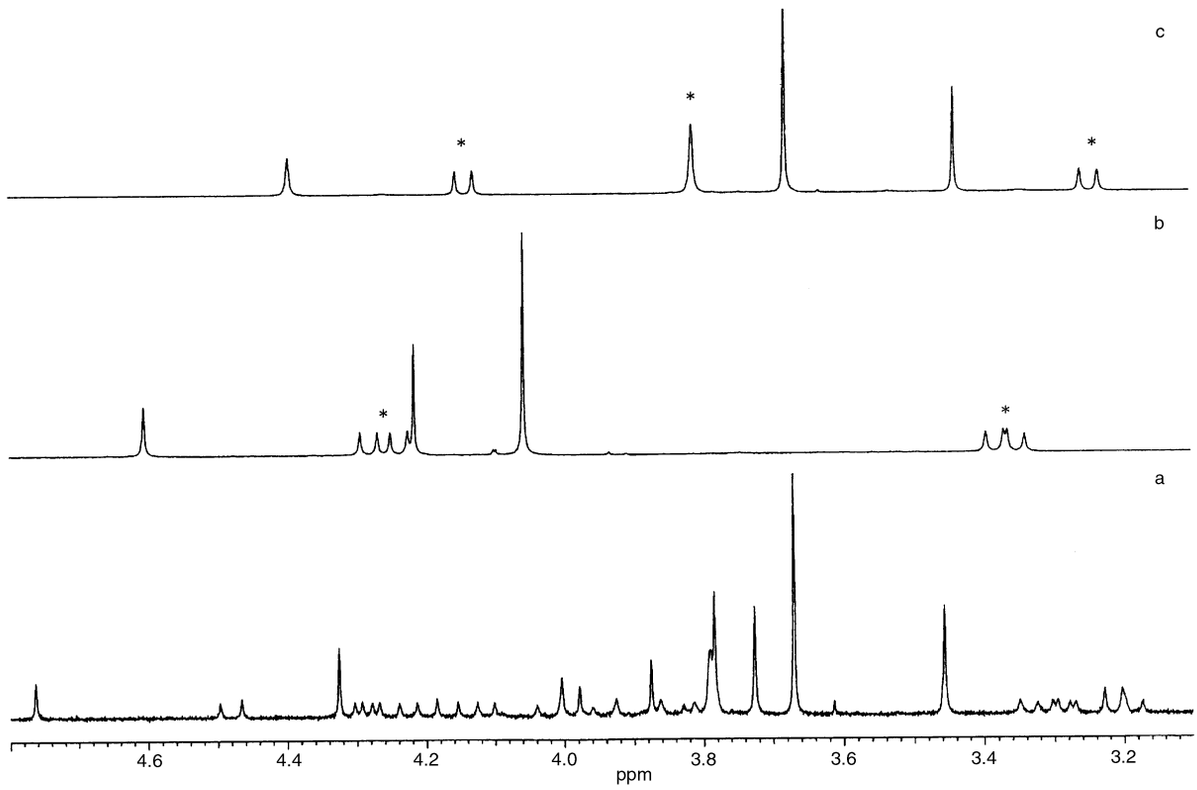


Fig. 5 Partial ^{1}H NMR spectra for (a) **L6**H; (b) **L6**Li; (c) **L6**Cs (499.7 MHz, $CDCl_3$, 296 K) (* identifies signals of ArCH_2Ar protons).

and NOESY (mixing time 0.9 s) spectra were obtained using standard procedures.

Preparations

Compounds **L1**H_2–**L4**H_2,[7] **L5**H_2,[23] and **1**[24] were prepared by reported procedures.

Ligand L6H. A mixture of **1** (4.22 g, 6.11 mmol), NaH (0.44 g, 18.3 mmol) and methyl bromoacetate (1.87 g, 12.2 mmol) in THF (100 mL) was refluxed for 20 h under nitrogen. After addition of water (1 mL) at room temperature, the THF was removed *in vacuo*. To the residue, CH_2Cl_2 and water were added. The organic layer was separated, washed with 1 M HCl and water, dried (Na_2SO_4), and the solvent removed *in vacuo*. The crude ester was hydrolyzed without purification.

To a solution of the residue in THF (100 mL), 16 mL of 25% aqueous NMe_4OH and 50 mL of H_2O were added and the mixture was refluxed for 36 h. After the THF was removed *in vacuo*, CH_2Cl_2 and concentrated HCl (until pH <1) were added. The organic layer was washed with 10% HCl and water, dried ($MgSO_4$) and evaporated. The residue was chromatographed on silica gel with CH_2Cl_2 as eluent. Yield 1.56 g, 21% (one spot fraction), mp 145–147 °C. IR (deposit from CH_2Cl_2 solution on a NaCl plate) ν_{max}/cm^{-1}: 3264 (OH), 1759 (C=O); δ_H (499.7 MHz; $CDCl_3$; 296 K) 0.82–1.54 (m, 36 H), 3.18–4.77 (m, 19 H), 6.50–7.28 (m, 8 H). Anal. Calcd. for $C_{49}H_{64}O_6 \cdot 0.4H_2O$: C 77.82, H 8.64. Found: C 77.80, H 8.59%.

Ligand L7H. A solution of **L6**H (1.08 g, 1.44 mmol) and oxalyl chloride (0.85 g, 6.69 mmol) in C_6H_6 (30 mL) was stirred at 60 °C for 14 h under nitrogen and then the solvent was removed *in vacuo*. A solution of the residue in THF (30 mL) was added to a mixture of NaH (0.11 g, 4.33 mmol) and trifluoromethanesulfonamide (0.32 g, 2.16 mmol) in THF (30 mL) and the mixture was stirred under nitrogen at room temperature for 16 h. Water (1 mL) was added and the THF was evaporated. To the residue, CH_2Cl_2 and water were added. The organic layer was separated, washed with aqueous Na_2CO_3 and water, dried (Na_2SO_4), and the solvent was removed *in vacuo*. After chromatography of the residue on silica gel with CH_2Cl_2–MeOH (97 : 3) as eluent, the residue was dissolved in CH_2Cl_2, washed with 10% aqueous HCl and water, and the solvent was removed *in vacuo*. Yield 1.03 g (81%), mp 134–135 °C. IR (deposit from CH_2Cl_2 solution on a NaCl plate), ν_{max}/cm^{-1}: 1750 (C=O); δ_H (499.7 MHz; $CDCl_3$; 296 K) 0.80–1.60 (br m, 36 H), 3.15–4.90 (br m, 19 H), 6.50–7.25 (br m, 8 H). Anal. Calcd. for $C_{50}H_{64}F_3NO_7S$: C 68.23, H 7.33, N 1.59. Found: C 67.99, H 7.30, N 1.61%.

General procedure for preparation of alkali metal salts L1M_2–L5M_2, L6M, and L7M

A 20 mmol dm^{-3} stock solution of a ligand in $CDCl_3$ was prepared. A 1.0 mL sample of the stock solution and the appropriate powdered alkali metal carbonate (5–7 fold excess) in a vial was stirred magnetically for 12 h at room temperature. The mixture was filtered and the filtrate was used for the NMR spectral measurements.

^{1}H NMR data for the alkali metal salts of L6M and L7M. *Cone* ***L6****Li*. δ_H (499.7 MHz; $CDCl_3$; 296 K) 1.13 (s, 18 H), 1.224 (s) + 1.231 (s) (18 H), 3.35 (d, *J* 12.5) + 3.38 (d, *J* 12.4) (4 H), 4.06 (s, 6 H), 4.22 (s) + 4.24 (d, *J* 12.5) + 4.28 (d, *J* 12.4) (7 H), 4.61 (s, 2 H), 7.01 (br d, 2 H), 7.02 (br d, 2 H), 7.122 (s) + 7.124 (s) (4 H). δ_C (125.7 MHz; $CDCl_3$; 296 K) 31.71 (ArCH_2Ar).

*Paco (****F****)* ***L6****Rb*. δ_H (499.7 MHz; $CDCl_3$; 296 K) 1.15 (s, 18 H), 1.35 (s, 9 H), 1.44 (s, 9 H), 3.25 (d, *J* 13.0, 2 H), 3.35 (s, 3 H), 3.70 (s, 6 H), 3.81 (s, 4 H), 4.13 (d, *J* 13.0, 2 H), 4.42 (s, 2 H), 6.83 (d, *J* 2.4, 2 H), 7.16 (d, *J* 2.4, 2 H), 7.20 (s, 2 H), 7.36 (s, 2 H).

*Paco (****F****)* ***L6****Cs*. δ_H (499.7 MHz; $CDCl_3$; 296 K) 1.17 (s, 18 H), 1.32 (s, 9 H), 1.45 (s, 9 H), 3.25 (d, *J* 12.8, 2 H), 3.44 (s, 3 H), 3.68 (s, 6 H), 3.81 (s, 4 H), 4.14 (d, *J* 12.8, 2 H), 4.40 (s, 2 H), 6.88 (d, *J* 2.4, 2 H), 7.16 (d, *J* 2.4) + 7.17 (s) (4 H), 7.37 (s, 2 H).

Cone ***L7Li***. δ_H (499.7 MHz; $CDCl_3$; 296 K) 1.13 (s, 18 H), 1.224 (s) + 1.232 (s) (18 H), 3.39 (d) + 3.41 (d) (4 H), 3.99 (s, 6 H), 4.13 (d, *J* 12.5, 2 H), 4.24 (s) + 4.25 (d) (5 H), 4.81 (s, 2 H), 7.01 (s, 2 H), 7.03 (s, 2 H), 7.14 (s, 4 H).

*Paco (**F**)* ***L7Rb***. δ_H (499.7 MHz; $CDCl_3$; 296 K) 1.13 (s, 18 H), 1.35 (s, 9 H), 1.44 (s, 9 H), 3.27 (d, *J* 13.1, 2 H), 3.34 (s, 3 H), 3.70 (s, 6 H), 3.73 (d, *J* 14.8, 2 H), 3.85 (d, *J* 14.8, 2 H), 4.12 (d, *J* 13.1, 2 H), 4.63 (s, 2 H), 6.85 (br s, 2 H), 7.05 (br s, 2 H), 7.21 (s, 2 H), 7.38 (s, 2 H).

*Paco (**F**)* ***L7Cs***. δ_H (499.7 MHz; $CDCl_3$; 296 K) 1.17 (s, 18 H), 1.32 (s, 9 H), 1.46 (s, 9 H), 3.26 (d, *J* 12.8, 2 H), 3.45 (s, 3 H), 3.68 (s, 6 H), 3.73 (d, *J* 15.1, 2 H), 3.85 (d, *J* 15.1, 2 H), 4.13 (d, *J* 12.8, 2 H), 4.50 (s, 2 H), 6.92 (d, *J* 2.4, 2 H), 7.08 (d, *J* 2.4, 2 H), 7.17 (s, 2 H), 7.39 (s, 2 H).

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