Kinetically Stable Complexes of Alkali Cations with Calixspherands: An Evaluation of Shielding

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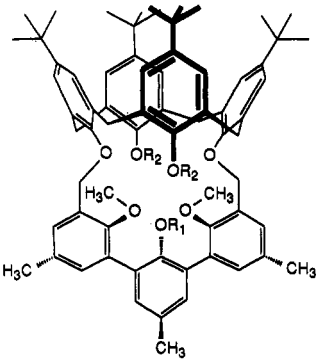
Abstract: Three new calixspherands (**2–4**) were synthesized in good yields (>60%) via a new method; *p-tert*-butylcalix[4]arene (**6**) is bridged with a *m*-terphenyl (**7–9**) and subsequently alkylated. ^{1}H NMR spectroscopy and X-ray crystallography showed that all the complexes are in a *partial cone* conformation. All the calixspherands form *kinetically* stable complexes with Na^+, K^+, and Rb^+. The kinetic stability was determined both by ^{1}H NMR spectroscopy, in $CDCl_3$ saturated with D_2O, and by a new method based on the exchange of radioactive rubidium or sodium in the complexes for nonradioactive sodium in different solvents. Both methods showed that the *kinetic* stability of the different complexes is strongly increased when the size of the group on the central aromatic ring of the *m*-terphenyl is increased. This effect is most pronounced for the rubidium complexes. The half-life times for decomplexation, in $CDCl_3$ saturated with D_2O, increased from 2.8 h for **[1·Rb]**$^+$ to 139 h and 180 days for **[2·Rb]**$^+$ and **[3·Rb]**$^+$, respectively. The "exchange method" shows that the rate of decomplexation is the rate-limiting step in the exchange of rubidium in the complex for sodium present in solution. These results can be explained in terms of increased shielding of the cavity from solvent molecules. The kinetic stabilities of the complex of **3** with Na^+, K^+, and Rb^+ are the highest ever reported.

Introduction

Modified calixarenes are known to form thermodynamically stable complexes with several cations.[1] These complexes have many applications. Selective ionophores for sodium, formed by the introduction of four carbonyl-containing groups (*i.e.* amides, esters, or ketones) on calix[4]arenes, are used in ion-sensitive field effect transistors (ISFETs)[2] and ion-selective electrodes (ISEs).[3] Potassium-selective ionophores such as calixcrowns,[4] obtained by bridging calix[4]arene with a poly(ethylene glycol) chain, are applied not only in ISFETs[5] but also in membrane transport.[6]

In the present work we have investigated *kinetically* stable complexes of alkali metal ions and in particular Rb^+, with as the ultimate goal the immobilization of rubidium for organ imaging.[7] Previously we have reported calixspherand **1** (Chart I) and showed that it forms complexes with Na^+ and K^+ which are kinetically stable on the human time scale,[8] with decomplexation half-life times at room temperature, in chloroform saturated with water,

Chart I



	R_1	R_2
1	CH_3	CH_3
2	CH_2CH_3	CH_3
3	$CH(CH_3)_2$	CH_3
4	CH_3	CH_2CH_3
2-d$_6$	CH_2CH_3	CD_3
3-d$_6$	$CH(CH_3)_2$	CD_3
4-d$_{10}$	CH_3	CD_2CD_3
10	CH_3	H
11	CH_2CH_3	H
12	$CH(CH_3)_2$	H

of 3.7 and 2.2 years, respectively. The X-ray structure determinations and NOESY spectra of the sodium complex and the free ligand indicated that the calix[4]arene moiety in the sodium complex is in a partial cone conformation, although in the free ligand it is in the cone conformation.[9] With Rb^+ a complex is formed with a much lower kinetic stability; the half-life time of decomplexation at room temperature of **[1·Rb]**$^+$ is only 2.8 h. The lower stability of the Rb^+ complex is a consequence of the larger Rb^+ cation forcing the methoxy groups of the calixspherand to rotate away from the cavity. This renders the cation more accessible to solvent molecules which will facilitate the decomplexation. The rotation of the methoxy groups is confirmed by their chemical shifts in the ^{1}H NMR spectra of different complexes and by molecular mechanics calculations.[9]

In order to improve the kinetic stability of Rb^+ complexes, the complexed Rb^+ should be better shielded from solvent molecules.

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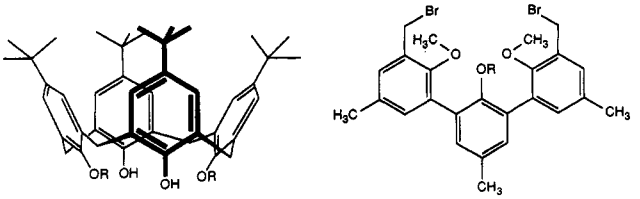
Chart II



5 R = CH_3
6 R = H

7 R = CH_3
8 R = CH_2CH_3
9 R = $CH(CH_3)_2$

Therefore, ethoxy and isopropoxy groups were selected to increase the shielding of the cavity. In principle there are five methoxy groups in calixspherand **1** which can be substituted by larger groups. Preliminary studies, however, showed that the introduction of three ethoxy groups on the *m*-terphenyl moiety did not give complexes with increased kinetic stabilities.

In this paper, we report a new synthesis of calixspherands. Via this new route novel calixspherands **2–4** (Chart I) were synthesized which have two larger groups on the calix[4]arene moiety or, alternatively, one larger group at the central aromatic ring of the *m*-terphenyl unit. The kinetic stabilities of the alkali cation complexes of the calixspherands were determined in two different ways. In the first method the rate of exchange of the cation between a nondeuterated and a partially deuterated ligand was determined by ^1H NMR spectroscopy in $CDCl_3$ saturated with D_2O.[10] In the second method the influence of cations on the decomplexation of a radioactive ion was studied in acetone and DMSO solutions containing other salts.

Results and Discussion

Synthesis. Previously calixspherand **1** was obtained by coupling of 26,28-dimethoxy-*p-tert*-butylcalix[4]arene (**5**) with *m*-terphenyl **7**[11](Chart II), in yields of less than 30%.[8] We now report a more efficient synthesis which gives **1** in a yield of more than 60%. In this new synthesis *p-tert*-butylcalix[4]arene (**6**) was first coupled with *m*-teranisyl **7** to calixspheranddiol **10** (Chart I) and subsequently the free hydroxy groups were alkylated. Efforts to prepare **10** under *high-dilution* conditions (*i.e* slow addition), however, always resulted in a low yield of bridged product and recovery of calix[4]arene. Attempts to prepare calixspheranddiol **10** *without high dilution* proved more fruitful. The best results were achieved when the "poly"anion[12] of *p-tert*-butylcalix[4]arene (**6**) was prepared first by reaction with 5 equiv of sodium hydride in THF in the presence of a catalytic amount (3 mol %) of 18-crown-6, followed by addition of a solution of *m*-terphenyl **7** in THF to a suspension of the resulting calix[4]-arene anion at reflux. In this way, it was possible to obtain **10** in yields over 80%.

The high yield when no high dilution was used can be explained as follows. After the first substitution on the bis(bromomethyl)-terphenyl which will be very fast, the monoalkylated calix[4]-arene forms most probably a dianion.[12,13] The most reactive phenolate of this dianion is that of a proximal phenol. However, the *m*-terphenyl moiety is too rigid for alkylation on a proximal phenolic group. Hence, the diametrically disubstituted product is formed. In addition, a sodium cation may act as a template around which the ligating sites of the *m*-terphenyl and the calix-[4]arene fold, in favor of diametrical disubstitution. This argument is supported by the fact that when the larger potassium cation was used, potassium hydride instead of sodium hydride, only small amounts of calixspheranddiol **10** were isolated, thus indicating that potassium is too large to act as a good template ion.

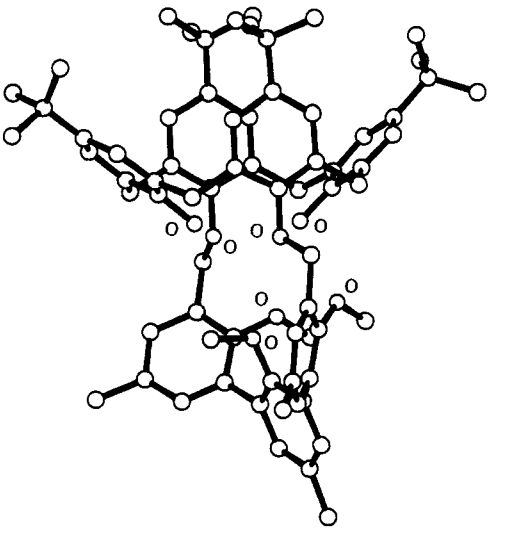


Figure 1. Crystal structure of calixspheranddiol **10**.

From the ^1H NMR spectrum the conformation of the calix-[4]arene moiety of **10** in solution was initially interpreted as a partial cone with two signals for the phenolic hydroxyl groups, two AB systems for the methylene protons of the calix[4]arene, and three signals for the *tert*-butyl groups in a ratio of 1:1:2. However, an X-ray crystal structure determination of **10** (Figure 1) revealed a cone structure for the calix[4]arene moiety in the solid state. In addition, the conformation of the calix[4]arene moiety in solution was analyzed by a two-dimensional NOESY spectrum. Cross-peaks were obtained between the protons of all the neighboring aryl rings of the calix[4]arene, which confirmed that **10** is in the cone conformation also in solution. Further evidence for the cone conformation in solution was obtained from the ^{13}C NMR spectrum, which showed only one signal for the methylene carbons at δ 30.6.[14] The one-dimensional ^1H NMR spectrum can be explained as follows. The methoxy groups at the outer phenyl rings of the terphenyl unit point toward one of the phenols of the calix[4]arene moiety, whereas the methoxy group at the central phenyl ring of the terphenyl unit points toward the other phenol of the calix[4]arene moiety. The terphenyl unit is fixed as a result of its high rigidity, and consequently the two phenolic rings are magnetically nonequivalent.

The subsequent step in this new calixspherand synthesis involved the alkylation of **10**. This was achieved with iodomethane and potassium *tert*-butoxide as base in THF to afford **1** as the potassium complex in a yield of 81%. It was also possible to use rubidium *tert*-butoxide[15] as base under the same conditions to obtain the corresponding rubidium complex.[16]

Alkylation of **10** with iodoethane afforded **4** as the potassium complex in a yield of 83%. However, attempts to alkylate with 1- or 2-iodopropane, 1-iodobutane, and 3-bromopropene were unsuccessful, indicating that there is insufficient space to accommodate larger alkyl groups.

In order to establish the structure of $[\mathbf{4}\cdot K]^+$, attempts were made to grow crystals suitable for an X-ray structure determination, which were successful although in very low yield. The structure of $[\mathbf{4}\cdot K]^+$ (Figure 2), with the calix[4]arene moiety in

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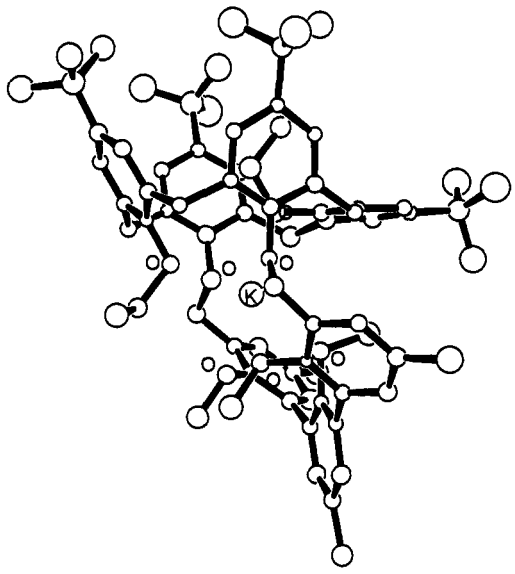
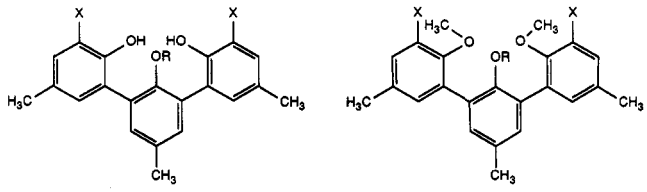


Figure 2. Crystal structure of $[4\cdot K]^+Pic^-\cdot CH_2Cl_2$. The picrate anion and the molecule of dichloromethane are omitted for clarity.

Chart III



13	R = X = H		**18**	R = CH_2CH_3	X = Br
14	R = CH_2CH_3	X = H	**19**	R = $CH(CH_3)_2$	X = Br
15	R = $CH(CH_3)_2$	X = H	**20**	R = CH_2CH_3	X = CHO
16	R = CH_2CH_3	X = Br	**21**	R = $CH(CH_3)_2$	X = CHO
17	R = $CH(CH_3)_2$	X = Br	**22**	R = CH_2CH_3	X = CH_2OH
			23	R = $CH(CH_3)_2$	X = CH_2OH

a partial cone conformation, resembles the flatened partial cone structure[8] of $[1\cdot Na]^+$. However, the ^1H NMR spectrum of $[4\cdot K]^+$ is rather different from the spectrum of $[1\cdot Na]^+$ (*vide infra*).

For the synthesis of the calixspherands **2** and **3**, we prepared the *m*-terphenyls **8** and **9** starting from triscresol **13**[17] (Chart III). Monoalkylation[18] of **13** with iodoethane in the presence of potassium hydrogen carbonate in acetone afforded **14** in 80% yield. The monoisopropoxyterphenyl **15** was synthesized according to the same procedure but in acetonitrile instead of acetone as the solvent. Treatment of **14** with bromine in dichloromethane gave the dibromide **16** in 84% yield. It was not possible, however, to use the same conditions for the bromination of **15**, as the liberated hydrogen bromide cleaved the isopropoxy group. The bromination was therefore achieved using *N*-bromosuccinimide in DMF[19] to give the dibromide **17** in moderate yield (71%). The two remaining phenolic positions in **16** and **17** were subsequently methylated with dimethyl sulfate to give **18** (94%) and **19** (92%), respectively. Metalation with *n*-butyllithium followed by quenching with DMF and acidic workup gave the dialdehydes **20** (70%) and **21** (75%), as was clear from the signal at δ 10.5 in the ^1H NMR spectra. Reduction of the dialdehydes **20** and **21** with sodium borohydride afforded the diols **22** (78%) and **23** (80%), respectively. Subsequent treatment of these diols with phosphorus tribromide gave the bis(bromomethyl)terphenyls **8** and **9** (Chart II) in reasonable yields (82% and 69%, respectively), as was proven by mass spectrometry. Although strong acid is liberated during the reaction, **9** could be obtained from **23** by applying a short reaction time (15 min).

The *m*-terphenyls **8** and **9** were subsequently coupled with *p-tert*-butylcalix[4]arene (**6**), under the same conditions as used for the synthesis of **10**, to afford the calixspheranddiols **11** (64%) and **12** (68%), respectively. Methylation of **11** and **12** using the same reaction conditions as those for **10** afforded the calixspherands **2** (87%) and **3** (95%) as their potassium complexes.

Structures of the Calixspherand Complexes in Solution. As mentioned in the previous section, all the calixspherands were isolated as their potassium complexes. The ^1H NMR spectra of the complexes of **2** and **3** indicate that their conformations, in solution, are comparable to that of the previously reported K^+ complex of calixspherand **1**,[8] *i.e.* with the calix[4]arene moiety in a partial cone conformation. In this conformation, the methoxy group of the rotated aromatic ring is located in the cavity of the calix[4]arene, as shown by the high-field absorption at δ 0.00 and 0.01 for **2** and **3**, respectively. The benzylic protons ($ArCH_2O$) appear as an AB system at δ 5.80 and 4.12, for **2**, and at δ 5.73 and 4.14, for **3**. The methylene protons of the calix[4]arene moiety also appear as two AB systems. In addition, the ^{13}C NMR spectra clearly show a partial cone conformation of both calixspherands by the characteristic shifts of the methylene carbons[14] at δ 34.9 and 29.8, for **2**, and at δ 34.9 and 29.7, for **3**.

In order to obtain the calixspherands (**2–4**) as free ligands, the potassium complexes were heated in a mixture of methanol/water (1:4) in a closed vessel at 120 °C for 3 days. In this way we were able to isolate the free ligands **2** and **4**. In the case of **3**, however, the potassium complex was recovered under these conditions, which is an indication of the very high stability of this complex. Since we anticipated that $[3\cdot Rb]^+$ would be less stable, $[3\cdot Rb]^+$ was synthesized in 85% yield, by using rubidium *tert*-butoxide[15] instead of potassium *tert*-butoxide in the final alkylation. The rubidium complex of **3** could be decomplexed by heating in a mixture of methanol/water (1:4) under reflux (90 °C) at normal pressure for 3 days.

Since the ^1H NMR spectra of the free ligands **2** and **3** were similar to that of the free ligand **1**, the conformation of the calix[4]arene moiety of **2** and **3** was interpreted as cone. Decomplexation of $[4\cdot K]^+$ (partial cone conformer, *vide supra*) afforded pure **4** as a, not further identified, *mixture of conformers*. This is possibly due to the rotation of the ethoxy groups through the cavity at elevated temperatures,[20] and consequently **4** is present as a mixture of at least two different conformers. Complexation of such a mixture of conformers of **4** with sodium, potassium, or rubidium picrate afforded the respective complexes *in a single conformation*. The ^1H NMR spectra of $[4\cdot K]^+$ and $[4\cdot Rb]^+$ are very similar but *different from the spectrum of* $[4\cdot Na]^+$ (Figure 3). Furthermore, the conformation of $[4\cdot K]^+$ was identical to that of the complex obtained from the alkylation of calixspheranddiol **10**, *viz.* a partial cone conformation. The structures of all three complexes of **4** in solution were solved by two-dimensional NOESY spectroscopy. In all complexes the calix[4]arene moiety is in a partial cone conformation. However, the difference is that in the sodium complex the methoxy group at the central aromatic ring of the terphenyl unit points toward the rotated phenyl ring of the calix[4]arene moiety (partial cone I, Figure 4), just as in the crystal structure of $[1\cdot Na]^+$. In the potassium and rubidium complex the two methoxy groups of the outer aromatic rings of the terphenyl unit point toward the rotated phenyl ring (partial cone II). This means that the conformation

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(20) At temperatures below 70 °C, only the smaller groups such as hydroxy or methoxy can rotate through the cavity, while at higher temperatures, the larger ethoxy group can also rotate. Groenen, L. C.; Van Loon, J.-D.; Verboom, W.; Harkema, S.; Casnati, A.; Ungaro, R.; Pochini, A.; Ugozzoli, F.; Reinhoudt, D. N. *J. Am. Chem. Soc.* **1991**, *113*, 2385–2392.

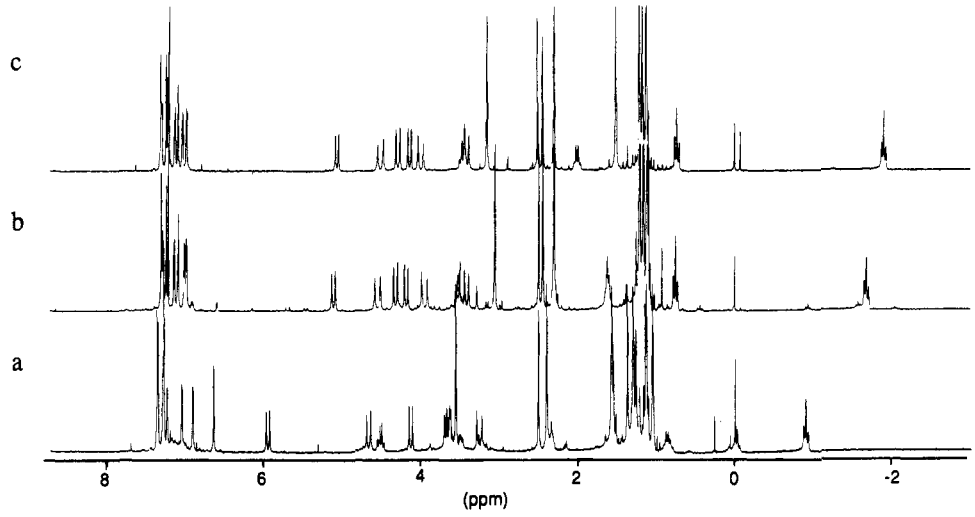

Figure 3. ^{1}H NMR spectra of [**4**·**Na**]$^+$ (a), [**4**·**K**]$^+$ (b), and [**4**·**Rb**]$^+$ (c).

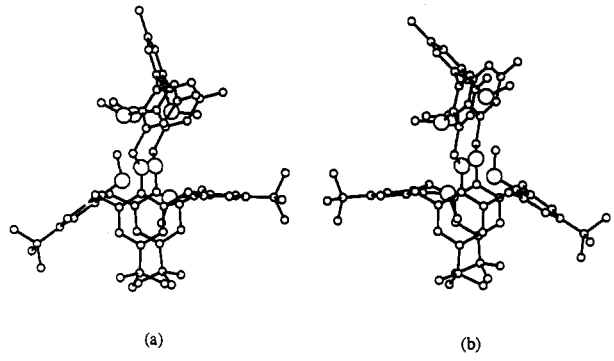

Figure 4. Schematic representations of partial cone I (a) and partial cone II (b).

of [**4**·**K**]$^+$ in solution is different from the observed conformation in the solid state (*vide supra*). Previously[9] we had calculated for calixspherand **1** that the preferred conformation for complexation with sodium is partial cone I, whereas the preferred conformation for the binding of potassium and rubidium was calculated to be partial cone II. Although for **1** the predicted difference in the structures of the sodium, potassium, and rubidium complexes could not be confirmed in solution, this difference is now confirmed for the complexes of **4** with Na^+, K^+, and Rb^+. The only difference between the structures of **1** and **4** is the *O*-alkyl substituents at the calix[4]arene moiety, CH_3 and CH_2CH_3, respectively.

Complexation Studies

Thermodynamic and Kinetic Stabilities in $CDCl_3$ Saturated with D_2O. A widely used method for the determination of the association constant (K_a), especially for highly lipophilic hosts, is the two-phase picrate extraction method.[21] For *kinetically* stable complexes with a relatively slow rate of formation, however, this method is not applicable, since it takes too long to establish an equilibrium.[10] Also other methods, such as polarography and titration calorimetry,[22] are not useful for the direct determination of association constants of such complexes. A better method to obtain the value for the association constants is by indirect methods in which K_a is calculated from the ratio of the complexation rate constant (k_c) and the decomplexation rate constant (k_d) by eq 1. Values for k_c and k_d can be obtained as described by Cram and Lein for the spherands,[10] methods that we used previously for calixspherand **1**.[8]

$$K_a = k_c/k_d \quad (1)$$

The *decomplexation* rate constant (k_d) can be determined by the exchange of Na^+, K^+, and Rb^+ from a non-deuterium-labeled complex to a (partially) deuterium-labeled free ligand. This exchange can be monitored by ^{1}H NMR spectroscopy from the disappearance of the well-separated signals at $\delta \sim 0$ of the methoxy or ethoxy groups (R_2 in Chart I) on the calix[4]arene moiety of the complexes. Therefore the calixspherands **2**-d_6, **3**-d_6, and **4**-d_{10}, in which R_2 is deuterated, were synthesized as described for **2**–**4**. When the exchange process is too slow at room temperature, the exchange can be achieved at higher temperatures. From experiments at three different temperatures, values for $\Delta H^{\ddagger}$ and $\Delta S^{\ddagger}$ can be obtained from an Eyring plot, and these can be used to extrapolate k_d to room temperature.[23]

The *complexation* rate constant (k_c) can be determined *via* a competition method that we developed to study the complexation kinetics of *tert*-butylammonium salts with simple crown ethers[24] and which has been used to study the complexation of spherands[10] and calixspherand **1**.[8] This method uses the rates of exchange of alkali metal picrates between a relatively weak complex (L·M^+) and the calixspherands as a function of time. The role of the weak complex is to provide a constant pre-equilibrium concentration of M^+Pic^-, sufficiently low to study the complexation rate by ^{1}H NMR spectroscopy. Because the rate of complexation and of decomplexation of L with M^+Pic^- is fast on the appropriate time scale and k_d for the calixspherands is much smaller than k_c, the rate-determining step is the *complexation* process. The time scale of the exchange process can be selected by the appropriate choice of L.

The rates of decomplexation and of complexation were determined for the Na^+, K^+, and Rb^+ complexes of **2** and **3**, and for the Na^+ complex of **4**, by the above-described methods. It was not possible to determine the rates of decomplexation and complexation for the K^+ and Rb^+ complexes of **4**, due to overlap of the signals for the ethoxy groups of the free ligand and of the complex. The ligand (L) that was used to provide a constant pre-equilibrium concentration of M^+Pic^- in the determination of k_c is hemispherand **24** (Chart IV).[17] The experimental values for k_d at three different temperatures are summarized in Table

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Chart IV

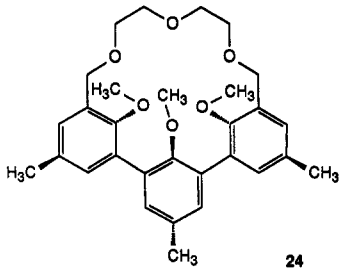

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Table I. Decomplexation Rate Constants (k_d) for Calixspherands **2–4** in $CDCl_3$ Saturated with D_2O, at Different Temperatures

host	guest	temp, °C	k_d, s^{-1}	$\Delta H^{\ddagger}$, kcal·mol^{-1}	$-T\Delta S^{\ddagger}$,[a] kcal·mol^{-1}
2	Na^+	60	1.0×10^{-7}		
		70	2.7×10^{-7}	22.0	7.3
		90	1.7×10^{-6}		
		25[b]	1.8×10^{-9}		
	K^+	60	5.0×10^{-7}		
		70	7.3×10^{-7}	22.5	6.0
		80	3.7×10^{-6}		
		25[b]	6.6×10^{-9}		
	Rb^+	40	6.4×10^{-6}		
		50	1.5×10^{-5}	18.1	7.3
		60	3.9×10^{-5}		
		25[b]	1.4×10^{-6}		
3	Na^+	70	1.9×10^{-7}		
		80	3.4×10^{-7}	27.6	2.7
		90	1.9×10^{-6}		
		25[b]	3.0×10^{-10}		
	K^+	70[c]	$\leq 5 \times 10^{-8}$		
		80	2.2×10^{-7}	42.8	9.8
		90	1.7×10^{-6}		
		25[b]	2.9×10^{-12}		
	Rb^+	60	4.1×10^{-6}		
		70	1.1×10^{-5}	24.7	2.7
		80	3.6×10^{-5}		
		25[b]	4.4×10^{-8}		
4[d]	Na^+	60	5.1×10^{-7}		
		70	6.9×10^{-7}	9.1	17.8
		90	1.7×10^{-6}		
		25[b]	8.6×10^{-8}		

[a] 25 °C. [b] Extrapolated to 25 °C. [c] An exact value could not be determined. Extrapolation to 25 °C was done with this value. [d] Determinations for K^+ and Rb^+ were not possible due to overlap of signals in the ^1H NMR spectra.

Table II. Complexation (k_c) and Decomplexation (k_d) Rate Constants, Association Constants (K_a), and Binding Free Energies ($-\Delta G°$) for Calixspherands **1–4** at 25 °C in $CDCl_3$ Saturated with D_2O

host	guest	k_c, $M^{-1}\cdot s^{-1}$	k_d,[a] s^{-1}	$(k_c/k_d)K_a$, M^{-1}	$-\Delta G°$, kcal·mol^{-1}
1[b]	Na^+	1.3×10^4	6.0×10^{-9}	2.1×10^{12}	16.8
	K^+	2.2×10^5	1.0×10^{-8}	2.2×10^{13}	18.1
	Rb^+	2.5×10^5	6.9×10^{-5}	3.6×10^9	13.0
2	Na^+	1.9×10^3	1.8×10^{-9}	1.1×10^{12}	16.4
	K^+	1.7×10^2	6.6×10^{-9}	2.6×10^{10}	14.2
	Rb^+	5.5×10^3	1.4×10^{-6}	4.4×10^9	13.1
3	Na^+	1.0×10^3	3.0×10^{-10}	3.3×10^{12}	17.1
	K^+	1.3×10^2	2.9×10^{-12}	4.5×10^{13}	18.6
	Rb^+	3.3×10^2	4.4×10^{-8}	7.5×10^9	13.5
4[c]	Na^+	1.7×10^3	8.6×10^{-8}	2.0×10^{10}	14.0

[a] From Table I except for **1**. [b] From ref 8. [c] Determinations for K^+ and Rb^+ were not possible due to overlap of signals in the ^1H NMR spectra.

I, together with the calculated values for k_d, $\Delta H^{\ddagger}$, and $-T\Delta S^{\ddagger}$ at 25 °C. Table II contains the values for k_c and the other kinetic and thermodynamic parameters obtained for the complexes of **2–4**. For comparison, Table II also contains the kinetic and thermodynamic parameters of **1**, which we described previously.[8]

The collected data show that the substitution of a methoxy group on the *m*-terphenyl moiety of the calixspherand by an ethoxy or isopropoxy group influences the rate of complexation as well as the rate of decomplexation. Most pronounced is the influence on the different Rb^+ complexes. Although, the *thermodynamic* stability, expressed as K_a, is the same for $[\mathbf{1}\cdot Rb]^+$, $[\mathbf{2}\cdot Rb]^+$, and $[\mathbf{3}\cdot Rb]^+$, within the experimental error, the *kinetic* stability is drastically increased. The half-life time for decomplexation ($t_{1/2} = \ln(2)/k_d$) increases from 2.8 h for $[\mathbf{1}\cdot Rb]^+$ *via* 139 h for $[\mathbf{2}\cdot Rb]^+$ to 180 days for $[\mathbf{3}\cdot Rb]^+$. These results can be explained by an increased shielding of the cavity from solvent molecules and an increase of the hydrophobic sleeve around the cavity; thereby, the energy barrier to decomplex the cations is enhanced. The same effect is found for the rate of complexation, which decreases also by an increased shielding. The *kinetic* stabilities of $[\mathbf{3}\cdot Na]^+$, $[\mathbf{3}\cdot K]^+$, and $[\mathbf{3}\cdot Rb]^+$ are the highest reported in the literature.[25] The rate of decomplexation of $[\mathbf{3}\cdot Na]^+$ is even lower than that for the spherand sodium complexes reported by Cram *et al.*[10]

The results obtained for $[\mathbf{4}\cdot Na]^+$ show that the substitution of methoxy groups for ethoxy groups does not always lead to an increased kinetic stability, although it is expected from CPK models that the complexed sodium ion is better shielded from solvent molecules. The decreased kinetic stability might be explained by the reduction of the number of ligating sites of the host that can be coordinated to the cation, because the larger ethoxy group is not able to rotate far enough into the cavity of the calix[4]arene moiety. The importance of the number of ligating sites for the kinetic and thermodynamic stability was previously shown both by Cram[26] and our group.[4]

Exchange Experiments. The NMR experiments give the kinetic stability of the complexes in chloroform solution. However, the stability of the complexes in polar and salt-containing solutions is even more important for our ultimate goal, *viz.* the *in vivo* use of rubidium complexes.[7] In principle the cations present in solution can assist in the decomplexation of the complexed cation *via* a bimolecular process (eq 2). On the other hand the exchange can occur in a two-step process in which the complexed cation first has to decomplex, whereupon other cations can complex with the ligand (eq 3).

$$M_1^+\cdot CSP + M_2^+ \rightleftarrows M_1^+ \circ CSP \circ M_2^+ \rightleftarrows M_1^+ + CSP\cdot M_2^+ \quad (2)$$

$$M_1^+\cdot CSP + M_2^+ \rightleftarrows M_1^+ + CSP + M_2^+ \rightleftarrows M_1^+ + CSP\cdot M_2^+ \quad (3)$$

In order to study the mechanism of exchange and the stability of the complexes in more polar solvents, we performed exchange experiments.[27] The calixspherands **1–4** were complexed with *radioactive* rubidium-86 or sodium-22 and subsequently dissolved in a solution of *nonradioactive* salt. These salt solutions were 10 mM in sodium, potassium, or rubidium picrate in DMSO or acetone. At certain time intervals, the complex was separated from the free salt and the ratio between complexed and free radioactive salt was determined. The ratios were plotted against time and the kinetic analysis was performed by nonlinear curve fitting[28] to give half-life times for the exchange process.

When the rubidium complexes of **1–4** were dissolved in DMSO containing sodium picrate, a fast disappearance of rubidium from $[\mathbf{1}\cdot Rb]^+$ was observed (Figure 5). However, the decomplexations of $[\mathbf{2}\cdot Rb]^+$, $[\mathbf{3}\cdot Rb]^+$, and $[\mathbf{4}\cdot Rb]^+$ were slower. In acetone a similar behavior was found, although all the rates of exchange were lower

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(26) Cram, D. J. *Angew. Chem.* **1986**, *25*, 1041–1060.
(27) Full details of this new method: *J. Chem. Soc., Perkin Trans. 2*, in press.
(28) Proost, J. H. *MULTIFIT: An interactive program for non-linear curve-fitting of several pharmacokinetic models and mathematical functions*; University of Groningen, Department of Pharmacology and Therapeutics: Groningen, The Netherlands, 1992.

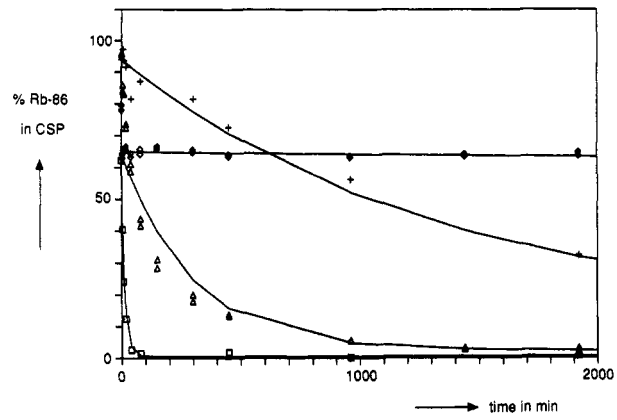


Figure 5. Exchange of $^{86}Rb^+$ for Na^+ in DMSO; □ = 1, + = 2, ◇ = 3, △ = 4.

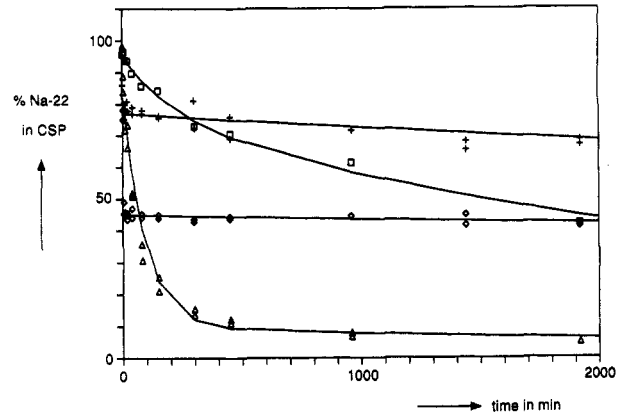


Figure 6. Exchange of $^{22}Na^+$ for Na^+ in DMSO; □ = 1, + = 2, ◇ = 3, △ = 4.

than those in DMSO. When, instead of sodium picrate, potassium picrate or rubidium picrate was used as external salt, the rates of exchange were equal within experimental error. The same experiments were carried out with the sodium complexes of **1–4**. The results, as obtained in DMSO, are shown in Figure 6. The experiments in acetone gave a slow exchange for the sodium complexes of **1–3**, whereas **[4·Na]**$^+$ showed a much faster exchange.

The fact that, within experimental error, there is no influence of the type of cation in solution on the rate of exchange is a strong indication that the rate-determining step of the exchange process is the decomplexation of the complexed cation. This means that the decomplexation process involves a simple dissociation (eq 3) of the cation complex rather than a bimolecular process (eq 2). Further evidence for this mechanism was obtained from experiments in which the concentration of salt in solution was varied. Within experimental error there is no influence of the salt concentration on the rate of exchange. These results show that the rate-limiting step in the exchange process is the dissociation, and therefore the observed exchange rates are equal to the rates of decomplexation.

From the kinetic analysis we obtained half-life times for exchange, which are depicted in Table III, together with the half-life times of decomplexation ($t_{1/2} = \ln(2)/k_d$) in chloroform as determined by ^1H NMR spectroscopy (*vide supra*). Comparison of the half-life times for the exchange obtained in acetone with those obtained in DMSO, and with the rates of decomplexation obtained in $CDCl_3$ (See Table III), shows that there is an effect of the solvent donor ability on the stability of the complexes.

The observed influence might be explained by the fact that the rubidium ion is less well solvated than the sodium ion. Therefore, the change from acetone to the better solvating solvent DMSO will have the largest effect on sodium. The observed effects are comparable with the results obtained by Cox *et al.* for the cryptands,[29] although the stabilities of the cryptand complexes are much more influenced by the donor ability of the solvent. Furthermore, the results indicate that there is not a change in the mechanism of exchange, when going from the less polar solvent acetone to the more polar DMSO. Such a change in mechanism was expected to occur for the cryptahemispherand complexes when the solvent was changed from chloroform to water.[8]

Table III shows that for the rubidium complexes the introduction of one or two ethoxy groups or an isopropoxy group as in **2**, **4**, and **3**, respectively, gives a large increase in the stability, compared to that of **1**. The half-life time for exchange in acetone increases from 1.3 h for **1** to 7 d for **2**, to 65 h for **4**, and to 22 d for **3**. The effect of increased shielding appears less pronounced for **4** than for **2** and **3**. This observation is in agreement with the data in chloroform. Therefore, it can be concluded that the substitution of methoxy groups for ethoxy or isopropoxy groups has a pronounced effect on the stability of the rubidium complex. For the sodium complexes, however, only the introduction of one ethoxy or isopropoxy group in **2** and **3**, respectively, gives an increased stability compared to that of **1**, whereas the introduction of two ethoxy groups in **4** gives a decreased stability compared to that of **1**.

This difference in the order of the stabilities, for the sodium and the rubidium complexes, might be explained by the fact that the structure of **[4·Na]**$^+$ is different from that of **[4·Rb]**$^+$ (*vide supra*). It was found, by two-dimensional ^1H NMR spectroscopy, that the structure of **[4·Na]**$^+$ is comparable to partial cone I in Figure 4, whereas the structure of **[4·Rb]**$^+$ is comparable to partial cone II. The fact that the order of the stabilities is changed might be caused by the fact that in **[4·Na]**$^+$ the oxygen atom of the rotated phenyl ring is not able to act as a ligating site, because the ethoxy group is too large to allow rotation far enough into the cavity of the calixarene to contact the sodium ion, which results in a reduced stability. The drastic influence of the loss of a ligating site on the stability of cation complexes was previously shown experimentally[4,26] and by calculations.[30]

Conclusions. A new and very efficient synthesis of the calixspherands was developed, which makes these ligands available in amounts needed for practical applications. Our results show that an increased shielding of the cavity from solvent molecules increases the kinetic stability of the complexes. The *kinetic* stabilities of the Na^+, K^+, and Rb^+ complexes of **3** are the highest reported in the literature.[25] Furthermore, it was shown that, not only in apolar solvents but also in polar solvents, the stability is sufficiently high for *in vivo* use. Finally, it was proved that the rate-limiting step in the exchange process is the decomplexation of the complexed cation.

Experimental Section

Melting points are uncorrected. ^1H NMR spectra (250 MHz) were recorded in deuteriochloroform ($CDCl_3$) with tetramethylsilane (Me_4Si) as an internal standard. Positive-ion fast atom bombardment (FAB) mass spectra were obtained with 3-nitrobenzyl alcohol as a matrix. High-resolution FAB mass spectra of the calixspherand complexes were obtained by peak matching. THF was freshly distilled from sodium benzophenone ketyl while dry diethyl ether (Et_2O) was obtained by distillation from lithium aluminum hydride ($LiAlH_4$) and acetonitrile was dried over molecular sieves (3 Å). Hexanes refers to petroleum ether with bp 60–80 °C. NaH was an 80% dispersion in mineral oil and was used as such. *n*-BuLi was used as a commercially available solution in *n*-hexane (1.6 M). Other chemicals were of reagent grade and were used without purification. Column chromatography was performed with silica gel 60 (SiO_2, E. Merck, particle size 0.040–0.063 mm, 230–240 mesh). All reactions were carried out in a nitrogen atmosphere. Standard workup

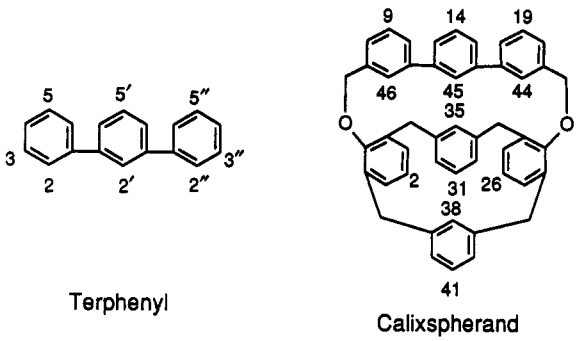
(29) Cox, B. G.; Garcia-Rosas, J.; Schneider, H. *J. Am. Chem. Soc.* **1981**, *103*, 1054–1059.
(30) Kollman, P. A.; Wipff, G.; Singh, U. C. *J. Am. Chem. Soc.* **1985**, *107*, 2212–2219.

Table III. Half-Life Times for the Exchange of the Different Calixspherand Complexes with Sodium Picrate in DMSO and Acetone As Determined by Radioactivity, Together with the Half-Life Times for Decomplexation in Chloroform As Determined by ^{1}H NMR Spectroscopy

		[1·Na]$^+$	[1·Rb]$^+$	[2·Na]$^+$	[2·Rb]$^+$	[3·Na]$^+$	[3·Rb]$^+$	[4·Na]$^+$	[4·Rb]$^+$
radioactive method	acetone	27 days	1.3 h	17 days	7 days	35 days	22 days	125 h	65 h
	DMSO	42 h	0.2 h	8 days	15 h	15 days	55 days	1.1 h	6.3 h
^{1}H NMR spectr	$CDCl_3$	1.3×10^3 days	2.8 h	1.5×10^3 days	154 h	2.6×10^4 days	187 days	92 days	*a*

[a] Could not be determined.

Chart V



means that the organic layers were finally washed with brine, dried over magnesium sulfate ($MgSO_4$), filtered, and concentrated *in vacuo*.

The full systematic name for calixspherand is 22*H*,34*H*-4,24-(methano-[1,3]benzenomethano)-7,11:12,16:17,21:29,33-tetrametheno-6*H*,28*H*-dibenzo[*b*,*k*][1,13]dioxacyclotriacontin. For convenience, however, the common name, *i.e.* calixspherand, has been used throughout this paper. The numbering for the calixspherand and the *m*-terphenyl is shown in Chart V. Compounds **6**,[31] **7**,[11] **13**,[11] and RbOtBu[15] were prepared according to literature procedures.

2'-Ethoxy-5,5',5''-trimethyl-1,1':3',1''-terphenyl-2,2''-diol (14). A mixture of **13** (1.60 g, 5 mmol), $KHCO_3$ (0.50 g, 5 mmol), and EtI (0.8 mL, 10 mmol) in acetone (50 mL) was heated under reflux for 3 days. The solvent was removed *in vacuo* and the residue redissolved in EtOAc (100 mL) and washed with 1 M aqueous HCl (50 mL), followed by standard workup. The residue was purified by flash chromatography (SiO_2, EtOAc/hexanes, 1:4) to give 1.4 g of **14** as a white foam: yield 80%; ^{1}H NMR δ 7.17–6.91 (m, 8 H, ArH), 6.48 (s, 2 H, OH), 3.47 (q, 2 H, J = 7.0 Hz, OCH_2CH$_3$), 2.38 (s, 3 H, ArCH$_3$), 2.33 (s, 6 H, ArCH$_3$), 0.88 (t, 3 H, J = 7.0 Hz, CH$_3$CH$_2$O); ^{13}C NMR δ 151.1, 150.2 (s, C$_{Ar}$O), 135.6, 132.0, 130.0, 125.5 (s, C$_{Ar}$), 132.5, 131.5, 130.0 (d, C$_{Ar}$H), 117.4 (d, C-3,3''), 71.1 (t, OCH$_2$CH$_3$), 20.9, 20.5 (q, ArCH$_3$), 15.0 (q, OCH$_2$CH$_3$); IR (KBr) 3376 (OH) cm^{-1}; mass spectrum (EI) m/e 348.173 (M$^+$, calcd for $C_{23}H_{24}O_3$ 348.173).

5,5',5''-Trimethyl-2'-(1-methylethoxy)-1,1':3',1''-terphenyl-2,2''-diol (15). A mixture of **13** (32.04 g, 0.1 mol), $KHCO_3$ (11 g, 0.11 mol), and *i*-PrI (11.3 mL, 0.11 mol) in CH_3CN (350 mL) was heated under reflux overnight. The solvent was removed *in vacuo* and the residue partitioned between CH_2Cl_2 (250 mL) and 1 M aqueous HCl (100 mL), followed by standard workup. The residue was purified by flash chromatography (SiO_2, CH_2Cl_2) and subsequent crystallization from hexanes to afford 24.0 g of **15** as white crystals: yield 66%; mp 123–126 °C (hexanes); ^{1}H NMR δ 7.19–6.91 (m, 8 H, ArH), 6.49 (s, 2 H, OH), 3.74 (heptet, 1 H, J = 6.2 Hz, OCH(CH$_3$)$_2$), 2.40 (s, 3 H, ArCH$_3$), 2.34 (s, 6 H, ArCH$_3$), 0.77 (d, 6 H, J = 6.2 Hz, OCH(CH_3)$_2$); ^{13}C NMR δ 151.1, 148.7 (s, C$_{Ar}$O), 135.4, 132.8, 130.1, 126.3 (s, C$_{Ar}$), 132.5, 131.5, 130.0 (d, C$_{Ar}$H), 117.5 (d, C-3,3''), 78.6 (d, OCH(CH$_3$)$_2$), 21.7 (q, OCH(CH$_3$)$_2$), 20.9, 20.6 (q, ArCH$_3$); IR (KBr) 3412 (OH) cm^{-1}; mass spectrum (EI) m/e 362.187 (M$^+$, calcd 362.188). Anal. Calcd for $C_{24}H_{26}O_3$: C, 79.53; H, 7.23. Found: C, 79.68; H, 7.15.

3,3''-Dibromo-2'-ethoxy-5,5',5''-trimethyl-1,1':3',1''-terphenyl-2,2''-diol (16). A solution of Br_2 (3.5 mL, 68 mmol) in CH_2Cl_2 (100 mL) was added slowly to a solution of **14** (10.66 g, 31 mmol) in CH_2Cl_2 (200 mL). After stirring the mixture for 30 min, 5% aqueous $NaHSO_3$ (100 mL) was added. The organic layer was separated and washed with H_2O (100 mL), followed by standard workup. The residue was crystallized from EtOH to afford 13.2 g of **16** as white crystals: yield 84%; mp 153–156 °C (EtOH); ^{1}H NMR δ 7.35 (d, 2 H, J = 2.0 Hz, ArH), 7.17 (s, 2 H, ArH), 7.09 (d, 2 H, J = 2.0 Hz, ArH), 6.72 (s, 2 H, OH), 3.46 (q, 2 H, J = 7.0 Hz, OCH_2CH$_3$), 2.38 (s, 3 H, ArCH$_3$), 2.31 (s, 6 H, ArCH$_3$), 0.85 (t, 3 H, J = 7.0 Hz, CH$_3$CH$_2$O); ^{13}C NMR δ 150.4, 147.8 (s, C$_{Ar}$O), 134.9, 132.2, 131.6, 126.7 (s, C$_{Ar}$), 132.6, 131.1, 131.0 (d, C$_{Ar}$H), 111.5 (s, C$_{Ar}$Br), 70.9 (t, OCH$_2$CH$_3$), 20.9, 20.3 (q, ArCH$_3$), 15.0 (q, OCH$_2$CH$_3$); IR (KBr) 3508, 3274 (OH) cm^{-1}; mass spectrum (EI) m/e 503.987 (M$^+$, calcd 503.994). Anal. Calcd for $C_{23}H_{22}Br_2O_3$: C, 54.57; H, 4.38. Found: C, 54.86; H, 4.31.

3,3''-Dibromo-5,5',5''-trimethyl-2'-(1-methylethoxy)-1,1':3',1''-terphenyl-2,2''-diol (17). NBS (10.79 g, 60.6 mmol) was slowly added to a solution of **15** (10.87 g, 30 mmol) in DMF (75 mL) and the mixture stirred for 24 h at room temperature in the dark. H_2O (200 mL) was then added and the mixture extracted with CH_2Cl_2 (2 × 100 mL). The organic extracts were combined and washed with 1 M aqueous HCl (2 × 100 mL), followed by standard workup. The residue was purified by flash chromatography (SiO_2, EtOAc/hexanes, 1:4) and crystallization from hexanes to afford 11.1 g of **17** as white crystals: yield 71%; mp 135–138 °C (hexanes); ^{1}H NMR δ 7.35 (d, 2 H, J = 1.6 Hz, ArH), 7.18 (s, 2 H, ArH), 7.10 (d, 2 H, J = 1.7 Hz, ArH), 6.80 (s, 2 H, OH), 3.66 (heptet, 1 H, J = 6.2 Hz, OCH(CH$_3$)$_2$), 2.39 (s, 3 H, ArCH$_3$), 2.32 (s, 6 H, ArCH$_3$), 0.76 (d, 6 H, J = 6.2 Hz, OCH(CH_3)$_2$); ^{13}C NMR δ 149.0, 147.8 (s, C$_{Ar}$O), 134.8, 132.3, 127.4 (s, C$_{Ar}$), 132.5, 132.3, 131.1 (d, C$_{Ar}$H), 111.7 (s, C$_{Ar}$Br), 78.6 (d, OCH(CH$_3$)$_2$), 21.8 (q, OCH(CH$_3$)$_2$), 20.9, 20.3 (q, ArCH$_3$); IR (KBr) 3316 (OH) cm^{-1}; mass spectrum (EI) m/e 518.009 (M$^+$, calcd 518.009). Anal. Calcd for $C_{24}H_{24}Br_2O_3$: C, 55.41; H, 4.65. Found: C, 55.38; H, 4.40.

3,3''-Dibromo-2'-ethoxy-2,2''-dimethoxy-5,5',5''-trimethyl-1,1':3',1''-terphenyl (18). A solution of **16** (5.06 g, 10 mmol), KOH (2.24 g, 40 mmol), and Me_2SO_4 (3.8 mL, 40 mmol) in a mixture of THF (80 mL) and H_2O (20 mL) was heated overnight under reflux. The THF was removed *in vacuo*, and 25% aqueous NH_3 (25 mL) and H_2O (25 mL) were added to the residue. The solution was then extracted with CH_2Cl_2 (3 × 50 mL), followed by standard workup. Purification was achieved by flash chromatography (SiO_2, EtOAc/hexanes, 5:95) to afford 5.0 g of **18** as a white sticky foam: yield 94%; ^{1}H NMR δ 7.36 (d, 2 H, J = 1.6 Hz, ArH), 7.14 (s, 2 H, ArH), 7.13 (d, 2 H, J = 1.6 Hz, ArH), 3.57 (s, 6 H, OCH$_3$), 3.40 (q, 2 H, J = 7.0 Hz, OCH_2CH$_3$), 2.35 (s, 3 H, ArCH$_3$), 2.31 (s, 6 H, ArCH$_3$), 0.77 (t, 3 H, J = 7.0 Hz, CH$_3$CH$_2$O); ^{13}C NMR δ 152.4 (s, C$_{Ar}$O), 134.4, 133.9, 132.3 (s, C$_{Ar}$), 132.9, 131.5 (d, C$_{Ar}$H), 117.0 (s, C$_{Ar}$Br), 68.9 (t, OCH$_2$CH$_3$), 60.6 (q, OCH$_3$), 20.7, 20.5 (q, ArCH$_3$), 15.3 (q, OCH$_2$CH$_3$); mass spectrum (EI) m/e 532.023 (M$^+$, calcd for $C_{25}H_{26}Br_2O_3$ 532.025).

3,3''-Dibromo-2,2''-dimethoxy-5,5',5''-trimethyl-2'-(1-methylethoxy)-1,1':3',1''-terphenyl (19) was similarly prepared, as described for **18**, from **17** (12.5 g, 24 mmol), KOH (5.39 g, 96 mmol), and Me_2SO_4 (9.1 mL, 96 mmol) in a mixture of THF (100 mL) and H_2O (50 mL). The crude product was purified by recrystallization from EtOH to afford 12.2 g of **19** as a white solid: yield 92%; mp 139–142 °C (EtOH); ^{1}H NMR δ 7.36 (d, 2 H, J = 1.7 Hz, ArH), 7.16–7.14 (m, 4 H, ArH), 3.62 (s, 6 H, OCH$_3$), 3.62–3.53 (m, 1 H, OCH(CH$_3$)$_2$), 2.34 (s, 3 H, ArCH$_3$), 2.32 (s, 6 H, ArCH$_3$), 0.67 (d, 6 H, J = 6.1 Hz, OCH(CH_3)$_2$); ^{13}C NMR δ 152.5, 151.0 (s, C$_{Ar}$O), 134.4, 134.2, 132.0, 131.9 (s, C$_{Ar}$), 132.8, 131.8, 131.6 (d, C$_{Ar}$H), 116.9 (s, C$_{Ar}$Br), 72.8 (d, OCH(CH$_3$)$_2$), 58.5 (q, OCH$_3$), 20.0 (q, OCH(CH$_3$)$_2$), 18.5, 18.3 (q, ArCH$_3$); mass spectrum (EI) m/e 546.041 (M$^+$, calcd 546.041). Anal. Calcd for $C_{26}H_{28}Br_2O_3$: C, 56.95; H, 5.15. Found: C, 56.81; H, 4.85.

2'-Ethoxy-2,2''-dimethoxy-5,5',5''-trimethyl-1,1':3',1''-terphenyl-3,3''-dicarboxaldehyde (20). To a solution of **18** (12.12 g, 23 mmol) in dry Et_2O (600 mL) was added *n*-BuLi (30 mL, 48 mmol) at −70 °C. After the mixture was stirred for 10 min, DMF (8 mL, 0.1 mmol) was added and the solution slowly warmed to room temperature. The reaction mixture was then partitioned between 1 M aqueous HCl (250 mL) and Et_2O (250 mL), followed by standard workup. The residue was crystallized from *n*-hexane to give 7.0 g of pure **20** as white crystals: yield 70%; mp 108–110 °C (*n*-hexane); ^{1}H NMR δ 10.46 (s, 2 H, CHO), 7.67 (d, 2 H, J = 2.3 Hz, ArH), 7.45 (d, 2 H, J = 2.3 Hz, ArH), 7.21 (s, 2 H, ArH), 3.63 (s, 6 H, OCH$_3$), 3.33 (q, 2 H, J = 7.0 Hz, OCH_2CH$_3$), 2.42 (s, 3 H, ArCH$_3$), 2.40 (s, 6 H, ArCH$_3$), 0.70 (t, 3 H, J = 7.0 Hz,

(31) Gutsche, C. D.; Iqbal, M. *Org. Synth.* **1989**, *68*, 234–237.

CH_3CH_2O); ^{13}C NMR δ 190.6 (d, C=O), 159.3, 152.7 (s, $C_{Ar}O$), 138.6, 131.6, 127.8 (d, $C_{Ar}H$), 133.6, 133.2, 131.3, 128.8 (s, C_{Ar}), 69.4 (t, OCH_2CH_3), 63.0 (q, OCH_3), 20.8, 20.6 (q, $ArCH_3$), 15.3 (q, OCH_2CH_3); IR (KBr) 1686 (C=O) cm^{-1}; mass spectrum (EI) *m/e* 432.195 (M^+, calcd 432.194). Anal. Calcd for $C_{27}H_{28}O_5 \cdot 0.25H_2O$: C, 74.21; H, 6.57. Found: C, 74.25; H, 6.35. Karl–Fischer titration calcd for $0.25H_2O$, 1.03; found, 1.01.

2,2″-Dimethoxy-5,5′,5″-trimethyl-2′-(1-methylethoxy)-1,1′:3′,1″-terphenyl-3,3″-dicarboxaldehyde (21) was similarly prepared, as described for **20**, from **19** (1.10 g, 2 mmol) in dry Et_2O (25 mL), *n*-BuLi (3 mL, 4.8 mmol) and DMF (0.8 mL, 10 mmol). The residue was crystallized from hexanes to afford 0.67 g of **21** as white crystals: yield 75%; mp 139–142 °C (hexanes); ^1H NMR δ 10.47 (s, 2 H, CHO), 7.68 (d, 2 H, *J* = 2.2 Hz, ArH), 7.48 (d, 2 H, *J* = 2.2 Hz, ArH), 7.24 (s, 2 H, ArH), 3.68 (s, 6 H, OCH_3), 3.54 (heptet, 1 H, *J* = 6.1 Hz, $OCH(CH_3)_2$), 2.43 (s, 3 H, $ArCH_3$), 2.41 (s, 6 H, $ArCH_3$), 0.62 (d, 6 H, *J* = 6.1 Hz, $OCH(CH_3)_2$); ^{13}C NMR δ 190.5 (d, C=O), 159.3, 151. 5 (s, $C_{Ar}O$), 138.7, 128.6, 127.6 (d, $C_{Ar}H$), 133.6, 133.3, 132.8, 131.7, 131.5 (s, C_{Ar}), 75.8 (d, $OCH(CH_3)_2$), 63.0 (q, OCH_3), 22.1 (q, $OCH(CH_3)_2$), 20.6, 20.5 (q, $ArCH_3$); IR (KBr) 1680 (C=O) cm^{-1}; mass spectrum (EI) *m/e* 446.210 (M^+, calcd 446.209). Anal. Calcd for $C_{28}H_{30}O_5 \cdot 0.2H_2O$: C, 74.71; H, 6.81. Found: C, 74.51; H, 6.69. Karl–Fischer titration calcd for $0.2H_2O$, 0.80; found, 0.82.

2′-Ethoxy-2,2″-dimethoxy-5,5′,5″-trimethyl-1,1′:3′,1″-terphenyl-3,3″-dimethanol (22). $NaBH_4$ (1.06 g, 28 mmol) was added to a solution of **20** (6.05 g, 14 mmol) in EtOH (60 mL) and the mixture stirred for 1 h. H_2O (50 mL) was added and the reaction mixture extracted with CH_2Cl_2 (2 × 100 mL), followed by standard workup. The residue was purified by flash chromatography (SiO_2, EtOAc/hexanes, 1:1) to afford 4.9 g of **22** as a white sticky foam: yield 78%; ^1H NMR δ 7.16 (s, 4 H, ArH), 7.13 (s, 2 H, ArH), 4.74 (s, 4 H, $ArCH_2OH$), 3.50 (s, 6 H, OCH_3), 3.38 (q, 2 H, *J* = 7.0 Hz, OCH_2CH_3), 2.42 (s, 2 H, OH), 2.36 (s, 3 H, $ArCH_3$), 2.34 (s, 6 H, $ArCH_3$), 0.73 (t, 3 H, *J* = 7.0 Hz, CH_3CH_2O); ^{13}C NMR δ 153.7, 152.6 (s, $C_{Ar}O$), 133.4, 133.0, 132.5, 132.2, 132.0 (s, C_{Ar}), 131.9, 131.4, 128.8 (d, $C_{Ar}H$), 68.9 (t, OCH_2CH_3), 61.9 (t, $ArCH_2OH$), 60.9 (q, OCH_3), 20.8 (q, $ArCH_3$), 15.4 (q, OCH_2CH_3); IR (KBr) 3405 (OH) cm^{-1}; mass spectrum (EI) *m/e* 436.222 (M^+, calcd for $C_{27}H_{32}O_5$ 436.225).

2,2″-Dimethoxy-5,5′,5″-trimethyl-2′-(1-methylethoxy)-1,1′:3′,1″-terphenyl-3,3″-dimethanol (23) was similarly prepared, as described for **22**, from **21** (2.23 g, 5 mmol) in EtOH (50 mL) and $NaBH_4$ (0.38 g, 10 mmol). The residue was crystallized from diisopropyl ether/hexanes to afford 1.8 g of pure **23** as a white solid: yield 80%; mp 143–146 °C ($(i\text{-}Pr)_2O$/hexanes); ^1H NMR δ 7.16 (s, 4 H, ArH), 7.14 (s, 2 H, ArH), 4.74 (d, 4 H, *J* = 5.5 Hz, $ArCH_2O$), 3.53 (s, 6 H, OCH_3), 3.61–3.49 (m, 1 H, $OCH(CH_3)_2$), 2.47 (t, 2 H, *J* = 5.9 Hz, OH), 2.36 (s, 3 H, $ArCH_3$), 2.33 (s, 6 H, $ArCH_3$), 0.62 (d, 6 H, *J* = 6.1 Hz, $OCH(CH_3)_2$); ^{13}C NMR δ 153.8, 151.4 (s, $C_{Ar}O$), 133.3, 132.8, 132.7, 132.5, 132.1 (s, C_{Ar}), 132.1, 131.3, 128.5 (d, $C_{Ar}H$), 74.9 (d, $OCH(CH_3)_2$), 61.9 (t, $ArCH_2O$), 60.9 (q, OCH_3), 22.3 (q, $OCH(CH_3)_2$), 20.7 (q, $ArCH_3$); IR (KBr) 3426 (OH) cm^{-1}; mass spectrum (EI) *m/e* 450.241 (M^+, calcd 450.241). Anal. Calcd for $C_{28}H_{34}O_5$: C, 74.64; H, 7.61. Found: C, 74.81; H, 7.58.

3,3″-Bis(bromomethyl)-2′-ethoxy-2,2″-dimethoxy-5,5′,5″-trimethyl-1,1′:3′,1″-terphenyl (8). To a solution of **22** (4.92 g, 11 mmol) in toluene (100 mL) was slowly added PBr_3 (1.2 mL, 13 mmol). The mixture was stirred at room temperature for 90 min, whereupon H_2O (100 mL) and saturated $NaHCO_3$ (25 mL) were added, successively. The toluene was then removed *in vacuo* and the remaining aqueous solution extracted with CH_2Cl_2 (3 × 50 mL), followed by standard workup. The residue was purified by flash chromatography (SiO_2, $CHCl_3$) to afford 5.1 g of **8** as a white sticky foam: yield 82%; ^1H NMR δ 7.19–7.14 (m, 6 H, ArH), 4.63 (s, 4 H, $ArCH_2Br$), 3.56 (s, 6 H, OCH_3), 3.36 (q, 2 H, *J* = 7.0 Hz, OCH_2CH_3), 2.37 (s, 3 H, $ArCH_3$), 2.33 (s, 6 H, $ArCH_3$), 0.73 (t, 3 H, *J* = 7.0 Hz, CH_3CH_2O); ^{13}C NMR δ 154.1, 152.5 (s, $C_{Ar}O$), 132.7, 132.5, 132.0, 130.8 (s, C_{Ar}), 133.2, 131.4, 130.9 (d, $C_{Ar}H$), 68.9 (t, OCH_2CH_3), 60.9 (q, OCH_3), 29.1 (t, $ArCH_2Br$), 20.8, 20.7 (q, $ArCH_3$), 15.4 (q, OCH_2CH_3); mass spectrum (EI) *m/e* 560.052 (M^+, calcd for $C_{27}H_{30}Br_2O_3$ 560.056).

3,3″-Bis(bromomethyl)-2,2″-dimethoxy-5,5′,5″-trimethyl-2′-(1-methylethoxy)-1,1′:3′,1″-terphenyl (9). PBr_3 (0.8 mL, 8.4 mmol) was added to a solution of **23** (3.15 g, 7 mmol) in benzene (100 mL). The mixture was stirred at room temperature for 15 min, whereupon H_2O (100 mL) and saturated $NaHCO_3$ (25 mL) were added, successively. The benzene was removed *in vacuo* and the residue extracted with CH_2Cl_2 (3 × 50 mL), followed by standard workup. The residue was purified by flash chromatography (SiO_2, CH_2Cl_2) to afford 2.8 g of **9** as a white foam: yield 69%; ^1H NMR δ 7.19 (s, 2 H, ArH), 7.18 (s, 2 H, ArH), 7.15 (s, 2 H, ArH), 4.64 (br s, 4 H, $ArCH_2Br$), 3.58 (s, 6 H, OCH_3), 3.52 (heptet, 1 H, *J* = 6.1 Hz, $OCH(CH_3)_2$), 2.37 (s, 3 H, $ArCH_3$), 2.33 (s, 6 H, $ArCH_3$), 0.60 (d, 6 H, *J* = 6.1 Hz, $OCH(CH_3)_2$); ^{13}C NMR δ 154.2, 151.5 (s, $C_{Ar}O$), 133.4, 133.1, 133.0, 132.6, 132.4, 131.4, 130.8, 130.7 (C_{Ar}), 75.3 (d, $OCH(CH_3)_2$), 60.9 (q, OCH_3), 29.2 (t, $ArCH_2Br$), 22.3 (q, $OCH(CH_3)_2$), 20.7 (q, $ArCH_3$); mass spectrum (EI) *m/e* 574.076 (M^+, calcd for $C_{28}H_{32}Br_2O_3$ 574.072).

General Procedure for the Synthesis of Calixspheranddiols 10–12 from *p-tert*-Butylcalix[4]arene (6) and 3,3″-Bis(bromomethyl)-1,1′:3′,1″-terphenyls (7–9). A mixture of **6**, NaH, and 3 mol % 18-crown-6 in THF was stirred at room temperature until no more hydrogen gas evolved (ca. 0.5 h). The mixture was then heated under reflux, and a solution of terphenyl in THF was added dropwise. The resulting mixture was heated under reflux for another 3 h and cooled to room temperature. H_2O (5 mL) was added, the THF removed *in vacuo*, and the residue partitioned between CH_2Cl_2 (100 mL) and 1 M HCl (50 mL), followed by standard workup. The residue was purified by flash chromatography (SiO_2, EtOAc/hexanes, 1:4) and crystallization from MeOH/CH_2Cl_2.

2,26,31,41-Tetrakis(1,1-dimethylethyl)-44,45,46-trimethoxy-9,14,19-trimethylcalixspherand-35,38-diol (10) was prepared in 84% yield (2.6 g) as a white solid from **6** (2.22 g, 3 mmol), NaH (0.45 g, 15 mmol), and 18-crown-6 in THF (700 mL), and a solution of **7** (1.65 g, 3 mmol) in THF (75 mL). Mp > 240 °C dec (CH_2Cl_2/MeOH); ^1H NMR δ 7.33 (s, 2 H, ArH), 7.12 (s, 2 H, ArH), 7.04 (d, 2 H, *J* = 1.8 Hz, ArH), 6.99 (br s, 4 H, ArH), 6.69 (d, 2 H, *J* = 2.3 Hz, ArH), 6.68 (s, 1 H, OH), 6.56 (d, 2 H, *J* = 2.3 Hz, ArH), 6.06 (s, 1 H, OH), 5.46 and 4.26 (ABq, 4 H, *J* = 9.6 Hz, OCH_2Ar), 4.87 and 3.36 (ABq, 4 H, *J* = 12.9 Hz, $ArCH_2Ar$), 4.24 and 3.17 (ABq, 4 H, *J* = 13.2 H, $ArCH_2Ar$), 3.56 (s, 6 H, OCH_3), 2.49 (s, 3 H, OCH_3), 2.43 (s, 3 H, $ArCH_3$), 2.29 (s, 6 H, $ArCH_3$), 1.36, 1.28 (s, 2 × 9 H, $C(CH_3)_3$), 0.85 (s, 18 H, $C(CH_3)_3$); ^{13}C NMR δ 158.3, 154.3, 151.8, 151.1, 151.0 (s, $C_{Ar}O$), 145.8, 140.4, 139.9 (s, C-2,26,31,41), 76.5 (t, OCH_2Ar), 60.3, 58.8 (q, OCH_3), 33.8, 33.7 (s, $C(CH_3)_3$), 31.9, 31.7, 31.0 (q, $C(CH_3)_3$), 30.6 (t, $ArCH_2Ar$), 21.2, 20.4 (q, $ArCH_3$); IR (KBr) 3456 (OH) cm^{-1}; mass spectrum (FAB) *m/e* 1058 ($(M + Na)^+$, calcd 1058). Anal. Calcd for $C_{70}H_{82}O_7 \cdot 0.5H_2O$: C, 80.50; H, 8.01. Found: C, 80.39; H, 7.94. Karl–Fischer titration calcd for $0.5H_2O$, 0.86; found, 0.82.

2,26,31,41-Tetrakis(1,1-dimethylethyl)-45-ethoxy-44,46-dimethoxy-9,14,19-trimethylcalixspherand-35,38-diol (11) was prepared in 64% yield (2.7 g) as a white solid from **6** (2.96 g, 4 mmol), NaH (0.6 g, 20 mmol), and 18-crown-6 in THF (700 mL) and a solution of **8** (2.25 g, 4 mmol) in THF (75 mL). Mp > 240 °C dec (CH_2Cl_2/MeOH); ^1H NMR δ 7.31 (s, 2 H, ArH), 7.11 (s, 2 H, ArH), 7.05 (br s, 2 H, ArH), 6.98 (s, 2 H, ArH), 6.96 (d, 2 H, *J* = 1.9 Hz, ArH), 6.74 (s, 1 H, OH), 6.70 (d, 2 H, *J* = 2.4 Hz, ArH), 6.57 (d, 2 H, *J* = 2.4 Hz, ArH), 5.76 (s, 1 H, OH), 5.44 and 4.29 (ABq, 4 H, *J* = 9.9 Hz, OCH_2Ar), 4.88 and 3.36 (ABq, 4 H, *J* = 12.9 Hz, $ArCH_2Ar$), 4.26 and 3.17 (ABq, 4 H, *J* = 13.2 Hz, $ArCH_2Ar$), 3.51 (s, 6 H, OCH_3), 2.75 (q, 2 H, *J* = 7.0 Hz, OCH_2CH_3), 2.48 (s, 3 H, $ArCH_3$), 2.30 (s, 6 H, $ArCH_3$), 1.35, 129 (s, 2 × 9 H, $C(CH_3)_3$), 0.85 (s, 18 H, $C(CH_3)_3$), 0.14 (t, 3 H, *J* = 7.0 Hz, OCH_2CH_3); ^{13}C NMR δ 158.6, 154.5, 151.9, 151.2, 151.1 (s, $C_{Ar}O$), 145.8, 140.3, 139.9 (s, C-2,26,31,41), 76.5 (t, OCH_2Ar), 68.3 (t, OCH_2CH_3), 60.4 (q, OCH_3), 33.8 (s, $C(CH_3)_3$), 31.9, 31.8, 31.1 (q, $C(CH_3)_3$), 30.7 (t, $ArCH_2Ar$), 21.2, 20.5 (q, $ArCH_3$), 14.4 (q, OCH_2CH_3); mass spectrum (FAB) *m/e* 1072 ($(M + Na)^+$, calcd 1072). Anal. Calcd for $C_{71}H_{84}O_7 \cdot 0.2CHCl_3$: C, 79.68; H, 7.91. Found: C, 79.30; H, 7.86. The presence of $CHCl_3$ was confirmed by ^1H NMR spectroscopy in CD_2Cl_2.

2,26,31,41-Tetrakis(1,1-dimethylethyl)-44,46-dimethoxy-9,14,19-trimethyl-45-(1-methylethoxy)calixspherand-35,38-diol (12) was prepared in 68% yield (3.6 g) as a white solid from **6** (3.70 g, 5 mmol), NaH (0.75 g, 25 mmol), and 18-crown-6 in THF (650 mL) and a solution of **9** (2.88 g, 5 mmol) in THF (75 mL). Mp > 280 °C dec (CH_2Cl_2/MeOH); ^1H NMR δ 7.28 (s, 2 H, ArH), 7.10 (s, 2 H, ArH), 7.09 (d, 2 H, *J* = 1.9 Hz, ArH), 6.98 (s, 2 H, ArH), 6.96 (d, 2 H, *J* = 1.9 Hz, ArH), 6.82 (s, 1 H, OH), 6.70 (d, 2 H, *J* = 2.3 Hz, ArH), 6.59 (d, 2 H, *J* = 2.3 Hz, ArH), 5.64 (s, 1 H, OH), 5.42 and 4.35 (ABq, 4 H, *J* = 10.4 Hz, OCH_2Ar), 4.84 and 3.36 (ABq, 4 H, *J* = 12.8 Hz, $ArCH_2Ar$), 4.27 and 3.16 (ABq, 4 H, *J* = 13.2 Hz, $ArCH_2Ar$), 3.42 (s, 6 H, OCH_3), 2.89 (heptet, 1 H, *J* = 6.2 Hz, $OCH(CH_3)_2$), 2.47 (s, 3 H, $ArCH_3$), 2.32 (s, 6 H, $ArCH_3$), 1.35, 1.29 (s, 2 × 9 H, $C(CH_3)_3$), 0.85 (s, 18 H, $C(CH_3)_3$), 0.29 (d, 6 H, *J* = 6.2 Hz, $OCH(CH_3)_2$); ^{13}C NMR δ 158.7, 154.6, 151.8, 151.3, 151.0 (s, $C_{Ar}O$), 145.7, 140.0, 139.8 (s, C-2,26,31,41), 76.6 (t, OCH_2Ar), 76.3 (d, $OCH(CH_3)_2$), 60.6 (q, OCH_3), 33.8, 33.7 (s, $C(CH_3)_3$), 31.9, 31.8, 31.1 (q, $C(CH_3)_3$), 30.7 (t, $ArCH_2Ar$), 22.0 (q, $CH(CH_3)_2$), 21.2, 20.6 (q, $ArCH_3$); mass spectrum (FAB) *m/e* 1085 ($(M + Na)^+$,

calcd 1085). Anal. Calcd for $C_{72}H_{86}O_7$: C, 81.32; H, 8.15. Found: C, 81.01; H, 8.00.

General Procedure for the Alkylation of Calixspheranddiols 10–12. Formation of Calixspherands 1–4. A solution of KO-*t*-Bu (4–5 equiv) in THF was slowly added to a solution of calixspheranddiol and alkyl iodide (4 equiv) in THF. After the addition of KO-*t*-Bu, another 6 equiv of alkyl iodide was added and the resulting solution stirred for 1 h at 50 °C. After the solution was cooled to room temperature, 1 M HCl (5 mL) was added and the THF removed *in vacuo*. The residue was redissolved in CH_2Cl_2 (100 mL) and the organic solution washed with 1 M HCl (50 mL) followed by standard workup. The residue was redissolved in MeOH. Undissolved material was removed by filtration and the filtrate evaporated to dryness to yield the respective calixspherands as their potassium iodide complexes. Potassium picrate complexes were obtained in the following way. The potassium iodide complex was dissolved in methanol, and an excess of potassium picrate was added and well stirred for 15 min. Successively, the methanol was evaporated *in vacuo*, chloroform was added to the residue, undissolved material was removed by filtration, and the solution was concentrated *in vacuo* to yield the potassium picrate complexes.

General Procedure for the Decomplexation of Calixspherand Complexes. (a) **Warning**: This reaction was done under pressure. A mixture of the potassium complex of the calixspherand (200 mg), methanol (4 mL), and water (16 mL) was heated in a closed vessel for 3 days at 120 °C. After the reaction mixture was cooled to room temperature, the vessel was opened and the suspension was extracted with CH_2Cl_2 (2 × 20 mL) followed by standard workup. The residue was redissolved in CH_2Cl_2 (10 mL), and methanol (10 mL) was added. The solvent was removed *in vacuo* until a white precipitate was formed. The precipitate was removed by filtration and the solid washed with methanol. (b) Decomplexation of the rubidium complexes was performed in the same way except that the reaction was not performed in a closed vessel but at ambient pressure.

2,26,31,41-Tetrakis(1,1-dimethylethyl)-35,38,44,45,46-pentamethoxy-9,14,19-trimethylcalixspherand (1) potassium picrate complex was prepared in 81% yield (1.1 g) as a yellow solid from **10** (1.04 g, 1 mmol), MeI (0.62 mL, 10 mmol), and KO-*t*-Bu (0.45 g, 4 mmol) in THF (100 mL) and was identical to previously described material.[8]

2,26,31,41-Tetrakis(1,1-dimethylethyl)-45-ethoxy-35,38,44,46-tetramethoxy-9,14,19-trimethylcalixspherand (2) potassium picrate complex was prepared in 87% yield (0.58 g) as a yellow solid from **11** (0.52 g, 0.5 mmol), MeI (0.31 mL, 5 mmol), and KO-*t*-Bu (0.28 g, 2.5 mmol) in THF (50 mL). Mp > 290 °C (CH_2Cl_2/(*i*-Pr)$_2$O); ^{1}H NMR δ 8.78 (s, 2 H, H_{pic}), 7.37 (s, 2 H, ArH), 7.35 (s, 2 H, ArH), 7.25 (d, 2 H, J = 2.3 Hz, ArH), 7.18 (d, 2 H, J = 1.7 Hz, ArH), 7.04 (d, 2 H, J = 1.7 Hz, ArH), 6.97 (d, 2 H, J = 2.3 Hz, ArH), 6.83 (s, 2 H, ArH), 5.80 and 4.12 (ABq, 4 H, J = 10.9 Hz, OCH_2Ar), 4.58 and 3.69 (ABq, 4 H, J = 12.6 Hz, ArCH_2Ar), 4.10 (s, 3 H, OCH_3), 3.78 and 3.35 (ABq, 4 H, J = 15.5 Hz, ArCH_2Ar), 3.68 (s, 6 H, OCH_3), 2.51 (s, 3 H, $ArCH_3$), 2.38 (s, 6 H, $ArCH_3$), 2.21 (q, 2 H, J = 7.1 Hz, OCH_2CH$_3$), 1.30, 1.18 (s, 2 × 9 H, C(CH_3)$_3$), 1.08 (s, 18 H, C(CH_3)$_3$), 0.00 (s, 3 H, OCH_3), –0.52 (t, 3 H, J = 7.0 Hz, OCH$_2$CH_3); ^{13}C NMR δ 155.2, 155.1, 154.4, 152.4, 151.9 (s, C_{Ar}O), 148.3, 147.6, 147.3 (s, C-2,26,31,41), 76.0 (t, OCH_2Ar), 69.3 (t, OCH_2CH$_3$), 62.9, 60.4 (q, OCH_3), 34.9, 29.8 (t, ArCH_2Ar), 34.4, 34.2, 34.1 (s, C(CH$_3$)$_3$), 31.5, 31.4, 31.1 (q, C(CH$_3$)$_3$), 21.2, 20.9 (q, $ArCH_3$), 13.1 (q, OCH$_2$CH$_3$); mass spectrum (FAB) m/e 1116 (M^+, calcd for $C_{73}H_{88}KO_7$ 1116). **Sodium picrate complex.** Mp > 290 °C (CH_2Cl_2/(*i*-Pr)$_2$O); ^{1}H NMR δ 8.79 (s, 2 H, H_{pic}), 7.35 (s, 4 H, ArH), 7.18 (s, 4 H, ArH), 7.02 (br s, 2 H, ArH), 6.91 (br s, 2 H, ArH), 6.80 (s, 2 H, ArH), 5.93 and 4.17 (ABq, 4 H, J = 11.2 Hz, OCH_2Ar), 4.58 and 3.68 (ABq, 4 H, J = 12.5 Hz, ArCH_2Ar), 4.20 (s, 3 H, OCH_3), 3.68 and 3.16 (ABq, 4 H, J = 15.1 Hz, ArCH_2Ar), 3.59 (s, 6 H, OCH_3), 2.51 (s, 3 H, $ArCH_3$), 2.39 (s, 6 H, $ArCH_3$), 1.87 (q, 2 H, J = 7. 0 Hz, OCH_2CH$_3$), 1.32, 1.16 (s, 2 × 9 H, C(CH_3)$_3$), 1.06 (s, 18 H, C(CH_3)$_3$), –0.06 (s, 3 H, OCH_3), –0.32 (t, 3 H, J = 7.0 Hz, OCH$_2$CH_3); mass spectrum (FAB) m/e 1100 (M^+, calcd 1100). Anal. Calcd for $C_{79}H_{90}N_3NaO_{14}$·2.8H_2O: C, 68.81; H, 6.99; N, 3.05. Found: C, 68.55; H, 6.56; N, 2.84. Karl–Fischer titration calcd for 2.8H_2O, 3.66; found, 3.67. **Rubidium picrate complex.** Mp 194–197 °C; ^{1}H NMR δ 8.77 (s, 2 H, H_{pic}), 7.38 (s, 2 H, ArH), 7.35 (s, 2 H, ArH), 7.25 (br s, 2 H, ArH), 7.18 (br s, 2 H, ArH), 7.05 (br s, 2 H, ArH), 6.98 (d, 2 H, J = 2.3 Hz, ArH), 6.85 (s, 2 H, ArH), 5.63 and 4.10 (ABq, 4 H, J = 10.6 Hz, OCH_2Ar), 4.50 and 3.65 (ABq, 4 H, J = 12.4 Hz, ArCH_2Ar), 3.92 (s, 3 H, OCH_3), 3.77 and 3.46 (ABq, 4 H, J = 15.6 Hz, ArCH_2Ar), 3.61 (s, 6 H, OCH_3), 2.62 (q, 2 H, J = 7.0 Hz, OCH_2CH$_3$), 2.50 (s, 3 H, $ArCH_3$), 2.36 (s, 6 H, $ArCH_3$), 1.29, 1.18 (s, 2 × 9 H, C(CH_3)$_3$), 1.07 (s, 18 H, C(CH_3)$_3$), –0.03 (s, 3 H, OCH_3), –0.72 (t, 3 H, J = 7.0 Hz, OCH$_2$CH_3); mass spectrum (FAB) m/e 1162 (M^+, calcd for $C_{73}H_{88}O_7$Rb 1162). Anal. Calcd for $C_{79}H_{90}N_3O_{14}$Rb·0.7H_2O: C, 67.60; H, 6.56; N, 2.99. Found: C, 67.97; H, 6.78; N, 2.59. Karl–Fischer titration calcd for 0.7H_2O, 0.90; found, 0.90. **Free ligand.** Mp > 270 °C dec (CH_2Cl_2/MeOH); ^{1}H NMR δ 7.25 (s, 2 H, ArH), 7.18 (s, 2 H, ArH), 7.09 (br s, 2 H, ArH), 7.00 (br s, 2 H, ArH), 6.94 (s, 2 H, ArH), 6.68 (d, 2 H, J = 2.3 Hz, ArH), 6.53 (br s, 2 H, ArH), 5.51 and 4.17 (ABq, 4 H, J = 10.1 Hz, OCH_2Ar), 4.59 and 3.30 (ABq, 4 H, J = 12.4 Hz, ArCH_2Ar), 4.10 (d, 2 H, J = 12.9 Hz, ArCH_2Ar), 3.69 (br s, 3 H, OCH_3), 3.46 (s, 6 H, OCH_3), 3.06–2.94 (m, 7 H, OCH_3, $ArCH_2Ar$, OCH_2CH$_3$), 2.45 (s, 3 H, $ArCH_3$), 2.32 (s, 6 H, $ArCH_3$), 1.35, 1.26 (s, 2 × 9 H, C(CH_3)$_3$), 0.85 (s, 18 H, C(CH_3)$_3$), 0.20 (t, 3 H, J = 7.1 Hz, OCH$_2$CH_3). Anal. Calcd for $C_{73}H_{88}O_7$: C, 81.37; H, 8.23. Found: C, 81.23; H, 8.42.

2,26,31,41-Tetrakis(1,1-dimethylethyl)-35,38,44,46-tetramethoxy-9,14,19-trimethyl-45-(1-methylethoxy)calixspherand (3) potassium picrate complex was prepared in 95% yield (0.90 g) as a yellow solid from **12** (0.74 g, 0.7 mmol), MeI (0.44 mL, 7 mmol), and KO-*t*-Bu (0.31 g, 2.8 mmol) in THF (80 mL). Mp > 280 °C (CH_2Cl_2/(*i*-Pr)$_2$O); ^{1}H NMR δ 8.78 (s, 2 H, H_{pic}), 7.38 (s, 2 H, ArH), 7.36 (s, 2 H, ArH), 7.26 (br s, 2 H, ArH), 7.21 (d, 2 H, J = 1.7 Hz, ArH), 7.04 (br s, 2 H, ArH), 6.99 (d, 2 H, J = 2.3 Hz, ArH), 6.88 (s, 2 H, ArH), 5.73 and 4.14 (ABq, 4 H, J = 10.7 Hz, OCH_2Ar), 4.54 and 3.69 (ABq, 4 H, J = 12.5 Hz, ArCH_2Ar), 4.03 (s, 3 H, OCH_3), 3.84 and 3.42 (ABq, 4 H, J = 15.4 Hz, ArCH_2Ar), 3.61 (s, 6 H, OCH_3), 2.90 (heptet, 1 H, J = 6.2 Hz, OCH(CH$_3$)$_2$), 2.51 (s, 3 H, $ArCH_3$), 2.37 (s, 6 H, $ArCH_3$), 1.30, 1.19 (s, 2 × 9 H, C(CH_3)$_3$), 1.09 (s, 18 H, C(CH_3)$_3$), 0.01 (s, 3 H, OCH_3), –0.44 (d, 6 H, J = 6.2 Hz, OCH(CH_3)$_2$); mass spectrum (FAB) m/e 1130 (M^+, calcd 1130). Anal. Calcd for $C_{80}H_{92}KN_3O_{14}$·0.6H_2O: C, 70.16; H, 6.86; N, 3.07. Found: C, 69.80; H, 6.98; N, 3.01. Karl–Fischer titration calcd for 0.6H_2O, 0.79; found, 0.75. **Sodium picrate complex.** Mp > 275 °C dec (CH_2Cl_2/(*i*-Pr)$_2$O); ^{1}H NMR δ 8.77 (s, 2 H, H_{pic}), 7.36 (br s, 4 H, ArH), 7.21 (br s, 4 H, ArH), 7.00 (br s, 2 H, ArH), 6.96 (d, 2 H, J = 2.2 Hz, ArH), 6.87 (s, 2 H, ArH), 5.85 and 4.16 (ABq, 4 H, J = 11.1 Hz, OCH_2Ar), 4.58 and 3.71 (ABq, 4 H, J = 12.6 Hz, ArCH_2Ar), 4.15 (s, 3 H, OCH_3), 3.86 and 3.28 (ABq, 4 H, J = 14.9 Hz, ArCH_2Ar), 3.59 (s, 6 H, OCH_3), 2.55–2.45 (m, 1 H, OCH(CH$_3$)$_2$), 2.50 (s, 3 H, $ArCH_3$), 2.37 (s, 6 H, $ArCH_3$), 1.30, 1.18 (s, 2 × 9 H, C(CH_3)$_3$), 1.07 (s, 18 H, C(CH_3)$_3$), –0.01 (s, 3 H, OCH_3), –0.42 (d, 6 H, J = 6.3 Hz, OCH(CH_3)$_2$); mass spectrum (FAB) m/e 1114 (M^+, calcd for $C_{74}H_{90}NaO_7$ 1114). Anal. Calcd for $C_{80}H_{92}N_3NaO_{14}$·1.4H_2O: C, 70.25; H, 6.99; N, 3.07. Found: C, 70.35; H, 7.05; N, 2.92. Karl–Fischer titration calcd for 1.4H_2O, 1.84; found, 1.87. **Rubidium picrate complex.** Mp > 290 °C (CH_2Cl_2/(*i*-Pr)$_2$O); ^{1}H NMR δ 8.78 (s, 2 H, H_{pic}), 7.38 (s, 2 H, ArH), 7.36 (s, 2 H, ArH), 7.25 (br s, 2 H, ArH), 7.22 (d, 2 H, J = 1.8 Hz, ArH), 7.05 (d, 2 H, J = 1.7 Hz, ArH), 7.00 (d, 2 H, J = 2.3 Hz, ArH), 6.89 (s, 2 H, ArH), 5.67 and 4.14 (ABq, 4 H, J = 10.6 Hz, OCH_2Ar), 4.51 and 3.68 (ABq, 4 H, J = 12.5 Hz, ArCH_2Ar), 3.96 (s, 3 H, OCH_3), 3.80 and 3.51 (ABq, 4 H, J = 15.4 Hz, ArCH_2Ar), 3.60 (s, 6 H, OCH_3), 3.07 (heptet, 1 H, J = 6.2 Hz, OCH(CH$_3$)$_2$), 2.51 (s, 3 H, $ArCH_3$), 2.37 (s, 6 H, $ArCH_3$), 1.31, 1.19 (s, 2 × 9 H, C(CH_3)$_3$), 1.09 (s, 18 H, C(CH_3)$_3$), 0.08 (s, 3 H, OCH_3), –0.33 (d, 6 H, J = 6.2 Hz, OCH(CH_3)$_2$); ^{13}C NMR δ 155.1, 154.6, 153.6, 152.5, 152.0 (s, C_{Ar}O), 147.9, 147.6, 147.0 (s, C-2,26,31,41), 78.6 (d, OCH(CH$_3$)$_2$), 75.4 (t, OCH_2Ar), 62.9, 59.9 (q, OCH_3), 34.9, 29.7 (t, $ArCH_2Ar$), 34.4, 34.2, 34.1 (s, C(CH$_3$)$_3$), 31.6, 31.3, 31.1 (q, C(CH$_3$)$_3$), 21.1, 20.9 (q, $ArCH_3$), 20.8 (q, OCH(CH$_3$)$_2$); mass spectrum (FAB) m/e 1176 (M^+, calcd for $C_{74}H_{90}O_7$Rb 1176). Anal. Calcd for $C_{80}H_{92}N_3O_{14}$Rb·0.7H_2O: C, 67.78; H, 6.64; N, 2.96. Found: C, 67.93; H, 6.74; N, 2.55. Karl–Fischer titration calcd for 0.7H_2O, 0.89; found, 0.91. **Free ligand.** Mp > 270 °C dec (CH_2Cl_2/MeOH); ^{1}H NMR δ 7.23 (s, 2 H, ArH), 7.19 (s, 2 H, ArH), 7.15 (d, 2 H, J = 1.7 Hz, ArH), 6.98 (br s, 2 H, ArH), 6.90 (s, 2 H, ArH), 6.66 (d, 2 H, J = 2.3 Hz, ArH), 6.50 (d, 2 H, J = 2.3 Hz, ArH), 5.56 and 4.20 (ABq, 4 H, J = 10.5 Hz, OCH_2Ar), 4.55 and 3.29 (ABq, 4 H, J = 12.4 Hz, ArCH_2Ar), 4.06 and 2.98 (ABq, 4 H, J = 13.0 Hz, ArCH_2Ar), 3.86 (br s, 3 H, OCH_3), 3.42 (s, 6 H, OCH_3), 3.49–3.42 (m, 1 H, OCH(CH$_3$)$_2$), 3.18 (br s, 3 H, OCH_3), 2.43 (s, 3 H, $ArCH_3$), 2.33 (s, 6 H, $ArCH_3$), 1.35, 1.25 (s, 2 × 9 H, C(CH_3)$_3$), 0.84 (s, 18 H, C(CH_3)$_3$), 0.36 (d, 6 H, J = 6.2 Hz, OCH(CH_3)$_2$). Anal. Calcd for $C_{74}H_{90}O_7$: C, 81.43; H, 8.31. Found: C, 81.70; H, 8.40.

2,26,31,41-Tetrakis(1,1-dimethylethyl)-35,38-diethoxy-44,45,46-trimethoxy-9,14,19-trimethylcalixspherand (4) potassium picrate complex was prepared in 83% yield (1.1 g) as a yellow solid from **10** (1.04 g, 1 mmol), KO-*t*-Bu (0.56 g, 5 mmol), EtI (0.8 mL, 10 mmol), and THF (150 mL). Mp > 270 °C dec (CH_2Cl_2/(*i*-Pr)$_2$O); ^{1}H NMR δ 8.77 (s,

2 H, H_{pic}), 7.35 (s, 2 H, ArH), 7.33 (d, 2 H, J = 2.3 Hz, ArH), 7.29 (s, 2 H, ArH), 7.19 (br s, 2 H, ArH), 7.14 (s, 2 H, ArH), 7.06 (br s, 2 H, ArH), 7.03 (d, 2 H, J = 2.3 Hz, ArH), 5.16 and 4.24 (ABq, 4 H, J = 11.0 Hz, OCH_2Ar), 4.60 and 4.00 (ABq, 4 H, J = 17.2 Hz, $ArCH_2Ar$), 4.37 and 3.47 (ABq, 4 H, J = 12.5 Hz, $ArCH_2Ar$), 3.57 (q, 2 H, J = 6.9 Hz, OCH_2CH_3), 3.11 (s, 6 H, OCH_3), 2.55 (s, 3 H, OCH_3), 2.50 (s, 3 H, $ArCH_3$), 2.36 (s, 6 H, $ArCH_3$), 1.67 (q, 2 H, J = 6.9 Hz, OCH_2CH_3), 1.27, 1.22 (s, 2 × 9 H, $C(CH_3)_3$), 1.17 (s, 18 H, $C(CH_3)_3$), 0.82 (t, 3 H, J = 6.9 Hz, OCH_2CH_3), −1.60 (t, 3 H, J = 6.9 Hz, OCH_2CH_3); ^{13}C NMR δ 155.2, 153.8, 152.9, 151.0, 150.2 (s, $C_{Ar}O$), 147.6, 147.0, 146.9 (s, C-2,26,31,41), 76.5 (t, OCH_2Ar), 71.6, 70.9 (t, OCH_2CH_3), 61.4, 61.4 (q, OCH_3), 36.1, 29.9 (t, $ArCH_2Ar$), 34.3, 34.2, 34.1 (s, $C(CH_3)_3$), 31.5, 31.3 (q, $C(CH_3)_3$), 21.3, 20.7 (q, $ArCH_3$), 14.5, 12.1 (q, OCH_2CH_3); mass spectrum (FAB) m/e 1130 (M^+, calcd for $C_{74}H_{90}KO_7$ 1130). **Sodium picrate complex.** Mp > 275 °C dec ($CH_2Cl_2/(i\text{-}Pr)_2O$); ^1H NMR δ 8.77 (s, 2 H, H_{pic}), 7.34 (s, 2 H, ArH), 7.33 (s, 2 H, ArH), 7.28 (br s, 2 H, ArH), 7.22 (d, 2 H, J = 1.7 Hz, ArH), 7.03 (d, 2 H, J = 1.7 Hz, ArH), 6.89 (d, 2 H, J = 2.3 Hz, ArH), 6.62 (s, 2 H, ArH), 5.93 and 4.12 (ABq, 4 H, J = 11.2 Hz, OCH_2Ar), 4.65 and 3.64 (ABq, 4 H, J = 12.5 Hz, $ArCH_2Ar$), 4.50 (q, 2 H, J = 7.1 Hz, OCH_2CH_3), 3.66 and 3.25 (ABq, 4 H, J = 16.0 Hz, $ArCH_2Ar$), 3.54 (s, 6 H, OCH_3), 2.50 (s, 3 H, $ArCH_3$), 2.39 (s, 6 H, $ArCH_3$), 1.54 (t, 3 H, J = 7.1 Hz, OCH_2CH_3), 1.36 (s, 3 H, OCH_3), 1.29 (s, 9 H, $C(CH_3)_3$), 1.13 (s, 18 H, $C(CH_3)_3$), 1.04 (s, 9 H, $C(CH_3)_3$), −0.01 (q, 2 H, J = 7.1 Hz, OCH_2CH_3), −0.90 (t, 3 H, J = 7.1 Hz, OCH_2CH_3); mass spectrum (FAB) m/e 1114 (M^+, calcd for $C_{74}H_{90}NaO_7$ 1114). **Rubidium picrate complex.** Mp > 270 °C dec ($CH_2Cl_2/(i\text{-}Pr)_2O$); ^1H NMR δ 8.78 (s, 2 H, H_{pic}), 7.37 (s, 2 H, ArH), 7.35 (d, 2 H, J = 2.3 Hz, ArH), 7.30 (s, 2 H, ArH), 7.20 (br s, 2 H, ArH), 7.17 (s, 2 H, ArH), 7.12 (br s, 2 H, ArH), 7.03 (d, 2 H, J = 2.2 Hz, ArH), 5.15 and 4.22 (ABq, 4 H, J = 10.7 Hz, OCH_2Ar), 4.59 and 4.08 (ABq, 4 H, J = 17.3 Hz, $ArCH_2Ar$), 4.36 and 3.49 (ABq, 4 H, J = 12.5 Hz, $ArCH_2Ar$), 3.54 (q, 2 H, J = 6.9 Hz, OCH_2CH_3), 3.23 (s, 6 H, OCH_3), 2.59 (s, 3 H, OCH_3), 2.52 (s, 3 H, $ArCH_3$), 2.38 (s, 6 H, $ArCH_3$), 2.08 (q, 2 H, J = 6.9 Hz, OCH_2CH_3), 1.27, 1.25 (s, 2 × 9 H, $C(CH_3)_3$), 1.19 (s, 18 H, $C(CH_3)_3$), 0.82 (t, 3 H, J = 6.9 Hz, OCH_2CH_3), −1.83 (t, 3 H, J = 6.9 Hz, OCH_2CH_3); mass spectrum (FAB) m/e 1176 (M^+, calcd for $C_{74}H_{90}O_7Rb$ 1176). Anal. Calcd for $C_{80}H_{92}N_3O_{14}Rb\cdot 1.8H_2O$: C, 66.84; H, 6.70; N, 2.92. Found: C, 67.24; H, 6.49; N, 2.77. Karl–Fischer titration calcd for $1.8H_2O$, 2.26; Found, 2.29. **Free ligand** was isolated as a complicated mixture of conformers. Because of the complicated ^1H NMR spectrum of the mixture, individual signals could not be assigned. However, upon reaction with rubidium picrate the mixture of conformers was converted *quantitatively* into a complex which was identical with $[4\text{-}Rb]^+Pic^-$ (*vide supra*). Mp 226–236 °C (CH_2Cl_2/MeOH). Anal. Calcd for $C_{74}H_{90}O_7\cdot 0.8H_2O$: C, 80.37; H, 8.35. Found: C, 80.26; H, 8.34. Karl–Fischer titration calcd for $0.8H_2O$, 1.30; found, 1.33.

Determination of the Rates of Decomplexation of Calixspherands 2–4 with MPic in $CDCl_3$.[10] Solutions of $[Host\cdot M]^+Pic^-$ (0.006 M) and of deuterated-Host (0.006 M) in $CDCl_3$ (saturated with D_2O at 25 °C) were prepared. Aliquots of each solution (300 μL) were mixed in an NMR tube and equilibrated at the desired temperature. When the temperature at which measurements were made was above 55 °C, the NMR tube was sealed to prevent evaporation of the solvent. The NMR tube was allowed to reach the desired temperature, and ^1H NMR spectra were taken at intervals (2–3 points) over 2–3 half-lives (at least 6 points). For **2** and **3** the concentration of nondeuterated complex was determined from the integrals of the signals for the methoxy group at $\delta \sim 0$ and the substituent at the central ring of the terphenyl. For $[4\cdot Na]^+$ the concentration of $[4\cdot Na]^+$ was determined from the integrals of the methyl group of the ethoxy group at δ −0.9 and the signal of the methyl groups of reference $PhMe_3Si$ at $\delta \sim 0.3$.

Determination of the Rates of Complexation of Calixspherands 2–4 with MPic in $CDCl_3$. The rates of complexation of the calixspherands **2–4** with MPic were determined as described by Cram and Lein[10] for the spherands. For **2** and **3** the ratio of complex and free ligand was determined from the integrals of the signals for the substituent at the central ring of the terphenyl in the complex and the free ligands. For the complexation of **4** with Na^+, the concentration of $[4\cdot Na]^+$ was determined from the integrals of the methyl group of the ethoxy group at δ −0.9 and the signal of the methyl groups of reference $PhMe_3Si$ at $\delta \sim 0.3$. We used as "donor" ligand for the complexation of MPic hemispherand **24** ($K_a^{NaPic} = 9.2 \times 10^8$ M^{-1}, $K_a^{KPic} = 4.6 \times 10^8$ M^{-1}, and $K_a^{RbPic} = 4.6 \times 10^7$ M^{-1}).[32]

(32) Bryant, J. A.; Helgeson, R. C.; Knobler, C. B.; de Grandpre, M. P.; Cram, D. J. *J. Org. Chem.* **1990**, *55*, 4622–4634.

Determination of the Rates of Exchange of Calixspherands 1–4 Using Radioactive Salts. The free ligands of the calixspherands were loaded with $^{22}Na^+$ or $^{86}Rb^+$ in the following way: The calixspherand (1 mg) was dissolved in acetone (1.6 mL), and an aqueous solution of $^{22}NaCl$ or $^{86}RbCl$ (40 μL, 1 mCi/mL) was added. After half an hour a 10 mM solution of sodium or rubidium picrate in acetone (0.16 mL) was added. Another 2 h later chloroform (1.6 mL) was added and the organic solution was extracted with water (4 × 1.6 mL) and stored for use.

The ion-exchange experiments were performed as follows: For each experiment 10–14 tubes were filled with 20–30 μL of the solution containing the radioactive calixspherand complex. In this way each tube contained 6–10 nmol of calixspherand complex and about 5000 cpm. The solvent was evaporated at room temperature and pressure overnight. To every tube was added 100 μL of a 10 mM solution of alkali picrate in acetone or DMSO. At certain time intervals chloroform (0.7 mL) and water (0.7 mL) were added and the tube was vortexed for 10 s, followed by centrifugation for 5 min at 2000 rpm. Afterward, part of the organic layer (0.5 mL) was transferred to a second tube, the volume in this tube was adjusted with water (0.5 mL), and both tubes were counted for 4 min. The exchange was followed for at least 24 h and at most 72 h. The exchange process was followed in time and data points were taken after 10 s, 5, 10, 20, 40, 80, 150, 300, and 450 min, and 16 and 24 h and for the longer experiments also after 32, 48, and 72 h.

For the calculation of the ratio of complexed and free salt the following assumption was made: All the counts in the organic layer are from the calixspherand cation complex, and all the counts in the water layer are from uncomplexed cations.

The number of counts was corrected because only 0.5 mL of the organic layer is transferred to a second tube and counted, when acetone was used as solvent, the volume of acetone added to the chloroform layer, and when DMSO was used as solvent, the volume of DMSO added to the water layer. In a separate experiment it was found that the partitioning of the solvents was independent from the salt concentration. Therefore, the total volume of the organic layer is 0.8 mL for acetone and 0.7 mL for DMSO, and consequently, the number of counts was multiplied by $^8/_5$ and $^7/_5$, respectively. The percentage of complexed radioactive cation ($*M^+$) was calculated in the following way:

For acetone:

$$\%\ \text{complexed}\ *M^+ = \{1.6N_{org}/(N_{org} + N_{water})\} \times 100\%$$

For DMSO:

$$\%\ \text{complex}\ *M^+ = \{1.4N_{org}/(N_{org} + N_{water})\} \times 100\%$$

N_{org} = background-corrected number of counts in 0.5 mL of the organic layer

N_{water} = background-corrected number of counts in the "aqueous" layer

The percentages were plotted against time, and the kinetic analysis was performed using a computer program for nonlinear curve fitting, MULTIFIT,[28] using the Marquardt algorithm[33] or the simplex algorithm[34] for the minimization of the residual weighted sum of squares.

X-ray Structure Determination of Compounds $[4\cdot K]^+Pic^-\cdot CH_2Cl_2$ and 10. The crystal structure of $[4\cdot K]^+Pic^-\cdot CH_2Cl_2$ was determined by X-ray diffraction. Crystal data are given in Table IV. Reflections were measured on an Enraf-Nonius CAD4 diffractometer, using graphite monochromated Mo Kα radiation (λ = 0.7107 Å, ω/2Θ scan mode, scan width (ω) 1.5 + 0.35 tan Θ, 1 ≤ Θ ≤ 20°). Measured intensities were corrected for Lorentz and polarization effects. The structure was solved by direct methods[35] and refined with full-matrix least squares methods using units weights. A total of 3009 reflections ($F^2 > 3\sigma F^2$; $R_{merge}(F) = 0.035$) were used in the refinement. The number of parameters refined was 417 (overall scale factor, atomic positional parameters, and isotropic thermal parameters for all non-hydrogen atoms; hydrogen atoms were put in calculated positions with a C–H distance of 1.08 Å). One *tert*-butyl group was found to exist in two different orientations. Both

(33) Press, W. H.; Flannery, B. P.; Teukolsky, S. A.; Vetterling, W. T. *Numerical Recipes*; Cambridge University Press: Cambridge, U.K., 1986.
(34) Nelder, J. H.; Mead, R. *Comput. J.* **1965**, *7*, 308–318.
(35) (a) Germain, G.; Main, P.; Woolfson, M. M. *Acta Crystallogr., Sect. A* **1971**, *A27*, 368–376. (b) Main, P.; Woolfson, M. M.; Lessinger, G.; Germain, G.; Declerq, G. P. *MULTAN80: A system of computer programs for automatic solution of crystal structures.*

Table IV. Experimental Data for the X-ray Diffraction Studies on Compounds **[4·K]$^+$Pic$^-$·CH$_2$Cl$_2$** and **10**

compound	**[4·K]$^+$Pic$^-$·CH$_2$Cl$_2$**	**10**
formula	$C_{81}H_{94}Cl_2KN_3O_{14}$	$C_{70}H_{82}O_7$
fw	1443.65	1035.42
lattice type	triclinic	monoclinic
space group	$P\bar{1}$	$P2_1/c$
T, K	188	273
cell dimensions		
a, Å	14.953(12)	11.087(3)
b, Å	15.708(9)	28.646(4)
c, Å	16.706(9)	24.674(7)
α, deg	78.76(3)	90
β, deg	81.84(2)	98.73(4)
γ, deg	75.95(2)	90
V, Å^3	3714.9	7205(5)
Z	2	4
D_{calc}, g/cm^3	1.279	0.96
μ, cm^{-1}	2.061	0.56
unique total data	6059	9348
unique obsd data	3009	4096
no. of variables	417	684
R	0.106	0.120
R_w	0.114	0.129

orientations were refined together applying occupancies of 0.7 and 0.3, respectively. All calculations were done with the SDP package.[36]

The crystal structure of **10** was determined by X-ray diffraction. Crystal data are given in Table IV. Reflections were measured on an Enraf-Nonius CAD4 diffractometer, using graphite monochromated Mo Kα radiation (λ = 0.7107 Å, $\omega/2\theta$ scan mode, scan width (ω) 1.4 + 0.34 tan θ, $3 < \theta < 22.5°$). The structure was solved by direct methods[35] and refined with full-matrix least squares methods. A total of 4096 reflections with $F_o^2 > 3\sigma(F_o^2)$ were used in the refinement. The structure refinement was hampered by the presence of disordered solvent molecules and by disorder in terminal atoms of two of the *tert*-butyl groups. It was not possible to fit a reasonable solvent model to the peaks in the difference electron density. Therefore carbon atoms were placed at the highest peaks and refined with isotropic thermal parameters. The number of parameters refined was 684 (scale factor, positional parameters of the heavy atoms; hydrogen atoms were put at calculated positions and treated as riding atoms; thermal parameters refined anisotropically for the heavy atoms of the calix[4]arene molecule, isotropically for the solvent atoms). All calculations were done with the SDP package.[36]

(36) *Structure Determination Package*; Frenz, B. A. and Associates Inc.: College Station, Texas, and Enraf-Nonius: Delft, The Netherlands, 1983.

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Supplementary Material Available: Tables of positional and thermal parameters, bond distances, and bond and torsional angles for **[4·K]$^+$Pic$^-$·CH$_2$Cl$_2$** and **10** (15 pages); observed and calculated structure factors of the X-ray structures of **[4·K]$^+$Pic$^-$·CH$_2$Cl$_2$** and **10** (58 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.