rification: IR $\nu_{max}$ (neat) 1730 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 9.59 (1 H, d, $J$ = 0.5 Hz, CHO); MS $m/z$ 546 ($M^+$); high-resolution mass spectrum calcd for $C_{33}H_{38}O_7$ $m/z$ 546.26174, found 546.26314. Anal. Calcd for $C_{33}H_{38}O_7 \cdot H_2O$: C, 70.19; H, 7.19. Found: C, 70.37; H, 7.53.

**2,6-Anhydro-3,4,5-tri-*O*-benzyl-7-*O*-(trimethylacetyl)-L-*glycero*-L-*gulo*-heptonic Acid (12).** To a solution of **11** (92 mg) in MeCN-$CCl_4$-$H_2O$ (2:2:3, 7 mL) were added $NaIO_4$ (144 mg) and $RuO_2 \cdot xH_2O$ (3 mg). The mixture was stirred for 2 h at room temperature, diluted with EtOAc, washed with water and brine, dried over $MgSO_4$, and concentrated to give a crude oil, which was chromatographed on a silica gel column. Elution with cyclohexane-EtOAc (1:1) and then with EtOAc containing 1% AcOH gave 38 mg (40%) of **12** as an oil: IR $\nu_{max}$ (neat) 3600-2500, 1727 $cm^{-1}$; $^1H$ NMR ($CDCl_3$ + $D_2O$) $\delta$ 1.17-1.21 (9 H, m), 3.53-3.82 (3 H, m, H-4,5,6), 4.00 (1 H, m, H-3), 4.21 (1 H, dd, $J$ = 4.9, 12.2 Hz, H-7), 4.45 (1 H, dd, $J$ = 2.0, 12.2 Hz, H-7'), 4.47 (1 H, d, $J$ = 10.2 Hz, H-2), 4.67-4.91 (6 H, m, 3 × $CH_2Ph$), 7.24-7.34 (15 H, m); MS $m/z$ 561 ($M^+$ - 1), 471 ($M^+$ - Bn), 365, 359. Anal. Calcd for $C_{33}H_{38}O_8$: C, 70.44; H, 6.81. Found: C, 70.31; H, 6.71.

**2,3,4-Tri-*O*-benzyl-1-*O*-(3-chlorobenzoyl)-6-*O*-(trimethylacetyl)-β-L-glucopyranose (13).** To a solution of **12** (24 mg) in $CH_2Cl_2$ (1 mL) were added 3-chloroperoxybenzoic acid (10.4 mg, 85% purity) and DCC (13 mg) at 0-5 °C with stirring. After 10 min the mixture was warmed to room temperature, stirred for 1 h, and filtered. The filtrate was chromatographed on a silica gel plate. Development with cyclohexane-EtOAc (9:1) gave 10 mg (34%) of **13** ($R_f$ = 0.333) as an oil: $[\alpha]^{25}_D$ +32° ($c$ 0.9, $CHCl_3$); IR $\nu_{max}$ (neat) 1733 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 1.18 (9 H, s), 3.60-3.86 (4 H, m, H-2,3,4,5), 4.25 (1 H, dd, $J$ = 4.9, 12.2 Hz, H-6), 4.36 (1 H, dd, $J$ = 2.0, 12.2 Hz, H-6'), 4.57-4.95 (6 H, m), 5.87 (1 H, d, $J$ = 7.8 Hz, H-1), 7.21-7.36 (15 H, m), 7.38 (1 H, t, $J$ = 7.8 Hz), 7.56 (1 H, dq, $J$ = 7.8, 1.0 Hz), 7.90 (1 H, dt, $J$ = 7.8, 1.0-1.5 Hz), 7.97 (1 H, t, $J$ = 2.0 Hz); MS $m/z$ 581 ($M^+$ - Bn). Anal. Calcd for $C_{39}H_{41}O_8Cl$: C, 69.58; H, 6.14; Cl, 5.27. Found: C, 69.33; H, 6.15; Cl, 5.13.

**2,3,4-Tri-*O*-benzyl-6-*O*-(trimethylacetyl)-α,β-L-glucopyranose (14).** A solution of **13** (7 mg) in THF (0.5 mL) and 0.1 M NaOH (0.25 mL) was stirred for 4 h at room temperature. The reaction mixture was diluted with EtOAc, washed with brine, dried ($MgSO_4$), and concentrated to give an oily residue, which was chromatographed on a silica gel column. Elution with cyclohexane-EtOAc (3:1) gave 3 mg (54%) of **14** as powder: $[\alpha]^{25}_D$ -26.4° ($c$ 0.32, $CHCl_3$); IR $\nu_{max}$ (neat) 3440, 1727 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 1.20-1.22 (9 H, m), 3.36-4.52 (6 H, m), 4.56-4.96 (6 H, m), 5.19-5.27 (1 H, m, H-1); MS $m/z$ 517 ($M^+$ - OH), 443, 425, 337, 319, 282, 253; high-resolution mass spectrum of ($M^+$ - OH) calcd for $C_{32}H_{37}O_6$ $m/z$ 517.25895, found 517.25885. Anal. Calcd for $C_{32}H_{38}O_7$: C, 71.89; H, 7.16. Found: C, 71.60; H, 7.00.

**Acylal Analogues 16a,b,c,f. General Procedure.** To a solution of the substrates **15a-f** (1.0 mmol) in a solvent (2-10 mL) cooled in an ice bath were added 3-chloroperoxybenzoic acid (1.1 mmol except for **15c**; 2.1 mmol for **15c**) and then 1,3-dicyclohexylcarbodiimide (1.1 mmol except for **15c**; 2.1 mmol for **15c**) with stirring. After evolution of $CO_2$ ceased at 0 °C or room temperature, the reaction mixture was filtered and chromatographed on a silica gel column or a silica gel TLC plate.

Physical data are as follows. **16a**: $[\alpha]^{25}_D$ -6.8° ($c$ 2.0, $CHCl_3$); IR $\nu_{max}$ (neat) 1762, 1740 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 2.16 (3 H, s), 7.2-7.8 (7 H, m), 7.8-8.1 [3 H, m, containing 1 H singlet at $\delta$ 7.92, PhC*H*(OAc)(OAr)]; MS $m/z$ 304 ($M^+$); high-resolution mass spectrum calcd for $C_{16}H_{13}O_4Cl$ $m/z$ 304.05028, found 304.05088. Anal. Calcd for $C_{16}H_{13}O_4cl$: C, 63.06; H, 4.30; Cl, 11.63. Found: C, 63.00; H, 4.40; Cl, 11.80.

**16b**: IR (neat) 1725 (neat) $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 3.53 (3 H, s), 5.45 (2 H, s), 7.2-8.1 (4 H, m); MS $m/z$ 200 ($M^+$, $^{35}Cl$); high-resolution mass spectrum calcd for $C_9H_9O_3Cl$ $m/z$ 200.02395, found 200.02315. Anal. Calcd for $C_9H_9O_3Cl$: C, 53.88; H, 4.52; Cl, 17.67. Found: C, 54.02; H, 4.37; Cl, 17.67.

**16c**: IR $\nu_{max}$ (neat) 1810, 1770, 1740 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 2.94 (1 H, dd, $J$ = 9.2, 18.0 Hz), 3.42 (1 H, dd, $J$ = 10.6, 18.0 Hz), 4.02 (1 H, ddd, $J$ = 5.9, 9.2, 10.6 Hz), 7.13 (1 H, d, $J$ = 5.9 Hz), 7.4-8.1 (8 H, m); MS $m/z$ 395 ($M^+$ - $CO_2$), 394 ($M^+$ - $CO_2$). Anal. Calcd for $C_{19}H_{12}O_8Cl_2$: C, 51.96; H, 2.75; Cl, 16.14. Found: C, 52.45; H, 3.05; Cl, 16.14.

**16f**: IR $\nu_{max}$ (neat) 1750, 1575 $cm^{-1}$; MS $m/z$ 413 ($M^+$ - 59), 317 ($M^+$ - 155). Anal. Calcd for $C_{20}H_{21}O_{11}Cl$: C, 50.80; H, 4.48; Cl, 7.50. Found: C, 50.23; H, 4.54; Cl, 7.48.

# Partially OH Depleted Calix[4]arenes

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The partially OH depleted dihydroxy- and trihydroxycalix[4]arenes **2** and **3** were synthesized in order to assess the relative importance of the cyclic hydrogen bond on the conformation of *p-tert*-butylcalix[4]arene. Both compounds were prepared from the same diethyl diphosphate ester precursor under different reductive cleavage conditions. The ring inversion barriers of **2** and **3** are <10 and 11.6 kcal $mol^{-1}$, respectively. The completely OH depleted calixarene **5** and the MeOH solvate of dihydroxycalixarene **2** exist in the crystal in a 1,2-alternate conformation. Trihydroxycalixarene **3** crystallizes as a 1:2 pyridine solvate in which **3** adopts a cone conformation. One pyridine molecule is hydrogen bonded to one OH group of **3**, while simultaneously being included into the cavity of another molecule of **3**. It is concluded that three phenolic units are sufficient to stabilize the cone conformation.

## Introduction

Two systems that have been extensively studied in the last years as host compounds for enzyme mimics are cyclodextrins[1] and calixarenes.[2] Both systems are capable of including small organic molecules into their cavities. However, the cyclodextrins are conformationally rigid whereas the free hydroxyl-containing calixarenes are conformationally flexible on the laboratory timescale. The conformational behavior of calix[4]arenes is normally discussed in terms of four ideal conformations: cone, partial cone, and 1,3- and 1,2-alternate (Figure 1).[3,4] For

(1) For a monograph on cyclodextrins, see: Bender, M. L.; Komiyama, M. *Cyclodextrin Chemistry*; Springer-Verlag: Berlin, 1978.

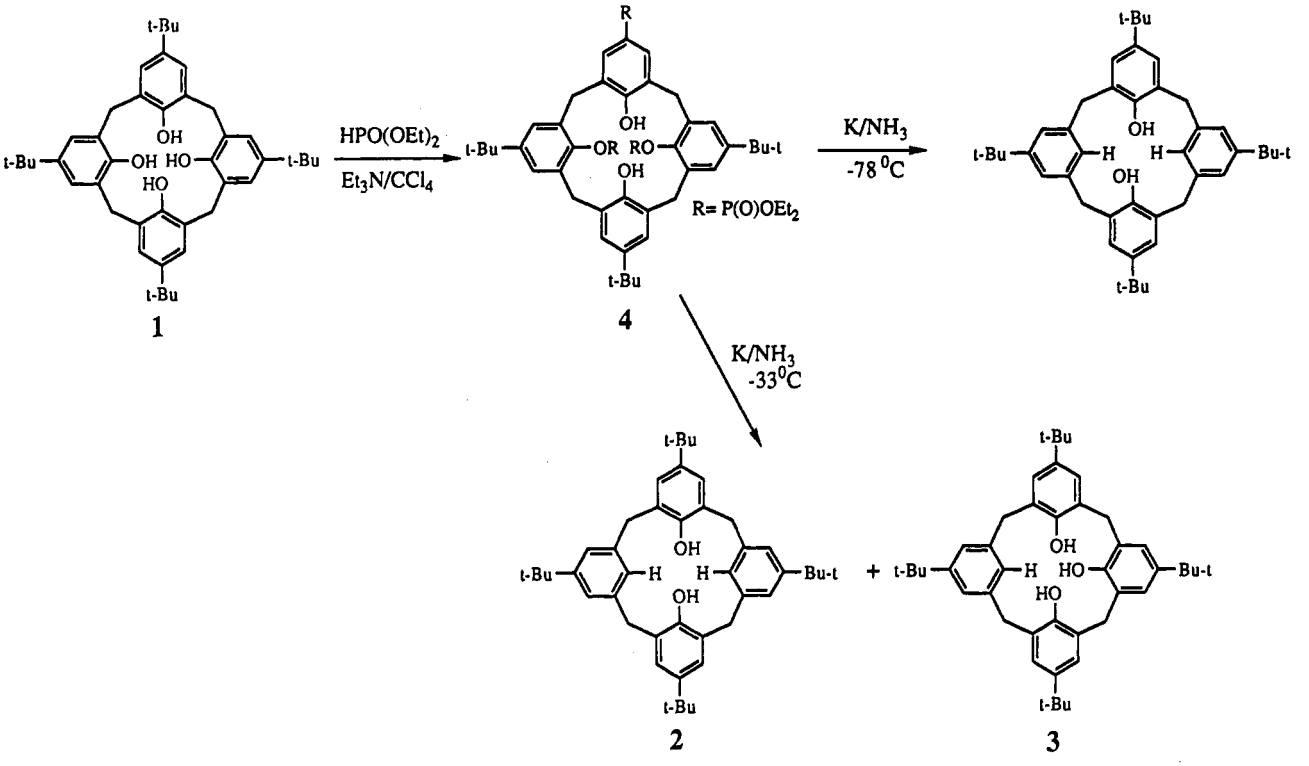
(2) For a comprehensive review on calixarenes, see: Gutsche, C. D. *Calixarenes*; Royal Society of Chemistry: Cambridge, 1989.

(3) Cornforth, J. W.; D'Arcy Hart, P.; Nicholls, G. A.; Rees, R. J. W.; Stock, J. A. *Br. J. Pharmacol.* **1955**, *10*, 73.

(4) These conformations are by no means exclusive. For example a "boat" conformation has been recently observed for a sterically crowded calixarene. See: Dahan, E.; Biali, S. E. *J. Org. Chem.* **1989**, *54*, 6003.

0022-3263/91/1956-0532$02.50/0 

**Scheme I**



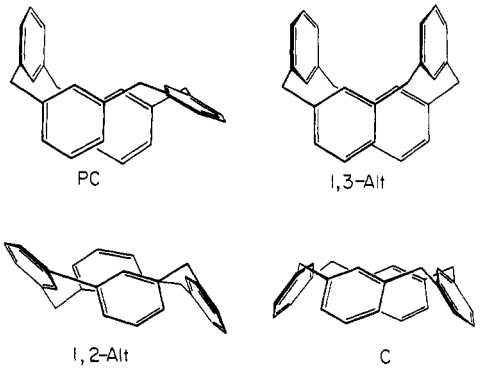




**Figure 1.** The four ideal conformations of a calix[4]arene system: PC, partial cone conformation; 1,3-Alt, 1,3-alternate conformation; 1,2-Alt, 1,2-alternate conformation; C, cone conformation.

the parent compound *p-tert*-butylcalix[4]arene (1) X-ray[5] as well as spectroscopic[6] data in solution indicate that the preferred conformation is the cone which has an inversion barrier of 15.7 kcal $mol^{-1}$ in $CDCl_3$.[6] It has been argued that the cone conformation is energetically preferred over the other conformations since it is the only one which allows a circular "flip flop"[7] hydrogen bonding pattern.[8] This pattern must be disrupted, at least to some extent, during the inversion pathway. Considering the great importance ascribed to the complete cyclic OH array, it is rather surprising that partially OH depleted calixarenes have not been described in the literature. We describe in this paper the preparation and crystal structures of the dihydroxy- and trihydroxy-*p-tert*-butylcalix[4]arenes (2 and 3), and qualitatively assess the relative importance of the complete cyclic OH array on the conformation and inversion barrier.

## Results and Discussion

**Preparation and NMR Data of 2 and 3.** In order to synthesize the partially OH depleted calixarenes we used the synthetic route developed by Kenner and Williams[9] and previously used by us for the complete removal of the OH groups of 1 and of *p-tert*-butylcalix[8]arene.[10] The key compound for the preparation of 2 and 3 was the bis(diethyl phosphate) ester 4 prepared by phosphorylation of 1 under mild conditions ($HPO(OEt)_2/Et_3N/CCl_4$, 0 °C).[11] Reductive cleavage of the phosphate groups (K/liquid $NH_3$, -78 °C) converted 4 into calixarene 2 in good yield (Scheme I). Unfortunately, the precursor for the preparation of 3 via reductive cleavage (the mono(diethyl phosphate) ester derivative of 1) could not be prepared by this route. For example, reaction of 1 with a large deficiency of phosphorylating agent resulted (judged by NMR) in unreacted 1 and small amounts of diphosphate 4, but not in monophosphate.[12]

The preparation of 3 was based on the observation that when the diethyl phosphate esters are treated with K/$NH_3$, some O–$PO(OR_2)$ bond cleavage takes place, in addition to the C(ipso)–O cleavage.[13] We reasoned that if

(5) Andreetti, G. D.; Ungaro, R.; Pochini, A. *J. Chem. Soc., Chem. Commun.* **1979**, 1005. Andreetti, G. D.; Pochini, A.; Ungaro, R. *J. Chem. Soc., Perkin Trans. 2* **1983**, 1773. Ungaro, R.; Pochini, A.; Andreetti, G. D.; Sangermano, V. *Ibid.* **1984**, 1979. Furphy, B. M.; MacB. Harrowfield, J.; Ogden, M. I.; Skelton, B. W.; White, A. H.; Wilner, F. R. *J. Chem. Soc., Dalton Trans.* **1989**, 2217.

(6) Gutsche, C. D.; Bauer, L. J. *J. Am. Chem. Soc.* **1985**, *107*, 6052.

(7) Saenger, W.; Betzel, C.; Hingerty, B.; Brown, G. M. *Angew. Chem., Int. Ed. Engl.* **1983**, *22*, 883. Saenger, W.; Betzel, Ch.; Hingerty, B.; Brown, G. M. *Nature* **1982**, *296*, 581. Saenger, W. *Ibid.* **1979**, *279*, 343.

(8) For a review on hydrogen bonding patterns of organic compounds, see: Etter, M. C. *Acc. Chem. Res.* **1990**, *23*, 120.

(9) Kenner, G. W.; Williams, N. R. *J. Chem. Soc.* **1955**, 522. See also: Rossi, R. A.; Bunnett, J. F. *J. Org. Chem.* **1973**, *38*, 2314.

(10) Goren, Z.; Biali, S. E. *J. Chem. Soc., Perkin Trans. 1* **1990**, 1484.

(11) Phosphorilation of 1 under drastic conditions ($Cl(O)P(OEt)_2$, 50% NaOH/$CH_2Cl_2$, phase-transfer catalyst) have been shown to afford the tetrakis(diethyl phosphate ester) derivative of 1.[9]

(12) In a related observation, it has been reported that the diazotation of calix[4]arene occurs in a all-or-nothing manner: Shinkai, S.; Araki, K.; Shibata, J.; Manabe, O. *J. Chem. Soc., Perkin Trans. 1* **1989**, 195.

(13) Shafer, S. J.; Closson, W. D.; van Dijk, J. M. F.; Piepers, O.; Buck, H. M. *J. Am. Chem. Soc.* **1977**, *99*, 5118.

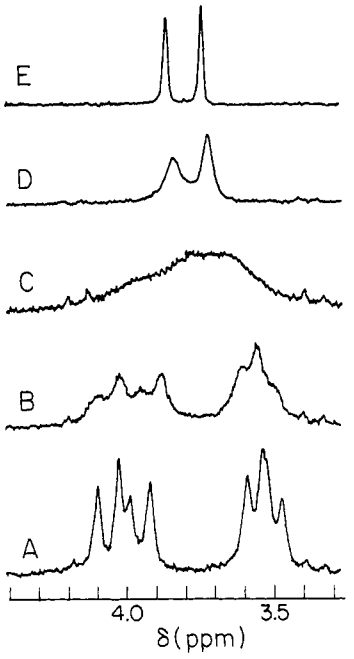



**Figure 2.** 200-MHz $^1H$ NMR spectrum of **3** in 1:1 $CDCl_3/CD_2Cl_2$. A: at 213 K, B: at 228 K, C: at 246 K, D: at 264 K, E: at 292 K.

both processes occur at similar rates in some molecules of **4**, one phosphate group will undergo O–P cleavage and the other will be reductively cleaved, giving **3**. Indeed, when **4** was treated with a large excess of K at −33 °C the product consisted of 67% **2** and 33% **3** (Scheme I). Calixarenes **2** and **3** were separated by medium-pressure chromatography ($SiO_2$; eluent, 40% $CH_2Cl_2$, 60% petroleum ether 60–80 °C). **2** and **3** are the first examples of calixarenes with partially depleted OH groups.

Both **2** and **3** display at room temperature in $CDCl_3$ $^1H$ and $^{13}C$ NMR spectra compatible with a flexible structure on the NMR timescale, as indicated by the appearance of the methylene protons (one ($\delta$ = 3.8) and two ($\delta$ = 3.75 and 3.87) singlets, respectively). Lowering the temperature down to 213 K did not change the spectrum of **2**, whereas for **3** broadening of the signals followed by decoalescence and resharpening as two pairs of doublets was observed (Figure 2). From the coalescence temperature ($T_c$ = 246 K), the chemical shift difference between the two pairs of exchanging protons ($\Delta\nu$ = 100.9 and 90.1 Hz) and the coupling constants (14.0 and 13.2 Hz), a barrier of 11.6 kcal mol$^{-1}$ was calculated for the ring inversion process of **3**.[14] The absence of a decoalescence process in **2** indicates (precluding accidental isochrony of the methylene protons or a planar conformation of the macrocyclic ring) that the barrier for ring inversion is <10 kcal mol$^{-1}$. It can be concluded therefore that the formal elimination of one OH group of **1** reduces the barrier of cone inversion by 4.1 kcal mol$^{-1}$, whereas the formal elimination of a second nonvicinal OH group further increases the mobility of the system by >1.6 kcal mol$^{-1}$.

**Crystal Conformations of 2 and 3.** In order to ascertain the preferred conformation of calixarenes **2** and **3** we determined the X-ray structure of **2** and **3**. Calixarene **2** crystallizes from $CHCl_3$/MeOH as a 1:1 MeOH solvate in which the calixarene molecule is located in an inversion center and therefore has crystallographic $C_i$ symmetry. As shown in Figure 3 it exists in a *1,2-alternate* conformation.[15] Each phenolic OH group is intermolecularly hydrogen bonded to a MeOH molecule, and each MeOH molecule is hydrogen bonded to two calixarene molecules, thus forming an infinite ribbon of calixarene and MeOH molecules. Unfortunately, all our efforts to crystallize **2** without solvent of crystallization resulted in crystals unsuitable for X-ray diffraction. In order to find out whether the preference for the 1,2-alternate conformation is due to packing or to intermolecular hydrogen bonding or is the intrinsic preferred conformation of the system, we determined by X-ray analysis the crystal structure of the completely OH depleted *p-tert*-butylcalix[4]arene (**5**). As shown in Figure 4, **5** also exists in the crystal in a 1,2-alternate conformation of crystallographic $C_i$ symmetry.[15] The dihedral angles between the mean plane of each of the phenyl rings and the mean plane of the methylene carbons are 29 and 84°. It is interesting to note that molecular mechanics calculations predicted incorrectly that the favored conformation of **5** should be the 1,3-alternate.[9] A similar overestimation of the relative stability of the 1,3-alternate conformation has been recently found in a molecular mechanics study of the conformational preferences of substituted calixarenes.[16] The similarity in the crystal conformations of **2** and **5** seems to indicate that the 1,2-alternate conformation represents the minimum energy conformation of the systems.

Calixarene **3** crystallizes from pyridine as a 1:2 solvate. The X-ray data indicate that **3** exists in a *cone* conformation (Figure 5), although due to orientational disorder of the calixarene molecules in the crystal the *R* factor of the refined structure is relatively high. Two oxygen atoms belonging to the phenol rings vicinal to the OH-depleted ring (O2 and O4) were refined with full occupancy, whereas the third oxygen atom was refined assuming half occupancy (O1 and O3) at the two remaining rings. Two *t*-Bu groups and one pyridine molecule showed orientational disorder. The nitrogen atom could be located for the hydrogen-bonded pyridine molecule (see below) but not for the other pyridine molecule. The dihedral angles between the planes of the phenyl rings and the mean plane defined by the four methylene carbons are 51 and 44° for the two rings with phenolic oxygens refined with full occupancy, and 72 and 51° for the remaining rings. These values are reminiscent to the corresponding angles found for the toluene solvate of **1** (57°).[5]

The inclusion pattern of the pyridine molecules is of interest. One of the two pyridines is included between the calixarene molecules (Figure 6), while the second pyridine molecule is externally (*exo*-calix) hydrogen bonded to O4, as indicated by the O4–N distance (2.69 Å). Interestingly, whereas the N-portion of the pyridine molecule is hydrogen bonded to one molecule of **3** outside its cavity, the carbon portion of the pyridine ring is included into the cavity of a neighboring molecule of **3** (an *endo*-calix complex, cf. Figure 5). The two nonvicinal phenolic oxygens (O2 and O4) are not within hydrogen bond distance ($r$ > 3.5 Å), and therefore in the pyridine complex of **3** there is no circular hydrogen bond. A summary of the X-ray diffraction data of **2**, **3**, and **5** is collected in Table I. A complete list of positional parameters and bond lengths and angles is available as supplementary material.

(14) For calculating the rate of exchange at the coalescence temperature we used the equation $k_{coalescence} = \pi(\Delta\nu^2 + 6J^2)^{1/2}/2^{1/2}$ (Kurland, R. J.; Rubin, M. B.; Wise, W. B. *J. Chem. Phys.* **1964**, *40*, 2426).

(15) An 1,2-alternate conformation has been observed previously for the $AlMe_3$ complex of the tetramethyl ether of **1** (Bott, S. W.; Coleman, A. W.; Atwood, J. L. *J. Inclusion Phenomena* **1989**, *7*, 61) and for the conformational frozen tetrathioureido derivative of **1** (Gutsche, C. D.; Rogers, J. S.; Stewart, D.; See, K.-A. *Pure Appl. Chem.* **1990**, *62*, 485).

(16) Grootenhuis, P. D. J.; Kollman, P. A.; Groenen, L. C.; Reinhoudt, D. N.; van Hummel, G. J.; Ugozzoli, F.; Andreetti, G. D. *J. Am. Chem. Soc.* **1990**, *112*, 4165.

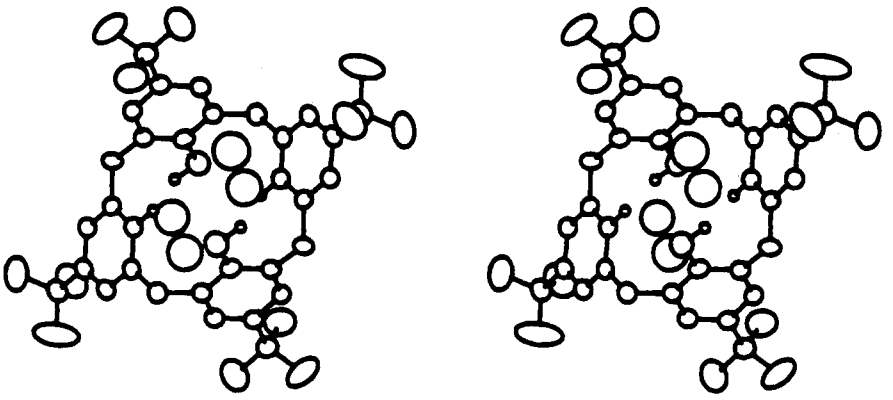


**Figure 3.** Stereoview of the crystal structure of the MeOH solvate of the dihydroxycalixarene 2.

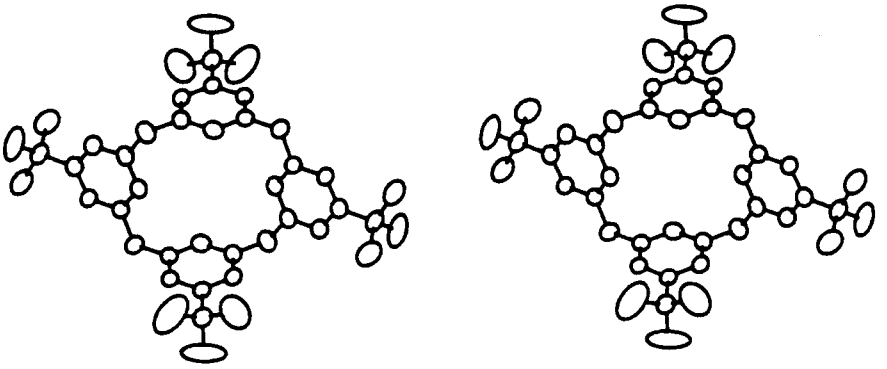


**Figure 4.** Stereoview of the crystal structure of the completely OH depleted calixarene 5.

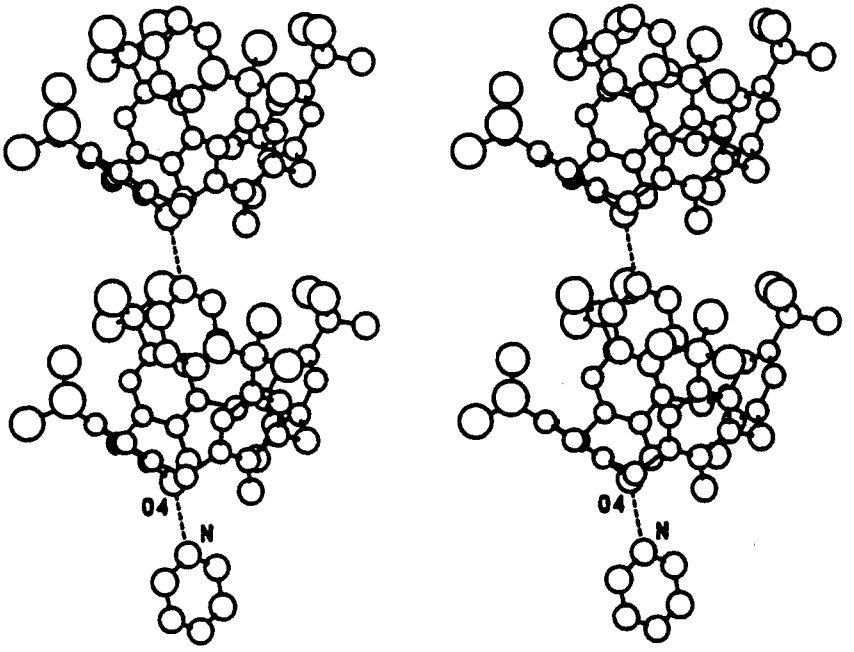



**Figure 5.** Stereoview of the crystal structure of the pyridine solvate of the trihydroxycalixarene 3. The dashed line indicates an hydrogen bond between O4 and the nitrogen atom of one of the pyridine molecules. The two atoms in the "lower rim" of the calix at rings vicinal to the hydrogen bonded ring represent half occupancies of an OH group and therefore depict a single disordered OH group (see text).

We conclude that three phenolic OH groups are sufficient to stabilize the cone conformation, and that the circular hydrogen bond present in 1 is not a prerequisite for the relative stabilization of the cone. The more extensively OH-depleted calix[4]arenes 2 and 3 prefer in the crystal a 1,2-alternate conformation.

## Experimental Section

NMR spectra were recorded on a Bruker WP 200 SY pulsed FT spectrometer. IR spectra were recorded on a Perkin Elmer 597 infrared spectrometer. Melting point were determined on a Melt-Temp II apparatus and are uncorrected. The preparation of the complete OH-depleted *p-tert*-butylcalix[4]arene (5) was described previously.[9]

**5,11,17,23-Tetra-*tert*-butyl-25,27-dihydroxy-26,28-bis((diethoxyphosphinyl)oxy)calix[4]arene (4).** Triethylamine (0.36 mL, 2.5 mmol) was added dropwise during 15 min to a stirred solution at 0 °C of 1 (0.4 g, 0.62 mmol), diethyl phosphite (0.33 mL, 2.6 mmol), and $CCl_4$ (0.8 mL, 8 mmol) in 50 mL of toluene. The mixture was left overnight at room temperature, washed successively with dilute HCl, dilute NaOH, and water, and

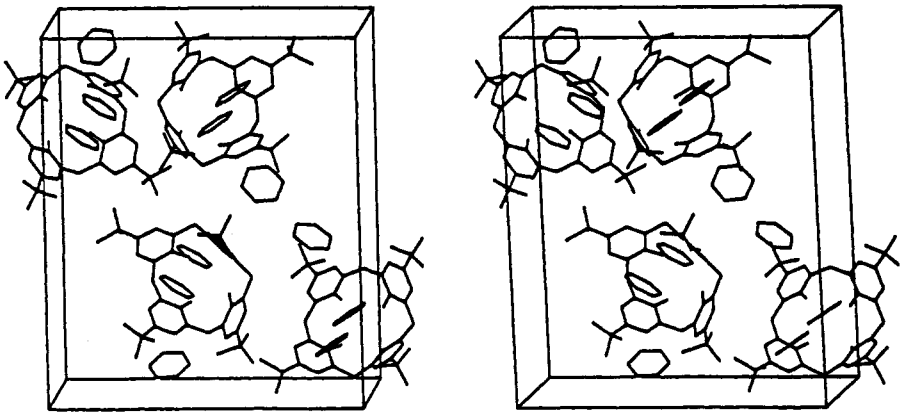


**Figure 6.** Stereoview of the packing arrangement of **3**.

**Table I. Summary of X-ray Diffraction Data**

| | 2 | 3 | 5 |
|---|---|---|---|
| formula | $C_{44}H_{56}O_2 \cdot CH_3OH$ | $C_{44}H_{56}O_3 \cdot 2C_5H_5N$ | $C_{44}H_{56}$ |
| space group | $C2/c$ | $P2_12_12_1$ | $I_2/c$ |
| $a$ (Å) | 15.071 (2) | 20.561 (2) | 28.154 (5) |
| $b$ (Å) | 16.568 (2) | 24.455 (3) | 5.936 (2) |
| $c$ (Å) | 15.813 (2) | 9.452 (1) | 22.188 (3) |
| $\beta$ | 97.88 (2) | 90.0 | 90.78 (2) |
| $V$ (Å$^3$) | 3911.2 | 4753.2 | 3707.8 |
| $Z$ | 4 | 4 | 4 |
| $\rho_{calc}$ (g cm$^{-3}$) | 1.10 | 1.11 | 1.05 |
| $\mu$(Cu K$\alpha$)(cm$^{-1}$) | 4.44 | 4.51 | 3.70 |
| no. of unique reflections | 2769 | 3253 | 2245 |
| no. of reflections with $I \geq 2\sigma(I)$ | 2425 | 2866 | 2065 |
| $R$ | 0.097 | 0.109 | 0.072 |

evaporated. The residue was dissolved in a minimum amount of hot dimethoxyethane, cooled, and filtered. Evaporation of the filtrate yielded 0.37 g (65%) of **4** as a white powder: mp 192 °C; $^1$H NMR $\delta$ 7.10 (s, 4 H, Ar-H), 6.68 (s, 4 H, Ar-H), 5.03 (OH), 4.38 (d, 4 H, $J$ = 14.1 Hz), 4.26 (m), 3.38 (d, 4 H, $J$ = 14.1 Hz), 1.31 (s, 18 H, $t$-Bu), 0.85 (s, 18 H, $t$-Bu); $^{13}$C NMR $\delta$ 150.2, 147.8, 142.5, 142.4, 135.5, 128.2, 126.0, 125.4, 64.7, 33.9, 33.8, 32.3, 31.7, 31.5, 30.8, 16.1; MS $m/z$ 921 (M, B), 164 (94). Anal. Calcd for $C_{52}H_{74}O_{10}P_2$: C, 67.81; H, 8.1; P, 6.73. Found: C, 67.96; H, 8.31; P, 6.75.

**5,11,17,23-Tetra-*tert*-butyl-25,27-dihydroxycalix[4]arene (2).** Potassium (4 g) was carefully added to 50 mL of liquid ammonia while cooling to −78 °C by a dry ice–acetone bath. A solution of **4** (0.96 g, 1.05 mmol) in 6 mL of dry ether was added dropwise to the stirred blue solution followed by 0.5 g of potassium metal. After 15 min, 6.2 g of $NH_4Cl$ was carefully added in small portions until the blue color was discharged and the ammonia solution became white. After evaporation of the ammonia, the residue was treated with 100 mL of hot ether. Filtration and evaporation of the ether gave 0.3 g (46%) of crude **2**. Further purification by column chromatography ($SiO_2$; eluent, 5% ethyl acetate, 95% petroleum ether 40–60 °C) gave 0.1 g (15%) of **2**: mp 270 °C; $^1$H NMR (200.13 MHz) $\delta$ 7.19 (s, br, 4 H), 6.97 (s, 4 H), 6.09 (s, br, 2 H), 4.11 (s, 2 H), 3.92 (s, br, 8 H), 1.31 (s, 18 H), 1.21 (s, 18 H); $^{13}$C NMR $\delta$ 151.5, 150.3, 143.1, 140.4, 127.0, 125.3, 123.9, 122.5, 37.4, 34.6, 33.8, 31.6, 31.4. Anal. Calcd for $C_{44}H_{56}O_2$: C, 85.66; H, 9.15. Found: C, 85.93; H, 9.40.

**5,11,17,23-Tetra-*tert*-butyl-25,26,27-trihydroxycalix[4]arene (3):** Potassium metal (2 g) was dissolved in 150 mL of liquid ammonia at −78 °C, the mixture was stirred for about 45 min, and an additional 0.5 g of K was introduced. After the mixture was stirred for 10 min, the acetone/dry ice was removed until vigorous reflux of the ammonia was observed. Diphosphate **4** (350 mg) was dissolved in a minimum amount of dry ether and added to the mixture. After the addition, the mixture was stirred for additional 15 min and reintroduced to the acetone/dry ice bath. After neutralization with $NH_4Cl$ (4 g) and evaporation of the ammonia, the solid residue was treated with 2 × 100 mL of hot ether. Filtration of the ether and evaporation afforded 200 mg of a 2:1 mixture (by NMR) of **2** and **3**. The two calixarenes were separated by medium-pressure chromatography (silica; eluent, 60% petroleum ether, 40% $CH_2Cl_2$): mp 260–262 °C; $^1$H NMR ($CDCl_3$, room temperature) $\delta$ 7.22 (s, 2 H), 7.16 (q, 4 H), 7.11 (d, 2 H), 7.01 (s, 1 H), 3.90 (s, 4 H), 3.80 (s, 4 H), 1.28 (s, 9 H), 1.25 (s, 18 H), 1.23 (s, 9 H); $^{13}$C NMR $\delta$ 150.74, 146.3, 143.11, 141.6, 136.86, 131.81, 130.63, 128.01, 126.67, 126.05, 125.99, 125.38, 124.22, 123.35, 37.19, 36.54, 34.46, 33.95, 31.58, 31.40, 31.31; IR (KBr) $\nu$ 3450–3270 cm$^{-1}$ (OH); MS $m/z$ 632 (M, B) 617 (M − Me, 41), 57 ($t$-Bu$^+$, 7). Anal. Calcd for $C_{44}H_{56}O_3$: C, 83.50; H, 8.92. Found: C, 83.80; H, 9.29.

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**Supplementary Material Available:** Numbering schemes (Figures 7–9) and tables of positional parameters, bond lengths, and bond angles for **2**, **3**, and **5** (21 pages). Ordering information is given on any current masthead page.