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Calix[8]arene anions: solid state structure of an inclusion compound with a tetrabutylammonium cation

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Abstract—Octakis(dimethylsiloxy)-octa-*p-tert*-butylcalix[8]arene was prepared from the parent *p-tert*-butylcalix[8]arene and 1,1,3,3-tetramethyldisilazane. Desilylation of the siloxy-calix[8]arene with tetrabutylammonium fluoride hydrate under different conditions afforded di- and tetraanionic derivatives. Determination of the solid state structure of the dianion revealed the formation of an inclusion compound with one tetrabutylammonium cation inside the macrocyclic cavity.

Interest in calixarenes and their derivatives arises from their potential applications in diverse areas such as host–guest chemistry, coordination chemistry, catalysis, biomimetic chemistry, sensors, and ion transport.[1] Anions derived from calixarenes,[2,3] which are obtained by deprotonation of the phenolic OH groups, can act as ligands toward main group and transition metals. This property has allowed the use of 'calixanions' to model oxo surfaces,[4] to selectively bind metals within a cavity,[2] and to assemble polymetallic systems.[5] A considerable number of studies have focused on the chemistry of anions derived from *p-tert*-butylcalix[*n*]arenes ($n = 4, 6$).[2] In contrast, the number of reports on the properties of the anions derived from *p-tert*-butylcalix[8]arene remains scarce.[3,6] Moreover, the structural information available on the eight-member macrocycles is dominated by complexes in which the calix[8]arene framework becomes relatively rigid. This is either due to the presence of intramolecular covalent bridges,[7] or to the chelating effect of the multiple oxygen atom donors in coordination compounds, which create oxygen–metal–oxygen bridges.[5]

In addition to the complexation chemistry of the calixanions, investigation of their host–guest properties may yield interesting results since the formation of inclusion compounds by neutral calixarenes can be reinforced by electrostatic interactions. Recently, the interaction of calixarenes with ammonium ions has been investigated due to their suitability for supramolecular systems.[8] In the cases reported to date, the presence of hydrogen bonds between the ammonium cations and small calix[*n*]arenes ($n = 4$–6) appears to be crucial for the formation of inclusion compounds. Despite these advances, the host–guest properties of the large calix[8]arenes remain largely unexplored. Herein, we wish to report the synthesis and characterization of di- and tetraanionic derivatives of *p-tert*-butylcalix[8]arene **1**, which feature ammonium counterions. In the case of the dianion, the single crystal X-ray crystal structure demonstrates that tetrabutyl ammonium cations within the calix[8]arene cavity can stabilize a 1,2,3,4-alternate conformation through non-covalent and electrostatic interactions, without the involvement of H-bonds.

The general procedure to obtain calixarene anions involves the use of alkaline or alkaline-earth compounds, such as the carbonates, as bases to deprotonate the phenolic positions of the calixarenes. The synthetic methodology developed by our group involves the initial silylation of all the phenolic positions of **1** upon reaction with 1,1,3,3-tetramethyldisilazane, with concomitant loss of NH_3 (Scheme 1). The product obtained, 49,50,51,52,53,54,55,56-octakis(dimethylsiloxy)-5,11,17,23,29,35,41,47- octa-*p-tert*-butylcalix[8]arene **2**, was authenticated by ^{1}H, ^{13}C, and ^{29}Si NMR, as well as negative

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Keywords: Calix[8]arene; Calixarene anions; Siloxides; Inclusion compounds; X-ray structures.

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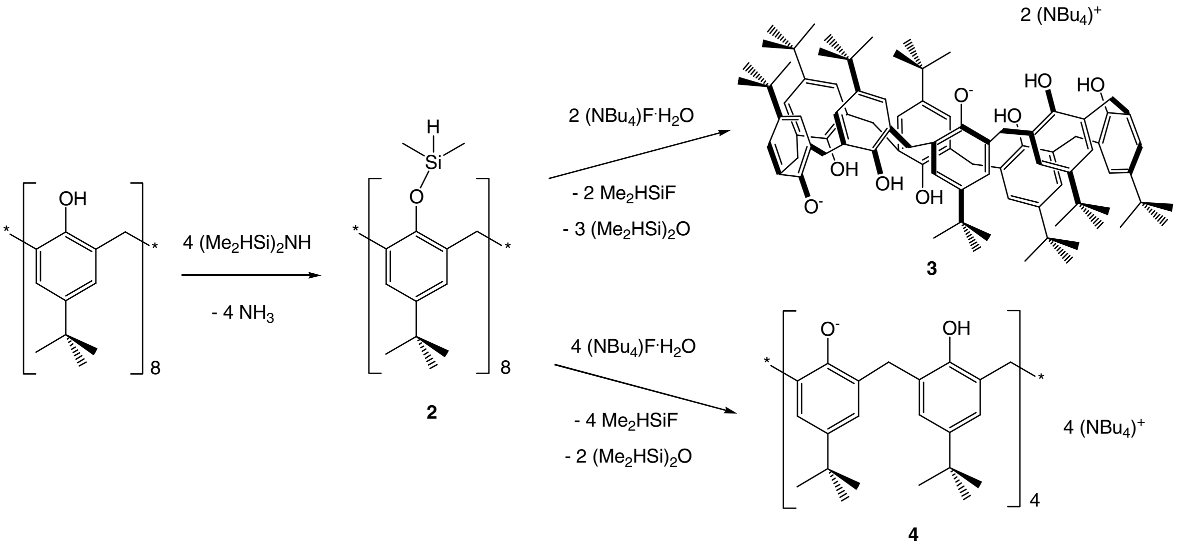

Scheme 1. Synthesis of compounds **2**–**4** from the parent calix[8]arene.

ion FAB mass spectrometry, and combustion analysis.[9] Compound **2** has siloxy functional groups that are amenable for deprotection with fluoride reagents, allowing the introduction of organic counterions with the appropriate dimensions to fit within the calix[8]arene cavity. Thus, treatment of **2** with 2 equiv of tetrabutyl ammonium fluoride monohydrate in toluene resulted in the loss of 2 equiv of Me_2HSiF as evidenced by the vigorous bubbling observed, and 3 equiv of $Me_2HSiOSiHMe_2$. The identity of the silicon-containing byproducts was established by monitoring the reaction by ^1H NMR spectroscopy in $CDCl_3$.

Colorless microcrystals of dianionic calix[8]arene **3** were obtained by slow evaporation of toluene from the aforementioned reaction mixture. Analysis of the ^1H NMR spectrum of **3** corresponds to a 2:1 ratio of $(Bu_4N)^+$ to calix[8]arene groups, based on the integration of the terminal $–CH_3$ resonance of the tetrabutyl ammonium cations compared to that of the calixarene *p*-*tert*-butyl groups. The NMR spectroscopic evidence characterizes **3** as a calix[8]arene dianion with two equivalent ammonium ions in solution at room temperature, as evidenced by the presence of one set of resonances for each *n*-butyl group.

The crystal structure[10] of **3** (Fig. 1) reveals the presence of two tetrabutyl ammonium ions in the asymmetric unit, one of them hosted inside the calix[8]arene dianion cavity. Analysis of the structure with the PLATON[11] software package revealed that there are no significant van der Waals contacts between the endocyclic ammonium ion and the calixarene framework. Thus, the cation is presumably acting as a guest mainly due to electrostatic forces. The macrocycle conformation can be described as flattened 1,2,3,4-alternate, similar to the 'pleated loop' conformation observed for the parent *p*-*tert*-butylcalix[8]arene.[12] This conformation of two independent four-member subunits is stabilized by the two semicircular arrays of intramolecular hydrogen bonds, which can be appreciated from a side view of the dianion (Fig. 2). The hydrogen atoms associated to the phenol oxygen atoms were located in the difference Fourier map, and the H···O distances were determined to be

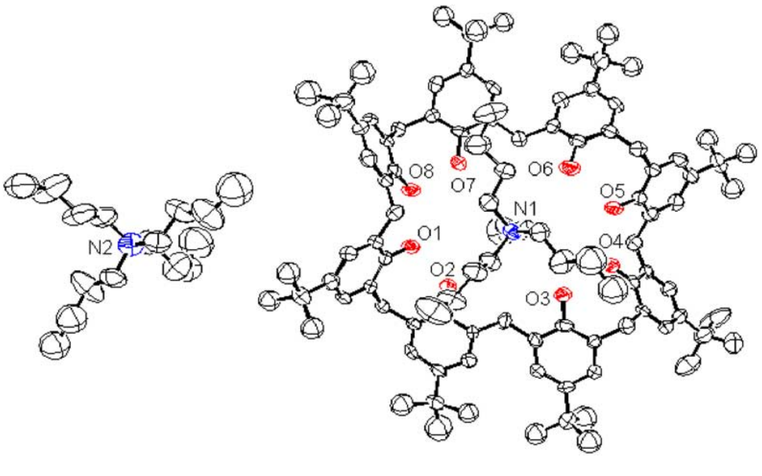

Figure 1. ORTEP diagram of **3**. Hydrogen atoms, two molecules of DMF, and one molecule of acetone were removed for clarity.

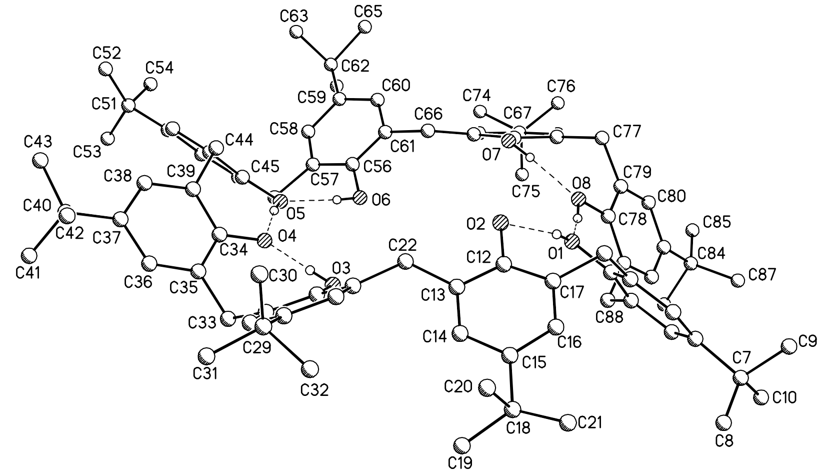

Figure 2. Side view of the calix[8]arene dianion of **3** with hydrogen-bond networks.

in the range 1.66–1.91 Å. One of the hydrogen-bonded networks is defined by the phenolic units that contain the oxygen atoms O1, O2, O7, and O8, with O2 formally bearing the negative charge. The second network is formed by the oxygen atoms O3–O6, with the formal negative charge residing on O4. Each network consists of three strong H-bonds, based on the O–H···O angles, which are close to linearity (average 170°) and the short H···O distances (average 1.78 Å).[13]

The observed structure differs from that of the closely related dipotassium complex of *p-tert*-butylcalix[8]-arene-dianion, which has a 'pinched' conformation in the solid state.[3b] This latter geometric arrangement is probably adopted due to the donor role of the OH groups, which bridge the potassium cations at the 'pinch'. In contrast with the 1,3 relative positions of the formally anionic O atoms of **3**, in the dipotassium analogue they occupy opposite ends of the macrocycle in 1,5 positions. Moreover, the intra-calixarene H-bonding network of the dipotassium complex is disrupted by the additional hydrogen bond of one ethanol ligand to the anionic oxygen atom.

When the desilylation of **2** was carried out under an inert atmosphere with 4 equiv of $(Bu_4N)F\cdot H_2O$ the tetra-anionic calix[8]arene derivative **4** was obtained, along with 4 equivalents of Me_2HSiF, and 2 equiv of $Me_2HSiOSiHMe_2$. The identity of **4** was established by ^1H and ^{13}C NMR, as well as negative-ion FAB mass spectrometry. Despite the anaerobic conditions employed in this preparation, all Si-O(phenol) bonds are cleaved during the course of the reaction due to the presence of one water molecule per mole of fluoride reagent. We have not been able to obtain X-ray quality crystals of **4** thus far, but the spectroscopic evidence, and combustion analysis support the proposed structure. This work introduces a novel method for the preparation of calix-anions with organic counterions from O-silylated derivatives. The deprotection of the silyl groups of **2** with anhydrous $(Bu_4N)F$, and the replacement of $(Bu_4N)^+$ with different organic cations are currently under investigation.

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References and notes

1. (a) Gutsche, C. D. *Calixarenes*; Royal Society of Chemistry: London, 1989; (b) Gutsche, C. D. *Calixarenes Revisited*; Royal Society of Chemistry: Cambridge, 1998; (c) Böhmer, V. *Angew. Chem., Int. Ed. Engl.* **1995**, *34*, 713; (d) *Calixarenes 2001*; Asfari, Z., Böhmer, V., Harrowfield, J., Vicens, J., Eds.; Kluwer: Dordrecht, 2001.
2. (a) Thuéry, P.; Asfari, Z.; Vicens, J.; Lamare, V.; Dozol, J.-F. *Polyhedron* **2002**, *21*, 2497; (b) Gueneau, E. D.; Fromm, K. M.; Goesmann, H. *Chem. Eur. J.* **2003**, *9*, 509; (c) Hanna, T. A.; Liu, L.; Angeles-Bonza, A. M.; Kou, X.; Gutsche, C. D.; Ejsmont, K.; Watson, W. H.; Zakharov, L. N.; Incarvito, C. D.; Rheingold, A. L. *J. Am. Chem. Soc.* **2003**, *125*, 6228.
3. (a) Harrowfield, J. M.; Ogden, M. I.; Richmond, W. R.; White, A. H. *J. Chem. Soc., Dalton Trans.* **1991**, 2153; (b) Clague, N. P.; Clegg, W.; Coles, S. J.; Crane, J. D.; Moreton, D. J.; Sinn, E.; Teat, S. J.; Young, N. A. *Chem. Commun.* **1999**, 379; (c) Clague, N. P.; Crane, J. D.; Moreton, D. J.; Sinn, E.; Teat, S. J.; Young, N. A. *J. Chem. Soc., Dalton Trans.* **1999**, 3535.
4. Floriani, C.; Floriani-Moro, R. *Adv. Organomet. Chem.* **2001**, *47*, 167.
5. (a) Wieser, C.; Dieleman, C. B.; Matt, D. *Coord. Chem. Rev.* **1997**, *165*, 93; (b) Redshaw, C. *Coord. Chem. Rev.* **2003**, *244*, 45.
6. (a) Geraci, C.; Chessari, G.; Piattelli, M.; Neri, P. *Chem. Commun.* **1997**, 921; (b) Consoli, G. M. L.; Cunsolo, F.; Geraci, C.; Neri, P. *Org. Lett.* **2001**, *3*, 1605.
7. (a) Geraci, C.; Bottino, A.; Piattelli, M.; Gavuzzo, E.; Neri, P. *J. Chem. Soc., Perkin Trans. 2* **2000**, 185; (b) Consoli, G. M. L.; Cunsolo, F.; Geraci, C.; Gavuzzo, E.; Neri, P. *Tetrahedron Lett.* **2002**, *43*, 1209; (c) Gregoli, L.; Russo, L.; Stefio, I.; Gaeta, C.; Arnaud-Neu, F.; Hubscher-Bruder, V.; Khazaeli-Parsa, P.; Geraci, C.; Neri, P. *Tetrahedron Lett.* **2004**, *45*, 6277.

8. (a) Garozzo, D.; Gattuso, G.; Kohnke, F. H.; Notti, A.; Pappalardo, S.; Parisi, M. F.; Pisagatti, I.; White, A. J. P.; Williams, D. J. *Org. Lett.* **2003**, *5*, 4025; (b) Darbost, U.; Rager, M.-N.; Petit, S.; Jabin, I.; Reinaud, O. *J. Am. Chem. Soc.* **2005**, *127*, 8517; (c) Garozzo, D.; Gattuso, G.; Notti, A.; Pappalardo, A.; Pappalardo, S.; Parisi, M. F.; Perez, M.; Pisagatti, I. *Angew. Chem., Int. Ed.* **2005**, *44*, 4892.
9. Experimental methods. The parent calix[8]arene **1** was prepared according to the literature procedure.[14] 1,1,3,3-Tetramethyldisilazane and [$(Bu_4N)F{\cdot}H_2O$] were purchased from Aldrich Chemical Co., and were used without further purification. Toluene was dried with Na/benzophenone prior to distillation under an atmosphere of N_2. All other solvents were used as received from commercial suppliers. ^{1}H and ^{13}C NMR spectra were recorded at 20 °C on a Jeol Eclipse spectrometer operating at 300 and 75 MHz, respectively. Fast atom bombardment (FAB) mass spectra were obtained on a JEOL JMS-SX-102A mass spectrometer operated at an accelerating voltage of 10 kV; samples were dissolved in a nitrobenzyl alcohol matrix by using xenon atoms at 6 keV. Elemental analyses were performed by Galbraith Laboratories (Knoxville, TN).

   Preparation of **2**: Compound **1** (0.50 g, 0.39 mmol) was suspended in anhydrous toluene (10 mL) in a Schlenk flask under an atmosphere of N_2. 1,1,3,3-Tetramethyldisilazane (0.18 mL, 0.84 mmol) was added, and the mixture was stirred for 15 h. The mixture was filtered and concentrated to dryness under reduced pressure. The white solid obtained was dissolved in hexanes, and colorless crystals of **2** were obtained by slow evaporation. Yield: 0.51 g (73%); mp 245–247 °C; ^{1}H NMR ($CDCl_3$, 300 MHz): 6.90 (s, 16H, Ar), 4.70 (s, 8H, Si*H*), 3.88 (br d, 16H, ArC*H*$_2$Ar), 1.08 (s, 72H, Bu^t), 0.01 (s, 48H, Si(C*H*$_3$)$_2$); ^{13}C NMR (75.5 MHz) 149.34, 143.44, 130.02, 125.69 (Ar), 34.08 (Ar*C*H$_2$Ar), 31.50 (*C*H$_3$), 31.18 (*C*(CH$_3$)$_3$), −0.61 (Si(*C*H$_3$)$_2$); ^{29}Si NMR (59.7 MHz) 5.10 ppm; MS (FAB): 1704 ([$M-SiH(CH_3)_2]^+$); $C_{104}H_{160}O_8Si_8$ (1763.09): calcd C, 70.85; H, 9.15. Found: C, 71.24; H, 8.88.

   Preparation of **3**: Compound **2** (0.24 g, 0.14 mmol) was dissolved in toluene (15 mL) in an Erlenmeyer flask. Addition of [$(Bu_4N)F{\cdot}H_2O$] (0.08 g, 0.28 mmol) resulted in gas evolution (Me_2SiHF). The mixture was stirred for 2 h at room temperature, after which a white solid started to deposit. The product was isolated by filtration, and purified by crystallization from a 1:1 methanol/chloroform mixture as **3**·($CHCl_3$, $3CH_3OH$). Yield: 0.09 g (40%); mp 267–268 °C (dec); ^{1}H NMR ($CDCl_3$, 300 MHz): 7.06 (s, 16H, Ar), 3.89 (br s, 16H, ArC*H*$_2$Ar), 3.00 (m, 16H, N(C*H*$_2$)), 1.49 (m, 16H, C*H*$_2$), 1.28 (m, 16H, C*H*$_2$), 1.25 (s, 72H, C(C*H*$_3$)$_3$), 0.84 (t, $J = 7$ Hz, 24H, C*H*$_3$); ^{13}C NMR (75.5 MHz): 128.51, 125.26, 118.18, 110.36 (Ar), 59.06 (*C*–N), 33.95, 31.69, 24.14 (*C*H$_2$), 19.77, 13.73 (*C*H$_3$); MS (FAB): 1779 [$(M-H)^-$]; $C_{120}H_{160}O_8Si_8$ (2006.35): calcd C, 74.23; H, 10.30; N, 1.40. Found: C, 74.01; H, 10.84; N, 1.75. Preparation of **4**: Compound **2** (0.24 g, 0.14 mmol) was dissolved in anhydrous toluene (15 mL) in a Schlenk flask under an inert atmosphere. Addition of solid [$(Bu_4N)F{\cdot}H_2O$] (0.15 g, 0.54 mmol) resulted in gas evolution (Me_2SiHF), after which the reaction mixture was further stirred for 2 h. The mixture was cannula-filtered into a Schlenk tube under an atmosphere of N_2, and volatile materials were evaporated under reduced pressure. The white solid obtained was washed with 5 mL of hexanes, and dissolved in dichloromethane to obtain colorless crystals of **4**·($3CH_2Cl_2$, H_2O) upon cooling to −20 °C. Yield: 0.20 g (67%); mp 280–282 °C; ^{1}H NMR ($CDCl_3$, 300 MHz): 7.28 (s, 16H, Ar), 3.92 (br s, 16H, ArC*H*$_2$Ar), 3.06 (br m, 32H, N(C*H*$_2$)), 1.50 (m, 32H, C*H*$_2$), 1.31 (m, 32H, C*H*$_2$), 1.27 (s, 72H, C(C*H*$_3$)$_3$), 0.89 (t, $J = 7$ Hz, 48H, C*H*$_3$); ^{13}C NMR (75.5 MHz): 153.45, 139.30, 128.22, 125.00 (Ar), 58.84 (*C*–N), 33.85, 31.85, 24.05 (*C*H$_2$), 19.73, 13.73 (*C*H$_3$); MS (FAB): 2260 [$(M-H)^-$]; $C_{154}H_{258}Cl_4N_4O_9$ (2451.57): calcd C, 75.45; H, 10.61; N, 2.29. Found: C, 75.66; H, 10.71; N, 1.97.
10. Crystal data for **3**·($CH_3C(O)CH_3$, 2DMF): $C_{129}H_{200}N_4O_{11}$, $M = 1982.93$, monoclinic, space group $P2_1/c$, $a = 29.861(3)$, $b = 23.195(3)$, $c = 18.947(2)$ Å, $\beta = 106.170(2)°$, $U = 12604(2)$ Å^3, $T = 291(2)$ K, $Z = 4$, $D_c = 1.045$ g cm^{-3}, μ(Mo Kα) $= 0.065$ mm^{-1}, $F(000) = 4360$. Prismatic crystals were obtained by slow evaporation of a 10:1 DMF/acetone solution. A crystal (0.26 × 0.22 × 0.18 mm) was mounted in a glass capillary and used for data collection on a Bruker SMART diffractometer equipped with an Apex CCD area detector. Frames were collected by omega scans, and integrated with the Bruker SAINT software package using the appropriate unit cell. The structure was solved using the SHELXS-97 program,[15] and refined by full-matrix least-squares on F^2 with the SHELXL-97 program.[16] The final refinement was based on 22,193 unique reflections and 1277 parameters: $R = 0.084$, $R_w = 0.168$, $\Delta\rho_{max} = 0.575$ and $\Delta\rho_{min} = -0.228$ e Å^{-3}. Crystallographic data (excluding structure factors) for the structure in this paper have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication number CCDC 277640. Copies of the data can be obtained, free of charge, on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK [fax: +44(0)-1223-336033 or e-mail: deposit@ccdc.cam.ac.uk].
11. Spek, A. L. *J. Appl. Cryst.* **2003**, *36*, 7.
12. Gutsche, C. D.; Gutsche, A. E.; Karaulov, A. I. *J. Inclusion Phenom.* **1985**, *3*, 447.
13. Jeffrey, G. A. *An Introduction to Hydrogen Bonding*; Oxford University Press: New York, 1997.
14. Gutsche, C. D.; Dhawan, B.; No, K. H.; Muthukrishnan, R. *J. Am. Chem. Soc.* **1981**, *103*, 3782.
15. Sheldrick, G. M. SHELXS-97. Crystal Structure Solution, Version 97-1, Institut Anorg. Chemie, University of Gottingen, 1990.
16. Sheldrick, G. M. SHELXL-97. Crystal Structure Refinement, Version 97-1, Institut Anorg. Chemie, University of Gottingen, 1997.