Calix[4]arene Salenes: A Bifunctional Receptor for NaH_2PO_4

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Introduction

Calix[4]arenes are important building blocks in supramolecular chemistry.[1,2] They can be selectively functionalized both at the phenolic OH groups (lower rim) and at the para positions of the phenol rings (upper rim).[3] The calixarene platform provides unique possibilities to organize several binding sites in an array complementary to a potential guest. Selective calixarene-based receptors for cations[4] and neutral molecules[5] have been synthesized in the past decade. Very recently the first representatives of calixarene-containing anion receptors have been reported.[6]

Previously we reported that neutral metalloclefts and metallomacrocycles containing both an immobilized Lewis acidic UO_2-center and amido C(O)NH units as additional binding sites are excellent receptors for anions with a high selectivity for dihydrogen phosphate $H_2PO_4^-$.[7] In the present paper we report, in addition to the synthesis of a new representative of a UO_2-containing anion receptor based on a calix[4]arene, the first example of a neutral calix[4]arene-based *bifunctional* receptor[8] which contains both anionic and cationic binding sites and is able to complex simultaneously anionic and cationic species.

Results and Discussion

The synthesis of receptors **8a,b** is depicted in Scheme 1. Calix[4]arene diester **1** was prepared by alkylation of unsubstituted calix[4]arene[9] with ethyl bromoacetate in the presence of 1 equiv of potassium carbonate as a base in refluxing acetonitrile in 88% yield. Nitration of **1** with 65% HNO_3 in a mixture of acetic acid and CH_2Cl_2 gave the dinitrocalix[4]arene **2** in 51% yield with the expected[10] selectivity on the more reactive phenol unit of **1**. Alkylation of **2** with ethyl bromoacetate and sodium carbonate as a base in refluxing acetonitrile afforded tetraester **3** in 70% yield. The ^1H NMR spectrum of **3** shows only two doublets (4.93 and 3.35 ppm, J = 13.9 Hz) for the methylene bridge protons which proves the "cone" conformation of the calix[4]arene skeleton. Subsequent reduction of **3** with $SnCl_2 \cdot 2H_2O$ in refluxing ethanol gave the corresponding diaminocalix[4]arene **4b** in 55% yield.

Reaction of 1,3-diaminocalix[4]arenes **4a**,[11]**b** with chloroacetyl chloride in the presence of Et_3N in CH_2Cl_2 gave the corresponding 1,3-bis(chloroacetamido)calix[4]arenes **5a,b** in 69 and 64% yields, respectively. Bisaldehydes **6a,b** were obtained by alkylation of 2-(2-allyloxy)-3-hydroxybenzaldehyde[12] with **5a,b** in the presence of potassium carbonate in 59 and 64% yields, respectively. Subsequent palladium-catalyzed deallylation[13] of calixarenes **6a,b** afforded bisaldehydes **7a,b** in quantitative yield which were used without purification for the cyclization step.

Reaction of bisaldehydes **7a,b** with *cis*-1,2-diaminocyclohexane[14] and $UO_2(OAc)_2 \cdot 2H_2O$ in refluxing ethanol under high dilution conditions gave the receptors **8a,b** which were isolated in 9 and 15% yields, respectively, after column chromatography. The moderate yields of compounds **8a,b** compared with known UO_2-containing metallomacrocycles[12,15] may be explained by the lack of a suitable template in the cyclization step. The absorptions in the ^1H NMR spectra at 9.34 and 9.48 ppm and in the IR spectra at 1615 and 1617 cm^{-1} for compounds **8a** and **8b**, respectively, proved imino bond formation. The presence of the UO_2 moiety is in agreement with the uranium–oxygen vibrations in the IR spectra at 895–905 cm^{-1}. Because of the "cone" conformation of the calix[4]arene unit in the ^1H NMR spectra there are only two doublets (4.30 and 3.12 ppm for **8a** and 4.80 and 3.19 ppm for **8b**) for the methylene bridge protons.

Compounds **8a,b** both contain the combination of a UO_2–Lewis acidic center and C(O)NH groups which is known to act as an anionic binding site.[7] In addition,

(1) Gutsche, C. D. *Calixarenes, Monographs in Supramolecular Chemistry*; Stoddart, J. F., Ed.; The Royal Society of Chemistry: London, 1989; Vol. 1.

(2) Vicens, J.; Böhmer, V. *Calixarenes: A Versatile Class of Macrocyclic Compounds*; Topics in Inclusion Science; Kluwer Academic Press: Dordrecht, 1991; Vol. 3.

(3) (a) van Loon, J.-D.; Verboom, W.; Reinhoudt, D. N. *Org. Prep. Proc. Int.* **1992**, *24*, 437. (b) van Dienst, E.; Iwema Bakker, W. I.; Engbersen, J. F. J.; Verboom, W.; Reinhoudt, D. N. *Pure Appl. Chem.* **1993**, *65*, 387.

(4) For recent examples on cation recognition by calixarene based receptors see: (a) Shinkai, S.; Fujimoto, K.; Otsuka, T.; Herman, H. L. *J. Org. Chem.* **1992**, *57*, 1516. (b) Arnaud-Neu, F.; Barrett, G.; Harris, S. J.; Owens, M.; McKervey, M. A.; Schwing-Weill, M.-J.; Schwinte, P. *Inorg. Chem.* **1993**, *32*, 2644. (c) Brzozka, Z.; Lammerink, B.; Reinhoudt, D. N.; Ghidini, E.; Ungaro, R. *J. Chem. Soc., Perkin Trans. 2* **1993**, 1037. (d) Beer, P. D.; Martin, J. P.; Drew, M. G. B. *Tetrahedron* **1992**, *48*, 9917. (e) Cobben, P. L. H. M.; Egberink, R. J. M.; Bomer, J. G.; Bergveld, P.; Verboom, W.; Reinhoudt, D. N. *J. Am. Chem. Soc.* **1992**, *114*, 10573.

(5) For recent examples of recognition of neutral molecules by calixarene-based hosts see: (a) Gutsche, C. D.; See, K. A. *J. Org. Chem.* **1992**, *57*, 4527. (b) van Loon, J.-D.; Janssen, R. G.; Verboom, W.; Reinhoudt, D. N. *Tetrahedron Lett.* **1992**, *33*, 5125. (c) Murakami, H.; Shinkai, S. *J. Chem. Soc., Chem. Commun.* **1993**, 1533.

(6) (a) Beer, P. D.; Dickson, C. A. P.; Fletcher, N.; Goulden, A. J.; Grieve, A.; Hodacova, J.; Wear, T. *J. Chem. Soc., Chem. Commun.* **1993**, 828. (b) Morzherin, Y.; Rudkevich, D. M.; Verboom, W.; Reinhoudt, D. N. *J. Org. Chem.* **1993**, *58*, 7602. (c) Beer, P. D.; Chen, Z.; Goulden, A. J.; Graydon, A.; Stokes, S. E.; Wear, T. *J. Chem. Soc., Chem. Commun.* **1993**, 1834.

(7) (a) Rudkevich, D. M.; Stauthamer, W. P. R. V.; Verboom, W.; Engbersen, J. F. J.; Harkema, S.; Reinhoudt, D. N. *J. Am. Chem. Soc.* **1992**, *114*, 9671. (b) Rudkevich, D. M.; Verboom, W.; Brzozka, Z.; Palys, M. J.; Stauthamer, W. P. R. V.; van Hummel, G. J.; Franken, S. M.; Harkema, S.; Engbersen, J. F. J.; Reinhoudt, D. N. *J. Am. Chem. Soc.*, in press.

(8) Only a few examples of macrocyclic bifunctional receptors are known: (a) Schmidtchen, F. P. *J. Org. Chem.* **1986**, *51*, 5161. (b) Reetz, M. T.; Niemeyer, C. M.; Harms, K. *Angew. Chem., Int. Ed. Engl.* **1991**, *30*, 1472. (c) Rudkevich, D. M.; Brzozka, Z.; Palys, M.; Visser, H. C.; Verboom, W.; Reinhoudt, D. N. *Angew. Chem., Int. Ed. Engl.* **1994**, *33*, 467.

(9) Gutsche, C. D.; Lin, L.-G. *Tetrahedron* **1986**, *42*, 1633.

(10) van Loon, J.-D.; Arduini, A.; Coppi, L.; Verboom, W.; Pochini, A.; Ungaro, R.; Harkema, S.; Reinhoudt, D. N. *J. Org. Chem.* **1990**, *55*, 5639.

(11) Timmerman, P. Thesis, University of Twente, 1994.

(12) van Staveren, C. J.; van Eerden, J.; van Veggel, F. C. J. M.; Harkema, S.; Reinhoudt, D. N. *J. Am. Chem. Soc.* **1988**, *110*, 4994.

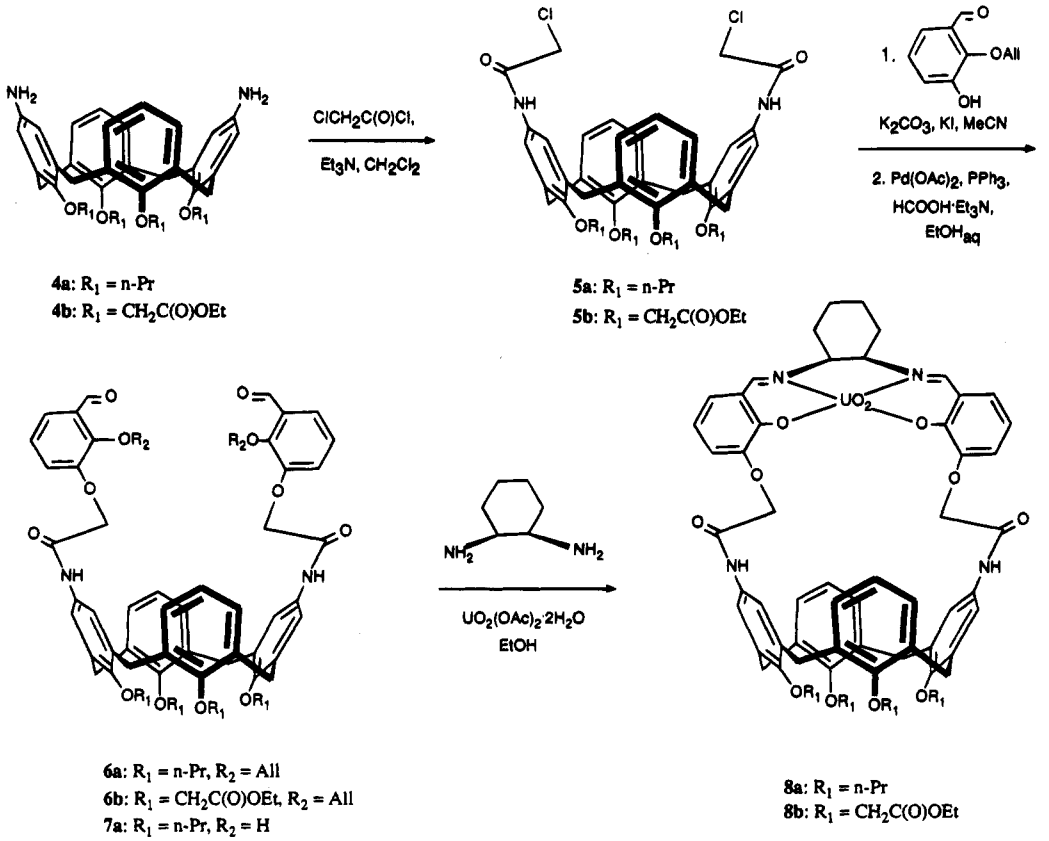
(13) Yamada, T.; Goto, K.; Mitsuda, Y.; Tsuji, J. *Tetrahedron Lett.* **1987**, *28*, 4557.

(14) We have chosen the *cis* isomer because in the chair conformer of the cyclohexyl moiety one nitrogen atom is located in the equatorial and another in the axial position. According to a CPK model, the nitrogens in these positions give after cyclization the desired cavity for immobilization of the uranyl cation.

(15) van Doorn, A. R.; Schaafstra, R.; Bos, M.; Harkema, S.; van Eerden, J.; Verboom, W.; Reinhoudt, D. N. *J. Org. Chem.* **1991**, *56*, 6083.

0022-3263/94/1959-3683$04.50/0

Scheme 1



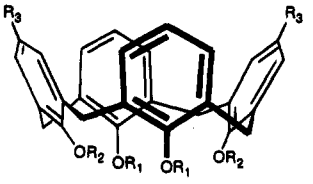
4a: R_1 = n-Pr
4b: R_1 = $CH_2C(O)OEt$

5a: R_1 = n-Pr
5b: R_1 = $CH_2C(O)OEt$

6a: R_1 = n-Pr, R_2 = All
6b: R_1 = $CH_2C(O)OEt$, R_2 = All
7a: R_1 = n-Pr, R_2 = H
7b: R_1 = $CH_2C(O)OEt$, R_2 = H

8a: R_1 = n-Pr
8b: R_1 = $CH_2C(O)OEt$

Chart 1



1: R_1 = $CH_2C(O)OEt$, R_2 = R_3 = H

2: R_1 = $CH_2C(O)OEt$, R_2 = H, R_3 = NO_2

3: R_1 = R_2 = $CH_2C(O)OEt$, R_3 = NO_2

calixarene **8b** contains also four preorganized ester fragments which are known to complex alkali metal cations with a high selectivity for Na^+.[16] A study of the binding ability of receptors **8a,b** shows that they both *selectively* bind dihydrogen phosphate $H_2PO_4^-$.[17] From ^1H NMR dilution experiments with $Bu_4N^+H_2PO_4^-$ in DMSO-d_6 association constants K_{ass} of $3.5 \times 10^2\ M^{-1}$ and $3.9 \times 10^2\ M^{-1}$ were calculated for **8a** and **8b**, respectively. The contribution of the C(O)NH–$H_2PO_4^-$ hydrogen bond interaction to the overall anion complexation can be clearly seen even in polar DMSO-d_6 from a significant downfield shift of the C(O)NH protons of ca. 0.4 ppm upon complexation. Only slight shifts were observed upon dilution experiments with tetrabutylammonium salts of Cl^-, HSO_4^-, and ClO_4^- anions which indicates their weak binding (K_{ass} < 10 M^{-1}).

In the negative FAB mass spectra of the 1:1 complexes of **8a** and **8b** with $Bu_4N^+H_2PO_4^-$, prepared by mixing of host and guest in MeCN, intense peaks corresponding to [**8a** + $H_2PO_4^-$]$^-$ and [**8b** + $H_2PO_4^-$]$^-$, respectively, were observed. Moreover, in the positive FAB mass spectrum of the 1:1 complex of **8b** and NaH_2PO_4, prepared by mixing of host and guest in MeCN–H_2O, 10:1, an intense peak corresponding to [**8b** + Na^+]$^+$ was observed, while the corresponding negative FAB mass spectrum of the same sample yielded an intense peak for [**8b** + $H_2PO_4^-$]$^-$, which proves the complexation of both cation and anion in one bifunctional receptor molecule.

Currently we are applying calix[4]arene-based bifunctional receptors for selective separation of alkali metal phosphates by transport through supported liquid membranes.[18]

Experimental Section

Melting points are uncorrected. ^1H NMR and ^{13}C NMR spectra were recorded in $CDCl_3$ with Me_4Si as internal standard unless stated otherwise. Fast atom bombardment (FAB) mass spectra were obtained with *m*-nitrobenzyl alcohol as a matrix. All solvents were purified by standard procedures. Petroleum ether refers to the fraction with bp 60–80 °C. All other chemicals were analytically pure and were used without further purification. Unsubstituted calix[4]arene[9] and compound **4a**[11] were prepared according to literature procedures. All reactions were carried out under an argon atmosphere.

In the workup procedures the (combined) organic layers were washed with water (2×) and dried with $MgSO_4$, whereupon the solvent was removed under reduced pressure. The presence of

(16) Arnaud-Neu, F.; Collins, E. M.; Deasy, M.; Ferguson, G.; Harris, S. J.; Kaitner, B.; Lough, A. J.; McKervey, M. A.; Marques, E.; Ruhl, B. L.; Schwing-Weill, M. J.; Seward, E. *J. Am. Chem. Soc.* **1989**, *111*, 8681.

(17) Only weak binding was obtained for the divalent HPO_4^{2-} anion.

(18) (a) Nijenhuis, W. F.; Buitenhuis, E. G.; de Jong, F.; Sudhölter, E. J. R.; Reinhoudt, D. N. *J. Am. Chem. Soc.* **1991**, *113*, 7963. (b) Nijenhuis, W. F.; van Doorn, A. R.; Reichwein, A. M.; de Jong, F.; Reinhoudt, D. N. *J. Am. Chem. Soc.* **1991**, *113*, 3607.

solvent in the analytical samples was confirmed by ^1H NMR spectroscopy.

25,27-Bis[(ethoxycarbonyl)methoxy]-26,28-dihydroxycalix[4]arene (1). A mixture of calix[4]arene[9] (4.02 g, 9.5 mmol), K_2CO_3 (1.44 g, 10.4 mmol), and bromoethyl acetate (2.1 mL, 19 mmol) in acetonitrile (150 mL) was refluxed for 18 h. After filtration the solvent was removed, and the residue was dissolved in CH_2Cl_2 (100 mL) and washed with water (2 × 100 mL). After evaporation of CH_2Cl_2 the crude product was recrystallized from MeOH to give pure **2** as a colorless solid: yield 88%; mp 166–168 °C (methanol); ^1H NMR δ 7.61 (s, 2 H), 7.13, 7.01 (d, 8 H, J = 8.0 Hz), 6.82, 6.78 (t, 4 H, J = 8.0 Hz), 4.81 (s, 4 H), 4.57, 3.41 (d, 8 H, J = 13.6 Hz), 4.43 (q, 4 H, J = 7.2 Hz), 1.32 (t, 6 H, J = 7.2 Hz); ^{13}C NMR δ 168.9, 153.0, 152.4 (s), 133.2, 129.2, 128.5, 128.2 (d), 125.6, 119.1 (s), 72.5, 61.4, 31.5 (t), 14.2 (q); MS-FAB m/z 597.7 [(M + H)$^+$, calcd 597.7]. Anal. Calcd for $C_{36}H_{36}O_8$: C, 72.47; H, 6.08. Found: C, 72.35; H, 6.00.

25,27-Bis[(ethoxycarbonyl)methoxy]-26,28-dihydroxy-5,17-dinitrocalix[4]arene (2). To a solution of diester **1** (3.93 g, 6.6 mmol) and acetic acid (13.6 mL, 235 mmol) in CH_2Cl_2 (100 mL) was added 65% HNO_3 (23.3 mL, 335 mmol) at 0 °C. The reaction mixture was stirred at this temperature for 15 min, whereupon water (100 mL) was added. The organic layer was separated, washed with water (3 × 100 mL), and evaporated to give product **2** as a yellow solid after recrystallization from toluene: yield 51%; mp 242–244 °C (toluene); ^1H NMR δ 8.97 (s, 2 H), 8.02 (s, 4 H), 7.00 (d, 4 H, J = 7.8 Hz), 6.87 (t, 2 H, J = 7.8 Hz), 4.71 (s, 4 H), 4.50, 3.53 (d, 8 H, J = 13.4 Hz), 4.44 (q, 4 H, J = 7.0 Hz), 1.31 (t, 6 H, J = 7.0 Hz); ^{13}C NMR δ 168.7, 159.2, 152.2, 139.9, 131.8 (s), 129.9, 129.0 (d), 128.2 (s), 125.3 (d), 72.4, 61.8, 31.3 (t), 14.2 (q); MS-FAB m/z 687.6 [(M + H)$^+$, calcd 687.7]. Anal. Calcd for $C_{36}H_{34}N_2O_{12}$: C, 62.97; H, 4.99; N, 4.08. Found: C, 62.80; H, 5.24; N, 3.84.

25,26,27,28-Tetrakis[(ethoxycarbonyl)methoxy]-5,17-dinitrocalix[4]arene (3). A mixture of calix[4]arene **2** (3.5 g, 5.1 mmol), Na_2CO_3 (5.6 g, 53 mmol), and bromoethyl acetate (5.7 mL, 51 mmol) in acetonitrile (150 mL) was refluxed for 48 h. After filtration the solvent was removed, and the residue was dissolved in CH_2Cl_2 (100 mL) and vigorously stirred with water for 15 h in order to remove sodium salts. After evaporation of CH_2Cl_2 the crude product was recrystallized from MeOH to give pure **3** as a colorless solid: yield 70%; mp 180 °C (EtOH); ^1H NMR δ 7.57 (s, 4 H), 6.7–6.5 (m, 6 H), 4.93, 3.35 (d, 8 H, J = 13.9 Hz), 4.86, 4.63 (s, 8 H), 4.20 (q, 8 H, J = 7.0 Hz), 1.29 (t, 12 H, J = 7.0 Hz); ^{13}C NMR δ 169.7, 169.4, 161.3, 161.3, 155.5, 143.0 (s), 136.3, 133.2 (d), 129.2 (s), 123.9 (d), 71.5, 71.3, 70.0, 60.8, 31.4 (t), 14.2, 14.1 (q); MS-FAB m/z 859.3 [(M + H)$^+$, calcd 859.3]. Anal. Calcd for $C_{44}H_{46}N_2O_{16}$·CH_3OH: C, 60.67; H, 5.66; N, 3.14. Found: C, 60.80; H, 5.34; N, 3.14.

5,17-Diamino-25,26,27,28-tetrakis[(ethoxycarbonyl)methoxy]calix[4]arene (4b). A solution of 1,3-dinitro tetraester **3** (3.4 g, 4 mmol) and $SnCl_2$·$2H_2O$ (8.9 g, 40 mmol) in ethanol (100 mL) was refluxed for 6 h. After the reaction mixture was poured onto ice it was adjusted to pH 8. After extraction with CH_2Cl_2 (2 × 100 mL), the organic layer was stirred with water for 5 h. Evaporation of the solvent gave **4b** as an orange oil: yield 55%; ^1H NMR δ 6.70–6.50 (m, 6 H), 5.99 (s, 4 H), 5.83, 3.12 (d, 8 H, J = 13.9 Hz), 4.72, 4.63 (s, 8 H), 4.20 (q, 8 H, J = 7.0 Hz), 3.21 (br s, 4 H), 1.30 (t, 12 H, J = 7.0 Hz); ^{13}C NMR δ 170.4, 170.3, 156.0, 149.2, 141.3, 135.2, 134.7 (s), 128.5, 122.7, 115.8 (d), 71.5, 71.2, 60.5, 60.4, 31.5 (t), 14.2 (q); MS-FAB m/z 799.3 [(M + H)$^+$, calcd 799.3]. Anal. Calcd for $C_{44}H_{50}N_2O_{12}$·$0.25CH_2Cl_2$: C, 64.79; H, 6.16; N, 3.41. Found: C, 64.42; H, 5.93; N, 3.34.

General Procedure for the Preparation of 5a,b. Chloroacetyl chloride (1.6 mL, 20 mmol) was added dropwise to a solution of 1,3-diamino compound **4a,b** (10 mmol) and Et_3N (2.8 mL, 20 mmol) in CH_2Cl_2 (75 mL) at rt. After the reaction mixture was stirred for 1 h, the organic layer was washed with 0.5 N HCl (2 × 50 mL) and water (2 × 50 mL) and evaporated. Column chromatography [neutral Al_2O_3 (activity I), ethyl acetate] gave pure **5a,b**.

5,17-Bis(2-chloroacetamido)-25,26,27,28-tetrapropoxycalix[4]arene (5a): yield 69%; mp 155–157 °C (ethyl acetate/petroleum ether); ^1H NMR δ 7.94 (br s, 2 H), 6.69 (s, 4 H), 6.6–6.4 (m, 6 H), 4.43, 3.12 (d, 8 H, J = 13.9 Hz), 4.10 (s, 4 H), 3.9–3.7 (m, 8 H), 2.0–1.6 (m, 8 H), 1.05 (t, 12 H, J = 7.2 Hz); ^{13}C NMR δ 170.0, 153.6, 137.7, 134.2, 130.8, 129.2 (s), 128.7, 122.2, 121.3 (d), 61.6, 42.4, 34.0, 31.6 (t), 14.9 (q); MS-FAB m/z 774.3 (M$^+$, calcd 774.3). Anal. Calcd for $C_{44}H_{52}Cl_2N_2O_6$: C, 68.12; H, 6.76; N, 3.61. Found: C, 68.00; H, 6.57; N, 3.59.

5,17-Bis(2-chloroacetamido)-25,26,27,28-tetrakis[(ethoxycarbonyl)methoxy]calix[4]arene (5b): yield 64%; mp 190–192 °C (ethyl acetate/petroleum ether); ^1H NMR δ 8.10 (br s, 2 H), 6.85 (s, 4 H), 6.7–6.6 (m, 6 H), 4.89, 3.23 (d, 8 H, J = 13.5 Hz), 4.71, 4.69 (s, 8 H), 4.21 (q, 8 H, J = 7.0 Hz), 4.09 (s, 4 H), 1.25 (t, 12 H, J = 7.0 Hz); ^{13}C NMR δ 170.0, 163.7, 155.6, 153.5, 135.5, 134.0, 131.2, 129.2 (s), 128.8, 123.2, 121.3 (d), 71.4, 71.3, 60.6, 42.4, 31.5 (t), 14.2 (q); MS-FAB m/z 950.3 (M$^+$, calcd 950.3). Anal. Calcd for $C_{48}H_{52}Cl_2N_2O_{14}$: C, 60.61; H, 5.47; N, 2.94. Found: C, 60.65; H, 5.65; N, 2.67.

General Procedure for the Preparation of 6a,b. A mixture of **5a,b** (1 mmol), 2-(2-allyloxy)-3-hydroxybenzaldehyde[12] (0.36 g, 2 mmol), K_2CO_3 (0.28 g, 2 mmol), and potassium iodide (0.17 g, 1 mmol) in acetonitrile (150 mL) was refluxed for 12 h. After filtration the solvent was removed and the crude product was purified by column chromatography [neutral Al_2O_3 (activity I), ethyl acetate].

5,17-Bis[[3-formyl-2-(2-propenyloxy)phenoxy]acetamido]-25,26,27,28-tetrapropoxycalix[4]arene (6a): yield 59%; mp 100–101 °C (CH_2Cl_2/petroleum ether); ^1H NMR δ 10.34 (s, 2 H), 8.14 (br s, 2 H), 7.39 (d, 2 H, J = 7.5 Hz), 7.2–7.0 (m, 4 H), 6.94 (s, 4 H), 6.6–6.4 (m, 6 H), 6.1–6.0 (m, 2 H), 5.5–5.0 (m, 4 H), 4.6–4.5 (m, 4 H), 4.53 (s, 4 H), 4.50, 3.16 (d, 8 H, J = 13.7 Hz), 3.85 (q, 8 H, J = 7.0 Hz), 2.0–1.8 (m, 8 H), 1.00, 0.95 (t, 12 H, J = 7.0 Hz); ^{13}C NMR δ 189.3 (d), 164.9, 156.3, 154.1, 151.1, 150.5, 135.8, 134.6 (s), 132.7 (d), 130.6, 130.3 (s), 128.2, 125.0, 122.3, 121.5, 120.9, 120.1 (d), 119.0, 76.8, 76.1, 68.8, 31.1, 23.2, 23.1 (t), 10.3, 10.2 (q); MS-FAB m/z 1059.2 (M$^+$, calcd 1059.3). Anal. Calcd for $C_{64}H_{70}N_2O_{12}$: C, 72.57; H, 6.66; N, 2.64. Found: C, 72.36; H, 6.55; N, 2.56.

25,26,27,28-Tetrakis[(ethoxycarbonyl)methoxy]-5,17-bis[3-formyl-2-[(2-propenyloxy)phenoxy]acetamido]calix[4]arene (6b): yield 64%; mp 69–71 °C (CH_2Cl_2/petroleum ether); ^1H NMR δ 10.33 (s, 2 H), 8.29 (br s, 2 H), 7.43 (d, 2 H, J = 7.5 Hz), 7.2–7.0 (m, 4 H), 6.99 (s, 4 H), 6.7–6.5 (m, 6 H), 6.1–6.0 (m, 2 H), 5.5–5.1 (m, 4 H), 4.91, 3.25 (d, 8 H, J = 13.4 Hz), 4.76, 4.74 (s, 8 H), 4.65–4.60 (m, 4 H), 4.54 (s, 4 H), 4.22 (q, 8 H, J = 7.0 Hz), 1.29 (t, 12 H, J = 7.0 Hz); ^{13}C NMR δ 189.3 (d), 170.1, 170.0, 165.0, 155.6, 153.3, 151.1, 150.8, 135.5, 134.0 (s), 132.7 (d), 131.2, 130.6 (s), 128.6, 125.1, 123.2, 121.6, 121.2, 120.2 (d), 118.9, 76.2, 71.4, 68.8, 60.6, 31.6 (t), 14.2 (q); MS-FAB m/z 1235.4 (M$^+$, calcd 1235.3). Anal. Calcd for $C_{68}H_{70}N_2O_{20}$: C, 66.12; H, 5.71; N, 2.27. Found: C, 65.97; H, 5.82; N, 2.34.

General Procedure for the Deallylation[13] of Aldehydes 6a,b. Formation of Aldehydes 7a,b. A mixture of **6a,b** (3 mmol), $Pd(OAc)_2$ (20 mg, 0.1 mmol), PPh_3 (125 mg, 0.5 mmol), Et_3N (3.7 g, 37 mmol), and HCOOH (1.65 g, 37 mmol) in 80% aqueous EtOH (60 mL) was refluxed for 1 h. The solvent was evaporated, and the total water volume was adjusted at 100 mL. The product was extracted with CH_2Cl_2 (3 × 100 mL) and washed with water (2 × 100 mL). The solvent was removed to give **7a,b** as yellow oils which were used without purification due to slow decomposition.

5,17-Bis[(3-formyl-2-hydroxyphenoxy)acetamido]-25,26,27,28-tetrapropoxycalix[4]arene (7a): yield 79%; ^1H NMR δ 9.91 (s, 2 H), 8.90 (br s, 2 H), 7.1–6.5 (m, 16 H), 4.41 (s, 4 H), 4.37, 3.17 (d, 8 H, J = 13.4 Hz), 3.8–3.6 (m, 8 H), 2.1–1.9 (m, 8 H), 1.0–0.9 (m, 12 H); MS-FAB m/z 978.3 [(M + H)$^+$, calcd for $C_{58}H_{60}N_2O_{12}$ 978.1].

25,26,27,28-Tetrakis[(ethoxycarbonyl)methoxy]-5,17-bis[(3-formyl-2-hydroxyphenoxy)acetamido]calix[4]arene (7b): yield 84%; ^1H NMR δ 9.93 (s, 2 H), 8.62 (br s, 2 H), 7.27 (d, 2 H, J = 7.5 Hz), 7.20, 7.17 (d, 4 H, J = 7.5 Hz), 6.9–6.8 (m, 6 H), 6.53 (s, 4 H), 4.96, 3.30 (d, 8 H, J = 13.4 Hz), 4.81, 4.74, 4.42 (s, 12 H), 4.25–4.20 (m, 8 H), 1.34 (t, 12 H, J = 7.0 Hz); MS-FAB m/z 1154.4 [(M − H)$^-$, calcd for $C_{62}H_{62}N_2O_{20}$ 1154.1].

General Procedure for the Synthesis of UO_2–Salenes 8a,b. Solutions of bisaldehydes **7a,b** (1.3 mmol) and *cis*-1,2-cyclohexanediamine (0.14 g, 1.3 mmol) in EtOH (50 mL) were added separately to a refluxing solution of $UO_2(OAc)_2$·$2H_2O$ (0.56 g, 1.3 mmol) in EtOH (500 mL) for 2 h, whereupon refluxing was continued for 1 h. After the solution was cooled, the solvent was evaporated. The residue was dissolved in CH_2Cl_2 (150 mL) and stirred with water for 15 h. After evaporation of CH_2Cl_2 the crude mixture was purified by column chromatography (SiO_2, CH_2Cl_2/ethyl acetate, 5:1) to give **8a,b** as orange solids.

5,17-[[[2,2′-[1,2-Cyclohexanediylbis[nitrilomethyl(2-hydroxy-3,1-phenylene)oxy]]bis(acetamido)](2−)]dioxouranium]-25,26,27,28-tetrapropoxycalix[4]arene (8a): yield 9%; mp 283−285 °C (acetonitrile); ^{1}H NMR (DMSO-d_6/$CDCl_3$, 8:1) δ 9.45 (br s, 2 H), 9.34 (s, 2 H), 7.31, 7.26 (d, 4 H, J = 8.0 Hz), 7.1−6.8 (m, 10 H), 6.45 (t, 2 H, J = 8.0 Hz), 4.81 (q, 4 H, J = 7.0 Hz), 4.55−4.50 (m, 2 H), 4.30, 3.12 (d, J = 13.5 Hz), 4.00, 3.61 (t, 8 H, J = 7.0 Hz), 2.3−2.0 (m, 8 H), 1.00, 0.97 (t, 12 H, J = 7.0 Hz); MS-FAB *m/z* 1325.7 (M^+, calcd 1325.3). Anal. Calcd for $C_{64}H_{70}N_4O_{12}U\cdot CH_3CN$: C, 58.02; H, 5.39; N, 5.13. Found: C, 58.32; H, 5.56; N, 5.15.

5,17-[[[2,2′-[1,2-Cyclohexanediylbis[nitrilomethyl(2-hydroxy-3,1-phenylene)oxy]]bis(acetamido)](2−)]dioxouranium]-25,26,27,28-tetrakis[(ethoxycarbonyl)methoxy]calix[4]arene (8b): yield 15%; mp 235−238 °C (EtOH); ^{1}H NMR (DMSO-d_6) δ 9.70 (br s, 2 H), 9.48 (s, 2 H), 7.43, 7.36 (d, 4 H, J = 8.0 Hz), 7.2−6.9 (m, 10 H), 6.65 (t, 2 H, J = 8.0 Hz), 5.24 (s, 4 H), 4.80, 3.19 (d, 8 H, J = 13.6 Hz), 4.69, 4.46 (s, 8 H), 4.7−4.6 (m, 2 H), 4.25, 4.10 (q, 8 H, J = 7.0 Hz), 2.4−2.3 (m, 2 H), 1.9−1.6 (m, 6 H), 1.30, 1.21 (t, 12 H, J = 7.0 Hz); MS-FAB *m/z* 1501.1 (M^+, calcd 1501.3). Anal. Calcd for $C_{68}H_{70}N_4O_{20}U$: C, 54.40; H, 4.70; N, 3.73. Found: C, 54.39; H, 4.86; N, 3.55.

Determination of Association Constants. The measurements were performed by ^{1}H NMR titration experiments in DMSO-d_6 at 298 K using a constant host concentration of 4 mM and a varying guest concentration of 0.3−30 mM. As a probe the chemical shift of the C(O)NH signal was used. The K_{ass} values were calculated by nonlinear regression as described in ref 19. The estimated error is <5%.

(19) de Boer, J. A. A.; Reinhoudt, D. N.; Harkema, S.; van Hummel, G. J.; de Jong, F. *J. Am. Chem. Soc.* **1982**, *104*, 4073.