

## Calix[4]arene Salenes: A Bifunctional Receptor for $\text{NaH}_2\text{PO}_4$

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### Introduction

Calix[4]arenes are important building blocks in supramolecular chemistry.<sup>1,2</sup> They can be selectively functionalized both at the phenolic OH groups (lower rim) and at the para positions of the phenol rings (upper rim).<sup>3</sup> 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<sup>4</sup> and neutral molecules<sup>5</sup> have been synthesized in the past decade. Very recently the first representatives of calixarene-containing anion receptors have been reported.<sup>6</sup>

Previously we reported that neutral metaloclefts and metallomacrocycles containing both an immobilized Lewis acidic  $\text{UO}_2$ -center and amido  $\text{C}(\text{O})\text{NH}$  units as additional binding sites are excellent receptors for anions with a high selectivity for dihydrogen phosphate  $\text{H}_2\text{PO}_4^-$ .<sup>7</sup> In the present paper we report, in addition to the synthesis of a new representative of a  $\text{UO}_2$ -containing anion receptor based on a calix[4]arene, the first example of a neutral calix[4]arene-based *bifunctional* receptor<sup>8</sup> 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<sup>9</sup> 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%  $\text{HNO}_3$  in a mixture of acetic acid and  $\text{CH}_2\text{Cl}_2$  gave the dinitrocalix[4]arene **2** in 51% yield with the expected<sup>10</sup> 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  $^1\text{H}$  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  $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$  in refluxing ethanol gave the corresponding diamino-calix[4]arene **4b** in 55% yield.

Reaction of 1,3-diamino-calix[4]arenes **4a**,<sup>11b</sup> with chloroacetyl chloride in the presence of  $\text{Et}_3\text{N}$  in  $\text{CH}_2\text{Cl}_2$  gave the corresponding 1,3-bis(chloroacetamido)-calix[4]arenes **5a,b** in 69 and 64% yields, respectively. Bialdehydes **6a,b** were obtained by alkylation of 2-(2-allyloxy)-3-hydroxybenzaldehyde<sup>12</sup> with **5a,b** in the presence of potassium carbonate in 59 and 64% yields, respectively. Subsequent palladium-catalyzed deallylation<sup>13</sup> of calixarenes **6a,b** afforded bialdehydes **7a,b** in quantitative yield which were used without purification for the cyclization step.

Reaction of bialdehydes **7a,b** with *cis*-1,2-diaminocyclohexane<sup>14</sup> and  $\text{UO}_2(\text{OAc})_2 \cdot 2\text{H}_2\text{O}$  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  $\text{UO}_2$ -containing metallomacrocycles<sup>12,15</sup> may be explained by the lack of a suitable template in the cyclization step. The absorptions in the  $^1\text{H}$  NMR spectra at 9.34 and 9.48 ppm and in the IR spectra at 1615 and 1617  $\text{cm}^{-1}$  for compounds **8a** and **8b**, respectively, proved imino bond formation. The presence of the  $\text{UO}_2$  moiety is in agreement with the uranium-oxygen vibrations in the IR spectra at 895–905  $\text{cm}^{-1}$ . Because of the "cone" conformation of the calix[4]arene unit in the  $^1\text{H}$  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  $\text{UO}_2$ -Lewis acidic center and  $\text{C}(\text{O})\text{NH}$  groups which is known to act as an anionic binding site.<sup>7</sup> In addition,

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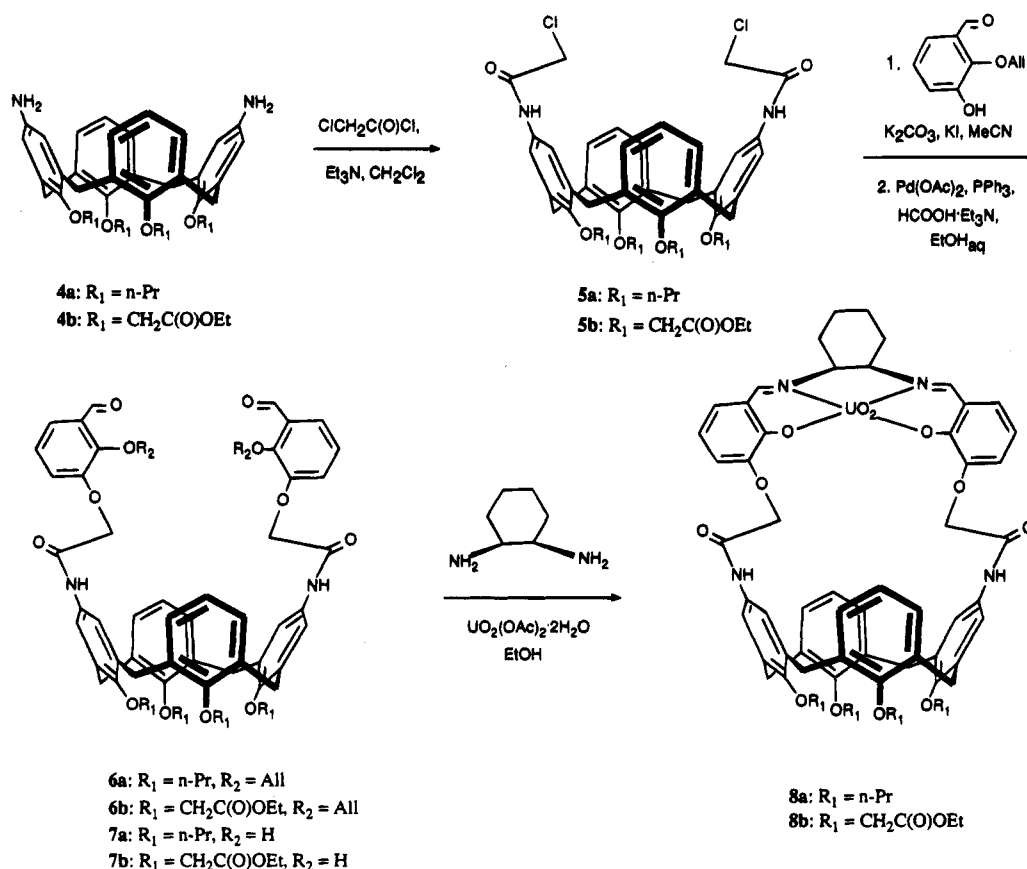
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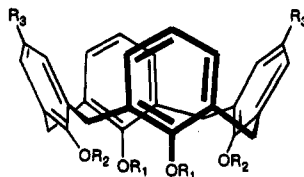
(14) We have chosen the *cis* isomer because in the chair conformer of the cyclohexyl moiety one nitrogen atom is located in the equatorial and another in the axial position. According to a CPK model, the nitrogens in these positions give after cyclization the desired cavity for immobilization of the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

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## Scheme 1



## Chart 1



- 1: R<sub>1</sub> = CH<sub>2</sub>C(O)OEt, R<sub>2</sub> = R<sub>3</sub> = H
- 2: R<sub>1</sub> = CH<sub>2</sub>C(O)OEt, R<sub>2</sub> = H, R<sub>3</sub> = NO<sub>2</sub>
- 3: R<sub>1</sub> = R<sub>2</sub> = CH<sub>2</sub>C(O)OEt, R<sub>3</sub> = NO<sub>2</sub>

calixarene **8b** contains also four preorganized ester fragments which are known to complex alkali metal cations with a high selectivity for Na<sup>+</sup>.<sup>16</sup> A study of the binding ability of receptors **8a,b** shows that they both *selectively* bind dihydrogen phosphate H<sub>2</sub>PO<sub>4</sub><sup>-</sup>.<sup>17</sup> From <sup>1</sup>H NMR dilution experiments with Bu<sub>4</sub>N<sup>+</sup>H<sub>2</sub>PO<sub>4</sub><sup>-</sup> in DMSO-*d*<sub>6</sub> association constants *K*<sub>ass</sub> of 3.5 × 10<sup>2</sup> M<sup>-1</sup> and 3.9 × 10<sup>2</sup> M<sup>-1</sup> were calculated for **8a** and **8b**, respectively. The contribution of the C(O)NH-H<sub>2</sub>PO<sub>4</sub><sup>-</sup> hydrogen bond interaction to the overall anion complexation can be clearly seen even in polar DMSO-*d*<sub>6</sub> 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<sup>-</sup>, HSO<sub>4</sub><sup>-</sup>, and ClO<sub>4</sub><sup>-</sup> anions which indicates their weak binding (*K*<sub>ass</sub> < 10 M<sup>-1</sup>).

In the negative FAB mass spectra of the 1:1 complexes of **8a** and **8b** with Bu<sub>4</sub>N<sup>+</sup>H<sub>2</sub>PO<sub>4</sub><sup>-</sup>, prepared by mixing of host and guest in MeCN, intense peaks corresponding to [**8a** + H<sub>2</sub>PO<sub>4</sub><sup>-</sup>]<sup>-</sup> and [**8b** + H<sub>2</sub>PO<sub>4</sub><sup>-</sup>]<sup>-</sup>, respectively, were observed. Moreover, in the positive FAB mass spectrum of the 1:1 complex of **8b** and NaH<sub>2</sub>PO<sub>4</sub>, prepared by mixing of host and guest in MeCN-H<sub>2</sub>O, 10:1, an intense peak corresponding to [**8b** + Na<sup>+</sup>]<sup>+</sup> was observed, while the corresponding negative FAB mass spectrum of the same sample yielded an intense peak for [**8b** + H<sub>2</sub>PO<sub>4</sub><sup>-</sup>]<sup>-</sup>, 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.<sup>18</sup>

## Experimental Section

Melting points are uncorrected. <sup>1</sup>H NMR and <sup>13</sup>C NMR spectra were recorded in CDCl<sub>3</sub> with Me<sub>4</sub>Si 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<sup>9</sup> and compound **4a**<sup>11</sup> 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<sub>4</sub>, whereupon the solvent was removed under reduced pressure. The presence of

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solvent in the analytical samples was confirmed by  $^1\text{H}$  NMR spectroscopy.

**25,27-Bis[(ethoxycarbonyl)methoxy]-26,28-dihydroxy-calix[4]arene (1).** A mixture of calix[4]arene<sup>9</sup> (4.02 g, 9.5 mmol),  $\text{K}_2\text{CO}_3$  (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  $\text{CH}_2\text{Cl}_2$  (100 mL) and washed with water ( $2 \times 100$  mL). After evaporation of  $\text{CH}_2\text{Cl}_2$  the crude product was recrystallized from MeOH to give pure **2** as a colorless solid: yield 88%; mp 166–168 °C (methanol);  $^1\text{H}$  NMR  $\delta$  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);  $^{13}\text{C}$  NMR  $\delta$  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)<sup>+</sup>, calcd 597.7]. Anal. Calcd for  $\text{C}_{38}\text{H}_{36}\text{O}_8$ : 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  $\text{CH}_2\text{Cl}_2$  (100 mL) was added 65%  $\text{HNO}_3$  (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 ( $3 \times 100$  mL), and evaporated to give product **2** as a yellow solid after recrystallization from toluene: yield 51%; mp 242–244 °C (toluene);  $^1\text{H}$  NMR  $\delta$  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);  $^{13}\text{C}$  NMR  $\delta$  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)<sup>+</sup>, calcd 687.7]. Anal. Calcd for  $\text{C}_{38}\text{H}_{34}\text{N}_2\text{O}_{12}$ : 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),  $\text{Na}_2\text{CO}_3$  (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  $\text{CH}_2\text{Cl}_2$  (100 mL) and vigorously stirred with water for 15 h in order to remove sodium salts. After evaporation of  $\text{CH}_2\text{Cl}_2$  the crude product was recrystallized from MeOH to give pure **3** as a colorless solid: yield 70%; mp 180 °C (EtOH);  $^1\text{H}$  NMR  $\delta$  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);  $^{13}\text{C}$  NMR  $\delta$  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)<sup>+</sup>, calcd 859.3]. Anal. Calcd for  $\text{C}_{44}\text{H}_{48}\text{N}_2\text{O}_{16}\text{CH}_3\text{OH}$ : 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  $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$  (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  $\text{CH}_2\text{Cl}_2$  ( $2 \times 100$  mL), the organic layer was stirred with water for 5 h. Evaporation of the solvent gave **4b** as an orange oil: yield 55%;  $^1\text{H}$  NMR  $\delta$  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);  $^{13}\text{C}$  NMR  $\delta$  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)<sup>+</sup>, calcd 799.3]. Anal. Calcd for  $\text{C}_{44}\text{H}_{50}\text{N}_2\text{O}_{12} \cdot 0.25\text{CH}_2\text{Cl}_2$ : 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  $\text{Et}_3\text{N}$  (2.8 mL, 20 mmol) in  $\text{CH}_2\text{Cl}_2$  (75 mL) at rt. After the reaction mixture was stirred for 1 h, the organic layer was washed with 0.5 N HCl ( $2 \times 50$  mL) and water ( $2 \times 50$  mL) and evaporated. Column chromatography [neutral  $\text{Al}_2\text{O}_3$  (activity I), ethyl acetate] gave pure **5a,b**.

**5,17-Bis(2-chloroacetamido)-25,26,27,28-tetrapropoxy-calix[4]arene (5a):** yield 69%; mp 155–157 °C (ethyl acetate/petroleum ether);  $^1\text{H}$  NMR  $\delta$  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);  $^{13}\text{C}$  NMR  $\delta$  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<sup>+</sup>,

calcd 774.3). Anal. Calcd for  $\text{C}_{44}\text{H}_{52}\text{Cl}_2\text{N}_2\text{O}_6$ : 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);  $^1\text{H}$  NMR  $\delta$  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);  $^{13}\text{C}$  NMR  $\delta$  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<sup>+</sup>, calcd 950.3). Anal. Calcd for  $\text{C}_{48}\text{H}_{52}\text{Cl}_2\text{N}_2\text{O}_{14}$ : 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<sup>12</sup> (0.36 g, 2 mmol),  $\text{K}_2\text{CO}_3$  (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  $\text{Al}_2\text{O}_3$  (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 ( $\text{CH}_2\text{Cl}_2$ /petroleum ether);  $^1\text{H}$  NMR  $\delta$  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);  $^{13}\text{C}$  NMR  $\delta$  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<sup>+</sup>, calcd 1059.3). Anal. Calcd for  $\text{C}_{64}\text{H}_{70}\text{N}_2\text{O}_{12}$ : 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 ( $\text{CH}_2\text{Cl}_2$ /petroleum ether);  $^1\text{H}$  NMR  $\delta$  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);  $^{13}\text{C}$  NMR  $\delta$  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<sup>+</sup>, calcd 1235.3). Anal. Calcd for  $\text{C}_{68}\text{H}_{70}\text{N}_2\text{O}_{20}$ : C, 66.12; H, 5.71; N, 2.27. Found: C, 65.97; H, 5.82; N, 2.34.

**General Procedure for the Deallylation<sup>13</sup> of Aldehydes 6a,b.** Formation of Aldehydes **7a,b.** A mixture of **6a,b** (3 mmol),  $\text{Pd}(\text{OAc})_2$  (20 mg, 0.1 mmol),  $\text{PPh}_3$  (125 mg, 0.5 mmol),  $\text{Et}_3\text{N}$  (3.7 g, 37 mmol), and  $\text{HCOOH}$  (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  $\text{CH}_2\text{Cl}_2$  ( $3 \times 100$  mL) and washed with water ( $2 \times 100$  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%;  $^1\text{H}$  NMR  $\delta$  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)<sup>+</sup>, calcd for  $\text{C}_{58}\text{H}_{60}\text{N}_2\text{O}_{12}$  978.1].

**25,26,27,28-Tetrakis[(ethoxycarbonyl)methoxy]-5,17-bis[[3-formyl-2-hydroxyphenoxy]acetamido]calix[4]arene (7b):** yield 84%;  $^1\text{H}$  NMR  $\delta$  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)<sup>–</sup>, calcd for  $\text{C}_{62}\text{H}_{52}\text{N}_2\text{O}_{20}$  1154.1].

**General Procedure for the Synthesis of  $\text{UO}_2$ -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  $\text{UO}_2(\text{OAc})_2 \cdot 2\text{H}_2\text{O}$  (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  $\text{CH}_2\text{Cl}_2$  (150 mL) and stirred with water for 15 h. After evaporation of  $\text{CH}_2\text{Cl}_2$  the crude mixture was purified by column chromatography ( $\text{SiO}_2$ ,  $\text{CH}_2\text{Cl}_2$ /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);  $^1\text{H NMR}$  (DMSO- $d_6$ /CDCl $_3$ , 8:1)  $\delta$  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 ( $\text{M}^+$ , calcd 1325.3). Anal. Calcd for  $\text{C}_{64}\text{H}_{70}\text{N}_4\text{O}_{12}\text{U}\cdot\text{CH}_3\text{CN}$ : 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);  $^1\text{H NMR}$  (DMSO- $d_6$ )  $\delta$  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 ( $\text{M}^+$ , calcd 1501.3). Anal. Calcd for  $\text{C}_{68}\text{H}_{70}\text{N}_4\text{O}_{20}\text{U}$ : 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  $^1\text{H NMR}$  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  $K_{\text{ass}}$  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.