Table II. Coulometric Data and Product Distributions for Electrolytic Reduction of Benzoyl Chloride in Acetonitrile

$[C_6H_5COCl]$, mM	electrode, electrolyte, potential[a]	n	product distribution, %		
			benzaldehyde	benzyl benzoate	stilbenediol dibenzoate
6	Hg, TEAP, −0.70	1.01	–	–	100
6	Hg, TBAP, −0.70	1.03	–	–	100
6	Hg, TEAP, −0.90	1.50	17	19	64
12	Hg, TEAP, −0.90	1.48	9	16	75
6	C, TEAP, −0.90	1.07	12	2	86
6	Hg, TBAP, −0.95	1.40	6	12	82

[a] Hg = mercury pool; C = reticulated vitreous carbon disk; TEAP = 0.1 M tetraethylammonium perchlorate; TBAP = 0.1 M tetra-*n*-butylammonium perchlorate; potential is in volts versus a saturated cadmium amalgam reference electrode (see the Experimental Section).

solvent front did show a signal for m/e 86 that we attribute to the presence of hexane. Though there is some evidence for the presence of hexane, *and thus for the occurrence of decarbonylation of the heptanoyl radical,* we have been unable to determine how important this process is.

Cyclic Voltammetric Behavior of Benzoyl Chloride. Although the electrochemical reduction of benzoyl chloride has been the subject of two earlier publications,[1,4] we have reexamined its behavior with particular emphasis on the production of benzaldehyde. Illustrated in Figure 1A is a cyclic voltammogram, recorded at 100 mV s^{-1} with a glassy carbon electrode, for benzoyl chloride in acetonitrile containing 0.1 M TEAP. With a peak potential of −0.62 V, the first wave is due to reductive cleavage of the carbon–chlorine bond of the acyl chloride; the second wave with a peak potential of −1.07 V is attributable to reduction of benzaldehyde (Figure 1B), a process not previously observed in cyclic voltammograms for benzoyl chloride. Additional poorly resolved waves seen in Figure 1A in the region from approximately −1.3 to −1.7 V arise from reductions of stilbenediol dibenzoate and diphenylacetylene, as reported by Cheek and Horine.[4]

Bulk Electrolyses of Benzoyl Chloride. Compiled in Table II are results from six electrolyses of benzoyl chloride. For an electrolysis at a mercury pool cathode held at −0.70 V, stilbenediol dibenzoate is the only product and the coulometric *n* value is essentially unity (Table II); these results mimic closely those reported by Cheek and Horine.[4] On the other hand, for potentials (−0.90 and −0.95 V) corresponding to the foot of the wave for reduction of benzaldehyde, electrolyses of benzoyl chloride at mercury lead to benzaldehyde and benzyl benzoate in moderate yields, although stilbenediol dibenzoate remains the major product, and the *n* value ranges from 1.4 to 1.5. Finally, the distribution of products obtained from electrolysis of benzoyl chloride at reticulated vitreous carbon is quite similar to those seen in Table II for electrolyses at mercury pool electrodes held at −0.90 or −0.95 V, although the *n* value is close to unity.

Mechanistic Aspects of the Reduction of Benzoyl Chloride. Because electrolyses of benzoyl chloride at potentials near or at the peak of the first voltammetric wave involve the transfer of only one electron per molecule, we conclude, in agreement with earlier proposals,[1,4] that stilbenediol dibenzoate is formed by reaction of unreduced benzoyl chloride with stilbenediolate. Electroreduction of benzaldehyde to benzyl alcohol, followed by reaction of the alcohol with unreduced benzoyl chloride, can account for the appearance of benzyl benzoate and for higher *n* values at more negative potentials in Table II.

In seeking to identify the intermediate that gives rise to benzaldehyde, we electrolyzed 6 mM solutions of benzoyl chloride at both mercury and carbon held at −0.90 V in acetonitrile containing 0.1 M TEAP and 200 mM D_2O and observed an average ratio of close to 3:1 for the relative intensities of mass spectrometric signals (30 eV) for benzaldehyde corresponding to, respectively, *m/e* 106 (C_6H_5CHO) and *m/e* 107 (C_6H_5CDO). Similar experiments, involving electrolysis of benzoyl chloride in acetonitrile-d_3 containing 0.1 M TEAP and residual H_2O, gave a ratio of approximately 1:9 for the *m/e* 106 and *m/e* 107 signals. There can be no doubt that benzoyl radicals and anions are both involved as intermediates in the reduction of benzoyl chloride, but most of the benzaldehyde appears to be produced from benzoyl radicals:

$$C_6H_5COCl + e^- \longrightarrow C_6H_5\dot{C}O + Cl^-$$

$$\left\{ \begin{array}{c} C_6H_5\dot{C}O + CH_3CN \longrightarrow C_6H_5CHO + {}^{\bullet}CH_2CN \\ \text{or} \\ C_6H_5\dot{C}O + e^- \longrightarrow C_6H_5CO^- \end{array} \right\}$$

$$C_6H_5CO^- + H_2O \longrightarrow C_6H_5CHO + OH^-$$

To probe the possibility that decarbonylation of the electrogenerated benzoyl radical results in the production of benzene, we performed experiments analogous to those described above for reduction of heptanoyl chloride, and we found evidence for the presence of a small quantity of benzene (*m/e* 78) only in the total ion chromatogram for the solvent front.

Registry No. Heptanoyl chloride, 2528-61-2; benzoyl chloride, 98-88-4; heptaldehyde, 111-71-7; hepatonic anhydride, 626-27-7; 7-tetradecene-7,8-diol diheptanoate, 137721-14-3; benzaldehyde, 100-52-7; benzyl benzoate, 93-97-0; stilbenediol dibenzoate, 96276-54-9.

Direct Synthesis of Calix[4]arenes with Two Different Phenolic Units in Alternating Order

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The chemistry of calix[4]arenes has reached a stage where not only are various derivatives available, but also selective functionalization becomes more and more possible.[1] Thus, the easy and efficient formation of 1,3-ester[2] or 1,3-ether derivatives[3] has led to the synthesis of various calix[4]arenes of the type ABAB (where A and B symbolize two different phenolic units) either by selective debutylation or by selective substitution of the free phenolic

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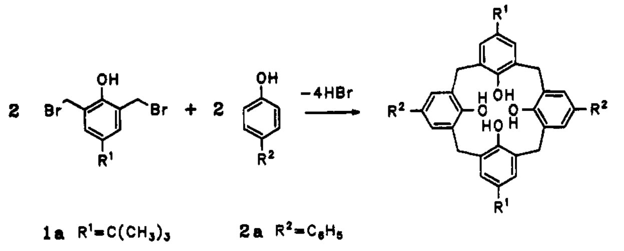
units.[4] 1,2-Diether derivatives recently obtained[5,6] will gain a similar importance.

Calix[4]arenes with different phenolic units can also be obtained by fragment condensation, either of a linear trimer with a bis(bromomethyl)phenol[7] or of a dimer with a bisbromomethylated dimer.[8] It is the aim of this short note to show that calix[4]arenes of the ABAB type can be synthesized even more simply by the direct reaction of a bis(bromomethyl)phenol with another phenol.

A calix[4]arene, consisting of two *p*-phenylphenol and two *p*-*tert*-anisol units was recently prepared in five steps starting with *tert*-butylcalix[4]arene[4b] [(1) selective O-methylation, (2) selective debutylation (3) mercuration, (4) iodination, (5) introduction of the phenyl group] with an overall yield of 27%. A further step would be necessary to obtain the free calixarene **3a** which, however, can be directly obtained in 9–11% yield by reaction of either **1a** with **2a** or **1b** with **2b**. The lower yield in the latter approach is clearly compensated for by the shorter synthetic pathway, at least if small quantities are required in a short time. In a similar way **3b** was obtained in 9% yield by reaction of **1c** with **2c**. The separate introduction of $EtOOCCH_2$ groups (which to the best of our knowledge has not been described completely up to now[1]) in the free para positions again would require four steps, while two steps would be necessary to introduce the methyl groups.[9]

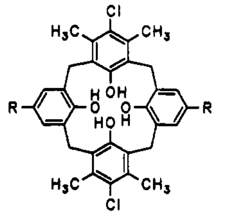


1a $R^1=C(CH_3)_3$ **2a** $R^2=C_6H_5$

1b $R^1=C_6H_5$ **2b** $R^2=C(CH_3)_3$ **3a** $R^1=C(CH_3)_3$ $R^2=C_6H_5$

1c $R^1=CH_2COOC_2H_5$ **2c** $R^2=CH_3$ **3b** $R^1=CH_2COOC_2H_5$ $R^2=CH_3$

In contrast to derivatization strategies, calix[4]arenes with meta-substituted phenolic units are also now available by the direct approach. Condensation of 2,6-bis(bromomethyl)-3,5-dimethyl-4-chlorophenol with **2b** or **2c** gave the calix[4]arenes **4b** and **4a** in 8% and 10% yields, respectively. Compounds of this type are interesting, since tetraester or tetraamide derivatives of **4** could show new complexation selectivities toward metal cations,[1] since the *m*-methyl groups will cause a distortion of the cone conformation.



4a $R=CH_3$

4b $R=C(CH_3)_3$

In conclusion, the synthesis described here represents an interesting and convenient alternative for the preparation of ABAB-type calix[4]arenes. Depending on the nature of A and B, due to its simplicity and in spite of the low yield (which can probably be optimized for special cases) this may even be the method of choice.

Experimental Section

All ^1H NMR spectra were recorded at 200 MHz in $CDCl_3$ if not indicated otherwise. Electron-impact mass spectra were obtained at 70 eV; special attention was given to the absence of masses higher than the molecular ion. Conditions for thin-layer chromatographic analyses and separations by flash chromatography were as previously reported.[7a,10]

Bisbromomethylated phenols **1a**[11] and **1b**[7a] were obtained by direct bromomethylation similar to the examples described below.

2,6-Bis(bromomethyl)-4-chloro-3,5-dimethylphenol. Gaseous hydrogen bromide was passed rapidly through a suspension of 7.8 g (0.05 mol) of 4-chloro-3,5-dimethylphenol and 3.3 g (0.11 mol) paraformaldehyde in 50 mL acetic acid. After 10 min a clear yellow solution was formed, the HBr stream was reduced, and soon a crystalline precipitate separated. After a total reaction time of 30 min the mixture was cooled, and the precipitate was filtered by suction and dried over KOH. Recrystallization from *n*-hexane/chloroform gave 9.8 g (57%) of colorless needles: mp 151–152 °C; ^1H NMR δ 5.33 (br s, 1 H, OH), 4.62 (s, 4 H, CH_2Br), 2.45 (s, 6 H, CH_3). Anal. Calcd for $C_{10}H_{11}Br_2ClO$: C, 35.07; H, 3.24; halogen, 8.76 mmol/g. Found: C, 35.53; H, 3.38; halogen, 8.50 mmol/g.

Ethyl 3,5-Bis(bromomethyl)-4-hydroxyphenylacetate (1c). 4-Hydroxyphenylacetate (31.6 g, 0.18 mol) and paraformaldehyde (12 g, 0.4 mol) in 70 mL of acetic acid were treated with gaseous HBr as described above, with the exception that the reaction mixture was cooled from the beginning in an ice bath. The crystalline mass obtained after several hours in the refrigerator was filtered by suction and dried over KOH. Recrystallization from toluene gave 39 g (60%) of white crystals: mp 127–128 °C; ^1H NMR (acetone-d_6) δ 7.30 (s, 2 H, ArH), 4.72 (s, 4 H, CH_2Br), 4.11 (q, $J = 7.2$ Hz, 2 H, Et), 3.56 (s, 2 H, $ArCH_2CO$), 1.22 (t, $J = 7.2$ Hz, 3 H, Et). Anal. Calcd for $C_{12}H_{14}Br_2O_3$: C, 39.34; H, 3.83; Br, 43.72. Found: C, 39.42; H, 3.86; Br, 43.92.

General Procedure for the Synthesis of Calix[4]arenes. Phenol (0.01 mol), bis(bromomethyl)phenol (0.01 mol), and $TiCl_4$ (0.02 mol) in 500 mL of dry dioxane were refluxed for 70–140 h. (Usually solutions of both reactants were added to the well-stirred yellow suspension formed by $TiCl_4$ in dioxane, but the order of addition of the reactants probably has no influence.) During the reaction the color changed from yellow to dark red and the appearance of the calixarene was monitored by TLC. After evaporation of the dioxane the dark brown residue was worked up by Soxhlet extraction and flash chromatography as already described for similar cases.[7a,10] Further details are given for the individual compounds.[12]

5,17-Di-*tert*-butyl-11,23-diphenyl-25,26,27,28-tetrahydroxycalix[4]arene (3a). This compound was prepared from **1a** (3.35 g) and **2a** (1.70 g) as well as from **1b** (3.56 g) and **2b** (1.50 g) with an insignificant difference in the yields of 11% and 9%, respectively. The yellow solid obtained after flash chromatography with CH_2Cl_2 was recrystallized from acetone to give a white powder (380 and 310 mg, respectively): mp 374–376 °C; ^1H NMR δ 10.39

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(12) Elemental analyses of the calixarenes resulted in C values 2% to 7% lower than the calculated values. This discrepancy has been observed by other authors in similar cases. It cannot be explained by included solvent, which would be found in the expected quantities in the ^1H NMR spectra, or by the presence of inorganic material from the chromatographic separation, since all samples were carefully recrystallized. A possible explanation could be the incomplete combustion of these high-melting compounds under the standardized conditions of the elemental analysis. We believe that the structure of the calixarenes is sufficiently proved by the spectral evidence (see the supplementary material).

(s, 4 H, ArOH), 7.39–7.15 (m, 18 H, ArH), 4.38 and 3.65 (d, J = 13.8 Hz, 4 H each, $ArCH_2Ar$), 1.25 (s, 18 H, $C(CH_3)_3$); MS *m/e* 688.4 (M^+, 100).

5,17-Bis[(ethoxycarbonyl)methyl]-11,23-dimethyl-25,26,27,28-tetrahydroxycalix[4]arene (3b)[13] from the reaction of 3.66 g of **1c** and 1.08 g of **2c**; the residue obtained after the evaporation of the dioxane was refluxed with 250 mL of ethanol for complete reesterification; after evaporation the further workup was done in the usual way. Flash chromatography (CH_2Cl_2) gave a yellow powder which was recrystallized from acetone to give slightly yellow crystals (279 mg, 9%): mp 258–260 °C; ^1H NMR δ 10.12 (s, 4 H, ArOH), 6.96 and 6.82 (s, 4 H each, ArH), 4.10 (q, J = 7 Hz, 4 H, CH_2CH_3), 4.15 and 3.47 (br d, 4 H each, $ArCH_2Ar$), 3.39 (s, 4 H, $ArCH_2CO$), 2.12 (s, 6 H, $ArCH_3$), 1.23 (t, J = 7 Hz, 6 H, CH_2CH_3); MS *m/e* 624 (M^+, 64).

5,17-Dichloro-4,6,11,16,18,23-hexamethyl-25,26,27,28-tetrahydroxycalix[4]arene (4a). Flash chromatography ($CHCl_3$) and recrystallization from acetone gave 285 mg (10%) of a slightly yellow powder: mp >355 °C dec; ^1H NMR δ 10.38 (s, 4 H, ArOH), 6.98 (s, 4 H, ArH), 3.94 (br s, 8 H, $ArCH_2Ar$), 2.48 (s, 12 H, CH_3), 2.17 (s, 6 H, CH_3); MS *m/e* 576.2 (M^+, 100). Anal. Calcd for $C_{34}H_{34}Cl_2O_4$: Cl, 12.28. Found: Cl, 12.60.

5,17-Di-*tert*-butyl-11,23-dichloro-4,6,16,18-tetramethyl-25,26,27,28-tetrahydroxycalix[4]arene (4b). Flash chromatography ($CHCl_3$) and recrystallization from acetone gave 265 mg (8%) of a colorless solid product: mp >350 °C dec; ^1H NMR δ 10.45 (s, 4 H, ArOH), 7.25 (s, 4 H, ArH), 4.15 and 3.8 (br d, 4 H each, $ArCH_2Ar$), 2.45 (s, 12 H, CH_3), 1.15 (s, 18 H, $C(CH_3)_3$); MS *m/e* 660.4 (M^+, 48). Anal. Calcd for $C_{40}H_{46}Cl_2O_4$: Cl, 10.72. Found: Cl, 10.60.

Registry No. **1a**, 5011-36-9; **1b**, 108817-12-5; **1c**, 134747-62-9; **2a**, 92-69-3; **2b**, 98-54-4; **2c**, 106-44-5; **3a**, 137695-95-5; **3b**, 137695-96-6; **4a**, 137695-97-7; **4b**, 137718-35-5; $TiCl_4$, 7550-45-0; 2,6-bis(bromomethyl)-4-chloro-3,5-dimethylphenol, 137695-98-8; 4-hydroxyphenylacetate, 3233-32-7; 4-chloro-3,5-dimethylphenol, 88-04-0.

Supplementary Material Available: NMR spectra of **3a,b** and **4a,b** in $CDCl_3$ at 200 and 400 MHz (7 pages). Ordering information is given on any current masthead page.

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[13] The calixarene **3b** was also obtained with essentially the same yield and identical physical properties by reaction of **1c** with the corresponding linear trimer (ethyl 2,6-bis(2-hydroxy-5-methylbenzyl)-4-hydroxyphenylacetate).