Cyclic Esters of Calixarenes with Phthalic Acid and Pyromellitic Acid; Synthesis and X-Ray Molecular Structures

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The reaction of phthaloyl dichloride with tert-butylcalix[4]-, calix[5]- and calix[6]-arene has been studied. While the 1,2-bridged macrocyclic ester is the main product in the case of calix[4]- and calix[6]-arene, the intramolecular bridging of the calix[5]arene occurs mainly in the 1,3-position. The derivatives of calix[4]- and calix[6]-arene could be further O-alkylated and the ester bonds may be easily hydrolysed in these derivatives. 1,2-Singly bridged derivatives of calix[4]- and calix[6]-arene were also obtained with $ClCH_2Br$. Reaction of tert-butylcalix[4]arene with pyromellitic acid tetrachloride leads to the formation of a new double calixarene.

The structures of two cyclic esters have been determined by X-ray crystallography. Crystals of compound 6c·0.2 MeOH are triclinic, space group $P\bar{1}$, with two molecules in a unit cell of dimensions $a = 10.9292(6)$, $b = 15.0534(10)$, $c = 16.8534(14)$ Å, $\alpha = 94.195(6)°$, $\beta = 90.044(6)°$, $\gamma = 100.171(5)°$, $R = 0.075$ for 2187 observed reflections. Crystals of compound 8·0.83 C_7H_8·0.38 C_6H_{14} are monoclinic, space group $P2_1/n$, with 4 molecules in a unit cell of dimensions $a = 14.5554(13)$, $b = 35.3802(24)$, $c = 15.0160(12)$ Å, $\beta = 99.782(7)°$, $R = 0.072$ for 4028 observed reflections. The phthaloyl residue is enclathrated in the molecular cavity of a neighbouring calix[6]arene in a self-inclusion process resulting from C–H $\cdots \pi$(arene) hydrogen-bonding interactions.

The rapid progress in calixarene chemistry has led not only to a huge variety of derivatives in which all hydroxy groups or all para-positions are substituted in the same way, but also to an increasing number of compounds in which only some of these groups have reacted. Selective functionalization of calix[4]-arenes[1] leading (in a more or less rational way) to single regioisomers or stereoisomers (conformational isomers) has been described for many different examples. To mention but a few the synthesis of all possible conformational isomers of tetrakisbutyl ethers,[2] the preparation of chiral tri-O-alkylated calix[4]arenes[3] or the construction of new, sophisticated chromoionophors[4] may be taken to illustrate the possibilities. A similar development has started now in the calix[6]arene series. Various partially O-alkylated[5-9] and O-acylated[10] derivatives have been obtained in a more or less selective manner, including cyclic ethers[11,12] and cyclic esters.[11,13] Very recently all possible methyl ethers of tert-butylcalix[6]arene have been described.[14] The situation with calix[5]arenes as well as with higher homologues is not yet as well explored. Recently we have prepared 1,3-crown ether derivatives[15] of tert-butylcalix[5]arene[16] which represent the first examples of selectively O-alkylated calix[5]arenes. Several 1,3,5,7-tetrakis-benzyl ethers of calix[8]arenes have been also described.[17]

While most bifunctional reagents lead to the connection of two opposite phenolic oxygens in calix[4]arenes[18-20] if intramolecular bridging occurs at all,† we could show that phthaloyl dichloride 2 forms the intrabridged 1,2-diester 3 in reasonable yield.[23] We therefore concluded that the phthaloyl residue might be developed in general into a suitable protective group for two adjacent OH groups in calixarenes, since it should be possible to hydrolyse these ester groups again, after further alkylation of the remaining OH groups. Although this hope has not yet been entirely fulfilled, some interesting results emerged from this idea. It should be mentioned that 1,2-diethers have been synthesized either by direct alkylation in the presence of a strong base (NaH) or by selective cleavage of adjacent methoxy groups in the tetrakismethyl ether.[24,25]

Results and Discussion

Cyclic Esters of Phthalic Acid and tert-*Butylcalix[4]arene.*—Reaction of tert-butylcalix[4]arene 1a with phthaloyl dichloride 2 in tetrahydrofuran (THF) in the presence of potassium tert-butoxide gave compound 3 in 30% yield while 26% of the original tetraol 1a could be recovered (as formerly described)[23] (Scheme 1). An increase of the concentrations to enforce a more complete conversion led, however, to a decrease in yield. CsF in acetonitrile, a reaction medium used to obtain the doubly intrabridged derivative 4 also gave lower yields of compound 3. A slight increase in the yield of compound 3 to 34% was obtained with sodium hydride in THF under conditions where compound 1a (6.5 g) was allowed to react in THF (250 cm³). Thus, although compound 3 can be isolated only by flash chromatography it represents an easily accessible starting material for further derivatization, since it may be obtained without special dilution conditions.

We have studied in some detail the further alkylation of diol 3 with ethyl bromoacetate 5. Reaction of compound 3 with excess of ester 5 (4–6 molar) in acetonitrile with K_2CO_3 or CsF as base gave the monoalkylated product 6a in 37–39% yield (isolated by flash chromatography) (Scheme 2). NaH in THF led to a slightly higher yield (43%) of this compound, while still no dialkylated product was isolable. However, reaction of diol 3 with ester 5 (4 mol equiv.) in THF–dimethylformamide (DMF) (50:50) in the presence of Cs_2CO_3 gave the two products 6b and 6c in 23 and 45% yield, respectively, which by ^{1}H NMR and mass spectroscopic evidence are both di-O-alkylated.

1a n = 4
(1b n = 5)
(1c n = 6)

2

3 (34%)

4 (18%)

Scheme 1

3

+

BrCH₂CO₂Et

5

6a (43%)

6b (23%)

6c (45%)
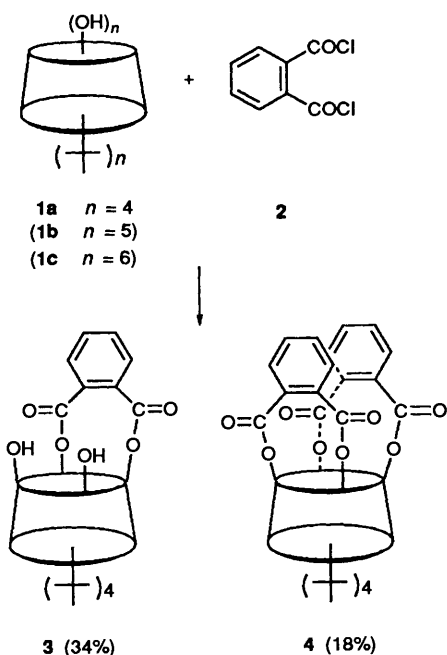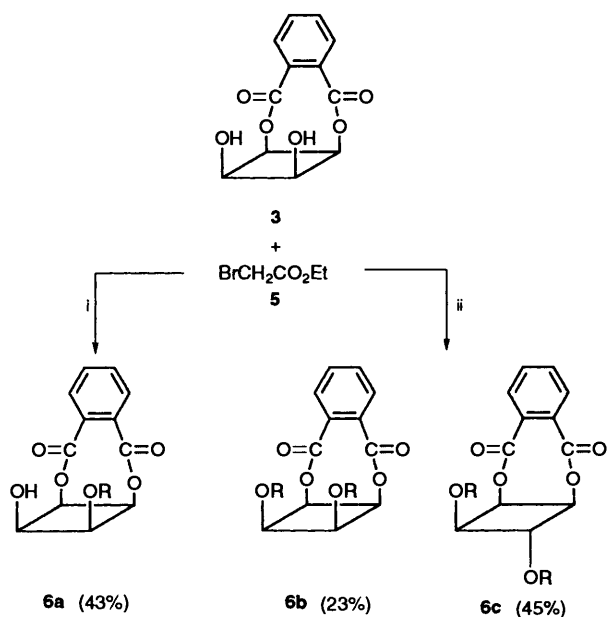
Scheme 2 Reagents: i, NaH, THF; ii, Cs₂CO₃, THF–DMF

Product **6b** shows two singlets for the *tert*-butyl protons and one pair of doublets for the diastereotopic protons of the OCH₂CO groups, which (*inter alia*) characterize it as a symmetrical product. This compound, in principle, could be in either the cone or the 1,2-alternate conformation. Owing to the fact that all three pairs of doublets (proportions 1:2:1) for the ArCH₂Ar groups (especially that with double intensity at δ 4.78 and 3.39 are found in the usual range, the cone conformation is most probable. For a 1,2-alternate conformation the environment for the two protons of the two CH₂ groups between ester and ether units would be more similar (although in principle different). Compound **6c** shows four singlets for the *tert*-butyl groups, two pairs of doublets for the diastereotopic protons of two different OCH₂CO groups and three pairs of doublets together with a (pseudo) singlet for the ArCH₂Ar. This shows that this stereoisomer is fixed in the partial cone

conformation. An independent and unambiguous confirmation was obtained in this case by X-ray analysis (see later).

Owing to its conformation compound **6c** is asymmetric and consequently chiral, while isomer **6b** has a symmetry plane. Molecular asymmetry (due to the substitution pattern, and independent of the conformation) is also found in the monoalkylated compound **6a**, demonstrated for instance by four signals for the *tert*-butyl groups. Four pairs of doublets for the ArCH₂Ar protons in the usual range (δ 4.45, 4.33, 4.15, 4.02, 3.51, 3.50, 3.39 and 3.26) suggest that a *syn* arrangement of the *O*-alkyl residue and a cone conformation are highly probable. It should be emphasized that the doublet observed for the diastereotopic OCH₂CO protons here as well as in the other cases has nothing to do with restricted rotation of this residue.

De Mendoza and co-workers showed that the ¹³C NMR signals of carbon atoms belonging to methylene bridges which are situated between two phenol rings of different (*anti*) orientations are found at δ_C 37–38, while those of methylene bridges between phenol rings of similar ((*syn*) orientations usually appear at δ_C 31–32.²⁶ In the ¹³C NMR spectrum of compound **6b** we find four signals in this region (δ_C 30–40): 32.5, 33.9, 34.3 and 35.1 ppm, none of them pointing to a 1,2-alternate conformation. On the other hand seven signals, at δ_C 32.1, 33.9, 34.2, 34.4, 34.9, 38.9 and 39.1, are found in the spectrum of compound **6c**, two of them (in agreement with Mendoza's observation) corresponding to the carbon atoms of the methylene bridge between the *anti* orientated phenol rings.

Hydrolysis of all ester groups in compounds **6a–c** was easily achieved by heating them with KOH in aq. methanol. Thus, the monoacid and two isomeric diacids were obtained. As in similar cases, these acids show ¹H NMR spectra with very broad signals, which were not useful for their characterization. The compounds were identified by the molecular ion in their FD-mass spectra, and in the case of the monoacid also *via* the ¹H NMR and ¹³C NMR spectra of the ethyl ester, which showed, for instance, three signals for *tert*-butyl groups (proportions 1:2:1) and two pairs of doublets for the two different ArCH₂Ar protons. That two different diacids are obtained from compounds **6b** and **6c**, with a stable *syn* or *anti* arrangement of the OCH₂CO₂H groups, could be demonstrated by their different R_f values on TLC.

Cyclic Esters of Phthalic Acid and tert-*Butylcalix*[5]- *and* tert-*Butylcalix*[6]-*arene.*—When phthaloyl dichloride **2** was treated with the larger members of the calixarene family we always obtained product mixtures which were difficult to separate. In the case of the *tert*-butylcalix[5]arene **1b** the only pure product which up to now could be isolated by flash chromatography (14%) was a singly bridged cyclic ester **7**. This was easily demonstrated by FD-mass spectrometry, while its ¹H NMR spectrum showed the following surprising result: there are three singlets for OH groups (δ 8.78, 8.57 and 6.77), five pairs of doublets for the methylene bridges and five singlets for the *tert*-butyl groups (δ 1.38, 1.30, 1.24, 1.14 and 1.11). For the aromatic protons of the *tert*-butylphenol units 9 (pseudo) singlets are discernible, one of them (δ 7.26) arising from two protons. This means that the phthaloyl bridge obviously enforces a rigid (on the NMR timescale) and asymmetric conformation at room temperature. This is a rather unexpected result since both possible macrocyclic esters (proximal or 1,2-bridged and distal or 1,3-bridged) should have a symmetry plane intersecting the phthaloyl residue as was found for the 1,2-bridged calix[4]arene **3** and also for 1,2- and 1,3-crown ether derivatives of compound **1b**.¹⁵ The entire lack of a symmetry element means that the molecule must be chiral, which was further confirmed by the doubling of some peaks in the presence of Pirkle's reagent. The rigid structure, on the other hand, may be the reason for the low yield. At 120 °C (C₂D₂Cl₄) the ¹H

NMR spectrum of compound 7 shows the expected pattern of a symmetrical compound: two broad singlets for the OH groups (ratio 2:1), two pairs of doublets (ratio 2:3, because two AX systems are superimposed) for the three different methylene bridges, and three singlets for the *tert*-butyl groups (2:2:1).


7

8
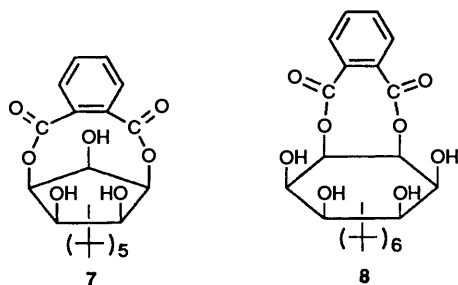
As pointed out elsewhere,[15] there is no entirely unambiguous way to distinguish between 1,2- or 1,3-disubstituted calix[5]-arenes just on the basis of the number of signals in the NMR spectrum, as is easily done in the calix[4]arene series. That one OH signal is found at δ 6.77 suggests, however, that this hydroxy group is isolated (no OH $\cdots$ OH hydrogen bond) from the other two which appear at lower field (δ 8.78 and 8.57). Therefore compound 7 should be the 1,3-bridged cyclic ester.

In the case of *tert*-butylcalix[6]arene **1c** a singly bridged ester 8 was isolated in 45% yield by flash chromatography, a yield even higher than that obtained with compound **1a**. Again, five singlets for the six *tert*-butyl groups (1.42, 1.39, 1.36 (2 × Bu^t), 1.33 and 1.17) are found in the ^{1}H NMR spectrum at room temperature, confirming the absence of a symmetry plane in the molecule, a conclusion which may be drawn also from the other signals (ArH, ArCH$_2$Ar) although not in such a clear way. For the OH protons a broad singlet at δ 9.96 (2 H) and two singlets at δ 8.44 and 8.22 are found, which is interpreted in terms of a continuous row of intramolecularly hydrogen-bonded OH groups. Hence, two adjacent phenolic residues are bridged by the phthaloyl group, a result which was confirmed by the X-ray analysis of this compound.

As in the case of compound 7 the ^{1}H NMR spectrum measured at high temperature (120 °C; C$_2$D$_2$Cl$_4$) shows the pattern of the symmetrical compound: two singlets for the OH groups (2:2), four pairs of doublets (1:2:2:1) for the methylene bridges, and three singlets for the *tert*-butyl groups (2:2:2).

When compound 8 was treated with an excess of ethyl bromoacetate 5 a complex reaction mixture was again obtained, from which a product could be isolated (40% yield) which, according to its FD-mass spectrum, must be a di-*O*-alkylated derivative of compound 8. The ^{1}H NMR spectra recorded at various temperatures show very broad signals. Therefore, a structure can be assigned only tentatively, where the two OH groups opposite the phthaloyl bridge are alkylated.

Further Macrocyclic Derivatives.—Formation of the cyclic 1,2-ester 3, obtained with phthaloyl dichloride, suggested that larger molecular assemblies might be obtainable if the dicarboxylic acid were to be replaced by the corresponding tetracarboxylic acid. In fact, if compound **1a** was treated with pyromellitoyl tetrachloride 10 (benzene-1,2,4,5-tetracarboxylic acid tetrachloride) under dilution conditions (THF, KOBu^t) the double calixarene 9 could be isolated in 29% yield by flash chromatography (Scheme 3). The ^{1}H NMR spectrum of compound 9 is very similar to that of compound 3. Two singlets for the *tert*-butyl groups, 3 pairs of doublets (proportions 1 : 2 : 1) for the methylene bridges and two pairs of doublets for the aromatic protons show that both calixarene substructures
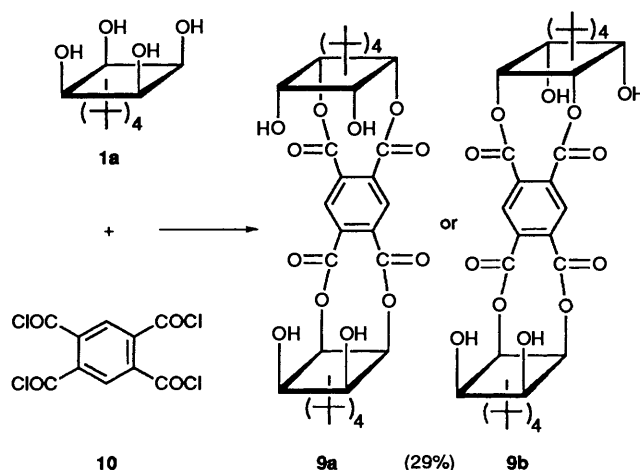
Scheme 3 *Reagents:* KOBu^t, THF

are connected to the bridging acid in an analogous way in both compounds. However, according to these data compound 9 may assume a U- or a Z-shaped form (9a or 9b), and it is not possible to rule out either of these possibilities. The strongest difference in chemical shifts, observed between analogous signals of compounds 3 and 9, is for the equatorial ArCH$_2$Ar proton found at the highest field (δ 3.32 vs. 2.89) and this can be explained, in principle, by slight conformational differences in either of the two forms of compounds 9 in comparison with compound 3. Unfortunately, the second stereoisomer could not be isolated, nor have single crystals of compound 9 been available up to now.

The recent publication of a doubly bridged calix[4]arene and a triply bridged calix[6]arene[22] which were obtained by reaction of the corresponding *tert*-butylcalixarenes with excess of BrCH$_2$Cl in DMF in the presence of Cs$_2$CO$_3$ prompts us to mention two singly bridged compounds, **11a** and **11b**, derived from calixarenes **1a** and **1c**, which we obtained under similar conditions using, however, a stoichiometric amount or a slight excess of the alkylating agent. This type of bridging was initially used by Cram *et al.*[27] to transform resorcinol-derived calix[4]arenes into rigid cavitands by 4 intramolecular OCH$_2$O bridges between the 8 *exo* hydroxy groups. In the light of the present results the reaction of the *endo* hydroxy groups of phenol-derived calixarenes seems not to be so easy.

11a   11b
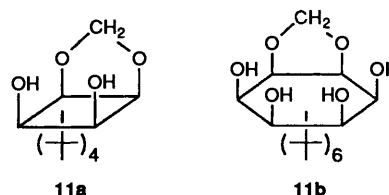
We obtained compounds **11a** and **11b** in 12 and 15% yield by flash chromatography; however, the reaction conditions are clearly not optimized. According to its ^{1}H NMR spectrum the calix[6]arene derivative **11b** is a flexible molecule with an effective symmetry plane, showing, for instance, three singlets of equal intensity for *tert*-butyl groups and a singlet and two pairs of doublets (proportions again 1:1:1) for the aromatic protons. Two singlets (ratio 1:1) for the OH protons (δ 9.11 and 7.83) may be taken as the most convincing proof for the presence of 1,2-bridging.

The conformational situation is more complicated for compound **11a**. At room temperature the ^{1}H NMR spectrum shows broad signals, while the low-temperature NMR spectra (−20 to −55 °C) gave sharper signals. Nevertheless, the assignment of

Table 1 The φ and χ torsion-angle values (°), which define the conformation of the phthaloyl-bridged calix[4]arene diester 6c.[28] Comparison with the torsion angles of the tetraethers I[29] and II[30] (partial cone conformations) and with the torsion angles of *m,p*-octamethylcalix[4]arene III[31] (cone conformation)
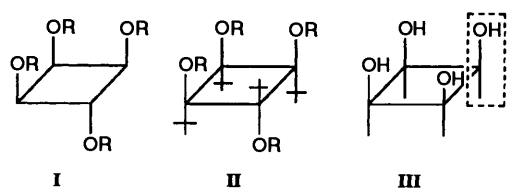
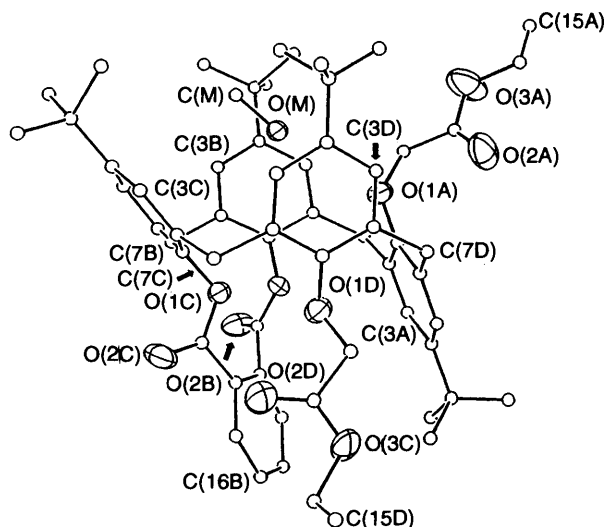|	6c		I		II		III	
Molecule	φ	χ	φ	χ	φ	χ	φ	χ
D–C	+68	−91	+62	−102	+75	−81	+72	−109
C–B	+90	−80	+97	−58	+80	−82	+112	−83
B–A	+130	+129	+116	+116	+139	+139	+76	−105
A–D	−128	−121	−117	−111	−142	−126	+109	−78

Fig. 1 A view of compound 6c·0.2MeOH with our labelling scheme. For clarity, the carbon and hydrogen atoms are drawn as small spheres of an arbitrary size. The oxygen atoms are depicted with their thermal parameters at the 35% probability level. Only one orientation of the disordered *tert*-butyl group on ring C is depicted
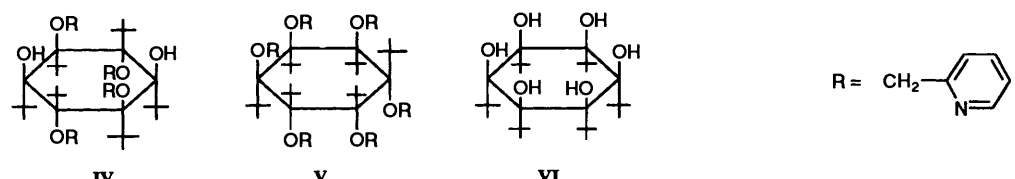
these signals to a single conformation is not possible. At high temperature (90 °C; $C_2D_2Cl_4$) the ^1H NMR spectrum shows the expected pattern of a flexible molecule with a symmetry plane, namely two singlets for the *tert*-butyl groups, four singlets for the methylene bridges (proportions 1:1:1:2, one belonging to the ether bridge), one singlet for the OH groups, and two doublets and a pseudo-singlet for the eight aromatic protons.

X-Ray Structure Analyses.—Although the crystals of compounds 6c and 8 diffracted relatively poorly (see Experimental section), we were able to obtain sufficient data to allow us to determine the details of their conformation unequivocally (Fig. 1). The conformation of compound 6c is defined by the angles which the aromatic rings make with the plane of the four methylene carbon atoms which link them, *viz.* − 108.9(3)° (A), 112.6(3)° (B), 127.6(3)° (C) and 100.7(3)° (D) (interplanar angles > 90° indicate that the aromatic ring system is tilted so that its *tert*-butyl group is directed *away from* the ring cavity; the negative angle indicates that the aryl group is inverted with respect to the other three aromatic systems). The aromatic rings A and C are at an interplanar angle of 19.0(3)° to one another but are orientated in opposite directions (the inverted ring A is

pitched away from the methylene carbon plane, ring C is tilted well back from the calix cavity). The aromatic rings B and D are at an angle of 33.4(3)° to one another, both rings being tilted so that their *tert*-butyl groups are pitched *away from* the calix cavity. The molecular conformation of compound 6c can also be described by an approach recently proposed by Ugozzoli and Andreetti,[28] using the torsion angles at the methylene carbon atoms, to which they assign the labels φ and χ. These torsion angles are listed in Table 1 and compared with the corresponding values of two tetraether derivatives [tetrakis-(pyridylmethyl) ether of calix[4]arene I[29] and tetrakis(pyridyl-methyl) ether of *tert*-butylcalix[4]arene II[30]] found also in the partial cone conformation. The sequence of the signs for φ and χ, namely + −, + −, + +, − − is characteristic of the partial cone conformation.[28] A calix[4]arene in the cone conformation, for instance, has the sequence + −, + −, + −, + − (see the example shown for comparison in Table 1).

The O $\cdots$ O separations of the adjacent phenolic oxygens are 3.81(1), 2.57(1), 3.05(1) and 4.11(1) Å in compound 6c, while the diagonal O $\cdots$ O separations are 4.74(1) Å [between O(1A) and O(1C) across the calixarene cavity] and 4.12(1) Å [between O(1B) and O(1D)]. The partial cone calix[4]arene 6c adopts a conformation in which the pendant CH_2CO_2Et group of the rotated aryl ring (A) is orientated *away from* the calixarene cavity produced by the other three aryl rings and with its carbonyl oxygen *exo* to the calixarene cup. The open cup conformation thus adopted by compound 6c is suitable for a solvent molecule being enclathrated in the cavity, and this is what we observe. A partial occupancy methanol molecule is enclathrated in the molecular cavity. The O(M) $\cdots$ O(1A) distance is 3.03 Å and is consistent with O–H $\cdots$ O hydrogen bonding between the hydroxy group of the methanol and the ethereal oxygen O(1A). We have previously reported calix[4]-arene structures which enclathrate small organic molecules within the molecular cavity, *e.g.* dichloromethane,[32] ethanol[33] and acetonitrile.[34]

Although broadly similar, the partial cone conformation adopted by compound 6c differs from structures I and II in the orientation of the aromatic rings (see the torsion angles in Table 1) and in the size of the calixarene cavity. This cavity can be considered to be intermediate in overall size between that observed in structure I (where the pyridyl group lies *exo* to the rather small cavity), and that described in structure II (where the more open cavity is filled by the inverted pyridyl ring). The structures of the partial cone conformers of *tert*-butylbis-(cyanomethoxy)dimethoxycalix[4]arene[35] and *tert*-butyldi-ethoxydimethoxycalix[4]arene[36] have also been recently reported, where the pendant group of the rotated aryl group lies

Table 2 The φ and χ torsion angle values (°), which define the conformation of **8**.[28] Comparison with the torsion angles of tetrakis(pyridylmethyl)calix[6]arene **IV**,[8] hexakis(pyridylmethyl)calix[6]arene **V**[37] and *tert*-butylcalix[6]arene **VI**[28,38]
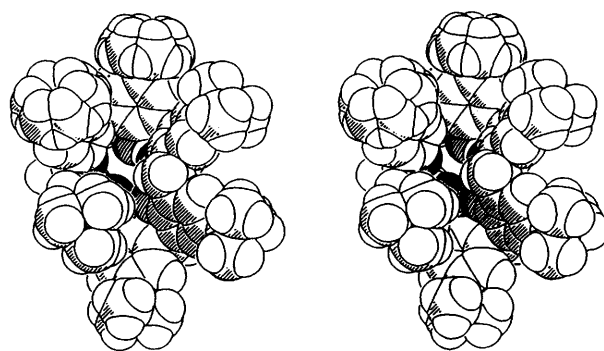

	8		**IV**		**V**		**VI**	
Molecule	φ	χ	φ	χ	φ	χ	φ	χ
B–A	+115	−85	−11	+87	−49	−85	+91	−100
A–F	+103	−33	+99	−78	+37	−101	−95	+94
F–E	+77	−97	+142	+147	+117	−7	+104	−84
E–D	+53	−96	−11	+87	+49	+85	+86	−93
D–C	+83	−93	+99	−78	−37	+101	−95	+96
C–B	−100	+82	+142	+147	−117	+7	+94	−94
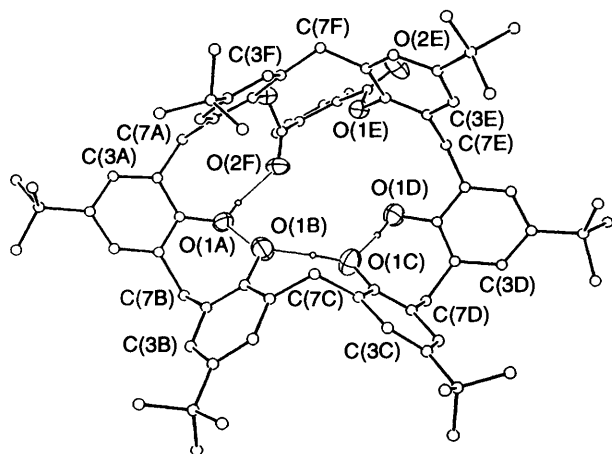
Fig. 2 An ORTEP view of the calix[6]arene **8** with our labelling scheme; thermal ellipsoids and atom sizes are as in Fig. 1

Fig. 3 A stereoview of the 'banana' shaped calixarene cavity in compound **8** with atoms depicted as their van der Waals spheres

outside the calix cavity, with a molecular conformation similar to that described in compound **I**.[29]

X-Ray analysis of the crystal of compound **8**·0.83C$_7$H$_8$· 0.38C$_6$H$_{14}$ shows that the calix[6]arene adopts a very distorted cone-shaped conformation in the solid state which is primarily determined by the four intramolecular O–H···O hydrogen bonds and by the steric demands that the phthaloyl residue exerts on the aromatic rings (E) and (F) (Fig. 2). The conformation of compound **8** can be defined by the angles which the aromatic rings make with the plane of four of the six methylene carbon atoms which are approximately coplanar, {C(7A), C(7B), C(7D), C(7E)}, *viz.* 163(1)° (A), 131(1)° (B), 120(1)° (C), 165(1)° (D), 102(1)° (E) and 97(1)° (F) [interplanar angles >90° indicate that the aromatic ring system is tilted so that its *tert*-butyl group is directed *back from* the ring cavity; methylene carbon atoms C(7C) and C(7F) are not coplanar with the four-atom methylene carbon plane defined above]. Aromatic rings (A) and (D) are tilted *far* back from this plane and are close to being coplanar with the four-atom methylene carbon plane. Aromatic rings (B) and (C) are tilted *well* back from the plane whilst planes (E) and (F) are almost perpendicular to it.

However, the molecular conformation of compound **8** is better and less ambiguously described by using the torsion angles φ and χ. The φ- and χ-values of compound **8** are listed in Table 2 and compared with the corresponding values for two other calix[6]arene derivatives {the tetrakis(pyridylmethyl) ether of *tert*-butylcalix[6]arene **IV**[8] and the hexakis(pyridyl-

methyl) ether of *tert*-butylcalix[6]arene **V**[37]} and for *tert*-butylcalix[6]arene **VI** itself. For compound **8** the sequence of signs is + −, + −, + −, + −, + −, − +, which is not characteristic of calix[6]arenes.[28] In fact no other example of a calix[6]arene or calix[6]arene derivative with this conformation (indicated by the sequence of signs) has been found in the crystalline state to date. The tetraether **IV** lying on a two-fold crystallographic axis has the sequence + −, + +, − +, + −, + +, − +, the hexaether **V** lying about an inversion centre has the sequence + −, + −, + +, − +, − +, − −, and the parent *tert*-butylcalix[6]arene **VI** adopting a 'pinched cone' conformation with approximate two-fold symmetry has + −, + −, − +, + −, + −, − +. The range of φ and χ angles and the sequence of signs indicate that the molecule has a very distorted conformation with an inversion occurring at the methylene carbon that links the B–C aromatic groups, showing that the macrocycle is formed by two subunits, which gives rise to two different sized compartments in the calix[6]arene. These φ and χ angles are listed in Table 2 for comparison with the same torsion angles of *tert*-butylcalix[6]arene.[38]

The three O···O separations of the adjacent phenolic oxygens are 2.74(1), 2.64(1) and 2.64(1) Å along the O(1D)– H···O(1C)–H···O(1B)–H···O(1A)   hydrogen-bonded chain. The corresponding H···O distances are 1.77, 1.50 and 1.84 Å. These hydroxy-group hydrogens were clearly located from difference maps at an intermediate stage of the refinement. The phenolic oxygen O(1A) is involved in hydrogen bonding with the carbonyl oxygen O(2F), the O(1A)···O(2F) distance being 2.66(1) Å, while the O(1A)···O(1F) distance is 4.28(1) Å. This carbonyl oxygen O(2F) is 0.87(1) Å removed from the eight-carbon-atom phthaloyl plane primarily resulting from the O–H···O hydrogen bonding compared with the
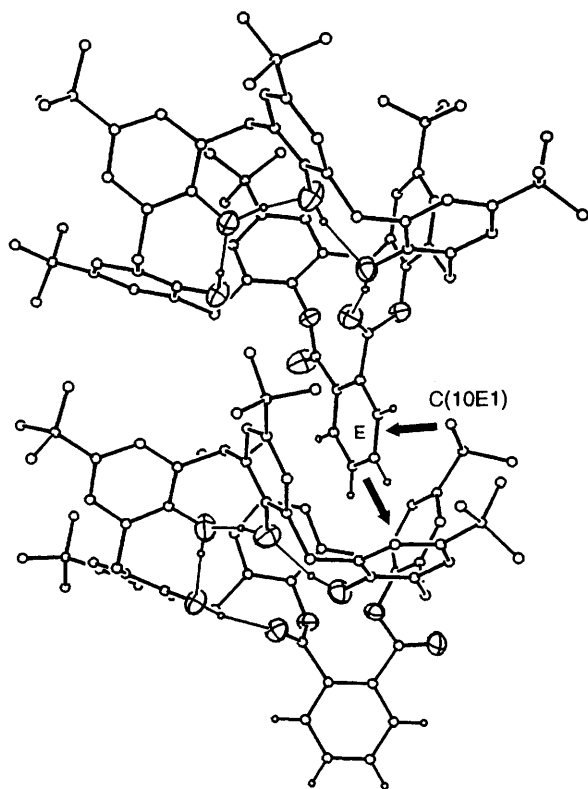
Fig. 4 An ORTEP view of enclathration of the phthaloyl residue of calix[6]arene 8 within the molecular cavity of another. The arrows indicate the direction of the C–H···π(arene) hydrogen-bonding interaction. Thermal ellipsoids and atom sizes are as in Fig. 1

'unperturbed' carbonyl oxygen O(2E) which is −0.20(1) Å from the plane. The {O(1F), C(12F), O(2F)} plane is at an angle of 74(1)° to the phthaloyl plane; 17(1)° is found for the corresponding {O(1E), C(12E), O(2E)} plane. The O(1D)···O(2E) and O(1D)···O(1E) distances are 5.10(1) and 3.54(1) Å, which are not hydrogen-bonding distances, and the carbonyl oxygen O(2E) is exo to the calix[6]arene cavity (Fig. 3).

The molecular cavity of the calix[6]arene 8 is best described as having a 'banana' shaped conformation in the solid state as a result of the steric demands of the phthaloyl residue and the hydrogen-bonding process described above. The major compartment of this 'curved' cavity is filled by the phthaloyl residue of a neighbouring molecule related by an n-glide. This self-inclusion process with repetition along the n-glide direction produces a one-dimensional polymeric chain.

The major driving forces in the enclathration of the phthaloyl residue in the calix[6]arene molecular cavity are the favourable C–H···π(arene) interactions that are formed (i) between the aromatic H(16E) of the phthaloyl group {C(13E)···C(18E)} and the aromatic ring {C(1D)···C(6D)} and (ii) between the methyl group C(10E1) of the disordered tert-butyl group attached to C(8E) and the phthaloyl group {C(13E)···C(18E)} (Fig. 4). The hydrogen H(16E)-to-{C(1D)···C(6D)} distances are in the range 2.73–3.20 Å, (C–H 0.95 Å) with H(16E) orientated towards the aromatic ring D centroid and the C(10E1)-to-{C(13E)···C(18E)} distances are in the range 3.45–3.71 Å. We have previously noted this effect in the structure of a calix[4]arene guest/host complex, where the enclathrated CH₂Cl₂ uses both C–H bonds to bind to two different arene rings.[32] A disordered partial occupancy toluene molecule partially fills the remaining calix[6]arene niche and partial occupancy n-hexane molecules reside in the lattice disordered about inversion centres.

Perrin and Lecocq[39] have reported that two types of inclusion compounds have been found in calixarenes, with the guest either outside (as a solvate) or enclathrated within the calixarene cones (frequently described as cryptato-cavitate or tubulato/intercalato clathrates using the nomenclature proposed by Weber and Josel[40]). We have recently reported a third type of inclusion in calixarenes in the above mentioned calix[4]-arene II where one of the aromatic rings is rotated so that its pyridine moiety is tightly accommodated inside the hydrophobic cavity as a self-inclusion monomer.[29] The present structure 8 (where the molecules are aligned in the lattice in the ac-plane as a one-dimensional molecular assembly) is best described as a self-inclusion polymer (Fig. 4).

We have seen this self-inclusion phenomenon previously in the structures of (i) a diester derivative of a calix[4]arene[41] and (ii) a calix[5]arene[42] but the present molecule 8 is a rare example of self-inclusion in a calix[6]arene. The structure of a 1,2,3-alternate tert-butylcalix[6]arene derivative,[38] where two of the ethereal chains partly fill the molecular cavity and the structure of dipropenylcalix[4]arene,[21] where dimers are formed by mutual enclathration of the allyl groups in the calixarene cavities. The major driving forces in these structures towards the formation of self-inclusion polymeric chains are the weaker C–H···π(arene) hydrogen bonds. They often form after the other, more favourable hydrogen-bond donors and acceptors have combined in various ways. The resulting C–H···π(arene) hydrogen bonds with a suitable pendant group either at the upper or lower rim of the calix[n]arene often dictate the overall packing arrangement.

Experimental

M.p.s were determined with a Büchi melting point apparatus or with a MEL TEMP 2 capillary melting point apparatus and are uncorrected. ¹H NMR (200 MHz) and ¹³C NMR (50.3 MHz) spectra were recorded on a Bruker AC 200 or a Nicolet NT-200 WB spectrometer; ¹H NMR (400 MHz) and ¹³C NMR (100.6 MHz) spectra were recorded on a Bruker AM 400 spectrometer. J Values are given in Hz. EI mass spectra were recorded with a Varian MAT CH 7 A (70 eV), FAB mass spectra with a Finnigan MAT 90, and FD mass spectra with a Finnigan MAT 90 (5 kV/10 mA/min) spectrometer. Flash column chromatography was performed on Merck silica gel 60 (230–400 mesh ASTM, 0.04–0.063 mm) with a N₂ pressure of 0.1–0.5 bar.*

THF was dried over sodium–benzophenone and distilled freshly before use. Acetonitrile (p.a. quality) was dried over molecular sieves (4 Å). CsF was heated for 1 h in vacuo at 100 °C before use. All reactions were carried out under dry argon or nitrogen.

Compound 3 was prepared as described in the literature[23] except that NaH was used as a base. Pyromellitoyl tetrachloride 10 was prepared according to a method of Hodd and Shadbolt.[43]

5,11,17,23-Tetra-tert-butyl-25-[(ethoxycarbonyl)methoxy]-26-hydroxy-27,28-(phthaloyldioxy)calix[4]arene 6a.—Ethyl bromoacetate 5 (501 mg, 3 mmol) was added to a suspension of compound 3 (389.2 mg, 0.5 mmol) and NaH (95%; 50.5 mg, 2 mmol) in THF (50 cm³). The reaction mixture was refluxed for 15 h, then filtered, and the solvent was removed under reduced pressure. The solid residue was purified by flash-column chromatography (CH₂Cl₂) to give compound 6a as a solid (185 mg, 43%), m.p. 294–296 °C; δ_H(200 MHz) 8.22 and 7.85 [2 × (1 H, dd, ³J 7.7 and 7.3, ⁴J 1.4, Phth Ar 2- and 2'-H)], 7.71 and

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* 1 bar = 10⁵ Pa.

7.62 [2 × (1 H, dt, ^3J 7.5, ^4J 1.7, Phth Ar 3- and 3'-H)], 7.31 (1 H, s, OH), 7.28, 7.25, 7.13, 7.12, 7.07, 6.98, 6.96 and 6.86 [8 × (1 H, d, ^4J 2.2–2.3, ArH)], 4.64 (1 H, d, ^2J 16.0, OCH$_2$CO$_2$), 4.45, 4.33, 4.15, 4.02, 3.51, 3.50, 3.39 and 3.26 [8 × (1 H, d, ^2J 12.3–14.3, ArCH$_2$Ar)], 4.12–4.01 (2 H, m, CH$_2$Me), 3.99 (2 H, d, ^2J 16.1, OCH$_2$CO$_2$), 1.25, 1.24, 1.17 and 1.14 [4 × (9 H, s, Bu^t)] and 1.22 (3 H, t, CH$_2$Me); m/z (FD) 864.8 (M$^+$. Calc. for C$_{56}$H$_{64}$O$_8$: M, 864.5).

5,11,17,23-*Tetra*-tert-*butyl*-25,26-*bis*[(*ethoxycarbonyl*)-*methoxy*]-27,28-(*phthaloyldioxy*)*calix*[4]*arene* **6b** (*Cone Isomer*) *and* **6c** (*Partial Cone Isomer*).—Cs$_2$CO$_3$ (162.9 mg, 0.5 mmol) was added to a solution of compound 3 (194.6 mg, 0.25 mmol) in THF–DMF (30 cm^3–30 cm^3) and the mixture was stirred for 30 min at 50 °C. Then a solution of the dichloride 5 (167 mg, 1 mmol) in THF (10 cm^3) was added dropwise and the mixture was refluxed for 16 h. After evaporation of the solvent the crude product was dissolved in CH$_2$Cl$_2$ and washed with water. The organic phase was dried over MgSO$_4$ and the solvent was removed. Two spots on the TLC plate indicated the formation of two products, which were separated by flash-column chromatography (CHCl$_3$–diethyl ether, 20 : 1).

Compound **6b**: solid (55 mg, 23%); m.p. 190–191 °C; δ_H(400 MHz) 7.96–7.94 (2 H, m, Phth Ar 2-H), 7.63–7.61 (2 H, m, Phth Ar 3-H), 7.24, 7.11, 6.94 and 6.86 [4 × (2 H, d, ^4J 1.7–2.3, ArH)], 4.78 and 3.39 [2 × (2 H, d, ^2J 13.1, ArCH$_2$Ar)], 4.38, 3.84, 3.43 and 3.23 [4 × (1 H, d, ^2J 12.7–14.1, ArCH$_2$Ar)], 4.32 and 4.00 [2 × (2 H, d, ^2J 16.1, OCH$_2$CO)], 4.18 (4 H, q, ^3J 7.1, CH$_2$Me), 1.27 (6 H, t, ^3J 7.2, CH$_2$Me) and 1.25 and 1.07 [2 × (18 H, s, Bu^t)]; m/z (FD) 952.0 (M$^+$. Calc. for C$_{60}$H$_{70}$O$_{10}$: M, 950.5).

Compound **6c**: solid (106 mg, 45%); m.p. 285–286 °C; δ_H(400 MHz) 7.80 and 7.74 [2 × (1 H, dd, ^3J 7.6, ^4J 1.2, Phth Ar 2-H)], 7.54 and 7.48 [2 × (1 H, dt, ^3J 7.5, ^4J 1.4, Phth Ar 3-H)], 7.32, 7.08, 7.06 and 6.88 [4 × (1 H, d, ^4J 2.2–2.4, ArH)], 7.16–7.15 (2 H, m, ArH), 6.97 (2 H, s, ArH), 4.88, 3.74, 3.44 and 3.38 [4 × (1 H, d, ^2J 12.9–13.9, ArCH$_2$Ar, syn)], 4.19–4.11 (2 H, m, CH$_2$Me, syn), 4.02 (2 H, s, ArCH$_2$Ar, anti), 4.01 and 3.78 [2 × (1 H, d, ^2J 15.9 and 18.2, OCH$_2$CO, syn)], 3.97 and 3.64 [2 × (1 H, d, ^2J 15.4 and 16.1, ArCH$_2$Ar, anti)], 3.54 (2 H, dq, ^3J 7.1, CH$_2$Me, anti), 2.73 and 2.49 [2 × (1 H, d, ^2J 15.8, OCH$_2$CO, anti)], 1.30, 1.21, 1.15 and 1.10 [4 × (9 H, s, Bu^t)], 1.27 (3 H, t, ^3J 7.2, CH$_2$Me, syn) and 0.69 (3 H, t, ^3J 7.1, CH$_2$Me, anti); m/z (FD) 950.9 (M$^+$. Calc. for C$_{60}$H$_{70}$O$_{10}$: M, 950.5).

5,11,17,23,29-*Penta*-tert-*butyl*-31,32,34-*trihydroxy*-33,35-(*phthaloyldioxy*)*calix*[5]*arene* **7**.—A mixture of compound **1b** (810.5 mg, 1 mmol) and K$_2$CO$_3$ (276.4 mg, 2 mmol) in THF (45 cm^3) was stirred for 40 min at 60 °C, then a solution of compound 2 (223.3 mg, 1.1 mmol) in THF (25 cm^3) was added at a rate of 10 cm^3 h^{-1}. The reaction mixture was stirred overnight at 70 °C before the solvent was removed under reduced pressure, and the residue was dissolved in CHCl$_3$, washed with brine, and the organic layer was dried over MgSO$_4$. After evaporation of the solvent the product mixture was separated by flash-column chromatography (CHCl$_3$–hexane, 10 : 1) to give the pure title product as a solid (127 mg, 14%), m.p. 235–237 °C; δ_H(400 MHz; room temp.) 8.78 and 8.57 [2 × (1 H, s, OH)], 8.39 (1 H, d, ^3J 7.7, Phth Ar 2-H), 7.80–7.78 (1 H, m, Phth Ar 2-H), 7.74–7.68 (2 H, m, Phth Ar 3-H), 7.47, 7.36, 7.24, 7.16, 7.10, 7.09, 7.06 and 7.02 [8 × (1 H, s, ArH)], 7.26 (2 H, s, ArH), 6.77 (1 H, s, OH), 4.16, 4.13, 4.05, 3.28, 3.90, 3.68, 3.62 and 3.58 [8 × (1 H, d, ^2J 12.1–15.9, ArCH$_2$Ar)], 3.49 (2 H, d, ^2J 14.4, ArCH$_2$Ar), 1.38, 1.30, 1.24, 1.14 and 1.11 [5 × (9 H, s, Bu^t)]; δ_H(200 MHz; CDCl$_2$CDCl$_2$; 393 K) 8.02 (2 H, br m, Phth ArH), 7.73–7.69 (2 H, m, Phth ArH), 7.30 (4 H, s, ArH), 7.24–7.10 (2 H, br s, OH), 7.04, 6.99

and 6.91 [3 × (2 H, s, ArH)], 6.37 (1 H, br s, OH), 4.12 and 3.53 [2 × (3 H, d, ^2J 14.2, 14.9, ArCH$_2$Ar)], 3.85 and 3.43 [2 × (2 H, d, ^2J 14.4 and 13.4, ArCH$_2$Ar)], 1.26 and 1.10 [2 × (18 H, s, Bu^t)] and 1.21 (9 H, s, Bu^t); m/z (FD) 940.7 (M$^+$. Calc. for C$_{63}$H$_{72}$O$_7$: M, 940.5).

5,11,17,23,29,35-*Hexa*-tert-*butyl*-37,38,39,40-*tetrahydroxy*-41,42-(*phthaloyldioxy*)*calix*[6]*arene* **8**.—Compound **1c** (2.918 g, 3 mmol) and K$_2$CO$_3$ (829 mg, 3 mmol) were suspended in a mixture of THF (75 cm^3) and DMF (10 cm^3) and the mixture was stirred for 40 min at 60 °C. A solution of compound **2** (609 mg, 3 mmol) in THF (25 cm^3) was added at a rate of 10 cm^3 h^{-1}, and the suspension was stirred overnight at 70 °C. The solvent was removed under reduced pressure and the crude product was purified by flash-column chromatography (CHCl$_3$) to afford compound **8** as a solid (1.48 g, 45%), m.p. 305–307 °C (decomp.); δ_H(400 MHz; room temp.) 9.96 (2 H, br s, OH), 8.44 and 8.22 [2 × (1 H, br s, OH)], 7.77–7.67 (4 H, m, Phth ArH), 7.48 (1 H, d, ^4J 1.7, ArH), 7.43 (1 H, s, ArH), 7.36 (1 H, d, ^4J 2.0, ArH), 7.24 (3 H, s, ArH), 7.20 (1 H, s, ArH), 7.18 (2 H, d, ^4J 1.8, ArH), 7.14 (1 H, d, ^4J 2.0, ArH), 7.00 and 6.85 [2 × (1 H, br s, ArH)], 4.37, 4.23 and 4.18 [3 × (1 H, d, ^2J 10.1–17.1, ArCH$_2$Ar)], 4.11–3.93 (2 H, br m, ArCH$_2$Ar), 3.93–3.77 (2 H, br m, ArCH$_2$Ar), 3.83 (1 H, d, ^2J 16.7, ArCH$_2$Ar), 3.65–3.48 (2 H, br m, ArCH$_2$Ar), 3.61 (1 H, d, ^2J 13.5, ArCH$_2$Ar), 3.44–3.30 (1 H, br s, ArCH$_2$Ar), 1.42, 1.39, 1.33 and 1.17 [4 × (9 H, s, Bu^t)] and 1.36 (18 H, s, Bu^t); δ_H(200 MHz; CDCl$_2$CDCl$_2$; 393 K) 9.43 (2 H, s, OH), 7.98 (2 H, br m, Phth ArH), 7.90 (2 H, s, OH), 7.68–7.63 (2 H, m, Phth ArH), 7.35 (2 H, s, ArH), 7.09 (6 H, s, ArH), 7.01 (2 H, d, ^4J 2.2, ArH), 6.77 (2 H, s, ArH), 4.25, 4.04 and 3.64 [3 × (1 H, d, ^2J 13.1–13.8, ArCH$_2$Ar)], 4.14 and 3.48 [2 × (2 H, d, ^2J 15.7 and 13.5, ArCH$_2$Ar)], 3.97 and 3.60 [2 × (2 H, s, ^2J 14.0 and 15.1, ArCH$_2$Ar)], 3.35 (1 H, s, ^2J 14.2, ArCH$_2$Ar) and 1.30, 1.26 and 1.09 [3 × (18 H, s, Bu^t)]; m/z (FD) 1103.3 (M$^+$. Calc. for C$_{74}$H$_{86}$O$_8$: M, 1102.6).

5,5',11,11',17,17',23,23'-*Octa*-tert-*butyl*-25,25',26,26'-*tetra*-*hydroxy*-27,27',28,28'-(*pyromellitoyltetraoxy*)*biscalix*[4]*arene* **9**.—KOBu^t (440 mg, 4 mmol) was added to a suspension of compound **1a** (1.48 g, 2 mmol) in THF (250 cm^3) and the mixture was refluxed for 45 min, before a solution of pyromellitoyl tetrachloride (330 mg, 1 mmol) in THF (50 cm^3) was added over a period of 4 h. The reaction mixture was kept at 80 °C overnight and then the solvent was evaporated. The residue was dissolved in CH$_2$Cl$_2$ (160 cm^3), the solution was washed with brine, dried over MgSO$_4$, filtered, and evaporated. The crude product was purified by flash-column chromatography (CH$_2$Cl$_2$–diethyl ether, 100 : 1) to give the title compound as a solid (430 mg, 29%), m.p. >330 °C; δ_H(400 MHz) 8.72 (2 H, s, Pyrom ArH), 7.69 (4 H, s, OH), 7.35, 7.23, 7.02 and 6.86 [4 × (4 H, d, ^4J 2.2–2.3, ArH)], 4.32 and 3.57 [2 × (4 H, d, ^2J 13.6, ArCH$_2$Ar)], 4.14, 3.83, 3.67 and 2.89 [4 × (2 H, d, ^2J 13.7–14.1, ArCH$_2$Ar)] and 1.29 and 1.17 [2 × (36 s, H, Bu^t)]; m/z (FAB) 1478.8 (M$^+$. Calc. for C$_{98}$H$_{110}$O$_{12}$: M, 1478.8).

5,11,17,23-*Tetra*-tert-*butyl*-25,26-*dihydroxy*-27,28-(*methyl*-*enedioxy*)*calix*[4]*arene* **11a**.—A solution of compound **1a** (740.55 mg, 1 mmol) and KOBu^t (449 mg, 4 mmol) in THF (200 cm^3) was refluxed for 30 min, then a solution of CH$_2$Br$_2$ (0.28 cm^3, 4 mmol) in THF (50 cm^3) was added at a rate of 2 cm^3 h^{-1} to the refluxing mixture. After 1 h of additional reflux the solvent was removed under reduced pressure, the residue was dissolved in CH$_2$Cl$_2$ (150 cm^3) and washed with brine (2 × 50 cm^3). The organic phase was dried over MgSO$_4$ and the solvent was evaporated off. The crude product was purified by flash-

Table 3 Summary of data collection, structure solution and refinement details

	6c	8
(a) Crystal data		
Empirical formula	$C_{60}H_{70}O_{10} \cdot 0.2CH_4O$	$C_{74}H_{86}O_8 \cdot 0.83C_7H_8 \cdot 0.38C_6H_{14}$
Formula M_r	951.2	1200.9
Colour, habit	colourless, block	colourless, block
Crystal size, mm	$0.15 \times 0.15 \times 0.25$	$0.30 \times 0.60 \times 0.65$
Crystal system	Triclinic	Monoclinic
a, Å	10.9292(6)	14.5554(13)
b, Å	15.0534(10)	35.3802(24)
c, Å	16.8534(14)	15.0160(12)
α, °	94.195(6)	90
β, °	90.044(6)	99.782(7)
γ, °	100.171(5)	90
V, Å³	2721.6(3)	7620(1)
Space group	$P\bar{1}$	$P2_1/n$
Z	2	4
Molecular symmetry	none	none
$F(000)$	1027	2617
D_{calc}, g cm⁻³	1.16	1.05
μ, mm⁻¹	0.07	0.07
(b) Data acquisition[a]		
Temp., °C	21	21
Unit-cell reflections (2θ-range, °)	25 (22–28)	25 (30–36)
$2\theta_{max}$(°) for reflections	48	48
hkl Range of reflections	$-12,12/0,17/-19,19$	$0,16/0,40/-17,17$
Variation in 3 standard reflections	< 1%	< 1%
Reflections measured	8530	12 421
Unique reflections	8529	11 913
R_{int}		0.008
Reflections with $I > n\sigma(I)$, n	2187, 2.0	4028, 3.0
(c) Structure solution and refinement[b]		
Solution method	direct methods	direct methods
H-atom treatment	riding	riding
No. of variables in LS	661 (block-diagonal)	878 (block-diagonal)
k in $w = 1/(\sigma^2 F_0 + kF_0^2)$	0.0010	0.0015
R, R_w, GoF	0.075, 0.076, 1.54	0.072, 0.097, 1.96
Density range in final Δ-map, e Å⁻³	$-0.22, 0.32$	$-0.36, 0.41$
Final shift/error ratio	< 0.02	< 0.07
Second extinction correction	0.469(099)	2.55(39)

[a] Data collection on an Enraf-Nonius CAD4 diffractometer with graphite-monochromatized Mo-Kα radiation (λ 0.7093 Å). [b] All calculations were done on a Silicon Graphics 4D-35TG computer system.

column chromatography to yield the title compound as a solid (80 mg, 12%) m.p. 247–249 °C; δ_H(200 MHz; $CDCl_2CDCl_2$; 363 K) 7.06 (4 H, pseudo-s, ArH), 7.02 and 6.98 [2 × (2 H, d, ^4J 2.1, ArH)], 4.94 (2 H, s, OH), 3.92, 3.85 and 3.77 [3 × (2 H, s, CH_2)], 3.82 (4 H, s, ArCH_2Ar) and 1.23 and 1.17 [2 × (18 H, s, Bu^t)]; m/z (EI) 660.2 (M$^+$. Calc. for $C_{45}H_{56}O_4$: M, 660.4).

5,11,17,23,29,35-Hexa-tert-butyl-37,38,39,40-tetrahydroxy-41,42-(methylenedioxy)calix[6]arene 11b.—A mixture of compound 1c (972.6 mg, 1 mmol) and Cs_2CO_3 (977 mg, 3 mmol) in DMF (125 cm³) was stirred for 30 min at room temperature. The mixture was warmed to 40 °C and a solution of CH_2BrCl (0.2 cm³, 3 mmol) in DMF (50 cm³) was added at a rate of 6 cm³ h⁻¹. The addition was repeated 4 times, the solvent was evaporated off under reduced pressure and the product mixture was separated by flash-column chromatography ($CHCl_3$) to afford the title compound as a pure solid (149 mg, 15%), m.p. 302–304 °C (decomp.); δ_H(200 MHz) 9.11 and 7.83 [2 × (2 H, s, OH)], 7.21 (4 H, s, ArH), 7.20, 7.19, 7.15 and 7.07 [4 × (2 H, d, ^4J 2.2–2.5, ArH)], 5.10 (2 H, br s, OCH_2O), 3.92 and 3.87 [2 × (6 H, s, ArCH_2Ar)] and 1.32, 1.316 and 1.25 [3 × (18 H, s, Bu^t)]; m/z (FD) 984.7 (M$^+$. Calc. for $C_{67}H_{84}O_6$: M, 984.6).

5,11,17,23-Tetra-tert-butyl-25-(carboxymethoxy)-26,27,28-trihydroxy calix[4]arene by Hydrolysis of Compound 6a.—A mixture of 1 mol dm⁻³ KOH (1.74 cm³, 1.74 mmol), compound 6a (100 mg, 0.116 mmol), MeOH (25 cm³) and water (2 cm³) was refluxed overnight. The clear solution was cooled and added dropwise to a mixture of ice and 1 mol dm⁻³ HCl to give a precipitate, which was washed with water to yield the title compound (81 mg, 99%) as a solid, m.p. 188–191 °C; m/z (EI) 706.5 (M$^+$. Calc. for $C_{46}H_{58}O_6$: M, 706.4).

5,11,17,23-Tetra-tert-butyl-25-[(ethoxycarbonyl)methoxy]-26,27,28-trihydroxycalix[4]arene.—The calix[4]arene mono-acid thus obtained (42 mg, 0.06 mmol) was esterified by being refluxed in absolute ethanol (30 cm³) in the presence of conc. H_2SO_4. Work-up gave the title compound (39.7 mg, 91%) as a solid, m.p. 269.5–271.5 °C; δ_H(400 MHz) 10.23 (1 H, s, OH at C-27), 9.26 (2 H, s, OH at C-26, C-28 OH), 7.09 (2 H, s, ArH), 7.05 (4 H, s ArH), 6.98 (2 H, d, ^4J 2.4, ArH), 4.88 (2 H, s, OCH_2CO), 4.48, 4.30, 3.43 and 3.42 [4 × (2 H, d, ^2J 12.6–14.1, ArCH_2Ar)], 4.40 (2 H, q, ^3J 7.1, CH_2Me), 1.39 (3 H, t, ^3J 7.1, CH_2Me), 1.23 and 1.19 [2 × (9 H, s, Bu^t)] and 1.20 (18 H, s, Bu^t); m/z (EI) 734.4 (M$^+$. Calc. for $C_{48}H_{62}O_6$: M, 734.5).

5,11,17,23-*Tetra*-tert-*butyl*-25,26-*bis*(*carboxymethoxy*)-27,28-*dihydroxycalix*[4]*arene* (syn *Isomer*) *by Hydrolysis of Compound* 6b.—A mixture of compound 6b (90 mg, 0.095 mmol) and 1 mol dm⁻³ KOH (1.9 cm³) in MeOH–water (33 cm³–3 cm³) was refluxed overnight. The crude product was purified by flash-column chromatography (CHCl₃–MeOH, 5:1) to give the title compound as a solid (52 mg, 72%), m.p. 275–277 °C (decomp.); m/z (FD) 764.5 (M⁺. Calc. for C₄₈H₆₀O₈: M, 764.4).

5,11,17,23-*Tetra*-tert-*butyl*-25,26-*bis*(*carboxymethoxy*)-27,28-*dihydroxycalix*[4]*arene* (anti *Isomer*) *by Hydrolysis of Compound* 6c.—A suspension of compound 6c (90 mg, 0.095 mmol) in a mixture of MeOH–water (25 cm³–3 cm³) and 1 mol dm⁻³ KOH (3.77 cm³) was refluxed for 2 days. Work-up as described for compound 6a gave the title compound as a solid (60 mg, 83%), m.p. 240–245 °C (decomp.); m/z (FD) 764.5 (M⁺. Calc. for C₄₈H₆₀O₈: M, 764.4).

Structural Analysis for Calixarenes 6c *and* 8.—Single crystals of compound 6c were obtained by gas-phase diffusion of n-hexane into a solution of compound 6c in benzene. Single crystals of compound 8 were obtained from a solution in CH₂Cl₂ by gas-phase diffusion of ethanol.

Both structures were solved by direct methods using SHELXS86[44] which revealed the non-hydrogen atoms of the calixarene core, and were refined using the NRCVAX[45] suite of programs. The remaining non-hydrogen atoms were located in subsequent difference Fourier syntheses. Details of the X-ray experimental conditions, cell data, data collection and refinement for molecules 6c·0.2 MeOH and 8·0.83C₇H₈·0.38C₆H₁₄ are summarized in Table 3.

Additional material available from the Cambridge Crystallographic Data Centre comprises atom coordinates and thermal parameters.* Copies of the structure factor listing are available from the authors.

Conclusion.—Reaction of *tert*-butyl-calix[4]- and -calix[6]-arene with phthaloyl dichloride may be used, in principle, to protect the OH groups of two adjacent phenolic units in a reversible way, while with *tert*-butylcalix[5]arene the bridging was observed only between two distal OH groups. Further alkylation of the remaining OH groups is possible but, in general, the introduction of the phthaloyl groups as well as the further alkylation leaves room for improvements, while the ester groups can be cleaved again in a clean way.

* See Instructions for Authors, *J. Chem. Soc., Perkin Trans. 1*, 1994, issue 1.

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