J. Am. Chem. Soc. 1995, 117, 586–601

Conformational Characteristics of Ethers and Esters of *p-tert*-Butylcalix[5]arene[1]

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Received April 25, 1994. Revised Manuscript Received October 27, 1994®

Abstract: As part of a program involving the chemistry of the calix[5]arenes, a variety of ethers and esters of *p-tert*-butylcalix[5]arene (**1b**) have been synthesized and their conformational behavior studied by means of variable temperature ^{1}H NMR spectroscopy. The following is shown: (a) The $\Delta G^\ddagger$ values for conformational interconversion diminish progressively as the OH groups of **1b** are changed to OMe groups, ascribed to continuously diminishing intramolecular hydrogen bonding that is not offset by the corresponding increase in steric hindrance. (b) The $\Delta G^\ddagger$ values for conformational interconversion of the pentaethers of **1b** increase as the OR groups get larger, ascribed to increasing steric hindrance. (c) The $\Delta G^\ddagger$ values for the conformational interconversion of the pentaesters of **1b** also increase with the size of the ester group and are somewhat higher than those for the pentaethers of corresponding carbon content, ascribed to the additional steric hindrance provided by the carbonyl oxygen. (d) The $\Delta G^\ddagger$ values for the conformational interconversion of the monoethers are higher than those of the corresponding pentaethers, ascribed to intramolecular hydrogen bonding and steric hindrance factors acting cooperatively. (e) Sufficiently large ether or ester groups confer limited conformational mobility, as in the case of the mono-*n*-propyl ether and the cyclopropylcarbanoate of **1b**, or complete conformational immobility, as in the case of the monobenzyl ether, pentabenzyl ether, pentaisobutanoate, pentapivaloate, pentabenzoate, and pentatosylate of **1b**. The conformational assignments are supported in three cases with X-ray crystallographic structures of the pentaisopropyl ether, pentaallyl ether, and mono-*n*-propyl ether.

Calixarenes are macrocyclic compounds available in a variety of ring sizes and are of interest both as complexation hosts for ions and molecules and as frameworks for elaborating more complex structures.[3] The chemistry of the cyclic tetrameric and cyclic hexameric compounds derived from the very readily accessible *p-tert*-butylcalix[4]arene (**1a**)[4] and *p-tert*-butylcalix[6]arene (**1c**),[5] respectively, has been extensively studied, while that of compounds derived from the much less readily accessible *p-tert*-butylcalix[5]arene (**1b**)[6,7] has lagged behind.[8] However, an improved synthesis procedure[9] now makes **1b** available in sufficient quantity (*ca.* 15% yield from *p-tert*-butylphenol and formaldehyde) to allow its chemistry to be investigated with modest ease.

One of the particularly interesting features of the calixarenes is their protean ability to assume a variety of shapes via conformational interconversions, the mobility[10] of the systems increasing with ring size.[11] Two pathways for this process can be envisaged, one involving a "lower rim through the annulus" motion in which the OR groups swing through the annulus, the other involving an "upper rim through the annulus" motion in which the para substituents swing through the annulus. In the

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® Abstract published in *Advance ACS Abstracts*, December 15, 1994.

(1) Paper 39 in a series entitled "Calixarenes". For paper 38 *cf.*: Alam, I.; Sharma, S. K.; Gutsche, C. D. *J. Org. Chem.* **1994**, *59*, 3716. A preliminary account of paper 39 was presented at the XVII International Symposium on Macrocyclic Chemistry in Provo, Utah, August 1992 (Abstract IS21) and a more complete acount was presented at the 2nd Workshop on Calixarene and Related Compounds, Kurume, Fukuoka, Japan, June 1993 (Abstracts IL-1).

(2) The author to whom inquiries concerning the X-ray crystallographic determinations should be directed.

(3) For reviews covering the literature to *ca.* 1989 *cf.*: (a) Gutsche, C. D. Calixarenes. In *Monographs in Supramolecular Chemistry*; Stoddart, F. R., Ed.; Royal Society of Chemistry: London, 1989. (b) *Calixarenes. A Versatile Class of Macrocyclic Compounds*; Vicens, J., Böhmer, V., Eds.; Kluwer Academic Publishers: Dordrecht, 1991. For a more recent review with an emphasis on conformational and complexation characteristics *cf.*: Shinkai, S. *Tetrahedron* **1993**, *49*, 8933.

(4) Gutsche, C. D.; Iqbal, M. *Org. Syn.* **1990**, *68*, 234.

(5) Gutsche, C. D.; Dhawan, B.; Leonis, M.; Stewart, D. *Org. Syn.* **1990**, *68*, 238.

(6) (a) Ninagawa, A.; Matsuda, H.; *Makromol. Chem. Rapid Commun.* **1982**, *3*, 65. (b) Markowitz, M. A.; Janout, V.; Castner, D. G.; Regen, S. L. *J. Am. Chem. Soc.* **1989**, *111*, 8192.

(7) The synthesis of *p*-benzylcalix[5]arene in 33% yield has been reported: Souley, B.; Asfari, Z.; Vicens, J. *Polish J. Chem.* **1992**, *66*, 959.

(8) The variable temperature ^{1}H NMR spectral behavior of a calix[5]arene containing *p*-methyl and *p-tert*-butyl groups has been studied: Kämmerer, H.; Happel, G.; Mathiasch, B. *Makromol. Chem.* **1981**, *182*, 1685. A brief study of the conformational behavior of several ethers of *p*-benzylcalix[5]arene has been reported: Souley, B.; Asfari, Z.; Vicens, J. *Polish J. Chem.* **1993**, *67*, 763. The introduction of functional groups into the para position has been reported: (a) Shinkai, S.; Koreishi, H.; Ueda, K.; Arimura, T.; Manabe, O. *J. Am. Chem.* **1987**, *109*, 6371. (b) Gutsche, C. D.; Alam, I. *Tetrahedron* **1988**, *44*, 4689. (c) Markowitz et al.[5b] The use of calix[5]arenes in monolayers has been studied by Regen and coworkers.[6b,41] Calix[5]arene-crown ethers have been synthesized by Kraft et al.[27] The conversion to calix[5]quinone has been reported: Reddy, P. A.; Kashyap, R. P.; Watson, W. H.; Gutsche, C. D. *Isr. J. Chem.* **1992**, *32*, 89. A monodeoxycalix[5]arene has been synthesized: Usui, S.; Deyama, K.; Kinoshita, R.; Odagaki, Y.; Fukazawa, Y. *Tetrahedron. Lett.* **1993**, *34*, 8127. The ion-complexation behavior of *p-tert*-butylcalix[5]arene derivatives has been reported by Barrett et al.[45]

(9) (a) Stewart, D. R.; Gutsche, C. D. *Org. Prep. Proc. Intl.* **1993**, *25*, 137. (b) Iwamoto, K.; Araki, K. Shinkai, A. *Bull. Chem. Soc. Jpn.* **1994**, *67*, 1499. Iwamoto et al. apparently unaware of the prior publication[9a] have described, in less explicit detail but with comparable results, an "improved synthesis" of *p-tert*-butylcalix[5]arene.

(10) The conformational mobility of a calixarene can be discussed, *inter alia*, in terms of (a) the number of available conformations, (b) the ease with which an aryl unit can rotate through the annulus, as judged on the basis of molecular models or molecular dynamics simulations, (c) the minimum size of subsituents on the upper and/or lower rim that are necessary to curtail conformational interconversion, and (d) the $\Delta G^\ddagger$ of conformational inversion as measured by variable temperature NMR spectroscopy.

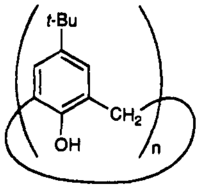
(11) Gutsche, C. D.; Bauer, L. J. *J. Am. Chem. Soc.* **1985**, *107*, 6052 report that the $\Delta G^\ddagger$ value for conformational inversion of **1b** is 2.5 kcal mol^{-1} less than that of **1a** and 0.2 kcal mol^{-1} greater than that of **1c**.

0002-7863/95/1517-0586$09.00/0

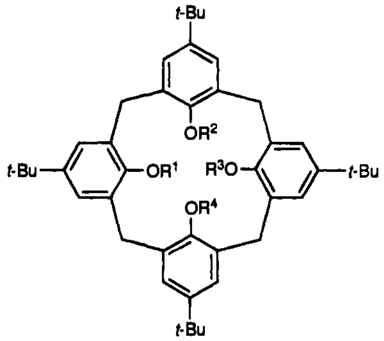
calix[4]arenes the upper rim through the annulus motion is not possible, this pathway being precluded even when the para substituents are as small as hydrogen. However, this motion has been shown to occur in the calix[6]arenes not only when the para substituents are hydrogens[12] but also when they are the much larger *tert*-butyl groups.[13] Molecular models indicate that the calix[5]arenes fall between these two situations, with conformational interconversion via the upper rim through the annulus pathway possible when the para substituents are hydrogens but not when they are *tert*-butyl groups except, possibly, at very high temperatures (*vide infra*). Thus, at normal experimental temperatures conformational interconversion of *p-tert*-butylcalix[5]arenes is restricted to the lower rim through the annulus pathway. The work described in this paper, therefore, focuses on the lower rim and explores the conformational behavior of the ethers and esters of *p-tert*-butylcalix[5]arene (**1b**) as a means for predicting and controlling the shapes of these cyclic pentamers.

The possibility for calix[4]arenes to exit in four "up/down" forms was first perceived in the 1950s by Cornforth and coworkers.[14] The subsequent designation of these structures as conformers followed from Barton's concepts of conformational analysis, and the conformers were later named by Gutsche and co-workers[15,16] as "cone", "partial cone", "1,2-alternate", and "1,3-alternate". An interesting phenomenon was observed by these workers[15] when they converted **1a** to its 1,3-dimethyl ether **2c** (which exists in the solid state as a somewhat flattened cone[17]) and to the tetramethyl ether **2e** (which exists in solution as a mixture of conformers[18]). Although CPK models indicate that both ethers **2c** and **2e** should be conformationally less flexible than the parent compound **1a**, variable temperature ^{1}H NMR spectroscopy proves **2e** to be almost identical in conformational mobility with **1a**, belying the reliability of inferring steric barriers from CPK models. The monomethyl ether **2a**, 1,2-dimethyl ether **2b**, and trimethyl ether **2d** have more recently been synthesized and studied[19,20] and found, like **2c**, to be less conformationally mobile than the parent compound **1a** or the tetramethyl ether **2e**. The bell-shaped curve that would be obtained if one were to plot conformational mobility *vs* the degree of O-methylation of **1a** can be ascribed to the synergistic interplay of intramolecular hydrogen bonding and steric factors. In **1a** intramolecular hydrogen bonding is at a maximum and serves to hold the compound in a cone conformation. In **2e** intramolecular hydrogen bonding is nonexistent, and only the steric interference arising from the OCH_3 groups determines the conformational mobility. In **2a**–**d** both hydrogen bonding[21] and steric interference reduce conformational mobility, the two effects combining to reach a maximum in the 1,2- and 1,3-dimethyl ethers **2b** and **2c**. As the size of the substituents attached to the phenoxy oxygens is increased beyond methyl, the conformational mobility decreases. Thus, the tetraethyl ether of **1a** is much less conformationally mobile than the tetramethyl ether **2e**,[16] and the tetrapropyl ether[22,23] and tetrabenzyl ether[16] of **1a** are conformationally fixed. These observations provide the reference point for the exploration of the conformational behavior of the ethers and esters of the next larger cyclic oligomer, *p-tert*-butylcalix[5]arene (**1b**).

Chart 1



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



	R1	R2	R3	R4
2a	CH_3	H	H	H
2b	CH_3	CH_3	H	H
2c	CH_3	H	CH_3	H
2d	CH_3	CH_3	CH_3	H
2e	CH_3	CH_3	CH_3	CH_3

Synthesis and Proof of Structure of Ethers and Esters of *p-tert*-Butylcalix[5]arene. The pentaethers **3g** and **4**–**10** were prepared from **1b** using either NaH and the alkyl halide in 9:1 THF/DMF, which afforded yields of 50–60%, or K_2CO_3, and the alkyl halide in refluxing acetonitrile, which afforded isolated yields of 75–90%. The latter method was particularly useful for preparing the pentaisopropyl ether **6**, for it effectively avoided the dehydrohalogenation of the alkylating agent isopropyl iodide. Pentaesters **11** and **12** were obtained in excellent yield by heating **1b** in the presence of the corresponding anhydride and a trace of acid. Pentaesters **13**–**17** were obtained by first refluxing **1b** with an excess of NaH in THF followed by dropwise addition of the appropriate acid chloride. The syntheses of the pentaisobutanoate **14**, pentapivaloate **16**, and pentabenzoate **17** produced other compounds as well. In the case of **16**, the two conformers of the pentaester were shown by HPLC to be present in yields of 9% and 30%, accompanied by 60% of the tetrapivaloate. In the case of **17** the pentabenzoate was isolated in 44% yield, accompanied by 20% of several unidentified compounds.

The partially etherified derivatives of **1b** were prepared using $KHCO_3$ and the alkylating agent in refluxing acetonitrile or acetone. In contrast to the preparation of methyl ethers of **1a**, for which good selective procedures are available, methylation of **1b** in all cases yielded mixtures of partially methylated products that required separation by chromatography. To judge

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[12] Gutsche, C. D.; Bauer, L. J. *J. Am. Chem. Soc.* **1985**, *107*, 6059.

[13] Otsuka, H.; Araki, K.; Shinkai, S. *Chem. Express* **1993**, *8*, 479. Otsuka, H.; Araki, K.; Sakaki, T.; Nakashima, K.; Shinkai, S. *Tetrahedron Lett.* **1993**, *34*, 7275. van Duynhoven, J. P. M.; Janssen, R. G.; Verboom, W.; Franken, S. M.; Casnati, A.; Pochini, A.; Ungaro, R.; de Mendoza, J.; Nieto, P. M.; Prados, P.; Reinhoudt, D. N. *J. Am. Chem. Soc.* **1994**, *116*, 5814.

[14] Cornforth, J. W.; Hart, P. D'Arcy, Nicholls, G. A.; Rees, R. J. W.; Stock, J. A. *Br. J. Pharmacol.* **1955**, *10*, 73.

[15] Gutsche, C. D.; Dhawan, B.; No, K. H.; Muthukrishnan, R. *J. Am. Chem. Soc.* **1981**, *103*, 3782.

[16] Gutsche, C. D.; Dhawan, B.; Levine, J. A.; No, K. H.; Bauer, L. J. *Tetrahedron* **1983**, *39*, 409.

[17] Grootenhuis, P. D. J.; Kollman, P. A.; Groenen, L. C.; Reinhoudt, D. N.; van Hummel, G. J.; Ugozzoli, F.; Andreetti, G. D. *J. Am. Chem. Soc.* **1990**, *112*, 4165.

[18] Groenen, L. C.; van Loon, J.-D.; Verboom, W.; Harkema, S.; Casnati, A.; Ungaro, R.; Pochini, A.; Ugozzoli, F.; Reinhoudt, D. N. *J. Am. Chem. Soc.* **1991**, *113*, 2385.

[19] Alfieri, C.; Dradi, E.; Pochini, A.; Ungaro, R. *Gazz. Chim. Ital.* **1989**, *119*, 335.

[20] Groenen, L. C.; Steinwender, E.; Lutz, B. T. G.; van der Maas, J. H.; Reinhoudt, D. N. *J. Chem. Soc., Perkin Trans. 2*, **1992**, 1893.

[21] Araki et al. (Araki, K.; Iwamoto, K.; Shinka, S.; Matsuda, T. *Bull. Chem. Soc. Jpn.* **1990**, *63*, 3480) have shown that methylation of **1a** reduces the strength of the hydrogen bonding but does not destroy it.

[22] Iwamoto, K.; Fujimoto, K.; Matsuda, T.; Shinkai, S. *Tetrahedron Lett.* **1990**, *31*, 7169.

[23] Iwamoto, K.; Araki, K.; Shinkai, S. *J. Org. Chem.* **1991**, *56*, 4955.

Table 1. IR and ^1H NMR Spectral Features of the OH and OCH_3 Groups of **1b** and **3a–3g**

compd	ν_{OH} (cm^{-1})	(at ca. 20 °C)	δ_{OH}^{a} (at ca. −60 °C)	δ_{OCH_3}^{b}
1b	3260	8.68 (5)	8.85 (5)	
3a	3372	8.01 (2)	8.12 (2)	3.88 (1)
	3464	7.95 (2)	7.96 (2)	
3b	3378	7.47 (2)	8.1 (3)	3.67 (2)
	3516 sh	7.45 (1)		
3c	3383	7.86 (2)	8.34 (2)	3.82 (2)
	3506	6.94 (1)	7.52 (1)	
3e	3395	6.91 (2)	7.65 (2)	3.22 (2)
	3516 sh			3.51 (1)
3f	3375	7.00(1)	7.64 (1)	2.98 (2)
	3420			3.53 (2)
3g				2.96 (5)

[a] The number of OH groups represented by the peak is shown in parentheses. [b] The number of OCH_3 groups represented by the peak is shown in parentheses.

the degree of nonselectivity in the preparation of **3a–g** (**3d** not isolated or detected) the isolated and HPLC yields of these compounds were compared with the yields predicted by a binomial distribution expression[24] when $p = 0.40$ (predicted values shown in parentheses): **1b** = <1% (7.8%), **3a** = 37% (26%), **3b**/**3c** = 20% (35%), **3e** = 38% (23%), **3f** = <1% (8%), **3g** = <1% (1%). The divergence between the observed and calculated yields suggests that the dimethyl ethers **3b** and/or **3c** are more reactive than the monomethyl ether **3a** or the trimethyl ether **3e**.

The melting points of the ethers and esters of **1b** cover an exceptionally wide range, from a low of 125 °C for the pentaallyl ether **7** to a high of 422–423 °C for the noncone conformer of the pentapivaloate **16**. The derivatives are generally insoluble in MeOH and EtOH, partially soluble in *i*-PrOH, acetone, *n*-BuOH, and hexane, and soluble to very soluble in chlorinated solvents, aromatic solvents, EtOAc, and THF.

The structures of the methyl ethers of **1b** were established by elemental analysis and ^1H NMR/^{13}C NMR spectroscopy. The structures of the dimethyl ethers **3b** and **3c** were tentatively assigned on the basis of the positions of the OH resonances in the ^1H NMR spectra (see Table 1), using data from the more symmetrical methyl ethers of **1c** as reference points.[25–27] The higher field resonance at δ 6.94 for the single proton of **3c** is attributed to an OH group sandwiched between adjoining OCH_3 groups which precludes hydrogen bonding to an adjacent OH group. The high field position of the OH resonance for the trimethyl ether [δ 6.91 (2 protons)] similarly provides support for a 1,2,4 pattern (**3e**) of substitution rather than a 1,2,3 pattern for compound **3d**.

Conformations of *p-tert*-Butylcalix[5]arene (1b). Calix[5]arenes resemble calix[4]arenes in having four up/down conformations which can be similarly designated as cone, partial cone, 1,2-alternate, and 1,3-alternate. These are shown in the upper row of Figure 1 using an iconographic representation[28] elaborated from one proposed by Kanamathareddy and Gutsche.[29] Molecular mechanics calculations[30,31] were carried out for each of the up/down conformers of **1a** and **1b**, and in both cases the cone conformation is calculated to be the most stable (energies in kcal mol^{-1} for **1a**: cone 46.01, partial cone 49.36, 1,2-alternate 53.21, 1,3-alternate 50.57; energies in kcal mol^{-1} for **1b**: cone 54.81, partial cone, 56.83, 1,2-alternate 61.00, 1,3-alternate 56.09).[32] X-ray crystallographic determinations show that *p*-H-calix[5]arene (complexed with acetone),[33] *p-tert*-butylcalix[5]arene (complexed with tetralin[34] and intermolecu-

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(24) The yields are based on a binomial distribution and were calculated using the expression (Bromberg, J. P. *Physical Chemistry*, Allyn and Bacon: Boston, 1980, p 395.): $P(n;N,p) = \{N!/[(N - n)!n!]\}p^nq^{N-n}$ which gives the probability of achieving n successes in N trials where the probability of success is p and the probability of failure q is equal to $1 - p$. As applied to the prediction of yields of the products of methylation of **1b**, $N = 5$, p is the number of equivalents of MeOTs per phenoxy group, and n is the number of OMe groups (1–5) in compounds **3a–g**. Implicit in these calculations are the assumptions that the reaction goes to completion and that the methylations of **1b** and methyl ethers **3a–f** occur at the same rate. The probability of methylation (p) is the ratio of the number of equivalents of MeOTs to the number of equivalents of ArOH groups. Small yields (<1%) were detected by HPLC.

(25) (a) Janssen, R. G.; Verboom, W.; Reinhoudt, D. N.; Casnati, A.; Freriks, M.; Pochini, A.; Ugozzoli, F.; Ungaro, R.; Nieto, P. M.; Carramolino, M.; Cuevas, F.; Prados, P.; de Mendoza, J. *Synthesis* **1993**, 380. (b) Otsuka, H.; Araki, K.; Shinkai, S. *J. Org. Chem.* **1994**, *59*, 1542.

(26) Kanamathareddy, S.; Gutsche, C. D. *J. Org. Chem.* **1994**, *59*, 3871.

(27) Kraft et al. (Kraft, D.; Arnecke, R.; Böhmer, V.; Vogt, W. *Tetrahedron* **1993**, *49*, 6019) have employed a similar argument.

(28) These representations are stylized projections of calix[5]arene conformations conveying information from which space-filling models can be easily constructed, employing the following guidelines: (a) The internal reference plane of the calixarene, which is generally defined either by the methylene carbons or the Ar(1) aryl carbons, is oriented parallel with the projection plane. (b) The macrocyclic framework of a calix[*n*]arene is represented by an *n*-sided polygon, the vertices of which represent the methylene carbons. (c) The aryl units are represented either by narrow rectangles or squares, depending on the angle that the plane of the aryl unit makes with the internal reference plane. If the angle is greater than ±45° (*i.e.*, for up/down orientations) a rectangle is used. If it is less than ±45° (*i.e.*, for flattened orientations) a square is used. (d) When a square representation is used, its offset position relative to the polygon indicates whether the para position of the aryl group is projecting toward the annulus (i.e., an "in" orientation) or away from the annulus (i.e., an "out" orientation). (e) A shaded rectangle or square indicates that the para position of the aryl group projects away from the viewer (i.e., a "down" orientation); an unshaded rectangle or square indicates that the aryl group projects toward the viewer (i.e., an up orientation). (f) The vertices of the polygon represent the methylene groups when the adjoining aryl moieties are in an up/up or up/down orientation. (g) For pleated loop conformations (*cf.* ref 37) and for other conformations in which one or both of a pair of adjoining aryl moieties assume in or out conformation the methylene groups are often best represented by a small circle that is shaded if their hydrogens project downward (a "below the plane" group) or unshaded if their hydrogens project upward (an "above the plane" group).

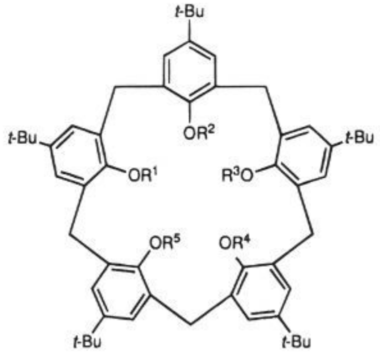
(29) Kanamathareddy, S.; Gutsche, C. D. *J. Am. Chem. Soc.* **1993**, *115*, 6572.

(30) Molecular mechanics calculations were carried out on a Silicon Graphics IRIS 4D 210 VGX computer using the QUANTA 3.2/CHARMm 21.3 program package which gives energies in kcal mol^{-1}. Except as noted below, the default parameters supplied with the program were used. Calixarenes were modeled by constructing the molecule in the ChemNote program and then importing it into the main QUANTA program. During this process, the partial charges assigned from charge templates were smoothed to zero over non-hydroxyl atoms only. Within QUANTA, the energy of the calixarene was minimized using the steepest decents (SD), the adopted-basis Newton Raphson (ABNR), and the full Newton Raphson (NR) routines. During iterations of these routines a 50 Å cut-off distance was used so that all nonbonded interactions were calculated, and these interactions were updated every five iterations for the SD and ABNR routines and every iteration for the NR routine. Importantly, a radially dependant dielectric function (RDIE), proportional to $1/r^2$, was used with a weighting factor of 1.00. After importing the calixarene from ChemNote, the energy was first minimized with the SD routine to remove the worst contacts and then with the ABNR routine to an energy gradient, rms force of *ca.* 0.3 kcal mol^{-1} Å^{-1}. The desired up/down conformer was generated by breaking one Ar–CH_2 bond, appropriately adjusting the macrocyclic torsions to the desired values, reforming the broken bond, and then energy minimizing the new up/down conformer with the ABNR routine to an rms force of *ca.* 0.3. The resulting structure was subjected to a systematic conformational search in which all ArOH bonds and at least two Ar–$C(CH_3)_3$ bonds were varied between the initial value and the initial value +180°. The energies of these conformers were minimized with 2000 iterations of the ABNR routine or until an rms force of *ca.* 0.05 was reached followed by the full Newton-Raphson routine to an rms force of 1×10^{-7} or less. The energy and structure of the lowest energy conformer from each search was then used for comparisons with other up/down conformers of the same size.

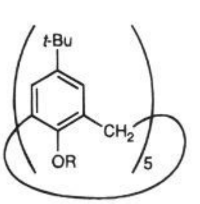
(31) (a) QUANTA/CHARMm v3.2, Molecular Simulations, Inc, 200 Fifth Ave. Waltham, MA 02143. (b) Brooks, B. R.; Bruccoleri, R. E.; Olafson, B. D.; States, D. J.; Swaminathan, S.; Karplus, M. *J. Comput. Chem.* **1983**, *4*, 187. (c) Momany, F. A.; Rone, R. *J. Comp. Chem.* **1992**, *13*, 888.

(32) Lipkowitz, K. B.; Pearl, G. *J. Org. Chem.* **1993**, *58*, 6729 urge "extreme caution" when using molecular modeling to predict calixarene structures and energies.

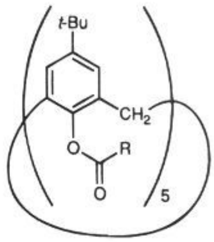
Chart 2



	R¹	R²	R³	R⁴	R⁵
3a	CH_3	H	H	H	H
3b	CH_3	CH_3	H	H	H
3c	CH_3	H	CH_3	H	H
3d	CH_3	CH_3	CH_3	H	H
3e	CH_3	CH_3	H	CH_3	H
3f	CH_3	CH_3	CH_3	CH_3	H
3g	CH_3	CH_3	CH_3	CH_3	CH_3

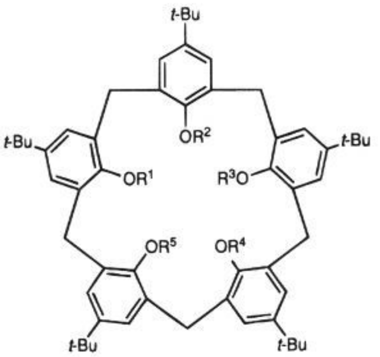


	R
4	C_2H_5
5	n-C_3H_7
6	i-C_3H_7
7	$CH_2CH{=}CH_2$
8	$CH_2C{\equiv}CH$
9	n-C_4H_9
10	$CH_2C_6H_5$



	R
11	CH_3
12	C_2H_5
13	n-C_3H_7
14	i-C_3H_7
15	–◁
16	$(CH_3)_3C$
17	C_6H_5

Chart 3



	R¹	R²	R³	R⁴	R⁵
18	C_2H_5	H	H	H	H
19	n-C_3H_7	H	H	H	H
20	CH_2Ph	H	H	H	H
21	CH_2Ph	CH_3	CH_3	CH_3	CH_3
22	CH_3	CH_2Ph	CH_2Ph	CH_2Ph	CH_2Ph
23	Ts	Ts	Ts	Ts	Ts

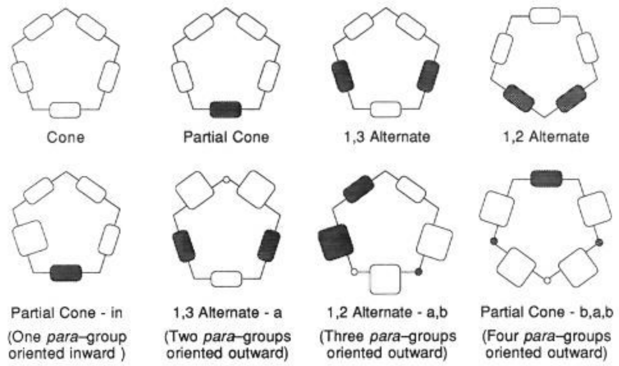


Figure 1. Conformations of calix[5]arenes.

larly self complexed[35]), and *p-tert*-octylcalix[5]arene (complexed with toluene)[36] all adopt the cone conformation in the solid state. The calculated $O\cdots H$ and $O-O$ distances indicate that intramolecular hydrogen bonding is somewhat weaker in **1b** than in **1a**, in agreement with the respective force constants for the $O-H$ stretching vibration in the IR (3160 cm^{-1} for **1a** and 3260 cm^{-1} for **1b**) and the position of the OH resonance in the ^{1}H NMR spectra (δ 10.2 for **1a** and δ 8.7 for **1b**).

Even with the calix[4]arenes the four up/down designations are insufficient to accommodate all possible conformations. The 1,3-dimethyl ether **2c**, for example, exists as a somewhat flattened cone in which two of the aryl groups are canted so that their para substituents project outward rather than up. As the size of the calixarene ring expands beyond four aryl units the systems become increasingly mobile,[10] and the necessity for defining other types of conformations escalates. The lower row of Figure 1 shows a representative sampling of these other conformers for *p-tert*-butylcalix[5]arene, some of which appear to have stabilities comparable to those of the the upper row conformations. For example, molecular mechanics calculations on the "1,2-alternate-a,b" and "partial cone-in" conformations[37] indicate them to have energies of 53.16 and 55.81 kcal mol^{-1}, respectively.

NMR Spectra of Calix[5]arenes. ^{1}H NMR spectral measurements have long proven to be the method of choice for assessing the conformational identity and flexibility of calix[4]arenes in solution. Such measurements are also useful for calix[5]arenes, although the lower symmetry of the cyclic pentamers frequently makes the conformational assignments more ambiguous. Table 2 shows the symmetry characteristics along with the predicted resonance patterns associated with the

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(33) Coruzzi, M.; Andreetti, G. D.; Bocchi, V.; Pochini, A.; Ungaro, R. *J. Chem. Soc., Perkin Trans. 2* **1982**, 1133.

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(35) Gallagher, J. F.; Ferguson, G.; Böhmer, V.; Kraft, D. *Acta. Crystallogr.* **1994**, *C50*, 73.

(36) Perrin, M.; Lecocq. S. *J. Incl. Phenom. Molec. Recogn.* **1991** ,*11*, 171.

Table 2. Symmetry Characteristics and ^{1}H NMR Resonance Patterns for Conformers of *p-tert*-Butylcalix[5]arene (**1b**)[a]

conformer	point group	^{1}H NMR Patterns of **1b**			ArCH$_2$Ar[b] δ36−38/ δ30−33
		ArH	ArCH2Ar	*t*-Butyl	
cone	C_{5v}	1 s	1 pair AX d	1 s	0/1
paco	C_s	2 pair d; 1 s (2:2:1)	2 pair AX d 1 pair AB d (2:1:2)	3 s (2:2:1)	1/2
1,2-alt	C_s	2 pair d; 1 s (2:2:1)	2 pair AX d 1 pair AB d (2:1:2)	3 s (2:2:1)	1/2
1,3-alt	C_s	2 pair d; 1 s (2:2:1)	1 pair AX d 2 pair AB d (1:2:2)	3 s (2:2:1)	2/1
1,2-alt-a,b	C_2	2 pair d; 1 s (2:2:1)	2 pair AX d 1 s (2:2:1)	3 s (2:2:1)	1/2
paco-in	C_1	5 pair d (1:1:1:1:1)	3 pair AX d 2 pair AB d (1:1:1:1:1)	5 s (1:1:1:1:1)	1/2

[a] Ratios of predicted resonances are given in parentheses. [b] Number of ^{13}C NMR resonance lines between δ36−38 and δ30−33, respectively, arising from Ar*C*H$_2$Ar.

ArH, ArCH$_2$Ar, and *tert*-butyl hydrogens for six of the conformations of **1b** shown in Figure 1. It should be noted that while the cone conformer is easily differentiated from the others, the partial cone, 1,2-alternate, 1,2-alternate-a,b, and 1,3-alternate conformers all have identical ArH and *tert*-butyl patterns and very similar ArCH$_2$Ar patterns.

^{13}C NMR spectra have come into play more recently as a means for assessing calix[4]arene conformations. de Mendoza and co-workers[38] have observed that the ArCH$_2$Ar resonance for a calix[4]arene appears at *ca.* δ 30−33 when adjacent aryl rings are *syn* (*i.e.* up, up) and at *ca.* δ 36−38 when they are *anti* (i.e. up, down). A similar difference is observed for the calix[6]arenes,[25] so it is reasonable to assume that it occurs in the calix[5]arenes as well. Table 2 also includes the expected ^{13}C NMR spectral patterns for the methylene carbons of six of the conformers of **1b** pictured in Figure 1 and shows that the cone conformer is unique in having a 0/1 ArCH$_2$Ar pattern; the partial cone, 1,2-alternate, and 1,2-alternate-a,b conformers have 1/2 patterns, and the 1,3-alternate conformer has a 2/1 pattern. The partial cone-in conformer is distinguished from the others by having a more complex spectrum and is a representative asymmetric conformation. Thus, the combination of ^{1}H and ^{13}C NMR spectra of the conformers of **1b** and its derivatives (if all OR groups are structurally identical) allows a definitive assignment of the cone and 1,3-alternate conformations but an uncertain distinction between partial cone, 1,2-alternate, and 1,2-alternate-a,b conformations.

Conformational Behavior of Pentaethers of 1b. The coalescence temperatures[39] (T_c) and barriers to conformational inversion ($\Delta G^\ddagger$) for the pentaethers **3g** and **4**−**10** were determined by variable temperature ^{1}H NMR spectroscopy,[40] with the results shown in Table 3. The T_c for the pentamethyl ether **3g** falls slightly below the threshold of measurability, putting its $\Delta G^\ddagger$ at or below 9.3 kcal mol^{-1}. The pentaethyl ether **4** is somewhat more conformationally constrained than **3g**, but it remains a highly mobile molecule. Even the penta-*n*-propyl ether **5** (variable temperature ^{1}H NMR spectrum shown in Figure 2), the pentaisopropyl ether **6**, the pentaallyl ether **7**, and the pentapropargyl ether **8** all are conformationally mobile molecules at ambient temperatures. The penta-*n*-butyl ether **9**, with a $\Delta G^\ddagger$ of 15.3 kcal mol^{-1}, has about the same conformational mobility as the cyclic tetramer **1a**. Benzyl groups, however, prove to be large enough to prevent rotation of the aryl moieties via the lower rim through the annulus pathway. Thus, the pentabenzyl ether **10** appears to be conformationally fixed on the ^{1}H NMR times scale and probably on the temporal scale as well. Similarly, Regen and co-workers[41] have found that the penta-*n*-octyl ether derived from **1b** adopts a stable cone conformation, a result that was later also reported by Shinkai and co-workers.[8b]

The ^{1}H NMR spectral pattern and the presence of only one

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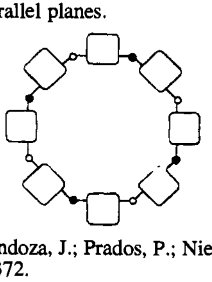
(37) Calixarenes in which all of the aryl units are either up or down have ArCH$_2$Ar methylene groups that remain in essentially the same plane and which, in fact, can be used to define the reference plane (see ref 28). Such methylene groups carry one hydrogen that falls above and one hydrogen that falls below this plane. In calixarenes larger than calix[4]arenes, however, conformations are also possible in which three adjacent units assume a "zig-zag" arrangement of the type shown by X-ray crystallography to be present in a linear phenol/formaldehyde tetramer (Paulus, E.; Böhmer, V. *Makromol. Chem.* **1984**, *185*, 1921). Both hydrogens of the ArCH$_2$Ar methylene groups in calixarene conformers possessing this feature are oriented either *above* or *below* an average plane passing through the adjoining aryl units and are designated by the symbols "a" (above) and "b" (below). To incorporate this nomenclatural feature into the iconographic representations (*cf.* ref 28) a small unfilled circle is used for the "above" orientation and a small filled circle for the "below" orientation. Thus, the pleated loop conformation of *p-tert*-butylcalix[8]arene (Gutsche, C. D.; Gutsche, A. E.; Karaulov, A. I. *J. Inc. Phenom.* **1985**, *3*, 447) would be designated as {$o_a o_b o_a o_b o_a o_b o_a o_b$} (abbreviated as [$o_a o_b$]$_4$) and would have the iconographic representation shown below. The hydrogen atoms of the four "a" methylenes and the four "b" methylenes of the cyclic octamer describe two parallel planes.



(38) Jaime, C.; de Mendoza, J.; Prados, P.; Nieto, P. M.; Sanchez, C. *J. Org. Chem.* **1991**, *56*, 3372.

(39) Coalescence points are generally more difficult to ascertain for the derivatives of **1b** than **1a**, because two resonance envelopes of unequal area are coalescing. The following procedure was used: (a) if a dip is seen between the methylene envelopes (spectrum A) the system is considered to be below the T_c; (b) if a long smooth transition is seen between the methylene envelopes (spectrum C) the system is considered to be above the T_c; (c) if a flat, gently sloping line is seen between the methylene envelopes (spectrum B) or if the transition between the envelopes is not smooth the system is considered to be at the T_c. The value of $\Delta\nu$ was taken as the average difference (in Hz) between the centers of the pairs of methylene doublets undergoing coalescence (observed at a sufficiently low temperature that the peaks are sharp). A value of 15 Hz was used for J_{AB}, based on the average value that is observed for ArCH$_2$Ar protons in calixarenes. All temperatures are corrected to MeOH or ethylene glycol spin temperatures. For compounds **5**, **6**, **7**, **9**, **11**, **12**, and **13** coalescence temperatures were also obtained for the ArH protons from which $\Delta G^\ddagger$ values[40] were calculated. In all cases these fall within ±0.2 kcal/mol of the values obtained from the coalescence temperatures of the ArCH$_2$Ar protons.

Spectrum A

Spectrum B

Spectrum C

(40) The rate constant (k_c in s^{-1}) for conformational interconversion at the coalescence temperature was calculated from the equation $k_c = 2.22 (\Delta\nu^2 + 6 J_{AB}{}^2)^{1/2}$. The free energy barrier to conformational interconversion in kcal mol^{-1} was calculated from the equation: $\Delta G^\ddagger = 4.58T_c(10.32 + \log T_c/k_c)/1000$. Assumimg an accuracy of ±5 °C for the value of T_c, an accuracy of ±15 Hz for the value of $\Delta\nu$, and an accuracy of ±2 Hz for the value of J_{AB}, it is estimated that the $\Delta G^\ddagger$ values may be accurate to ±0.4 kcal/mol. However, since this treatment was not designed for multisite exchange phenomena the variations in the values obtained might be larger.

(41) Dedek, P.; Janout, V.; Regen, S. L. *J. Org. Chem.* **1993**, *58*, 6553.

Table 3. Conformational Characteristics of *p-tert*-Butylcalix[5]arene and its Pentaethers and Pentaesters

compound					
no.	OR group	conformation(s)	T_c (°C)	$\Delta G^{\ddagger}$ (kcal mol^{-1})	solvent
1b	H	cone	−2	13.2	$CDCl_3$
3g	methyl ether	mixture	≤ −70	≤9.3	$CDCl_3$
4	ethyl ether	1,2-alt or paco[a]	−33	11.1	$CDCl_3$
5	*n*-propyl ether	1,2-alt or paco[a]	4	12.6	$CDCl_3$
6	isopropyl ether	1,2-alt	−2	12.3	$CDCl_3$
7	allyl ether	1,2-alt	−12	11.8	$CDCl_3$
8	propargyl ether	cone and unknown	15	13.4	$CDCl_3$
9	*n*-butyl ether	1,2-alt or paco[a]	61	15.3	$CDCl_3$
9	*n*-butyl ether	1,2-alt or paco[a]	65	15.5	$CDCl_2CDCl_2$
10	benzyl ether	cone	≫115	≫20	$CDCl_2CDCl_2$
11	acetate	1,2-alt, 1,3-alt, or paco	45	15.3	$CDCl_3$
12	propanoate	1,2-alt, 1,3-alt, or paco	45	15.4	$CDCl_2CDCl_2$
13	*n*-butanoate	1,2-alt, 1,3-alt, or paco	88	17.5	$CDCl_2CDCl_2$
14	isobutanoate	1,2-alt, 1,3-alt, or paco	>135	>20	$CDCl_2CDCl_2$
15	cyclopropylcarbanoate	1,2-alt,1,3-alt, or paco	130	19.4	$CDCl_2CDCl_2$
16	pivaloate	cone and either 1,2-alt or paco	≫115	≫20	$CDCl_2CDCl_2$
17	benzoate	cone	≫115	≫20	$CDCl_2CDCl_2$
23	tosylate	cone	≫115	≫20	$CDCl_2CDCl_2$

[a] The 1,3-alternate conformation is also a possibility, although a less likely one.

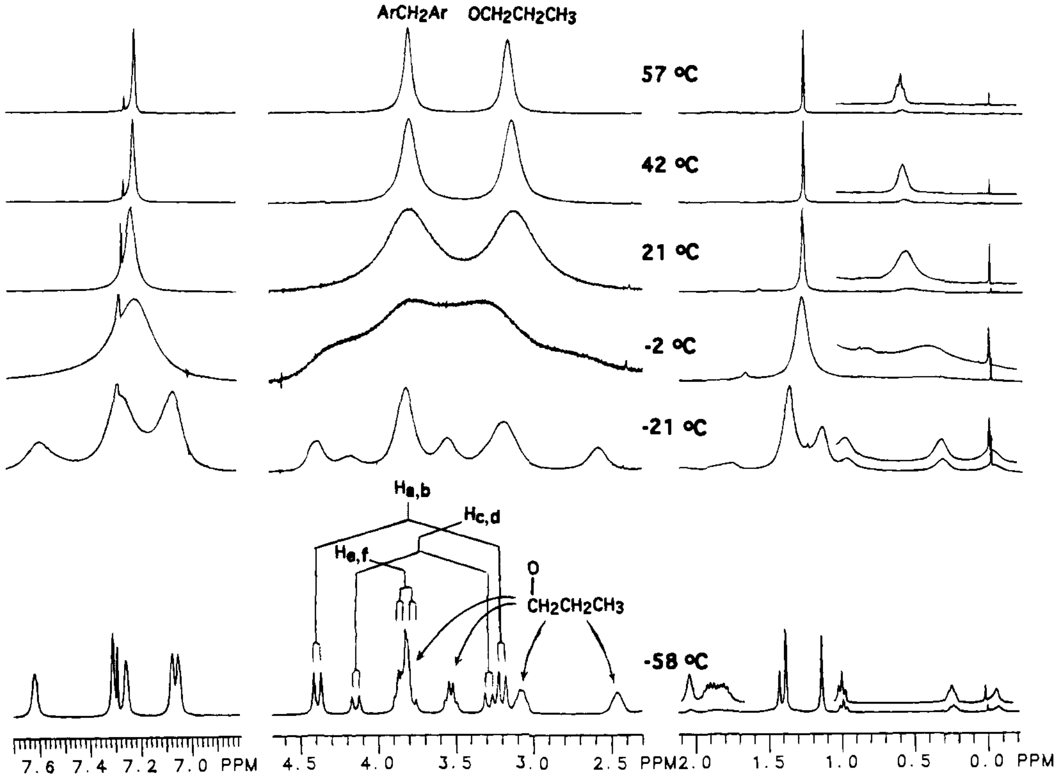
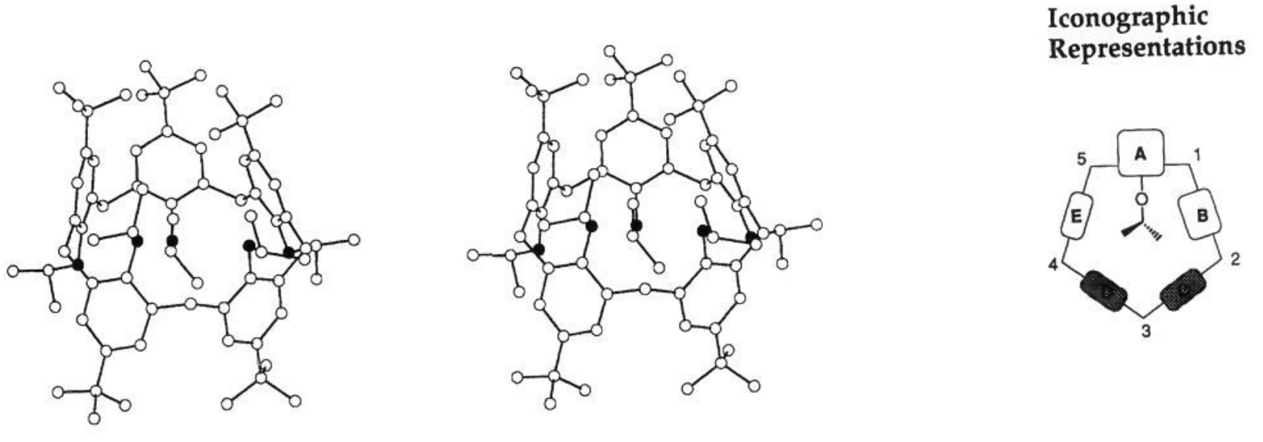


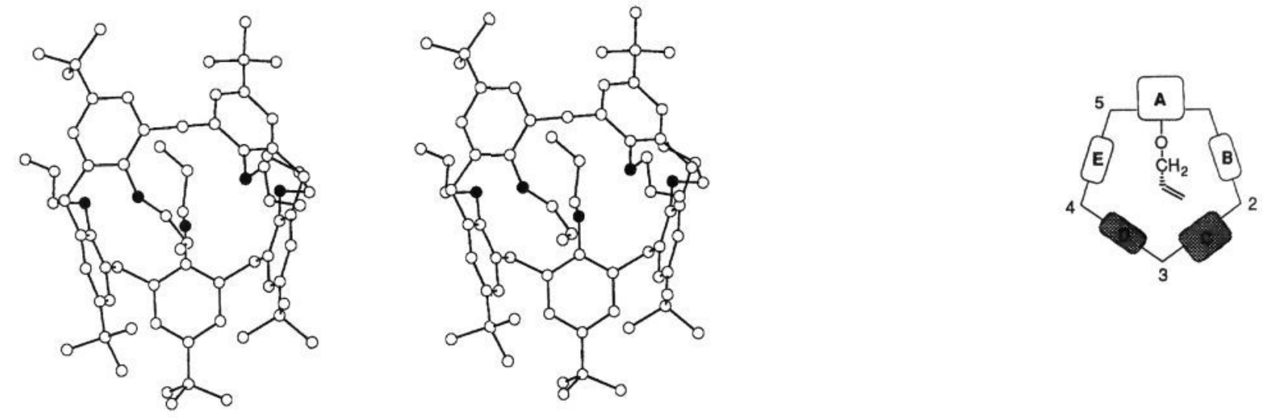
Figure 2. Variable temperature ^1H NMR spectrum of penta-*n*-propyl ether **5** in $CDCl_3$ at 300 MHz. Within each spectral region the tallest peak is full scale except when arising from the solvent.

ArCH$_2$Ar methylene carbon resonance in the ^{13}C NMR spectrum of the pentabenzyl ether **10** indicate a cone conformation, but the conformational state of the other pentaethers at temperatures where their conformational interconversion is slow on the ^1H NMR time scale is less clear. In the pentaethyl ether **4** the two resonances in the low temperature spectrum (−57 °C) arising from the terminal Me groups [at δ 0.75 (six protons) and δ −0.15 (three protons)] seem to rule out a cone conformation and suggests that two Me groups are near the faces of the aryl moieties. The low temperature (−58 °C) ^1H NMR spectrum of the penta-*n*-propyl ether **5** is commensurate with a 1,2-alternate, 1,3-alternate or partial cone conformation. Two upfield resonances arise from the terminal Me groups (δ 0.2 and δ −0.1 in a 2:1 ratio) indicating that here, also, one or more of the Me groups reside within the cavity; in addition a Me resonance at δ 1.0 appears.

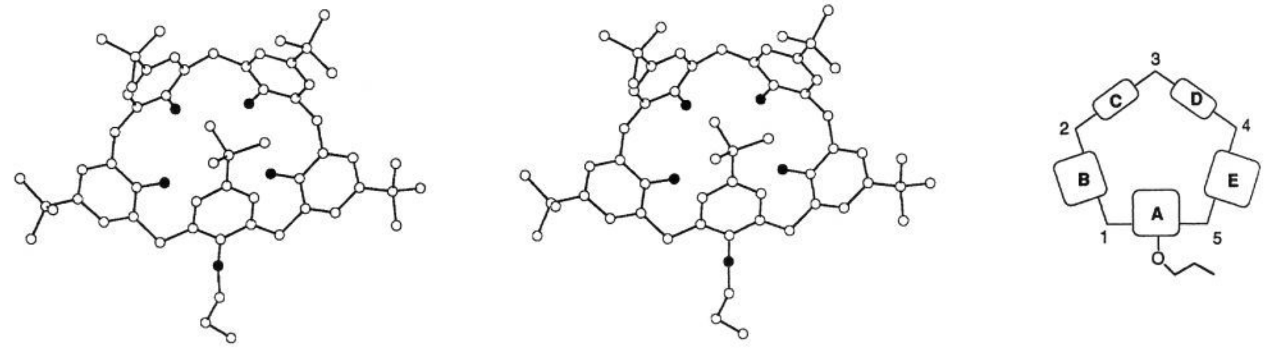
The inward orientation of the terminal Me groups of the ether moieties is substantiated by the X-ray crystallographic structure (see Figure 3) of the pentaisopropyl ether **6** which shows the compound to be in a 1,2-alternate conformation in which the middle "up" unit is tilted outward while the other up units are tilted slightly inward. The unit that is tilted outward has its isopropyl group within the annulus of the lower rim, while the isopropyl groups on the other units project outward. The ^1H NMR spectrum of **6** below −10 °C shows a Me resonance at a high upfield position (δ −1.3), in agreement with the X-ray crystallographic structure. Other features of the ^1H NMR spectrum of **6** are also commensurate with a 1,2-alternate



Penta-*i*-propyl Ether 6



Pentaallyl Ether 7



Mono-*n*-propyl Ether 19

Figure 3. X-ray crystallographic structures of the pentaisopropyl ether **6**, the pentaallyl ether **7**, and the mono-*n*-propyl ether **19**. In the iconographic representations of **6** and **7** only the alkoxy residue attached to the "in" aryl residue is shown.

conformer, indicating that the solid state and solution state conformations are very similar. The X-ray crystallographic structure of the pentaallyl ether **7** (see Figure 3) shows that it also assumes a 1,2-alternate conformation, although the middle up unit is not tilted outward to the same extent as in **6**. The more linear geometry of the allyl ether moiety probably prevents its terminal group from occupying a position within the annulus of the lower rim. The ^{1}H NMR and ^{13}C NMR spectra of **7** are commensurate with a 1,2-alternate conformation, and it seems likely that the solid state and solution state conformations are the same in this case as well. However, the partial cone conformation for the solution state cannot be rigorously excluded. In contrast to the other pentaethers, the variable temperature ^{1}H NMR spectrum of the pentapropargyl ether **8** indicates that at least two different conformations are present at low temperatures, one of which is a cone.

Conformational Behavior of Pentaesters of 1b. The ambient temperature ^{1}H NMR spectrum of the pentaacetate **11** (see Figure 4) shows a broad, semiresolved set of resonances arising from the ArCH$_2$Ar protons that coalesce to a singlet at higher temperature. Analysis of this variable temperature spectrum[39] produces a T_c of *ca.* 45 °C, corresponding to a $\Delta G^\ddagger$ of 15.3 kcal mol^{-1}. This is 2.1 kcal mol^{-1} greater than the $\Delta G^\ddagger$ for the parent compound, showing that **11** is slightly less

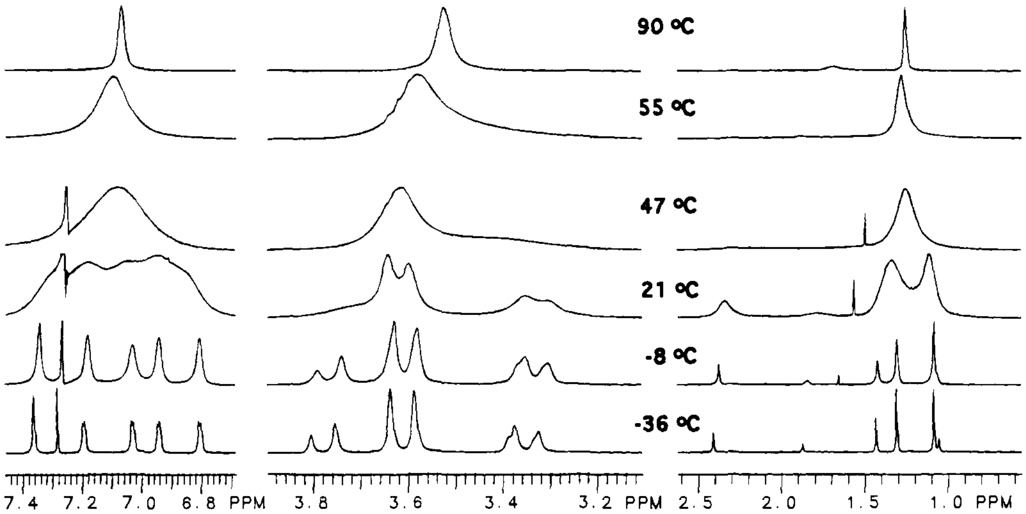


Figure 4. Variable temperature ^{1}H NMR spectrum of pentaacetate **11** in $CDCl_3$ or $CDCl_2CDCl_2$ at 300 MHz.

conformationally mobile than **1b**. The low temperature ^{1}H NMR spectrum of **11** has five sets of ArH resonances in a 1:1: 1:1:1 ratio (four doublets and one singlet—see Table 1), three pairs of doublets from the $ArCH_2Ar$ hydrogens, three singlets in a 1:2:2 ratio from the *tert*-butyl hydrogens, and three widely separated singlets from the COMe hydrogens at δ 2.38, 1.85, and 1.05. This pattern is compatible with a partial cone, 1,2-alternate or 1,3-alternate conformation. The upfield position of two ester Me resonances suggests that it is either a 1,2- or a 1,3-alternate conformation, since a partial cone conformer would be expected to have only *one* of the ester Me resonances shifted upfield. The ^{13}C NMR spectrum shows a pair of downfield resonances and one upfield resonance from the $ArCH_2Ar$ methylene carbons, a pattern that is in accord with a 1,2-alternate or a partial cone conformation. On the basis of these observations the 1,2-conformer is chosen as the most likely. This assignment is also supported by the fact that the pentaisopropyl ether (see Figure 3) is a 1,2-alternate conformer, the geometry of the isopropyl and acetyl groups being somewhat similar.

The conformational behavior of the penta-*n*-propanoate **12**, penta-*n*-butanoate **13**, pentaisobutanoate **14**, pentacyclopropylcarbanoate **15**, pentapivaloate **16**, and pentabenzoate **17** were studied in like fashion. The results, shown in Table 3, indicate that as the size of the OR group increases, the conformational mobility diminishes. The dividing line between mobile and immobile (on the ^{1}H NMR time scale) is crossed at the isobutanoate **14**, with the cyclopropylcarbanoate **15** falling right at the border. Although the resonance patterns of the ArH, $ArCH_2Ar$, and *tert*-butyl hydrogens of **14** broaden upon heating, they retain their patterns even at 135 °C. Those of **15**, however, have changed to broad, almost structureless singlets at this temperature. The joining of the methyl groups of **14** to form the cyclopropyl groups of **15** apparently reduces the bulk of the ester moieties just enough to allow them to slide through the annulus. The ^{1}H NMR spectra at temperatures well below the T_c for the acetate, propanoate, *n*-butanoate, isobutanoate, cyclopropylcarbonate, and one of the pivaloates (the one isolated in larger yield) all are similar in possessing five aryl peaks, three *tert*-butyl singlets, and three pairs of doublets for the $ArCH_2Ar$ methylene hydrogens, as illustrated in Figure 4 for the acetate. This is commensurate with a partial cone, a 1,2- or a 1,3-alternate conformation. The pentacyclopropylcarbanoate **15** forms gemlike crystals, but its X-ray structure was poorly resolved although indicating that the compound is a flattened 1,2-alternate conformer, quite similar to **6** and **7** (see Figure 3) in which one of the cyclopropyl residues lies directly in the center of the cavity. The ambient temperature ^{1}H NMR spectra of the pentabenzoate **17**, pentatosylate **23**, and the other pentapivaloate **16** (the compound isolated in smaller yield), on the other hand, contain one singlet for the *tert*-butyl groups and only one pair of doublets for the $ArCH_2Ar$ methylenes, indicating that these esters assume the cone conformation. This is supported by the presence of only a single resonance at δ 29.5 arising from the $ArCH_2Ar$ methylene carbons in the ^{13}C NMR spectra of these compounds.

Conformational Behavior of Partial Ethers, Mixed Ethers, and a Partial Ester of 1b. In contrast to the methyl ethers of the cyclic tetramer **1a**, where partial methylation results in decreased mobility, the methyl ethers of the cyclic pentamer **1b** become increasingly mobile as more methyl groups are added. At or just above ambient temperature the spectra of **3a,b,c,e,f** all show three singlets in a 2:2:1 ratio for the $ArCH_2Ar$ protons produced by a rapidly equilibrating set of conformers. As the temperature is lowered these patterns broaden, eventually pass through a coalescence point, and then resolve into a new set of broad bands at very low temperatures. A representative example is seen in Figure 5, which shows the variable temperature ^{1}H NMR spectrum of the monomethyl ether **3a**. The coalescence temperatures (T_c) and energy barriers to conformational inversion ($\Delta G^{\ddagger}$) for the partial methyl ethers of **1b** were determined to be **3a** = −31 °C (11.1 kcal mol^{-1}), **3b** = −52 °C (10.1 kcal mol^{-1}), **3c** = −40 °C (10.6 kcal mol^{-1}, **3e** = −53 °C (10.0 kcal mol^{-1}), **3f** = −52 °C (10.1 kcal mol^{-1}).

Whereas the $\Delta G^{\ddagger}$ for conformational inversion of the 1,3-dimethyl ether **2c** of the cyclic tetramer is >18 kcal mol^{-1}, the $\Delta G^{\ddagger}$ for the 1,3-dimethyl ether **3c** of the cyclic pentamer is only 10.1 kcal mol^{-1}. One of the reasons for this large difference in conformational mobility is well illustrated by a lower rim view of the computer-generated, energy-minimized space-filling models (see Figure 6) which shows that the annulus of **3c** is considerably larger than that of **2c**. As a consequence, much less steric interference to conformational inversion in **3c** ensues from the increased size of OMe as compared with OH. Also, energy calculations indicate that intramolecular hydrogen bonding is stronger in **2c** than in **3c**. Similar arguments can be adduced to explain the relative conformational mobilities of the other methyl ethers derived from **1a** and **1b**. Table 1 (*vide supra*) shows the IR and ^{1}H NMR features associated with the OH groups of the methyl ethers **3a**–**g**.

At ambient temperature the pentamethyl, pentaethyl, and

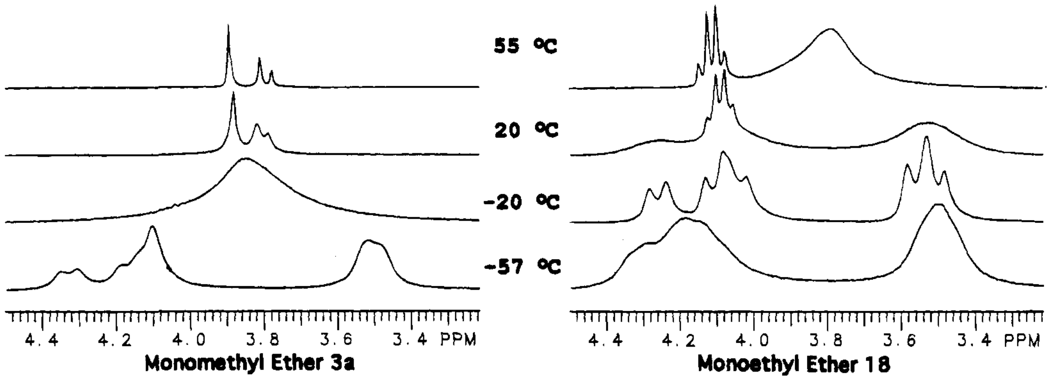
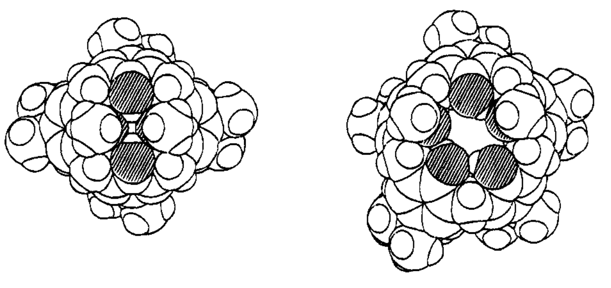


Figure 5. Variable temperature ^{1}H NMR spectra of monomethyl ether **3a** and monoethyl ether **18** in $CDCl_3$ solution at 300 MHz.



2c **3c**

Figure 6. Lower rim views of computer-generated space-filling models of the cone conformers of the 1,3-dimethyl ethers **2c** and **3c**.

Table 4. Conformations and Barriers to Conformational Interconversion for Monoethers and Monobenzyl Tetramethyl Ether of *p-tert*-Butylcalix[5]arene **1b**

compd no.	substituent	solvent	conformation(s)[a]	T_c °C	$\Delta G^\ddagger$ (kcal mol^{-1})
3a	monomethyl	$CDCl_3$	unknown	−30	11.1
18	monoethyl	$CDCl_3$	cone	30	14.1
	monoethyl	Pyr-d_5	cone	−40	10.7
19	mono-*n*-propyl	$CDCl_2CDCl_2$	cone-in	140	19.9
	mono-*n*-propyl	Pyr-d_5	cone or cone-in	90	16.9
20	monobenzyl	$CDCl_2CDCl_2$	cone or cone-in	$\gg$95	$\gg$20
	monobenzyl	Pyr-d_5	cone or cone-in	$\gg$90	$\gg$20
21	monobenzyl tetramethyl	$CDCl_3$	cone or cone-in	>65	>15

penta-*n*-propyl ethers of **1b** all are conformationally mobile on the ^{1}H NMR time scale. The question to be answered is whether a partially etherified **1b** might, as in the case of **1a**, be less conformationally mobile than either the parent compound or the fully etherified derivative. To probe this question, the monomethyl ether **3a** (*vide supra*), monoethyl ether **18**, mono-*n*-propyl ether **19**, and monobenzyl ether **20** were synthesized and their conformational behavior studied. The results are shown in Table 4. The variable temperature ^{1}H NMR spectra of the monomethyl ether **3a** and monoethyl ether **18** in $CDCl_3$ (see Figure 5) reveal that both of these molecules are conformationally mobile, although **3a** much more so than **18**. The monomethyl ether has an estimated T_c of *ca.* −30 °C, corresponding to a $\Delta G^\ddagger$ of 11.1 kcal mol^{-1}, while that of the monoethyl ether occurs at *ca.* 30 °C, corresponding to a $\Delta G^\ddagger$ of 14.1 kcal mol^{-1}. The high temperature spectrum in each case shows three singlets in a 2:2:1 ratio arising from three sets of nonequivalent $ArCH_2Ar$ hydrogens in the rapidly equilibrating set of conformers.[42] The considerably higher barrier to conformational inversion in **18** indicates, however, that steric hindrance is starting to be a significant contributor in determining the conformational mobility of the calix[5]arene ring system. When the nonpolar solvent $CDCl_3$ or $CDCl_2CDCl_2$ is replaced with the more polar, basic solvent pyridine-d_5, the T_c of **18** falls to *ca.* −40 °C, corresponding to a $\Delta G^\ddagger$ of 10.7 kcal mol^{-1}. The considerably lower $\Delta G^\ddagger$ in pyridine indicates that intramolecular hydrogen bonding is also playing a significant role in maintaining the conformation, as demonstrated in earlier experiments[43] with *p-tert*-butylcalix[8]arene where the T_c plunges from 53 °C (100 MHz spectrum) to below −93 °C when $CDCl_3$ is changed to pyridine-d_5/CS_2. A cone conformation is assigned to **18** on the basis of the ^{1}H NMR patterns and the presence of only a pair of ^{13}C NMR resonances for $ArCH_2Ar$ methylenes at δ 30.9 and 31.8. Also, the pattern of the OH resonances is identical with that of the mono-*n*-propyl and monobenzyl ethers.

The mono-*n*-propyl ether **19** is correspondingly less mobile than the monoethyl ether **18** and falls near the dividing line between a conformationally mobile and immobile calixarene on the ^{1}H NMR time scale. Analysis of the variable temperature ^{1}H NMR spectra of **19** (see Figure 7) gives an estimated[44] T_c of *ca.* 140 °C in $CDCl_2CDCl_2$ and a measured T_c of 90 °C in pyridine-d_5, corresponding to $\Delta G^\ddagger$ values of *ca.* 20 and 16.9 kcal mol^{-1}, respectively. In contrast to the solid state conformations of **6** and **7**, the conformation of **19** is a somewhat distorted cone in which the *tert*-butyl group is oriented inward (hence a cone-in conformation), and the propoxy group is oriented outward (see Figure 3). McKervey and co-workers[45] have made similar observations for the pentakis[(ethoxycarbonyl)methyl] ether of **1b** where the X-ray crystallographic structure shows a distorted cone conformation in which one of the aryl groups is canted inward so that its *tert*-butyl group covers the top of the upper rim cavity. The ^{1}H NMR spectrum of **19** is commensurate with the X-ray crystallographic conformation.

The monobenzyl ether **20** shows little change in its ^{1}H NMR spectral patterns over the temperature range 20−95 °C in either $CDCl_2CDCl_2$ or pyridine-d_5 (see Figure 7 for 95 °C spectrum), indicating that it is conformationally very much less mobile than even the mono-*n*-propyl ether **19**. That a single conformer of **20** is present is inferred from the similarity of the spectra in

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[42] It should be noted that the $ArCH_2Ar$ methylene hydrogens arising from a rapidly equilibrating set of monoether conformers such as **18** appear as three singlets in a 2:2:1 ratio, while those arising from conformationally fixed monoethers such as **20** appear as three sets of doublets in a 2:2:1 ratio. The latter frequently consist of one pair of AX doublets ($\Delta\delta$ > 1), one pair of AB doublets ($\Delta\delta \ll 1$), and one pair of doublets somewhere between AX and AB ($\Delta\delta$ < 1).

[43] Gutsche, C. D.; Bauer, L. J. *Tetrahedron Lett.* **1981**, *22*, 4763.

[44] The broadening of the resonance pattern of **19** in $CDCl_2CDCl_2$ at 90 °C is comparable to that of **19** in pyridine-d_5 at *ca.* 45 °C , *i.e.*, 50 °C below its coalescence temperature in this solvent. Thus, adding 50 °C to the 90 °C spectrum of **19** provides an estimated coalescence temperature of 140 °C for **19** in $CDCl_2CDCl_2$.

[45] Barrett, G.; McKervey, M. A.; Malone, J. F.; Walker, A.; Arnaud-Neu, F.; Guerra, L.; Schwing-Weill, M.-J.; Gutsche, C. D.; Stewart, D. R. *J. Chem. Soc., Perkin Trans. 2* **1993**, 1475.

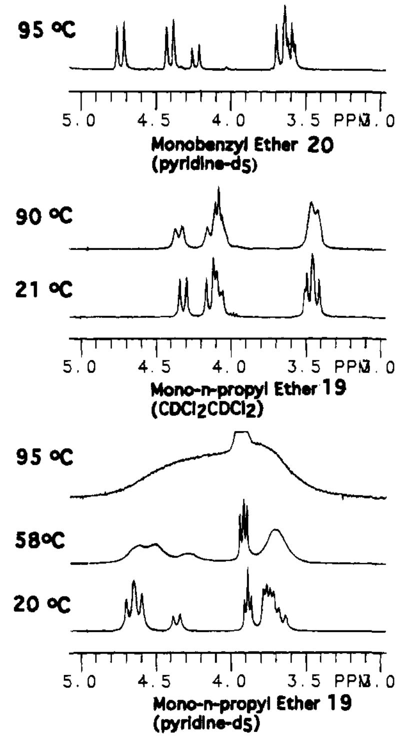

Figure 7. Variable temperature ^{1}H NMR spectrum of mono-*n*-propyl ether **19** in $CDCl_2CDCl_2$ and pyridine-d_5 and the 95 °C ^{1}H NMR spectrum of monobenzyl ether **20** in pyridine-d_5 at 300 MHz.

nonpolar and polar solvents where, in each case, only three resonances for the *tert*-butyl groups and three pairs of doublets for the $ArCH_2Ar$ methylene hydrogens[42] and observed. The ^{13}C NMR spectrum does not show a resonance at δ 36−38, indicting the absence of *anti*-oriented aryl units. By analogy with the mono-*n*-propyl ether it is assumed to be in a cone-in conformation. It is interesting to note that the effect of pyridine as a solvent is to shift the position of the resonance of four *tert*-butyl groups downfield by *ca.* δ 0.15 and to shift two $ArCH_2Ar$ doublets from δ 4.05 and 4.35 to δ 4.58 and 4.86, while leaving the position of the $OCH_2C_6H_5$ methylene resonance unchanged. Similar though somewhat less pronounced shifts are observed with the mono-*n*-propyl ether **19**, perhaps caused by the occlusion of pyridine in the cavity of these molecules.

The monobenzyl tetramethyl ether **21** was synthesized to further explore the role of hydrogen bonding in determining the conformational mobility of monoethers. Like the monobenzyl ether **20**, it shows only slight broadening of the resonances associated with the $ArCH_2Ar$ methylene, OMe, and *tert*-butyl hydrogens upon heating to 135 °C, although more significant broadening occurs as the temperature is lowered to −56 °C. The latter change is postulated to be the result of partial conformational mobility wherein the aryl units carrying OMe groups swing into the annulus, while the aryl unit carrying the $OCH_2C_6H_5$ remains fixed. The sharply defined resonances at ambient temperature might arise from a single conformer that is preferred at the higher temperatures or from a set of conformers that are interconverting rapidly on the ^{1}H NMR time scale. The absence of a signal at δ 37−38 in the ^{13}C NMR spectrum of **21**, however, suggests that only conelike conformers are present. A conformational search using molecular mechanics calculations[30] with **21** produces a number of conformers of comparable energy, including those illustrated in Figure 8. The monomethyltetrabenzyl ether **22** also appears to exist in a single, fixed conformation, the ^{1}H NMR spectrum showing a well resolved pattern that is in accord with a distorted cone.

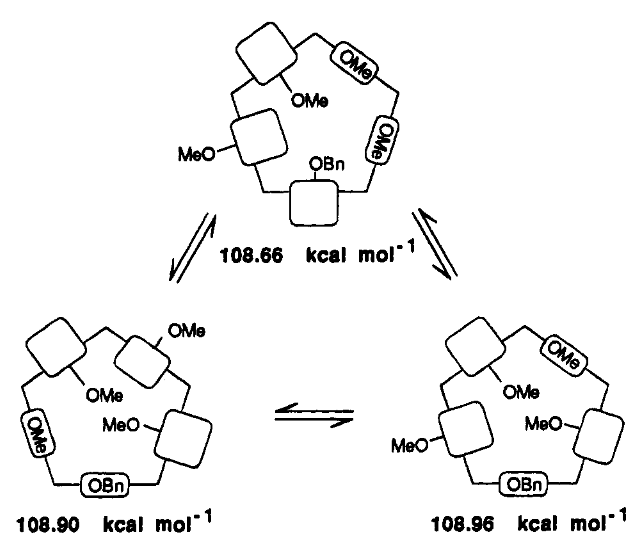

Figure 8. Iconographic representation of the three low energy conformers of the monobenzyl tetramethyl ether **21**.

The one partial ester that has been studied is the tetrapivaloate of **1b** which shows three high-field ^{13}C NMR resonances (δ 30.5, 28.86, 28.81) arising from the $ArCH_2Ar$ carbons and, on this basis, is assigned a cone conformation. It is formed in considerably higher yield than either of the two pentapivaloates that were isolated and is the putative precursor of the cone conformer and, possibly, the noncone conformer. Like the pentapivaloates, the tetrapivaloate is conformationally immobile.

Conformational Stability at High Temperatures. No change in the ^{1}H NMR spectrum of the pentaisobutanoate **14** was observed upon heating the compound in diphenyl ether (bp 259 °C) for 8 h or neat at 320 °C for 10 min, indicating that the initial conformation is retained under these conditions. Decomposition occurs when **14** is heated above its mp (340−342 °C) for a few minutes, and the ^{1}H NMR of the material is equivocal as to whether or not a conformational change has occurred. Clearer evidence for high temperature-induced conformational change was obtained when the pentabenzoate **17** was heated for 1 min at 380 °C (mp 396−398 °C, with prior melting and resolidification). The pair of doublets arising from the cone conformer of the unheated compound is completely replaced by a pattern showing a singlet and two pairs of doublets (2:1 ratio), corresponding to one or more noncone conformers. An even more definitive result was obtained when the cone and noncone conformers of the pentapivaloate **16** were heated for a few minutes at 400 °C, which is slightly below their melting points of 421−423 °C. The ^{1}H NMR spectrum (see Figure 9) of the cone conformer becomes more complex, particularly in the $ArCH_2Ar$ methylene region where the pair of doublets centered at δ 3.88 and 3.34 is partially replaced by a multiline pattern extending from *ca.* δ 3.75 to 3.2. Similarly, the pattern of the noncone conformer[46] becomes more complex after the compound is heated, and it includes the pair of doublets associated with the cone conformer. Thus, it appears that under rather extreme temperature conditions, just short of the decomposition point of very high melting compounds, conformational interconversions may occur. What is uncertain, however, is whether they are occurring via the upper rim through the annulus or lower rim through the annulus pathway, neither of which can be effected with CPK models without breaking and remaking bonds.

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[46] The cone and noncone conformers of the pentapivaloate **16** have virtually identical melting (decomposition) points. We are indebted to one of the referees for calling this to our attention, thereby providing the rationale for examining the behavior of these compounds at highly elevated temperatures.

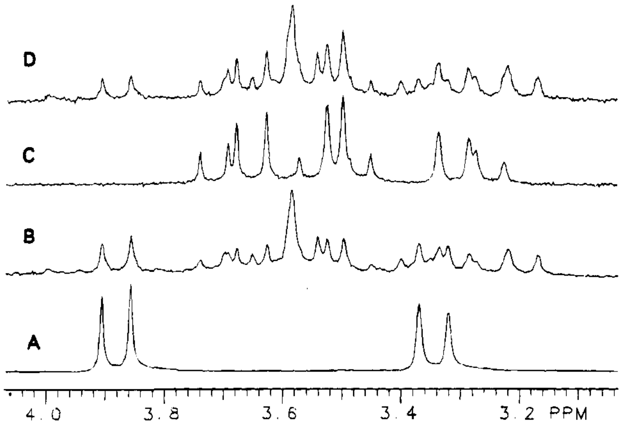

Figure 9. ^{1}H NMR spectra ($ArCH_2Ar$ region) of pentapivaloates **16** in $CDCl_3$ at 300 MHz at 25 °C: (A) cone conformer unheated; (B) cone conformer after heating at 400 °C; (C) noncone conformer unheated; (D) noncone conformer after heating at 400 °C.

Conclusions. The calix[5]arenes are especially attractive members of the calixarene family, because they possess a larger cavity than the calix[4]arenes while retaining the capability of assuming a true cone conformation. Furthermore, even the noncone conformations possess clefts that can be useful in host–guest interactions. In common with all of the underivatized members of the calixarene family, the *p-tert*-butylcalix[5]arenes are conformationally mobile at room temperature via the lower rim through the annulus pathway. Upon conversion to ethers and esters, however, the conformational mobility changes, generally in the direction of diminished mobility. The present research was designed to quantitate the effect of various substituents attached to the phenoxy oxygens on the conformational mobility of compounds derived from *p-tert*-butylcalix[5]arene. The results, shown in graphical form in Figure 10 can be summarized as follows: (a) As shown in plot-A, hydrogen bonding plays a role in determining the conformational mobility; the decrease in $\Delta G^{\ddagger}$ resulting from the conversion of OH to OMe can be ascribed to a progressive loss of intramolecular hydrogen bonding that is not offset by the increased steric hindrance resulting from the larger size of OMe compared with OH. (b) As shown in plot-B, steric effects also play a role in determining the conformational mobility; as the size of OR increases from OMe to OEt to OPr to OBu the $\Delta G^{\ddagger}$ increases. (c) As shown in plot-C, the shape of a three-carbon OR group has relatively little effect on $\Delta G^{\ddagger}$; the *n*-Pr, *i*-Pr, allyl, and propargyl ethers have approximately the same $\Delta G^{\ddagger}$ values. (d) As shown in plot-D, the added steric interaction arising from the carbonyl oxygen makes OCOR groups more effective in reducing conformational mobility than OR groups of corresponding carbon content, and the cyclopropylcarbanoate falls just below the line of conformational immobility. (e) As shown in plot-E, intramolecular hydrogen bonding and steric hindrance factors can act cooperatively in reducing conformational mobility; the monoethyl and mono-*n*-propyl ethers are appreciably less mobile than the pentaethyl and penta-*n*-propyl ethers, although with sufficiently large groups (*i.e.*, benzyl) the pentaethers can be made conformationally immobile.

In addition to the ethers and esters for which it was possible to obtain $\Delta G^{\ddagger}$ values for conformational interconversion, several other derivatives were studied which possess $\Delta G^{\ddagger}$ values that are too high to be measured by variable temperature ^{1}H NMR spectroscopy. Included in this category are the monobenzyl ether, pentabenzyl ether, pentaisobutanoate, pentapivaloate, and pentabenzoate which, for all practical purposes, are conformationally fixed. In still other instances such as the monobenzyl tetramethyl ether the molecules appear to possess some conformational mobility, presumably the result of pseudorotational motions of the ArOMe moieties.

Experimental Section[47]

5,11,17,23,29-Penta-*tert*-butyl-31-methoxy-32,33,34,35-tetrahydroxycalix[5]arene (3a). A stirred suspension of 1.00 g (1.23 mmol) of **1b**, 0.118 g (0.616 mmol) of methyl tosylate (98%), and 0.247 g (2.47 mmol) of $KHCO_3$ in 50 mL of dry acetone was heated at reflux in an inert atmosphere for 24 h. After cooling to room temperature the solvent was removed *in vacuo*, and the residue was partitioned between 75 mL of $CHCl_3$ and 50 mL 1 N HCl. The $CHCl_3$ layer was separated, washed with 100 mL of H_2O, and dried with anhydrous $MgSO_4$. An HPLC analysis of this solution showed the product to consist of *ca.* 1:1 mixture of **1b** and **3a** with traces (*ca.* 1% total) of dimethyl ethers **3b** and **3c**, 1,2,4-trimethyl ether **3e**, tetramethyl ether **3f**, and pentamethyl ether **3g**. The $CHCl_3$ was removed *in vacuo*, and the residue was subjected to flash chromatography (SiO_2, toluene–hexanes 7:3 v/v) to give 0.45 g of **1b** after trituration with MeOH and 0.45 g of **3a** (80% based on recovered **1b**) after recrystallization from *i*-PrOH: mp 280–281 °C; ^{1}H NMR ($CDCl_3$) δ 8.01 (s, 2, Ar*OH*), 7.95 (s, 2, Ar*OH*), 7.22 (d, 2, J = 2.5 Hz, Ar*H*), 7.16 (d, 2, J = 2.5 Hz, Ar*H*), 7.19 (d, 4 H J = 2.6 Hz, Ar*H*), 7.14 (s, 2, Ar*H*), 3.88 (br s, 7, OCH_3 and $ArCH_2Ar$), 3.82 (br s, 4, $ArCH_2Ar$), 3.77 (br s, 2, $ArCH_2Ar$), 1.30 (s, 18, $C(CH_3)_3$), 1.24 (s, 18, $C(CH_3)_3$), 1.13 (s, 9, $C(CH_3)_3$); ^{13}C NMR ($CDCl_3$) δ 151.2, 149.2, 147.6, 147.5, 143.9, 142.7, 132.0, 126.9, 126.5, and 126.3 (Ar), 126.0, 125.9, 125.8, and 125.5 (ArH), 62.6 (OCH_3), 34.2 and 33.8 ($C(CH_3)_3$), 31.9 ($ArCH_2Ar$), 31.6 and 31.4 ($C(CH_3)_3$), 31.3 ($ArCH_2Ar$), 31.2 ($C(CH_3)_3$), 30.7 ($ArCH_2Ar$); IR (KBr) 3464 and 3372 cm^{-1} (OH). Anal. Calcd for $C_{56}H_{72}O_5$: C, 81.51; H, 8.79. Found: C, 81.46; H, 8.77.

5,11,17,23,29-Penta-*tert*-butyl-31,33-dimethoxy-32,34,35-trihydroxycalix[5]arene (3c). A stirred suspension of 3.00 g (3.70 mmol) of **1b**, 1.41 g (7.42 mmol) of methyl tosylate (98%), and 1.11 g (11.1 mmol) of $KHCO_3$ in 100 mL of dry acetone was heated at reflux in an inert atmosphere for 24 h. The reaction mixture was worked up as described above for **3a**, and a HPLC analysis showed that ca. 75% of the crude product is a mixture of monomethyl ether **3a** and 1,2,4-trimethyl ether **3e**, and ca. 25% is a combination of dimethyl ethers **3b** and **3c**. Traces of **1b**, tetramethyl ether **3f**, and pentamethyl ether **3g** were also observed by HPLC analysis. The crude product was subjected to flash chromatography (SiO_2, 100% toluene) to give 1.14 g (37%) of **3a**. The column was then further eluted with a six-step gradient (100% toluene to 100% $CHCl_3$) to give 0.62 g (20%) of a mixture of **3b** and **3c**. The column was then eluted isocratically ($CHCl_3$) to give 1.18 g (38%) of **3e**. The mixture of **3b** and **3c** was separated by flash chromatography (CH_2Cl_2-hexanes 3:1 v/v) to give 0.49 g (16%) and 0.13 g (4.2%) of an upper spot and a lower spot, respectively, of dimethyl ethers. The upper spot material is assumed to be **3c**: mp shrinks at 136 °C, forms a glass at 140 °C, and is a viscous liquid by 180 °C; ^{1}H NMR ($CDCl_3$) δ 7.86 (s, 2, Ar*OH*), 7.20 (d, 2, J = 2.4 Hz, Ar*H*), 7.19 (s, 2, Ar*H*), 7.15 (d, 2, J = 2.4 Hz, Ar*H*), 7.08 (d, 2, J = 2.4 Hz, Ar*H*), 6.94 (s, 1, O*H*), 3.91 (br s, 4, $ArCH_2Ar$), 3.86 (br s, 4, $ArCH_2Ar$), 3.83 (br s, 2, $ArCH_2Ar$), 3.82 (s, 6, OCH_3), 1.33 (s, 9, $C(CH_3)_3$), 1.27 (s, 18, $C(CH_3)_3$), 1.06 (s, 18, $C(CH_3)_3$); ^{13}C NMR ($CDCl_3$) δ 151.4, 150.3, 149.2, 147.1, 142.5, 141.5, 132.1, 127.0, and 126.5 (Ar), 126.3, 126.1, 125.9, 125.8, and 125.3 (ArH), 62.4 (OCH_3), 34.2 and 33.9 ($C(CH_3)_3$), 31.9(1) ($ArCH_2Ar$), 31.7(1), 31.6(2), and 31.2(2) ($C(CH_3)_3$), 31.1(2) and 30.2(2) ($ArCH_2Ar$);

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[47] Unless otherwise noted, starting materials were obtained from commercial suppliers and used without further purification. THF was freshly distilled from Na-benzophenone. The melting points of all compounds were taken in sealed and evacuated capillary tubes on a Mel-Temp apparatus (Laboratory Devices, Cambridge, MA) using a 500 °C thermomenter calibrated against a thermocouple. ^{1}H NMR and ^{13}C NMR spectra were recorded on a Varian XL-300 spectrometer at 300 and 75 MHz, respectively. TLC analyses were carried out on Analtech silica gel plates (absorbant thickness 250 μm) containing a fluorescent indicator. Chromatography was carried out with J. T. Baker silica gel no. JT7042-2 (40–63 μm particles) on columns filled to a height of *ca.* 6 in. Elution rates were 2 in/min. Analytical samples were recrystallized from at least two different solvents and were often stirred with MeOH before drying at 100–140 °C and 0.05 Torr for at least 24 h. Microanalyses were performed by Desert Laboratories, Tucson, AZ.

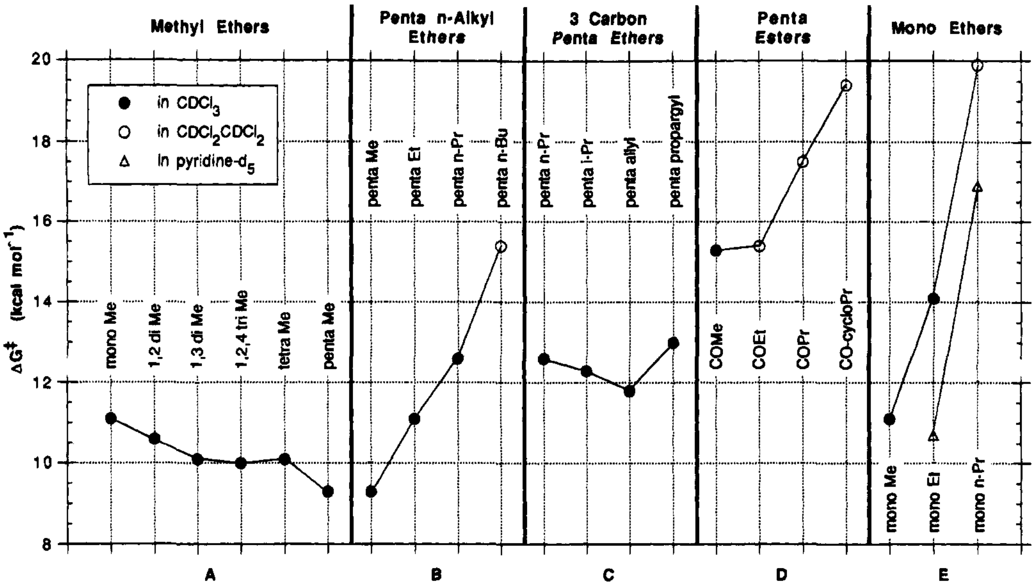

Figure 10. Energy barriers ($\Delta G^{\ddagger}$) to conformational inversion for conformationally mobile ethers and esters of *p-tert*-butylcalix[5]arene.

IR (KBr) 3506 and 3383 (OH) cm^{-1}. Anal. Calcd for $C_{57}H_{74}O_5$: C, 81.58; H, 8.89. Found: C, 81.42; H, 8.84.

5,11,17,23,29-Penta-*tert*-butyl-31,32-dimethoxy-33,34,35-trihydroxycalix[5]arene (3b). The lower TLC spot material from the chromatographic separation described above is assumed to be **3b**: mp 227–228 °C; ^{1}H NMR ($CDCl_3$) δ 7.47 (s, 2, ArO*H*), 7.45 (s, 1, ArO*H*), 7.17 (d, 2, *J* = 2.4 Hz, Ar*H*), 7.14 (s, 2, Ar*H*), 7.12 (d, 2, *J* = 2.4 Hz, Ar*H*), 7.10 (d, 2, *J* = 2.7 Hz, Ar*H*), 7.02 (d, 2, *J* = 2.4 Hz, Ar*H*), 4.01 (s, 2, ArC*H*$_2$Ar), 3.82 (s, 4, ArC*H*$_2$Ar), 3.79 (s, 4, ArC*H*$_2$Ar), 3.67 (s, 6, OC*H*$_3$), 1.26 (s, 18, C(C*H*$_3$)$_3$), 1.25 (s, 9, C(C*H*$_3$)$_3$), 1.13 (s, 18, C(C*H*$_3$)$_3$); ^{13}C NMR ($CDCl_3$ δ 152.7, 149.2, 148.7, 146.9, 143.0, 132.8, 132.7, 127.7, 127.3, and 127.1 (Ar), 126.2, 126.0, 125.9, and 125.7 (ArH), 61.9 (OCH_3), 34.2 and 34.0 (*C*(CH$_3$)$_3$), 32.3 (Ar*C*H$_2$Ar), 31.59(2), 31.55(1), and 31.3(2) (C(*C*H$_3$)$_3$), 30.3 (Ar*C*H$_2$Ar); IR (KBr) 3516 and 3378 (OH) cm^{-1}. Anal. Calcd for $C_{57}H_{74}O_5$: C, 81.58; H, 8.89. Found: C, 81.48; H, 8.71.

5,11,17,23,29-Penta-*tert*-butyl-31,32,34-trimethoxy-33,35-dihydroxycalix[5]arene (3e) was isolated from the chromatographic separation described above: mp 125-130 °C (turned to a glass or a viscous liquid); ^{1}H NMR ($CDCl_3$) δ 7.11 (d, 2, *J* = 2.4 Hz, Ar*H*), 7.08 (d, 2, *J* = 2.4 Hz, Ar*H*), 7.10 (s, 4, Ar*H*), 6.91 (br s, 2, O*H*), 6.88 (s, 2, Ar*H*), 3.92, (s, 2, ArC*H*$_2$Ar), 3.87 (s, 4, ArC*H*$_2$Ar), 3.83 (s, 4, ArC*H*$_2$Ar), 3.51 (s, 3, OC*H*$_3$), 3.22 (s, 6, OC*H*$_3$), 1.26 (s, 18, C(C*H*$_3$)$_3$), 1.17 (s, 18, C(C*H*$_3$)$_3$), 1.00 (s, 9, C(C*H*$_3$)$_3$); ^{13}C NMR ($CDCl_3$) δ 153.0, 152.9, 149.5, 146.6, 145.7, 142.1, 133.1, 133.0, 132.9, 127.8, and 127.1 (Ar), 126.4, 126.3, 126.0, 125.8, and 125.3 (ArH), 61.5 and 61.2 (O*C*H$_3$), 34.1, 34.0, and 33.9 (*C*(CH$_3$)$_3$), 31.9 (Ar*C*H$_2$Ar), 31.6, 31.3, and 31.2 (C(*C*H$_3$)$_3$), 31.1 and 30.3 (Ar*C*H$_2$Ar); IR (KBr) 3516 sh and 3395 (OH) cm^{-1}. Anal. Calcd for $C_{58}H_{76}O_5$: C, 81.65; H, 8.98. Found: C, 81.84; H, 8.86.

5,11,17,23,29-Penta-*tert*-butyl-31,32,33,34-tetramethoxy-35-hydroxycalix[5]arene (3f). A stirred suspension of 2.00 g (2.47 mmol) of **1b**, 2.08 g (10.85 mmol) of methyl tosylate (97%), and 5.11 g (36.98 mmol) of K_2CO_3 in 60 mL of dry MeCN was heated at reflux in an inert atmosphere for 20 h. The reaction mixture was worked up as described above for **3a**, and the crude product was subjected to gradient flash chromatography (SiO_2, $CHCl_3$-hexane 3:2 to 100% $CHCl_3$) to give 1.15 g of **3g** (53%) after recrystallization from $CHCl_3$-MeOH and 0.54 g of **3f** (25%) after recrystallization from $CHCl_3$–MeOH: mp 230.5–232 °C; ^{1}H NMR ($CDCl_3$) δ 7.13 (d, 2, *J* = 2.6 Hz, Ar*H*), 7.07 (d, 2, *J* = 2.6 Hz, Ar*H*), 7.03 (s, 2, Ar*H*), 7.00 (br s, 1, O*H*), 6.92 (s, 4, Ar*H*), 3.93 (s, 2, ArC*H*$_2$Ar), 3.88 (s, 4, ArC*H*$_2$Ar), 3.78 (s, 4, ArC*H*$_2$Ar), 3.53 (s, 6, OCH_3), 2.98 (s, 6, OC*H*$_3$), 1.21 (s, 9, C(C*H*$_3$)$_3$), 1.17 (s, 18, C(C*H*$_3$)$_3$), 1.04 (s, 18, C(C*H*$_3$)$_3$); ^{13}C NMR ($CDCl_3$) δ 154.3, 152.8, 149.2, 146.1, 145.2, 141.9, 134.5, 133.7, 133.6, 133.3, 127.3, (Ar), 126.0, 125.9, 125.7, 125.2, (ArH), 61.0, 60.5, (O*C*H$_3$), 34.1, 34.0, 33.8 (*C*(CH$_3$)), 31.9 (Ar*C*H$_2$Ar), 31.6, 31.4, 31.3 (C(*C*H$_3$)$_3$), 30.5 (Ar*C*H$_2$Ar); IR (KBr) 3420 and 3375 (OH) cm^{-1}. Anal. Calcd. for $C_{59}H_{78}O_5$: C, 81.71; H, 9.07; Found: C, 81.98; H, 9.01.

5,11,17,23,29-Penta-*tert*-butyl-31,32,33,34,35-pentamethoxycalix[5]arene (3g). A stirred suspension of 1.00 g (1.23 mmol) of **1b**, 4.10 g (21.6 mmol) of methyl tosylate (98%), and 2.56 g (18.5 mmol) of K_2CO_3 in 50 mL of dry MeCN was heated at reflux in an inert atmosphere. After 18 h a 10-mL portion of MeOH (0.25 mol) was added, and reflux was continued for 1 h. After cooling the reaction mixture to room temperature, the solvent was removed *in vacuo*, and the residue was partitioned between 75 mL of $CHCl_3$ and 50 mL of 1 N HCl. The $CHCl_3$ layer was separated, washed with 100 mL of H_2O, and dried with anhydrous $MgSO_4$. The $CHCl_3$ was removed *in vacuo*, and the residue was recrystallized from *i*-PrOH–$CHCl_3$ to give 0.91 g (84%) of **3g** as fine white crystals: mp 360–361 °C; ^{1}H NMR ($CDCl_3$) δ 7.07 (s, 10, Ar*H*), 3.80 (s, 10, ArC*H*$_2$Ar), 2.96 (s, 15, OC*H*$_3$), 1.20 (s, 45, C(C*H*$_3$)$_3$); ^{13}C NMR ($CDCl_3$) δ 154.2, 145.1, and 133.6 (Ar), 126.1 (ArH), 60.1 (O*C*H$_3$), 34.1 (*C*(CH$_3$)$_3$), 31.8 (Ar*C*H$_2$Ar), 31.5 (C(*C*H$_3$)$_3$); IR (KBr) no (OH) stretch; FAB MS, *m/e* 880 [M$^+$, calcd 881]. Anal. Calcd for $C_{60}H_{80}O_5$: C, 81.77; H, 9.15. Found: C, 81.55; H, 9.46.

5,11,17,23,29-Penta-*tert*-butyl-31,32,33,34,35-pentaethoxycalix[5]arene (4). A stirred suspension of 1.00 g (1.23 mmol) of **1b**, 3.78 g (18.5 mmol) of ethyl tosylate (98%), and 2.56 g (18.5 mmol) of K_2CO_3 in 50 mL of dry MeCN was heated at reflux in an inert atmosphere for 24 h. The reaction mixture was worked up as described above for **3g**, and the crude product was recrystallized from *i*-PrOH–$CHCl_3$ to give 0.96 g (82%) of **4** as small, colorless rhombs: mp 224-225 °C; ^{1}H NMR ($CDCl_3$) δ 7.17 (s, 10, Ar*H*), 3.76 (br s, 10, ArC*H*$_2$Ar), 3.22 (br q, 10, *J* = 5.3 Hz, OC*H*$_2$CH$_3$), 1.25 (s, 45, C(C*H*$_3$)$_3$), 0.82 (br t, 15, OCH$_2$C*H*$_3$); ^{13}C NMR ($CDCl_3$) δ 153.4, 144.6, and 133.4 (Ar), 126.4 (ArH), 68.3 (O*C*H$_2$CH$_3$), 34.1 (*C*(CH$_3$)$_3$), 32.2 (br s, Ar*C*H$_2$Ar), 31.5 (C(*C*H$_3$)$_3$), 15.4 (OCH$_2$*C*H$_3$); IR (KBr) no (OH) stretch; FAB MS, *m/e* 950 [M$^+$, calcd 950]. Anal. Calcd for $C_{65}H_{90}O_5$: C, 82.06; H, 9.53. Found: C, 82.47; H, 9.52.

5,11,17,23,29-Penta-*tert*-butyl-31,32,33,34,35-penta-*n*-propoxycalix[5]arene (5). A stirred suspension of 1.00 g (1.23 mmol) of **1b**, 1.82 mL (3.17 g, 18.5 mmol) of 1-iodopropane (99%), and 2.56 g (18.5 mmol) of K_2CO_3 in 50 mL of dry MeCN was heated at reflux in an inert atmosphere for 21 h. The reaction mixture was worked up as described above for **3g**, and the crude product was recrystallized from 25 mL of acetone to give 1.05 g (83%) of **5** as fine white needles: mp 179–180 °C; ^{1}H NMR ($CDCl_3$) δ 7.22 (br s, 10, Ar*H*), 3.77 (v br s, 10, ArC*H*$_2$Ar), 3.11 (v br s, 10, OC*H*$_2$CH$_2$CH$_3$), 1.28 (s, 45, C(C*H*$_3$)$_3$), 1.28 (br s, 10, OCH$_2$C*H*$_2$CH$_3$), 0.82 (br t, 15, OCH$_2$CH$_2$C*H*$_3$); ^{13}C NMR ($CDCl_3$) δ 153.5, 144.4, and 133.4 (ArH), 126.6 (ArH), 74.7 (O*C*H$_2$CH$_2$CH$_3$), 34.1 (*C*(CH$_3$)$_3$), 31.5 (C(*C*H$_3$)$_3$), 31.5 (br s, Ar*C*H$_2$Ar), 22.9

(br s, $OCH_2CH_2CH_3$), 10.3 ($OCH_2CH_2CH_3$); IR (KBr) no (OH) stretch. Anal. Calcd for $C_{70}H_{100}O_5$: C, 82.30; H, 9.87. Found: C, 82.53; H, 9.98.

5,11,17,23,29-Penta-*tert*-butyl-31,32,33,34,35-penta-2-propoxycalix[5]arene (6). A stirred suspension of 1.00 g (1.23 mmol) of **1b**, 2.46 mL (4.19 g, 24.7 mmol) of 2-iodopropane (99%), and 2.56 g (18.5 mmol) of K_2CO_3 in 50 mL of dry MeCN was heated at reflux in an inert atmosphere for 22 h. The reaction mixture was worked up as described above for **3g**, and the crude product was recrystallized from acetone to give 1.03 g (82%) of **6** as small white cubes. The mother liquor was concentrated to give a second crop of 0.025 g (2%): mp 275–276.5 °C; ^{1}H NMR ($CDCl_3$) δ 7.18 (s, 10, Ar*H*), 3.96 (br s, 5, $OC\mathit{H}(CH_3)_2$), 3.74 (v br s, 10, $ArC\mathit{H}_2Ar$), 1.24 (s, 45, $C(C\mathit{H}_3)_3$), 0.83 (br s, 30, $OCH(C\mathit{H}_3)_2$); ^{13}C NMR ($CDCl_3$) δ 152.1, 143.5, and 132.9 (Ar), 126.7 (ArH), 74.2 ($O\mathit{C}H(CH_3)_2$), 34.0 ($\mathit{C}(CH_3)_3$), 33.1 (v br s, $Ar\mathit{C}H_2Ar$), 31.6 ($\mathit{C}(CH_3)_3$), 21.9 ($OCH(\mathit{C}H_3)_2$); IR (KBr) no (OH) stretch. Anal. Calcd for $C_{70}H_{100}O_5$: C, 82.30; H, 9.87. Found: C, 82.50; H, 9.88.

5,11,17,23,29-Penta-*tert*-butyl-31,32,33,34,35-pentaalloxycalix[5]arene (7). A stirred suspension of 1.00 g (1.23 mmol) of **1b**, 2.13 mL (2.98 g, 0.616 mmol) of allyl bromide, and 2.56 g (18.5 mmol) of K_2CO_3 in 50 mL of dry Me_2CO was heated at reflux in an inert atmosphere for 10 h. The product was worked up as described above for **3g**, and the crude product was recrystallized from cold acetone to give 1.14 g (91%) of **7** as fine white needles: mp 129-130.5 °C to a very viscous liquid or glass; ^{1}H NMR ($CDCl_3$) δ 7.19 (s, 10, Ar*H*), 5.55 (br s, 5, $OCH_2C\mathit{H}{=}CH_2$), 5.05 (br d, 5, *trans*-$OCH_2CH{=}C\mathit{H}_2$), 4.84 (br s, 5, *cis*-$OCH_2CH{=}C\mathit{H}_2$), 3.75 (br s, $ArC\mathit{H}_2Ar$), 3.53 (br s, $OC\mathit{H}_2CH{=}CH_2$), 1.26 (s, 45 $C(C\mathit{H}_3)_3$); ^{13}C NMR ($CDCl_3$, 55 °C) δ 153.3 and 145.0 (Ar), 134.7 ($OCH_2\mathit{C}H{=}CH_2$), 133.6, (Ar), 126.8 (ArH), 116.3 ($OCH_2CH{=}\mathit{C}H_2$), 73.6 ($O\mathit{C}H_2CH{=}CH_2$), 34.2 ($\mathit{C}(CH_3)_3$), 32.3 ($Ar\mathit{C}H_2Ar$), 31.6 ($C(\mathit{C}H_3)_3$). Anal. Calcd for $C_{70}H_{90}O_5$: C, 83.12; H, 8.97. Found: C, 83.16; H, 9.15.

5,11,17,23,29-Penta-*tert*-butyl-31,32,33,34,35-pentapropargoxycalix[5]arene (8). A stirred suspension of 1.00 g (1.23 mmol) of **1b**, 3.66 g (24.6 mmol) of propargyl bromide, and 2.56 g (18.5 mmol) of K_2CO_3 in 50 mL of dry Me_2CO was heated at reflux in an inert atmosphere for 24 h. The reaction mixture was worked up as described above for **3g**, and a TLC analysis (toluene/hexane 4:1 (v/v)) of the product showed the presence of a faster eluting impurity which was not removed by recrystallizations from *i*-PrOH or *n*-heptanes; an HPLC analysis of the recrystallized product showed it still contained 8% of the unknown impurity. Therefore, the recrystallized product was subjected to flash chromatography (SiO_2, toluene/hexanes 20:1) and recrystallized from cold *n*-heptane to give 0.90 g (73%) of **8** as fine white needles: mp 181–182 °C; ^{1}H NMR ($CDCl_2CDCl_2$, 70 °C) δ 7.05 (s, 10, Ar*H*), 4.18 (br s, 10, $OC\mathit{H}_2C{\equiv}CH$), 3.88 (br s, 10, $ArC\mathit{H}_2Ar$), 2.25 (br s, 5, $OCH_2C{\equiv}C\mathit{H}$), 1.17 (s, 45, $C(C\mathit{H}_3)_3$); ^{13}C NMR ($CDCl_2CDCl_2$ at 70 °C) δ 152.0, 145.8, and 133.7 (Ar), 126.2 (ArH), 80.6 ($OCH_2\mathit{C}{\equiv}CH$), 74.8 ($OCH_2C{\equiv}\mathit{C}H$), 60.5 ($O\mathit{C}H_2C{\equiv}CH$), 34.0 ($\mathit{C}(CH_3)_3$), 32.2 ($Ar\mathit{C}H_2Ar$), 31.4 ($C(\mathit{C}H_3)_3$); IR (KBr) no (OH) stretch, 3310, 3294, and 3277 (≡C-H) cm^{-1}, 2156 (C≡C) cm^{-1}. Anal. Calcd for $C_{90}H_{100}O_5$: C, 83.96; H, 8.05. Found: C, 84.23; H, 8.49.

5,11,17,23,29-Penta-*tert*-butyl-31,32,33,34,35-penta-*n*-butoxycalix[5]arene (9). A stirred suspension of 1.00 g (1.23 mmol) of **1b**, 0.118 g (18.5 mmol) of 1-iodobutane, and 0.247 g (2.47 mmol) of K_2CO_3 in 50 mL of dry MeCN was heated at reflux in an inert atmosphere for 24 h. The reaction mixture was worked up as described above for **3g**, and the crude product was recrystallized from cold acetone to give 1.16 g (86%) of **9** as fine white needles: mp 158–160 °C; ^{1}H NMR ($CDCl_3$, −22 °C) δ 7.55 (d, 2, J = 2.4 Hz, Ar*H*), 7.30 (s, 4, Ar*H*), 7.23 (d, 2, J = 2.2 Hz, Ar*H*), 7.05 (d, 2, J = 2.2 Hz, Ar*H*), 7.02 (d, 2, J = 2.2 Hz, Ar*H*), 4.40 (d, 2, J = 13.9 Hz, $ArC\mathit{H}_2Ar$), 4.16 (d, 1, J = 13.5 Hz, $ArC\mathit{H}_2Ar$), 3.87–3.80 (m, n-$C_4\mathit{H}_9O$), 3.79 (s, 4, $ArC\mathit{H}_2Ar$), 3.63–3.55 (m, 2, n-$C_4\mathit{H}_9O$), 3.31–3.23 (m, 4, n-$C_4\mathit{H}_9O$ and $ArC\mathit{H}_2Ar$), 3.20 (d, 2, J = 14.0 Hz, $ArC\mathit{H}_2Ar$), 2.89–2.81 (m, 2, n-$C_4\mathit{H}_9O$), 2.06 (br t, n-$C_4\mathit{H}_9O$), 1.9–1.6 (m, 6, n-$C_4\mathit{H}_9O$), 1.6–1.2 (m, n-$C_4\mathit{H}_9O$), 1.41 (s, 9, $C(C\mathit{H}_3)_3$), 1.37 (s, 18, $C(C\mathit{H}_3)_3$), 1.14 (s, 18, $C(C\mathit{H}_3)_3$), 1.2–0.95 (m, n-$C_4\mathit{H}_9O$), 0.92 (t, 6, J = 7.1 Hz, n-$C_4\mathit{H}_9O$), 0.67 (t, 6, J = 7.2 Hz, n-$C_4\mathit{H}_9O$), 0.58 (br t, 2, J = 7.1 Hz, n-$C_4\mathit{H}_9O$), 0.40–0.33 (m, 1, n-$C_4\mathit{H}_9O$), -0.05 (br t, 1, n-$C_4\mathit{H}_9O$); ^{13}C NMR ($CDCl_3$, 20 °C) δ 153.5–152.0 (m, Ar), 144.4 (s, Ar), 135.0–132.5 (m, Ar), 129–125 (m, ArH), 73.2 (br s, $O\mathit{C}H_2CH_2CH_2CH_3$), 38.5 (br s, $Ar\mathit{C}H_2Ar$), 34.1 ($\mathit{C}(CH_3)_3$), 32.5 ($Ar\mathit{C}H_2Ar$), 31.6 ($C(\mathit{C}H_3)_3$), 29.5 (br s, n-C_4H_9O), 28.5 (br s, n-C_4H_9O), 26.3 (br s, n-C_4H_9O), 19 (br s, n-C_4H_9O), 14.0 (s, n-C_4H_9O); IR (KBr) no (OH) stretch. Anal. Calcd for $C_{75}H_{110}O_5$: C, 82.52; H, 10.16. Found: C, 82.64; H, 10.12.

5,11,17,23,29-Penta-*tert*-butyl-31,32,33,34,35-pentabenzoxycalix[5]arene (10). A stirred suspension of 1.00 g (1.23 mmol) of **1b**, 1.82 mL (3.17 g, 18.5 mmol) of benzyl bromide (98%), and 2.56 g (18.5 mmol) of K_2CO_3 in 50 mL of dry MeCN was heated at reflux in an inert atmosphere for 11 h. The reaction mixture was worked up as described above, and the crude product was recrystallized from MeCN–$CHCl_3$ to give 1.32 g (85%) of **10** as a white powder: mp 224–225 °C; ^{1}H NMR ($CDCl_3$) δ 7.23 (m, 25, benzyloxy Ar*H*), 6.85 (s, 10, Ar*H*), 4.37 (s, 10, $OC\mathit{H}_2Ar$), 4.29 (d, 5, J = 13.9 Hz, $ArC\mathit{H}_2Ar$), 3.00 (d, 5, J = 13.9 Hz, $ArC\mathit{H}_2Ar$), 1.01 (s, 45, $C(C\mathit{H}_3)_3$); ^{13}C NMR ($CDCl_3$) δ 151.7, 145.1, 138.3, and 134.1 (Ar), 129.2, 127.8, 127.2, and 125.4 (ArH), 75.5 ($O\mathit{C}H_2Ar$), 33.9 ($\mathit{C}(CH_3)_3$), 31.4 ($C(\mathit{C}H_3)_3$), 29.6 ($Ar\mathit{C}H_2Ar$); IR (KBr) no (OH) stretch. Anal. Calcd for $C_{90}H_{100}O_5$: C, 85.67; H, 7.99. Found: C, 86.01; H, 8.07.

5,11,17,23,29-Penta-*tert*-butyl-31,32,33,34,35-pentaacetoxycalix[5]arene (11). A stirred solution of 1.00 g (1.23 mmol) of **1b** in 50 mL of Ac_2O containing 2 drops of concentrated H_2SO_4 was heated at reflux under N_2. After 4 h the Ac_2O was removed *in vacuo*, and the residue was partitioned between 50 mL of $CHCl_3$ and 100 mL of H_2O. The $CHCl_3$ layer was separated, dried with $MgSO_4$, and evaporated *in vacuo*. The residue was recrystallized from $CHCl_3$/MeOH to give 1.24 g of **11** (98%) as a white powder. An analytical sample was prepared by three recrystallizations from *i*-PrOH, *n*-butanol, and a mixture these two solvents, respectively: mp 267–269 °C; ^{1}H NMR ($CDCl_3$) δ 7.4 - 6.6 (v br m, 10, Ar*H*), 3.86–3.46 (br m, 7, $ArC\mathit{H}_2Ar$), 3.46–3.20 (br d, 3, $ArC\mathit{H}_2Ar$), 2.34 (br s, 6, $C\mathit{H}_3C{=}O$), 1.79 (br s, 3, $C\mathit{H}_3C{=}O$), 1.33 (br s, 27, $C(C\mathit{H}_3)_3$), 1.10 (br s, 24, $C(C\mathit{H}_3)_3$ and $C\mathit{H}_3C{=}O$); ^{13}C NMR ($CDCl_3$) δ 168.9 (br s, $\mathit{C}{=}O$), 148.1 (br s, Ar), 145.2 (br, s Ar), 132.9 (br s, Ar), 131.0 (br s, Ar), 127.0–125.5 (br m, ArH), 35.3–34.9 (br s, $Ar\mathit{C}H_2Ar$), 34.3 ($\mathit{C}(CH_3)_3$), 31.4 ($C(\mathit{C}H_3)_3$), 20.7–19.9 ($\mathit{C}H_3C{=}O$); IR (KBr) no (OH) stretch, 1761 (C=O) cm^{-1}; FAB MS, *m/e* 1021 [M$^+$ calcd 1021]. Anal. Calcd for $C_{65}H_{80}O_{10}$: C, 76.44; H, 7.90. Found: C, 76.34; H, 8.02.

5,11,17,23,29-Penta-*tert*-butyl-31,32,33,34,35-pentapropanoyloxycalix[5]arene (12). A stirred solution of 1.00 g (1.23 mmol) of **1b** in 60 mL of propionic anhydride containing 2 drops of concentrated H_2SO_4 was heated at reflux under N_2. The product was worked up as described above for **11**, and the crude product was twice recrystallized from $CHCl_3$–MeOH to give 1.31 g (98%) of **12** as a white powder: mp 310.5–312 °C; ^{1}H NMR ($CDCl_3$) δ 7.32 (br s, 2, Ar*H*), 7.14 (br s, 4, Ar*H*), 6.99 (br s, 2, Ar*H*), 6.93 (sh, 2, Ar*H*), 3.67–3.53 (br m, 7, $ArC\mathit{H}_2Ar$), 3.31–3.27 (br d, 3, $ArC\mathit{H}_2Ar$), 2.53 (br s, 4, $CH_3C\mathit{H}_2C{=}O$), 2.03 (br s, 2, $CH_3C\mathit{H}_2C{=}O$), 1.74 (br s, 4, $CH_3C\mathit{H}_2C{=}O$), 1.34 (br s, 18, $C(C\mathit{H}_3)_3$), 1.24 (sh, 9, $C(C\mathit{H}_3)_3$), 1.15 (br s, 24, $C(CH_3)_3$ and $C\mathit{H}_3CH_2C{=}O$), 0.706 (br s, 3, $C\mathit{H}_3CH_2C{=}O$), 0.461 (br s, 6, $C\mathit{H}_3CH_2C{=}O$); ^{13}C NMR ($CDCl_2CDCl_2$, 89 °C) δ 172.3 ($\mathit{C}{=}O$), 148.1, 145.4, and 131.9 (Ar), 126.4 (ArH), 34.24 ($\mathit{C}(CH_3)_3$), 31.39 ($C(\mathit{C}H_3)_3$), 26.62 ($CH_3\mathit{C}H_2C{=}O$), 8.68 ($\mathit{C}H_3CH_2C{=}O$); IR (KBr) no (OH) stretch, 1755 (C=O) cm^{-1}. Anal. Calcd for $C_{70}H_{90}O_{10}$: C, 77.03; H, 8.31. Found: C, 76.95; H, 8.14.

5,11,17,23,29-Penta-*tert*-butyl-31,32,33,34,35-penta-*n*-butanoyloxycalix[5]arene (13). A 1.11 g portion of NaH (27.8 mmol as a 60% dispersion in mineral oil) was introduced into a dry, three-necked, round-bottomed flask fitted with a stirring bar, septum, an oven-dried condenser, and a stopper under an N_2 atmosphere. The dispersion was washed twice with 10–15 mL of dry THF and then stirred at reflux with 40 mL of THF and 1.00 g (1.23 mmol) of **1b**. After 3 h of reflux, the mixture was cooled to ambient temperature, and 3.27 mL (3.35 g, 30.8 mmol) of *n*-butanoyl chloride was added dropwise. The mixture was heated at reflux for 3 h, cooled, and quenched with *i*-PrOH. The THF was removed *in vacuo*, and the residue was partitioned between 75 mL each of $CHCl_3$ and H_2O. The pH was adjusted to *ca.* 7 with saturated aqueous $NaHCO_3$, and the $CHCl_3$ layer was separated, washed with 100 mL of H_2O, and dried with $MgSO_4$. The $CHCl_3$ was removed *in vacuo*, and the residue was recrystallized from *n*-heptane to give 1.20 g of **13** (85%) as a white powder: mp 265.5–267 °C; ^{1}H NMR ($CDCl_3$) δ 7.34 (br s, 2, Ar*H*), 7.29 (br s, 2, Ar*H*), 7.13 (br s, 2, Ar*H*), 6.95 (br s, 4, Ar*H*), 3.72−3.48 (m, 7, ArCH_2Ar), 3.28 (d, 3, *J* = 14.8 Hz, ArCH_2Ar), 2.57−2.42 (m, 4, CH$_3$CH$_2$CH_2CO$_2$), 2.02−1.64 (m, CH$_3$CH_2CH$_2$CO$_2$), 1.78−1.67 (m, 6, CH$_3$CH_2CH$_2$CO$_2$), 1.38−1.12 (m, CH$_3$CH_2CH$_2$CO$_2$), 1.39 (s, 9, C(CH_3)$_3$), 1.35 (s, 18, C(CH_3)$_3$), 1.17 (s, 18, C(CH_3)$_3$), 1.01 (t, 6, *J* = 7.4 Hz, CH_3CH$_2$CH$_2$CO$_2$), 0.664 (m, 9, CH_3CH$_2$CH$_2$CO$_2$); ^{13}C NMR (CDCl$_3$) δ 172.2, 171.7, 147.7, 147.4, 145.61, 145.57, 144.6, 132.7, 132.4, 131.5, 131.3, and 131.1 (Ar), 127.5, 126.9, 126.5, 126.0, and 125.0 (ArH), 37.0 (ArCH$_2$Ar), 35.6 (ArCH$_2$-Ar/C_4H$_7$O$_2$), 34.4 and 34.2 (C(CH$_3$)$_3$), 33.5 (ArCH$_2$Ar/C_4H$_7$O$_2$), 31.5 and 31.3 (C(CH$_3$)$_3$), 30.6 and 29.8 (ArCH$_2$Ar/C_4H$_7$O$_2$), 18.2 and 17.3 (CH$_3$$CH_2CH_2CO_2$), 13.9, 13.6, and 13.2, (CH$_3$CH$_2$CH$_2$CO$_2$); IR (KBr) no (OH) stretch, 1755 (C=O) cm^{-1}. Anal. Calcd for $C_{75}H_{100}O_{10}$: C, 77.55; H, 8.68. Found: C, 77.41; H, 8.67.

5,11,17,23,29-Penta-*tert*-butyl-31,32,33,34,35-pentaisobutanoyloxycalix[5]arene (14). The procedure described above for **13** was followed, using 1.00 g (1.23 mmol) of **1b** and 3.30 mL (3.35 g. 30.8 mmol) of isobutryl chloride, to give a crude product that was partitioned between 75 mL each of CHCl$_3$ and H$_2$O. The pH was adjusted to *ca.* 7 with saturated aqueous NaHCO$_3$, and the CHCl$_3$ layer was separated, washed with 100 mL of H$_2$O, and dried with MgSO$_4$. The CHCl$_3$ was removed *in vacuo*, and the residue was twice recrystallized from acetone−CHCl$_3$ to give 0.72 g of **14** (50%) as a white powder: mp 340−342 °C; ^{1}H NMR (CDCl$_3$) δ 7.49 (d, 2, *J* = 2.4 Hz, Ar*H*), 7.36 (s, 2, Ar*H*), 7.09 (d, 2, *J* = 2.4 Hz, Ar*H*), 6.98 and 6.96 (pr AB d, 4, *J* = 2.4 Hz, Ar*H*), 3.62 (s, 4, ArCH_2Ar), 3.48 (d, 1, *J* = 14.5 Hz, ArCH_2Ar), 3.47 (d, 2, *J* = 14.6 Hz, ArCH_2Ar), 3.30 (d, 2, *J* = 14.7 Hz, ArCH_2Ar), 3.22 (d, 2, *J* = 14.7 Hz, ArCH_2Ar), 2.71 (m, 2, *J* = 6.9 Hz, O$_2$CH(CH$_3$)$_2$), 2.41 (m, 3, *J* = 7.0 Hz, O$_2$CH(CH$_3$)$_2$), 1.42 (s, 9, C(CH_3)$_3$), 1.37 (s, 18, C(CH_3)$_3$), 1.30 (d, 6, *J* = 6.8 Hz, O$_2$CCH(CH_3)$_2$), 1.24 (d, 6, *J* = 6.9 Hz, O$_2$CCH(CH_3)$_2$), 1.16 (s, 18, C(CH_3)$_3$), 1.00 (d, 6, *J* = 6.9 Hz, O$_2$CCH(CH_3)$_2$), 0.80 (d, 6, *J* = 7.2 Hz, O$_2$CCH(CH_3)$_2$), 0.37 (d, 6, *J* = 7.3 Hz, O$_2$CCH(CH_3)$_2$); ^{13}C NMR (CDCl$_3$) δ 175.7, 175.5, and 175.3 (C=O), 148.2, 147.4, 147.3, 145.7, 144.9, 132.2, 131.75, 131.67, 131.64, and 131.0 (Ar), 127.6, 126.8, 126.7, 126.0, and 125.7 (ArH), 38.0 (ArCH$_2$Ar), 34.4, 34.2, 33.8, 33.3, and 33.2 (ArCH$_2$Ar, (CH$_3$)$_2$$C$HC=O, or C(CH$_3$)$_3$), 31.6 and 31.5 (C(CH$_3$)$_3$), 31.40 and 31.35 (ArCH$_2$Ar and/or (CH$_3$)$_2$$C$HC=O), 31.23 (C($CH_3$)$_3$), 29.7 and 27.8 (Ar$CH_2$Ar and/or (CH$_3$)$_2$$C$HC=O), 19.8, 19.2, 18.6, 18.5, and 16.8 ((CH$_3$)$_2$CHC=O). Anal. Calcd for $C_{75}H_{100}O_{10}$: C, 77.55; H, 8.68. Found: C, 76.96; H, 8.73.

5,11,17,23,29-Penta-*tert*-butyl-31,32,33,34,35-penta(cyclopropylcarbonyloxy)calix[5]arene (15). The procedure described above for **13** was followed, using 1.00 g (1.23 mmol) of **1b** and 2.95 mL (3.35 g, 30.8 mmol) of cyclopropanecarbonyl chloride, to give a crude product that was partitioned between 75 mL each of CHCl$_3$ and H$_2$O. The pH was adjusted to *ca.* 7 with saturated aqueous NaHCO$_3$, and the CHCl$_3$ layer was separated, washed with 100 mL of H$_2$O, and dried with MgSO$_4$. The CHCl$_3$ was removed *in vacuo*, and the residue was recrystalized first from CHCl$_3$−MeOH and then from acetone to give 1.00 g (70%) of **15** as white rhombs: mp 380−382 °C; ^{1}H NMR (CDCl$_3$) δ 7.39 (br s, 2, Ar*H*), 7.34 (s, 2, Ar*H*), 7.24 (d, 2, *J* = 2.4 Hz, Ar*H*), 7.10 (d, 2, *J* = 2.4 Hz, Ar*H*), 6.81 (br s, 2, Ar*H*), 3.66 (d, 2, *J* = 15.0 Hz, ArCH_2Ar), 3.61 (d, 1, *J* = 15.0 Hz, ArCH_2Ar), 3.59 and 3.52 (pr AB d, 4, *J* = 14.8 and 14.8 Hz, ArCH_2Ar), 3.32 (d, 1, *J* = 14.6 Hz, ArCH_2Ar), 3.23 (d, 2, *J* = 14.8 Hz, ArCH_2Ar), 2.18 (br m, 1, O$_2$CH(CH$_2$)$_2$), 1.83 (br m, 2, O$_2$CH(CH$_2$)$_2$), 1.58 (br m, 2, O$_2$CH(CH$_2$)$_2$), 1.38 (s, 9, C(CH_3)$_3$), 1.34 (s, 18, C(CH_3)$_3$), 1.12 (s, 9, C(CH_3)$_3$), 1.4−0.9 (br m, O$_2$CH(CH_2)$_2$), 0.8−0.4 (br m, O$_2$CH(CH_2)$_2$), −0.35 (br m, O$_2$CH(CH_2)$_2$); ^{13}C NMR (CDCl$_3$) δ 173.6 and 173.5 (C=O), 148.4, 147.6, 147.2, 145.8, 145.0, 133.0, 132.8, 132.3, 131.7, and 131.0 (Ar), 127.4, 127.3, 126.5, 126.3, and 124.6 (ArH), 37.5 (ArCH$_2$Ar), 34.4 and 34.2 (C(CH$_3$)$_3$), 31.54, 31.48, and 31.33 (C(CH$_3$)$_3$), 30.9, 30.5 and 28.5 (ArCH$_2$Ar), 12.7, 12.6, and 12.4 (O$_2$CCH(CH$_2$)$_2$), 10.1, 9.92, 9.73, 9.28, and 8.93 (O$_2$CCH(CH$_2$)$_2$). Anal. Calcd for $C_{75}H_{90}O_{10}$: C, 78.23; H, 7.88. Found: C, 78.57; H, 7.69.

5,11,17,23,29-Penta-*tert*-butyl-31,32,33,34,35-pentapivaloyloxycalix[5]arene (16). The procedure described above for **13** was followed, using 1.00 g (1.23 mmol) of **1b** and 3.83 mL (3.75 g, 30.8 mmol) of pivaloyl chloride (98%), to give a crude product that was partitioned between 75 mL of CHCl$_3$ and 100 mL of H$_2$O. The CHCl$_3$ layer was separated, washed with 50 mL of 5% NaHCO$_3$ and 100 mL of H$_2$O, and dried with MgSO$_4$. The residue was recrystallized from CHCl$_3$−MeOH to give 1.27 g of a white powder. HPLC analysis of this powder showed it to contain *ca.* 9% of **16** in the cone conformer, *ca.* 30% of **16** in a noncone conformer, and *ca.* 60% of a tetrapivaloyl compound. These were separated and purified in the following manner. The crude product was subjected to gradient flash chromatography (SiO$_2$, toluene−CH$_2$Cl$_2$, 2:3 to 3:2) to give fairly pure tetraester and a mixture of **16** (**cone**) and **16** (**noncone**). Fractions containing the tetraester were combined and recrystallized from acetone−CHCl$_3$ to give 0.36 g (24%) of the tetraester as fine white crystals. The mixture of the two pentaesters was twice recrystallized from toluene to give 0.105 g (7%) of **16** (**cone**). The toluene from the first filtrate was removed *in vacuo*, and the residue recrystallized twice from CHCl$_3$−acetone to give 0.35 g (24%) of **16** (**noncone**) as a white powder.

Cone Conformer of 16: isolated as described above: mp 421−423 °C (dec and some sublimation); ^{1}H NMR (CDCl$_3$) δ 7.02 (s, 10, ArH), 3.89 (d, 5, *J* = 14.7 Hz, ArCH$_2$Ar), 3.35 (d, 5, *J* = 14.9 Hz, ArCH$_2$Ar), 1.43 (s, 45, C(CH$_3$)$_3$), 1.06 (s, 45, C(CH_3)$_3$); ^{13}C NMR (CDCl$_3$) δ 177.6 (C=O), 147.1, 144.2, and 132.2 (Ar), 126.0 (ArH), 39.4 (O=CC(CH$_3$)$_3$), 34.2 (C(CH$_3$)$_3$), 31.4 (C(CH$_3$)$_3$), 28.4 (ArCH$_2$-Ar), 28.0 (C(CH$_3$)$_3$); IR (KBr) no (OH) stretch, 1748 (C=O) cm^{-1}. Anal. Calcd for $C_80H_{110}O_{10}$: C, 78.01; H, 9.00. Found: C, 78.17; H, 9.07.

Noncone Conformer of 16: isolated as described above; mp 422−423 °C (dec and some sublimation); ^{1}H NMR (CDCl$_3$) δ 7.37 (d, 2, *J* = 2.4 Hz, ArH), 7.29 (s, 2, ArH), 7.29 (d, 2, *J* = 2.4 Hz, ArH), 7.12 (d, 2, *J* = 2.4 Hz, ArH), 6.74 (br s, 2 ArH), 3.72 (d, 1, *J* = 14.1 Hz, ArCH$_2$Ar), 3.65 (d, 2, *J* = 15.1 Hz, ArCH$_2$Ar), 3.54 and 3.48 (AB pr d, 4, *J* = 14.1 Hz, ArCH$_2$Ar), 3.31 (d, 2, *J* = 15.2 Hz, ArCH$_2$Ar), 3.25 (d, 1, *J* = 14.2 Hz, ArCH$_2$Ar), 1.57 (s, 9, C(CH_3)$_3$), 1.48 (s, 18, C(CH_3)$_3$), 1.40 (s, 9, C(CH_3)$_3$), 1.29 (s, 18, C(CH_3)$_3$), 1.13 (s, 18, C(CH_3)$_3$), 0.94 (s, 18, C(CH_3)$_3$); ^{13}C NMR (CDCl$_3$) δ 178.1, 177.6, and 177.5 (C=O), 147.6, 147.4, 147.3, 147.1, 144.9, 144.3, 134.0, 132.7, 132.5, and 132.1 (Ar), 127.7, 126.8, 126.4, 126.1, and 125.9 (ArH), 39.3, 39.2, and 39.0 (C(CH$_3$)$_3$), 35.3 (ArCH$_2$Ar), 34.9, 34.5, and 34.3 (C(CH$_3$)$_3$), 31.9, 31.6, and 31.4 (C(CH$_3$)$_3$), 29.6 and 28.4 (ArCH$_2$Ar), 28.3, 28.0 and 27.5 (C(CH$_3$)$_3$); IR (KBr) no (OH) stretch, 1748 (C=O) cm^{-1}. Anal. Calcd for $C_{80}H_{110}O_{10}$: C, 78.01; H, 9.00. Found: C, 77.83; H, 8.84.

5,11,17,23,29-Penta-*tert*-butyl-31,32,33,34-tetrapivaloyloxy-35-hydroxycalix[5]arene was isolated as described above as a white powder: mp 395−397 °C (some sublimation); ^{1}H NMR (CDCl$_3$) δ 7.26 (s, 2, ArH), 7.21 (s, 2, ArH) , 7.16 (br s, 2, ArH), 6.62 (br s, 2, ArH), 6.64 (br s, 2, ArH), 3.99 (s, 1, ArOH), 3.96 (d, 2, *J* = 14.9 Hz, ArCH2Ar), 3.87 (d, 2, *J* = 14.8 Hz, ArCH$_2$Ar), 3.83 (d, 1, *J* = 14.5 Hz, ArCH$_2$Ar), 3.41 (d, 2, *J* = 14.9 Hz, ArCH$_2$Ar), 3.32 (d, 3, *J* = 15 Hz, ArCH$_2$Ar), 1.45 (s, 18, C(CH$_3$)$_3$), 1.44 (s, 18, C(CH$_3$)$_3$), 1.35 (s, 9, C(CH$_3$)$_3$), 1.24 (s, 18, C(CH$_3$)$_3$), 0.77 (br s, 18, C(CH$_3$)$_3$); ^{13}C NMR (CDCl$_3$) δ 177.7 and 177.4 (C=O), 150.0, 147.7, 147.6, 144.6, 143.3, 132.6, 132.3, 132.1, 131.1, and 127.2 (Ar), 127.1, 126.5, 126.2, 125.0, and 124.6 (ArH), 39.5 and 39.3 (OCC(CH$_3$)$_3$), 34.4, 34.06, and 34.02 (C(CH$_3$)$_3$), 31.7, 31.4, and 31.2 (ArC(CH$_3$)$_3$), 30.5, 28.86, and 28.81 (ArCH$_2$Ar), 28.0 and 27.8 (OCC(CH$_3$)$_3$). Anal. Calcd for $C_{75}H_{104}O_9$: C, 78.36; H, 9.12. Found: C, 78.61; H, 8.90.

5,11,17,23,29-Penta-*tert*-butyl-31,32,33,34,35-pentabenzoyloxycalix[5]arene (17). A 1.11 g portion of NaH (27.8 mmol as a 60% dispersion in mineral oil) and 1.00 g (1.23 mmol) of **1b** was treated with 3.61 mL (4.38 g, 30.8 mmol) of benzoyl chloride (99%) in the manner described above for **11**. After 3 h at reflux the reaction was quenched with MeOH and the reaction mixture worked up to give a crude product that was recrystallized from cold CHCl$_3$−MeOH (*ca.* 40 mL) to give 1.06 g of a white powder. This contained several faster-eluting components (*ca.* 20%) that were removed by flash chromatography (SiO$_2$, EtOAc−hexanes, 1:5). Fractions containing **17** were recrystallized from CHCl$_3$−MeOH to give 0.72 g (44%) of **17**: mp 396−398 C; ^{1}H NMR (CDCl$_3$) δ 7.83 (m, 10, Ar′H), 7.21 (m, 5, Ar′H), 7.12 (s, 10, ArH), 6.87 (m, 10, Ar′H), 4.04 (d, 5, *J* = 14.7 Hz, ArCH$_2$-Ar), 3.45 (d, 5, *J* = 14.7 Hz, ArCH$_2$Ar), 1.12 (s, 45, C(CH$_3$)$_3$); ^{13}C NMR (CDCl$_3$) δ 165.9 (C=O), 147.8, 144.3, 132.9, 132.8, 130.2, 129.2, 128.5, and 126.1 (Ar), 34.3 (C(CH$_3$)$_3$), 31.4 (C(CH$_3$)$_3$), 29.5 (ArCH$_2$-Ar); IR (KBr) no (OH) stretch, 1736 (C=O) cm^{-1}. Anal. Calcd for $C_{90}H_{95}O_{10}$: C, 80.87; H, 7.16. Found: C, 80.93; H, 6.92.

5,11,17,23,29-Penta-*tert*-butyl-31-ethoxy-32,33,34,35-

Table 5. Crystallographic Data for the Pentaisopropyl Ether **6**, Pentaallyl Ether **7**, and Mono-*n*-propyl Ether **19**[a]

	6	**7**·acetone	**19**·0.5*n*-C_6H_{14}
formula	$C_{70}H_{100}O_5$	$C_{73}H_{96}O_6$	$C_{61}H_{83}O_5$
fw	1021.56	1069.56	896.32
cryst syst	triclinic	monoclinic	triclinic
space group	$P\bar{1}$	$P2_1/c$	$P\bar{1}$
a, Å	14.115 (6)	13.062 (6)	13.978 (1)
b, Å	18.657 (6)	21.961 (6)	17.591 (2)
c, Å	14.122 (4)	23.246 (4)	12.108 (1)
α, deg	102.05° (2)	90°	91.712° (9)
β, deg	117.81° (2)	93.35° (2)	91.813° (8)
γ, deg	87.05° (4)	90°	75.563° (9)
V, Å^3	3212 (2)	6657 (2)	2881.0 (5)
Z	2	4	2
d_{calcd}, g cm^{-3}	1.056	1.067	1.033
μ(Cu Kα) (cm^{-1})	4.62	4.78	4.62
trans coeff, min./max.	0.87/1.00	0.88/1.00	0.88/1.00
no. of data collected	10116	10734	15327
R_{int}	0.143	0.023	0.066
no. of unique data	9543	10228	11914
no. of unique data[b]	6223	5867	5428[c]
no. of params	790	793	587
data/param ratio	7.88	7.40	9.25
R_d	0.069	0.078	0.107
R_w	0.067	0.083	0.128

[a] All measurements were made using a Rigaku AFC6S diffractometer and Cu Kα (1.541 78 Å) radiation at 296 K with an ω-2θ scan mode on colorless, stable crystals. [b] Observation criterion: $I > 3\sigma(I)$. [c] Observation criterion: $I > 4\sigma(I)$. [d] Compound **6** has disordered Me groups which could be resolved; **7** and **19** have disordered Me groups which were not resolved and result in large anisotropic thermal motion. After the geometry of the host was determined, the structure was not futher refined due to disordered Me_2CO molecules which could not be localized.

Table 6. Macrocyclic Dihedral Angles (in deg) for X-ray Structures of 6, 7, and 19

macrocyclic dihedrals[a]	pentaisopropyl ether **6**	pentaallyl ether **7**	mono-*n*-propyl ether **19**
A-1	−82.6	−84.3	−133.3
B-1	142.2	132.9	50.5
B-2	−73.7	−70.2	−75.9
C-2	−73.7	−70.3	121.0
C-3	125.2	122.8	−95.3
D-3	−111.5	−106.8	99.7
D-4	70.7	61.5	−110.9
E-4	63.8	57.8	79.9
E-5	−133.5	−133.4	−72.3
A-5	88.2	94.1	157.5

[a] The labels "dihedrals" correspond to the iconographic representations shown for the X-ray structures in Figure 3.

tetrahydroxycalix[5]arene (18). A stirred suspension of 1.00 g (1.23 mmol) of **1b** and 0.495 g (4.93 mmol) of anhydrous $KHCO_3$ in 50 mL of dry MeCN was heated at reflux in an inert atmosphere. After 1 h the heating was stopped, and 0.251 g (1.23 mmol) of EtOTs (98%) in 10 mL of MeCN was added, and heating was resumed. After 36 h at reflux, the solvent was removed in vacuo, and the residue was partitioned between 75 mL of $CHCl_3$ and 50 mL of 1 N HCl. The $CHCl_3$ layer was separated, washed with 100 mL of H_2O, and dried with anhydrous $MgSO_4$. The $CHCl_3$ was removed *in vacuo*, and the residue was subjected to flash chromatography (SiO_2, 100% toluene) to give 1.06 g of **1b** after trituration with MeOH and 0.968 g (87%) of **18** after recrystallization from $CHCl_3$−MeOH: mp 298.5−300.5 °C; ^{1}H NMR ($CDCl_3$) δ 8.08 (s, 2, OH), 7.96 (s, 2, OH), 7.21−7.16 (m, 10, ArH), 4.25 (br s, 5, $ArCH_2Ar$), 4.09 (q, 2, J = 6.8 Hz, $O\mathit{C}H_2CH_3$), 3.53 (br s, 5, ArH), 1.56 (t, 3, J = 6.8 Hz,OCH_2CH_3), 1.29 (s, 18, $C(CH_3)_3$), 1.24 (s, 18, $C(CH_3)_3$), 1.13 (s, 9, $C(CH_3)_3$); ^{13}C NMR ($CDCl_3$) δ 150.3, 149.3, 147.7, 143.9, 142.7, 132.4, 127.0, and 126.6 (Ar), 126.0, 125.9, 125.8, 125.6, and 125.5 (ArH), 71.4 (OCH_2CH_3), 34.2 and 33.9 ($\mathit{C}(CH_3)_3$), 31.8 ($ArCH_2Ar$), 31.6 and 31.4 ($C(CH_3)_3$), 30.9 ($ArCH_2$-Ar), 31.3 ($C(\mathit{CH}_3)_3$), 15.4 ($OCH_2\mathit{CH}_3$). Anal. Calcd for $C_{57}H_{74}O_5$: C, 81.58; H, 8.89. Found: C, 81.47; H, 9.02.

5,11,17,23,29-Penta-*tert*-butyl-31-*n*-propoxy-32,33,34,35-tetrahydroxycalix[5]arene (19). A stirred suspension of 2.00 g (2.47 mmol) of **1b** and 0.494 g (4.93 mmol) of anhydrous $KHCO_3$ in 50 mL of dry acetone was heated at reflux in an inert atmosphere. After 30 min at reflux, 0.11 mL (0.16 g, 1.3 mmol) of 1-bromopropane (99%) was added and reflux continued for 24 h. The reaction mixture was worked up as described above for **18**, and the crude product was subjected to flash chromatography (SiO_2, toluene−hexanes 4:1 v/v) to give 0.67 g of **1b** after trituration with MeOH and 0.86 g (61%) of **19** as clear rhombs after recrystallization from *n*-heptane: mp 295.5−297 °C with evolution of gas at 230 °C; ^{1}H NMR ($CDCl_3$) δ 8.00 (s, 2, OH), 7.92 (s, 2, OH), 7.21 (s, 4, ArH), 7.20 (d, 2, J = 2.4 Hz, ArH), 7.17 (d, 2, J = 2.4 Hz, ArH), 7.13 (s, 2, ArH), 4.34 (d, 2, J = 13.7 Hz, $ArCH_2Ar$), 4.14 (d, 2, J = 14.0 Hz, $ArCH_2Ar$), 4.06 (d, 1, J = 14.1 Hz, $ArCH_2Ar$), 4.03 (t, 2, J = 6.8 Hz, $OCH_2CH_2CH_3$), 3.50 (d, 1, J = 14 Hz, $ArCH_2Ar$), 3.49 (d, 2, J = 14.2 Hz, $ArCH_2Ar$), 3.45 (d, 2, J = 14.1 Hz, $ArCH_2Ar$), 2.04 (m, 2, J = 7.0 Hz, $OCH_2\mathit{C}H_2CH_3$), 1.29 (s, 18, $C(CH_3)_3$), 1.24 (s, 18, $C(CH_3)_3$), 1.20 (t, 3, J = 6.7 Hz, OCH_2CH_2-CH_3), 1.10 (s, 9, $C(CH_3)_3$); ^{13}C NMR ($CDCl_3$) δ 150.2, 149.2, 147.6, 147.3, 143.9, 142.6, 132.1, 126.9, 126.5, and 126.4 (Ar), 126.0, 125.9, 125.6, 125.5, and 125.4 (ArH), 77.4 ($OCH_2CH_2CH_3$), 34.1 and 33.9 ($\mathit{C}(CH_3)_3$), 31.8 ($ArCH_2Ar$), 31.6 and 31.5 ($C(\mathit{CH}_3)_3$), 31.4 ($ArCH_2$-Ar), 31.2 ($C(\mathit{CH}_3)_3$), 30.7 ($ArCH_2Ar$), 23.3 ($OCH_2\mathit{CH}_2CH_3$), 10.7 ($OCH_2CH_2\mathit{CH}_3$). Anal. Calcd for $C_{58}H_{76}O_5$: C, 81.65; H, 8.98. Found: C, 82.25; H, 9.35.

5,11,17,23,29-Penta-*tert*-butyl-31-*n*-benzoxy-32,33,34,35-tetrahydroxycalix[5]arene (20). A stirred suspension of 2.00 g (2.47 mmol) of **1b** and 0.494 g (4.93 mmol) of anhydrous $KHCO_3$ in 50 mL of dry MeCN was heated at reflux in an inert atmosphere. After 1 h, 0.105 mg (0.835 mmol) of benzyl chloride (97%) in 10 mL of MeCN was added, and reflux was continued for 24 h. After cooling the reaction mixture to room temperature the solvent was removed in vacuo, and the residue was partitioned between 75 mL of $CHCl_3$ and 50 mL of 1 N HCl. The $CHCl_3$ layer was separated, washed with 100 mL of H_2O, and dried with anhydrous $MgSO_4$. The $CHCl_3$ was removed in vacuo. The residue was subjected to flash chromatography (SiO_2, toluene−hexanes 1:1 v/v) to give 0.79 g of **1b** after trituration with MeOH and 0.21 g (68%) of **20** after recrystallization from $CHCl_3$−MeOH: mp 295.5−297 °C ^{1}H NMR ($CDCl_3$) δ 7.80 (s, 2, OH), 7.72−7.68 (m, 2, ArH), 7.68 (s, 2, ArOH), 7.52−7.40 (m, 3, ArH), 7.19 (s, 4, ArH), 7.18 (d, 2, J = 2.5 Hz, ArH), 7.16 (d, 2, J = 2.5 Hz, ArH), 7.13, (s, 2, ArH), 5.15 (s, 2, OCH_2Ar), 4.41 (d, 2, J = 13.7 Hz, $ArCH_2$-Ar), 4.09 (d, 2, J = 13.9 Hz, $ArCH_2Ar$), 4.06 (d, 1, J = 14.0 Hz, $ArCH_2$-Ar), 3.47 (d, 1, J = 14 Hz, $ArCH_2Ar$), 3.44 (d, 2, J = 13.9 Hz, $ArCH_2Ar$), 3.43 (d, 2, J = 13.9 Hz, $ArCH_2Ar$), 1.28 (s, 18, $C(CH_3)_3$), 1.22 (s, 18, $C(CH_3)_3$), 1.09 (s, 9, $C(CH_3)_3$); ^{13}C NMR ($CDCl_3$) δ 150.1, 149.2, 147.6, 147.5, 143.9, 142.7, 136.4, and 132.2 (Ar), 128.8, 128.6, and 128.3 (ArH), 126.9, 126.42, and 126.38 (Ar), 126.0, 125.9, 125.7, 125.50, and 125.45 (ArH), 77.5 (OCH_2Ar), 34.2 and 33.9 ($\mathit{C}(CH_3)_3$), 31.65 ($ArCH_2Ar$), 31.6 and 31.4 ($C(\mathit{CH}_3)_3$), 31.38 ($ArCH_2Ar$), 31.2 ($C(\mathit{CH}_3)_3$), 30.8 ($ArCH_2Ar$). Anal. Calcd for $C_{62}H_{76}O_5$: C, 82.62; H, 8.50. Found: C, 82.97; H, 8.37.

5,11,17,23,29-Penta-*tert*-butyl-31-benzoxy-32,33,34,35-tetramethoxycalix[5]arene (21). A stirred suspension of 0.901 g (1.00 mmol) of the monobenzyl ether **20**, 2.69 g (14.0 mmol) of methyl tosylate (97%), and 1.66 g (12.0 mmol) of K_2CO_3 in 50 mL of dry MeCN was heated at reflux in an inert atmosphere for 14 h. The reaction mixture was worked up as described above for **3g**, and the crude product was recrystallized from $CHCl_3$/MeOH to give 0.843 g (88%) of a white powder. This was subjected to flash chromatography (SiO_2, toluene) to remove a small amount of slower-eluting material, giving 0.71 g (75%) of **21**: mp 229−230.5 °C; ^{1}H NMR ($CDCl_3$) δ 7.49−7.46 (m, 2, benzyloxy ArH), 7.38−7.27 (m, 3, benzyloxy ArH), 7.16 (d, 2, J = 2.5 Hz, ArH), 7.10 (d, 2, J = 2.5 Hz, ArH), 7.05 (d, 2, J = 2.4 Hz, ArH), 7.03 (s, 2, ArH), 6.97 (d, 2, J = 2.4 Hz, ArH), 4.83 (s, 2, OCH_2Ar), 4.19 (d, 2, J = 14.0 Hz, $ArCH_2Ar$), 3.90−3.68 (m, 6, $ArCH_2Ar$), 3.52 (d, 2, J = 14.0 Hz, $ArCH_2Ar$), 2.97 (s, 6, OCH_3), 2.55 (s, 6, OCH_3), 1.19 (s, 18, $C(\mathit{CH}_3)_3$), 1.18 (s, 18, $C(CH_3)_3$), 1.10 (s, 9, $C(CH_3)_3$); ^{13}C NMR ($CDCl_3$) δ 154.3, 154.1, 152.4, 145.6, 145.2, 145.0, 138.1, 133.71, 133.68, 133.59 and 133.55 (Ar), 128.4, 127.7, 127.6, 126.8, 126.4, 126.1, 125.6, and 125.5 (ArH), 74.9 (OCH_2Ar), 60.1 and 59.9 (OCH_3), 34.1 and 34.0 ($\mathit{C}(CH_3)_3$), 33.1 and 32.2.($ArCH_2$-

Ar), 31.5 (4) and 31.4 (1) (C(*C*H$_3$)$_3$), 30.9 (ArCH$_2$Ar). Anal. Calcd for $C_{66}H_{84}O_5$: C, 82.80; H, 8.84. Found: C, 82.58; H, 8.89.

5,11,17,23,29-Penta-*tert*-butyl-31,32,33,34-tetrabenzoxy-35-methoxycalix[5]arene (22). A stirred suspension of 0.825 g (1.00 mmol) of the monomethyl ether **3a**, 2.79 g (12.0 mmol) of benzyl bromide (98%), and 1.66 g (12.0 mmol) of K_2CO_3 in 50 mL of dry MeCN was heated at reflux in an inert atmosphere for 18 h. The reaction mixture was worked up as described above for **3g**, and the crude product was recrystallized from CHCl$_3$/MeOH to give 0.975 g (82%) of **22** as a white powder: mp 211−212.5 °C; ^{1}H NMR (CDCl$_3$) δ 7.42−7.39 (m, 4, Ar′H), 7.32−7.08 (m, 18, ArH), 7.03 (d, 2, *J* = 2.6 Hz, ArH), 6.92 (d, 2, *J* = 2.4 Hz, ArH), 6.73 (pr AB d, 4, *J* = 2.6 Hz, ArH), 4.79 (s, 4, OCH$_2$Ar), 4.71 and 4.62 (pr AB d, 4, *J* = 11.8 Hz, OCH$_2$Ar), 4.56 (d, 2, *J* = 14.2 Hz, ArCH$_2$Ar), 4.42 (d, 2, *J* = 13.4 Hz, ArCH$_2$Ar), 4.25 (d, 1, *J* = 14.2 Hz, ArCH$_2$Ar), 3.20 (d, 2, *J* = 14.2 Hz, ArCH$_2$Ar), 3.16 (d, 2, *J* = 13.4 Hz, ArCH$_2$Ar), 2.91 (d, 2, *J* = 14.3 Hz, ArCH$_2$Ar), 2.10 (s, 3, OCH$_3$), 1.35 (s, 9, C(CH$_3$)$_3$), 1.15 (s, 18, C(CH$_3$)$_3$), 0.848 (s, 18, C(CH$_3$)$_3$); ^{13}C NMR (CDCl$_3$) δ 155.7, 152.4, 152.1, 145.2, 145.0, 144.9, 138.2, 137.9, 134.6, 134.5, 133.8 and 133.1 (Ar), 128.5, 128.2, 128.0, 127.5, 126.9, 126.1, 125.6, and 124.4 (ArH), 75.9 and 75.7 (OCH$_2$Ar), 61.6 (OCH$_3$), 34.1 and 33.9 (*C*(CH$_3$)$_3$), 31.7-(2), 31.5(2), and 31.2(1) (C(*C*H$_3$)$_3$), 30.4, 30.2, and 28.8 (ArCH$_2$Ar). Anal. Calcd for $C_{84}H_{96}O_5$: C, 85.09; H, 8.16. Found: C, 84.91; H, 8.19.

5,11,17,23,29-Penta-*tert*-butyl-31,32,33,34,35-penta-*p*-toluenesulfonyloxycalix[5]arene (23). A 1.11 g portion of NaH (27.8 mmol as a 60% dispersion in mineral oil) and 1.00 g (1.23 mmol) of **1b** were treated with 5.93 g (30.8 mmol) of *p*-toluenesulfonyl chloride (99%) following the procedure described above for **13**. The reaction mixture was worked up to give a crude product that was partitioned between 75 mL of CHCl$_3$ and 100 mL of H$_2$O. The CHCl$_3$ layer was separated, washed with 50 mL 5% NaHCO$_3$, washed with 100 mL of H$_2$O, and dried with MgSO$_4$. The residue was recrystallized from CHCl$_3$/MeOH (*ca.* 40 mL) to give 1.51 g of **23** (77%) as a white powder: mp 293−295 °C dec; ^{1}H NMR (CDCl$_3$) δ 7.75 (d, 10, *J* = 8.4 Hz, Ar′H), 7.32 (d, 10, *J* = 8.1 Hz, Ar′H), 6.77 (s, 10, ArH), 4.08 (d, 5, *J* = 15.3 Hz, ArCH$_2$Ar), 2.79 (d, 5, *J* = 15.4 Hz, ArCH$_2$Ar), 0.97 (s, 45, C(CH$_3$)$_3$); ^{13}C NMR (CDCl$_3$) δ 148.3, 144.8, 142.9, 134.3, and 133.1 (Ar), 129.8, 129.0, and 126.1 (ArH), 34.2 (*C*(CH$_3$)), 31.2 (C(*C*H$_3$)), 30.7 (ArCH$_2$Ar), 21.8 (Ar′CH$_3$); IR (KBr) no (OH) stretch. Anal. Calcd for $C_{90}H_{100}O_{15}S_5$: C, 68.33; H, 6.37. Found: C, 68.00; H, 6.25.

Crystallographic Information. Crystallographic details for **6**, **7**, and **19** are given in Table 5, a set of torsion angles for these compounds is given in Table 6.

Acknowledgment. This work was generously supported by grants from the National Science Foundation and the Robert A. Welch Foundation, to whom we express our thanks. For the mass spectrographic determinations we are indebted to Professor Clive A. Slaughter and Dr. Bikash C. Pramanik, University of Texas Southwesterrn Mdeical Center at Dallas and to the Washington University Mass Spectometry Resource Center partially supported by NIH Grant RR00954.

Supplementary Material Available: Tables of coordinates, bond distances, bond angles, and anisotropic thermal parameters for **6**, **7**, and **19** (44 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

JA9412667