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p-Triallylcalix[4]arene: The Final Member of the *p*-Allylcalix[4]arenes

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Abstract: The heat-induced Claisen rearrangement of calix[4]arene triallyl ether **6a** produced the title compound, *p*-triallylcalix[4]arene (7). The triallyl ether **6a** was prepared from calix[4]arene 1,3-diallyl ether (**1a**) in a three-step process. Benzoylation of 1,3-diallyl ether **1a**, under separate reaction conditions, resulted in the formation of either one of the isomeric pair of monobenzoates **2** or **3a**. The allylation of **3a** and subsequent debenzoylation yielded calix[4]arene triallyl ether **6a**. The synthesis and structural assignment of these calix[4]arene derivatives are discussed. Further study of this four-step conversion for other calix[4]arene trialkyl ether derivatives is also presented.

Introduction

It is well demonstrated that the heat-induced Claisen rearrangement can easily convert allyloxycalixarenes to the corresponding *p*-allylcalixarenes.[1] These calixarene derivatives, i.e. the calixarene allyl ethers and the *p*-allyl-calixarenes, which all possess easily modifiable double bonds, have a great potential as synthetic intermediates for preparing calixarenes with an appropriate functionality on either the "upper rim" or "lower rim" for host-guest complexation studies.[2] Recently, separate preparation of four calix[4]arene allyl ethers (out of five possible ethers), in a one-step process has been established;[3] however, all attempts to prepare the final member in this family, the triallyl ether **6a**, by a one-step method have failed. Surprisingly, the literature survey indicated that the tris-(*n*-propoxy)- and tris-[(2-pyridylmethyl)oxy]calix[4]arenes were the only examples reported for the calix[4]arene trialkyl ethers.[4] Hence, in order to study all possible calix[4]arene alkyl ethers, a general synthetic route for calix[4]arene trialkyl ethers was explored. In this paper, we report a four-step synthesis of the calix[4]arene triallyl ether and its Claisen rearrangement product, as well as its application in other calix[4]arene trialkyl ether cases.

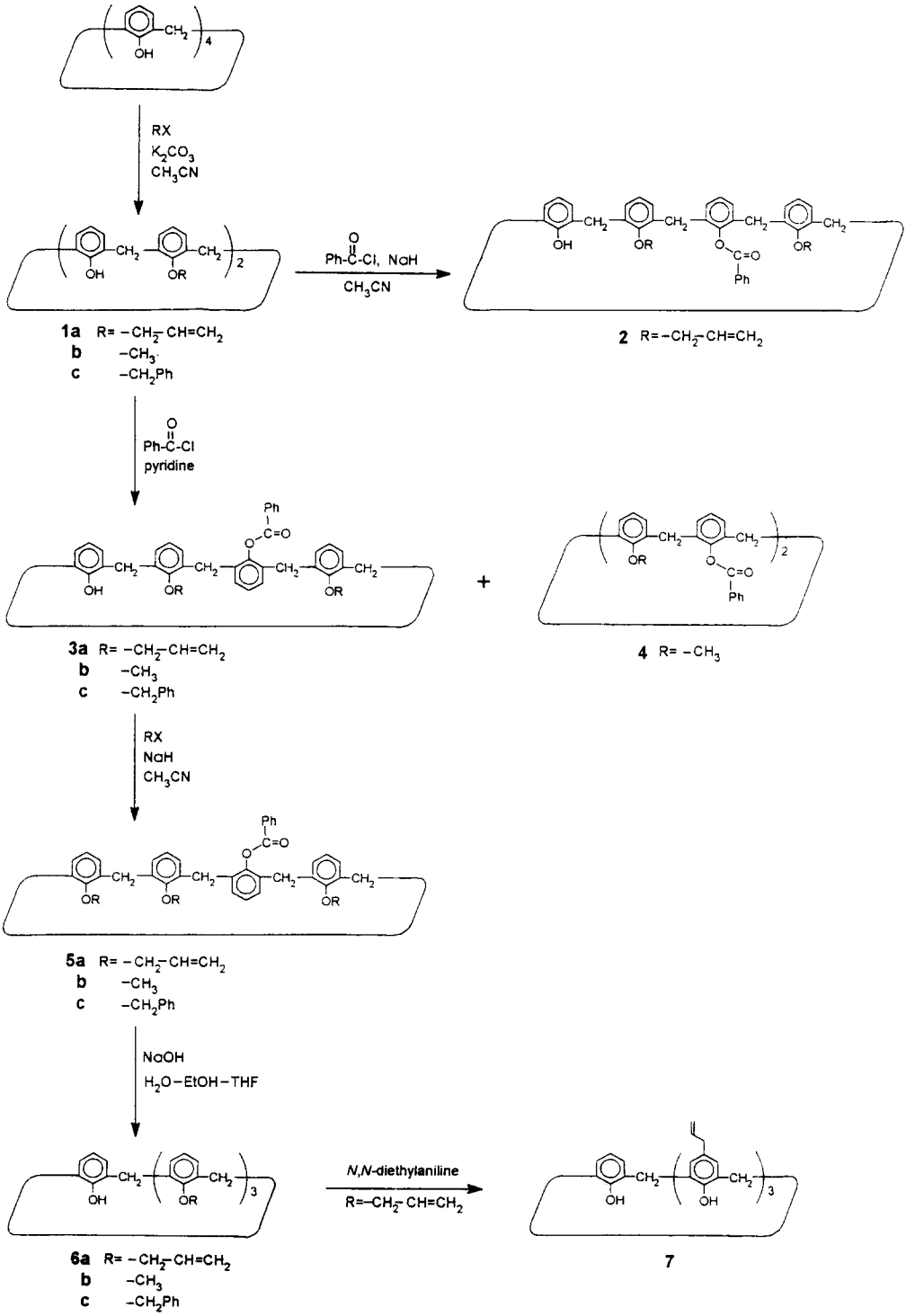
Results and Discussion:

Triallyloxycalix[4]arene (6a) and *p*-triallylcalix[4]arene (7). When all attempts of preparing calix[4]arene triallyl ether **6a** in one-step process failed in our laboratory, a multi-step procedure was developed. In the literature, Gutsche and Lin reported a three-step synthesis for calix[4]arene monoallyl ether, in which the three phenolic hydroxy groups were first protected by benzoate esters and after the introduction of monoallyloxy group, these ester moieties were cleaved.[5] It is obvious to examine the same concept for the preparation of calix[4]arene triallyl ether by protecting only one of the phenolic groups. Unfortunately, when calix[4]arene was reacted with benzoyl chloride under basic conditions, the monobenzoate was not detected, instead, only the starting material, 1,3-dibenzoate, and tribenzoate could be isolated.[6] Thus, an alternative approach to the synthesis of calix[4]arene triallyl ether was necessary.

It has been observed that the reaction between calix[4]arene and benzoyl chloride under basic conditions also fails to produce the tetrabenzoate.[6,7] It is believed that the inability to produce tetrabenzoate was the result of steric hindrance of the benzoyloxy groups. Therefore, it was rationalized that reaction between calix[4]arene diallyl ether and benzoyl chloride under basic conditions would yield only the monobenzoate derivative due to these same factors. The benzoate product **3a** was obtained in good yield when 1,3-diallyl ether **1a** and benzoyl chloride were stirred in pyridine for a long period of time. It was also found that another benzoate product **2** was obtained separately in a different condition, i.e. refluxing of ether **1a** with benzoyl chloride in acetonitrile with the prescence of NaH. Characterization of these two products, according to ^{1}H-NMR and MS spectral data, revealed that both the products **2** and **3a** were infact the corresponding monobenzoate derivatives. Monobenzoates **2** and **3a** are known to exist as a pair of conformational isomers and the exact structure of each product will be discussed in the next section.

Theoretically, monoallylation of monobenzoate-diallyl ethers **2** and **3a** is expected to produce two different sets of monobenzoate-triallyl ether conformers, and debenzoylation should convert those triallylated conformers into the same set of calix[4]arene triallyl ethers. When compounds **2** and **3a** were triallylated under standard calixarene ether formation conditions, only a single conformer **5a** was derived from **3a,** whereas, a mixture of products was produced from **2**. Hence, only the easily attainable **3a** was triallylated, and the easily isolable triallylated product **5a** was hydrolyzed in basic conditions to yield triallyloxycalix[4]arene (**6a**). This four-step synthetic route converted calix[4]arene into its triallyl ether derivative with an overall yield of 20-25%.

Finally, triallyl ether **6a** in refluxing *N,N*-diethylaniline under an inert atmosphere yielded the corresponding Claisen rearrangement product, *p*-triallylcalix[4]arene (**7**). The room temperature ^{1}H-NMR spectrum of product **7** exhibited not only the same magnitude of chemical shift but also identical splitting patterns for every hydrogen as that of the other partial *p*-allylcalix[4]arenes. However, *p*-triallylcalix[4]arene could be easily identified from those of the other partial *p*-allylcalix[4]arenes by its integration ratios, and the *m/e* values provided additional proof for the *p*-triallyl substituted structure.



1a R= –CH_2–CH=CH_2
b –CH_3
c –CH_2Ph

2 R=–CH_2–CH=CH_2

3a R= –CH_2–CH=CH_2
b –CH_3
c –CH_2Ph

4 R= –CH_3

5a R= –CH_2–CH=CH_2
b –CH_3
c –CH_2Ph

6a R= –CH_2–CH=CH_2
b –CH_3
c –CH_2Ph

7

Structural assignment for monobenzoates 2 and 3a. The similarity of the ^{1}H-NMR spectra between calix[4]arene *syn*-1,3-dibenzoate and 1,3-diallyl ether **1a** suggested that **1a** also possessed a *syn*-1,3-conformational structure ($H^{\alpha}R^{\alpha}H^{\alpha}R^{\alpha}$).[7] Therefore, the monobenzoate derivatives of **1a** are expected to possess an "up-up-up" ($H^{\alpha}R^{\alpha}R^{\alpha}R^{\alpha}$) or an "up-down-up" ($H^{\alpha}R^{\alpha}R^{\beta}R^{\alpha}$) conformation.[8] Although, spectral evidence for compounds **2** and **3a** clearly indicated that both compounds were monobenzoate derivatives of **1a**, the ^{1}H-NMR spectra of the two conformational isomers **2** and **3a** were observed to be very different, as shown in Figure 1. The ^{1}H-NMR spectrum of **3a** consisted of two sets of well-resolved doublet pairs, associated with calixarene methylene hydrogens, whereas three doublets with integral ratio of 2:1:1 were observed in the spectrum of **2** for the same hydrogens.[9] This spectral pattern of three doublets with integral ratio of 2:1:1 was also observed in all the ^{1}H-NMR spectra of calix[4]arene monoalkyl ethers.[10,11] It has been known that a strong intramolecular hydrogen-bonding interaction holds the three free phenolic hydroxy groups in the same region. Therefore, compound **2** can also be expected to possess the same general structure,viz. three substituents point to the same side, since it exhibits similar ^{1}H-NMR spectral feature as that of the calix[4]arene methylene hydrogen. Hence, the "up-up-up" ($H^{\alpha}R^{\alpha}R^{\alpha}R^{\alpha}$) conformational structure was assigned to compound **2**, and the "up-down-up" ($H^{\alpha}R^{\alpha}R^{\beta}R^{\alpha}$) conformation was then assigned to **3a**. These results are consistent with the assignment of a tri-substituent calix[4]arene reported by Pappalardo et al.[12]

Studies of the three-dimensional structure of diallyl ether-monobenzoate derivatives **2** and **3a** indicated that the magnetic interaction between two allyloxy moieties and the benzoate group would be strong for the compound having an "up-up-up" conformation; whereas, the same interaction between those three substituents would be less significant for the compound having an "up-down-up" conformation. This difference in the magnetic interactions was clearly observed from the variation in the chemical shift of the allyloxy and benzoate hydrogens in the ^{1}H-NMR spectra of **2** and **3a**. All the allyloxy hydrogens in compound **2** exhibited an upfield shift due to the shielding effect caused by the nearby benzoate. For example, the allyloxy double bond hydrogens (C-CH=CH_2) were shifted upfield by 0.7, 0.9, and 0.6 ppm, respectively; whereas the benzoate *ortho* hydrogens, which were deshielded by the nearby allyloxy groups, displayed downfield shifted double doublets at 8.92 ppm. The other monobenzoate **3a** also exhibited an upfield shift for the allyloxy hydrogens, but the differences in the chemical shifts were smaller, i.e. the same hydrogens were shifted upfield by 0.3, 0.5, and 0.2 ppm. The benzoate group, which pointed in the opposite direction,on the other hand, showed no sign of deshielding, i.e. all aromatic hydrogens in compound **3a** displayed signals between 6.1-7.5 ppm, common for aromatic hydrogen.

Although monoallylation of the "up-down-up" ($H^{\alpha}R^{\alpha}R^{\beta}R^{\alpha}$) conformer **3a** could produce the "up-down-up-up" ($R^{\alpha}R^{\beta}R^{\alpha}R^{\alpha}$) and "up-down-up-down" ($R^{\alpha}R^{\beta}R^{\alpha}R^{\beta}$) isomers, only one single conformational product could be isolated. The $R^{\alpha}R^{\beta}R^{\alpha}R^{\beta}$-conformer, which possesses a better symmetrical magnetic enviroment, was expected to display a singlet and a pair of doublets with integral ratio of 1:1 for the calix[4]arene methylene hydrogens; whereas, the spectrum of $R^{\alpha}R^{\beta}R^{\alpha}R^{\alpha}$-conformer was expected to display two sets of doublet pairs. When the spectrum of monobenzoate-triallyl ether **5a** was recorded, two sets of doublet pairs were observed, and hence, the $R^{\alpha}R^{\beta}R^{\alpha}R^{\alpha}$-

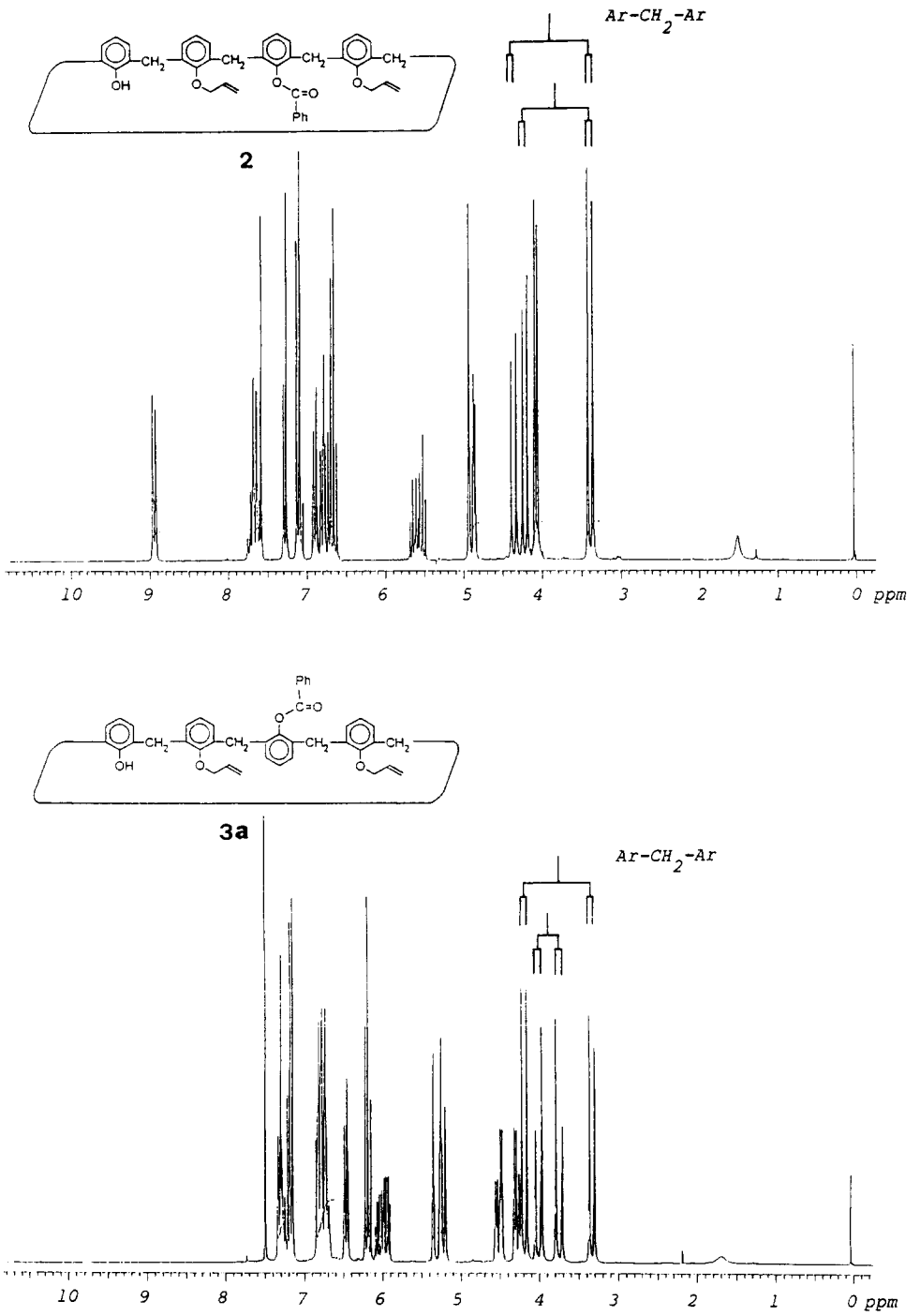


Figure 1. The ^{1}H-NMR spectra of 1,3-diallyloxy-2-benzoyloxycalix[4]arenes **2** and **3a**.

conformational structure was assigned to compound **5a**. Finally, hydrolysis of the benzoates, which would not influence the position of the allyloxy groups, yielded the triallyloxycalix[4]arene (**6a**) with an "up-up-up-up" ($H^{\alpha}R^{\alpha}R^{\alpha}R^{\alpha}$) conformation.

The exact conformation of the tetraallyloxylated calix[4]arenes can be accurately identified by their ^{1}H-NMR spectral patterns. Triallyl ether **6a** was allylated further to give tetraallyloxycalix[4]arene (**8**) in order to further verify the conformation of compounds **5a** and **6a**. When compound **6a** was refluxed with allyl bromide and NaH in acetonitrile for 30 min., the starting compound **6a** was observed to have totally disappeared and the resulting product was isolated following the standard procedures to afford a colorless crystalline **8**. The ^{1}H-NMR spectrum of this tetraallylated **8** displayed only one pair of doublets for the calix[4]arene methylene hydrogens. This pattern has been known to arise from the tetra-substituent compounds having a "cone" conformation. This result clearly suggests that the three original allyloxy groups must arrange in an "up-up-up" conformation ($H^{\alpha}R^{\alpha}R^{\alpha}R^{\alpha}$) in order to produce the "cone" conformational products, otherwise, the "1,3-alternate" and/or the "partial cone" products would be produced, then a totally different spectral pattern would be observed.

Calix[4]arene trialkyl ethers (6b and 6c). In the preceeding, we have demonstrated a new synthetic route for preparation of calix[4]arene triallyl ether, and it is interesting to investigate the generality of this synthetic scheme towards affording other calix[4]arene trialkyl ethers. When calix[4]arene 1,3-dialkyl ethers were prepared in our laboratory, according to the procedure reported by Reinhoudt et al,[3b] more reactive benzyl bromide and less steric hindered methyl iodide reagents were only observed to produce the corresponding 1,3-dialkyl ethers with adequate yield. Therefore, the present synthetic methodology is examined for the production of calix[4]arene tribenzyl and trimethyl ether only.

The preparation of calix[4]arene tribenzyl ether from 1,3-dibenzyl ether **1c** was identical to the synthesis of triallyl ether. The monobenzoylation of ether **1c** in pyridine yielded 1,3-dibenzyloxy-2-benzoyloxycalix[4]arene (**3c**), and the monobenzylation of **3c** with benzyl bromide and NaH in acetonitrile produced 1,2,3-tribenzyloxy-4-benzoyloxycalix[4]arene (**5c**) with a good yield. Finally, hydrolysis of **5c** under basic condition afforded the corresponding tribenzyloxycalix[4]arene (**6c**). Due to the similarity of the ^{1}H-NMR spectral pattern with the corresponding allyloxy compounds, the conformations of compounds **5c** and **6c** was assigned to the conformations of corresponding allyloxy compounds **5a** and **6a**.

The preparation of calix[4]arene trimethyl ether from 1,3-dimethyl ether **1b** was different from the above two cases. When ether **1b** was benzoylated with benzoyl chloride, the two methyl moieties were not sufficiently sterically hindered to inhibit the introduction of the second benzoyl group; therefore, a mixture of mono- and dibenzoates was produced. When benzoylation of ether **1b** was carried out in room temperature for 48 hours, only the dibenzoylated product **4** was afforded. The ^{1}H-NMR spectrum of this dibenzoated product **4** indicated that the product was composed of two conformational isomers with an approximate ratio of 3:1. The exact structure of each component could not be determined due to the separation problem. The monobenzoylate **3b**, which was intermediate for the

trimethoxy product **6b**, was always produced along with either the starting material or the dibenzoate **4** or both. Column chromatography was therefore applied to separate the monobenzoate **3b** from starting material. Methylation of compound **3b** produced the 1,2,3-trimethoxy-4-benzoyloxycalix[4]arene (**5b**), which upon hydrolysis yielded the trimethoxycalix[4]arene (**6b**). The size of the methoxy moieties were not able to suppress the "through-the-annulus" free rotation.[13] Consequently, the interconversion between each conformer resulted in broadening the ^{1}H-NMR signals, which in turn restricted the conformational analysis of the compounds **3b**, **5b**, and **6b**.

Conclusion:

In this paper, we report the preparation of the final member of allyloxycalix[4]arene and *p*-allylcalix[4]arene families. The synthetic scheme developed for this purpose has been observed to be general for the synthesis of trialkyloxycalix[4]arenes. This synthetic scheme can be further explored for the preparation of calix[4]arene with three different alkyloxy substituents by introducing the second alkyloxy group at the trialkylation stage and the third alkyloxy group after hydrolysis. The conformation of these calix[4]arene derivatives can be rationally established, and the information obtained from these derivatives would be valuable for determining the structure of other calix[4]arene derivatives and also for designing the "host" molecules.

EXPERIMENTAL

All reagents were obtained from Merck Chemical Company and used without further purification. Melting points were taken in capillary tubes on a Mel-Temp apparatus (Laboratory Devices, Cambridge, MA) and are uncorrected. ^{1}H-NMR spectra are recorded on a Varian Gemini 200 spectrometer and chemical shifts are reported as δ values in ppm relative to TMS (δ=0.00) as an internal standard. FAB-MS spectra were taken on a JOEL JMS-HX 110 spectrometer and elemental analyses were obtained on a Perkin-Elmer 240C analyzer. TLC analyses were carried out on Merck aluminium back silica gel 60 F_{254} plates (absorbant thickness 0.2 mm). Chromatographic separations were performed with Merck silica gel (230-400 mesh ASTM) on columns of 25 mm diameter filled to height of 150 mm.

25,27-Diallyloxy-26,28-dihydroxycalix[4]arene (1a). A slurry of 2.12 g (5.0 mmol) of calix[4]arene, 0.69 g (5.0 mmol) of K_2CO_3, and 1.0 mL (1.43 g, 11.8 mmol) of allyl bromide in 100 mL of CH_3CN was refluxed for 4 h. The solvent was removed and the residue was treated with diluted HCl to give a white solid, which was recrystallized from $CHCl_3$ and CH_3OH to yield 1.56 g (62%) of colorless plate-like crystals: mp 204-205°C (Lit.[3b] 187-188°C); ^{1}H-NMR ($CDCl_3$) δ 8.02 (s, 2H, ArOH), 6.62-7.08 (m, 12H, ArH), 6.18-6.37 (m, 2H, C=CH-C), 5.39-5.85 (m, 4H, C=CH_2), 4.53-4.57 (d, J= 7Hz, 4H, OCH_2C), 4.29-4.35 (d, J= 13Hz, 4H, $ArCH_2Ar$), 3.36-3.42 (d, J= 13Hz, 4H, $ArCH_2Ar$).

25,27-Dimethoxy-26,28-dihydroxycalix[4]arene (1b). Following the same procedure as for compound **1a**, 2.12 g (5.0 mmol) of calix[4]arene was methylated with 1.0 mL (2.26 g, 15.9 mmol) of methyl iodide to yield 1.40 g (62%) of colorless crystals: mp 313-314°C (Lit.[3b] >300°C; dec.); ^{1}H-NMR ($CDCl_3$) δ 7.78 (s, 2H, ArOH), 6.65-7.11 (m, 12H, ArH), 4.28-4.35 (d, J= 13Hz, 4H, $ArCH_2Ar$), 3.99 (s, 6H, $ArOCH_3$), 3.38-3.45 (d, J= 13Hz, 4H, $ArCH_2Ar$).

25,27-Dibenzyloxy-26,28-dihydroxycalix[4]arene (1c). Following the same procedure as for compound **1a**, 2.12 g (5.0 mmol) of calix[4]arene was benzylated with 2.0 mL (2.88 g, 16.8 mmol) of benzyl bromide to yield 2.15 g (71%) of colorless crystals: mp 238-239°C (Lit.[3b] 220-223°C); ^{1}H-NMR ($CDCl_3$) δ 7.84 (s, 2H, ArOH), 6.63-7.69 (m, 22H, ArH), 5.08 (s, 4H, $ArCH_2O$), 4.29-4.36 (d, J= 13Hz, 4H, $ArCH_2Ar$), 3.32-3.39 (d, J= 13Hz, 4H, $ArCH_2Ar$).

25,27-Diallyloxy-26-benzoyloxy-28-hydroxycalix[4]arene (2). A slurry of 0.65 g (1.29 mmol) of 25,27-diallyloxycalix[4]arene (**1a**), 0.46 g (19.2 mmol) of NaH, and 1.50 mL (1.82 g, 12.9 mmol) of benzoyl chloride in 50 mL of CH_3CN was refluxed for 2 h. The solvent was removed and the residue was treated with CH_3OH to leave a white solid, which was recrystallized from $CHCl_3$ and CH_3OH to yield 0.48 g (61%) of colorless, small, needle-like crystals: mp 189-190°C; ^{1}H-NMR ($CDCl_3$) δ 8.90-8.97 (d, J= 9Hz, 2H, ArH), 7.59 (s, 1H, ArOH), 6.63-7.70 (m, 15H, ArH), 5.49-5.70 (m, 2H, C=CH-C), 4.85-4.94 (m, 4H, $C=CH_2$), 4.33-4.40 (d, J= 13Hz, 2H, $ArCH_2Ar$), 4.19-4.26 (d, J= 13Hz, 2H, $ArCH_2Ar$), 4.06-4.10 (d, J= 7Hz, 4H, OCH_2C), 3.36-3.43 (d, J= 13Hz, 4H, $ArCH_2Ar$); FAB-MS *m/z*: 608 (M^+). Anal. Calcd for $C_{41}H_{36}O_5$: C, 80.92; H, 5.92%. Found: C, 80.76; H, 5.99%.

25,27-Diallyloxy-26-benzoyloxy-28-hydroxycalix[4]arene (3a). A sample of 1.26 g (2.50 mmol) of 25,27-diallyloxycalix[4]arene (**1a**) was dissolved in 20 mL of pyridine and 2.0 mL (2.42 g, 17.2 mmol) of benzoyl chloride was added. The mixture was stirred at rt for 30 h and 300 mL of diluted HCl was added. The insoluble material was filtered and recrystallized from $CHCl_3$ and CH_3OH to yield 1.26 g (83%) of colorless powder: mp 186-187°C; ^{1}H-NMR ($CDCl_3$) δ 7.50 (s, 1H, ArOH), 6.15-7.33 (m, 17H, ArH), 5.91-6.08 (m, 2H, C=CH-C), 5.19-5.37 (m, 4H, $C=CH_2$), 4.47-4.57 (dd, J= 13Hz, 6Hz, 2H, OCH_2C), 4.22-4.32 (dd, J= 13Hz, 6Hz, 2H, OCH_2C), 4.15-4.22 (d, J= 13Hz, 2H, $ArCH_2Ar$), 3.97-4.05 (d, J= 15Hz, 2H, $ArCH_2Ar$), 3.71-3.79 (d, J= 15Hz, 2H, $ArCH_2Ar$), 3.30-3.37 (d, J= 13Hz, 2H, $ArCH_2Ar$); FAB-MS *m/z*: 608 (M^+). Anal. Calcd for $C_{41}H_{36}O_5$: C, 80.92; H, 5.92%. Found: C, 81.15; H, 6.08%.

25,27-Dimethoxy-26-benzoyloxy-28-hydroxycalix[4]arene (3b). A sample of 0.23 g (0.51 mmol) of 25,27-dimethoxycalix[4]arene (**1b**) was dissolved in 8 mL of pyridine and 1.2 mL (1.45 g, 10.3 mmol) of benzoyl chloride was added. The mixture was stirred at rt for 12 h and 100 mL of diluted HCl was added. The insoluble material was

extracted with $CHCl_3$ and further separated by column chromatography (15 cm in height, $CHCl_3$/*n*-hexane : 1/2). The first elutant was the starting material **1b**, and upon further recrystallization from $CHCl_3$ and CH_3OH, the second eluted component yielded 0.12 g (43%) of colorless crystals: mp 290-291°C; ^{1}H-NMR ($CDCl_3$) δ 7.15 (s, 1H, ArOH), 6.24-7.44 (m, 17H, ArH), 4.12-4.18 (d, J= 13Hz, 2H, $ArCH_2Ar$), 3.92-4.00 (d, J= 14Hz, 2H, $ArCH_2Ar$), 3.76 (s, 6H, $ArOCH_3$), 3.64-3.72 (d, J= 14Hz, 2H, $ArCH_2Ar$), 3.32-3.38 (d, J= 13Hz, 2H, $ArCH_2Ar$); FAB-MS *m/z*: 557 (M^++1). Anal. Calcd for $C_{37}H_{32}O_5$: C, 79.86; H, 5.76%. Found: C, 79.57; H, 5.67%.

25,27-Dibenzyloxy-26-benzoyloxy-28-hydroxycalix[4]arene (3c). A sample of 0.80 g (1.30 mmol) of 25,27-dibenzyloxycalix[4]arene (**1c**) was dissolved in 10 mL of pyridine and 5.0 mL (6.05 g, 43.1 mmol) of benzoyl chloride was added. The mixture was stirred at rt for 24 h and then following the same procedure as for compound **3a** to yield 0.73 g (78%) of colorless crystals: mp 213-214°C; ^{1}H-NMR ($CDCl_3$) δ 7.43 (s, 1H, ArOH), 6.15-7.33 (m, 27H, ArH), 5.08-5.14 (d, J= 12Hz, 2H, $ArCH_2O$), 4.79-4.85 (d, J= 12Hz, 2H, $ArCH_2O$), 4.08-4.15 (d, J= 13Hz, 2H, $ArCH_2Ar$), 3.94-4.02 (d, J= 14Hz, 2H, $ArCH_2Ar$), 3.71-3.79 (d, J= 14Hz, 2H, $ArCH_2Ar$), 3.21-3.28 (d, J= 13Hz, 2H, $ArCH_2Ar$); FAB-MS *m/z*: 709 (M^++1). Anal. Calcd for $C_{49}H_{40}O_5$: C, 83.03; H, 5.65%, for $C_{49}H_{40}O_5 \cdot 1/2H_2O$: C, 82.00; H, 5.72%. Found: C, 82.04; H, 5.62%.

25,27-Dimethoxy-26,28-dibenzoyloxycalix[4]arene (4). A sample of 0.23 g (0.51 mmol) of 25,27-dimethoxycalix[4]arene (**1b**) was dissolved in 8 mL of pyridine and 2.50 mL (3.03 g, 21.5 mmol) of benzoyl chloride was added. The mixture was stirred at rt for 48 h and 100 mL of diluted HCl was added. The insoluble material was filtered and recrystallized from $CHCl_3$ and CH_3OH to yield 0.21 g (64%) of colorless crystals, composed of an approximate ratio of 3:1 mixture of two conformational isomeric products: mp 386-387°C; ^{1}H-NMR ($CDCl_3$) δ 5.95-8.05 (m, 22H, ArH), 3.31-4.11 (m, 8H, $ArCH_2Ar$), 3.89, 3.14 (two s, 6H, $ArOCH_3$); FAB-MS *m/z*: 661 (M^++1). Anal. Calcd for $C_{44}H_{36}O_6$: C, 80.00; H, 5.45%. Found: C, 79.71; H, 5.56%.

25,26,27-Triallyloxy-28-benzoyloxycalix[4]arene (5a). A slurry of 2.44 g (4.0 mmol) of 25,27-diallyloxy-26-benzoyloxy-28-hydroxycalix[4]arene (**3a**), 1.92 g (80 mmol) of NaH, and 8.0 mL (11.44 g, 94.5 mmol) of allyl bromide in 80 mL of CH_3CN was refluxed for 4 h. The solvent was removed and the residue was treated with CH_3OH to leave a white solid, which was recrystallized from $CHCl_3$ and CH_3OH to yield 1.86 g (72%) of colorless, needle-like crystals: mp 195-196°C; ^{1}H-NMR ($CDCl_3$) δ 6.35-7.72 (m, 17H, ArH), 6.06-6.26 (m, 2H, C=CH-C), 5.56-5.73 (m, 1H, C=CH-C), 5.22-5.41 (m, 4H, $C=CH_2$), 4.83-4.93 (m, 2H, $C=CH_2$), 4.12-4.38 (m, 8H, OCH_2C and $ArCH_2Ar$), 3.80-3.87 (d, J= 13Hz, 2H, $ArCH_2Ar$), 3.43-3.50 (d, J= 13Hz, 2H, $ArCH_2Ar$), 3.11-3.17 (d, J= 13Hz, 2H, $ArCH_2Ar$); FAB-MS *m/z*: 649 (M^++1). Anal. Calcd for $C_{44}H_{40}O_5$: C, 81.48; H, 6.17%. Found: C, 81.22; H, 6.31%.

25,26,27-Trimethoxy-28-benzoyloxycalix[4]arene (5b). Following the same procedure as for compound **5a**, 0.52 g (0.86 mmol) of 25,27-dimethoxy-26-benzoyloxy-28-hydroxycalix[4]arene (**3b**) was trimethylated with 0.5 mL (1.13 g, 8.0 mmol) of methyl iodide for 5 h to yield 0.46 g (86%) of colorless, needle-like crystals: mp 240-241°C; ^{1}H-NMR ($CDCl_3$) δ 6.30-7.60 (bm, 17H, ArH), 2.85-4.15 (bm, 17H, $ArCH_2Ar$ and $ArOCH_3$); FAB-MS *m/z*: 571 (M^++1). Anal. Calcd for $C_{38}H_{34}O_5$: C, 80.00; H, 5.96%. Found: C, 79.89; H, 6.01%.

25,26,27-Tribenzyloxy-28-benzoyloxycalix[4]arene (5c). Following the same procedure as for compound **5a**, 0.48 g (0.68 mmol) of 25,27-dibenzyloxy-26-benzoyloxy-28-hydroxycalix[4]arene (**3c**) was tribenzylated with 2.0 mL (2.88 g, 16.8 mmol) of benzyl bromide for 1 h to yield 0.36 g (66.5%) of colorless, needle-like crystals: mp 182-183°C; ^{1}H-NMR ($CDCl_3$) δ 6.14-7.48 (m, 32H, ArH), 4.63 (s, 2H, $ArCH_2O$), 4.55-4.60 (d, J= 12Hz, 2H, $ArCH_2O$), 4.46-4.51 (d, J= 12Hz, 2H, $ArCH_2O$), 3.83-3.89 (d, J= 13Hz, 2H, $ArCH_2Ar$), 3.60-3.68 (d, J= 13Hz, 2H, $ArCH_2Ar$), 3.40-3.47 (d, J= 13Hz, 2H, $ArCH_2Ar$), 2.80-2.87 (d, J= 13Hz, 2H, $ArCH_2Ar$); FAB-MS *m/z*: 799 (M^++1). Anal. Calcd for $C_{56}H_{46}O_5$: C, 84.21; H, 5.76%. Found: C, 84.16; H, 5.85%.

25,26,27-Triallyloxy-28-hydroxycalix[4]arene (6a). A solution of 0.65 g (1.0 mmol) of 25,26,27-triallyloxy-28-benzoyloxycalix[4]arene (**5a**) in 30 mL of THF was treated with a solution of 2.50 g of NaOH in 6 mL of H_2O and 15 mL of EtOH, the mixture was then refluxed for 4 h. The solvent was removed and the residue was treated with CH_3OH to obtain a white solid, which was recrystallized from $CHCl_3$ and CH_3OH to afford 0.34 g (62.5%) of colorless crystals: mp 117-118°C; ^{1}H-NMR ($CDCl_3$) δ 6.45-7.19 (m, 12H, ArH), 6.11-6.31 (m, 3H, C=CH-C), 5.13-5.49 (m, 6H, $C=CH_2$), 5.25 (s, 1H, ArOH), 4.65-4.69 (d, J= 7Hz, 2H, OCH_2C), 4.35-4.46 (m, 8H, OCH_2C and $ArCH_2Ar$), 3.28-3.35 (d, J= 13Hz, 2H, $ArCH_2Ar$), 3.21-3.27 (d, J= 13Hz, 2H, $ArCH_2Ar$); FAB-MS *m/z*: 544 (M^+). Anal. Calcd for $C_{37}H_{36}O_4$: C, 81.62; H, 6.62%. Found: C, 81.47; H, 6.60%.

25,26,27-Trimethoxy-28-hydroxycalix[4]arene (6b). Following the same procedure as for compound **6a**, 0.54 g (0.95 mmol) of 25,26,27-trimethoxy-28-benzoyloxycalix[4]arene (**5b**) was hydrolyzed to yield 0.34 g (77%) of colorless crystals: mp 173-174°C; ^{1}H-NMR ($CDCl_3$) δ 6.44-7.36 (m, 12H, ArH), 5.81 (s, 1H, ArOH), 4.34-4.40 (d, J= 13Hz, 4H, $ArCH_2Ar$), 3.02-3.98 (m, 13H, $ArCH_2Ar$ and $ArOCH_3$); FAB-MS *m/z*: 467 (M^++1). Anal. Calcd for $C_{31}H_{30}O_4$: C, 79.83; H, 6.45%. Found: C, 80.10; H, 6.48%.

25,26,27-Tribenzyloxy-28-hydroxycalix[4]arene (6c). Following the same procedure as for compound **6a**, 0.17 g (0.21 mmol) of 25,26,27-tribenzyloxy-28-benzoyloxycalix[4]arene (**5c**) was hydrolyzed to yield 0.09 g (61%) of colorless crystals: mp 185-186°C; ^{1}H-NMR ($CDCl_3$) δ 6.40-7.37 (m, 27H, ArH), 5.34 (s, 1H, ArOH), 5.05 (s, 2H, $ArCH_2O$), 4.73 (s, 4H, $ArCH_2O$), 4.30-4.37 (d, J= 13Hz, 2H, $ArCH_2Ar$), 4.08-4.14 (d, J= 13Hz, 2H, $ArCH_2Ar$), 3.11-3.18 (d, J= 13Hz, 2H, $ArCH_2Ar$), 2.94-3.00 (d, J= 13Hz, 2H, $ArCH_2Ar$); FAB-MS *m/z*: 694 (M^+).

Anal. Calcd for $C_{49}H_{42}O_4$: C, 84.73; H, 6.05%, for $C_{49}H_{42}O_4 \cdot 1/4H_2O$: C, 84.18; H, 6.08%. Found: C, 84.17; H, 6.02%.

5,11,17-Triallyl-25,26,27,28-tetrahydroxycalix[4]arene (7). A sample of 1.35 g (2.48 mmol) of 25,26,27-triallyloxy-28-hydroxycalix[4]arene (**6a**) was refluxed in 10 mL of *N,N*-diethylaniline for 4 h in an argon atmosphere. The reaction mixture was poured into 100 mL of diluted HCl to produce an off white solid, which was extracted with $CHCl_3$ and the color impurities were removed by a short column chromatography (6 cm in height, $CHCl_3$/*n*-hexane : 1/3). Further recrystallization from $CHCl_3$ and CH_3OH yielded 0.72 g (53%) of colorless crystals: mp 166-167°C; ^{1}H-NMR ($CDCl_3$) δ 10.21 (s, 4H, ArOH), 7.04-7.08 (d, J= 8Hz, 2H, ArH), 6.96 (s, 6H, ArH), 6.71-6.79 (t, J= 8Hz, 1H, ArH), 5.80-6.00 (m, 3H, C=CH-C), 5.02-5.10 (m, 6H, C=CH_2), 4.15-4.40 (bd, 4H, ArCH_2Ar), 3.40-3.65 (bd, 4H, ArCH_2Ar), 3.18-3.22 (d, J= 7Hz, 6H, ArCH_2C),; FAB-MS *m/z*: 544 (M^+). Anal. Calcd for $C_{37}H_{36}O_4$: C, 81.62; H, 6.62%, for $C_{37}H_{36}O_4 \cdot 2H_2O$: C, 79.00; H, 6.76%. Found: C, 78.68; H, 6.50%.

25,26,27,28-Tetraallyloxycalix[4]arene (8). A slurry of 0.26 g (0.48 mmol) of 25,26,27-triallyloxy-28-hydroxycalix[4]arene (7), 0.24 g (10 mmol) of NaH, and 0.80 mL (1.14 g, 9.4 mmol) of allyl bromide in 30 mL of CH_3CN was refluxed for 30 min. The solvent was removed and the residue was treated with CH_3OH to leave a white solid, which was recrystallized from $CHCl_3$ and CH_3OH to yield 0.16 g (57%) of colorless, needle-like crystals: mp 195-196°C (Lit.[1b] 184-185°C); ^{1}H-NMR ($CDCl_3$) δ 6.50-6.70 (m, 12H, ArH), 6.20-6.40 (m, 4H, C=CH-C), 5.08-5.28 (m, 8H, C=CH_2), 4.34-4.38 (d, J= 7Hz, 8H, OCH_2C), 4.27-4.34 (d, J= 13Hz, 4H, ArCH_2Ar), 3.12-3.19 (d, J= 13Hz, 4H, ArCH_2Ar).

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