



X-Ray Structure of an Inclusion Compound of 5,5'-Biscalix[4]arene-hexabenzooate with Toluene *

ALESSANDRA BOTTINO¹, GRAZIA M.L. CONSOLI¹, FRANCESCA CUNSOLO¹, CORRADA GERACI¹, CONSIGLIA TEDESCO², SIMONA ANTINUCCI² and PLACIDO NERI^{2**}

¹Istituto per lo Studio delle Sostanze Naturali di Interesse Alimentare e Chimico-Farmaceutico, CNR, Via del Santuario 110, I-95028 Valverde (CT), Italy; ²Dipartimento di Chimica, Università di Salerno, Via S. Allende 43, I-84081 Baronissi (SA), Italy

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Abstract

The structure of the 1:3 complex between 5,5'-biscalix[4]arene-hexabenzooate and toluene has been determined by a single crystal X-ray diffraction study. The two calix[4]arene subunits of the 5,5'-biscalix[4]arene system are related by an inversion center and are joined by an eclipsed biphenyl *para-para* linkage. Each calix[4]arene moiety displays a 1,3-*alternate* conformation and includes a toluene molecule within two opposite benzoate groups, while a third toluene molecule lies close to a crystallographic inversion center.

Introduction

The synthesis of di- or polytopic calixarene receptors [1], which could show interesting cooperative complexation or self-assembling properties [2], is a current research theme in the field of supramolecular chemistry. In this regard, we have recently introduced the 5,5'-biscalix[*n*]arene systems (*n* = 4, 6, 8) in which two calix[*n*]arene units are connected "head-to-head" with a biphenyl-like *para-para* linkage [3]. The synthetic strategy, recently also extended by Gutsche and coworkers to the preparation of 5,5'-biscalix[5]arene [4] and by us to the synthesis of *p-tert-butyl*-5,5'-biscalix[4]arene [5], requires the FeCl₃-mediated oxidative coupling of a properly protected calix[*n*]arene followed by a deprotection step. The intermediate protected 5,5'-biscalix[*n*]arenes are usually not isolated. However, in order to shed light on some aspects of these reactions, we have now isolated the intermediate formed in the synthesis of 5,5'-biscalix[4]arene **1**, namely 5,5'-biscalix[4]arene-hexabenzooate **3** (Scheme 1). This derivative crystallizes from toluene giving an inclusion compound whose interesting structural features we wish to report here.

Experimental

The synthesis of host compound **3**, according to Scheme 1, has been described previously [3a]. The results of a

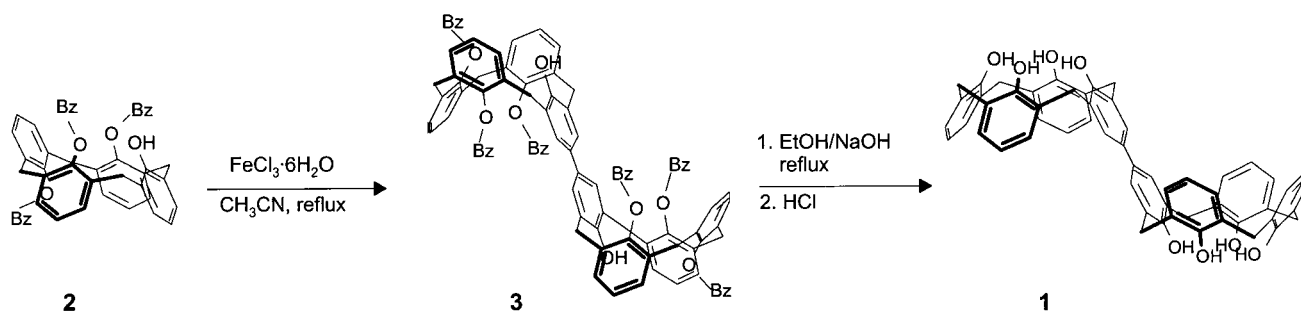
deeper investigation on these reactions will be reported in due course. **25,25',26,26',27,27'-Hexakis(benzoyloxy)-5,5'-biscalix[4]arene-28,28'-diol (3)**: m.p. > 310 °C dec.; ¹H NMR (250 MHz, CDCl₃) δ: 3.53 and 3.78 (AB, *J* = 14.2 Hz, ArCH₂Ar, 8H), 3.68 and 3.78 (AB, *J* = 15.0 Hz, ArCH₂Ar, 8H), 5.10 (s, OH, 2H), 6.62 (s, ArH, 4H), 6.63–6.70 (overlapped, ArH, 4H), 6.81 (d, *J* = 3.0 Hz, ArH, 8H), 6.84 (bs, ArH, 2H), 7.07 (d, *J* = 2.7 Hz, ArH, 2H), 7.10 (d, *J* = 2.7 Hz, ArH, 2H), 7.32 (dd, *J* = 6.7 and 5.5 Hz, BzH, 6H), 7.37 (dd, *J* = 7.7 and 7.7 Hz, BzH, 6H), 7.59 (t, *J* = 7.7 Hz, BzH, 2H), 7.65 (t, *J* = 7.0 Hz, BzH, 4H), 7.97 (d, *J* = 7.2 Hz, BzH, 12H); FAB(+) MS 1470 *m/z* [MH⁺]. *Anal. Calcd* for C₉₈H₇₀O₁₄: C, 79.98; H, 4.79. *Found*: C, 79.89; H, 4.84.

X-ray crystallography

5,5'-Biscalix[4]arene derivative **3** was crystallized as the 1:3 inclusion compound with toluene by slow evaporation from a toluene solution. A single crystal suitable for X-ray diffraction measurements was selected and mounted on a glass fiber. All diffraction measurements were performed using a Rigaku AFC7S diffractometer with graphite monochromated Mo-K α radiation (λ = 0.71069 Å). Crystallographic data and refinement details are reported in Table 1. The crystallographic asymmetric unit consists of half the 5,5'-biscalix[4]arene-hexabenzooate moiety, a toluene molecule plus another half toluene molecule. The structure was solved by direct methods using SIR92 [6] and refined on F² using SHELXL93 [7]. A rigid body refinement was performed for the toluene molecule in general position, assuming a perfect *D*_{6h} symmetry for the aromatic ring and considering ideal-

* Dedicated to the memory of Professor Guido Sodano (Università di Salerno), suddenly deceased.

** Author for correspondence. Fax: +39-089-965296; E-mail: neri@unisa.it



Scheme 1.

ized positions for methyl groups. The toluene molecule on the inversion center, evidently disordered, was treated as two distinct toluene molecules equally sharing the same site with opposite orientation.

Anisotropic displacement parameters were used for all non-hydrogen atoms except those belonging to the solvent molecules, for which an unique isotropic displacement parameter was used. Hydrogen atoms were positioned geometrically and refined using a riding model, the methyl group hydrogen atoms were assumed to be disordered over two sites rotated 60° to each other. Packing bond length calculations were performed by means of the program PARST97 [8], while the molecular and packing diagrams were obtained with the program ORTEP III [9].

Results and discussion

5,5'-Biscalix[4]arene **1** is obtainable by direct oxidative coupling with ferric chloride [10] of *p*-H-calix[4]arene [11]. The yields are usually low probably because extensive polymerization and polyoxidation processes take place [3a]. To avoid this problem we resorted to a protection-deprotection procedure, using as starting material Gutsche's *p*-H-calix[4]arene-tribenzoate **2** [11]. FeCl_3 -mediated oxidative coupling of **2** directly followed by alkaline hydrolysis gave 5,5'-biscalix[4]arene **1** (Scheme 1) in 55% yield [3a]. The obvious intermediate, dimeric hexabenzoate **3**, is usually not isolated for simplification of the procedure. However, to shed light on this reaction we decided to isolate **3**, which can also be considered a protected biscalix[4]arene derivative useful for subsequent chemical manipulations [5]. Thus, column chromatography of the raw oxidation mixture afforded **3** in 40% yield [12], which gave consistent FAB(+) MS and ^1H NMR spectra (see experimental).

Slow evaporation of a toluene solution of biscalixarene derivative **3** gave crystals of an inclusion compound suitable for X-ray analysis. The crystal structure of the calixarene molecule is shown in Figure 1. Each calixarene aromatic ring is labeled with a capital letter and each atom of the unit is progressively numbered. The atoms of the benzoyl groups are progressively numbered, named after the calixarene ring to which they belong plus adding the symbol Bz. Symmetry related atoms are labeled with an asterisk.

In the crystal structure the two calix[4]arene subunits of **3** are related by an inversion centre. Therefore, the connect-

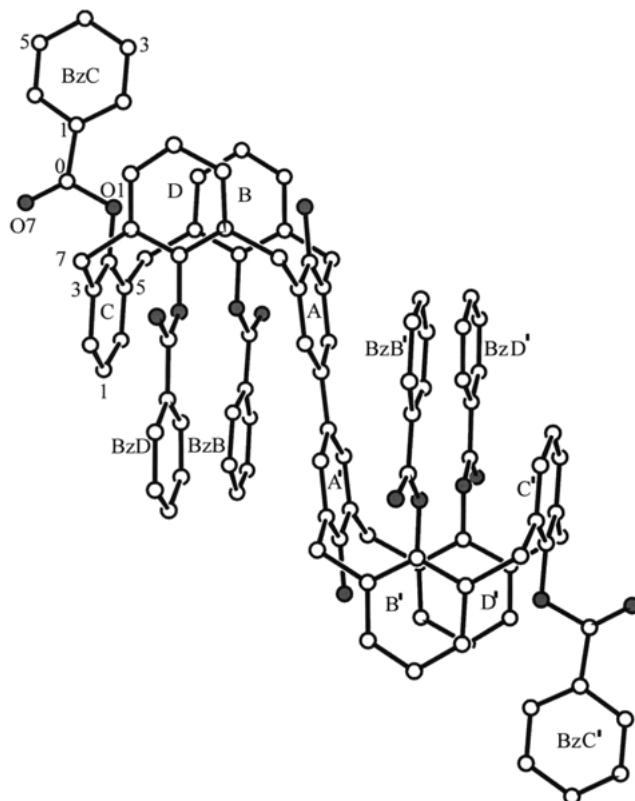


Figure 1. Crystal structure of 5,5'-biscalix[4]arene-hexabenzoate **3**. Each calixarene unit is labeled with a capital letter and each atom of the unit is progressively numbered. The atoms of the benzoyl groups are named after the calixarene unit to which they belong, progressively numbered and indicated by the symbol Bz.

ing aryl rings show an eclipsed conformation around the C(1A)–C(1A*) bond giving a planar biphenyl system [the C(2A)–C(1A)–C(1A*)–C(6A*) angle is $0(2)^\circ$]. In contrast, significant torsion angles (35° and 20°) for this bond were instead observed in two X-ray crystal structures of **1** [3a, d]. The C(1A)–C(1A*) and C(4A)–O(1A) bond distances are respectively 1.49(2) Å and 1.41(1) Å, thus indicating that both the Ar–Ar and opposite C–O bonds have a prevalent character of a single bond. A list of selected bond lengths and angles is reported in Table 2.

Each calix[4]arene subunit displays a *1,3-alternate* conformation [13] with canting angles between the mean plane of the four methylene carbon atoms and the planes of the aromatic rings of $83.9(3)^\circ$, $88.0(2)^\circ$, $86.0(3)^\circ$, and $86.2(2)^\circ$. This result indirectly demonstrates that the start-

Table 1. Crystallographic data and refinement details for compound **3**

Chemical formula (a.u.)	C ₄₉ H ₃₅ O ₇ 1.5 (C ₇ H ₈)
Formula weight (a.u.)	873.97
Crystal size (mm)	0.2 × 0.2 × 0.3
Crystal colour	Colourless
Crystal system	Triclinic
Space group	P-1
Unit cell dimensions	$a = 13.532(14) \text{ \AA}$, $\alpha = 105.21(5)^\circ$ $b = 14.315(12) \text{ \AA}$, $\beta = 100.09(6)^\circ$ $c = 13.159(6) \text{ \AA}$, $\gamma = 94.63(8)^\circ$
Cell volume (Å ³)	2400(3)
Z	2
Crystallographic density (mg/m ³)	1.208
Absorption coefficient MoK α (mm ⁻¹)	0.078
θ range (°)	2.01–22.50
Range of h, k, l	$0 < h < 14$ $-15 < k < 15$ $-14 < l < 13$
No. of reflections used in refinement	6248
No. of parameters	512
$R [F^2 > 2\sigma(F^2)]$	0.0764 (1421 reflections)
wR_2 (all data)	0.3040
Weighting scheme	$1/[\sigma^2(F_0^2) + 0.1000P]^2$, where $P = (F_0^2 + 2F_c^2)/3$
Goodness of fit	1.089
$\Delta\rho_{\max}, \Delta\rho_{\min}$ (eÅ ⁻³)	0.53–0.65

Table 2. Most significant bond lengths (Å) and bond angles (°) for compound **3**

C(1A) (1A')	1.49(2)	O(1A) C(4A)	1.411(10)
C(6A) C(1A) C(1A)	122.6(13)	C(6A) C(1A) C(2A)	115.3(9)
C(1A) C(2A) C(3A)	123.4(10)	C(2A) C(1A) C(1A)	122.2(13)
C(4A) C(3A) C(7A)	120.8(10)	C(4A) C(3A) C(2A)	117.4(10)
C(5A) C(4A) C(3A)	123.4(10)	C(2A) C(3A) C(7A)	121.9(10)
C(3A) C(4A) O(1A)	116.9(10)	C(5A) C(4A) O(1A)	119.7(11)
C(4A) C(5A) C(7D)	123.5(10)	C(4A) C(5A) C(6A)	115.8(10)
C(1A) C(6A) C(5A)	124.6(9)	C(6A) C(A5) C(7D)	120.7(10)
		C(3A) C(7A) C(3B)	115.2(9)

ing Gutsche's *p*-H-calix[4]arene-tribenzoate **2** possesses an *up-down-up* (*u-d-u*) arrangement of the three benzoylated rings, while the fourth OH-bearing aryl remains relatively free-swinging through the annulus [14]. Obviously, in the case of compound **2** this phenol ring preferentially adopts (in solution) an *up* orientation to give a *partial-cone* conformation, whereas in the crystal structure of **3** it prefers a *down* orientation, probably for packing reasons, thus originating a *1,3-alternate* conformation. This last conformation of **3** appears to be also predominant in solution as indicated by the small ¹H NMR chemical shift separation observed for ArCH₂Ar protons ($\Delta\delta = 0.25$ and 0.10) [15].

A packing diagram of the inclusion compound is shown in Figure 2 and a more detailed picture of the interactions of the solvent molecules is given in Figure 3. Three molecules of toluene are included in the unit cell, one has its center of gravity located on an inversion site, the other two are

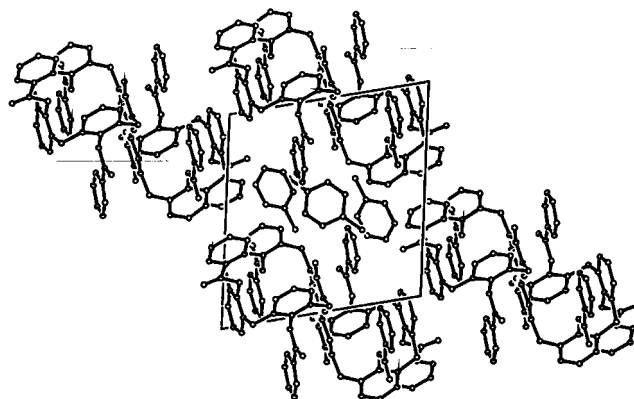


Figure 2. Packing diagram of the inclusion compound of 5,5'-biscalix[4]arene-hexabenzoate with toluene.

symmetry related. The atoms belonging to the first molecule are labeled with S and those of the other toluene molecules with T. The first toluene molecule is disordered and interacts mainly with the carboxylic oxygen atom O(7BzD) and the two other toluene molecules [shortest contacts are: C(7S)···O(7BzD) = 3.38(1) Å, C(3S)···O(7BzD) = 3.62(1) Å, C(1S)···C(2T) = 3.77(1) Å, C(2S)···C(2T) = 3.79(1) Å].

The angle between the aromatic planes of the toluene molecules is 32.1(4)°. The two symmetry related toluene molecules, besides the above interactions, mainly display van der Waals contacts with the benzoyl moieties [shortest van der Waals contacts are: C(7T)···C(5BzD) = 3.33(2) Å, C(6T)···O(7BzB) = 3.51(1) Å, C(3T)···O(1A) = 3.64(1) Å, C(7T)···C(6BzD) = 3.67(2) Å, C(5T)···C(6BzB) = 3.75(1)

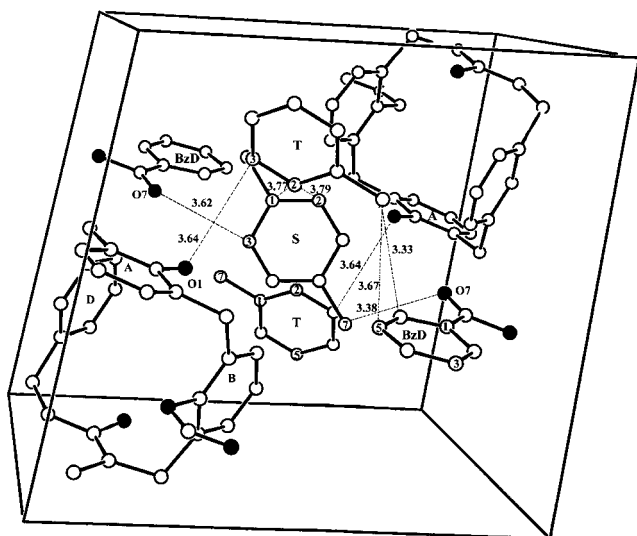


Figure 3. Van der Waals contacts between the toluene molecules and the host calixarene molecule.

Å, $C(6T) \cdots C(4BzD) = 3.78(2)$ Å, $C(5T) \cdots C(4BzD) = 3.78(2)$ Å].

The shortest observed packing distance is $3.33(2)$ Å and involves the atom C(7T) of the toluene molecule in general position and C(5BzD) (i.e., the atom at the *ortho* position of the benzoyl group on ring D). This small value is mainly due to the difficulties of adequately describing the disorder in the solvent molecules and no special interaction between the methyl group and the aromatic ring can be inferred.

The angles between the C(1T)–C(6T) aromatic ring and the other aromatic rings of the calixarene unit range from $63.0(4)^\circ$ to $71.0(4)^\circ$, while those between the C(1S)–C(6S) toluene ring and the other calixarene aromatic rings range from $60.8(3)^\circ$ to $79.0(3)^\circ$.

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