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Crystal Structure of 1,3-Alternate 25,26,27,28-Tetra(*tert*-butoxyethoxy)calix[4]arene: a Selective Ag^+ Extractant *

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Abstract

Alkylation of calix[4]arene by 2-*tert*-butoxyethyl bromide led to the tetraalkylated calix[4]arene in the 1,3-alternate, the conformation of which has been established by X-ray crystallography. This spatial structure included a cavity potentially useful for host–guest complexes achieved with metal cations, especially with Ag^+. The title compound crystallizes in the monoclinic space group Cc with cell constants a = 29.901(2), b = 8.139(1), c = 22.264(3) Å, α = 90°, β = 117.08(1)° and γ = 90°. This conformer represents an example for Ag^+-tunneling across an aromatic cavity. This behaviour could lead to important implications with regard to the metal cation-π interaction expected for metal transport through ion channels, metal inclusion in fullerenes, intercalation of metal cations into graphites, etc.

Introduction

Calixarenes are macrocyclic molecules made up of phenolic units linked by methylene bridges. They have been extensively studied for the last two decades and received increasing attention in the field of supramolecular chemistry [1–3]. These compounds are of current interest as starting materials for the preparation of a wide variety of molecular receptors and ionophores [4–7].

It is shown that metals are ideal partners for shaping or assembling calixarenes, thus allowing the construction of a number of large molecular systems, leading to various applications. The potential applications range from use as highly specific ligands for analytical chemistry, sensor techniques and medicinal diagnostics to their use in the decontamination of waste water and the construction of artificial enzymes [1–4]. Moreover, calixarenes can be involved in the synthesis of new materials for non-linear optics or for ultrathin layers and sieve membranes with molecular pores [8].

In calix[4]arenes, the substituents of the hydroxy functions frequently immobilize the molecule in a single conformation, e.g., cone, partial-cone, 1,2- or 1,3-alternate, which is actually related to the observed conformation. In particular, it has been established that tetraalkylated calix[4]arenes in the 1,3-alternate conformation show an unusually high affinity for K^+ and Ag^+ [9–10]. In particular, from these previous studies it has been shown that the 25,26,27,28-tetra(ethoxyethoxy)calix[4]arene in the 1,3-alternate conformation extracted significantly Ag^+, to a level of 66.7%. The chelating behaviour of Ag^+ is related to its affinity with the π-donor system [11-13]. This consistently supports the view that the high extractability of 1,3-alternate 25,26,27,28-tetra(ethoxyethoxy)calix[4]arene is rationalized in terms of π-donor participation.

In this context, we have focused part of our efforts on reactions generating 25,26,27,28-tetra(*tert*-butoxyethoxy)calix[4]arene **1** in the 1,3-alternate conformation [14]. As a structural analogue of the previous calix[4]arene, this new compound **1** could be a selective Ag^+ extractant. Moreover, it could represent further other examples for Ag^+-tunneling across an aromatic cavity and could have important implications with regard to the metal cation-π interaction expected for metal transport through ion channels, metal inclusion in fullerenes, intercalation of metal cations into graphites, etc. [9–10]. The X-ray crystallographic structure of **1** is reported. The measured intramolecular distances were found to be in accordance with the possibility of an ionophoric site able to chelate Ag^+. This result was confirmed by an Ag^+ experimental extraction procedure permitting us to quantify the extraction level by **1**.

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[*] **Supplementary Data** to this article relating to the crystal structure of calix[4]arene **1** are deposited with the British Library as Supplementary Publication No. CCDC 162275.

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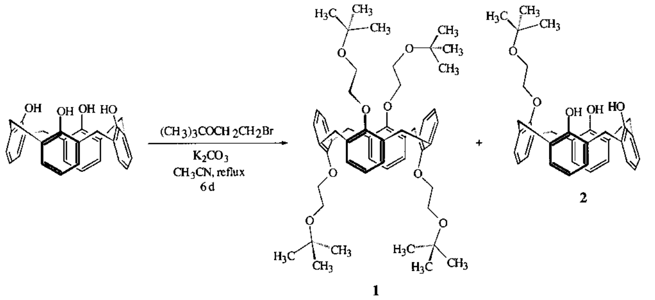

Scheme 1. Synthesis of compound **1**.

Experimental

Materials

This compound was obtained as follows: commercialy calix[4]arene was reacted with 2.2 equiv of 2-*tert*-butoxyethyl bromide in the presence of 2.4 equiv of K_2CO_3 as a base in refluxing CH_3CN for 6 days as previously reported [14]. Final purification of the crude product by chromatography on silica gel led to the tetraalkylated calix[4]arene **1** in the 1,3-alternate conformation as a white solid and to the monoalkylated calix[4]arene **2** in the cone conformation (Scheme 1). These different conformations have been assessed by ^1H and ^{13}C NMR studies [14].

X-ray crystallographic determination

A crystal of 1,3-alternate calix[4]arene **1**, suitable for X-ray diffraction studies, was obtained by recrystallisation from chloroform-methanol solution. A clear prism of calix[4]arene **1** was mounted on a CAD-4 Enraf-Nonius diffractometer equipped with graphite monochromated CuKα radiation (λ = 1.54178 Å). Cell constants and an orientation matrix for data collection were obtained from a least-squares refinement using the setting angles of 25 carefully centered reflections in the range $50.0° < 2\theta < 70.0°$. Based upon the systematic absences of hkl: $h + k = 2n$ and $h0l$: $l = 2n$, packing considerations, and a statistical analysis of intensity distribution, the space group *Cc* (No. 9) was selected for the structure. This was established by the successful solution of the structure.

The data were collected at a temperature of 20 ± 1 °C using the ω-θ scan technique to a maximum 2θ value of 109.8°

Of the 3104 reflections which were collected, 3035 were unique (R_{int} = 0.031). The intensities of two representative reflections which were measured after every 200 reflections remained constant throughout data collection indicating crystal and electronic stability (no decay correction was applied). The linear absorption coefficient for CuKα is 5.93 cm^{-1}. An empirical absorption correction, based on azimuthal scans of two reflections, was applied which resulted in transmission factors ranging from 0.84 to 0.99. The data were corrected for Lorentz and polarization effects. A correction for secondary extinction was applied (coefficient = 4.80×10^{-4}).

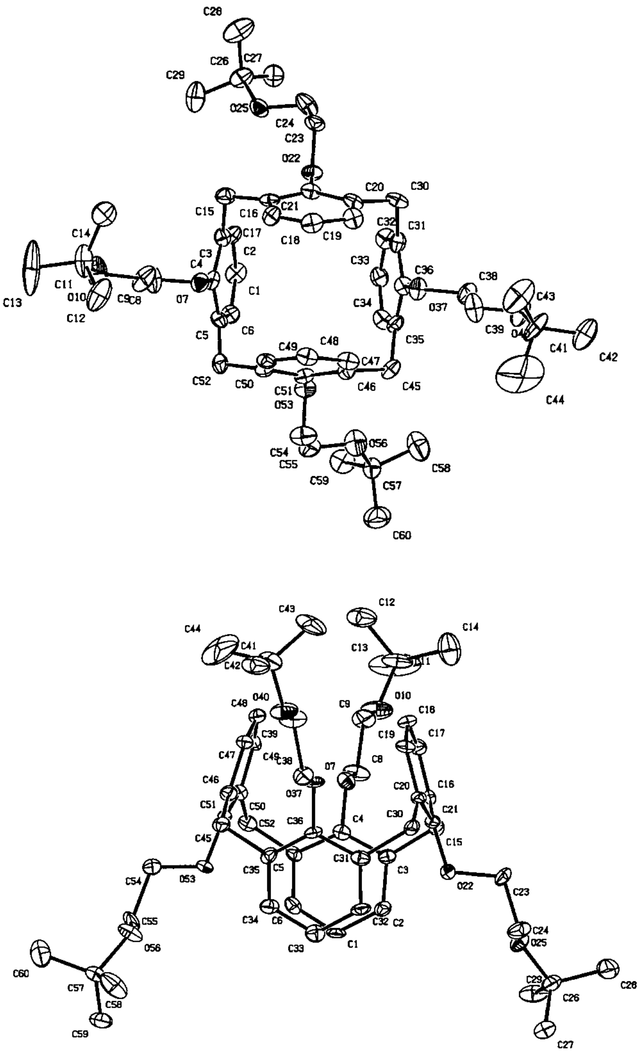

Figure 1. Top and side view of the crystal structure of **1** with our numbering scheme. Displacement ellipsoids are drawn at the 30% probability level and the hydrogen atoms are omitted for clarity.

The structure was solved by direct methods [15], and refined on (F) by full-matrix least-squares methods [16]. The final cycle of full-matrix least-squares refinement was based on 2168 observed reflections [$I > 2.00\sigma(I)$] and 542 variable parameters and converged with agreement factors of R = 0.043 and R = 0.0732 (All data).

Results and discussion

A top and side view of the crystal structure of compound **1** is shown in Figure 1. A summary of the crystallographic data for the molecule is listed in Table 1. Selected geometrical parameters for the macrocycle are compiled in Tables 2 and 3. The calix[4]arene **1** is in a distorted 1,3-alternate conformation. The phenyl rings and substituents are related by an approximate 4-fold inversion axis.

The dihedral angles between the aromatic units of the calix[4]arene skeleton through the methylene carbons are 107.6(7)°, 106.9(8)°, 110.3(8)°, and 109.4(8)°, respectively. All phenyl rings have a small, but well-defined, deviation

Table 2. Selected interatomic distances and angles (Å, °)

Interatomic distances					
C1–C6	1.362(14)	O10–C11	1.448(14)	O53–C34	3.146(16)
C1–C2	1.367(14)	C11–C12	1.526(17)	C16–O7	3.190(11)
C2–C3	1.403(14)	C11–C14	1.575(17)	O22–O53	6.410(10)
C3–C4	1.406(14)	C3–C15	1.527(14)	O37–O7	6.412(10)
C4–C5	1.373(13)	O7–C17	3.097(14)	C33–C1	4.220(10)
C4–O7	1.404(12)	O7–C49	3.138(11)	C18–C48	3.969(10)
C5–C6	1.396(14)	O22–C32	3.161(14)	C11–C41	13.402(19)
C5–C52	1.465(13)	O22–C2	3.191(12)	C26–C57	12.201(16)
O7–C8	1.405(12)	O37–C47	3.071(14)	C51–C21	5.493(16)
C8–C9	1.448(14)	O37–C19	3.066(12)	C4–C36	5.627(15)
C9–O10	1.398(13)				
Bond angles					
C6–C1–C2	119.8(10)	C1–C6–C5	123.0(10)	C12–C11–C13	104.7(11)
C1–C2–C3	120.9(10)	C8–O7–C4	113.9(8)	O10–C11–C14	113.4(11)
C2–C3–C4	116.1(9)	O7–C8–C9	109.2(10)	C12–C11–C1	105.4(11)
C5–C4–C3	124.0(10)	O10–C9–C8	109.9(11)	C13–C11–C14	120.4(12)
C5–C4–O7	119.1(9)	C9–O10–C11	117.3(9)	C2–C3–C15	122.2(9)
C3–C4–O7	116.4(9)	O10–C11–C12	113.3(11)	C4–C3–C15	121.6(9)
C4–C5–C6	115.3(10)	O10–C11–C13	99.6(10)		

Table 3. Selected torsion angles (°)

O(7)–C(8)–C(9)–O(10)	177.0(9)	O(37)–C(38)–C(39)–O(40)	−178.6(8)
O(22)–C(23)–C(24)–O(25)	73.9(12)	O(53)–C(54)–C(55)–O(56)	76.0(12)

Table 1. Crystallographic data for calix[4]arene **1**

Empirical formula	$C_{52}H_{72}O_8$
FW, amu	825.10
Crystal habit, color	Colorless prism
Lattice	Monoclinic
Space group	*Cc* (No. 9)
a, Å	29.901 (2)
b, Å	8.139 (1)
c, Å	22.264 (3)
α, deg	90.0
β, deg	117.08 (1)
γ, deg	90.0
V, Å^3	4824.3 (9)
Z	4
D_x, Mg m^{-3}	1.136
μ, mm^{-1}	0.593
F_{000}	1792
R^a	0.0431
R (All data)	0.0732
GoF	1.050
Max. peak in final diff. Map, e-/Å^3	0.216
Min. peak in final diff. Map, e-/Å^3	−0.160

$^aR = \Sigma||F_o| - |F_o||/\Sigma|F_o|$.

from planarity in a boat-like fashion, the C atoms connected to O having the largest distance to the mean plane of the ring. The four oxygen atoms bearing the alkoxy chains are slightly directed out of the cavity (distance 6.410(10) Å between O22–O53, distance 6.410(10) Å between O37–O7), leading to a shortening of the distance between the corresponding para C-atoms (4.220(10) Å between C33–C1 and 3.969(10) Å between C18–C48). In fact, the interplanar angle of the first two aromatic rings bearing the *t*-butoxyethoxy substituents (C1–C6, C31–C36) is 29.2(3)°, while the angle between the other phenol groups bearing the same *t*-butoxyethoxy substituents (C16–C26, C46–C51) is 31.8(3)°. The 2-*t*-butoxyethoxy chains in this 1,3-alternate isomer seem to adopt a sensible symmetrical regular conformation, described by the four torsion angles O–C–C–O, 76.0(12)°, 73.9(12)°, 177.0(9)°, and −178.6(8)°, revealing the two types of lateral chains. The crystalline cohesion was achieved by numerous van der Waals interactions. Moreover, in the crystal lattice there are no solvent accessible voids.

Careful examination of the structure of 1,3-alternate calix[4]arene **1** reveals that the size of the ionophoric hole (3.97–4.22 Å/6.41 Å) is acceptable for complexing Ag^+ (ionic diameter about 2.30 Å [17]). We thus estimated the extraction ability of **1** for Ag^+ according to the method of Ikeda and Shinkai [9–10]. We prepared an aqueous phase (5 mL) containing $AgNO_3$ (0.01 M), picric acid (0.238 mM), and dichloromethane (5 mL) with calixarene **1** (2.50 mM).

The two-phase mixture was shaken for 12 h at 25 °C. The extractability was determined spectrophotometrically from the decrease in the absorbance of the aqueous phase containing the picrate ion [18]. The absorbance A was measured at 355 nm (maximum absorption of the picrate ion, ϵ = 14285 mol^{-1} L cm^{-1}). An experiment without calixarene was run under the same conditions, which yielded the blank absorbance A_0. The cation percentage extraction was calculated as the ratio $100 \times (A_0 - A)/A_0$.

The 1,3-alternate 25,26,27,28-tetra(*tert*-butoxyethoxy)-calix[4]arene **1** extracted Ag^+ at a 62.1% level which is comparable with the percentage determined by Ikeda and Shinkai for the 1,3-alternate 25,26,27,28-tetra(ethoxyethoxy)calix[4]arene selected as a reference (Ex = 66.7%) [9–10]. All these results confirm that an ionophoric cavity composed of four $ROCH_2CH_2O$-groups (R = Et or *t*-Bu) in the 1,3-alternate conformation is sufficient for calix[4]arene structure to present a significant Ag^+ affinity. In an other hand, no particular influence was noticed here in relation to the steric effect of the *t*-butyl groups.

The significant extractability of compound **1** and the X-ray crystallographic data suggest that Ag^+-complexes with 1,3-alternate conformer **1** may be stabilized not only by the interactions with two phenolic oxygens, but also by the π-donor participation of the two benzene rings. A similar behavior was noticed for 1,3-alternate 25,26,27,28-tetra(ethoxyethoxy)calix[4]arene supported by ^1H NMR studies [9–10].

Conclusion

The extraction ability of **1** for Ag^+ was established through a classical analytical procedure. The intramolecular distances of the 1,3-aternate calix[4]arene cavity were measured from the X-ray crystallographic structure of **1** and found acceptable for complexing Ag^+. These results are useful to establish that Ag^+ could be bound to the edge of the 1,3-alternate cavity through interactions with two distal benzene rings and two distal phenolic oxygen atoms. Hence, the chelating behavior of **1** may be understood in terms of metal cation-π interaction, as previously described for a structurally related calix[4]arene. Such interactions are thought to have biological or physical implications, e.g., metal transport across ion channels, metal inclusion in π-base cavities (particularly in fullerenes), intercalation of metal cations into graphites, etc. It appears that calix[4]arenes could represent interesting models for their study.

References

1. C.D. Gutsche: in J.F. Stoddart (ed.): *Calixarenes. Monographs in Supramolecular Chemistry*, Vol. 1, Cambridge: Royal Society of Chemistry (1989).
2. J. Vicens and V. Böhmer (ed.): *Calixarenes: A Versatile Class of Macrocyclic Compounds*, Dordrecht: Kluwer, 1991.
3. C.D. Gutsche: in J.F. Stoddart (ed.): *Calixarenes Revisited. Monographs in Supramolecular Chemistry*, Vol. 2, London: Royal Society of Chemistry (1998).
4. V. Böhmer: *Angew. Chem. Int. Ed. Engl.* **34**, 713 (1995).
5. A.F. Danil de Namor, R.M. Cleverley, and M.L. Zapata-Ormachea: *Chem. Rev.* **98**, 2495 (1998).
6. A. Ikeda and S. Shinkai: *Chem. Rev.* **97**, 1713 (1997).
7. P. Froidevaux, J.M. Harrowfield, and A.N. Sobolev: *Inorg. Chem.* **39**, 4678 (2000).
8. C. Wieser, C.B. Dieleman, and D. Matt: *Coord. Chem. Rev.* **165**, 93 (1997).
9. A. Ikeda and S Shinkai: *Tetrahedron Lett.* **33**, 7385 (1992).
10. A. Ikeda and S. Shinkai: *J. Am. Chem. Soc.* **116**, 3102 (1994).
11. M. Igoda, Y. Kuwatani, T. Yamouchi, and M. Oda: *J. Chem. Soc., Chem. Commun.* 65 (1988).
12. R. Leppkes and F. Vogtle: *Chem. Ber.* **116**, 215 (1983).
13. J.L. Pierre, P. Baret, P. Chautemps, and M. Arnaud: *J. Am. Chem. Soc.* **103**, 2986 (1981).
14. J. Guillon, J.-M. Léger, P. Sonnet, C. Jarry, and M. Robba: *J. Org. Chem.* **65**, 8283 (2000).
15. G.M. Sheldrick: *SHELXS 97. Program Crystal Structure Solution*, Germany: University of Göttingen (1997).
16. G.M. Sheldrick: *SHELXL 97. Program for Crystal Structure Refinement*, Germany: University of Göttingen (1997).
17. R.W. Hay: in J. Burgess and R. Crichton (ed.): *Bio-inorganic Chemistry*, Chichester: Ellis Horwood (1984).
18. F. Arnaud-Neu, M.-J. Schwing-Weill, K. Ziat, S. Cremin, S. J. Harris, and M.A. McKervey: *New J. Chem.* **15**, 33 (1991).