J Incl Phenom Macrocycl Chem (2008) 60:169–172
DOI 10.1007/s10847-007-9366-4

ORIGINAL ARTICLE

Synthesis and conformation studies of multiple bridged *p-tert*-butylcalix[7]arene diphosphates

Haibing Li · Dejun Xiong · Yuanyin Chen · Peng Xie · Jian Wan

Received: 9 April 2007 / Accepted: 14 August 2007 / Published online: 14 September 2007

Abstract *p-tert*-Butylcalix[7]arene reacting with phosphorus pentachloride and then with water afforded two stereoisomers *p-tert*-butylcalix[7]arene diphosphates **2a** and **2b**, representing the first phosphorus multiple bridged calix[7]arene. The more accurate structure of 2a was investigated with the aid of Gaussian03 calculations.

Keywords Calixarene · Calix[7]arene · Multiple bridging · Phosphate · Conformation

Introduction

Calixarenes are a family of cavity-shaped cyclic molecules obtained from formaldehyde and *para*-substituted phenol via ring-closing condensation under alkaline conditions [1]. In order to recognize guest molecule efficiently, it is usually desirable to freeze the conformation of calixarene, especially in case of higher member of the calixarene family. For example, capping the calix[6]arenes with trisfunctional reagent [2] or doubly bridging it with bisfunctional reagents [3] are efficient routes to reduce the mobility of the conformation of calix[6]arene, especially, doubly capping it with trisfunctional reagent. Biali et al. synthesized bisphosphate-bridged calix[6]arene by pyrolysis of the product of calix[6]arene and $ClPO(OEt)_2$ [4]. Leeuwen et al. obtained diphosphite-bridged calix[6]arene from calix[6]arene and PCl_3 directly [5]. Gloede and coworkers reported calix[8]arene containing three bridging phosphate units [6]. Lately, they reported to synthesize calix[9]arene with PCl_5 and then with water to give the *p-tert*-butylcalix[9]arene triphosphate [7]. Just recently, we reported the synthesis of *p-tert*-butyltetrahomodioxacalix[6]arene diphosphate [8]. Up to date, the chemistry of even-numbered calix[n]arenes (n = 4,6,8) is approaching maturity. In contrast, the odd-number calixarenes (n = 5,7, etc.) most often obtained as by-products during the synthesis of even-numbered calixarene, remained much less studied. Improved approach for the synthesis of *p-tert*-butylcalix[7]arene, obtainable in 25% yield, has been reported by Gutsche and coworkers to open a door to investigate the calix[7]arene chemistry [9]. Thus, several calix[7]arene intramolecular bridged derivative have been reported by Neri and coworkers [10]. More recently, we reported the synthesis of 1,3- and 1,4-diacetylamido-bridged *p-tert*-butylcalix[7]arene [11]. Multiple bridging of calixarenes is expected to be more effective to limit the conformational mobility than double bridging [1c]. Furthermore, phosphorus-containing calixarenes are of particular interest for the complexation of cations, especially the cations of the f-block elements [12]. Here, we report the synthesis and conformation studies of the first phosphorus multiple bridged *p-tert*-butylcalix[7]arene employing multifunctional capped reagents.

H. Li (✉) · D. Xiong · P. Xie · J. Wan
Key Laboratory of Pesticide and Chemical Biology of Ministry of Education, College of Chemistry, Central China Normal University, Wuhan 430079, China
e-mail: lhbing@mail.ccnu.edu.cn

Y. Chen
Department of Chemistry, Wuhan University, Wuhan 430072, China

Experimental

Material and methods

The ^1H NMR and ^{31}P NMR spectra were recorded at 400 MHz and 162 MHz, respectively, on Varian Mercury

400 spectrometer. TMS was used as an internal standard for NMR. ESI mass spectra was obtained from a Finnigan LCQ Advantage mass spectrometry service. Elemental analyses were performed with Yanaco MT-5. *p-tert*-butylcalix[7]arene was synthesized according to the literature procedures [9]. All other chemicals were commercially available and used without further purification.

Synthesis of *p-tert*-butylcalix[7]arene diphosphates **2a** and **2b**

A mixture of *p-tert*-butyl calix[7]arene 1 (0.227 g, 0.2 mmol) and phosphorus pentachloride (0.208 g, 1 mmol) was stirred in dry dichloromethane (15 mL) in room temperature for 12 h, simultaneously adding triethylamine (4 mL) slowly. The residue was refluxed for 2 h in the solution of concentrated HCl (15 mL) and dioxane (4 mL). After filtrated and washed with hexane, the residue was subjected to PTLC ($CHCl_3/CH_3OH$ = 500/l v/v) to give the yellow solid 2a (0.03 g, 12% yield) and 2b (0.02 g, 8% yield).

p-tert-Butylcalix[7]arene Diphosphate ***2a***

R_f = 0.3 ($CHCl_3/CH_3OH$ = 100/l v/v); ^{1}H NMR(400 MHz, $CDCl_3$): δ0.88 (s, 9H, $C(CH_3)_3$), 1.04 (s,18H, $C(CH_3)_3$), 1.25 (s, 18H, $C(CH_3)_3$), 1.31(s,18H, $C(CH_3)_3$), 3.58 (d, 2H, J = 14.4Hz, $ArCH_2Ar$), 3.82 (d, 1H, J = 14.0Hz, $ArCH_2Ar$), 3.93 (d, 2H, J = 14.6Hz, $ArCH_2Ar$), 3.94 (s, 4H, $ArCH_2Ar$), 4.33 (d, 1H, J = 14.0Hz, $ArCH_2Ar$), 4.46 (brs, 2H, $ArCH_2Ar$), 4.60 (d, 2H J = 14.4Hz, $ArCH_2Ar$), 6.32, 6.96, 7.00, 7.17, 7.18, 7.19, 7.25 (s each, 2H each, ArH), 7.24 (s, 1H, ArOH). ^{31}P NMR ($CDCl_3$)δ = –17.80 ppm; Anal calc. for $C_{77}H_{92}O_9P_2$: C, 75.59; H, 7.58; P, 5.06; found: C, 75.55; H, 7.55; P, 5.05; ESI-MS m/z = 1247.7 $[M+Na]^+$

p-tert-Butylcalix[7]arene Diphosphate ***2b***

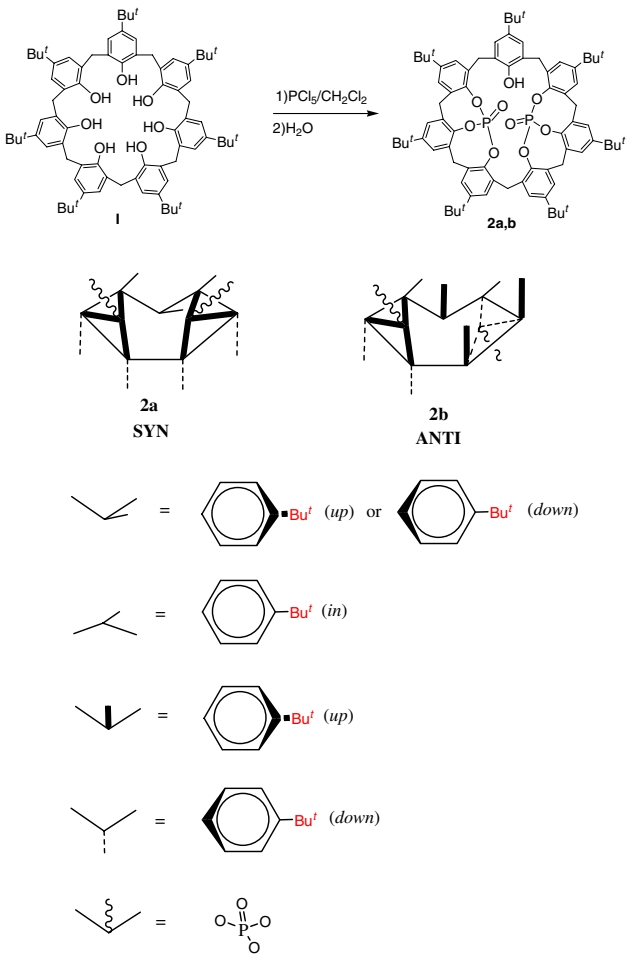
R_f = 0.35 ($CHCl_3/CH_3OH$ = 100/L v/v); ^{1}H NMR (400 MHz, $CDCl_3$): δ0.86(s, 9H, $C(CH_3)_3$), 1.09(s, 9H, $C(CH_3)_3$), 1.23 (s, 9H, $C(CH_3)_3$), 1.25(s, 9H, $C(CH_3)_3$), 1.32 (s, 9H, $C(CH_3)_3$), 1.33 (s, 9H, $C(CH_3)_3$), 1.39 (s, 9H, $C(CH_3)_3$), 3.53 (d, 1H, J = 12.8 Hz, $ArCH_2Ar$), 3.58 (m, 2H, $ArCH_2Ar$), 3.80 (m, 2H, $ArCH_2Ar$), 4.23 (m 4H, $ArCH_2Ar$), 4.54 (d 1H J = 12.8 Hz, $ArCH_2Ar$), 4.69 (m, 4H, $ArCH_2Ar$), 6.38, 6.49, 6.97, 7.00, 7.11, 7.17, 7.25(s each, 2H each, ArH), 7.24 (s, 1H, ArOH) ^{31}P NMR ($CDCl_3$)δ = –19.76, –24.83 ppm; Anal calc. for $C_{77}H_{92}O_9P_2$: C,75.59; H, 7.58; P, 5.06; found: C, 75.55; H, 7.60; P, 5.04; ESI-MS m/z = 1223.7 $[M+H]^+$

Results and discussion

Treatment of *p-tert*-butyl-calix[7]arene **1** with 5 equiv. Of phophorus pentachloride in dry dichloromethane and subsequent hydrolysis afforded two compounds **2a** and **2b** which were obtained in 12% and 8% yield respectively after preparative thin layer chromatography (PTLC) (Scheme 1) (see Fig. 1).

All new compounds are characterized by ESI-MS spectra, elemental analysis, ^{1}H NMR and ^{31}P NMR spectroscopy. The elemental analysis data indicate that the two compounds **2a** and **2b** have same composition with the molecular formula $C_{77}H_{92}O_9P_2$. The ESI-MS spectra show expected molecular ion peaks 1247.7 $[M+Na]^+$ and 1223.7 $[M+H]^+$ for **2a** and **2b**, respectively. The multiple bridged system **2** can be viewed as having two subunits, each formed by three proximal phenolic oxygens bridged by a phosphorus atom. Depending on the mutual orientation of the two subunits, *SYN* and *ANTI* isomers are available.

The ^{31}P NMR spectrum of **2a** shows a broad peak at δ = –17.80 which indicates the two P atoms are identical.



Scheme 1

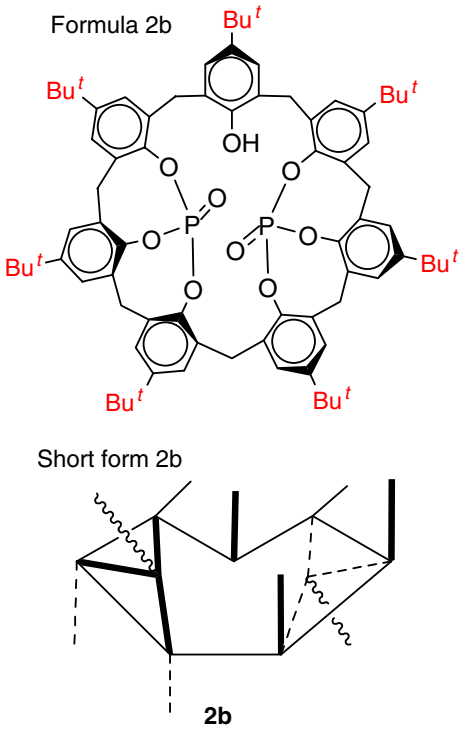


Fig. 1 Conversion of the full formula of **2b** to a short form

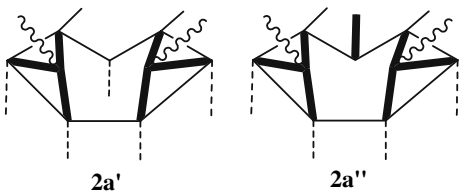


Fig. 2 Conformers of **2a**

The ^{1}H NMR spectrum of **2a** shows four singlets (ratio 1:2:2:2) for the *tert*-butyl groups, three pairs of doublets and one singlet mixed with a doublet for the methylene protons, and one singlet for the hydroxyl proton. This is accordance with the *SYN* isomer structure. The ^{31}P NMR spectrum of **2b** shows two sharp peaks at $\delta = -19.76, -24.83$ which indicates the two P atoms are different. The ^{1}H NMR spectrum of **2b** shows seven singlets in a ratio of 1:1:1:1:1:1:1 for the *tert*-butyl groups, obviously indicating that the structure of **2b** is asymmetrical. This is accordance with the *ANTI* isomer structure, **2b**.

The structure of multiple bridged calix[7]arene diphosphates **2a** and **2b** are illustrated in Fig. 2. For stereoisomers **2a** and **2b,** there are six proximal phenolic oxygens bridged by two phosphorus atom and the last free rotation *tert*-butylphenol. It suggests *SYN* isomer **2a** has two conformers **2a**′ and **2a**″ (Fig. 3). It is not possible to assign the conformation, although we believe **2a**′ is more plausible because the HO–Ar gives probably a H-bridge bond to O-atom of P–O–Ar [13].

A real structure for **2a,b** cannot be given, because single crystals are not obtained for X-ray studies, unfortunately. In order to investigate the structure of **2a,** an insight was obtained by conformational search using the **Gaussian03** Program Package [14]. With this procedure an asymmetrical lowest energy structure whose conformation was similar to **2a**′ was found (Fig. 3), which very likely corresponds to the frozen conformation evidenced by NMR studies. The result of the modeling is in accordance with the interpretation. By the terms of the energies of the optimized calculated conformations for **2a**′ and **2a**″**, 2a**′ is more stable than **2a**″ and an energy barrier of 519.8 KJ/mol is

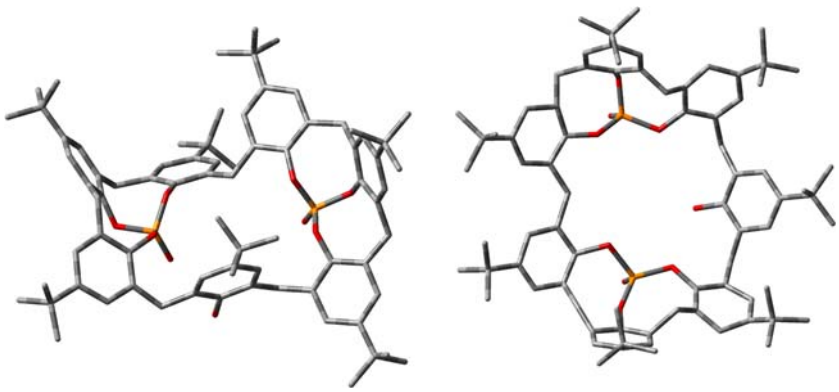


Fig. 3 Compound model of the asymmetrical lowest Gaussian03-energy conformation (left) and of the averaged symmetrical structure (right) of compound **2a**

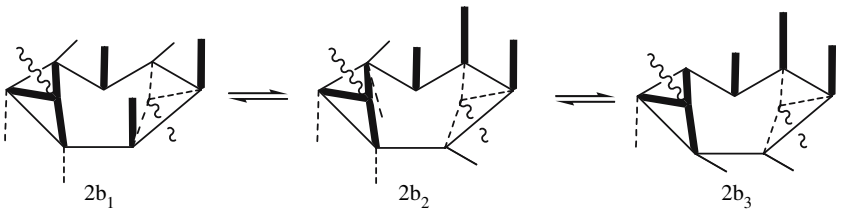


Fig. 4 Dynamic behavior of **2b**

calculated between them. An independent modeling with imposed symmetry equivalences, gave an idealized symmetrical structure (Fig. 3), which can be considered as representative of the averaged conformation observed from the NMR spectra.

It is known that cyclic calixarene phosphates are dynamic systems [7, 15]. The aromatic rings can not only exchange their positions from the ''up'' position to the ''in'' position but also from the ''down'' position to the ''in'' position and vice versa. For example this dynamic behavior for the phosphate **2b** should lead to an equilibrium between $\mathbf{2b_1}$, $\mathbf{2b_2}$, and $\mathbf{2b_3}$, illustrated in Fig. 4 (see Fig. 1). The broad signals of Ar–CH_2–Ar in the ^{1}H NMR spectra originate from the dynamic behavior.

Acknowledgements This work was financially supported by the National Natural Science Foundation of China (20602015), Program for Distinguish Young Scientist of Hubei Province and Program for Chenguang Young Scientist for Wuhan (200750731283).

References

1. (a) Gutsche, C.D.: Calixarenes Revisited. The Royal Society of Chemistry, Cambridge (1998). (b) Ikeda, A., Shinkai, S.: Novel cavity design using calyx[n]arene skeletons: toward molecular recognition and metal binding. Chem. Rev. **97**, 1713–1734 (1997). (c) Böhmer, V.: Calixarenes, macrocycles with (almost) unlimited possibilities. Angew. Chem., Int. Ed. Engl. **34**, 713–745 (1995).
2. Li, J.S., Chen, Y.Y., Lu, X.R.: Syntheses of novel tripodal calyx[n]cryptands (n = 4, 6) and their extraction abilities toward cations. Eur. J. Org. Chem. **2000**, 485–490 (2000).
3. (a) Chen, Y.Y., Li, H.B.: Syntheses of novel types of calix[6]bis-crowns and related compounds. New J. Chem. **25**, 340–343 (2001). (b) Chen, Y.Y., Li, H. B.: Synthesis and characterization of p-tert-butylcalix[6]-1,4-crown-4-2,6-crown-5, p-tert-butylcalix[6]-1,4-benzocrown-4-2,3-crown-5. Chem. Lett. **29**, 1208 (2000). (c) Li, H. B., Chen, Y. Y.: An interesting approach to bis-calix[5]arene analogue fromcalix[6]arene. Chin. Chem. Lett. **13**, 205–206 (2002).
4. (a) Grynszpan, F., Aleksiuk, O., Biali, S.E.: Phosphorus polybridged calixarenes. J. Chem. Soc. Chem. Commun. **13**, doi: 10.1039C39930000013 (1993). (b) Aleksiuk, O., Grynszpan, F., Biali, S.E.: Preparation, structure and steredynaics of phosphorus-bridged calixarenes. J. Incl Phenom. Macrocyclic Chem. **19**, 237–256 (1994).
5. Parlevliet, F.J., Zuideveld, M.A., Kiener, C., Kooijman, H., Spek, A.L., Kamer, P.C.J., Van leeuwen, N.M.: Synthesis of a calix[6]arene-derived diphosphite, Its palladium and platinum complexes, and the remarkable activity of (syn-calix[6]arene diphosphite)Pd(CH3)(CH3CN)OTf in carbonmonoxide and ethene copolymerization. Organometallics **18**, 3394–3405 (1999).
6. Gloede, J., Ozegowski, S., Matt, D., Cian, A.D.: Shaping calixarene frameworks. Synthesis and structure of a calix[8]arene containing three bridging phosphate units. Tetrahedron Lett. **42**, 9139–9142 (2001).
7. Gloede, J., Ozegowski, S., Costisella, B., Gutche, C.D.: Threefold bridged p-tert-butylcalix[9]arene triphosphate. Eur. J. Org. Chem. **2003**, 4870–4873 (2003).
8. Li, H.B. Chen, Y.Y.: Phosphate doubly capped tetrahomodioxacalix[6]arene. Chin. Chem. Lett. **14**, 143–144 (2003).
9. Stewart, D.R., Gutsche, C.D.: Isolation, characterization, and conformational characteristics of p-tert-butylcalix[9-20]arenes1. J. Am. Chem. Soc. **121**, 4136–4146 (1999).
10. (a) Marco, M., Luisa, G., Carmine, G., Placido, N.: Regioselective intramolecular bridging of p-tert-butylcalix[7]arene. Tetrahedron Lett. **43**, 9521–9525 (2002). (b) Marco, M., Luisa, G., Carmine, G., Placido, N.: Regioselective double intramolecular bridging of p-tert-butylcalix[7]arene. Tetrahedron Lett. **45**, 3387–3391 (2004).
11. Luo, Z.Y., Gong, S.L., Zhang, C.L., Zheng, Q., Chen, Y.Y.: Synthesis of 1,3- and 1,4-diacetylamido-bridged p-tert-butylcalix[7]arenas. Synlett. **5**, 795–797 (2006).
12. Thuery, P., Nierlich, M.M., Harrowfield, J.M., Ogden, M.: In: Asfari, Z., Böhmer, V., Harrowfield, J. M., Vicens, J. (eds.) Calixarenes 2001, pp. 561–582. Kluwer Academic Publ., Dordrecht, (2001).
13. Gloede, J., Keitel, I., Costisella, B., Kunath, A., Schneider, M.: Inhärent chirale 1,2-verbrückte calix[4]aren-diphoshhatesynthese, eigenschaften und isomerentrennung. Phosphor. Sulf. Silicon **117**, 67–88 (1996).
14. Gaussian03 Program Package for Linux2003.
15. Gloede, J., Ozegowski, S., Keitel, I., Buttke, K., Gruner, M., Costisella, B., Pritzkow, W., Stephan, H., Bartoschek, M.Z.: Zweifach und dreifach intramolekular verbrückte p-tert-butylcalix[8]aren-triphosphate-synthese, struktur undstereochemie. Anorg. Allg. Chem. **632**, 123–132 (2006).