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Synthesis of Novel *p-tert*-Butylcalix[4]arene Derivative: Structural Characterization of a Methanol Inclusion Compound

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Abstract: A *p*-tertbutylcalix[4]arene derivative was synthesized from a reaction of the diisothiocyanate *p*-tertbutylcalix[4]arene, obtaining crystals that were then characterized by mass spectroscopy, Raman spectroscopy, and single-crystal X-ray diffraction. The molecule presents two acid carbamothioic-n-ethoxy-methyl-ester substituent groups. Through crystallization of this compound, it was also found that it includes a methanol molecule within the aromatic cavity. The inclusion of the methanol molecule is due to favorable CH···π interactions.

Keywords: calix[4]arene; crystal structure; synthesis

1. Introduction

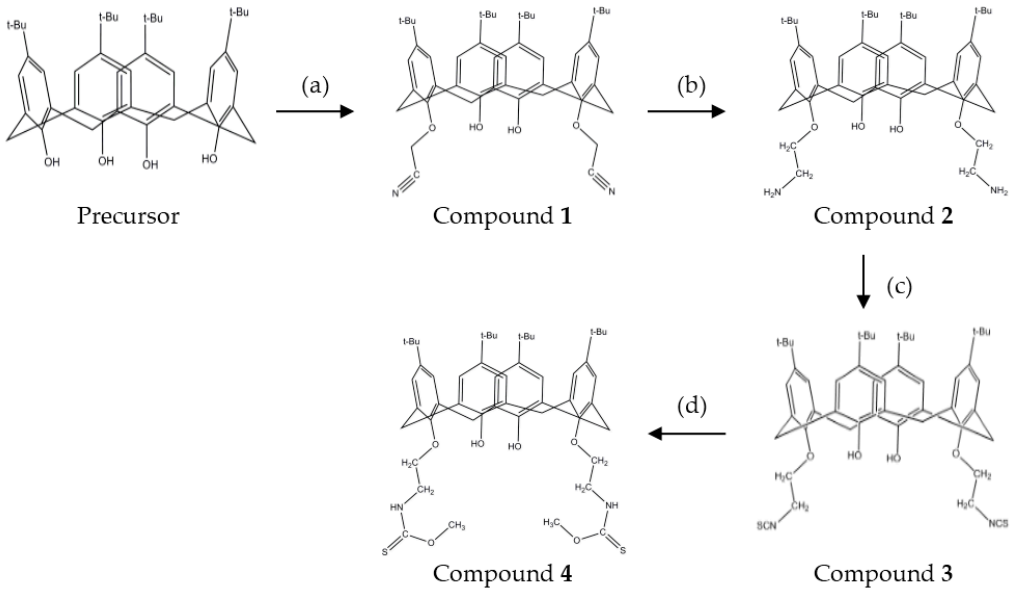
Calix[n]arenes constitute a family of well-known cyclic compounds that are synthesized by the base-catalyzed condensation of formaldehyde with *para*-substituted phenols, usually *p-tert*-butylphenol (cyclocondensation). Calix[n]arenes adopt a basket-shaped conformation in the solid state with a ring size that is dependent on the base that is used [1]. These macrocycles have been the subject of a variety of studies because of their interesting and technologically useful properties [2–4]. Their technological applications [5,6] include nanodevices with nanoparticles capable of detecting metal cations, polyaromatic hydrocarbons, and pesticides. The potential uses of chiral calix[n]arenes for enantioselective recognition [7], asymmetric catalysis [3], and as membrane carriers for the transport of chiral amino acids [8] are particularly interesting.

Different chemical modifications of calix[n]arenes have been used as artificial receptors for cations, anions, and neutral organic molecules. This is due to the interactions that occur between the hydrophilic areas of calix[n]arenes (lower rim) and different species. These interactions are primarily hydrogen bonds. Moreover, these compounds may host different molecules or ions within the hydrophobic cavity due to the interactions generated by the aromatic fraction. Different types of guests, including neutral molecules [9] such as acetonitrile [10], and various ions [11] such as the ammonium ion [12], have been reported. The crystal structures of calix[n]arenes makes them attractive building blocks, as they can easily be functionalized as required; for example, *p-tert*-butylcalix[4]arene is available through the functionalization of the hydroxyl groups (lower rim) or the *para* positions of the phenyl rings (upper rim). Additionally, intermolecular interactions lead to the formation of supramolecular arrays in crystal packing [13].

This paper presents the characterization by single crystal X-ray diffraction, Raman spectroscopy, and mass spectroscopy of the derivative 5,11,17,23-tetra-tert-butyl-25,27-di[acidcarbamothioic-n-

ethoxy-methyl-ester]-26,28-dihydroxy calix[4]arene (compound **4**), which crystallizes with a molecule of methanol in its cavity. Calixarenes have been studied in our research group with regard to their supramolecular chemistry and applications as extractants, transporters, optical sensors, and in medical research [14].

Compound (**4**) was obtained by stepwise substitution of its precursor, *p-tert*-butylcalix[4]arene (Scheme 1). The crystallographic analysis reveals the supramolecular array produced by the different interactions of XH···π and inter- and intra-molecular hydrogen-bonds. The cone conformation of the derivative remains.



Scheme 1. Representative diagram of the synthesis of compound (**4**): (**a**) K_2CO_3, $BrCH_2CN$, CH_3CN, reflux, 8 h; (**b**) $LiAlH_4$, THF, N_2, 4 h; (**c**) $BaCO_3$ CH_2Cl_2 and thiophosgene, 24 h at RT; (**d**) hot $CHCl_3/CH_3OH$ at R.T.

2. Results and Discussion

2.1. Spectroscopic Characterization

The derivative 5,11,17,23-tetra-tert-butyl-25,27-di[acidcarbamothioic-n-ethoxy-methyl-ester]-26,28-dihydroxy calix[4]arene (compound **4**) was obtained through the reaction synthesis of *p-tert*-butylcalix[4]arene (**1**). Scheme 1 shows the reaction steps (see Section 3.1. for sample preparation).

Compounds (**3**) and (**4**) were studied by Mass-Spectrometry Imaging. The spectrum, shown in Figure 1, clearly exhibited one peak at *m/z* 883.48. This analysis established the molecular mass of (**4**) which is consistent with the molecular formula determined by single-crystal diffraction (see Table 3).

Figure 2 shows the Raman spectra of the selected crystals of compounds (**1**), (**3**), and (**4**). The spectra may be qualitatively analyzed in terms of the vibration modes of the related substituted *p-tert*-butylcalix[4]arene. Vibrational modes of *p-tert*-butyl groups, hydroxyl groups, and aromatic rings (~1600 to 500 cm^{-1}) are observed in the spectra. However, significance differences in the C=N stretching modes were observed (see inset of Figure 2). The absorption mode of the CN group in (**1**) (at 2258.2 cm^{-1}) shifted to 2105.6 cm^{-1} in (**3**). In addition to shifting, the shapes of the peaks also changed (the CN group peak in **3** is broad). On the other hand, compound (**4**) did not show this vibration mode, implying the absence of the CN group in its structure.

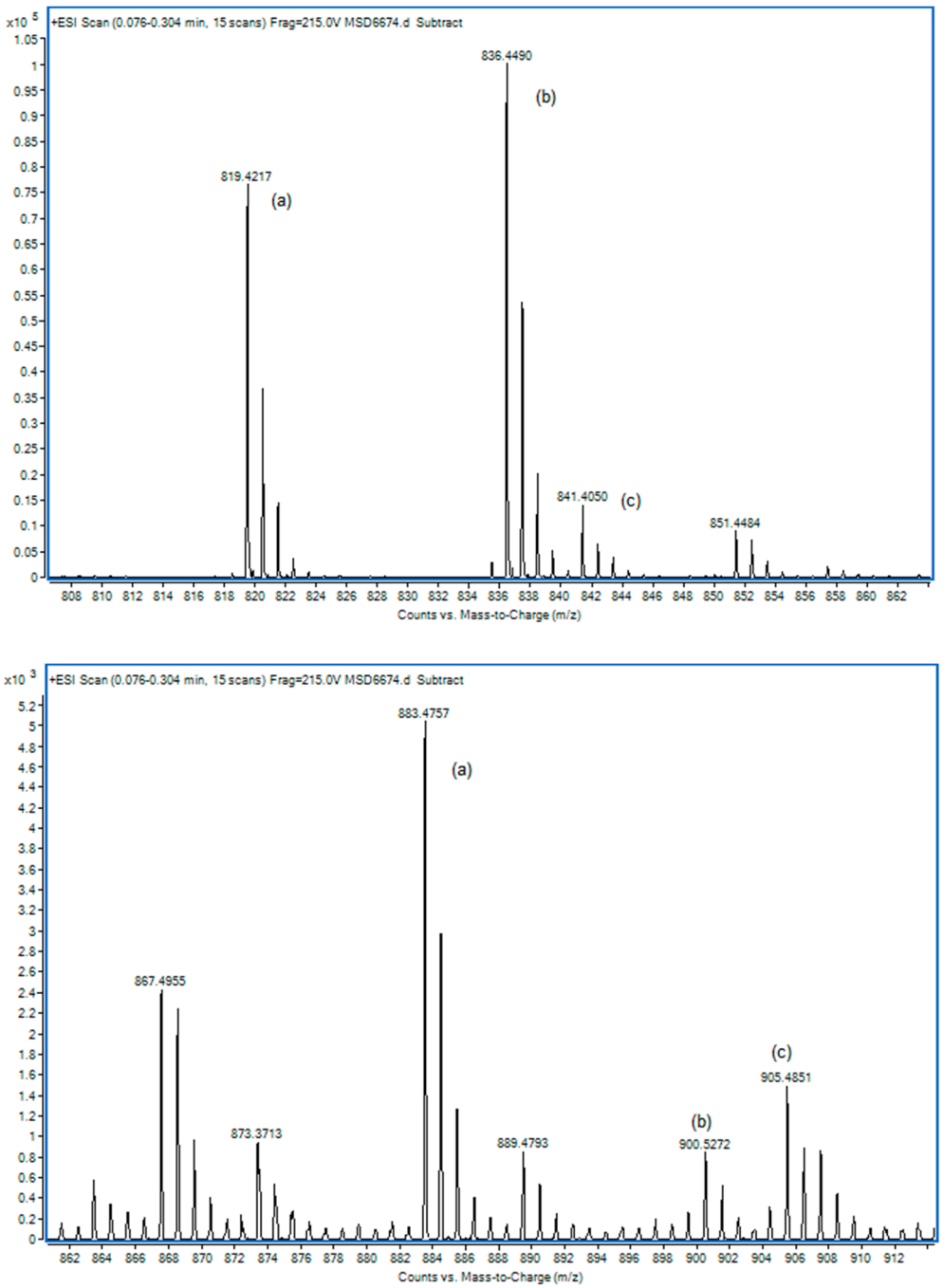


Figure 1. (**top**) Positive ion ESI-MS of compound (**3**); 819.4217 ($M + H^+$) (**a**) (MW819), (**b**) (MW836) $X + NH_4^+$ and (**c**) (MW 841) $X + Na^+$ (**bottom**) Positive ion ESI-MS of compound (**4**); 883.4757 (**a**) (MW883) $M + H^+$, (**b**) (MW900) $M + NH_4^+$ and (**c**) $M + Na^+$.

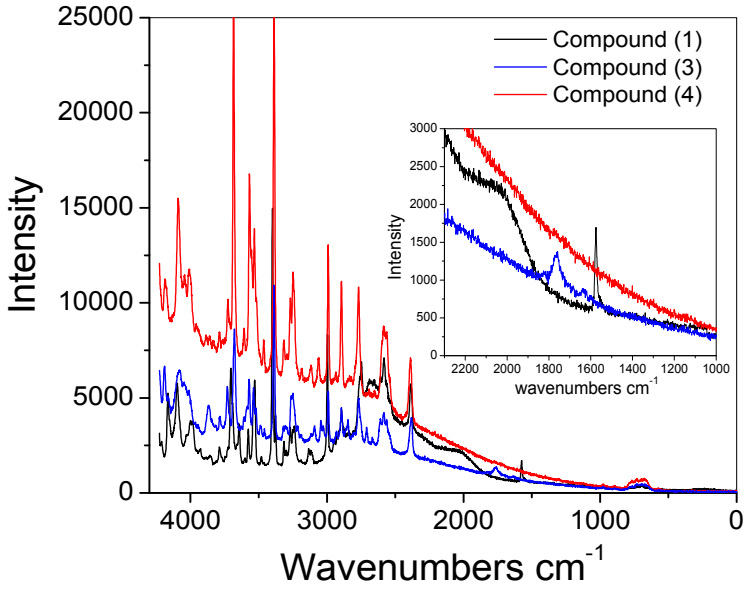


Figure 2. Raman spectra of compounds (**1**), (**3**), and (**4**) in solid state. The insert shows the C=N stretching band.

2.2. Crystal Structure

The crystal structure of (**4**) was determined by single crystal X-ray diffraction. The asymmetric unit consists of the *p-tert*-butylcalix[4]arene derivative and one methanol solvent molecule. The molecular structure with the atom labels is shown in Figure 3.

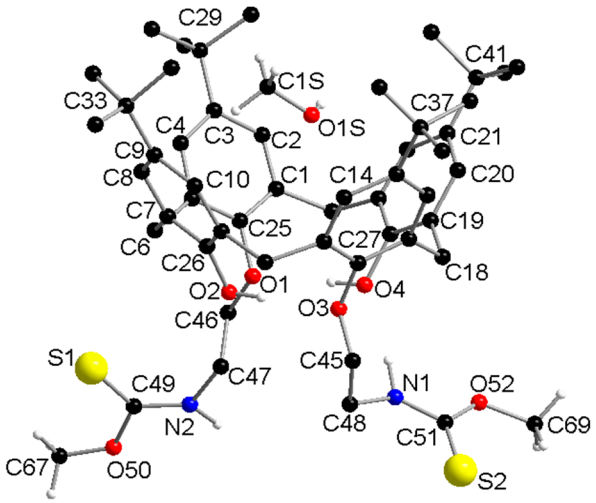


Figure 3. Crystal structure of compound (**4**). Some H-atoms has been omitted by clarity.

The molecule presents two acidcarbamothioic-n-ethoxy-methyl-ester substituent groups at C25 and C27 (of the aromatic rings). The torsion C17-C27-O3-C45 angle is 95.4(6)°.The orientation of another chain group substituent with respect to its aromatic ring [C1-C25-O1-C46] is 93.6(7)°. Compound (**4**) showed a terminal methoxy group and a carbonothioyl group. The C=S bond distances are 1.600(11) Å [S1-C49-O50 = 120.7(10)°] and 1.624(7) Å [S2-C51-N1 = 124.8(6)°]. These bonds and angles are highly similar to the C=S bond distance in the cyanoformamide organic compound [1.600(11) Å]. All other relevant structural parameters (bond distances and angles) are as expected and are in acceptable agreement with their analogs (see Table 1) [14].

Table 1. Selected structural parameters (Å, °).

Bond Length			Angles
C1-C2	1.374(8)	C25-O1-C46	113.9(4)
S1-C49	1.600(11)	C27-O3-C45	113.7(4)
S2-C51	1.624(7)	C49-O50-C67	123.1(12)
O50-C49	1.434(17)	C51-O52-C69	119.1(7)
O52-C51	1.335(10)	C48-N1-C51	124.8(6)
O50-C67	1.32(2)	C47-N2-C49	124.9(8)
O52-C69	1.430(12)	S1-C49-O50	120.7(10)
N1-C48	1.441(10)	S1-C49-N2	126.3(10)
N2-C47	1.411(11)	O50-C49-N2	113.0(9)

In crystal packing, the calixarene molecules are linked by hydrogen bonds, weak intermolecular contacts, and N-H···π and C-H···π interactions (Table 2). The packing structure contains a C67-H67C···O50 intermolecular contact with a bond distance of 2.26(4) Å, with H-acceptor distances that are less than the sum of the van der Waals radii. This intermolecular contact links two calixarenes, leading to the formation of dimers. These intermolecular interactions generate a graph-set descriptor D motif (see Figure 4) [15], which is an important influence on the orientation of calixarenes in crystal packing.

Table 2. Hydrogen-bond and intermolecular interactions (Å, °).

D-X···A	d(D-X)	d(X···A)	d(D···A)	<(DXA)
C67-H67C···O50 [i]	0.97(4)	2.26(4)	3.222(2)	176(3)
N1-H1N···O4 [ii]	1.17(11)	2.06(10)	3.193(7)	161(8)
O2-H2···O3 [ii]	0.8200	1.93	2.746(6)	175.00
O4-H4···O1 [ii]	0.8200	1.96	2.778(6)	179.00
C67-H67A···S1 [ii]	0.9600	2.45	2.98(2)	115.00
C69-H69A···S2 [ii]	0.9600	2.46	2.983(11)	114.00
C1S-H1S1···Cg2 [ii]	0.9600	2.72	3.61(2)	73.0
N2-H2N···Cg4 [iii]	1.13(7)	2.17(7)	3.290(8)	79.0

Symmetry codes: (i) = 1 − x, −1 − y, 2 − z; (ii) = x, y, z; (iii) = 1 − x, −y, 2 − z.

The intramolecular hydrogen-bonds involved in O2–H2···O3 and O4–H2A···O1 generate two graph-set descriptor S(8) motifs (Figure 5, Table 2) [15]. The intramolecular contact distances between the phenolic and ethereal oxygen atoms O1···O2 is 2.971(7) Å [103.7(3)°], and the distance for O1···O4 is 2.778(6) Å [109.1(3)°]. This result shows that the derivative maintains the cone conformation.

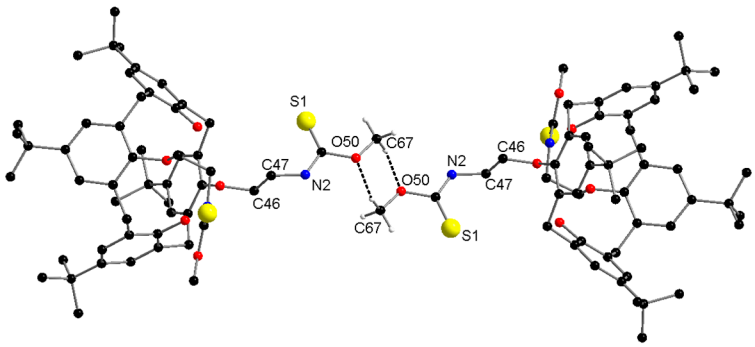


Figure 4. Dimers of compound (**4**). The methanol solvent molecule and H atoms not involved in the intermolecular interactions have been omitted for clarity.

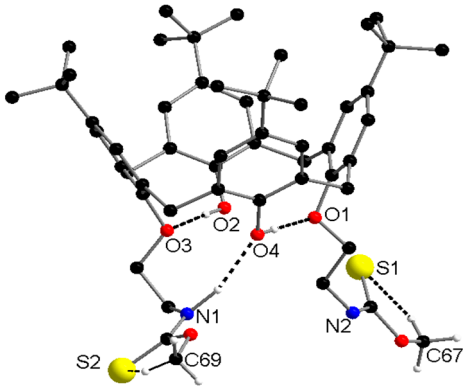


Figure 5. View of intramolecular interactions in compound (**4**). The H atoms not involved in the intermolecular interactions and the solvent methanol molecule have been omitted for clarity.

The intramolecular interactions involved in C69-H69A···S2 and C67-H67A···S1 generate graph-set descriptor S(5) motifs (Figure 5, Table 2). The three-dimensional supramolecular network is reinforced by C-H···π interactions [16]. The inclusion of the methanol molecule is due to favorable C1S-H1S1···Cg2 interactions. The calixarene accommodates the methanol molecule between the channels (Figure 6, Table 2). A similar inclusion compound has been observed in tetraethyl *p-tert*-butylcalix[4]arene tetracarbonate in which one acetonitrile molecule lies within the cavity [10]. Additionally, N-H···π interactions generate N2-H2N···Cg4 intermolecular interactions that connect the calixarenes (Figure 6, Table 2).

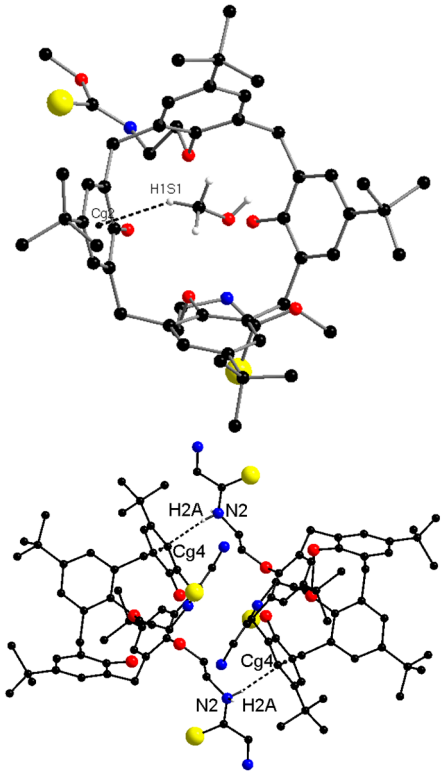


Figure 6. View of intermolecular interactions in compound (**4**): (**top**) Cavity and a methanol molecule through interaction of C-H···π. (**bottom**) N-H···π interactions. The H-atoms not involved in the intermolecular interactions have been omitted for clarity.

3. Materials and Methods

3.1. Sample Preparation

The compound 25,27-bis(aminoethoxy)calix[4]arene (**2**) was chosen as the starting material. It can be readily obtained in two steps from p-tert-butylcalix[4]arene (**1**), by the reaction with bromoacetonitrile and the reduction of the cyano-group with $LiAlH_4$ [2] (see Scheme 1).

We performed the transformation of (**2**) into the corresponding diisothiocyanate derivative (**3**) with excellent yields using thiophosgene [17,18]. The reaction was conducted in a round-bottom flask with 4.08 mmol of (**2**), 8.2 mmol of barium carbonate, and 20 mL of dichloromethane. The mixture was stirred at room temperature in a closed system. Then, 4.1 mmol of thiophosgene was added to the closed system, and the new mixture was stirred at room temperature for 24 h. After this reaction period time, dichloromethane was added and the mixture was filtered; the filtrate was extracted with water in a separating funnel. The organic phase was collected and dried with sodium sulfate, filtered, and evaporated under vacuum [2]. The resulting yellowish solid was purified using a chromatographic column with dichloromethane as the mobile phase.

5,11,17,23-tetra-tert-butyl-25,27-bis(cyanomethoxy)-26-28-dihydroxycalix[4]arene (**1**). White solid, yield 80%. Melting point: 265–267 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C), δ 7.12 (s, 4H, Ar**H**), 6.73 (s, 4H, Ar**H**), 5.55 (s, 2H, ArO**H**), 4.81 (s**,** 4H, OCH_2CN**),** 4.25 (d, 4H, *J* = 13.4 Hz, $ArCH_2Ar$), 3.47 (d, 4H, *J* = 13.4 Hz, $ArCH_2Ar$), 1.33 (s, 18H, $C(CH_3)_3$), 0.88 (s, 18H, $C(CH_3)_3$).

5,11,17,23-tetra-tert-butyl-25,27-bis(aminoethoxy)-26-28-dihydroxycalix[4]arene (**2**). White solid, yield 65%. Melting point: 222–224 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C), δ 7.04 (s, 4H, Ar**H**), 6.98 (s, 4H, Ar**H**), 4.35 (d, 4H, *J* = 12.9 Hz, $ArCH_2Ar$), 4.07 (t, 4H, *J* = 4.7 Hz, OCH_2CH_2N), 3.39 (d, 4H, *J* = 12.9 Hz, $ArCH_2Ar$), 3.30 (t, 4H, *J* = 4.7 Hz, OCH_2CH_2N), 1.24 (s, 18H, $C(CH_3)_3$), 1.11 (s, 18H, $C(CH_3)_3$).

5,11,17,23-tetra-tert-butyl-25,27-bis(isothiocyanoethoxy)-26-28-dihydroxycalix[4]arene (**3**). White solid, yield70%. Meltingpoint: 259–261°C. ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C), δ 7.06 (s, 4H, Ar**H**), 6.93 (s, 2H, ArO**H**), 6.82 (s, 4H, Ar**H**), 4.27 (d, 4H, *J* = 13.1 Hz, $ArCH_2Ar$), 4.26–4.15 (m, 8H, OCH_2CH_2NCS), 3.39 (d, 4H, *J* = 13.1 Hz, $ArCH_2Ar$), 1.29 (s, 18H, $C(CH_3)_3$), 0.97 (s, 18H, $C(CH_3)_3$).

Finally, single-crystals were obtained from a solution of (**3**) (0.6 mmol) in boiling chloroform (0.5 mL) with hot methanol added dropwise (1 mL). This solution was left for one week, at which point needle crystals were observed and dried. The product that was obtained corresponded to 5,11,17,23-tetra-tert-butyl-25,27-di[acidcarbamothioic-n-ethoxy-methyl-ester]-26,28-dihydroxy calix[4]arene (**4**). The reaction yield was very low. The mechanism of step (d) is similar to the one reported by Katrtizky et al. [19].

3.2. Single Crystal X-ray Diffraction

H atoms of the N1 and N2 were found in difference Fourier maps and refined freely. All other H atoms were positioned geometrically and treated as riding atoms, with C-H = 0.97–0.93 Å and O-H = 0.82 Å (Hydroxyl). Displacement factors were taken as $U_{iso}(H) = 1.2U_{eq}$ (C), $U_{iso}(H) = 1.5U_{eq}$ (C), and $U_{iso}(H) = 1.5U_{eq}$ (O). The crystal data, data collection, and refinement are summarized in Table 3. Data collection: Bruker SMART (BRUKER 1996, Madison, WI, USA); cell refinement: Bruker SAINTPLUS V6.02 (BRUKER 1997); data reduction: Bruker SHELXTL V6.10 (BRUKER 2000); program used to solve the structure: SHELXS97 (Sheldrick, 1990, Madison, WI, USA); program used to refine the structure: SHELXL97 (Sheldrick, 1997, Stuttgart, Germany) [20,21]. Molecular graphics: DIAMOND (Brandenburg, 1999, Bonn, Germany); software used to prepare the material for publication: PLATON (Spek, 2003, Utrecht, The Netherlands) [22,23]. Complete crystallographic data have been deposited with the Cambridge Crystallographic Data Centre, CCDC 1469895. These data can be obtained free of charge from the Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

Table 3. Crystal data and structure refinement parameters.

Empirical Formula	**$C_{52}H_{70}N_2O_6S_2$, CH_4O**
Formula weight	915.31
Crystal size (mm^3)	$0.4 \times 0.3 \times 0.09$
Crystal system, Space group	Triclinic, P-1
a (Å)	12.571(3)
b (Å)	14.759(3)
c (Å)	16.835(3)
α (°)	67.08(3)
β (°)	68.96(3)
γ (°)	78.37(3)
Volume ($Å^3$)	2678.1(12)
Z	2
Temperature	298 K
ρ calculated/$g{\cdot}cm^{-3}$	1.135
μmm^{-1}	0.148
hkl range	−13/14, −17/17,−20/20
θ range (°)	3.5–25.0
Reflections collected	35842
Unique reflections (R_{int})	9405 [0.111]
Observed data (I > 2σ (I))	9405
R [(F^2 > 2σ (F^2))	0.1124
w$R(F^2)$	0.2077
S = GooF	1.34
Parameters	603
Δρmax, Δρmin	0.77 e $Å^{-3}$, −0.70 e $Å^{-3}$

3.3. Raman and Mass Spectroscopy

The Raman spectra in selected crystals were recorded in the frequency range between 150 and 3500 cm^{-1} using a micro-Raman Renishaw system 1000 (Barueri, SP, Brazil) equipped with a Leica-DMLM microscope (Barueri, SP, Brazil). The spectra data were collected at room temperature with a laser line of 633 nm and a laser power of 1 mW. The spectra of the samples are uniform throughout the scanned region of single crystals.

The ESI-MS experiments were performed on a Mass spectrometer LC/MSD-TOF (2006) Agilent Technologies (Santa Clara, CA, USA) with capillary voltage positive of 4 KV, fragmentor of 215 V, gas temperature 325 °C with double nebulizer. The sample is introduced into the source through a pumping system Agilent 1100 HPLC (Waldbronn, Germany) using a flow rate of 200 microliter/min of H_2O:CH_3CN 1:1.

4. Conclusions

A new *p-tert*-butylcalix[4]arene derivative has been obtained and characterized by Raman spectroscopy, ESI-MS, and single-crystal X-ray diffraction. The results showed an inclusion compound. Supramolecular arrays produced by different intra and intermolecular interactions, such as hydrogen bonds and (C,N)-H···π interactions, were revealed. Raman analysis and mass spectroscopy confirmed the solved structure based on the obtained molecular weight and the absence of precursor signals on the carbamothioic derivative. The inclusion of a solvent molecule confirms the supramolecular nature of the derivative calix[4]arenes. This work demonstrates the possibility of the inclusion of a compound that is anchored in the cavity of calix[4]arene derivatives, which is crucial for their applications in pharmacology.

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Author Contributions: Silvana Moris and Paul Jara conceived, designed, and performed the experiments; Silvana Moris and Claudio Saitz-Barria analyzed the data and contributed reagents/materials/analysis tools; Antonio Galdámez performed and analyzed the X-ray Diffraction data. All authors wrote and approved the manuscript. Part of this work constitutes the doctoral thesis of Silvana Moris.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Asfari, M.-Z.; Böhmer, V.; Harrowfield, J.; Vicens, J. *Calixarenes 2001*; Springer: Berlin, Germany, 2001; p. 577.
2. Zhang, W.-C.; Huang, Z.-T. Synthesis of 4-tert-butylcalix[4]arenes Bearing two Schiff-Base units at the Lower Rim. *Synthesis* **1997**, *9*, 1073–1076. [CrossRef]
3. Kim, H.J.; Lee, M.H.; Mutihac, L.; Vicens, J.; Kim, J.S. Host-guest sensing by calixarenes on the surfaces. *Chem. Soc. Rev.* **2012**, *41*, 1173–1190. [CrossRef] [PubMed]
4. Gutsche, C.D.; Stoddart, J.F.; Aida, T. *Calixarenes Revisited*; The Royal Society of Chemistry: Cambridge, UK, 1998; pp. 75–77.
5. Ozmen, M.; Ozbek, Z.; Bayrakci, M.; Ertul, S.; Ersoz, M. Applied Surface Science Preparation of Langmuir–Blodgett thin films of calix[6]arenes and *p-tert* butyl group effect on their gas sensing properties. *Appl. Surf. Sci.* **2015**, *359*, 364–371. [CrossRef]
6. Jin, C.; Fukuda, M.; Wu, C. A pyrene-armed hexahomotrioxacalix[3]arene as a multi-sensor via synergistic and demetallation effects. *Tetrahedron* **2015**, *71*, 9593–9597. [CrossRef]
7. Mokhtari, B.; Pourabdollah, K. Applications of calixarene nano-baskets in pharmacology. *J. Incl. Phenom. Macrocycl. Chem.* **2011**, *73*, 1–15. [CrossRef]
8. Bozkurt, S.; Yilmaz, M.; Sirit, A. Chiral Calix[4]arenes Bearing Amino Alcohol Functionality as Membrane Carriers for Transport of Chiral Amino Acid Methylesters and Mandelic Acid. *Chirality* **2012**, *136*, 129–136. [CrossRef] [PubMed]
9. Perrin, M.; Ehlinger, N.; Lecocq, S.; Dumazet, I.; Lamartine, R. Crystal Structures of Two Calix[10]arenes Complexed with Neutral Molecules. *J. Incl. Phenom. Macrocycl. Chem.* **2001**, *82282*, 273–276. [CrossRef]
10. McKervey, M.A.; Seward, E.M.; Ferguson, G.; Ruhl, B. Molecular Receptor. Synthesis and X-ray Crystal Structure of a Calix[4]arene tetracarbonate-acetonitrile (1:1) Clathrate. *J. Org. Chem.* **1986**, *51*, 3581–3584. [CrossRef]
11. Huang, G.; Jiang, D.; Wang, D. Intercalation of thiacalix[4]arene anion via calcined/restored reaction into LDH and efficient heavy metal capture. *J. Mol. Liq.* **2016**, *220*, 346–353. [CrossRef]
12. Arduini, A.; Demuru, D.; Pochini, A.; Secchi, A. Recognition of quaternary ammonium cations by calix[4]arene derivatives supported on gold nanoparticles. *Chem. Commun.* **2005**, 645–647. [CrossRef] [PubMed]
13. Zhao, B.-T.; Liu, Y.; Zhang, H.-Y. Supramolecular architecture of self-adhesive calix[4]arene thiourea derivative by hydrogen bonding and π–π interactions. *J. Mol. Struct.* **2004**, *691*, 25–31. [CrossRef]
14. Collins, E.; Harrisc, S.J.; Owens, M.; Ferguson, G.; Estate, I.; McKervey, M.A. Chemically Modified Calix[4]arenes. Regioselective Synthesis of 1,3-(Distal) Derivatives and Related Compounds. X-ray Crystal Structure of a Diphenol-Dinitrile. *J. Chem. Soc. Perkin Trans.* **1991**, *3*, 2–3. [CrossRef]
15. Berstein, J.; Davis, R.; Shimoni, L.; Chang, N.-L. Patterns in Hydrogen Bonding: Functionality and Graph Set Analysis in Crystals. *Angew. Chem. Int. Ed. Engl.* **1995**, *34*, 1555–1573. [CrossRef]
16. Boeyens, J. The conformation of six-membered rings. *J. Cryst. Mol. Struct.* **1978**, *8*, 317–320. [CrossRef]
17. Fernandez, J.M.G.; Mellet, C.O.; Fuentes, J. Chiral2-Thioxotetrahydro-1,3-O,N-heterocycles and Bicyclic Oxazine-2-t hionest from Carbohydrates. 2. Stereocontrolled Synthesis of Oxazolidine Pseudo-C-nucleosides and bicyclic oxazine-2-thiones. *J. Org. Chem.* **1993**, *58*, 5192–5199. [CrossRef]
18. Torres-pinedo, A.; Saitz, C.; Santoyo-Gonzalez, F. An Efficient Synthesis of Bis(calix[4]arenes), Bis (crown ether)-Substituted Calix[4]arenes, Aza-Crown Calix[4]arenes, and Thiaza-Crown Calix[4]arenes. *Eur. J. Org. Chem.* **2000**, *21*, 3587–3593.
19. Katritzky, A.R.; Bernard, M.K.; Long, Q.-H. The reactions of some alkoxycarbonylisothiocyanates with alcohols, phenols and amines. *Org. Prep. Proced. Int.* **1993**, *25*, 83–90. [CrossRef]
20. Bruker. *SMART, SAINTPLUS V6.02, SHELXTL V6.10 and SADABS*; Bruker Analytical X-ray Instruments Inc.: Madison, WI, USA, 2000.

21. Sheldrick, G.M. *SHELXL-97. Program for the Refinement of Crystal Structures*; University of Göttingen: Stuttgart, Germany, 1997.
22. Brandenburg, K. *DIAMOND. Visual Crystal Structure Information System*; Version 2.1e; Crystal Impact GbR: Bonn, Germany, 1999.
23. Spek, A.L. Single-crystal structure validation with the program PLATON. *J. Appl. Crystallogr.* **2003**, *36*, 7–13. [CrossRef]