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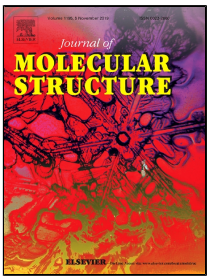

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Graphical abstract

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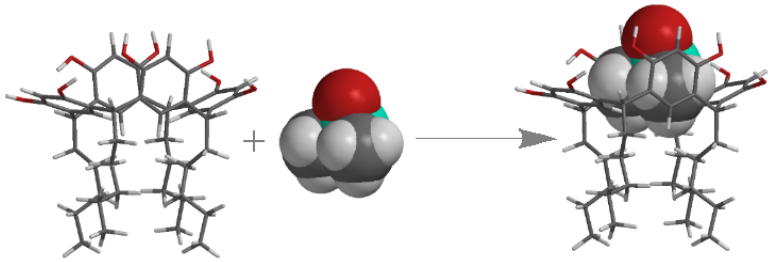

Host-guest inclusion systems of tetra(*alkyl*)resorcin[4]arenes with choline in DMSO: Dynamic NMR studies and X-ray structural characterization of the 1:1 inclusion complex

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Abstract

The host-guest complex of *C*-tetra(*methyl*)calix[4]resorcinarene **(1)**, *C*-tetra(*pentyl*)calix[4]resorcinarene **(2)**, and *C*-tetra(*nonyl*)calix[4]resorcinarene **(3)** with choline in DMSO was examined via dynamic NMR. Under these conditions, only *C*-tetra(*methyl*)calix[4]resorcinarene formed a complex with choline. In order to establish the role of DMSO during the solubilization/complexation process, titration was carried out with resorcinarenes and DMSO in $CDCl_3$. Our careful NMR analysis was based on the assignment of ^{1}H-NMR signals of the resorcinarenes in $CDCl_3$ after the addition of variable amounts of DMSO, which showed an interesting host-guest interaction with *C*-tetra(*pentyl*)calix[4]resorcinarene. With both solvents, it is possible to define stable cone conformational arrangements based on the signals shown in the spectra of all the experiments. The results show the formation of a 1:1 inclusion complex between DMSO and *C*-tetra(*pentyl*)calix[4]resorcinarene. Suitable crystals of *C*-tetra(*pentyl*)resorcinarene in DMSO were characterized through an X-ray crystal structure determination and showed the inclusion of a molecule of DMSO in the cavity of the resorcinarene. The asymmetric unit contains one molecule of water and five molecules of DMSO, and analysis indicated

that resorcinarene prefers a cone configuration (*rccc* conformation) in the solid state. In the crystal array, classical hydrogen bond O-H···O interactions and intermolecular contacts were observed.

Keywords

- Host-guest interaction
- Resorcinarene
- Crown and boat conformation
- Inclusion complex

1. Introduction

The development and use of selective organic cation receptors has been driven by the important roles organic cations play in different processes. Since organic cations are positively charged, a logical way to achieve cation binding is to employ macrocyclic systems that generate electrostatic interactions in the cavities[1]. The host-guest system includes various molecular interactions. Among these are cation-π interactions[2,3], and the binding of hydrogen with guest molecules and different organic solvents[2]. Thus resorcinarenes are known to be artificial receptors for ions and organic molecules. Many possible structural variations lead to potential applications, such as voltammetric sensors[4], dendrimers synthesis[5,6], dyeing of fibers[7,8], NMR solvating agents[9], chemical receptors for molecules and ions[10,11], absorption of heavy metal ions[12], and a stationary phase for HPLC[13], among others. An important use of host-guest systems in *C*-tetra(*alkyl*)calix[4]resorcinarene is as a chemosensor for alkylammonium ions[1,14,15].
The activity of the resorcinarenes as chemosensors is associated with their structure in solution, where macrocyclic compounds may exist in various isomeric states: cone, partial cone, boat, 1,2-alternate, and 1,3-alternate[16,17]. Thondorf and co-workers[18] have demonstrated that resorcinarene systems undergo conformations and conformational interconversions and have established that the general stability of the four conformations in order of stability is cone, partial cone, 1,2-alternate, and 1,3-alternate. Of these isomers, the cone conformer (*rccc*) is the most thermodynamically stable compound. Alternatively, the conformation of resorcinarenes can be rigidified into a cone by linking the hydroxyl groups of the upper rim, which provides a greater degree of preorganization. Resorcinarenes substituted in the lower rim can be in cone conformation in the crystal

state[19,20]. In solution, the isomer (*rccc*) may adopt cone and boat conformations[21,22], which interconvert rapidly at room temperature.[23] studies of the conformational properties of resorcinarenes modified on the lower rim show that the most stable conformer in solution is the cone, and this trend is favored by bulky substituents in the macrocyclic ring[24]. Cone and boat conformations are the most common conformations in the host-guest processes in solution. In addition, the solvent can have an influence on the capacity of the chemosensor, since it can compete with the analyte, as shown in some papers[2,25,26].

Continuing our studies of the structure and properties of the resorcinarene derivatives[25,27,28] in solution, we report the host-guest interaction of representative calix[4]resorcinarenes with choline, as well as the solvent effect (DMSO) and the incidence of the substituents in the process. These interactions were followed by ^{1}H-NMR titration and XRD analysis of a suitable solvate of *C*-tetra(*pentyl*)calix[4]resorcinarene isolated from the reaction mixture, and the interaction of the DMSO with the macrocyclic system was confirmed.

2. Experimental section

2.1. Materials

All the reagents and solvents used in the synthesis of *C*-tetra(*alkyl*)calix[4]resorcinarenes were of analytical grade and used without further purification. Resorcinol (99%), hexanaldehyde (99%), acetaldehyde (99%), decanaldehyde (99%) and hydrochloric acid (37%) were purchased from Merck. A Thermo Fisher Scientific Nicolet iS10 FT-IR spectrometer was employed for recording IR spectra, using KBr pellets. A BRUKER Avance 400 (400.131 MHz for ^{1}H and 100.263 MHz for ^{13}C) was used for recording nuclear magnetic resonance spectra in dimethyl sulfoxide ($(CD_3)_2SO$) and for NMR titration in $CDCl_3$ using tetramethylsilane (TMS) as the internal reference. The chemical shifts are given in δ units (ppm). The melting point was determined with Bibby Scientific Limited Stone, Staffordshire, ST15 0SA, UK equipment and is uncorrected.

2.2. General Synthesis of calix[4]resorcinarenes

The macrocycles were produced according to the procedure used by the research group[23,29,30]. Hydrochloric acid (10 mL) was carefully added to a solution of resorcinol (5.2 mmol) and the respective aldehyde (acetaldehyde, hexanaldehyde, and decanaldehyde, 5.2 mmol) dissolved in a water/ethanol (1:1) mixture. Then the reaction mixture was refluxed and stirred for various periods, depending of the starting aldehyde: 1 h (acetaldehyde), 12 h (hexanaldehyde) and 24 h (decanaldehyde). The precipitate was separated, washed with water/ethanol (1:1) mixture and allowed to dry.

_C_-tetra(*methyl*)calix[4]resorcinarene (1):

Yield: 41,12%; Mp: > 250°C (decomposition). IR(KBr) (cm^{-1}) = 3418 (OH), 2969 (ArCH), 2932-2874 (aliphatic CH), 1612 (C=C). ^{1}H-NMR ($(CD_3)_2SO$), δ, ppm): 1.26 (d, 12H, CH_3), 4.42 (c, 4H, CH), 6.11 (s, 4H, H *ortho* to OH), 6.73 (s, 4H, H *meta* to OH), 8.53 (s, 8H, OH). ^{13}C-NMR ($(CD_3)_2SO$), δ, ppm): 20.3, 29.1, 104.0, 124.8, 126.4, 152.7.

_C_-tetra(*pentyl*)calix[4]resorcinarene (2):

Yield: 75%; Mp: > 250°C (decomposition). IR(KBr) (cm^{-1}) = 3415 (OH), 2928-2857 (aliphatic CH), 1620 (C=C). ^{1}H-NMR ($(CD_3)_2SO$), δ, ppm): 0.85 (t, 12H, CH_3), 1.19 (m, 8H, CH_2), 1.28 (m, 16H, CH_2), 2.03 (m, 8H, CH_2), 4.24 (t, 4H, CH), 6.17 (s, 4H, H *ortho* to OH), 7.16 (s, 4H, H *meta* to OH), 8.76 (s, 8H, OH). ^{13}C-NMR ($(CD_3)_2SO$), δ, ppm): 14.1, 22.4, 27.6, 31.6, 33.1, 34.1, 102.5, 123.2, 124.4, 151.8

_C_-tetra(*nonyl*)calix[4]resorcinarene (3):

Yield: 60%; Mp: > 250°C (decomposition). IR(KBr) (cm^{-1}) = 3258 (OH), 2925 (ArCH), 2853 (aliphatic CH), 1619 (C=C). ^{1}H-NMR ($(CD_3)_2SO$), δ, ppm): 0.83 (t, 12H, CH_3), 1.20 (m, 54H, CH_2), 1.96 (br. s, 8H, CH_2), 4.21 (t, 4H, CH), 6.15 (s, 4H, H *ortho* to OH), 7.07 (s, 4H, H *meta* to OH), 8.88 (br. s, 8H, OH). ^{13}C-NMR ($(CD_3)_2SO$), δ, ppm): 13.8, 22.1, 27.8, 28.8, 28.9, 29.2, 29.2, 29.3, 31.4, 34.2, 102.4, 123.0, 124.3, 151.7.

2.3. X-Ray Structure Determination of 2

Colorless crystals of **2**·5(DMSO)·H_2O were obtained from a dimethylsulfoxide-water(1:1) solution of **2** by slow evaporation at room temperature. The crystals were

removed from the vial and covered with a layer of a viscous perfluoropolyether. A suitable crystal was selected with the aid of a microscope, mounted on a cryoloop, and placed in the low-temperature nitrogen stream of the diffractometer. The intensity data sets were collected at 200 K on a Bruker-Nonius KappaCCD diffractometer equipped with an Oxford Cryostream 700 unit. The molybdenum radiation used was graphite monochromated and enhanced with a MIRACOL collimator. The crystallographic data are presented in Table 1.

The structure was determined using the WINGX package[31] by direct methods (SHELXS-2013)[32] and refined by least-squares against F^2 (SHELXL-2014/7). Compound **2** crystallized with a molecule of water and five molecules of dimethylsulfoxide. Two DMSO molecules exhibited disorder (atoms S(4), O(4), C(4)a and C(4)b, and atoms S(5), O(5), C(5)a and C(5)b), which were treated conventionally by using the PART tool, allowing free refinement of the occupancy factors with the FVAR command. The final values for the occupancy factors were 69.0 and 31.0% for one molecule and 51.0 and 49.0% for the other one. All non-hydrogen atoms were anisotropically refined. Methyl, methylene, methane, and aromatic hydrogen atoms were positioned geometrically and refined by using a riding model, whereas hydrogen atoms of the water molecule and the hydroxyl groups were isotropically refined. Moreover, SADI and DELU restraints were employed for both disordered molecules of DMSO. Additionally, the water molecule was treated with DFIX instructions.

2.4. NMR Titration

For the NMR titration, 18.46 µL DMSO (analytical grade) was added to 800 µL $CDCl_3$ and a ^{1}H-NMR was performed. Increasing amounts of *C*-tetra(*pentyl*)calix[4]resorcinarene were added to the solvent mixture, and after each addition the ^{1}H-NMR spectrum was taken. 25 mg was initially added to 175 mg of resorcinarene.

^{1}H-NMR titrations were done by subsequently adding increasing amounts of the *C*-tetra(*pentyl*)calix[4]resorcinarene (from 0 to 200 mg) in a mixture of DMSO (0.26 mmol) with $CDCl_3$ (800 µL) and recording the spectra after each addition at room temperature.

In the NMR titration with choline, a mixture of 600 µL of DMSO-$_{d6}$ with 10 mg of *C*-tetra(*pentyl*)calix[4]resorcinarene was added to 2 mg of choline and the ^{1}H-NMR spectrum was taken.

3. Results and Discussion

To study the effect of the alkyl substituent in the lower rim and its influence on the binding ability and complexation preferences, we used resorcinarenes with different substituents: *C*-tetra(*methyl*)calix[4]resorcinarene (**1**), *C*-tetra(*pentyl*)calix[4]resorcinarene (**2**) and *C*-tetra(*nonyl*)calix[4]resorcinarene (**3**). These compounds were obtained through the acid-catalyzed cyclocondensation of resorcinol with aldehyde (ethanal, hexanal, and decanal, respectively) in a 1:1 mixture of ethanol:water to reflux in a manner similar to that described in the literature[10,33] (Scheme 1). The products were purified by recrystallization and were characterized using spectroscopic techniques such as FT-IR, ^{1}H-NMR, and ^{13}C-NMR (see the Experimental Section).

Being calixarenes[34], resorcinarenes can assume different conformations, which depend on the rotational disposition of their single bonds[35], the solvents, and the substituents in the lower rim. If the calix[4]resorcinarene is small and non-bulky, such as the methyl group, the observed ^{1}H-NMR spectra show characteristic signals for two conformations: cone and boat[24]. However, if the substituent in the lower rim is bulky, such as the nonyl group, the possibility of forming the boat conformer is very low[16]. Calix[4]resorcinarene systems can be dynamic with respect to solvent interactions, but the cone conformation is retained in solution with aprotic solvents such as DMSO or $CHCl_3$[2].

^{1}H-NMR spectra of synthesized resorcinarenes in DMSO-$_{d6}$ were consistent with the presence of one conformer. In the ^{1}H-NMR spectra of all the compounds, three signals that confirmed the cone conformation could be seen: a signal between 4.00 and 4.50 ppm for the bridge proton and another two in the aromatic zone for H *ortho* and *meta* to OH. These signals are coherent with other analogue macrocycles. ^{1}H-NMR signals in DMSO-$_{d6}$ exhibit a great tendency to retain the cone conformation in solution, which is desirable for molecular recognition processes.

Binding studies

As mentioned above, the macrocyclic cone conformation produced by lower rim substituents and solvents is an important factor in the process of complexation. For this reason, the ^{1}H-NMR titrations described here were performed in DMSO-d_6. Other factors were the good solubility of resorcinarenes **1-3** and the subsequently formed complexes with choline. For all the compounds studied, the ^{1}H-NMR spectra contained signals corresponding to the resorcinarene backbone (depending on the substitution pattern) and a signal between 4.00 and 4.50 ppm which was ascribed to the CH bridge. Hydroxyl protons are sometimes prone to proton exchange with the residual water molecules in DMSO, and they can widen or disappear completely, making them unsuitable for monitoring the binding. During the titrations, the change in chemical shift values was observed not only for the CH bridge signals but also for the choline signal (methyl groups). ^{1}H-NMR spectra of mixtures of choline and **1** were investigated, as depicted in Figure 1. The signals for the aromatic ring protons of **1** shifted slightly downfield (protons in the *ortho* position to the hydroxyl, 0.02 ppm and the *meta* protons to the hydroxyl, 0.06 ppm). This behavior may be due to the greater interaction of the *meta* protons of **1** (lower *rim*) with the methyl groups of choline. This interaction of choline with the bottom of the cavity can be confirmed by the downfield shift of the methylene protons of choline.

After performing the titration experiments, association constants of resorcinarenes with choline were estimated using the HypNMR2008 (v.4.071).20. computer program [36], and the results are shown in Table 2. As can be seen from the calculated association constant values, the binding of choline by **1** showed a constant log β 2.96, which indicates a high degree of affinity with a 1:1 stoichiometric ratio. This is not surprising, since the only structural feature responsible for binding is the structural arrangement of resorcinarene. Thus the cation coordination is possibly dictated by hydrogen bonds and π interactions in the resorcinarene cavity. According to this observation, similar behavior was expected in the coordination process with the other resorcinarenes; however, no effect was observed during the NMR titration.

To understand these results, we evaluated the effect that DMSO can have on the complexation process, so ^{1}H-NMR titration was done between **1**-**3** and DMSO in $CDCl_3$ as a solvent. The results shown in Table 1 indicate a high affinity of **2** with DMSO and for **1** and **3** the formation of a complex was not found. During the titration of receptor **2** with DMSO, we noticed that a signal at 2.55 ppm was shifted to the upper field (0.55 ppm). This signal corresponds to the protons of DMSO (Figure 2) and shows the interaction of **2** with DMSO. The chemical shift variation for protons of methyl groups of DMSO as a function of their concentration is shown in Figure 3. The observed downfield shifts of the guest under conditions of fixed guest and varying host concentrations were carried out using the HypNMR2008 (v.4.071).20. computer program [36] (Figure 2).

Also, macrocyclic ring **2** exhibits a signal shift of its aromatic protons and CH bridge, which allows concluding that the strongest interaction is observed at the bottom of the cavity. After performing the titration experiments, the association constants of **2** with DMSO were estimated using the HypNMR2008 (v.4.071).20. computer program [36], and the results are shown in Table 2 with 1:1 stoichiometry and stability constant log β = 4.88. Analysis of the inclusion complex between **2** and DMSO (Scheme 2) provided the most accurate and detailed information to date on the molecular binding interactions.

Single-Cristal X-Ray Diffraction Analysis

Our attempts to grow single crystals for compounds **1** and **3** were unsuccessful. However, a crystalline sample of **2** was obtained from a dimethylsulfoxide-water (1:1) solution by slow evaporation at room temperature. An X-Ray diffraction determination revealed the structure of the inclusion complex **2**-DMSO (Figure 4), which crystallized with four additional molecules of DMSO and a water molecule. The crystallographic data are shown in Table 2.

The C···C diagonal distances for the resorcinarene skeleton are C(16)···C(56) 5.264(4) Å, C(13)···C(53) 9.416(5) Å, C(36)···C(76) 5.174(5) Å, and C(33)···C(73) 7.453 Å (see Figure 4 and Table 3), giving centroid-to-centroid distances of 6.30 and 7.34 Å, respectively. If the quotient of the shortest centroid-to-centroid distance divided by the longest one is considered, the resultant cone-boat conformation

index (CBConf index) could be informative about the conformation of the macrocycle. The CBConf index ranges from 1.00 for a perfect cone conformation (if both centroid-to-centroid distances are equal) to a value close to 0.50 for a boat conformation (if the longest centroid-to-centroid length is approximately twice that of the shortest). The value of the CBConf index for the crystal structure of complex **2**·DMSO was 0.86, so the geometry of the resorcinarene skeleton could be described as intermediate between cone and boat, although it is closer to a cone conformation. The structures of complexes **2**·^{t}BuOH and **2**·MeOH have previously been determined. The resorcinarene skeletons in these inclusion compounds are held in the cone conformation, with CBConf index values of 0.99 (with centroid-to-centroid distances of 6.82 and 6.87 Å) and 0.98 (with distances of 6.76 and 6.93 Å). The intermediate geometry in **2**·DMSO is the result of three O-H···O hydrogen bonds in the macrocycle with O···O bond distances of O(12)···O(74) 2.752(4) Å, O(14)···O(32) 2.684(4) Å, and O(72)···O(54) 2.792(4) Å (average value 2.74 Å) (see Table 4 for the rest of the hydrogen bond parameters). The longer fourth O···O distance, O(34)···O(52) of 3.074(4) Å, denotes the lack of hydrogen bonding interaction. However, the geometry of the analogous alcohol complexes is set by four hydrogen bonds, with shorter O···O distances of 2.651(3)-2.677(3) Å (average 2.67 Å) for **2**·^{t}BuOH and 2.689(3)-2.712(2) Å (average 2.70 Å) for **2**·MeOH[37].

The structure of complex **2**·DMSO shows a dimethylsulfoxide molecule (S(1), O(1), C(1a) and C(1b)) nestled in the resorcinarene cavity (Figure 4) through CH··· π interactions with *C*(*methyl*)-centroid distances ranging from 3.43 to 3.55 Å (Table 5). The macrocycle is also connected to other molecules of DMSO by O-H···O hydrogen bonds (Figure 5), with O···O distances between hydroxyl groups and the oxygen atoms of dimethylsulfoxide molecules ranging from 2.52(2) to 2.80(2) Å (Table 4). Additionally, these DMSO molecules participate in weak C-H···O hydrogen bonding interactions with C···O separations from 3.31(2) to 3.647(5) Å (Table 4). Finally, the water molecule is bound to the resorcinarene skeleton by hydrogen bonds with O···O distances of 2.844(6) and 2.924(5) Å (Figure 5).

The analysis of the crystal packing reveals that molecules of complex **2**·DMSO are connected by the water molecules, constructing an infinite chain (Figure 6). Simultaneously, the dimethylsulfoxide molecules of the inclusion complex are involved in a zigzag pattern of the resorcinarene skeletons (Figure 7). These two arrangements produce

a layered array, which is sustained by hydrophobic interactions between the *n*-pentyl groups. The DMSO crystallization molecules contribute to the formation of the packing in layers through the C-H···O hydrogen bonding interactions.

Analysis of the crystal structure and the association constants of the inclusion complex of **2** with DMSO and the association constants provided the most accurate and detailed information to date on the molecular interactions that bind choline and DMSO with resorcinarenes. According to these results, the binding of DMSO and **2** is stronger than for choline. The solvent effect in the interactions of choline with **2** consists of the binding of DMSO in the bottom of the cavity and showed an interesting effect on the alkyl chain size in the lower rim of the resorcinarene moiety. An increase in the alkyl chain size (methyl, pentyl, and nonyl) results in a decrease in the affinity of choline with the resorcinarene cavity. So taking into account hydrophobic interactions in the lower rim of resorcinarenes, in **1** these interactions were less than for **2** and **3**, and the cavity was selective for choline. For **2**, these interactions were larger than for **1,** and the cavity was stretched and selective for DMSO, while the alkyl substituents in **3** exhibited the greatest hydrophobic interactions and non-selectivity for choline and DMSO.

Conclusions

A detailed study of the interaction of *C*-tetra(*methyl*)calix[4] resorcinarene (**1**), *C*-tetra(*pentyl*)calix[4]resorcinarene (**2**), and *C*-tetra(*nonyl*)calix[4]resorcinarene (**3**) with choline and DMSO was performed with the help of ^{1}H-NMR titrations. According to the ^{1}H-NMR titration, in DMSO-d_6 choline binds *C*-tetra(*methyl*)calix[4] resorcinarene (**1**) with 1:1 stoichiometry and a stability constant log β = 2.2, while for resorcinarene **2** and **3,** no complex formation was found. With ^{1}H-NMR titration between resorcinarenes and DMSO in $CDCl_3$, the formation of an inclusion complex was observed with resorcinarene **2,** with 1:1 stoichiometry and stability constant log β = 3.2. Analysis of the inclusion complex between **2** and DMSO provided the most accurate and detailed information to date on the molecular binding interactions. Finally, an analysis of the crystal structures of the inclusion complex *C*-tetra(*pentyl*)calix[4]resorcinarene·DMSO provided the most accurate and detailed information about the solvate that was formed, confirming the great affinity of this resorcinarene with the solvent.

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Table 1- Crystallographic data for **2**·5(DMSO)·H_2O

Crystal parameters	Data / Values
CCDC[a] deposition number	1841816
Empirical formula	$C_{58}H_{96}O_{14}S_5$
Formula weight	1177.64
Temperature	200(2) K
Wavelength	0.71073 Å
Crystal system	Monoclinic
Space group	$P2_1/c$
Unit cell dimensions	a = 14.6491(2) Å b = 37.725(3) Å, β= 101.371(1)° c = 11.723(1) Å
Volume	6351(1) $Å^3$
Z	4
D_{cal}	1.232 $g.cm^{-3}$
Absorption coefficient	0.242 mm^{-1}
F(000)	2544
Crystal size	0.40 x 0.28 x 0.12 mm^3
Theta range for data collection	3.04 to 27.00°
Index ranges	-18 to 18 -48 to 47 -14 to 14
Reflections collected	94595
Unique data	13826 [R(int) = 0.112]
Observed data ($I > 2\sigma(I)$]	7243
Goodness-of-fit on F^2	1.044
Final R[b] indices [$I>2\sigma(I)$]	$R1$ = 0.073, w$R2$ = 0.136
R[b] indices (all data)	$R1$ = 0.166, w$R2$ = 0.175
Largest diffraction peak and hole	0.500 and -0.493 e·$Å^{-3}$

[a] Cambridge Crystallographic Data Centre. [b] $R1 = \Sigma||F_o|-|F_c||/[\Sigma|F_o|]$, $wR2 = \{[\Sigma w(F_o^2-F_c^2)^2]/[\Sigma w(F_o^2)^2]\}^{1/2}$

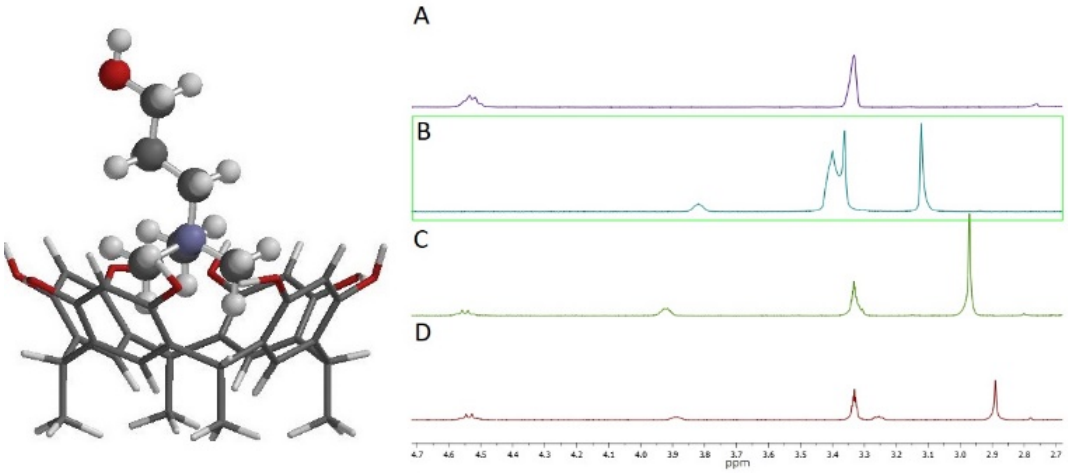
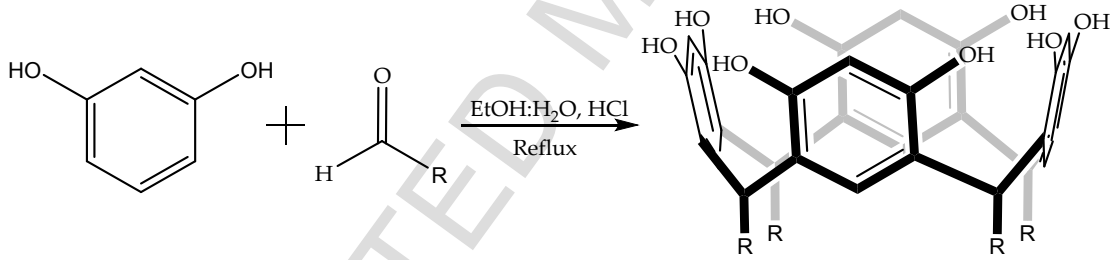


Fig. 1. ^{1}H-NMR spectra (DMSO-d_6, 400 MHz, 298 K) of (A) **1**; (B) Choline; (C) Choline and **1** (0.1:1); (D) Choline and **1** (1:1)



Scheme 1. Synthetic route to C-tetra(alkyl)calix[4]resorcinarene.

Table 2: Constants of **1**, **2** and **3** with DMSO and choline

	Guest	Resorcinarenes		
		(1)	(2)	(3)
Log β	DMSO	-------	4.88	-------
	Choline	2.96	-------	-------

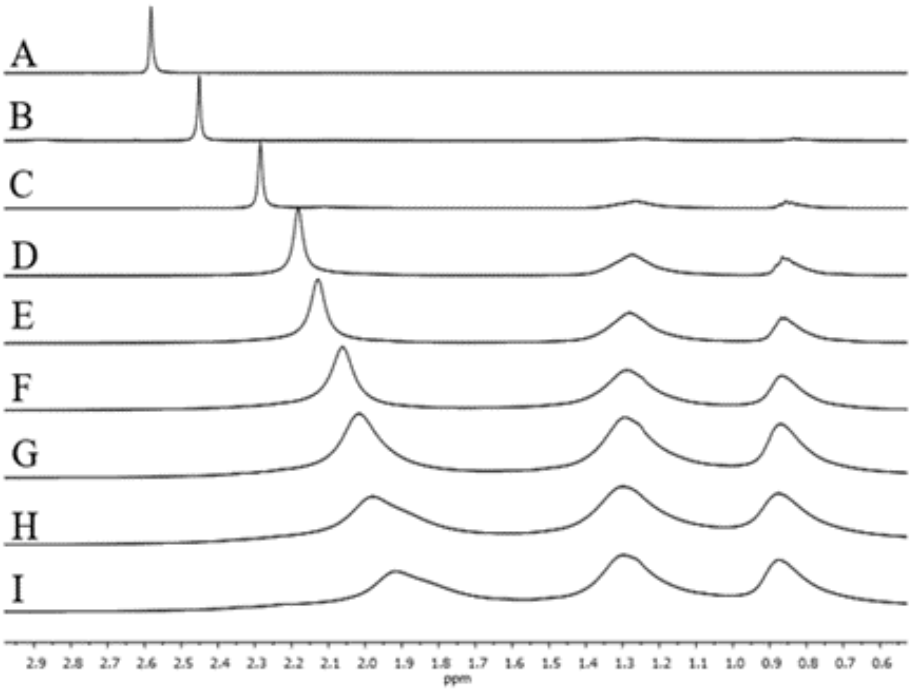
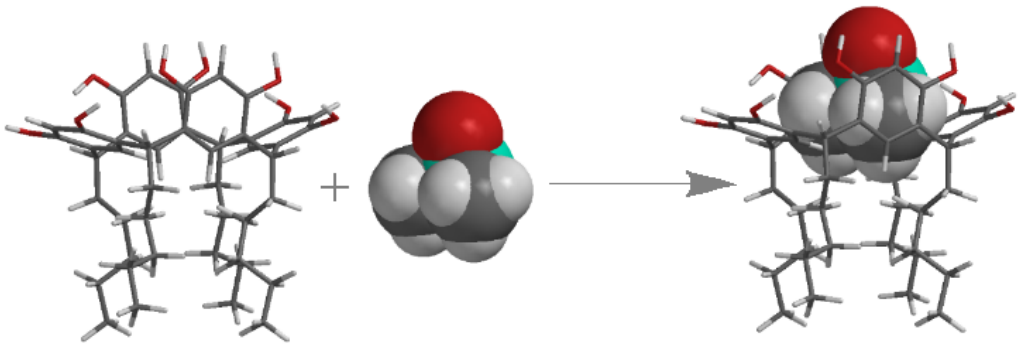


Fig. 2. ^{1}H-NMR titration spectra for DMSO with **2** in $CDCl_3$ as solvent. (A) DMSO-$CDCl_3$, adding quantities successive of **2** in molar ratio of (B) 0.12, (C) 0.25, (D) 0.37, (E) 0.50, (F) 0.62, (G) 0.75, (H) 0.87, (I) 1.0



Scheme 2: Interaction **2** (Host) with DMSO (Guest)

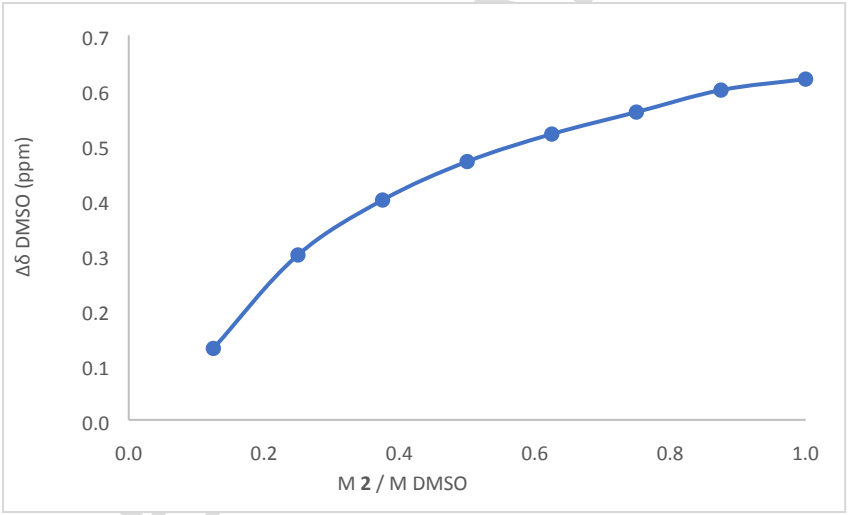


Fig 2. Plot of Δδ DMSO (ppm) for DMSO with **2** in $CDCl_3$ as solvent from ^{1}H-NMR titration

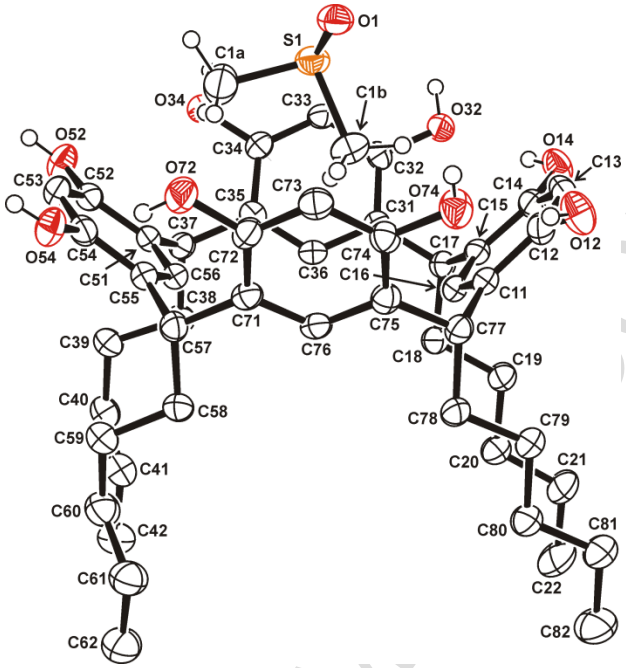


Fig. 4. ORTEP diagram of the complex **2**·DMSO (thermal ellipsoids at the 50% probability level). All hydrogen atoms linked to carbon are omitted for clarity, except those in the DMSO molecule

Table 3. Selected distances for **2**·5(DMSO)·H_2O

Atoms	Length (Å)	Atoms	Length (Å)
C(16)···C(56)	5.264(4)	C(13)···C(53)	9.416(5)
C(36)···C(76)	5.174 (5)	C(33)···C(73)	7.453(5)

Table 1. Relevant hydrogen bonds[a] for **2**·5(DMSO)·H_2O.

D-H···A	D···A/Å	H···A/Å	D-H···A/°
O(12)-H(12)···O(74)	2.752(4)	1.99(4)	162(4)
O(14)-H(14)···O(32)	2.684(4)	1.97(4)	158(5)
O(72)-H(72)···O(54)	2.792(4)	2.00(4)	165(4)
O(52)-H(52)···O(3)	2.696(4)	1.88(5)	166(5)
O(54)-H(54)···O(5)	2.52(2)	1.77(4)	177(5)
O(54)-H(54)···O(5)'	2.80(2)	2.05(4)	171(4)
O(32)-H(32)···O(1)i	2.587(3)	1.72(4)	175(4)
O(34)-H(34)···O(4)i	2.68(2)	1.91(4)	170(4)
O(34)-H(34)···O(4)'i	2.62(3)	1.85(5)	176(4)
O(74)-H(74)···O(2)ii	2.636(4)	1.89(4)	170(5)
O(1)w-H(1)w···O(52)	2.844(6)	2.05(8)	161(7)
O(1)w-H(2)w···O(12)ii	2.924(5)	2.18(9)	149(6)
C(3b)-H(3b)1···O(4)	3.55(2)		
C(3b)-H(3b)1···O(4)'	3.55(4)		
C(4a)-H(4a)2···O(72)	3.31(2)		
C(5a)-H(5a)1···O(3)	3.44(2)		
C(2a)-H(2a)2···O(1)ii	3.486(6)		
C(2a)-H(2a)1···O(32)iv	3.647(5)		
C(2b)-H(2b)3···O(14)v	3.515(5)		

[a]Data for the two positions of disordered DMSO molecules are included. Symmetry code: (i) x, –y + 1/2, z + 1/2; (ii) x – 1, y, z; (iv) x – 1, y, z – 1; (v) x – 1, –y + 1/2, z – 1/2. A = acceptor; D = donor

Table 2. Selected *C*(*methyl*)-centroid distances for the complex **2**·DMSO.

Atoms	Length (Å)
C(1a)···Ct(5)	3.43
C(1b)···Ct(1)	3.45
C(1b)···Ct(3)	3.45
C(1b)···Ct(7)	3.55

Ct(1): centroid for the ring C(11)-C(16). Ct(3): centroid for the ring C(31)-C(36). Ct(5): centroid for the ring C(51)-C(56). Ct(7): centroid for the ring C(71)-C(76).

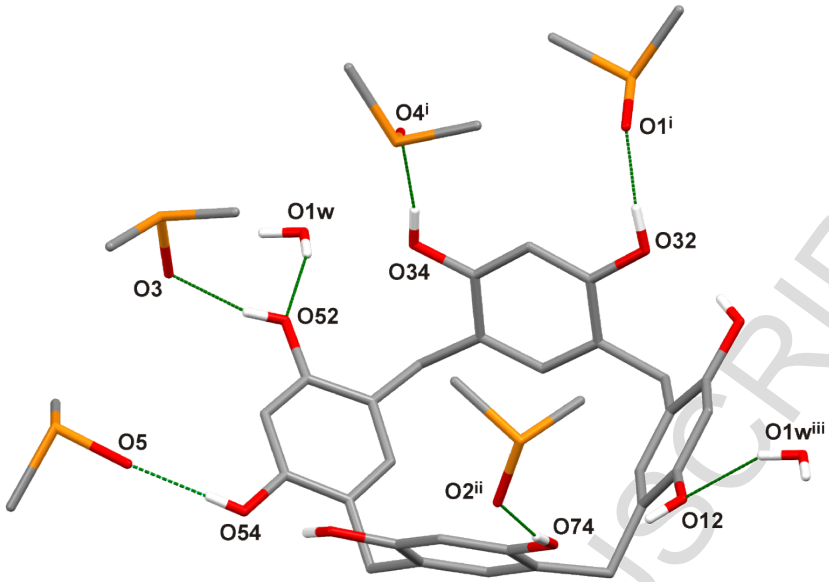


Fig. 3. DMSO and water molecules connected to the resorcinarene skeleton by hydrogen bonding interactions. Symmetry code: (i) x, –y + 1/2, z + 1/2; (ii) x – 1, y, z; (iii) 1 + x, y, z.

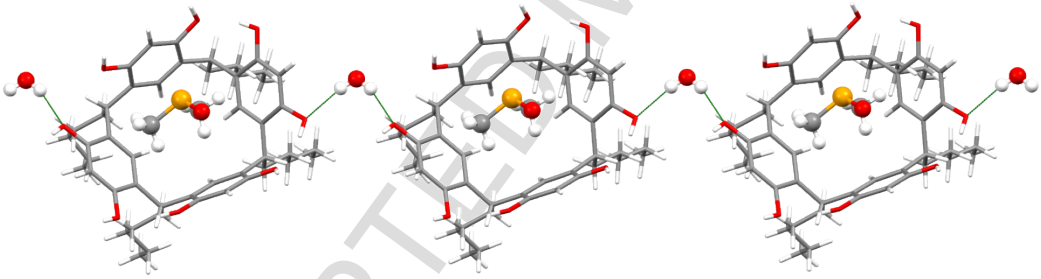


Fig 4. Complexes **2**·DMSO connected by water molecules through hydrogen bonding interactions

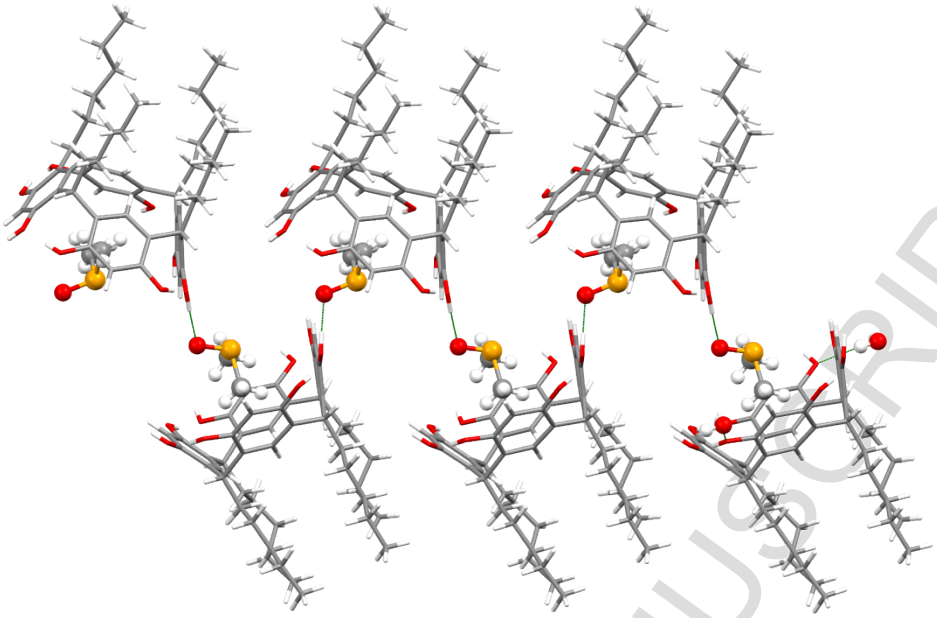


Fig 5. Zigzag pattern of the resorcinarene skeletons in the crystal packing of complex **2**·DMSO

- Alkyl chain affect the complex.
- Crown conformer complex choline
- DMSO affects complexation