Tetrahedron 64 (2008) 7112–7121

Contents lists available at ScienceDirect

Tetrahedron

journal homepage: www.elsevier.com/locate/tet

The synthesis of *p*-*tert*-butyl thiacalix[4]arenes functionalized with secondary amide groups at the lower rim and their extraction properties and self-assembly into nanoscale aggregates

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ARTICLE INFO

Article history:
Received 14 February 2008
Received in revised form 29 April 2008
Accepted 15 May 2008
Available online 17 May 2008

Keywords:
Self-assembly
p-*tert*-Butyl thiacalix[4]arenes
Molecular recognition
Picrate extraction
Dynamic light scattering (DLS)

ABSTRACT

In this work, the synthesis of novel *p*-*tert*-butyl thiacalix[4]arenes functionalized with the secondary amide groups at the lower rim in *cone*, *partial cone*, and 1,3-*alternate* conformations is described. The ability of novel thiacalixarene derivatives to form dimeric associates held together by hydrogen bonds of *p*-*tert*-butyl thiacalixarenes and to recognize metal ions of s (Li^+, Na^+, K^+, Cs^+, Mg^{2+}, Ca^{2+}, Ba^{2+}), p (Al^{3+}, Pb^{2+}), and d (Fe^{3+}, Co^{3+}, Ni^{2+}, Cu^{2+}, Ag^+, Cd^{2+}, Hg^{2+}) elements was investigated by the picrate extraction method and dynamic light scattering (DLS). As was established, the thiacalix[4]arenes investigated are poor extractants for all the metal ions. Meanwhile they self-associate to form dimers of similar size (1.1–2.7 nm) and nanoscale particles consisting of *p*-*tert*-butyl thiacalix[4]arenes and silver cations with hydrodynamic diameters of 70–170 nm.

1. Introduction

The design and synthesis of a variety of host molecules is an interesting topic in the field of supramolecular chemistry[1,2] because of the specified applications of these novel compounds[3] and necessity of the basic research of molecular recognition,[4–6] self-assembly,[7–10] and self-organizing[11,12] processes. These synthetic receptors are irreplaceable as base elements in the development of sensors,[13–15] and as selective carriers in industrial membrane extraction technologies,[4,16,17] highly affine and convertible effectors,[18–20] and catalysts.[21] One of the popular molecular platforms for the design of molecular receptors is the calix[4]arene.[22,23] The advantage of the host molecules consisting of the modification at the upper and lower rim of the appropriate macrocyclic platform[24] and the replacement of original methylene bridges between the aromatic units in calixarenes by sulfur,[24–26] nitrogen,[3,27] and silicon[28] atoms allows varieties of the receptor properties of these molecules over a wide range. Besides, the calix[4]arenes are able to form supramolecular aggregates consisting of two, three or more receptor molecules.[29,30] The ability of the host molecules to self-assemble is caused by H-bonding, van der Waals, π–π, donor–acceptor, and some lipophilic interactions between various substituents.[3,21] The dimeric covalent binding[3,17,31,32] and self-assembling[33–35] associates of the calix[4]arene derivatives are able to selectively include various substrates. This makes it possible to use them as containers for sensing, fixation, and storage of molecules.[17] In this work, we describe the synthesis of novel *p*-*tert*-butyl thiacalix[4]arenes functionalized with secondary amide groups at the lower rim in *cone*, *partial cone*, and 1,3-*alternate* conformations and study the ability of these molecules both to form dimeric associates, which are held together by a seam of hydrogen bonds of *p*-*tert*-butyl thiacalix[4]arenes and to recognize metal ions of s (Li^+, Na^+, K^+, Cs^+, Mg^{2+}, Ca^{2+}, Ba^{2+}), p (Al^{3+}, Pb^{2+}), and d (Fe^{3+}, Co^{3+}, Ni^{2+}, Cu^{2+}, Ag^+, Cd^{2+}, Hg^{2+}) elements as shown by the picrate extraction method and dynamic light scattering (DLS).

2. Results and discussion

2.1. Synthesis of stereoisomers of tetrasubstituted at the lower rim *p*-*tert*-butyl thiacalix[4]arenes containing secondary amide fragments

Thiacalix[*n*]arenes provide a unique opportunity to modify the macrocyclic platform and a wide variation of hydrophilic–lipophilic properties. This is especially important because the selective

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0040-4020/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tet.2008.05.057

modification at the upper rim of a macrocyclic platform by suitable heteroatom groups often increases the efficiency and selectivity of the linkage for the macrocycles.[26] Thus, the introduction of secondary amide groups at the lower rim of the *p-tert*-butyl thiacalix[4]arenes **1**–**5** should result in a decrease of both n-donor ability and steric congestion of the amide fragments.[36,37] This leads to an increase in the efficiency of the binding of p and d metal cations.[36,37] Meanwhile, the lesser electron donation properties of the carbonyl fragments should result in a change of the binding effectiveness toward alkali and alkaline earth metal cations.[38] The receptor molecules substituted with amide containing groups are able to form intra and/or intermolecular hydrogen bonds between H-donating NH-fragments and carbonyl groups.[39,40]

It is very difficult to predict the influence of the association of the secondary amide fragments on the receptor properties of *p-tert*-butyl thiacalix[4]arenes functionalized with amide groups at the lower rim in three conformations owing to the influence of two factors, namely, the competition of NH-fragments with the metal cations for the lone pair of the carbonyl groups and the spatial preorganization of the amide groups.

There are two approaches to obtain stereoisomers of tetraamides on the basis of thiacalix[4]arene **1** described in the literature:

- direct interaction of the initial macrocycle **1** with an appropriate alkylation agent (Fig. 1a);[41,42]
- modification of thiacalix[4]arene based tetraether stereoisomers (Fig. 1b).[43,44]

The first approach makes it possible to significantly shorten the synthetic path to the target compound but requires special selection of experimental conditions to obtain a certain stereoisomer for each alkylation agent. In addition, collateral reactions may occur when thiacalix[4]arenes with secondary amide groups are obtained. We have therefore chosen the two-stage strategy for synthesis of thiacalix[4]arene derivatives containing amide functions. In the first step, the initial macrocycle **1** was alkylated with bromoethylacetate in the presence of the alkali metal carbonates, which determined the appropriate conformation (*cone*, *partial cone* and 1,3-*alternate*) of the thiacalix[4]arene macrocycle. In the second step, the stereoisomers of tetraesters **2** obtained were modified to the corresponding *p-tert*-butyl thiacalix[4]arene derivatives.

The capability of the receptor to bind a substrate is defined by the spatial location of the binding site and by its chemical nature. The relative position of the amide groups of *p-tert*-butyl thiacalix[4]arene derivatives is defined by the conformation of the

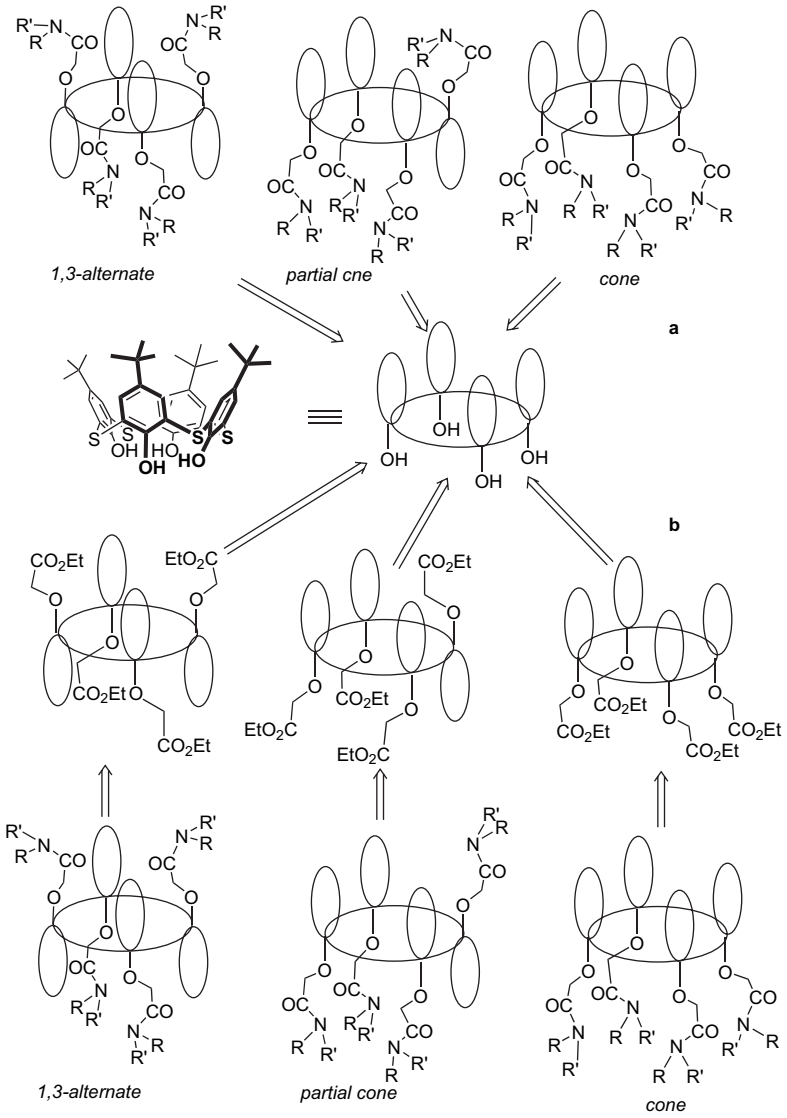


Figure 1. Scheme of synthesis of amide stereoisomers on the basis of thiacalix[4]arene.

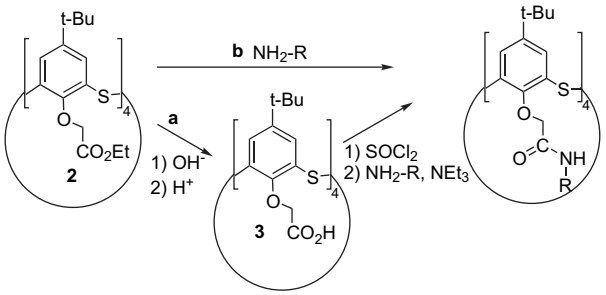


Figure 2. Synthetic approaches to the synthesis of amides on the basis of thiacalix[4]arene.

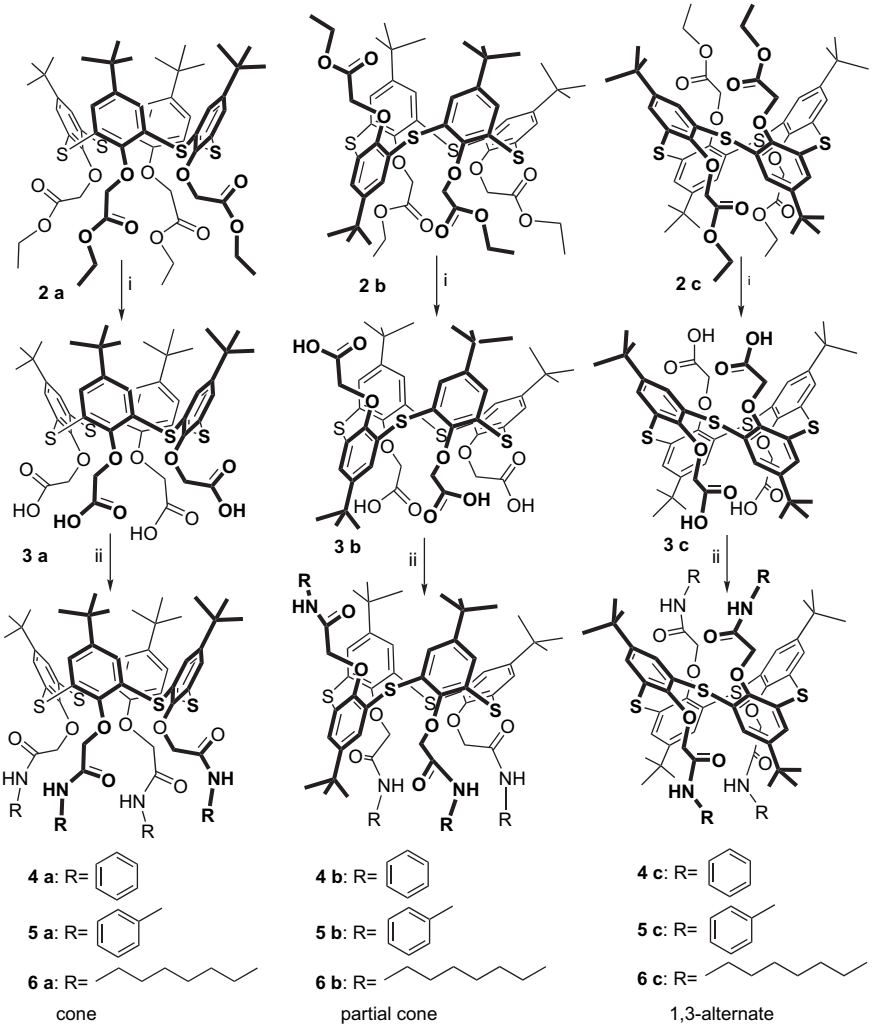
macrocycle ring. The variation of different substituents at the nitrogen atom of the amide groups (Fig. 1, R, R′) provides the possibility to change π-donor ability and steric capacity of amide groups, as well as the acidity of the amide protons (in the case of the secondary amides). Additional centers coordinating the substrate can also be incorporated in the fragments R and R′ (Fig. 1).

It is known that the receptors, which effectively bind groups of cations show low selectivity toward individual cations.[45] This is true also for tertiary amides based on *p-tert*-butyl thiacalix[4]arene, which are effective receptors for metal cations.[41,46] However, it should be mentioned that the secondary amide fragment is the less effective π-donor than the tertiary amide.[45] Thus, the substitution of the tertiary amide group of the thiacalix[4]arene derivative with a secondary one may reduce the efficiency of cation binding. It can be assumed that, the secondary amides on the basis of *p-tert*-butyl thiacalix[4]arene (Fig. 1, R=H) will show selective binding of selected metal cations. The introduction of different substituents to the amide group will give thiacalix[4]arene derivatives, which differ in their π-donor and lipophilic abilities.

To obtain the amides on the basis of the *p-tert*-butyl thiacalix[4]arene from precursors **2** two approaches can be used: (a) the hydrolysis of the stereoisomers of tetraethers **2** to appropriate tetraacids **3** followed by their conversion to chloroanhydrides and then to amides in the presence of a base to neutralize the educed HCl[47] and (b) direct interaction of appropriate amines with tetraethers **2**[48] (Fig. 2).

Three isomeric acids **3**[49] were transformed to corresponding chloroanhydrides by boiling in $SOCl_2$ (see Scheme 1). Tetraamides **4**–**6** were obtained by interaction of a number of primary amines (aniline, benzylamine, and *n*-octylamine) with chloroanhydrides of tetraacid stereoisomers **3** in the presence of triethylamine in methylene chloride. Then they were isolated by recrystallization from a mixture of ethanol and methylene chloride. The reaction yields ranged from 72 to 94% (Table 1).

^1H and ^{13}C NMR spectra of the compounds obtained corresponded to the structure of the stereoisomers of thiacalix[4]arene tetraamides. It should be emphasized that the adsorption band of associated amide group (3300–3250 cm^{-1}) was present in the IR



Scheme 1. Reagents and conditions: (i) LiOH, H_2O/THF; HCl; (ii) $SOCl_2$, reflux; RH, NEt_3,CH_2Cl_2, rt.

Table 1
Compound yields **4**–**6** (%)

	4	5	6
cone	94	90	75
partial cone	92	90	76
1,3-*alternate*	90	89	72

Table 2
Yields of products in the aminolysis reaction of the esters **2** (%)

Compound, R=	*cone*	*partial cone*	1,3-*alternate*
6, C_8H_{17}	95	86	89
7, $C_{12}H_{25}$	92	91	93
8, $C_{18}H_{37}$	92	96	81

spectra of all the conformers of the compounds **4**–**6**. The peak of molecular ion was also found in the mass spectra of the compounds **4**–**6**.

To reduce the steps in the synthetic path to the target products, we have investigated the synthesis of amides on the basis of thiacalix[4]arene by the aminolysis of the stereoisomers of appropriate tetraethers **2** (Scheme 2, Fig. 2). For carbon acid amides, this is a classical reaction of organic chemistry.[50] However, it should be mentioned that the reactivity of functional groups in macrocyclic compounds often dramatically differs from that of analogs.[45] We investigated the interaction of the stereoisomers of tetraethers **2** with primary aliphatic amines (*n*-octyl-, *n*-dodecyl-, and *n*-octadecylamine) in the presence of ammonium chloride.

The yield of target compounds obtained by aminolysis depends on the temperature of the reaction mixture and on the excess of the primary amine (Scheme 2). From the room temperature up to 100 °C, no changes in the reaction mixture composition were observed. Increasing the temperature up to 150 °C and the use of the 5-fold excess of the amine resulted in the formation of the macrocycles **6**–**8** with high yields of 81–96% (Table 2). With the lesser excess (to two amine equivalents per each ester group) or higher temperature inseparable mixture of the products was obtained. The yields of the compounds **6** obtained by the aminolysis of tetraethers **2** with *n*-octylamine were found to be higher than those of the two-stage synthesis of these compounds (Table 2).

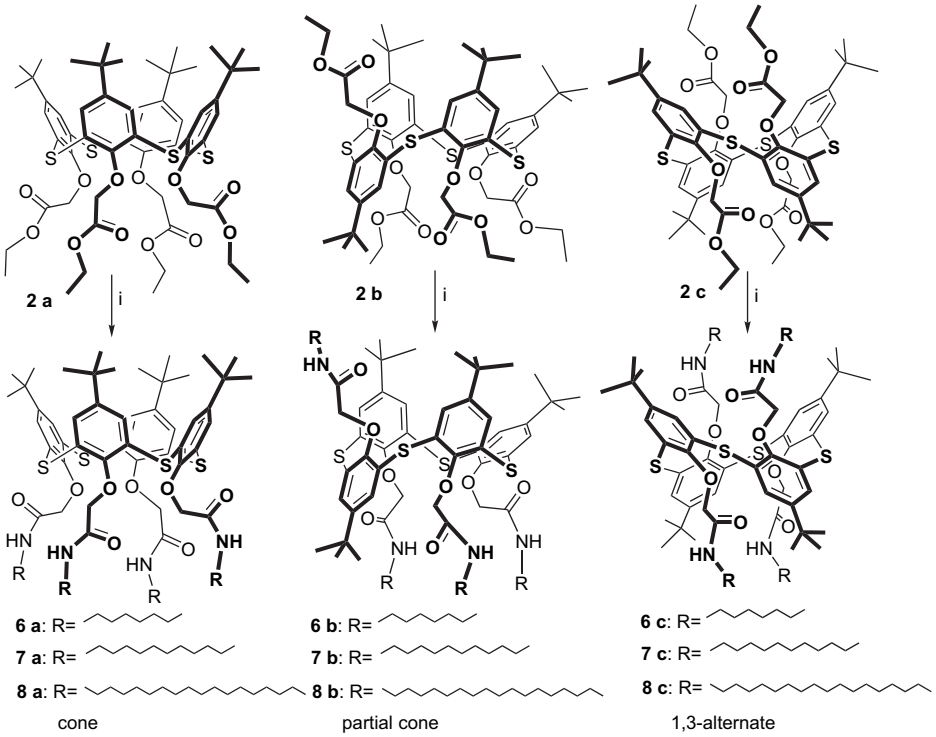
The synthesis of tetraamides on the basis of thiacalix[4]arene by aminolysis of the stereoisomers of tetraethers **2** has been already described in the works of Lhotak group.[43,44] The interaction of the stereoisomers of tetraethers **2** with a range of aliphatic diamines led to the products of the intra-molecular cyclization. The method of aminolysis we suggest has some advantage over that published by Lhotak group,[43,44] i.e., higher yields of the target products (81–96%) and simpler treatment of the reaction mixture. Individual products were isolated by washing the reaction mixture with the water/ethyl alcohol mixture. Nevertheless, it should be mentioned that the use of labor-intensive procedure of the reaction mixture treatment as well as lower yields of the target products in Lhotak's investigation can be related to the use of bifunctional amines as initial compounds.

The method proposed in this work for the synthesis of tetraamides on the basis of *p*-*tert*-butyl thiacalix[4]arene can be used only for the primary amines, which act as active nucleophiles. The side reactions under rather severe conditions of aminolysis (150 °C) prevent from the use of amines containing reactive functional groups in the side chains in the aminolysis of the stereoisomers of tetraethers of thiacalix[4]arene **2**.

The structure and the composition of the amides on the basis of thiacalix[4]arene obtained in the present work were determined by elemental analysis and by ^{1}H and ^{13}C NMR spectroscopy, IR-spectroscopy, and mass-spectrometry.

The spectral characteristics of the tetraoctylamides **6** obtained by the aminolysis of the stereoisomer of the tetraether **2** and synthesized from tetraacids via chloranhydride **3** are similar, and hence the conformation of the macrocycle ring does not change under conditions of aminolysis of tetraether **2** with *n*-octylamine. The attribution of the macrocycle ring conformation of amides **7** and **8** can be made by the comparison of their ^{1}H NMR spectra with those of the amides **6**.

Considering the ^{1}H NMR spectra of the compounds **6**–**8** in more detail, for all the three compounds (*cone* conformation) the protons



Scheme 2. Reagents and conditions: (i) RNH_2, NH_4Cl, 150 °C.

Table 3
Percent of extraction (%E) of metal ions by conformational isomers of the thiacalix[4]arene derivatives **4**–**8**

	Ag^{+}	Li^{+}	Na^{+}	K^{+}	Cs^{+}	Mg^{2+}	Ca^{2+}	Ba^{2+}	Al^{3+}	Fe^{3+}	Ni^{2+}	Cu^{2+}	Co^{3+}	Pb^{2+}	Hg^{2+}	Cd^{2+}
Absorption with CH_2Cl_2	4	1	2	1	1	1	0	1	6	28	5	3	5	6	10	5
cone-**4**	6	1	0	3	2	4	1	2	7	25	6	5	4	5	10	8
partial cone-**4**	4	1	2	1	1	2	1	2	6	33	5	8	7	5	9	5
1,3-*alternate*-**4**	11	3	5	1	4	4	2	2	9	36	8	9	9	8	13	9
cone-**5**	8	1	1	1	2	2	3	2	7	25	5	6	5	4	10	5
partial cone-**5**	5	1	1	1	2	2	1	1	6	27	5	5	4	5	10	4
1,3-*alternate*-**5**	7	1	1	1	1	2	1	1	5	31	5	6	5	6	12	6
cone-**6**	11	1	1	5	2	1	1	1	6	29	4	5	5	6	10	5
partial cone-**6**	8	1	1	2	1	3	4	3	7	30	8	7	7	6	9	4
1,3-*alternate*-**6**	22	9	11	8	10	11	8	9	21	38	21	19	22	21	22	17
cone-**7**	11	1	1	2	1	4	1	1	4	27	3	5	5	6	13	5
partial cone-**7**	10	2	1	1	1	5	3	3	9	27	5	8	7	7	9	4
1,3-*alternate*-**7**	18	2	3	3	3	7	5	3	14	29	8	10	10	11	17	10
cone-**8**	36	35	25	30	25	47	30	33	48	54	52	49	38	52	32	53
partial cone-**8**	3	3	1	2	1	3	2	2	8	28	6	7	8	7	16	9
1,3-*alternate*-**8**	16	5	8	6	4	7	4	4	15	37	12	10	11	13	19	14

Extraction condition: $[L]_{org.,init}=2.5\times10^{-3}$ M, $[MPic]_{aq,init.}=2.32\times10^{-4}$ M.[46]

of the *tert*-butyl groups and those of aliphatic radicals in the amide groups (excluding the protons of the methylene groups at the nitrogen atom, which are shown as multiplet at 3.25 ppm) give a set of signals from 0.8 to 1.7 ppm. The singlet at 4.1 ppm corresponds to the oxymethylene fragment of the substituents. The aromatic protons of aryl groups of the macrocycle give a singlet at 7.54 ppm. The triplet at 7.8 ppm corresponds to the protons of the amide groups.

IR spectra of the compounds 1,3-*alternate*-(**6**–**8**) are similar to each other. There are absorption bands of carbonyl groups (1649–1654 cm^{-1}), of associated and none-associated amide protons and absorption bands C–O–C (1267 cm^{-1}) as well.

^{1}H NMR and IR spectra of the compounds *partial cone*-(**7** and **8**) and *cone*-(**7** and **8**) are also similar to those of appropriate *partial cone*-**6** and *cone*-**6** stereoisomers. Thus, the identity of the spectral characteristics of the stereoisomers of tetradodecyl- and tetraoctadecylamides **7** and **8** with those of tetraoctylamides makes it possible to conclude that the interaction of the stereoisomers of tetraethers **2** with *n*-dodecyl- and *n*-octadecylamine does not lead to the changes in the macrocycle conformation. Summarizing the results, nine new derivatives of thiacalix[4]arene were obtained with high yields by one-stage synthesis from the stereoisomers of the tetraethers of thiacalix[4]arene **2**.

2.2. Picrate extraction method, the percents of extraction, extraction constants log K_{ex}, and the complex stoichiometry

The abilities of the *p*-*tert*-butyl thiacalix[4]arene tetrasubstituted with the secondary amide fragments in three conformations to molecular recognition of alkaline, alkaline earth metal ions, and p and d elements were estimated using the picrate extraction method. This method is widely used for the investigation of complexion properties of the synthetic receptors toward metal cations[46,51,52] and includes the determination of the degree of extraction by host molecules from water into an organic phase.

The alkaline (Li^{+}, Na^{+}, K^{+}, Cs^{+}), alkaline earth (Mg^{2+}, Ca^{2+}, Ba^{2+}) metal cations, and p (Al^{3+}, Pb^{2+}) and d (Fe^{3+}, Co^{3+}, Ni^{2+}, Cu^{2+}, Ag^{+}, Cd^{2+}, Hg^{2+}) elements were chosen as guests because of their biochemical significance and/or toxicity properties.[53,54] The degree of guest extraction by the *p*-*tert*-butyl thiacalix[4]arenes **4**–**8** functionalized with secondary amide substituents as well as the extraction constants and the stoichiometry of the silver cation–calixarene complexes in organic phase were determined as described below. The influence of lipophilic alkyl and aryl substituents on the binding efficiency toward metal cations was also investigated.

One can see (Table 3) that all the secondary amides **4**–**8** are very poor extractants for metal cations. The low binding efficiency toward alkaline and alkaline earth metals by *p*-*tert*-butyl thiacalix[4]arene derivatives is related to the poor donor ability of the substituted carbonyl group and strong hydrogen bonding between the protons of NH groups and carbonyl fragments of the amide groups, which compete with cations for the coordination sites near oxygen atoms of the carbonyl and phenolic groups. The latter assumption can be also confirmed by the absorption band of the associated amide groups (3290–3320 s m^{-1}) observed in the IR spectra of all the secondary amides.

Thus, the poor extraction ability of the amides **4**–**8** toward these cations can be explained by the association of secondary amide groups, which compete for coordination with the cation-substrate.

High values of the extraction percent of Fe^{3+} cation for all the investigated receptors can be related to the lipophilic character of the complex formed that promoted the effective extraction of the iron(III) picrate with pure dichloromethane. The percentage of extraction of all the investigated metal ions by secondary amides 1,3-*alternate*-**6**, **8**, and *cone*-**8** (Table 3) strongly differs from those of other thiacalix[4]arenes. The extraction efficiency increases in the range 1,3-*alternate*-**8**<1,3-*alternate*-**6**<*cone*-**8**. Probably these receptors are also able to extract picric acid. This was examined for conformational isomers of the *p*-*tert*-butyl thiacalix[4]arene **4**–**8** tetrasubstituted with phenyl, benzyl, octyl, dodecyl, and octadecyl groups (Table 4).

As shown, 1,3-*alternates*-**6**,**8** and *cone*-**8** are able to extract picric acid from aqueous solution. The extraction efficiency changes in the range 1,3-*alternate*-**6**<*cone*-**8**<1,3-*alternate*-**8** in accordance with the increase of the electron donation properties of substituents and with the individual orientation of the binding site for each stereoisomer.

Based on recent publications,[34,55,56] non-covalent self-assembly promoted by silver cations has received our attention. In the literature,[48] the ability of thiacalix[4]arenes to form ensembles with silver triflate was described. The problem was if the aggregates with S–Ag–S bridging fragments are formed in the conditions of extraction procedure.

Table 4
Percent of extraction (%E) of picric acid by thiacalix[4]arene derivatives **4**–**8**

	4	**5**	**6**	**7**	**8**
cone	5	5	3	6	38
partial cone	5	6	6	6	8
1,3-*alternate*	10	6	18	6	91

Extraction condition: $[L]_{org.,init}=2.5\times10^{-3}$ M, $[MPic]_{aq,init.}=2.32\times10^{-4}$ M.[46]

The extraction constants and the stoichiometry of the complexes consisting of the silver cation and *p-tert*-butyl thiacalix[4]-arenes functionalized with phenyl-**4** and benzyl-**5** groups at the lower rim in *cone*, *partial cone*, and 1,3-*alternate* conformations were investigated by picrate extraction method. As shown, the stoichiometry of complexation for all the receptors does not depend on their configuration and was approximately equal to 1:1. The log K_{ex} values varied from 3.2 to 4.2. This corresponds rather well with the assumption of aggregate formation with S–Ag–S bridges. The most effective configuration of amides **4** and **6** is 1,3-*alternate* and is less for *cone* and *partial cone*. The extraction efficiency for macrocycles-**5** with benzylamide groups decreases in the opposite direction: *cone*, *partial cone*>1,3-*alternate* (Table 5).

The stoichiometry and low extraction constants confirm the assumption that the formation of intra- and intermolecular hydrogen bonding between the amide groups prevents donor ability of the substituted carbonyl groups and the complexes exist with alternating *p-tert*-butyl thiacalix[4]arene molecules and silver cations. One of the possible alternatives[29,30,35] is the system consisting of dimeric associates[57] that are held together by a seam of hydrogen bonds and silver cations.

2.3. Dynamic light scattering

In accordance with the assumptions proposed, the ability of the systems to self-associate and aggregate with silver cations in the organic phase was examined by dynamic light scattering[29,34,58] using the same conditions as picrate extraction. Silver nitrate was used as a substrate and the measurements were carried out 3 h after the solution preparation at 20 °C. The kinetic stability of the systems was proven in repeated measurements under similar conditions after 28 h.

Table 5
Percent extraction (%E), extraction constants log K_{ex}, and stoichiometry complexes of **4**–**6** with silver cation forming in the organic phase

	Percent	Stoichiometry	log K_{ex}
cone-**4**	29	0.9	3.3
partial cone-**4**	10	0.8	3.2
1,3-*alternate*-**4**	29	1.0	4.0
cone-**5**	29	1.2	4.2
partial cone-**5**	26	0.9	4.1
1,3-*alternate*-**5**	35	0.8	3.6
cone-**6**	44	0.8	3.6
partial cone-**6**	51	0.8	3.6
1,3-*alternate*-**6**	60	0.8	4.1

Extraction condition: $[L]_{org.,init}=10^{-4}$–2.5×10^{-3} M, $[MPic]_{aq,init.}=2.32\times10^{-4}$ M.[46]

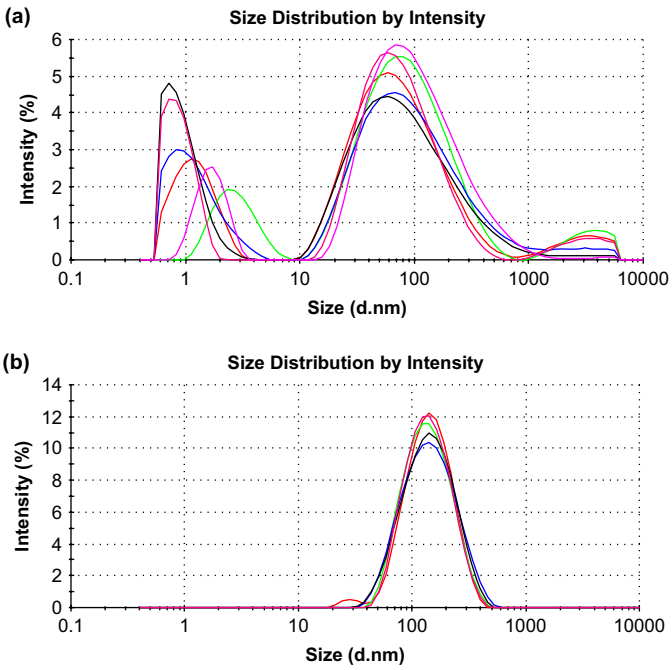


Figure 3. The systems consisting of benzyl-**5** in *partial cone* conformation and silver cations are submitted: (a) through 3 h and (b) through 28 h.

All the *p-tert*-butyl thiacalix[4]arene derivatives with secondary amide fragments except benzyl-**5** (1,3-*alternate*) and dodecyl-**7** (*partial cone*) are able to form dimeric associates of about 1.1–2.7 nm (Table 6). Also, aggregates with a hydrodynamic diameter of more than 1200 nm were observed for the same systems as in the case of peptide molecules.[59] While the self-associates of about 1.1–2.7 nm are counted in different time intervals, the equilibrium is shifted toward dimer accumulation followed by the increase of the dispersion intensity of these particles. Thus, the dispersion intensity (%) of the systems consisting of *p-tert*-butyl thiacalix[4]arenes functionalized with phenylamide fragments in *partial cone* and 1,3-*alternate* conformations changed during 28 h from 37% to 89% and from 72% up to 86%, respectively. Conversely, the part of aggregates with the size of more than 1200 nm and polydispersity index decreased in accordance with predominant formation of the dimers in the system stabilization processes. A similar tendency was observed for the systems consisting of *p-tert*-butyl thiacalix[4]arene derivatives and silver cations, the equilibrium shifted to the preferable formation of the aggregates of about 70–170 nm (Fig. 3).

Table 6
The size of the particles in the system consisting of thiacalix[4]arene derivatives **4**–**8** in CH_2Cl_2 (HPLC), nm, polydispersity index

	Peak mean **1** int, d nm/Peak area **1** int, %		Peak mean **2** int, d nm/Peak area **2** int, %		Peak mean **3** int, d nm/Peak area **3** int, %3		PDI	
	3 h	28 h	3 h	28 h	3 h	28 h	3 h	28 h
cone-**4**		1.9/67.8				1500/32.2		0.595
partial cone-**4**	1.0/37.0	2.7/88.6			4376/63.0	2514/11.4	0.822	0.201
1,3-*alternate*-**4**	1.9/72.5	2.5/86.0			1256/27.5	2786/14.0	0.449	0.225
cone-**5**	1.2/19.7	2.0/26.0	119.0/80.3	296.2/74.0			0.416	0.738
partial cone-**5**		2.7/80.5				1903/19.5		0.339
1,3-*alternate*-**5**								
cone-**6**	0.8/40.9				4897/59.1		1.000	
partial cone-**6**		2.1/13.2		270.3/84.6		4010/2.1		0.540
1,3-*alternate*-**6**	2.2/73.1				2726/26.9		0.512	
cone-**7**		2.0/68.4				1006/31.6		0.578
partial cone-**7**								
1,3-*alternate*-**7**	1.3/7.7	1.1/12.5	303.0/85.0		4144/6.5	5093/87.5	0.421	1.000
cone-**8**		1.8/55.5				3660/44.5		1.000
partial cone-**8**	2.2/11.7		115.0/88.3				0.429	
1,3-*alternate*-**8**	2.7/67.6				2180/37.4		0.674	

Table 7
The size of the particles in the system consisting of thiacalix[4]arenes derivatives **4**–**8** and silver cation in CH_2Cl_2 (HPLC), nm, polydispersity index

	Peak mean **1** int, d nm/Peak area **1** int, %		Peak mean **2** int, d nm/Peak area **2** int, %		Peak mean **3** int, d nm/Peak area **3** int, %		PDI	
	3 h	28 h	3 h	28 h	3 h	28 h	3 h	28 h
cone-**4**		1.5/6.1		124.7/81.6		5016/9.1		0.211
partial cone-**4**	1.6/39.9		215.3/60.1	124.7/100			0.894	0.187
1,3-*alternate*-**4**		1.4/21.7		70.8/69.9	4450/100	4243/8.4	1.000	0.287
cone-**5**	1.3/2.7		70.4/97.3	120.2/100			0.241	0.150
partial cone-**5**	1.5/20.5		117.8/76.0	153.2/100	3346/3.53		0.591	0.189
1,3-*alternate*-**5**	0.8/10.2		145.7/83.3	153.7/98.6	4250/6.4	5277/1.4	0.391	0.247
cone-**6**	1.6/26.0		69.4/74.0	169.5/97.6		5113.3/2.4	0.417	0.229
partial cone-**6**	1.7/8.9		134.0/83.7	150.4/93.7	3985/6.1	5150/2.7	0.211	0.241
1,3-*alternate*-**6**	1.6/41.5		191.0/46.9	88.4/40.5 340.1/60.2	3555/11.3		0.703	0.339
cone-**7**	2.1/35.6		224.2/44.2	120.6/91.8 22.4/8.2	2682/20.2		0.547	0.136
partial cone-**7**	3.1/57.9			121.2/97.9	2743/42.1	4775/2.1	0.493	0.213
1,3-*alternate*-**7**	1.9/1.2		167.0/96.0	149.5/95.0	3490/3.6	4470/5.0	0.488	0.292
cone-**8**	2.8/52.7	2.9/7.50	33.6/19.1	92.0/84.1	3967/28.2	5025/5.9	0.517	0.109
partial cone-**8**	3.5/38.2		635.0/62	91.2/99.6		5290/0.4	0.825	0.133
1,3-*alternate*-**8**	2.2/18.6		152.0/59.8	139.0/99.2	3912/19.3	5560/1.7	0.583	0.190

The formation of nanoscale particles with hydrodynamic diameter of about 70–170 nm, (Table 7) after the addition of silver ions confirms again the aggregation via S–Ag–S bridges. The decrease in the part of the particles of about 1.1–2.7 nm may be due to the aggregation of preliminary formed dimers into the associated structures of about 70–170 nm by a seam of hydrogen bonds and silver cations.

For systems **7** and **8**, the hydrodynamic size of nanoscale particles tends to increase in the order *cone*, *partial cone*, 1,3-*alternate*. It is interesting that the hydrodynamic diameter of the particles containing silver cations and amides **4** and **6** are changed in the opposite direction: 1,3-*alternate*<*cone*, *partial cone*. These results coincide well with picrate extraction characteristics, i.e., increase of log K_{ex} value is accompanied by the decrease in the hydrodynamic size of particles (see Table 7 for benzyl-**5** derivatives in *cone*, *partial cone*, and 1,3-*alternate* conformations).

3. Conclusion

Thus, new *p*-*tert*-butyl thiacalix[4]arenes functionalized with secondary amide groups at the lower rim in *cone*, *partial cone*, and 1,3-*alternate* conformations were synthesized and their receptor properties for metal ions of s (Li^+, Na^+, K^+, Cs^+, Mg^{2+}, Ca^{2+}, Ba^{2+}), p (Al^{3+}, Pb^{2+}) and d (Fe^{3+}, Co^{3+}, Ni^{2+}, Cu^{2+}, Ag^+, Cd^{2+}, Hg^{2+}) elements were studied using the picrate extraction method and dynamic light scattering (DLS). As was established, the thiacalix[4]arenes investigated are poor extractants for all the metal ions. Meanwhile they self-associate to form dimers of similar size (1.1–2.7 nm) and nanoscale particles consisting of *p*-*tert*-butyl thiacalix[4]arenes and silver cations with hydrodynamic diameters of 70–170 nm. It was shown, that the size of the particles consisting of silver cations and dimeric blocks of *p*-*tert*-butyl thiacalix[4]arenes tetrasubstituted at the lower rim depends on the nature of the secondary amide fragment and the conformation of the receptor molecule. The study of the ability of similar receptor structures to form nanoscale aggregates with metal cations in organic phase has recently received increasing attention.

4. Experimental

4.1. General procedure of the synthesis of compounds 4(a–c), 5(a–c), and 6(a–c)

Compounds **3**(**a**–**c**) (1 g, 1.05×10^{-3} mol) were placed into a round-bottom flask and $SOCl_2$ (10 mL, 0.084 mol) was added. The mixture was refluxed for 1.5 h, excess of $SOCl_2$ was removed; remainder was dried under reduced pressure for 2 h. The solution of amine (aniline, benzylamine, octylamine) (33.6×10^{-3} mol) and triethylamine (5 mL, 0.04 mol) in 50 mL of methylene chloride was added. The mixture was stirred at room temperature overnight. The reaction was quenched by addition of 2 M HCl (30 mL). The organic layer was separated, dried (mol. sieves, 3 Å) and evaporated in vacuo. The residue was crystallized from the ethanol/methylene chloride.

*4.1.1. 5,11,17,23-Tetra-tert-butyl-25,26,27,28-tetrakis[(phenylamidocarbonyl)-methoxy]-2,8,14,20-tetrathiacalix[4]arene (cone-**4a**)*

Yield: 1.18 g (90%). Mp: 226 °C. ^{1}H NMR (300 MHz, 373 K, $CDCl_3$) δ 9.41 (s, 4H, NH), 7.57–7.55 (m, 8H, ArH), 7.39 (s, 8H, ArH), 7.19–7.14 (m, 8H, ArH), 7.04–6.99 (m, 4H, ArH), 4.98 (s, 8H, OCH_2CO), 1.14 (s, 36H, $(CH_3)_3C$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 166.5, 157.6, 147.7, 137.1, 135.0, 128.8, 127.9, 124.6, 120.4, 74.9, 34.3, 31.1. IR (KBr) ν_{max} 1265, 1683, 2870, 2962, 3301. MS (ESI): calcd for $[M+Na]^+$ m/z=1275.4, found m/z=1275.6. El. Anal. Calcd for $C_{72}H_{76}N_4O_8S_4$: C, 68.98; H, 6.11; N, 4.47; S, 10.23. Found: C, 68.91; H, 6.01; N, 4.44; S, 10.48.

*4.1.2. 5,11,17,23-Tetra-tert-butyl-25,26,27,28-tetrakis[(phenylamidocarbonyl)-methoxy]-2,8,14,20-tetrathiacalix[4]arene (partial cone-**4b**)*

Yield: 1.18 g (90%). Mp: 277 °C. ^{1}H NMR (300 MHz, 373 K, $CDCl_3$) δ 9.52 (s, 1H, NH), 9.21 (s, 2H, NH), 8.15 (s, 1H, NH), 7.82 (s, 2H, ArH), 7.71 (s, 2H, ArH), 7.64–7.61 (m, 4H, ArH), 7.53–7.06 (m, 20H, ArH), 4.91 (d, J=15.4 Hz, 4H, OCH_2CO), 4.73 (d, J=15.4 Hz, 4H, OCH_2CO), 4.72 (s, 2H, OCH_2CO), 4.61 (s, 2H, OCH_2CO), 1.39 (s, 9H, $(CH_3)_3C$), 0.94 (s, 9H, $(CH_3)_3C$), 0.89 (s, 18H, $(CH_3)_3C$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 166.1, 165.5, 157.2, 149.0, 148.6, 148.0, 137.2, 137.0, 136.8, 136.7, 135.8, 132.8, 132.2, 129.0, 128.8, 127.9, 127.3, 127.1, 126.3, 125.1, 124.5, 124.4, 120.5, 120.0, 119.4, 73.9, 34.2, 31.3, 30.7. IR (KBr) ν_{max} 1260, 1694, 2870, 2906, 2961, 3295. MS (ESI): calcd for $[M+Na]^+$ m/z=1275.4, found m/z=1275.5. El. Anal. calcd for $C_{72}H_{76}N_4O_8S_4$: C, 68.98; H, 6.11; N, 4.47; S, 10.23. Found: C, 68.53; H, 6.07; N, 4.27; S, 10.31.

*4.1.3. 5,11,17,23-Tetra-tert-butyl-25,26,27,28-tetrakis[(phenylamidocarbonyl)-methoxy]-2,8,14,20-tetrathiacalix[4]arene (1,3-alternate-**4c**)*

Yield: 1.17 g (89%). Mp: 266 °C. ^{1}H NMR (300 MHz, 373 K, $CDCl_3$) δ 8.51 (s, 4H, NH), 7.48–7.42 (m, 16H, ArH), 7.36 (m, 8H, ArH), 7.14 (m, 4H, ArH), 4.88 (s, 8H, OCH_2CO), 0.69 (s, 36H, $(CH_3)_3C$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 166.1, 156.5, 149.4, 137.5, 131.0, 129.5, 127.2, 125.3,

119.9, 70.6, 34.5, 30.6. IR (KBr) ν_{max} 1255, 1693, 2871, 2906, 2960, 3288, 3393. MS (ESI): calcd for $[M+Na]^+$ m/z=1275.4, found m/z=1275.6. El. Anal. Calcd for $C_{72}H_{76}N_4O_8S_4$: C, 68.98; H, 6.11; N, 4.47; S, 10.23. Found: C, 68.25; H, 6.10; N, 4.34; S, 10.92.

*4.1.4. 5,11,17,23-Tetra-tert-butyl-25,26,27,28-tetrakis[(benzylamidocarbonyl)-methoxy]-2,8,14,20-tetrathiacalix[4]arene (cone-**5a**)*

Yield: 1.29 g (94%). Mp: 227 °C. ^{1}H NMR (300 MHz, 373 K, $CDCl_3$) δ 8.04 (t, J=5.7 Hz, 4H, NH), 7.32 (s, 8H, ArH), 7.31–7.23 (m, 20H, ArH), 4.79 (s, 8H, OCH_2CO), 4.48 (d, J=5.7 Hz, 8H, NCH_2Ar), 1.09 (s, 36H, $(CH_3)_3C$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 168.1, 147.5, 138.2, 134.8, 128.5, 128.1, 127.9, 127.2, 74.4, 43.0, 34.1, 31.1. IR (KBr) ν_{max} 1263, 1675, 2870, 2961, 3323. MS (ESI): calcd for $[M+Na]^+$ m/z=1331.5, found m/z=1331.7. El. Anal. Calcd for $C_{76}H_{84}N_4O_8S_4$: C, 69.69; H, 6.46; N, 4.28; S, 9.79. Found: C, 69.30; H, 6.57; N, 4.27; S, 10.42.

*4.1.5. 5,11,17,23-Tetra-tert-butyl-25,26,27,28-tetrakis[(benzylamidocarbonyl)-methoxy]-2,8,14,20-tetrathiacalix[4]arene (partial cone-**5b**)*

Yield: 1.26 g (92%). Mp: 216 °C. ^{1}H NMR (300 MHz, 373 K, $CDCl_3$) δ 9.03 (t, J=6.5 Hz, 1H, NH), 8.27 (t, J=6.5 Hz, 2H, NH), 7.65 (s, 2H, ArH), 7.53 (s, 2H, ArH), 7.43–7.15 (m, 21H, ArH, NH), 6.97 (d, J=2.4 Hz, 2H, ArH), 6.87–6.83 (m, 2H, ArH), 5.03 (s, 2H, OCH_2CO), 4.85 (d, J=14.9 Hz, 2H, OCH_2CO), 4.67 (dd, ^2J=14.5 Hz, ^3J=6.5 Hz, 2H, NCH_2Ar), 4.59 (d, J=5.9 Hz, 2H, NCH_2Ar), 4.43 (dd, 2H, ^2J=14.5 Hz, ^3J=6.5 Hz, NCH_2Ar), 4.40 (s, 2H, OCH_2O), 4.28 (d, J=14.9 Hz, 2H, OCH_2CO), 4.16 (d, J=5.9 Hz, 2H, NCH_2Ar), 1.32 (s, 9H, $(CH_3)_3C$), 1.16 (s, 9H, $(CH_3)_3C$), 0.95 (s, 18H, $(CH_3)_3C$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 168.4, 167.9, 159.2, 158.0, 147.4, 146.7, 146.4, 138.3, 137.7, 136.3, 135.0, 134.7, 133.3, 128.7, 128.5, 128.4, 128.1, 127.9, 127.8, 127.6, 127.4, 127.3, 125.7, 125.5, 74.3, 73.7, 69.4, 43.1, 42.8, 31.3, 30.9. IR (KBr) ν_{max} 1261, 1677, 2870, 2908, 2962, 3300. MS (ESI): calcd for $[M+Na]^+$ m/z=1331.5, found m/z=1331.6. El. Anal. Calcd for $C_{76}H_{84}N_4O_8S_4$: C, 69.69; H, 6.46; N, 4.28; S, 9.79. Found: C, 70.00; H, 6.53; N, 4.12; S, 10.32.

*4.1.6. 5,11,17,23-Tetra-tert-butyl-25,26,27,28-tetrakis[(benzylamidocarbonyl)-methoxy]-2,8,14,20-tetrathiacalix[4]arene (1,3-alternate-**5c**)*

Yield: 1.24 g (90%). Mp: 230 °C. ^{1}H NMR (300 MHz, 373 K, $CDCl_3$) δ 8.22 (t, J=5.7 Hz, 4H, NH), 7.44 (s, 8H, ArH), 7.33–7.28 (m, 20H, ArH), 4.49 (d, $^3J_{HH}$=5.7 Hz, 8H, NCH_2Ar), 4.11 (s, 8H, OCH_2CO), 1.05 (s, 36H, $(CH_3)_3C$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 168.5, 157.0, 147.8, 138.3, 133.9, 129.9–127.4, 71.4, 43.5, 34.4, 31.2. IR (KBr) ν_{max} 1262, 1660, 2870, 2960, 3312. MS (MALDI-TOF): calcd for $[M]^+$ m/z=1309.8, found m/z=1313.8. El. Anal. Calcd for $C_{76}H_{84}N_4O_8S_4$: C, 69.69; H, 6.46; N, 4.28; S, 9.79. Found: C, 68.25; H, 6.41; N, 4.15; S, 9.85.

*4.1.7. 5,11,17,23-Tetra-tert-butyl-25,26,27,28-tetrakis[(octylamidocarbonyl)-methoxy]-2,8,14,20-tetrathiacalix[4]arene (cone-**6a**)*

Yield: 0.98 g (75%). Mp: 116 °C. ^{1}H NMR (300 MHz, 373 K, $CDCl_3$) δ 7.76 (t, J=4.6 Hz, 4H, NH), 7.33 (s, 8H, ArH), 4.80 (s, 8H, OCH_2CO), 3.38–3.31 (m, 8H, $HNCH_2(CH_2)_6CH_3$), 1.66–1.50, 1.43–1.19 (m, 48H, $HNCH_2(CH_2)_6CH_3$), 1.10 (s, 36H, $(CH_3)_3C$), 0.86 (t, J=7.3 Hz, 12H, $HN(CH_2)_7CH_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 167.9, 157.5, 147.5, 134.8, 127.9, 74.6, 39.5, 34.2, 32.4, 31.8, 31.1, 29.7, 29.3, 27.1, 22.7, 14.1. IR (KBr) ν_{max} 1263, 1677, 2959, 3305. MS (ESI): calcd for $[M+Na]^+$ m/z=1419.8, found m/z=1419.9. El. Anal. Calcd for $C_{80}H_{124}N_4O_8S_4$: C, 68.73; H, 8.94; N, 4.01; S, 9.17. Found: C, 68.65; H, 9.09; N, 4.15; S, 9.14.

*4.1.8. 5,11,17,23-Tetra-tert-butyl-25,26,27,28-tetrakis[(octylamidocarbonyl)-methoxy]-2,8,14,20-tetrathiacalix[4]arene (partial cone-**6b**)*

Yield: 1.01 g (76%). Mp: 158 °C. ^{1}H NMR (300 MHz, 373 K, $CDCl_3$) δ 8.64 (t, J=6.2 Hz, 1H, NH), 7.98 (t, J=5.5 Hz, 2H, NH), 7.78 (s, 2H, ArH), 7.62 (s, 2H, ArH), 7.49 (d, J=2.4 Hz, 2H, ArH), 7.15 (t, J=6.5 Hz, 1H, NH), 7.05 (d, J=2.4 Hz, 2H, ArH), 4.99 (s, 2H, OCH_2CO), 4.89 (d, J=14.5 Hz, 2H, OCH_2CO), 4.38 (s, 2H, OCH_2CO), 4.37 (d, J=14.5 Hz, 2H, OCH_2CO), 3.55–3.24, 3.16–3.08 (m, 8H, $HNCH_2(CH_2)_6CH_3$), 2.61–2.52, 1.73–1.60, 1.21–1.14 (m, 48H, $HNCH_2(CH_2)_6CH_3$), 1.34 (s, 9H, $(CH_3)_3C$), 1.31 (s, 9H, $(CH_3)_3C$), 1.03 (s, 18H, $(CH_3)_3C$), 0.90–0.81 (m, 12H, $HN(CH_2)_7CH_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 168.5, 168.2, 167.8, 159.3, 158.1, 155.3, 147.4, 146.6, 146.4, 136.4, 135.1, 134.8, 133.4, 127.5, 127.3, 125.7, 125.6, 74.5, 73.8, 69.6, 39.5, 39.3, 39.0, 34.3, 34.2, 34.1, 31.8, 31.7, 31.7, 31.2, 31.1, 31.0, 29.7, 29.7, 29.4, 29.3, 29.2, 29.1, 27.15, 27.1, 26.7, 22.6, 22.5, 14.0. IR (KBr) ν_{max} 1265, 1633, 2855, 2925, 2957, 3287. MS (ESI): calcd for $[M+Na]^+$ m/z=1419.8, found m/z=1419.9. El. Anal. Calcd for $C_{80}H_{124}N_4O_8S_4$: C, 68.73; H, 8.94; N, 4.01; S, 9.17. Found: C, 68.45; H, 8.93; N, 3.96; S, 9.39.

*4.1.9. 5,11,17,23-Tetra-tert-butyl-25,26,27,28-tetrakis[(octylamidocarbonyl)-methoxy]-2,8,14,20-tetrathiacalix[4]arene (1,3-alternate-**6c**)*

Yield: 0.95 g (72%). Mp: 62 °C. ^{1}H NMR (300 MHz, 373 K, $CDCl_3$) δ 7.79 (t, J=6.1 Hz, 4H, NH), 7.54 (s, 8H, ArH), 4.09 (s, 8H, OCH_2CO), 1.22 (s, 36H, $(CH_3)_3C$), 3.30–3.22 (m, 8H, $HNCH_2(CH_2)_6CH_3$), 1.66–1.58, 1.37–1.23 (m, 48H, $HNCH_2(CH_2)_6CH_3$), 0.88 (t, J=6.4 Hz, 12H, $HN(CH_2)_7CH_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 167.9, 156.7, 147.2, 133.3, 127.0, 71.0, 39.4, 34.2, 31.7, 30.0, 29.5, 29.1, 27.1, 22.5, 14.0. IR (KBr) ν_{max} 1264, 1654, 2854, 2925, 2956, 3320, 3419. MS (ESI): calcd for $[M+Na]^+$ m/z=1419.8, found m/z=1420.0. El. Anal. Calcd for $C_{80}H_{124}N_4O_8S_4$: C, 68.73; H, 8.94; N, 4.01; S, 9.17. Found: C, 68.68; H, 9.04; N, 3.95; S, 9.12.

4.2. General procedure of the synthesis of compounds 6(a–c), 7(a–c) and 8(a–c)

Compounds **2**(**a**–**c**) (1 g, 0.9×10^{-3} mol) and ammonium chloride (0.01 g, 0.2×10^{-3} mol) were placed into a round-bottom flask and the amine (*n*-octylamine, *n*-dodecylamine, *n*-octadecylamine) (1.8×10^{-2} mol) was added and mixed at 150 °C for 2 h. Then the reaction mixture was cooled to room temperature, ethanol (100 mL) was added, the residue was filtered and dried at lower pressure.

*4.2.1. 5,11,17,23-Tetra-tert-butyl-25,26,27,28-tetrakis[(octylamidocarbonyl)-methoxy]-2,8,14,20-tetrathiacalix[4]arene (cone-**6a**)*

Yield: 1.25 g (95%). Mp: 116 °C.

*4.2.2. 5,11,17,23-Tetra-tert-butyl-25,26,27,28-tetrakis[(octylamidocarbonyl)-methoxy]-2,8,14,20-tetrathiacalix[4]arene (partial cone-**6b**)*

Yield: 1.13 g (86%). Mp: 158 °C.

*4.2.3. 5,11,17,23-Tetra-tert-butyl-25,26,27,28-tetrakis[(octylamidocarbonyl)-methoxy]-2,8,14,20-tetrathiacalix[4]arene (1,3-alternate-**6c**)*

Yield: 1.09 g (74%). Mp: 62 °C.

*4.2.4. 5,11,17,23-Tetra-tert-butyl-25,26,27,28-tetrakis[(dodecylamidocarbonyl)-methoxy]-2,8,14,20-tetrathiacalix[4]arene (cone-**7a**)*

Yield: 1.41 g (92%). Mp: 100 °C. ^{1}H NMR (300 MHz, 373 K, $CDCl_3$) δ 7.73 (t, J=6.0 Hz, 4H, NH), 7.34 (s, 8H, ArH), 4.81 (s, 8H, OCH_2CO), 3.38–3.31 (m, 8H, $HNCH_2(CH_2)_{10}CH_3$), 1.63–1.53, 1.35–1.25 (m, 80H, $HNCH_2(CH_2)_{10}CH_3$), 1.12 (s, 36H, $(CH_3)_3C$), 0.88 (t, J=7.1 Hz, 12H, $HN(CH_2)_{11}CH_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 167.8, 157.5, 147.3, 134.7, 127.9, 74.4, 39.4, 34.1, 31.7, 30.9, 29.6, 29.5, 29.1, 27.0, 22.5, 13.8. IR (KBr) ν_{max} 1264, 1678, 2959, 3304. MS (ESI): calcd for $[M]^+$ m/z=1622.6, found m/z=1622.0. El. Anal. Calcd for $C_{96}H_{156}N_4O_8S_4$:

C, 71.06; H, 9.69; N, 3.45; S, 7.90. Found: C, 71.10; H, 10.07; N, 3.44; S, 8.22.

4.2.5. 5,11,17,23-Tetra-tert-butyl-25,26,27,28-tetrakis[(dodecyl-amidocarbonyl)-methoxy]-2,8,14,20-tetrathiacalix[4]arene (partial cone-**7b**)

Yield: 1.39 g (91%). Mp: 166 °C. ^{1}H NMR (300 MHz, 373 K, $CDCl_3$) δ 8.66 (t, J=6.1 Hz, 1H, NH), 7.98 (t, J=6.1 Hz, 2H, NH), 7.79 (s, 2H, ArH), 7.62 (s, 2H, ArH), 7.48 (d, J=2.7 Hz, 2H, ArH), 7.11 (t, J=6.1 Hz, 1H, NH), 7.05 (d, J=2.7 Hz, 2H, ArH), 4.99 (s, 2H, OCH_2CO), 4.87 (d, J=16.1 Hz, 2H, OCH_2CO), 4.39 (c, 2H, OCH_2CO), 4.36 (d, J=16.1 Hz, 2H, OCH_2CO), 3.54–3.37, 3.34–3.21, 3.18–3.07 (m, 8H, $HNCH_2(CH_2)_{10}CH_3$), 1.70–1.59, 1.28–1.19 (m, 80H, $HNCH_2(CH_2)_{10}CH_3$), 1.33 (s, 9H, $(CH_3)_3C$), 1.30 (s, 9H, $(CH_3)_3C$), 1.04 (s, 18H, $(CH_3)_3C$), 0.87 (t, J=7.3 Hz, 12H, $HN(CH_2)_{11}CH_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 168.5, 168.2, 167.8, 159.3, 158.0, 155.3, 147.4, 146.5, 146.4, 136.3, 135.1, 134.8, 133.3, 127.4, 127.2, 125.7, 125.5, 74.4, 73.8, 69.6, 39.5, 39.3, 38.9, 34.2, 34.1, 31.8, 31.2, 31.1, 30.9, 29.5, 29.3, 27.1, 26.6, 22.6, 14.0. IR (KBr) ν_{max} 1264, 1678, 2959, 3304, 1255, 1654, 2854, 2925, 2956, 3320. MS (ESI): calcd for $[M]^+$ m/z=1622.6, found m/z=1622.8. El. Anal. Calcd for $C_{96}H_{156}N_4O_8S_4$: C, 71.06; H, 9.69; N, 3.45; S, 7.90. Found: C, 71.19; H, 9.07; N, 3.45; S, 8.26.

4.2.6. 5,11,17,23-Tetra-tert-butyl-25,26,27,28-tetrakis[(dodecyl-amidocarbonyl)-methoxy]-2,8,14,20-tetrathiacalix[4]arene (1,3-alternate-**7c**)

Yield: 1.42 g (93%). Mp: 56 °C. ^{1}H NMR (300 MHz, 373 K, $CDCl_3$) δ 7.78 (t, J=5.0 Hz, 4H, NH), 7.54 (s, 8H, ArH), 4.08 (s, 8H, OCH_2CO), 3.34–3.19 (m, 8H, $HNCH_2(CH_2)_{10}CH_3$), 1.69–1.52, 1.39–1.24 (m, 80H, $HNCH_2(CH_2)_{10}CH_3$), 1.22 (s, 36H, $(CH_3)_3C$), 0.88 (t, J=7.2 Hz, 12H, $HN(CH_2)_{11}CH_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 167.9, 156.8, 147.3, 133.3, 127.0, 71.1, 39.5, 34.2, 31.8, 31.0, 29.6, 29.3, 27.1, 22.6, 14.0. IR (KBr) ν_{max} 1260, 1649, 2851, 2920, 2956, 3310, 3418. MS (ESI): calcd for $[M]^+$ m/z=1622.6, found m/z=1623.0. El. Anal. Calcd for $C_{96}H_{156}N_4O_8S_4$: C, 71.06; H, 9.69; N, 3.45; S, 7.90. Found: C, 70.15; H, 9.69; N, 3.34; S, 7.79.

4.2.7. 5,11,17,23-Tetra-tert-butyl-25,26,27,28-tetrakis[(octadecyl-amidocarbonyl)-methoxy]-2,8,14,20-tetrathiacalix[4]arene (cone-**8a**)

Yield: 1.69 g (92%). Mp: 105 °C. ^{1}H NMR (300 MHz, 373 K, $CDCl_3$) δ 7.74 (t, J=4.9 Hz, 4H, NH), 7.34 (s, 8H, ArH), 4.80 (s, 8H, OCH_2CO), 3.38–3.31 (m, 8H, $HNCH_2(CH_2)_{16}CH_3$), 1.67–1.55, 1.37–1.25 (m, 144H, $HNCH_2(CH_2)_{16}CH_3$), 1.11 (s, 36H, $(CH_3)_3C$), 0.87 (t, J=7.4 Hz, 12H, $HN(CH_2)_{17}CH_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 168.0, 157.5, 147.4, 134.8, 128.0, 74.5, 39.5, 34.2, 31.8, 31.0, 29.6, 29.3, 27.1, 22.6, 14.0. IR (KBr) ν_{max} 1265, 1677, 2960, 3304. MS (ESI): calcd for $[M]^+$ m/z=1959.2, found m/z=1959.8. El. Anal. Calcd for $C_{120}H_{204}N_4O_8S_4$: C, 73.57; H, 10.50; N, 2.86; S, 6.55. Found: C, 73.82; H, 10.80; N, 2.85; S, 6.21.

4.2.8. 5,11,17,23-Tetra-tert-butyl-25,26,27,28-tetrakis[(octadecyl-amidocarbonyl)-methoxy]-2,8,14,20-tetrathiacalix[4]arene (partial cone-**8b**)

Yield: 1.76 g (96%). Mp: 135 °C. ^{1}H NMR (300 MHz, 373 K, $CDCl_3$) δ 8.63 (t, J=5.1 Hz, 1H, NH), 7.91 (t, J=5.1 Hz, 2H, NH), 7.79 (s, 2H, ArH), 7.62 (s, 2H, ArH), 7.49 (d, J=2.8 Hz, 2H, ArH), 7.11 (t, J=5.1 Hz, 1H, NH), 7.05 (d, J=2.8 Hz, 2H, ArH), 4.99 (s, 2H, OCH_2CO), 4.86 (d, J=14.5 Hz, 2H, OCH_2CO), 4.39 (s, 2H, OCH_2CO), 4.36 (d, J=14.5 Hz, 2H, OCH_2CO), 3.54–3.37, 3.34–3.23, 3.16–3.08 (m, 8H, $HNCH_2(CH_2)_{10}CH_3$), 2.56–0.85 (m, 156H, $HNCH_2(CH_2)_{16}CH_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 168.4, 168.2, 167.8, 165.0, 159.3, 158.1, 155.4, 147.4, 146.6, 146.3, 136.3, 135.1, 134.8, 133.3, 127.9, 125.6, 74.5, 73.8, 69.7, 39.5, 39.4, 39.0, 34.2, 34.1, 31.9, 31.0, 29.6, 29.3, 28.3, 27.1, 26.7, 22.6, 14.0. IR (KBr) ν_{max} 1253, 1656, 2852, 2921, 2957, 3326. MS (ESI): calcd for $[M]^+$ m/z=1959.2, found m/z=1959.6. El. Anal. Calcd for $C_{120}H_{204}N_4O_8S_4$: C, 73.57; H, 10.50; N, 2.86; S, 6.55. Found: C, 73.27; H, 10.75; N, 2.76; S, 6.21.

4.2.9. 5,11,17,23-Tetra-tert-butyl-25,26,27,28-tetrakis[(octadecyl-amidocarbonyl)-methoxy]-2,8,14,20-tetrathiacalix[4]arene (1,3-alternate-**8c**)

Yield: 1.49 g (81%). Mp: 66 °C. ^{1}H NMR (300 MHz, 373 K, $CDCl_3$) δ 7.78 (t, J=4.9 Hz, 4H, NH), 7.54 (s, 8H, ArH), 4.08 (s, 8H, OCH_2CO), 3.32–3.21 (m, 8H, $HNCH_2(CH_2)_{16}CH_3$), 1.63–1.47, 1.37–1.22 (m, 128H, $HNCH_2(CH_2)_{16}CH_3$), 1.21 (s, 36H, $(CH_3)_3C$), 0.87 (t, J=7.4 Hz, 12H, $HN(CH_2)_{17}CH_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 167.9, 156.8, 147.3, 133.3, 127.1, 71.1, 39.5, 34.2, 31.8, 31.0, 29.6, 29.3, 27.1, 22.6, 14.0. IR (KBr) ν_{max} 1259, 1649, 2850, 2918, 3316, 3419. MS (ESI): calcd for $[M]^+$ m/z=1959.2, found m/z=1959.4. El. Anal. Calcd for $C_{120}H_{204}N_4O_8S_4$: C, 73.57; H, 10.50; N, 2.86; S, 6.55. Found: C, 73.42; H, 10.80; N, 2.74; S, 6.21.

4.3. Determination of extraction parameters

4.3.1. The degree of extraction

The alkali and alkaline earth metal picrates were prepared by stepwise addition of 2.32×10^{-4} M aqueous picric acid solution to 0.1 M aqueous solution of metal hydroxide (LiOH, NaOH, KOH, CsOH, $Ba(OH)_2$, $Ca(OH)_2$) until neutralization, which was checked by pH control with a glass pH-electrode. Other picrates were prepared by stepwise addition of a 3.02×10^{-4} M of $Mg(NO_3)_2$, $Al(NO_3)_3$, $Pb(NO_3)_2$, $Fe(NO_3)_3$, $Co(NO_3)_3$, $Ni(NO_3)_2$, $Cu(NO_3)_2$, $AgNO_3$, $Cd(NO_3)_2$, $Hg(NO_3)_2$ to 2.32×10^{-4} M aqueous picric acid solution; in this case, the solutions were weakly acidic (pH 4). Distilled water was used for preparation of all aqueous solutions. Aqueous picrate solution (3 mL, 2.32×10^{-4} M) and 3 mL of a 2.32×10^{-4} M solution of thiacalix[4]arene derivatives in CH_2Cl_2 (chemically pure) were shaken for 30 min at room temperature (22 °C). The absorbance A_i of the aqueous phase after extraction, and, that of the aqueous phase before extraction, A_0, were measured at the wavelength of the maximum absorption of the picrate ion, λ_{max}=355 nm. The percentage of the cation extracted was calculated as the ratio $100\times(A_0-A_i)/A_0$.

4.3.2. Extraction constants log K_{ex} and stoichiometry of the complexes

Extraction experiments were performed at various ligand concentrations (1×10^{-4}–2.5×10^{-4}). Silver picrate was prepared by stepwise addition of a 1.6×10^{-2} M of $AgNO_3$ to 2.32×10^{-4} M aqueous picric acid solution; in this case, the solutions were weakly acidic (pH 4). The log K_{ex} and n values were determined from the plot of $\log(a/1-a)$ versus $\log[L]_{org.}$ as described elsewhere.[42]

4.4. Dynamic light scattering (DLS)

The particle sizes were determined by Zetasizer Nano ZS instrument at 20 °C. The instrument contains a 4 mW He–Ne laser operating at a wavelength of 633 nm and incorporates non-invasive backscatter optics (NIBS). The measurements were performed at the detection angle of 173° and the measurement position within the quartz cuvette was automatically determined by the software. The solutions of the systems investigated were prepared by addition of silver nitrate to 10 mL of 10^{-3} M solution of thiacalixarene derivatives in CH_2Cl_2 (HPLC). The mixture was mechanically shaken for 2 h and then magnetically stirred in thermostated water bath at

20 °C for 1 h. The final concentration of silver nitrates in 10 mL CH_2Cl_2 (HPLC) was 2.32×10^{-4} M.

Acknowledgements

The financial support from RFBR (06-03-32160), CRDF (RUC1-2825-KA-06), joint program of CRDF and Ministry of Science and Education of Russian Federation 'Fundamental Researches and Higher Education' (REC-007) is gratefully acknowledged.

Supplementary data

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.tet.2008.05.057.

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