Journal of Inclusion Phenomena and Macrocyclic Chemistry (2006) 56: 337–344
DOI 10.1007/s10847-006-9104-3

Synthesis and Cation-Binding Properties of Novel *p*-Isopropenylcalix[*n*]arenes and Their Acetylated Derivatives

S. YORDANOVA[1], S. MILOSHEV[1,*], I. BERLINOVA[2] and B. DIAKOVSKI[1]
[1]*Department of Polymer Engineering, University of Chemical Technology and Metallurgy, Kliment Ohridski 8, 1756, Sofia, Bulgaria;* [2]*Institute of Polymers, Bulgarian Academy of Sciences, 1113, Sofia, Bulgaria*

(Received: 14 November 2005; in final form: 21 February 2006)

Key words: acetylation, complexation, *p*-isopropenylcalix[*n*]arene acetates, *p*-isopropenylcalix[*n*]arenes, solvent extraction, synthesis

Abstract

A novel two-step method was developed to prepare individual *p*-isopropenylcalix[*n*]arenes [$n = 4, 6, 8$]. In the first step, linear phenolic oligomers were prepared in a basic medium from *p*-isopropenylphenol and paraformaldehyde. The second step, cyclization of the linear oligomers was carried out at higher temperatures. Ethylene glycol was used as medium, and sodium tetraborate-decahydrate as the catalyst. O-Acetylated derivatives were obtained by acetylation of the phenolic hydroxyl groups of *p*-isopropenylcalix[*n*]arenes [$n = 4, 6, 8$]. The *p*-isopropenyl-calix[*n*]arenes and their acetylated derivatives were characterized by IR, ^{1}H NMR and UV spectroscopy, and elemental analysis. Their ability to extract metal cations from aqueous solutions was evaluated via metal picrate extraction experiments. A parallel investigation of the cation-binding ability of the *p*-tert-butylcalix[*n*]arenes [$n = 4, 6, 8$] and their acetylated derivatives was also performed. The *p*-isopropenylcalix[6]arene hexaacetate is the most effective extracting agent for metal picrates, and shows strong affinity towards Rb cation.

Introduction

Calixarenes [1] are cavity-shaped cyclic molecules made up of phenol units linked via methylene groups. In recent years, a lot of papers and patents on the synthesis of cyclic phenol-formaldehyde oligomers and studies of their properties have been published [2]. Increasing attention has been focused on their application in the field of host-guest chemistry [1, 3a, 4] because they possess excellent inclusion ability toward many ions and neutral molecules [3b].

Depending on the number of aromatic units in the cyclic array and on the functionalization, calixarenes possess a hydrophobic cavity that is capable of including not only metal or simple organic ions [5] but also a variety of organic compounds [4, 6]. Their functionalization at the lower and upper rim yields compounds with interesting properties. For example, functionalized calixarenes were applied as ionophores for metal ions, and as optical or electrochemical sensors for alkaline metal ions [7]. Calixarene-based receptors are among the most effective and selective for metal cations. They are widely used for transport and extraction for various inorganic ions such as Na^+, K^+, Cs^+ [8–10], lanthanides and actinides [11], as well as for organic cationic species [12]. Furthermore, calixarene derivatives can be used as chemical sensors [13], enzyme mimetics [14], and allosteric molecules [15].

Unmodified calixarenes are sparingly soluble in organic solvents, which limits their application as complexation agents [1]. To overcome this problem numerous synthetic routes were developed for their modification at the lower and upper rim [5a, 16, 17]. The attachment of different reagents to the phenolic groups (lower rim) resulted in soluble derivatives with pronounced complex-formation properties [1, 3a]. *p*-Tert-butylcalix[*n*]arene ester and ether derivatives revealed greater complexation ability than that of the corresponding unmodified calixarenes [3a].

In contrast to the widely studied *p*-tert-butylcalix[*n*]arenes and their derivatives, *p*-isopropenylcalix[*n*]arenes are a novel class of calixarenes, which contain *p*-isopropenyl groups at the upper rim, conjugated with the aromatic ring [18]. This enables their ready modification at the upper rim, and endows them with a complex-formation ability towards metal ions. That is why we have been interested in the synthesis of *p*-isopropenylcalix[*n*]arenes ($n = 4, 6, 8$) derivatives and in studies of their complex-formation properties.

The main objectives of this paper are: (i) to synthesize and characterize individual *p*-isopropenylcalix[*n*]arenes ($n = 4, 6, 8$), (ii) to synthesize and

* Author for correspondence. E-mail: stmiloshev@yahoo.com

characterize O-acetylated *p*-isopropenylcalix[*n*]arenes and (iii) to study their complex-formation with metal ions. The cation-binding abilities of the *p*-isopropenylcalix[*n*]arenes and their O-acetylated derivatives have been evaluated by solvent extraction of aqueous metal picrates (MePic, Me = Na^+, Li^+, K^+, Cs^+, Rb^+, NH_4^+, Co^{2+}, Al^{3+}, Ba^{2+}, Zn^{2+}, Mg^{2+}, Cu^{2+}) with regard to the size of the calixarene and the presence of substituents at the lower rim.

Experimental

Materials and methods

The *p*-isopropenylphenol was prepared according to the method of Verchovskaja [19]. The *p*-tert-butylcalix[4]-, -[6]- and -[8]arenes (noted **7**, **8**, **9**) were purchased from Aldrich. 5,11,17,23-Tetra-*p*-tert-butyl-25,26,27,28-tetra-acetoxy-calix[4]arene (**10**), 5,11,17,23,29,35-hexa-tert-butyl-37,38,39,40,41,42-hexaacetoxy-calix[6]arene (**11**) and 5,11,17,23,29,35,41,47-octa-*p*-tert-butyl-49,50,51, 52,53,54,55,56-octaacetoxy-calix[8]arene (**12**) were prepared as previously described [20]. All chemicals were of reagent grade and were commercially available. The solvents were purified according to standard procedures and stored over molecular sieves.

The melting points were determined by a Thermal Analysis DSC Q100 TA Instrument at a heating rate of 20 °C/min under nitrogen atmosphere. ^{1}H NMR spectra were recorded on a Bruker spectrometer (TMS was used as an internal standard) at 400 MHz. The Fourier transform infrared spectra (FT-IR) were recorded on a Brucker FT-IR spectrometer. The absorption bands of the metal picrate solutions were measured with a UV/Visible spectrophotometer ''Ultrospec 1000''. The HPLC separation was carried out with a Waters Symmetry® C18 (5 μm, 4.6 × 150 mm) column. As an eluent a mixture of methanol/water (containing 0.02v TFA acid) in a ratio of 60:40 (v/v) was used, with a flow rate of 0.4 mL/min and at 22 °C. UV detection was set at 254 nm. Gel permeation chromatography (GPC) data were obtained with a Waters HPLC system (UV and RI detectors, pumps, injector and data station) with two columns (300 × 6.9 mm Plgel 500 Å) in THF, calibrated with polystyrene standards and recalibrated by calixarenes and *p*-cresol standards at 45 °C. UV/Vis spectra were recorded with a Waters 991 photodiode array UV detector equipment with a data station at λ = 190–500 nm. Elemental analyses were performed at the Centre Research Laboratory of the Institute of Chemical Technology and Metallurgy.

Syntheses of p-isopropenylcalix[n]arenes **(1–3)**

The typical synthesis of *p*-isopropenylcalix[*n*]arenes (**1–3**) proceeded in two reaction steps: (i) synthesis of linear phenolic oligomer and (ii) cyclization of the linear oligomer obtained in the first step.

Synthesis of p-isopropenylcalix[4]arene **(1)**

(i) Synthesis of linear tetramer

20 g (0.149 mol) of *p*-isopropenylphenol, 5.37 g (0.179 mol) of paraformaldehyde and 0.27 g (0.0067 mol) of solid 98% NaOH were dissolved in 40 mL of i-propanol. The reaction mixture was heated at 100 °C under stirring for 2 h. Finally it yielded a viscous mass containing about 80% of linear phenolic tetramers, namely the dihydroxymethylated and monohydroxymethylated tetramers, the remainder being dimers and the monomer was determined by means of HPLC and GPC chromatography.

(ii) Synthesis of p-isopropenylcalix[4]arene

The reaction mixture obtained by the procedure described above was neutralized with hydrochloric acid and was transferred into a round three-neck flask equipped with a stirrer and a thermometer. Then, 2.27 g (0.006 mol) of sodium tetraborate-decahydrate and 200 mL of hot ethylene glycol were added under stirring. The reaction mixture was refluxed for 2 h. Then, the mixture was cooled to 90 °C and poured into 1 L of cold water. The precipitate obtained was filtered off and dried under vacuum at 40 °C. The dried product contains mainly *p*-isopropenylcalix[4]arene and remaining linear oligomers of *p*-isopropenylphenol. It was dissolved at 50 °C in a mixture of 90 cm^3 acetone and 30 cm^3 tetrahydrofuran (THF). The linear oligomers were dissolved in this mixture, whereas the cyclic *p*-isopropenylcalix[4]arene was dispersed. The dispersed product was separated by filtration, washed and dried under vacuum at 40 °C. After recrystallization from a mixture of chloroform and methanol (2:8), pure *p*-isopropenylcalix[4]arene was obtained in an 45% yield.

p-Isopropenylcalix[4]arene ***1***: m.p.345 °C – IR (KBr): ν = 3368 (OH), 1654 (C = C conjugated double bond with the aromatic ring), the ''fingerprint'' region at 1500–1000, and 885–824 cm^{-1} doublet typical of tetra-substituted aromatic ring. – ^{1}H NMR (400 MHz, DMSO-d_6): δ = 9.25 (s, 4H, O*H*), 6.67 (s, 8H, Ar*H*), 4.47-4.64 (m, 8H, -C = CH_2), 4.38-4.41 (d, 4H, H*ax* of ArCH_2Ar), 3.41-3.51 (d, 4H, H*eq* of ArCH_2Ar), 2.29 ppm (t, 12H, CH_3-C =). – UV-Vis (THF): 232, 238, 256, 283 nm. – $C_{40}H_{40}O_4$ (584.74): calcd. C 82.16, H 6.89; found C 82.11, H 6.74.

Synthesis of p-isopropenylcalix[6]arene **(2)**

(i) Synthesis of linear hexamer

20 g (0.149 mol) of *p*-isopropenylphenol, 8.94 g (0.298 mol) of paraformaldehyde and 0.3 g (0.0075 mol) of solid 98% NaOH were dissolved in 40 mL of i-propanol. This mixture was refluxed under stirring until a viscous mass was formed. After neutralization of the reaction mixture with hydrochloric acid and

evaporation, a sample was taken and investigated by means of HPLC and GPC chromatography. It was found that this reaction had given the linear dihydroxymethylated hexamer.

(ii) Synthesis of p-isopropenylcalix[6]arene

The obtained linear hexamer was dissolved in 200 mL of ethylene glycol and placed into a round three-neck flask equipped with a stirrer and a thermometer. Then, 2.27 g (0.006 mol) sodium tetraborate-decahydrate were added under stirring. The reaction mixture was heated to reflux for 3 h. The mixture was cooled to 90 °C and poured into 1 L of cold water. The obtained precipitate was filtered and dried under vacuum at 40 °C. The dried product was dispersed in hot acetone. After cooling and filtration, *p*-isopropenylcalix[6]arene was obtained in a 58% yield.

p-Isopropenylcalix[6]arene **2**: m.p. 410 °C. – IR (KBr): $\nu = 3368$ (OH), 1654 (C=C conjugated double bond with the aromatic ring), the "fingerprint" region at 1500–1000, 887–831 cm^{-1}. – ^1H NMR (400 MHz, DMSO-d_6): $\delta = 9.23$ (s, 6H, O*H*), 6.65 (s, 12H, Ar*H*), 4.44–4.67 (m, 12H, -C=CH_2), 3.54 (s, 12H, ArCH_2-Ar), 2.25 ppm (t, 18H, CH_3-C=). – UV-Vis (THF): 232, 241, 256, 283 nm. – $C_{60}H_{60}O_6$ (877.12): calcd. C 82.16, H 6.89; found C 82.08, H 6.76.

*Synthesis of p-isopropenylcalix[8]arene (**3**)*

(i) Synthesis of linear octamer

A mixture of 20 g (0.149 mol) of *p*-isopropenylphenol, 26.7 mL (0.36 mol) of 37% formalin and 0.3 g (0.0075 mol) of solid 98% NaOH was stirred at reflux temperature for 3 h. After that the reaction mixture was neutralized with hydrochloric acid and evaporated. It was established that about 62% of linear dihydroxymethylated octamer was obtained.

(ii) Synthesis of p-isopropenylcalix[8]arene

The procedure for cyclization of linear octamer is the same as the procedure for cyclization of linear hexamer. The dried product was dissolved in 200 cm^3 THF. Then 400 cm^3 *n*-hexane were added and a precipitate was formed. The precipitated product was separated from the organic layer by filtration and then was dispersed in 600 cm^3 water. After that it was filtrated and dried under vacuum at 40 °C, *p*-isopropenylcalix[8]arene was obtained in a 65% yield.

p-Isopropenylcalix[8]arene **3**: m.p. 432 °C. – IR (KBr): $\nu = 3369$ (OH), 1654 (C=C conjugated double bond with the aromatic ring), the "fingerprint" region at 1500–1000, 886, 830 and 753 cm^{-1}. – ^1H NMR (400 MHz, DMSO-d_6): $\delta = 9.23$ (s, 8H, O*H*), 6.67 (s, 16H, Ar*H*), 4.55–4.67 (m, 16H, –C=CH_2), 4.37 (d, 8H, ArCH_2Ar), 3.51 (d, 8H, ArCH_2Ar), 2.26 ppm (t, 24H, CH_3-C=). – UV-Vis (THF): 232, 241, 256, 283 nm. – $C_{80}H_{80}O_8$ (1169.49): calcd. C 82.16, H 6.89; found C 82.05, H 6.80.

General procedure for syntheses of O-acetylated p-isopropenylcalix[n]arenes **(4–6)**

10.0 g of *p*-Isopropenylcalix[4]arene (0.017 mol) (**1**) were dissolved in 100 mL of pyridine, and 10 mL of acetic anhydride were added. The reaction mixture was stirred at 75 °C for 2 h and then poured into 1 L of water. The precipitate was filtered off, washed with water, and dried to yield 9.5 g of acetylated *p*-isopropenylcalix[4]arene (**4**). The chemical and physical spectral characteristics of these products **4–6** are given below.

5,11,17,23-Tetra-p-isopropenyl-25,26,27,28-tetraacetoxy-calix[4]arene ***4***: m.p. 317 °C. – IR (KBr): $\nu = 1740$ cm^{-1} (O–C=O). – ^1H NMR (400 MHz, CDCl_3-d_6): $\delta = 6.91$ (s, 8H, Ar*H*), 4.45–4.52 (m, 8H, –C=CH_2), 4,2 (d, 4H, ArCH_2Ar), 3.57 (s, 4H, ArCH_2 Ar), 2.28 (s, 12H, COCH_3), 1.68 (t, 12H, CH_3-C=). – UV-Vis (THF): 243, 256, 262, 273 nm. – $C_{48}H_{48}O_8$ (752.89): calcd. C 76.57, H 6.43; found C 76.48, H 6.39.

5,11,17,23,29, 35-Hexa-p-isopropenyl-37,38,39,40,41, 42-hexaacetoxy-calix[6]arene ***5***: Compound 5 was obtained by the same procedure as that for **4** with a 85% yield. m.p. 342 °C. – IR (KBr): $\nu = 1745$ cm^{-1} (O–C=O). – ^1H NMR (CDCl_3-d_6): $\delta = 6.92$ (s, 12H, Ar*H*), 4.51 (m, 12H, –C=CH_2), 3.58 (s, 12H, ArCH_2Ar), 2.29 (s, 18H, COCH_3), 1.59 ppm (t, 18H, CH_3-C=). – UV-Vis (THF): 243, 256, 263, 271 nm.

5,11,17,23,29,35,41, 47-Octa-p-isopropenyl-49, 50,51, 52,53,54,55,56-octaacetoxy-calix[8]arene ***6***: Compound 6 was obtained by the same procedure as that for **4** with a 95% yield. m.p. 387 °C. – IR (KBr): $\nu = 1746$ cm^{-1} (O–C=O). – ^1H NMR (CDCl_3-d_6): $\delta = 6.93$ (s, 16H, Ar*H*), 4.37 (m, 16H, –C=CH_2), 3.59 (s, 16H, ArCH_2-Ar), 2.29 (s, 24H, COCH_3), 1.6 ppm (t, 24H, CH_3-C=). – UV-Vis (THF): 242, 258, 262, 274 nm.

Metal picrates

Metal picrates were prepared by neutralizing picric acid (Merck) with the appropriate metal hydroxide or chloride in ethanol, according to the method of Wong *et al.* [21]. They were dried *in vacuo* and purified by recrystallization from absolute ethanol.

Extraction procedure

The extraction procedure employed is similar to the procedures outlined by others [22]. Stock solutions (1.0×10^{-5} M) of metal picrates were prepared in deionized water. The solutions (1.25×10^{-4} M) of the *p*-isopropenylcalix[*n*]arenes were prepared in dichloromethane. Equal volumes (5.0 mL) of the two solutions were placed in a centrifuge tube equipped with a screw cap and equilibrated for an hour in a thermostat at 25 °C. After equilibration, the whole mixture was extracted with a Vortex-Genie for 1 min. The procedure was repeated twice to ensure complete extraction. The mixture was then centrifuged for 10 min to complete phase separation. The absorbance A of the metal picrates

remaining in the aqueous phase was then measured spectrophotometrically at 355 nm. The percentage extraction values (%E) are derived from the expression $100(A_0-A)/A_{0,}$ where A_0 is the absorption of the aqueous solution in a blank experiment without calixarene. In the blank experiments no detectable picrate extraction was observed.

Results and discussion

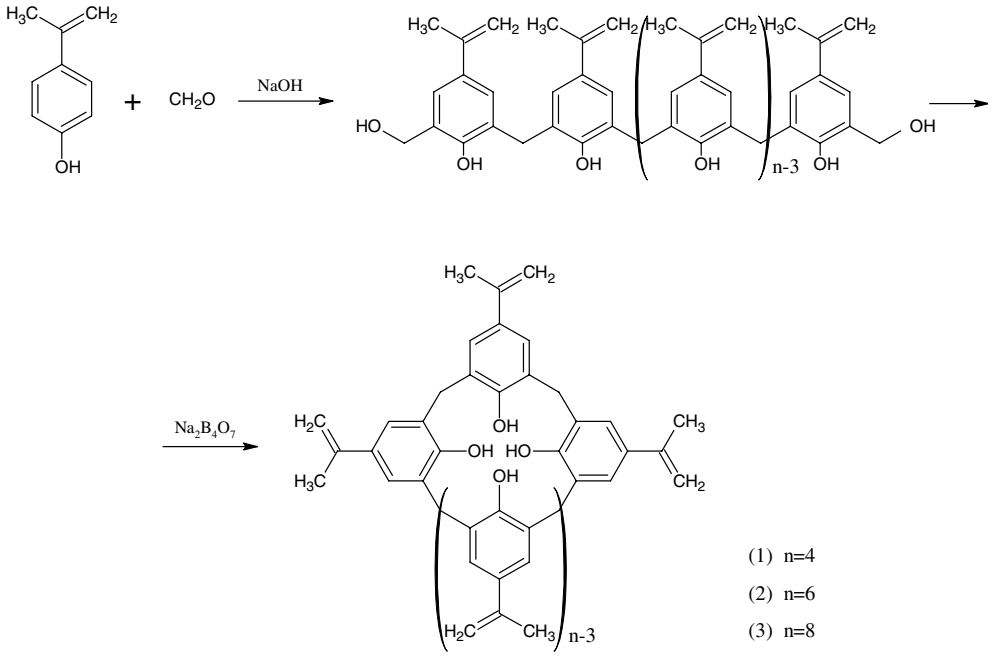
The cation-binding properties of the calixarenes depend on the nature of the functional groups attached to their lower and upper rim positions [23, 24]. A number of papers concerning the complexation abilities of *p*-tert-butylcalixarenes and their derivatives have been published [7, 24]. It has been reported that the affinity of *p*-tert-butylcalixarenes towards metal ions is greater than that of debutylated calixarenes [1]. It may be anticipated that the cation-binding properties of calix[*n*]arenes with diverse composition could be regulated by modifying both the upper and the lower rim. Recently we synthesized *p*-isopropenylcalixarenes, which have a *p*-isopropenyl group at the upper rim [18]. This group contains a double bond, which π-MO can participate in π,π-conjugation with the delocalizated π-electrons of aromatic ring. This conjugation leads to additional delocalization of the chemical bonds in the *p*-isopropenylcalixarenes and enables easier modification at the upper rim by addition reactions. On the other hand, π-MO might take part and in σ,π-conjugation with adjacent σ-MO (of CH_3 group). The presence of this hyperconjugation in the *p*-isopropenylcalixarenes supposes enhanced metal-ion complexation abilities.

Synthesis and characterization of the p-isopropenylcalix[n]arenes and of the O-acetylated p-isopropenylcalix[n]arenes

We developed a novel two-step method for the synthesis of individual *p*-isopropenyl-calix[4]arene, -calix[6]arene and -calix[8]arene with satisfactory yield. The synthetic approach is depicted in Scheme 1.

The fist step includes the synthesis of linear phenolic oligomers in a basic reaction medium, starting from *p*-isopropenylphenol and a formaldehyde source, similarly to the method described in a patent [2e]. The number of phenolic units in the oligomer is determined by the reaction conditions such as temperature, duration and relative concentration of the reactants. The chain of the oligomers becomes longer when the reaction time and the folmaledehyde–phenol ratio are increased. The linear phenolic oligomers were not separated from the reaction mixture. The second step includes the cyclization of these linear oligomers in a solvent with a high boiling point. Ethylene glycol was used as a medium, and sodium tetraborate-decahydrate as a catalyst, according to the method described earlier [18].

p-Isopropenyl-calix[4]arene (**1**), -calix[6]arene (**2**) and -calix[8]arene (**3**) were characterized by means of IR, ^{1}H NMR and UV spectroscopy, and elemental analysis. In the infrared spectrum, *p*-isopropenylcalix[4]arene exhibits a characteristic stretching band at 3300 cm^{-1} corresponding to the OH group. It is indicative of intramolecular hydrogen bonding, which is strongest for the cyclic tetramer. In the UV spectra of *p*-isopropenylcalixarenes absorption maxima at 238, 256 and 283 nm have been observed (Figure 1). The absorption maximum at $\lambda = 256$ nm is assigned to the double bond of the isopropenyl group. In the UV spectra an



Scheme 1. Synthesis of *p*-isopropenylcalix[*n*]arenes.

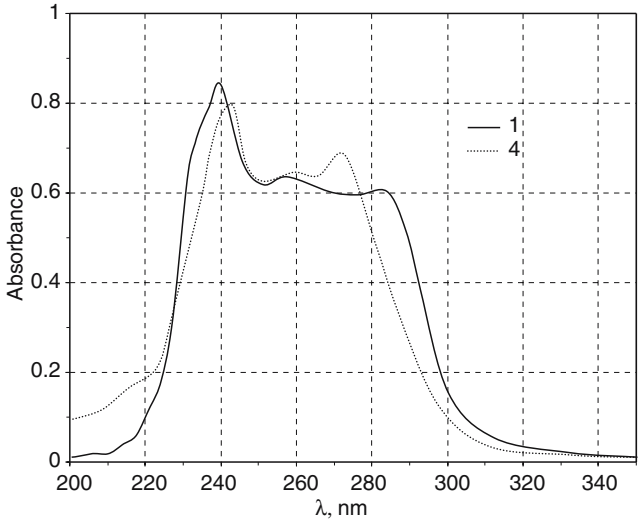


Figure 1. UV-Vis spectra of: *p*-isopropenylcalix[4]arene tetraacetate (4); parent *p*-isopropenylcalix[4]arene (1).

absorption plateau between 240 and 283 nm is observed, which is typical of a calixarene. In the ^{1}H NMR spectrum of *p*-isopropenylcalix[4]arene, the resonance of the methylene protons appears at δ 3.41 and δ 4.38, as a pair of doublets. This pattern is consistent with the presence of methylene groups linking the aromatic rings and of a cyclic structure as well. The protons from the $C=CH_2$ group, which double bond is conjugated with the aromatic ring, display resonance at δ 4.47–4.64 ppm. A special feature of the ^{1}H NMR spectrum of the *p*-isopropenylcalix[4]arene is the chemical shift to the lower field of the singlet arising from the hydroxyl proton - more than 9 ppm (9.25 ppm), which is typical of calixarenes but does not correlate with the strength of hydrogen bonding.

Acetylation of *p*-isopropenylcalix[*n*]arenes was carried out following the procedure described by Mita [16]. Acetic acid anhydride was used as O-acetylating reagent (Scheme 2). O-Acetylated *p*-isopropenylcalix[*n*]arenes (**4–6**) were obtained with high yields. The acetylated compounds were characterized by elemental analysis, and by IR, UV, ^{1}H NMR spectroscopy.

The UV spectrum of *p*-isopropenylcalix[4]arene tetraacetate (**4**) is shown in Figure 1. The main absorption bands of **4** at $\lambda = 243$ nm and $\lambda = 273$ nm are different from those of the original *p*-isopropenylcalix[4]arene. The absorption band at $\lambda = 256$ nm, which is typical of the $>C=CH_2$ double bond, did not change after acetylation.

In the ^{1}H NMR spectrum of **4** the resonance at δ 4.45–4.52 ppm, assigned to $>C=CH_2$ did not shift after acetylation. The results suggest that the isopropenyl group at the upper rim has not been modified during the acetylation of the hydroxyl groups at the lower rim. The ^{1}H NMR and IR spectral characteristics of **4** are summarized in Table 1.

The very strong absorption band at 1740 cm^{-1} is due to the presence of an ester bond. The signals at 2.28 ppm for the methyl protons of the acetyl group (–OCOCH_3) also indicate that the product is acetylated. The completeness of the acetylation is evidenced by the lack of signal for O*H* protons at 9.25 ppm in ^{1}H NMR spectrum as well as the lack of a stretching band at 3300 cm^{-1} in IR spectrum. Consequently, the final product is a fully acetylated *p*-isopropenylcalix[4]arene.

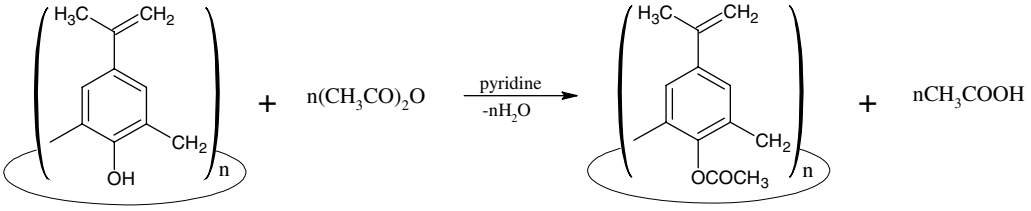
The solubility of the acetylated compounds are summarized in Table 2. Their solubility in various solvents such as acetone, methylethylketone, tetrahydrofuran, acetonitrile, ethyl acetate, chloroform, 1,2-dichloromethane was evaluated.

The incorporation of acetyl pendant groups at the lower rim of the *p*-isopropenylcalix[*n*]arens (like of *p*-tert-butylcalixarenes) significantly enhances their solubility in common organic solvents.

Extraction of metal picrates

The thermodynamic aspects of host-guest complex formation have been assessed in a variety of ways. Picrate extractions and determination of stability constants in homogeneous solution have been most frequently employed. The extraction data can be important in evaluating the cation binding properties of *p*-isopropenylcalix[*n*]arenes as a function of variables such as the size of the cavity and the presence of substituents at the lower rim.

In particular, the picrate extraction procedure is convenient to apply. Picrate salts are easily prepared. Being air and moisture stable they offer the advantage of working in open glass systems. The aqueous solutions of metal picrate salts have absorption at room temperatures in the range of 351–357 nm. All calixarenes used in the present work are insoluble in water while the metal picrate salts are insoluble in the organic phase in the



n=4 p-isopropenylcalix[4]arene tetraacetate (**4**)

n=6 p-isopropenylcalix[6]arene hexaacetate (**5**)

n=8 p-isopropenylcalix[8[arene octaacetate (**6**)

Scheme 2. Acetylation of *p*-isopropenylcalix[*n*]arenes.

Table 1. Proton NMR and IR spectral data for *p*-isopropenylcalix[4]arene (**1**) and *p*-isopropenyl-calix[4]arene tetraacetate (**4**)

Compound	^{1}H NMR (ppm)						IR (cm^{-1})	
	Ar*H*	ArCH_2Ar	O*H*	O$COCH_3$	C=CH_2	CH_3	υ_{OH}	υ_{OCO}
1	δ 6.67	δ 4.38–4.41 δ 3.41–3.51	δ 9.25	–	δ 4.47–4.64	δ 2.29	3368	–
4	δ 6.91	δ 4.2 δ 3.57	–	δ 2.28	δ 4.45–4.52	δ 1.68	–	1740

Table 2. Solubility of *p*-isopropenylcalix[*n*]arenes (**1–3**) and O-acetylated *p*-isopropenyl-calix[*n*]arens (**4–6**)

	M_w	Solubility						
		EA	MEK	AcN	$CHCl_3$	CH_2Cl_2	THF	Acetone
1	585	–	–	–	+–	+–	++	–
2	877	–	–	–	+–	+–	++	–
3	1170	–	–	–	+–	+–	++	–
4	753	++	+–	++	++	++	++	++
5	1129	++	+–	++	++	++	++	++
6	1506	++	+–	++	++	++	++	++

M_w – average molecular weight, Da; ++ soluble (5mg/mL); +– not readily soluble (> 2 mg/mL); – insoluble (< 1 mg/mL); EA – ethyl acetate; MEK – methylethyl ketone; AcN – acetonitrile; $CHCl_3$ – chloroform; CH_2Cl_2 – dichloromethane; THF – tetrahydrofuran.

absence of calixarenes. Therefore, we have employed a standard solvent extraction [22] as a convenient method for studying ionophoric properties of *p*- isopropenylcalix[*n*]arenes toward metal cations.

The solvent extraction of aqueous metal picrates was performed at 25 °C with *p*-isopropenylcalix[*n*]arenes (**1–3**) and O-acetylated *p*-isopropenylcalix[*n*]arens (**4–6**) dissolved in dichloromethane. Experiments were also performed using *p*-tert-butylcalix[*n*]arenes (**7–9**) and O-acetylated *p*-tert-butylcalix[*n*]arenes (**10–12**) as complexation agents. When the cation forms a complex with the ligand and is transported into the organic phase the picrate anion, which accompanies the complex, renders the organic phase yellow. None of picrate salt was transferred to the organic phase in the absence of a ligand.

A typical example of metal-ion extraction by calixarene derivative is presented in Figure 2. *p*-Isopropenylcalix[6]arene hexaacetate dissolved in CH_2Cl_2 reveal an absorption at $\lambda_{max} = 271$ nm. After complex formation with metal picrate a new absorption appears at $\lambda_{max} = 394$nm and the color of the calixarene solution changed to yellow.

Table 3 summarizes the results of the extractions carried out with different picrate salts. They demonstrate that the acetylated calixarenes extract the metal ions more effectively than the corresponding parent calixarenes. The data in Table 3 suggest that *p*-isopropenylcalix[*n*]arenes (**1–3**) are relatively inefficient metal picrate extractants. They are not able to extracted Zn^{2+}, Cu^{2+}, NH_4^+, Al^{3+} picrates. However, they display pronounced affinity towards Rb^+ and Cs^+ picrates. The efficiency of metal ion complexation by *p*-isopropenylcalix[6]arene (**2**) decreases in the following sequence: $Rb^+ > Cs^+ > Li^+ > Co^{3+} > Na^+ > K^+ > Mg^{2+}$. The compound **2** has a metal-ion complexation ability better than that of *p*-isopropenylcalix[4]arene (**1**) and *p*-isopropenylcalix[8]arene (**3**). Evidently, the cation interaction with calixarenes depends not only on the nature of the cation but is also sensitive to the structure of the calixarene.

The diameter of the calixarene cavity at the oxygen atoms of the phenolic hydroxyl group is known to be: ca. 1.0 Å for the cyclic tetramer, 2.4 Å for the cyclic hexamer, and 4.8 Å for the cyclic octamer [1]. Thus the opening of the cyclic *p*-isopropenylcalix[6]arene (**2**)

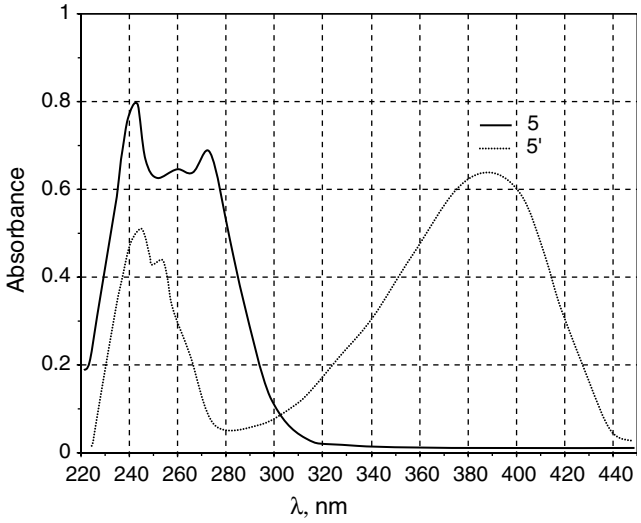


Figure 2. UV-Vis spectra of *p*-isopropenylcalix[6]arene tetraacetate (5) and its complex with Rb picrate (5′).

Table 3. Percentage of extraction of aqueous metal picrates by derivatives **1–12** dissolved in dichloromethane[a]

Calixarene Ligand	Percent of picrate extracted (%)[b]											
	Li^+	Na^+	K^+	Rb^+	Cs^+	Zn^{2+}	Cu^{2+}	Ba^{2+}	NH_4^{2+}	Al^{3+}	Co^{3+}	Mg^{2+}
1	0.5	0.6	0.4	1.4	1.6	0	0	0.4	0	0	0.9	0.3
2	1.2	0.8	0.5	6.5	3.5	0	0	0.7	0	0	0.9	0.5
3	0.8	0.4	0.3	4.8	0.9	0	0	0.2	0	0	0	0
4	8.7	5.1	5.8	8.4	5.4	1.6	2.7	6.0	0.7	0	4.1	4.0
5	31.3	30.3	28.3	63.2	22.8	20.6	24.0	26.3	19.6	16.3	15.9	16.3
6	2.9	3.2	3.4	4.1	3.1	1.7	1.8	4.3	2.3	0	3.7	2.7
7	0.9	0.5	0.7	1.2	1.1	0	0	1.3	0	0	1.6	1.1
8	0.9	0.5	0.5	1.3	1.3	0	0	1.7	0	0	1.6	1.2
9	1.0	0.5	0.8	1.5	1.5	0	0	0.9	0	0	0	0
10	3.2	0.9	4.7	3.9	3.5	5.8	12.4	5.9	3.3	9.4	2.5	5.4
11	5.3	6.6	4.3	9.0	9.5	14.9	19.6	5.5	5.4	21.5	2.2	4.8
12	0	0	1	0	2.8	0	1.5	4.7	0	0	0.8	0.4

[a]Temperature 25 °C; aqueous phase (5 mL), [picrate] = 1×10^{-5} M; organic phase (dichloromethane, 5 mL), [ligand] = 1.25×10^{-4} M.
[b]Defined as percent picrate extracted into the organic phase (average of three independent extraction experiments).

might fit the size of Li cation better than **1** and **3** do. However, as a whole, the *p*-isopropenylcalix[*n*]arenes slightly extract metal picrates. Their extractabilities are comparable with those of the unmodified *p*-tert-butylcalixarenes.

Since one of the main interests in this study was to assess the effect of the substituent at the lower and upper rim of calyx[*n*]arene on its complexation properties O-acetylated *p*-isopropenylcalix[*n*]arenes and O-acetylated *p*-tert-butylcalix[*n*]arenes were prepared. The data summarized in Table 3 show that the acetylated derivatives exhibit better extraction properties compared to those of the parent compounds. Consequently, the introduction of acetyl pendant groups at the lower rim of calix[*n*]arenes increases their extraction affinity toward metal picrates. In contrast to parent *p*-isopropenyl- and *p*-tert-butyl-calixarenes, the acetylated derivatives showed some affinity towards Zn, Cu and NH_4 picrates. For Al picrate, compounds 4–6 showed low extractabilities compared with 10–12. From all studied *p*-isopropenylcalixarenes only compound **5** is able to extract Al picrate (16.3%). The metal-ion extraction by *p*-isopropenylcalix[6]arene hexaacetate (**5**) decreases in the following sequence: Rb^+ (63.2%) > Li^+ (31.3%) > Na^+ (30.3%) > K^+ (28.3%) > Ba^{2+} (26.3%) > Cu^{2+} (24%) > Cs^+ (22.8%) > Zn^{2+} (20.6%) > NH_4^+ (19.6%) > Al^{3+} (16.3%) = Mg^{2+} (16.3%) > Co^{3+} (15.9%). Besides, this compound (**5**) shows ten times higher avidity to Rb^+ compared to the parent compound **2** and seven times higher avidity to Rb^+ compared to the compounds **11**. The extractability of **5** to Rb picrate was high (63.2%) and showed good selectivity for metal picrates. Moreover, its extractability towards all metal picrates is higher than that of compounds **4** and **6**.

Compared with the cation-binding ability of O-acetylated *p*-isopropenylcalix[*n*]arenes (**4–6**), O-acetylated *p*-tert-butylcalix[*n*]arenes (**10–12**) showed lower affinity towards metal cations. Obviously, influence upon metal-ion extractability of calixarenes renders not only the substituent at the lower rim but also the type of the substituent at the upper rim. The higher affinity of acetylated *p*-isopropenylcalixarenes to metal picrates probably is due to the presence of a double bond at the upper rim, which π-MO on one hand takes part in π,π-conjugation (with the delocalizated π-electrons of aromatic ring) and on the other hand takes part in σ,π–conjugation (with adjacent σ-MO). The presence of such conjugations and electron donating group at the upper rim in *p*-isopropenylcalixarenes might be the cause for their higher cation-binding ability.

Conclusions

Individual *p*-isopropenylcalix[*n*]arenes (where $n = 4, 6, 8$) noted **1, 2, 3** and their acetate-derivatives i.e. **4, 5** and **6** have been synthesized applying a two-step procedure. Their chemical structure has been confirmed by FT-IR, UV, and ^{1}H NMR spectroscopy. The complexation properties of these novel compounds (**1–6**) have been evaluated via metal picrate extraction experiments. The acetylated derivatives (**4–6**) show better extraction ability towards metal picrates compared to that of the parent *p*-isopropenylcalixarenes. The data for the percent extraction suggest that the acetylated *p*-isopropenylcalix[6]arene (**5**) is the most effective extracting agent for metal picrates, especially for Rb^+, and displays selectivity for metal picrates. It has been demonstrated that the O-acetylated *p*-isopropenylcalix[*n*]arenes (**4–6**) extract the metal cations more effectively than O-acetylated *p*-tert-butylcalix[*n*]arenes (**10–12**).

In conclusion, the *p*-isopropenylcalixarene derivatives have potential for selective complex-formation with different metal-ions and especially for Rb salts.

Acknowledgements

The authors are indebted to the financial support from University of Chemical Technology and Metallurgy, Sofia, Bulgaria (Grant No 10143).

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