



Extracting and complexing properties of di-, tri- and tetra ThiaCalix [4] arenes

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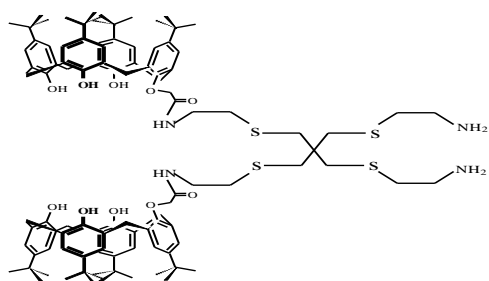
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Abstract: In the present work, the focus is the study of complexing and extracting properties of three nanoscale derivatives namely multicalixarenes 2C, 3C and 4C which the latter structure is a dendrimer structure of first generation. The metal cations included in this study are the alkali metal, alkaline earth metal, some transition metals, heavy metals and lanthanides. This study was conducted essentially in methanol to determine the stoichiometry of the complexes formed, or the location of the coordination sites, and finally to evaluate selectivity's. These studies have been conducted by UV-visible spectrophotometry, conductivity and proton NMR. The liquid-liquid extraction picrates metal cations followed by UV-visible showed strong selectivity dicalixarenic derived for sodium. The solid liquid extraction of metal picrates followed by ¹H-NMR shows an intra- or intermolecular exchange of cations within the calixarene units studied nanocomposites.

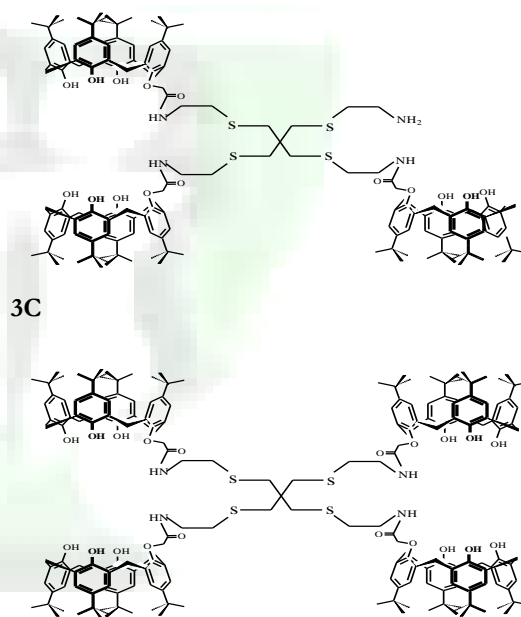
Key words: Dendrimer; complexation; Extraction; UV spectrophotometry; Conductometry; ¹H-NMR

Introduction

Calixarenes have been widely exploited in all areas of supramolecular chemistry over the past three decades [1-5] and many recent developments have concerned their applications in the production of chemical entities with the dimensions of nanometers, as in “nanochemistry” [6]. A special family of new molecular nano-objects based on the chemistry of calixarenes associated to the one of dendrimers are the ‘calix-dendrimers’ or multi-calixarenes [7-10]. Recently Matthews and co-workers have prepared amino-functionalized multi-calixarenes which low cellular toxicity, effective DNA binding and, when featuring aliphatic amines, are efficient gene transfection agents [11]. The present note reports the complexation properties of three hyper branched molecules 2C–4C constructed by the reaction of tetrapodal C(CH₂SCH₂CH₂NH₂)₄ with monocarboxylethylcalix[4] arene in a previous work [12].



2C



3C

4C

Figure I: Studied derivatives

These multi-calixarenes contains three potential chelating sites at the level of the N, S atoms, OH functionalities and primary amido groups. The complexation study was investigated behavior of alkali, alkaline earth, transition metals and lanthanides. This study was conducted by Uv-spectrophotometry, Conductometry and ¹H-NMR. The extraction experiments of M^{x+} metal

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picrates from water into dichloride methane were performed according to a procedure described in the literature [13-14].

Materials and Methods

¹H NMR, Bruker SY 200 (300 MHz, δ in ppm from TMS, in CDCl₃, TMS as standard). All products and solvents were commercial and used without further purification. The UV spectra were recorded on a Perkin Elmer Lambda (11) spectrophotometer. Conductance measurements were recorded on a conduct meter Tacussel CDM210 with cell constant 0.719.

Extraction Studies

The extraction experiments of metal picrates from water into dichloride methane were performed according to a procedure described in the literature [13-14]: Equal volumes (5 ml) of neutral aqueous solution of metal picrate (2.5×10^{-4} M) and CH₂Cl₂ solution (5 ml) of calixarene derivatives (2.5×10^{-4} M) were mixed and magnetically shaken in a thermo-regulated water bath at 20°C for 30 min and then left standing for 2 to 6 h in order to obtain a complete separation of the two phases. The concentration of metal picrate remaining in the aqueous phase was determined from the absorbance *A* at 355 nm. The percentage extraction (%E) was derived from the following expression in which *A*₀ is the absorbance of the aqueous solution of a blank experiment without calixarene: %E = 100(*A*₀ - *A*)/*A*₀

Stability constant measurements



The stability constants β_{xy} being the concentration ratios $[M_xL_y^{xn+}]/[M^{n+}]^x[L]^y$ and corresponding to the general equilibrium:



(where *M*^{*n*+}=metal ion, *L* = ligand) were determined in methanol by UV-absorption spectrophotometry at 25°C. The ionic strength was been maintained at 0.01 M using Et₄NNO₃. The spectra of ligand solutions of concentrations ranging between 10⁻⁴ and 2×10⁻⁴ M and increasing concentration of metal ion were recorded between 240 nm and 320 nm. Generally, the metal to ligand ratio *R* at the end of the titration did not exceed 20 and the equilibria were quasi-instantaneous for all the systems. Addition of the metal ion salts to the ligand induced in the spectra changes large enough to allow the analysis of the resulting data using the program "Letagrop"⁷. Best values for the formation constants β_{xy} of the various complex species and their molar absorptivity coefficients for various wavelengths, are deduced from the best fit between the experimental and calculated UV spectra. The best fit is reflected by the lowest value of *U* (the sum of *U* values for all lambda given) corresponding to the square sum of a differences

between experimental and calculated absorbance's ($U = \sum (A_{cal} - A_{exp})^2$). The β_{xy} values correspond to the arithmetic means of at least three independent experiments.

Results and Discussion

Extraction study

Power extracting derivatives 2C, 3C and 4C of picrates alkali metal cations is evaluated by determining the extraction percentage (% E) from water to dichloromethane. The extraction percentages of picrates alkali metal cations are summarized in Table I.

Table I: % E of alkali picrates from water to dichloromethane (à 20°C)

	Li ⁺	Na ⁺	K ⁺	Rb ⁺	Cs ⁺
2C	a	55.22	a	a	a
3C	49.15	69.32	21.63	27.42	30.02
4C	67.51	78.25	43.80	45.83	44.67

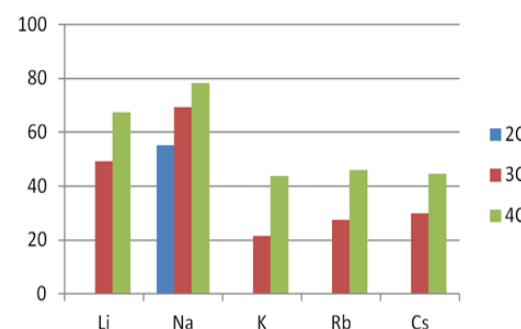


Figure II: representation of extraction percentages of the three derivatives

Based on these results, we have found that ligands behave very differently, in fact, a ligand have no affinity with almost all picrates studied (2C), a ligand with a moderate power extracting Towards all picrates studied (3C) and a ligand how has the best extracting percentage (4C). These results lead us to conclude that the number of the calixarenic units are the only factors dominate the extraction since the three ligands that differ only by these two factors.

Note the high selectivity of 2C ligand for the sodium in the series of alkali cations, since none of the other cations is extracted. This selectivity is particularly important as that observed in the case of ligand 3C. Indeed, the latter extract the Na⁺ 20 times more than Li⁺ and 50 to 40 times more than K⁺ and Cs⁺, respectively. These results suggest the conclusion that the three ligands are selective for Na⁺.

Complexation study

UV-Spectrophotometry: The general form of the spectrum of ligands is preserved from the beginning until the end of the complexation. The reports of the end of complexation are between

1.5 and 15.5. The UV absorption spectra relating to the complexation of Eu^{3+} show a hyperchromic shift at the shoulder. Two isobestic points are formed with Eu^{3+} translating one balance (Figure III). For La^{3+} , a single point isobestic formed. The reports of the end of complexation are between 1.5 and 4.8.

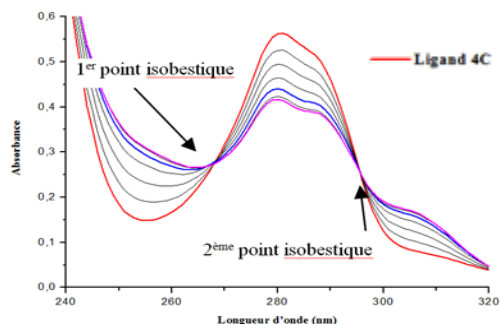


Figure III: UV absorption spectra relating to the complexation of Eu^{3+} by the ligand 4C in methanol ($C_L = 2,65 \times 10^{-5}\text{M}$)

From these spectral changes, we determined the stoichiometry and the stability constants of the formed species presented in Table II.

Table II: Stability of the complexes of the ligands 2C, 3C and 4C with studied metals in methanol

	ML	Li^+	Na^+	K^+	Rb^+	Cs^+
2C	1:1	$3,26 \pm 0,06$	$4,96 \pm 0,10$	$3,9 \pm 0,05$		
	2:1				$8,94 \pm 0,06$	$8,58 \pm 0,09$
3C	1:1	$3,45 \pm 0,07$	$3,56 \pm 0,03$	$3,23 \pm 0,01$		
	2:1				$8,68 \pm 0,07$	$8,79 \pm 0,01$
4C	1:1	$2,91 \pm 0,13$	$3,42 \pm 0,04$			
	2:1			$8,07 \pm 0,03$	$7,8 \pm 0,04$	$8,74 \pm 0,04$

	ML	Ni^{2+}	Cu^{2+}	Cd^{2+}	Hg^{2+}
2C	1:1			$4,64 \pm 0,03$	$3,56 \pm 0,01$
	2:1	$9,19 \pm 0,06$	$9,51 \pm 0,13$		
3C	1:1	$4,28 \pm 0,05$		$4,98 \pm 0,10$	$4,60 \pm 0,08$
	2:1		$8,77 \pm 0,07$		
4C	1:1	$4,02 \pm 0,04$	$4,51 \pm 0,01$	$4,25 \pm 0,05$	$5,73 \pm 0,01$

	ML	Eu^{3+}	La^{3+}
2C	1:1		$5,59 \pm 0,01$
	2:1	$8,91 \pm 0,02$	
3C	1:1		$4,74 \pm 0,14$
	2:1	$8,97 \pm 0,02$	
4C	1:1		$6,37 \pm 0,03$
	2:1	$9,9 \pm 0,01$	

Complex stability profiles of the three ligands ML type with alkali metals in methanol are shown in Figure IV.

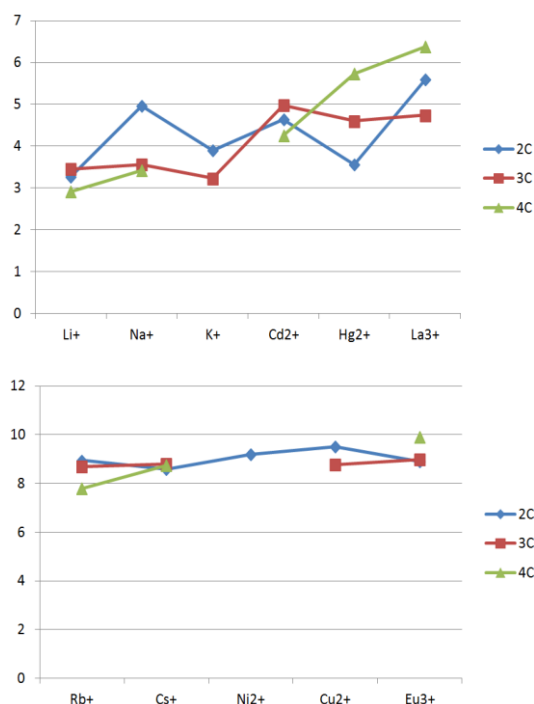


Figure IV: Complex cations stability profiles (a) ML type; (b) M_2L type with 2C, 3C and 4C

In examining the results for the mononuclear species, we note that, for alkali, selectivity's to grow in this direction: $4\text{C} < 3\text{C} < 2\text{C}$. For other cations (Cd, Hg and La), selectivity's grow in the opposite direction to the previous, in effect: $2\text{C} < 3\text{C} < 4\text{C}$. This can be explained by the polyvalent cations made that need more donor sites are better stabilized in the complex while the monovalent cations require the least number of these sites to better complex. Therefore, a larger number of chelating site cavity cause an exchange possibility therefore complexing less stability. The same conclusion is valid for the binuclear species.

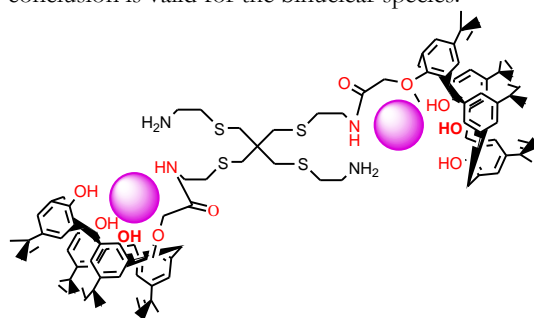


Figure V: Proposal location of cations in the 2C cavities for M_2L complex

Conductometric Titration

In order to confirm the stoichiometry of the complexes obtained by UV spectrophotometry, we proceeded with the conductivity. A ligand solution was assayed by increasing volumes of a solution of metal. Monitoring the conductance of the solution allowed to trace the curve showing the variation of the conductance as a function of $R_{\text{M/L}}$ ratio. The

report corresponding to the change of the slope allows us to determine the stoichiometry of the formed species. The curves obtained show that the conductivity increases as a function of increasing amounts of the added metal. The metal is in this free event. Once complexation has occurred, the conductance decreases slightly. The metal included in the calixarenic structure becomes less mobile. As shown in Figure VI as an examples, in the case of titration of the derivative 3C by cesium and derivative 4C by potassium, induce variations in conductance as a function of $R_{M/L}$ ratio, that shows a change in slope at a ratio of two. The complex formed is M_2L . That confirms the results obtained by UV spectrophotometry.

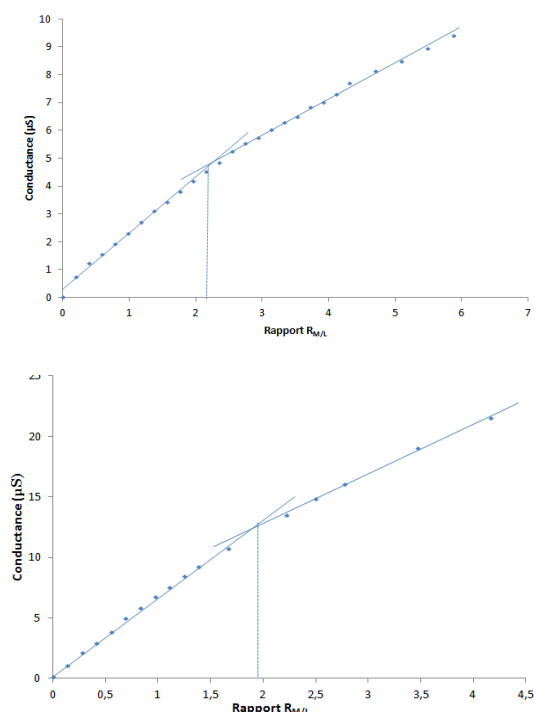


Figure VI.(a): Conductimetric titration of 3C ligand by Cs^+ ; (b) Conductimetric titration of 4C ligand by K^+ .

In conclusion, from Conductivity measurements, we can confirmed the determined stoichiometry obtained by UV spectrophotometry.

¹H-NMR

The study of the complexation by UV spectrophotometry is a technique which we have used to determine the stoichiometry and the stability constants of the complexes formed. At another stage and in the aim to locate the site responsible for the complexation of the cation, we proceeded to the study of solid-liquid extraction of some metallic picrates by the three calixarene derivative (2C, 3C and 4C) in the deuterated chloroform followed by proton NMR.

According to the proton NMR spectrum of the complex (4C. Cs^+), we note that the most significant changes in the chemical shifts are those relating to CONH proton amide functions, followed by proton CH_2 groups of heart and those of CH_2 of methylene bridges calixarene units. Complexation also affects proton groups ArOH, OCH_2CO , CH_2NH and Ar.

In conclusion, the complexation of Cs^+ by the ligand 4C affects all hydrogens including those in the heart of the dendrimer suggesting that the inclusion of the two cations leads to a rearrangement of the molecule to better coordinate them.

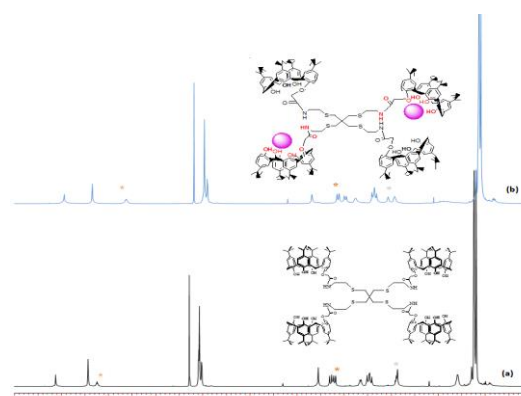


Figure VII: ¹H-RMN ($CDCl_3$) spectrum of (a) 4C ligand and (b) 4C. (Cs^+)₂ complex

By examining changes in chemical shifts of 4C derived following the complexation of Li^+ , we note that the most important are those relating to CONH proton amide functions followed by those protons CH_2 of methylene bridges calixarene units.

In comparison with the spectrum of the complexation of Cs^+ by 4C, we note that the 4C- Li^+ complexation spectrum shows by lower chemical shifts. In addition, the proton OCH_2CO groups, CH_2N and $C(CH_2)_4$ are hardly affected. The lack of movement variation of these protons suggests an external complexation compared to the heart of the dendrimer. Furthermore, compared to the spectrum of the complexation of Cs^+ by 4C where the signals are well defined, the signals corresponding to the complexation of Li^+ coalescing suggesting an exchange of the cation is intra or intermolecular (Figure VIII).

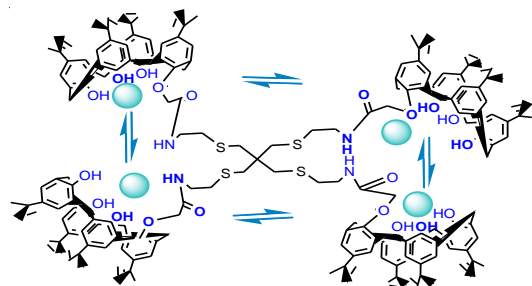


Figure VIII: Possibility of intramolecular exchange of the Cesium cation in the 4C derivative

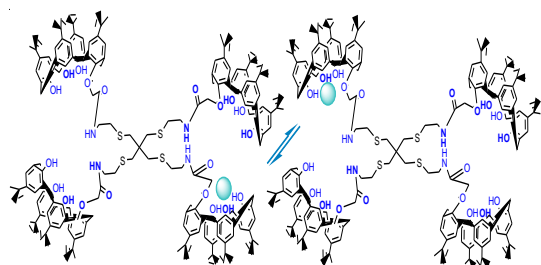


Figure IX: Possibility of intramolecular exchange of the Lithium in 4C cavities

In the presence of ligand 4C, the divalent mercury picrate is extracted from its solid state in deuterated chloroform. Spectral variations confirmed and leave out that the most affected protons by this complexation are those of CONH, ArOH and some of those of the group C(CH₂)₄. Therefore, likely mercury cation coordination engages in at least the oxygen atoms of the carbonyl and phenolic oxygens as those provided by the results obtained by UV spectrophotometry.

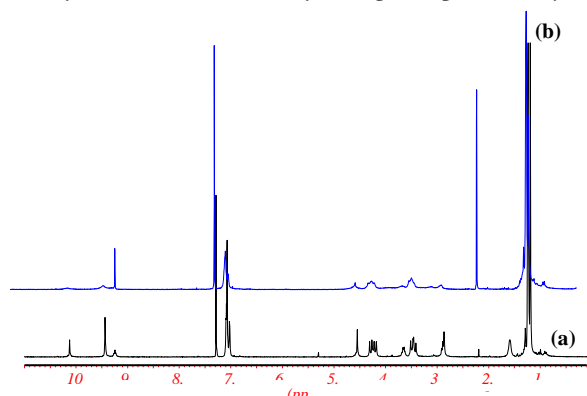


Figure X: ¹H-RMN (CDCl₃) spectrum of 4C ligand (a) and complex 4C. (Hg²⁺) (b)

The ¹H-NMR spectrum of the lithium picrate extraction by 3C derivative shows a significant coalescence of signals. Therefore, integration curves are undefined and unclear, which did not allow us to calculate changes in chemical shifts with precision. We stuck to extract specific information picrates proton signal, which is a broad singlet appears at 8.92 ppm and whose integration ratio to Ar proton signal confirms the formation of a species ML (figure XI). Again, there is coalescence of the spectrum when the Li⁺

complexing suggesting a cation exchange inter- or intramolecularly in the presence of the ligand 3C.

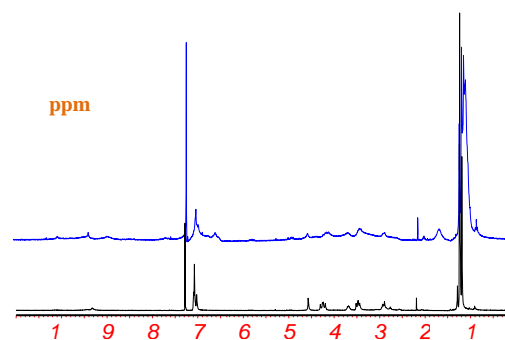


Figure XI: ¹H-RMN spectrum (CDCl₃) of (a) 3C ligand and (b) complex 3C. (Li⁺)

¹H-NMR spectrum recorded after the extraction of metal picrate shows the formation of a binuclear species M₂L determined from the integration ratio of the signal of the picrate. Changes in chemical shifts are generally low and neighboring 0 ≤ Δδ (ppm) ≤ 0.11, but still more important for calixarene protons such as ArCH₂Ar, Ar-H suggesting proximity cations there.

Conclusion

In this project, the interest has focused on the study of complexing and extractant properties of calix-dendrimer derivatives. Three ligands, of which the number of calixarene units around the central heart varies, were used. Extraction picrates of alkali metal cations by 2C, 3C and 4C derivatives show a high selectivity for sodium. The obtained results by UV-Vis spectrophotometry in methanol shows that the size of the cations is a dominant factor for the nature of the species on the one hand and for the stability of mononuclear complex (Li⁺, Na⁺, K⁺) on the other hand unlike binuclear.

As regards the obtained stoichiometries complexes with alkali metal cations, results are difficult to interpret given the structure of the three ligands studied: mononuclear with small cations and binuclear with large cations. As for transition metal cations, adding a calixarenic unit promotes the formation of the complex type ML and highlights the importance of the contribution of NH₂ groups to coordinate the second cation in the case of M₂L particularly in the case of copper. For heavy metal cations, the three ligands form mononuclear complexes with La³⁺ and binuclear complexes with Eu³⁺. The stability of complexes is improved while adding a unit calixarenic suggesting the intervention of calixarene oxygen in coordination of cations. At another point, the conductivity has been used as a technique for confirming the stoichiometrie's obtained by UV-Vis spectrometry.

The solid-liquid extraction of picrates metal followed by $^1\text{H-NMR}$ shows an intra- or intermolecular exchange of Li^+ cations in the dendrimer 4C and 3C cavities. These results are derived from the coalescence of signals during the complexation. Complexation of Cs^+ by 4C provides a spectrum whose signals are well defined and almost all hydrogens are affected. The cavity formed by all hard sites (oxygen and nitrogen) of the amine function may be suggested as locating Cs^+ cations in 4C.

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