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Complexation and Transport of Alkali and Alkaline Earth Metal Cations by *p-tert*-Butyldihomooxacalix[4]arene Tetraketone Derivatives

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Complexation and Transport of Alkali and Alkaline Earth Metal Cations by *p-tert*-Butyldihomooxacalix[4]arene Tetraketone Derivatives

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The binding properties of three *p-tert*-butyldihomooxacalix[4]arene tetraketone derivatives (*tert*-butyl 2b, adamantyl 2c and phenyl 2d) in the cone conformation and one derivative (methyl 2a) in a partial cone conformation, towards alkali and alkaline earth metal cations have been established by extraction studies of metal picrates from water into dichloromethane, stability constant measurements in methanol and acetonitrile, and by ^{1}H NMR spectrometry. Transport experiments of metal picrates through a dichloromethane membrane were also performed. The results are compared to those obtained with closely-related calix[n]arene derivatives (*n* = 4 and 5) and discussed in terms of the substituents, size and conformational effects. Methylketone 2a is a poor binder for all the cations studied, due to its partial cone conformation. Ketones 2b, 2c and 2d show high extraction and complexation levels for the alkali cations, with similar profiles and preference for K^+ and Na^+ (plateau selectivity). Towards alkaline earth cations, these ketones show a strong peak selectivity for Ba^{2+} in extraction, but a plateau selectivity for Ca^{2+}, Sr^{2+} and Ba^{2+} in complexation. The nature of the substituent attached to the ketone function has some influence on their binding properties, with phenylketone 2d being a slightly weaker binder than ketones 2b and 2c. ^{1}H NMR titrations confirm the formation of 1:1 complexes between the ketones and the cations studied, also indicating that they should be located inside the cavity defined by the phenoxy and carbonyl oxygen atoms. Ketones 2b, 2c and 2d show transport rates that do not follow, in general, the same trends observed in extraction and complexation.

Keywords: Calixarene; Dihomooxacalix[4]arene; Ketone derivative; Metal binding; ^{1}H NMR titration; Transport

INTRODUCTION

Over the last fifteen years the interest in calixarenes [1,2] has increased nearly in an exponential way. One of the most important features of these compounds is their diversity. Calixarenes find applications [3,4] as catalysts, as sensors (ion- and molecule-selective electrodes, field effect transistors, chromogenic and fluorescent sensors, non-linear optical compounds), as model structures for biomimetic studies, and in ion and molecular separations. More than 300 patents have been issued for a variety of practical applications of calixarenes. Many of these describe the use of calixarenes in systems in which selective ion complexation plays the main role.

Recent research in the host–guest chemistry of calixarenes has shown the vast ability of these compounds as selective binders and carriers, and also as building blocks for the construction of highly complex host molecules. The parent compounds are readily available and can be further lower or upper rim functionalised into a variety of derivatives. Many studies have focused on the binding ability towards metal ions, predominantly alkali and alkaline earth cations, of calixarene derivatives bearing carbonyl groups at their lower rims [5,6]. Among these derivatives, functionalised calix[n]arenes (mainly $n = 4$ [7–13], but also $n = 5$ [14], $n = 6$ [9,11,14] and $n = 8$ [9,11]), biscalix[4]arenes [15,16]

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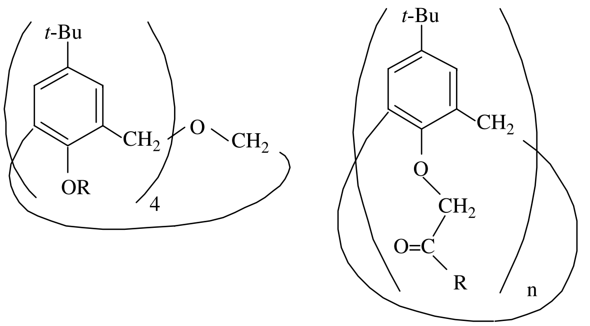


1 R = H

2a R = CH_2COMe

2b R = CH_2COBu^t

2c R = CH_2COAd

2d R = CH_2COPh

3a R = Me n = 4

3b R = Bu^t n = 4

3d R = Ph n = 4

4a R = Me n = 5

4b R = Bu^t n = 5

FIGURE 1 Structural formulae of calixarenes.

and thiacalix[4]arenes [17] with ketone groups have been synthesised and studied.

Dihomooxacalix[4]arenes with extra oxygen and carbon atoms in the macrocyclic ring are more flexible molecules than calix[4]arenes, but still possess a cone conformation. Thus, they are potential host molecules for larger cations. For some years, we have been synthesising dihomooxacalix[4]arene derivatives with carbonyl group containing substituents on the lower rim. The binding properties of such compounds bearing ketone [18], ester [19] and amide [20] groups towards alkali and alkaline earth metal cations have been reported.

The present paper reports the binding properties of four tetraketone (methyl **2a**, *tert*-butyl **2b**, adamantyl **2c** and phenyl **2d**; Fig. 1) derivatives of *p-tert*-butyldihomooxacalix[4]arene (**1**) towards alkali and alkaline earth metal cations. This has been assessed by extraction studies of metal picrates from an aqueous solution into dichloromethane, stability constant measurements in methanol and acetonitrile based on UV absorption spectrophotometry, and by proton NMR titrations. Transport experiments of metal picrates through a dichloromethane membrane were also performed. The results are discussed in terms of the influence that different substituent groups attached to the ketone function may have on the binding ability of the ligands. The data are also compared to those obtained with closely-related calix[4]- and [5]arene derivatives.

RESULTS AND DISCUSSION

Extraction Studies

The ionophoric properties of tetraketones **2a**, **2b**, **2c** and **2d** towards alkali and alkaline earth metal cations were first evaluated by the standard picrate extraction method [21]. The results, expressed as a percentage of cation extracted (% *E*), are reported in Table I. The corresponding values for tetraketones **3a** and **3d**, and pentaketones **4a** and **4b** are included for comparison. Those compounds had already been prepared. *tert*-Butyl [22], adamantyl [22] and phenyl [18] ketones possess the cone conformation in solution, while methylketone [22] presents a partial cone conformation (partial cone B) [23].

The data reveal that the three ketones (**2b**, **2c** and **2d**) in the cone conformation show high extraction levels for all the alkali cations (% *E* ranges from 23 to 85). Potassium is the best extracted (% *E* ranges from 70 for **2d** to 85 for **2c**), although ketones display a plateau selectivity between that cation and Na^+, with a slight preference for the former. As observed by us before for diethylamide dihomooxa derivative [20], this behaviour is due to their larger cavity sizes and, consequently, higher conformational flexibility, compared with that of the calix[4]arene analogues. In fact, dihomooxacalix[4]arenes fall between calix[4] and [5] arenes. Ketones **3a** [14] and **3d** [18] (Table I), being more rigid, show a sharp peak selectivity for Na^+, as do the majority of the calix[4]arenes. On the contrary, ketone **4b** [14] has an even larger cavity size, although still possessing a cone conformation, and therefore shows a plateau selectivity from Na^+

TABLE I Percentage extraction of alkali and alkaline earth metal picrates from H_2O into CH_2Cl_2[†],[‡]

	Li^+	Na^+	K^+	Rb^+	Cs^+	Mg^{2+}	Ca^{2+}	Sr^{2+}	Ba^{2+}
Ionic radius[¶]/Å	0.78	0.98	1.33	1.49	1.65	0.78	1.06	1.27	1.43
2a	1.0	4.2	8.7	6.4	3.7	0.46	2.6	1.7	1.6
2b	26	76	81	62	28	16	13	21	52
2c	23	82	85	66	30	13	15	23	63
2d[§]	62	68	70	55	26	14	9.6	17	57
3a[‖]	6.5	42.3	8.7	7.6	9.6	–	–	–	–
3d[§]	15	55	27	26	17	7.2	6.8	8.4	6.0
4a[‖]	0.5	1.7	10.2	11.2	7.8	–	–	–	–
4b[‖]	58.4	80	81.9	81	79	–	–	–	–

[†] $C_M = C_L = 2.5 \times 10^{-4}$ M, organic to aqueous phase ratio = 1, *T* = 25°C. [‡] Values with uncertainties less than 5%. [¶] Goldschmidt, V. M. *Skrifter Norske Videnskaps-Akad. Oslo, I, Mat.-Naturv. Kl,* **1926**; data quoted in Marcus, I. *Ion Properties*; Marcel Dekker: New York, 1997; pp. 46–47. [§] Data taken from Ref. [18]. [‖] Data at 20°C taken from Ref. [14].

to Cs^+ with almost no discrimination between them. The extraction of alkali metal cations by *tert*-butyl and adamantyl ketones of *p-tert*-butylcalix[4]arene was carried out some time ago with metal picrates, but in basic conditions [9]. Therefore, the comparison with the present data determined in neutral conditions is not possible.

The nature of the residue attached to the ketonic carbonyl groups has some influence on the extraction level. Except for the smallest cations (Li^+ and Mg^{2+}), adamantylketone (**2c**) shows the highest phase-transfer percentages, closely followed by *tert*-butylketone (**2b**) and more distantly by phenylketone (**2d**). However, it is important to point out the very high extraction level of Li^+(62%) exhibited by this ketone. The higher basicity of the carbonyl oxygens in derivatives **2b** and **2c** due to the presence of the *tert*-butyl and adamantyl groups, respectively, more donating than the phenyl group (ketone **2d**), can explain the obtained results. Moreover, the larger size of adamantyl group compared to that of *tert*-butyl, can produce a better preorganization of the ligand prior to extraction.

Methylketone **2a** is a very poor phase-transfer agent for all the cations studied, which appears to be due to its conformation. In the partial cone conformation only six donating sites can surround the cation, compared to the eight sites in the cone conformation. However, **2a** shows a small preference for K^+(9% *E*), as do the other ketones. The behaviour of **2a** is similar to that described for methylketone **4a** [14] (Table I), which is conformationally mobile at room temperature.

In the alkaline earth cation series, the most important aspect of the extraction data is the very high extraction level shown by ketones **2b**, **2c** and **2d** for Ba^{2+}, compared with the low percentages displayed towards the other cations. As mentioned before, adamantylketone is also the best extractant for the alkaline earth metal cations, but phenylketone shows in general the highest selectivity towards Ba^{2+}($S_{Ba^{2+}/Sr^{2+}} = 3.4$; $S_{Ba^{2+}/Mg^{2+}} = 4.1$; $S_{Ba^{2+}/Ca^{2+}} = 5.9$.)

Complexation Studies

The stability constants β of alkali and alkaline earth metal 1:1 complexes were determined in methanol and acetonitrile for ligands **2a**, **2b** and **2d** by UV absorption spectrophotometry from the spectral changes undergone by the ligands upon stepwise addition of the metal ions in solution. Limitations in solubility prevented adamantylketone **2c** from being studied.

Table II summarizes the results in both solvents and allows comparison with the data for *tert*-butylketone **3b** in methanol and for phenylketone **3d** in acetonitrile, obtained previously by us [9]. They

TABLE II Stability constants ($\log \beta$)† of alkali and alkaline earth metal 1:1 complexes in methanol and acetonitrile ($I = 10^{-2}$ M, Et_4NCl or Et_4ClO_4, $T = 25°C$)

Solvent	Ligand	Li^+	Na^+	K^+	Rb^+	Cs^+	Mg^{2+}	Ca^{2+}	Sr^{2+}	Ba^{2+}
MeOH	**2a**	≤1.5	≤1.5	≤1.5	≤1.5	≤1.5	≤1.5	≤1.5	≤1.5	≤1.5
	2b	2.9 ± 0.2	5.00 ± 0.07	5.86 ± 0.06	4.6 ± 0.1	4.16 ± 0.07	2.16 ± 0.09	5.36 ± 0.02	4.0 ± 0.1	5.2 ± 0.1
	2d	2.9 ± 0.2	6.53 ± 0.01	6.5 ± 0.1	4.42 ± 0.07	2.52 ± 0.04	2.9 ± 0.2	4.45 ± 0.01	4.24 ± 0.04	4.2 ± 0.1
	3a‡	2.7	5.1	3.1	3.6	3.1	–	–	–	–
	3b‡	1.8	4.3	5.0	1.6	≤1	–	–	–	–
	4a¶	≤1.5	≤1.5	3.34	3.6	3.22	–	–	–	–
MeCN	**2**^{a}	3.58 ± 0.02	3.7 ± 0.2	4.3 ± 0.1	4.3 ± 0.3	4.78 ± 0.01	≤1.5	5.22 ± 0.06	3.3 ± 0.1	6.33 ± 0.07
	2b	4.5 ± 0.1	≥7	≥7	5.50 ± 0.08	4.67 ± 0.02	4.0 ± 0.2	6.20 ± 0.04	5.68 ± 0.03	5.8 ± 0.1
	2d	5.5 ± 0.2	≥7	≥7	5.50 ± 0.07	3.2 ± 0.3	3.98 ± 0.08	≥7	4.87 ± 0.02	4.15 ± 0.02
	3^{a}	5.8‡	5.6‡	4.4‡	1.7‡	3.7‡	3.3§	12.16§	7.90§	5.14§
	3d‡	6.3	6.1	5.1	4.5	5.6	–	–	–	–

† Confidence interval corresponding to ± the standard deviation on the mean value of several experiments. ‡ Data taken from Ref. [9]. ¶ Data taken from Ref. [14]. § Data taken from Ref. [13].

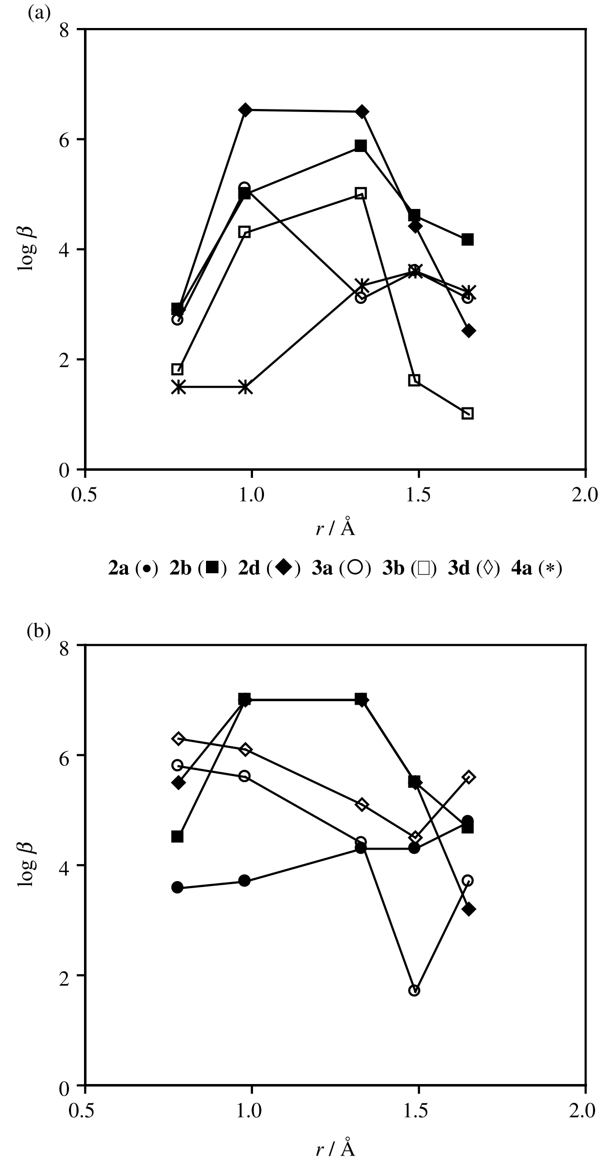


FIGURE 2 Logarithms of the stability constants (log β) of alkali cation complexes *vs* the cation ionic radius (r). (a) in methanol and (b) in acetonitrile.

are also illustrated in Figs. 2 and 3 for alkali and alkaline earth metal ions, respectively. Data available for the methylketones of *p*-*tert*-butylcalix[4]arene [9] and *p*-*tert*-butylcalix[5]arene [14] (**3a** and **4a**, respectively) are also included in this Table, although they are not quite comparable because their conformations (cone for **3a** and mobile at room temperature for **4a**) differ from that (partial cone) of methylketone **2a**, studied in this work. Stability constants for complexes of alkali and some alkaline earth cations with phenyl derivative **2d** in both solvents have already been published by us [18]. However, in order to compare the three derivatives in the same conditions, new experiments have been performed with **2d**, and all data have been analysed with the same programs [24,25]. The values presented here are in general higher than the previous ones, but the trends in both series of metal ions remain similar.

In methanol, the stability constants range from about 1.5 log units for **2a** complexes to a maximum of 6.5 log units for Na^+ and K^+ complexes with **2d**. In acetonitrile, the stability constants for Na^+, K^+ and Ca^{2+} complexes with **2b** and **2d** are even higher ($\log \beta \geq 7$). Competitive potentiometry involving Ag^+ as an auxiliary cation, often used to determine the stability constants of very stable complexes, was not possible here to check or evaluate the highest stability constants because Ag^+ forms too weak complexes with ligands **2a** and **2d** in acetonitrile (the higher value of 3.6 log units is obtained with **2d**) [26] and ligand **2b** is not soluble enough to reach a concentration suitable for potentiometric titrations.

Alkali Metal Cations

In methanol, both ligands **2b** and **2d** exhibit a plateau selectivity for Na^+ and K^+, although derivative **2b** shows preference for K^+. Their behaviour is intermediate between tetramethylketone **3a** in the cone conformation, which has a marked preference for Na^+ and pentamethylketone **4a**, which is mobile at room temperature and whose selectivity is shifted towards the larger cations K^+, Rb^+ and Cs^+ [14]. It is worthy to note that the complexation profiles of alkali cations with ligands **2b** and **2d** are very close to those observed in extraction.

The comparison between ligands **2b** and **3b** in the cone conformation and bearing the same *tert*-butyl residue on the ketone functions, allows the evaluation of the effect due to the presence of the additional oxygen and carbon atoms in the macrocyclic framework of **2b**. The complexation profile of **2b** is similar to that of **3b**, but higher log β values are obtained with the dihomooxa derivative **2b** for all the alkali cations ($\Delta \log \beta = 0.7$–3.2). Nevertheless, the presence of the two extra atoms in the macrocyclic ring of the latter, leads to a decrease of the selectivity for K^+ ($S = \beta_{\mathrm{LK}}^{+}/\beta_{\mathrm{LM}}^{+}$) from **3b** to **2b**, e.g. from 2.5×10^3 to 18.2 when $M^+ = Rb^+$ and from $\geq 10^4$ to 50 when $M^+ = Cs^+$. The larger cavity size and hence the greater flexibility of the dihomooxa derivative may account for these differences.

The influence of the residues on the ketonic functional group can be seen from the comparison of **2b** and **2d**. The *tert*-butylketone **2b** forms more stable complexes than the phenylketone **2d**, except for Na^+ and K^+ cations. On the basis of electronic considerations this situation has been expected, since the phenyl groups possess a marked electron withdrawing character (Taft constant $\sigma^* = 0.75$) [27], which should decrease the basicity of the carbonyl groups, while the *tert*-butyl group is more electron donating ($\sigma^* = -0.3$). As already noted, the bulky

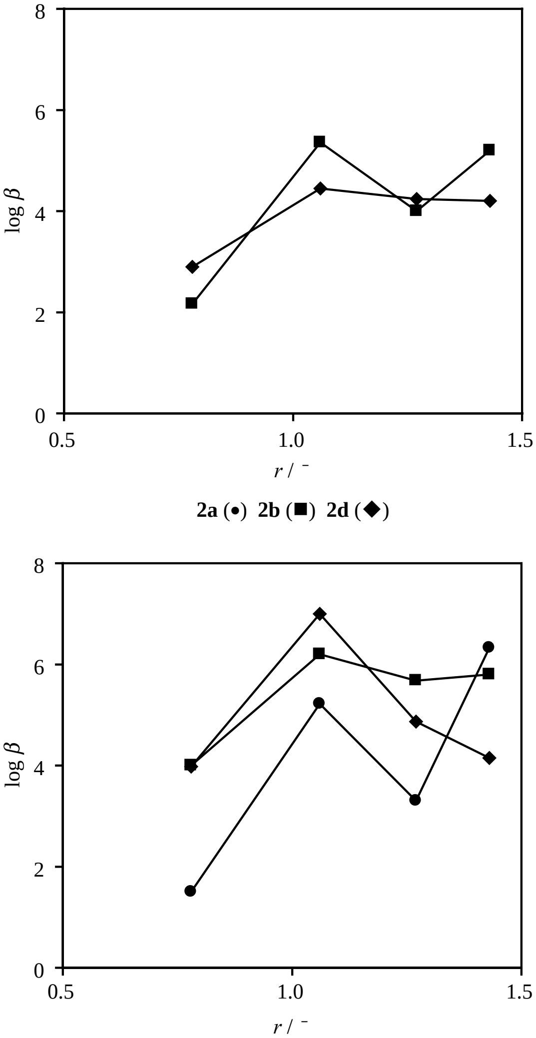


FIGURE 3 Logarithms of the stability constants (log β) of alkaline earth cation complexes *vs* the cation ionic radius (r). (a) in methanol and (b) in acetonitrile.

tert-butyl substituents, due to steric interference, may enlarge the hydrophilic cavity, which thus becomes too large for the smaller cations [9]. Apparently, this effect may predominate over the electronic effect for ligand **2b**, and explain the relatively low log β value of its complex with Na^+, comparing to that for **2d**.

In acetonitrile, the stability constants for the complexes with ligands **2b** and **2d**, ranging from 3.2 to ≥ 7 log units, are globally higher than in methanol, in agreement with the respective donor numbers of the solvents [28]. This effect is expected to be more pronounced for the smallest cations. In fact, the Li^+ complexes with both ligands show a higher increase in stability, than that observed with the larger Rb^+ and Cs^+ cations. The selectivity patterns of **2b** and **2d** are similar, and mirror those observed for the two ligands in methanol, exhibiting a maximum of stability for Na^+ and K^+ complexes. However, the differences observed between the two ligands are less marked in acetonitrile than in methanol, the complexes of Na^+, K^+, and Rb^+ having the same stability with both ligands. The only differences are observed for the Li^+ and Cs^+ complexes, which are more stable with **2d** and with **2b**, respectively. Ligand **2d** behaves in acetonitrile quite differently from its counterpart **3d**, which was observed to complex Li^+ and Na^+ better than the other cations.

With the partial cone ligand **2a** in methanol, very tiny spectral changes were observed during the titration of the ligand against alkali metal cations, which may indicate weak binding of these cations (log $\beta \leq 1.5$). This conclusion is further supported by the very low extraction levels found with this ligand and certainly related to its conformation, which restricts the effective binding sites to only three functional groups. However, in acetonitrile there is evidence for the formation of the alkali cation complexes, which are less stable than those with the other ligands in the cone conformation and whose stability slightly increases in the series.

Alkaline Earth Cations

While alkaline earth cations show no significant complexation with calix[4]arene ketone derivatives in methanol [13,29], they are complexed to some extent by the dihomooxa ketone derivatives 2b and 2d in cone conformation (Table II, Fig. 3). For instance, the highest values were obtained with the ligand **2b** and the cations Ca^{2+} (log $\beta = 5.4$) and Ba^{2+} (log $\beta = 5.2$). The latter value is higher than that found for the Ba^{2+} complex with *tert*-butyl ketone 4b (log $\beta = 1.8$) [30]. The two ligands 2b and 2d present a selectivity profile in favour of the larger cations Ca^{2+}, Sr^{2+} and Ba^{2+}, although the complex of Sr^{2+} with 2b is less stable than the Ca^{2+} and Ba^{2+} homologues. The selectivity Ca^{2+}/Mg^{2+} is high for 2b ($S_{Ca^{2+}/Mg^{2+}} = 1.6 \times 10^3$), but reduced for 2d ($S_{Ca^{2+}/Mg^{2+}} = 35.5$). It is interesting to note that the complexation profile does not match with the extraction profile, since Ca^{2+} and Sr^{2+} are fairly well complexed but only weakly extracted by these ligands.

In acetonitrile, **2b** behaves as in methanol, showing a marked affinity for the larger cations. Ligand **2d** behaves slightly differently, exhibiting a peak selectivity for Ca^{2+}.

As observed with alkali metal ions in methanol, the behaviour of the partial cone ligand **2a** is again different from that of ligands **2b** and **2d** in cone conformation, forming very weak complexes (log $\beta \leq 1.5$) towards alkaline earth cations in this solvent. However, in acetonitrile, there is significant complexation of these cations and the sequence of stability follows the order $Mg^{2+} < Sr^{2+} < Ca^{2+} < Ba^{2+}$.

In both solvents and for cations with similar ionic radii, the ketones form generally less stable complexes with the bivalent cations than with the monovalent cations. The exceptions are ligands **2a** in acetonitrile and **2b** in both solvents with Ca^{2+} and Ba^{2+} relative to Na^+ and Rb^+ cations, respectively. Thus, not only electronic considerations but also other factors involving the ligands and the cations, such as the size and solvation parameters, must be considered to explain the observed results.

Proton NMR Studies

To obtain further information on the complexation of ketones **2a**, **2b**, **2c** and **2d** with metal cations, namely concerning the binding sites, ^{1}H NMR studies were performed. Extensive titration experiments were carried out between all the alkali and alkaline earth cations and ketones **2b** and **2c**, between Li^+, Na^+, K^+ and Ba^{2+} and ketone **2d**, and finally between K^+ and **2a**. Variable amounts of the salts were added to the calixarenes and the proton spectra were recorded after each addition.

Different situations were found after the addition of the salts to the ligands.

Titration of ketone **2a** with KSCN initially induces broadening of the signals until the [salt]/[ligand] ratio reaches the unity value, when the signals become sharp. This indicates a fast exchange rate between the free and complexed ligand on the NMR time scale, at room temperature, and consequently a weak affinity of ligand **2a** towards K^+. This is in agreement with the extraction results and stability constants. The ^{1}H NMR titration experiment suggests a 1:1 metal-to-ligand stoichiometry, since all signals remain unchanged after subsequent additions of the salt. Ketones **2b**, **2c** and **2d** show similar behaviours towards Li^+, Na^+, K^+ and Ba^{2+} cations. These titrations show that with [salt]/[ligand] ratios lower than 1, both signals of the complexed and uncomplexed ligands are present in the spectra, indicating that on the NMR time scale the exchange rate between the two species is slow, at room temperature. This reflects a high affinity of these ligands towards those cations, as previously observed in extraction and complexation. Upon reaching 1:1 ratios, all the signals for the free ligands disappear and those of the complexed ligands remain unaltered after subsequent additions of the salts, indicating a 1:1 metal-to-ligand stoichiometry. Small differences can, however, be observed among these spectra. The complexation pattern of **2b**, **2c** and **2d** with Na^+ and K^+ is identical, slightly differing from that with Li^+ and Ba^{2+}. In particular, the peaks in the methylene region are less overlapped for the latter and the position of the aromatic peaks relative to that of $CDCl_3$ peak is also different. This behaviour had already been observed with diethylamide derivative [20].

Titrations of ketones **2b** and **2c** with Rb^+ and Cs^+ cations required a slightly different procedure, since the solubility in methanol of the Rb and Cs salts used is lower than that of the other metal salts. Thus, it was necessary to decrease the concentration of both ligands and salts (see Materials and Methods). These titrations also show that with [salt]/[ligand] ratios lower than 1, both signals of the free and complexed ligands are present in the spectra. Upon addition of 1 equiv of the salts the peaks of the free ligands disappeared and no further changes were detected on those of the complexed ligands after subsequent additions of the salts, indicating a 1:1 metal-to-ligand stoichiometry.

No complexation was observed in the case of Mg^{2+}. In fact, the extraction level obtained for these ketones towards Mg^{2+} was low, as were the stability constant values.

With Ca^{2+} and Sr^{2+}a quite different situation was found for both ligands **2b** and **2c**. Three sets of sharp signals with approximately the same intensity, in the case of Ca^{2+}, corresponding to the free ligand and to two other complexed ligands are present in the spectra, from the addition of the first aliquot (0.5 equiv) of salts. With 1 equiv of the salts all the peaks of the free ligand disappear, and further additions produce an increase of one of the complexes relative to the other, as shown in Fig. 4 for ligand **2c**. For Sr^{2+}a very similar behaviour was observed, although signals showed different intensities from the first aliquot of added salt. One of the complexes was clearly minor and it almost disappeared upon the addition of 3 equiv of the salt (Fig. 4).

In order to determine the stoichiometry of these complexes, a Job plot based on ^{1}H NMR data between ketone **2b** and Ca^{2+} cation was carried out. The Job's plot shown in Fig. 5 clearly indicates the formation of a 1:1 metal-to-ligand complex (complex A), but no unambiguous stoichiometry can be directly established from the curve for the weaker complex (complex B), due to the predominance of complex A [31]. Complex B exhibits a plateau rather than a maximum between 0.5 and 0.6 mole fraction of **2b**. A possible stoichiometry for complex B is a 1:2 metal-to-ligand stoichiometry, since the intensity of B peaks decreases as the addition of the salt proceeds, and the maximum for a 1:2 complex (ML_2) on a Job's plot appears at 0.67 mole fraction.

Proton NMR data of the free and complexed ligands are collected in Tables III, IV, V and VI.

In the case of methylketone (**2a**), in a partial cone conformation, complexation of K^+ affects differently its proton chemical shifts (Table III). The largest upfield shifts are recorded for the bridging axial methylene protons ($ArCH_2Ar$) and the oxygen

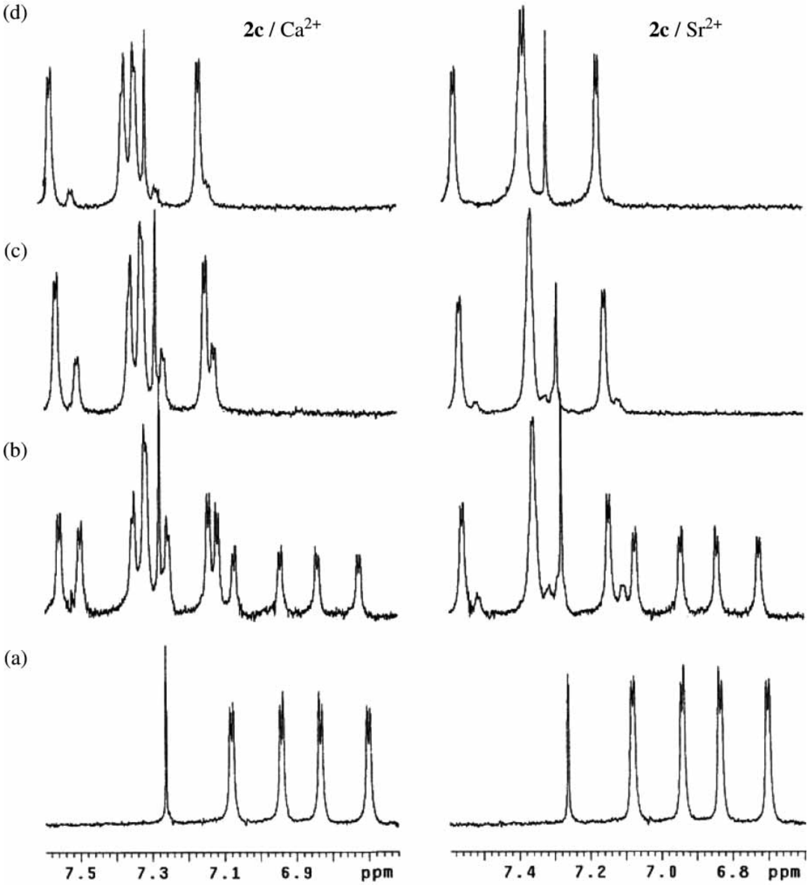


FIGURE 4 Aromatic region of the ^1H NMR spectra of **2c** in $CDCl_3$, 22°C and 300 MHz. (a) free ligand, (b) upon addition of 0.5, (c) 1 equiv and (d) 3 equivs of the salts (Ca and Sr perchlorates, respectively).

bridge equatorial methylene protons (CH_2OCH_2). Different variations are observed for the three $ArCH_2Ar$ groups. The axial methylene proton (H3, Scheme 1) of the CH_2 bridge between rings in a syn orientation experiences a very large upfield shift ($\Delta\delta = 0.62$), compared to those of CH_2 bridges between rings in an anti orientation ($\Delta\delta = 0.29$ and 0.08). The methylene protons of the three OCH_2CO groups undergo the largest downfield shifts, whereas the corresponding protons of the inverted moiety undergo only small and upfield shifts. Identical situations are observed for methyl protons of $COCH_3$ groups and aromatic protons. Thus, the inverted moiety shows very small and opposite shift variations compared to those of the non-inverted moieties. Accordingly, these results indicate that K^+ must be inside the cavity defined by the phenoxy and carbonyl oxygen atoms, for a total of six binding sites.

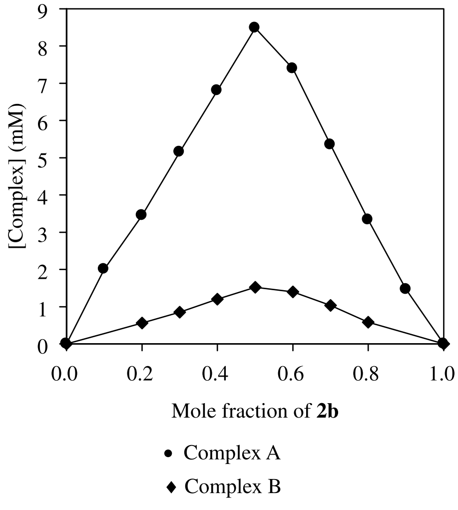


FIGURE 5 Job's plot based on ^1H NMR data for the system $\mathbf{2b} + Ca^{2+}$; total concentration 2×10^{-2} M in $CDCl_3$–CD_3OD (9:1, v/v).

Complexation of the cations (except Mg^{2+}) affects all the proton chemical shifts in ligands **2b**, **2c** and **2d** (Tables IV, V and VI). The most pronounced shift changes are observed, in all cases, for the bridging axial methylene protons ($ArCH_2Ar$) and the oxygen bridge equatorial methylene protons (CH_2OCH_2), which move upfield, and by the aromatic protons, which move downfield. The methylene protons of the OCH_2CO groups undergo also large shift variations, being upfield for Na^+, K^+, Rb^+ and Cs^+, and downfield for Li^+ and the divalent cations. The smallest variations are recorded for the protons of

TABLE III Relevant proton chemical shifts (δ, ppm) of ligand **2a** and its 1:1 metal complex

	t-Bu	$COCH_3$	$ArCH_2Ar$		CH_2OCH_2		OCH_2CO	ArH
			eq	ax	eq	ax		
2a	1.09, 1.17, 1.26, 1.36	0.11, 1.78, 2.11, 2.14	3.31, 3.84, 3.85	4.55, 3.96, 4.03	4.25, 4.29	4.70, 4.95	1.94, 2.37; 4.02, 4.76; 4.22, 4.75; 4.36, 4.67	7.00, 7.03, 7.07, 7.10, 7.17, 7.20, 7.20, 7.31
2a + K^+	1.15, 1.16, 1.21, 1.29	0.02, 2.19, 2.33, 2.38	3.63, 3.77, 3.79	3.93, 4.04, 4.32	3.97, 4.07	4.69, 4.78	1.91, 2.19; 4.18, 5.39; 4.60, 5.12; 4.84, 4.86	6.95, 7.01, 7.09, 7.11, 7.11, 7.21, 7.31, 7.45

the alkyl residues (*t*-Bu, Ad and Ph) attached to the ketone function and *tert*-butyl groups. Similar observations have been made for dihomooxa diethylamide [20] and closely related calix[4]arene derivatives [12,13,32,33].

A closer examination of the spectral changes upon complexation indicates considerable differences between the alkali and alkaline earth cation series. Also Li^+ and Ba^{2+} behave sometimes differently from the rest of the cations of their respective series. The aromatic protons and both axial and equatorial methylene protons ($ArCH_2Ar$) show the largest chemical shift variations for the alkaline earth cations, while the oxygen bridge equatorial methylene protons (CH_2OCH_2) are affected to a higher extent by the alkali cations. Other relevant protons exhibit similar shift changes upon complexation with both cation series.

A systematic observation of the data reveals that the axial methylene protons of both $ArCH_2Ar$ groups (H2 and H3, Scheme 2) experience similar upfield shifts ($\Delta\delta \approx 0.40$) for the alkali cations, but the upfield shift experienced by H3 is significantly higher ($\Delta\delta \approx 0.90$) than that experienced by H2 ($\Delta\delta \approx 0.60$) for the alkaline earth cations. The highest shifts are observed for Ca^{2+} and ketones **2c** and **2b** ($\Delta\delta = 0.94$ and $\Delta\delta = 0.93$, respectively). As observed for other calixarenes, the variation in chemical shift experienced by the equatorial methylene protons ($ArCH_2Ar$) is downfield and much smaller than that of the axial protons. Again, the alkaline earth cations produce higher downfield shift changes ($\Delta\delta \approx 0.39$) than the alkali cations ($\Delta\delta \approx 0.13$). The CH_2OCH_2 resonances behave differently, as reported before [20]. The axial and equatorial methylene protons of the oxygen bridge move upfield (the exceptions are the complexation of Ba^{2+} by ketones **2b**, **2c** and **2d** and also complexation of Li^+ by **2d**, which produce downfield shifts on the axial protons) and the equatorial protons experience larger shift variations than the axial ones. However, this difference is negligible for the alkaline earth cations. These results suggest that the oxygen bridge conformation changes significantly upon complexation, with the equatorial protons undergoing a higher shielding effect for the alkali cations, but with both CH_2 protons undergoing similar shielding effect for the alkaline earth cations.

The deshielding effect observed for the aromatic protons indicates the involvement of the phenolic oxygens in complexation, as reported previously [33]. The largest upfield shifts shown by the complexed ligands protons adjacent to the oxygen donor atoms can be explained in terms of variations of both shielding and deshielding effects of the aromatic rings and carbonyl groups upon cation binding to those donor atoms. Therefore, this

TABLE IV Relevant proton chemical shifts (δ, ppm) of ligand **2b** and its 1:1 metal complexes

	t-Bu	ArCH$_2$Ar		CH$_2$OCH$_2$		OCH$_2$CO	ArH
		eq	ax	eq	ax		
2b	0.96, 1.16	3.28, 3.28	4.63, 4.72	4.68	4.84	4.62, 4.86, 5.17, 5.21	6.73, 6.86, 6.97, 7.09
2b + Li^{+}	1.07, 1.21	3.42, 3.47	4.72, 4.53	4.18	4.80	4.98, 5.05, 5.29, 5.48	6.99, 7.06, 7.06, 7.43
2b + Na^{+}	1.16, 1.24	3.41, 3.42	4.32, 4.34	4.22	4.45	4.86, 4.88, 4.94, 4.98	7.09, 7.23, 7.29, 7.48
2b + K^{+}	1.19, 1.23	3.44, 3.39	4.18, 4.26	4.13	4.51	4.73, 4.76, 4.84, 4.86	7.08, 7.26, 7.35, 7.47
2b + Rb^{+}	1.19, 1.22	3.44, 3.39	4.17, 4.25	4.09	4.71	4.63, 4.74[†], 4.89	7.05, 7.30, 7.40, 7.44
2b + Cs^{+}	1.10, 1.24	3.40, 3.32	4.20, 4.36	4.09	4.98	4.60, 4.72, 4.82, 4.98	6.95, 7.28, 7.28, 7.38
2b + Mg^{2+}	0.97, 1.16	3.29, 3.29	4.65, 4.68	4.68	4.86	4.65, 4.87, 5.17, 5.25	6.77, 6.88, 6.98, 7.07
2b + Ca^{2+}	1.16, 1.25	3.74, 3.70	3.85, 3.79	4.32	4.43	5.06, 5.10, 5.16, 5.21	7.16, 7.34, 7.38, 7.58
2b + Sr^{2+}	1.17, 1.23	3.74, 3.71	3.99, 3.89	4.29	4.52	5.01, 5.10, 5.19, 5.32	7.16, 7.38, 7.39, 7.58
2b + Ba^{2+}	1.14, 1.22	3.59, 3.61	4.23, 3.88	4.20	5.16	4.91, 5.04, 5.06, 5.25	7.09, 7.37, 7.45, 7.45

[†] Singlet corresponding to four protons.

TABLE V Relevant proton chemical shifts (δ, ppm) of ligand **2c** and its 1:1 metal complexes

	t-Bu	ArCH$_2$Ar		CH$_2$OCH$_2$		OCH$_2$CO	ArH
		eq	ax	eq	ax		
2c	0.95, 1.15	3.27, 3.27	4.61, 4.71	4.69	4.85	4.63, 4.83, 5.15, 5.16	6.70, 6.84, 6.94, 7.08
2c + Li^{+}	1.08, 1.25	3.41, 3.46	4.76, 4.54	4.16	4.82	4.94, 5.02, 5.29, 5.46	6.99, 7.05, 7.06, 7.44
2c + Na^{+}	1.15, 1.25	3.38, 3.38	4.30, 4.34	4.20	4.43	4.82, 4.83, 4.89, 4.95	7.08, 7.22, 7.27, 7.47
2c + K^{+}	1.18, 1.23	3.41, 3.35	4.16, 4.23	4.11	4.51	4.71[†], 4.80, 4.81	7.07, 7.24, 7.33, 7.45
2c + Rb^{+}	1.18, 1.22	3.38, 3.32	4.13, 4.21	4.06	4.75	4.57, 4.68[‡], 4.87	7.03, 7.28, 7.38, 7.41
2c + Cs^{+}	1.09, 1.25	3.39, 3.30	4.17, 4.36	4.06	4.97	4.53, 4.67, 4.78, 4.97	6.94, 7.27, 7.27, 7.37
2c + Mg^{2+}	0.96, 1.16	3.28, 3.28	4.62, 4.68	4.66	4.88	4.67, 4.86, 5.15, 5.16	6.76, 6.86, 6.96, 7.06
2c + Ca^{2+}	1.15, 1.25	3.70, 3.69	3.78, 3.77	4.32	4.38	4.99, 5.08, 5.10, 5.19	7.15, 7.33, 7.36, 7.57
2c + Sr^{2+}	1.16, 1.23	3.71, 3.67	3.95, 3.83	4.30	4.47	4.97, 5.01, 5.11, 5.27	7.16, 7.36, 7.36, 7.57
2c + Ba^{2+}	1.14, 1.22	3.58, 3.59	4.17, 3.84	4.19	5.16	4.86, 4.99†, 5.21	7.08, 7.35, 7.44, 7.44

[†] Doublet corresponding to four protons. [‡] Singlet corresponding to four protons.

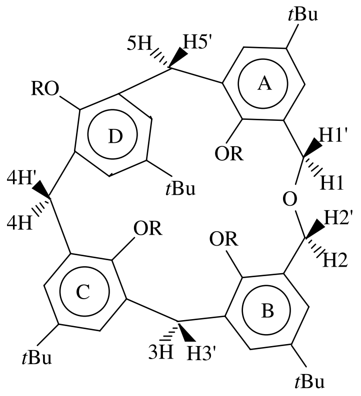
suggests that for 1:1 complexes all the cations must be inside the cavity defined by the phenoxy and carbonyl oxygen atoms. Moreover, Gutsche [34] has observed that the difference in the chemical shifts between the axial and equatorial protons of the ArCH$_2$Ar bridges indicates the degree of flattening of the cone conformation. If this value is larger than 0.9 ppm it means that the aromatic rings are more parallel to each other and the macrocycle adopts a distorted cone conformation. Upon complexation with all these cations, the axial protons are shielded and the equatorial ones are deshielded, resulting in smaller chemical shift differences between them. This indicates that upon complexation the pendant arms of the ligands move closer together to bind the cations, resulting in a more symmetrical conformation.

Comparable spectral changes were observed for *tert*-butyl, adamantyl and phenyl ketones, although the latter has shown slight differences relative to the others. The magnitude of the shift variations follows, in general, the same trend as that observed in extraction and stability constants for the alkali cations. However, this is only partially observed in the alkaline earth series, since Ca^{2+} and Sr^{2+} show the largest changes and the extraction results do not follow this behaviour. All these observations are attributed to more or less marked conformational rearrangements produced on the pendant arms of the ligands by the bound cations.

TABLE VI Relevant proton chemical shifts (δ, ppm) of ligand **2d** and its 1:1 metal complexes

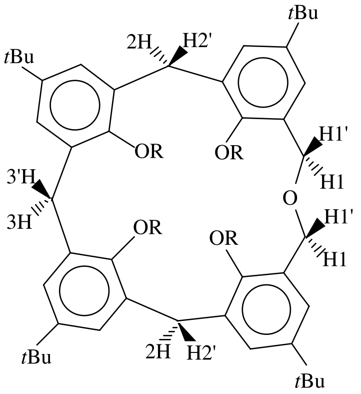
	t-Bu	ArCH$_2$Ar		CH$_2$OCH$_2$		OCH$_2$CO	ArH
		eq	ax	eq	ax		
2d	1.07, 1.14	3.41, 3.42	5.10, 5.05	4.57	5.08	5.21, 5.48, 5.67, 5.72	6.91, 6.94, 6.95, 7.08
2d + Li^{+}	1.15, 1.30	3.59, 3.67	5.32, 4.81	4.33	5.49	5.40, 5.54, 5.98, 6.23	7.15, 7.16, 7.21, 7.56
2d + Na^{+}	1.20, 1.29	3.54, 3.54	4.62, 4.83	4.30	4.82	5.41, 5.42, 5.49, 5.52	7.17, 7.33, 7.39, 7.58
2d + K^{+}	1.24, 1.26	3.55, 3.49	4.42, 4.49	4.19	4.87	5.23, 5.28[†], 5.52	7.14, 7.35, 7.45, 7.54
2d + Ba^{2+}	1.17, 1.26	3.68, 3.67	4.63, 4.27	4.24	5.50	5.48, 5.57, 5.64, 5.85	7.13, 7.44, 7.52, 7.53

[†] Singlet corresponding to four protons.



R = CH_2COMe

SCHEME 1



R = CH_2COR' R' = Bu^t,Ad,Ph

SCHEME 2

Ion Transport

Transport experiments were carried out in a CH_2Cl_2 liquid membrane system, similar to that employed by Lamb *et al.* [35]. The transport rates V, in $\mu mol\,h^{-1}$ for ketones **2a**, **2b**, **2c** and **2d**, are presented in Table VII and Fig. VI.

Table VII shows that ketones **2b**, **2c** and **2d** are reasonably good neutral carriers for all the cations, with the exception of Na^+, K^+ and Mg^{2+}. These ketones display a transport rate sequence the reverse of that for the efficiency of extraction and for the stability constants in methanol (for ketones **2b** and **2d**). Whereas K^+ and Na^+ are the most extracted and efficiently complexed cations, they become the most slowly transported ones (V less than $0.2\,\mu mol\,h^{-1}$). The opposite is observed with Cs^+ and Li^+, which being the least bound cations are the fastest transported ones. Towards alkaline earth metal cations a slightly different situation is observed. These ketones are good binders for Ba^{2+} but transport this cation inefficiently, whereas with Ca^{2+} an opposite behaviour was found relative to the extraction, but not to the complexation. Moreover, adamantylketone **2c** is now the worst carrier in contrast to the extraction process, where it was the best extractant. However, **2c** presents the highest Cs^+/K^+, Cs^+/Na^+ and Ca^{2+}/Mg^{2+} transport selectivities ($S = V_{M1^{n+}/M2^{n+}} = 22.2$, 31.9 and 36.3, respectively).

Interestingly, phenylketone **2d** is the most efficient carrier, showing the highest transport rate value found in this work ($2.7\,\mu mol\,h^{-1}$ for Cs^+).

Methylketone **2a** is a reasonable neutral carrier for alkali cations, with V ranging from $0.12\,\mu mol\,h^{-1}$ for Li^+ up to $0.9\,\mu mol\,h^{-1}$ for Cs^+, but it transports the alkaline earth cations to a very low extent (V less than $0.16\,\mu mol\,h^{-1}$). Once more, the partial cone conformation exhibited by this derivative can explain its different behaviour relative to that of the other ketones.

The ion transport behaviour of these ketones may be interpreted in terms of the rate of complexation and decomplexation at both CH_2Cl_2/H_2O interfaces [36]. It seems that the ligands that form more stable complexes extract their preferred cations efficiently from the source phase, but release them slowly at the receiving phase. This results in saturation of the carriers, giving slow transport rates. By contrast, the less well bound cations should be quickly released at the receiving phase, resulting in higher transport rates.

According to the different behaviours of the ligands, Lehn [37] characterized them as selective carriers (the most efficiently bound cation is also the fastest transported) or selective receptors (the best bound cation is the most slowly transported one). Based on this classification, ketones **2b**, **2c** and **2d** can be considered as selective receptors. The same behaviour was previously observed for diethylamide dihomooxa derivative [20].

TABLE VII Transport rate ($V/\mu mol\,h^{-1}$) of alkali and alkaline earth picrates through a CH_2Cl_2 liquid membrane at 25°C[†]

	Li^+	Na^+	K^+	Rb^+	Cs^+	Mg^{2+}	Ca^{2+}	Sr^{2+}	Ba^{2+}
2[a]	0.12	0.41	0.7	0.8	0.9	0.016	0.09	0.09	0.16
2b	0.8	0.13	0.12	0.44	1.5	0.016	0.6	0.9	0.49
2c	0.8	0.048	0.07	0.15	1.5	0.008	0.29	0.13	0.09
2d[‡]	1.8	0.17	0.21	0.8	2.7	0.06	1.5	0.7	0.15

[†] Reproducibility of ± 10%. [‡] Data taken from Ref. [18].

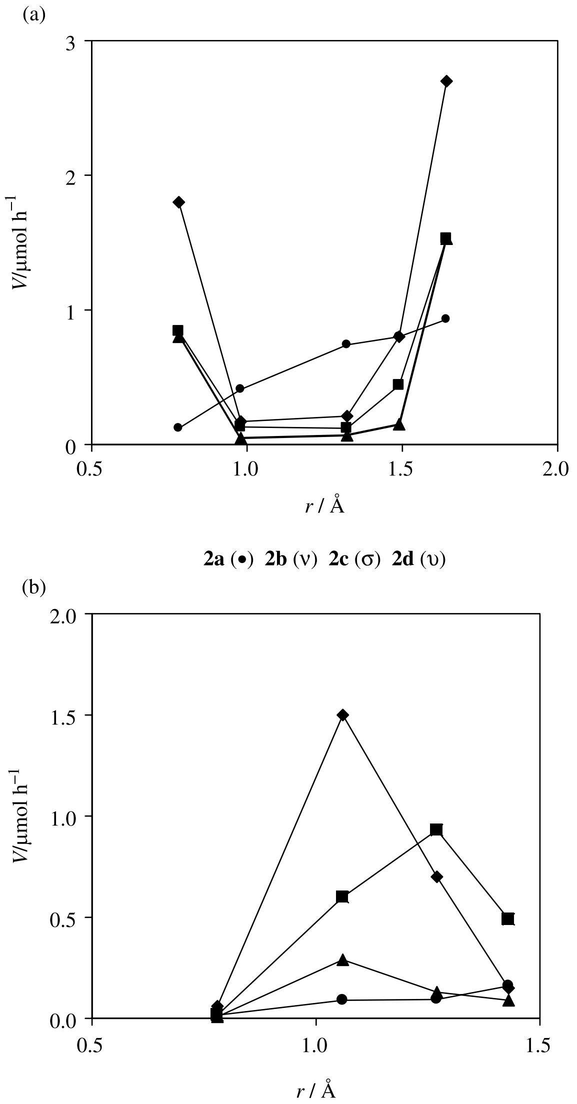


FIGURE 6 Transport rate ($V/\mu\text{mol h}^{-1}$) of metal picrates through a CH_2Cl_2 liquid membrane *vs* the cation ionic radius (*r*). (a) alkali and (b) alkaline earth metals.

CONCLUSIONS

Extraction studies from an aqueous solution into CH_2Cl_2 and stability constant measurements in methanol and acetonitrile have shown that ketones **2b**, **2c** and **2d**, in the cone conformation, are good binders for most of the studied cations. In the alkali series, their extraction and complexation profiles are similar, showing a plateau selectivity for Na^+ and K^+. In general, these dihomooxa ketones exhibit higher extraction percentages and log β values than the calix[4]arene ketone analogues. However, they are less selective ligands. This behaviour is consistent with the larger cavity size of the former derivatives compared to that of the latter. Towards alkaline earth cations, the extraction pattern does not match exactly the complexation pattern. In extraction, ketones show a strong peak selectivity for Ba^{2+}, whereas in complexation a plateau selectivity for Ca^{2+}, Sr^{2+} and Ba^{2+} is observed. The residues attached to the ketonic carbonyl groups have some influence on the binding ability of the ligands. Although comparable results had been obtained with the three derivatives, ketone **2d** showed slightly weaker binding properties than ketones **2b** and **2c**. Proton NMR titrations confirmed the formation of 1:1 complexes between all the ketones and alkali and Ba^{2+} cations. In the case of Mg^{2+} no complexation was observed, and with Ca^{2+} and Sr^{2+}, besides the 1:1 complexes, minor amounts of another complex with a different ligand:metal stoichiometry were formed. These NMR experiments also suggested that the cations should be encapsulated into the cavity defined by the phenoxy and carbonyl oxygen atoms. Ketones **2b**, **2c** and **2d** are reasonable neutral carriers displaying, in general, transport rate sequences reversed of those shown in extraction and complexation. Hence, these ligands can be considered as selective receptors. Methylketone **2a** is a poor binder for all the alkali and alkaline earth cations, due to its partial cone conformation. As a carrier, **2a** showed also an atypical behaviour compared to the other ketones.

MATERIALS AND METHODS

Extraction Studies

Equal volumes (5 mL) of aqueous solutions of metal picrates (2.5×10^{-4} M) and solutions of the calixarenes (2.5×10^{-4} M) in CH_2Cl_2 were vigorously shaken for 2 min, and then thermostated in a water bath with mechanical stirring, at 25°C overnight. After complete phase separation, the concentration of picrate ion in the aqueous phase was determined spectrophotometrically ($\lambda_{max} = 354$ nm). For each cation-calixarene system the absorbance measurements were repeated, at least, four times. Blank experiments showed that no picrate extraction occurred in the absence of a calixarene. The details of metal picrate preparation have already been described [18].

Stability Constant Determination

The stability constants β defined as the concentration ratio $[ML^{n+}]/([M^{n+}][L])$ (where M^{n+} = cation and L = ligand) were determined in methanol (Carlo Erba, 99.9%) and acetonitrile (Riedel-deHaën, analytical reagent) used without further purification by UV absorption spectrophotometry, at 25°C and constant ionic strength provided by 0.01 M Et_4NClO_4 (Fluka, purum), Et_4NCl (Fluka, purum) or Et_4NNO_3 (Acros) according to the procedure already described [38]. The spectra were recorded on a Shimadzu UV-2101-PC or a Perkin Elmer Lambda 11 spectrophotometer. The ligand concentrations were *ca.* 10^{-4} M and the spectra were treated by programs Letagrop [24] or Specfit [25]. The treatment of the same experiment by both programs led to similar values within the experimental error. The metal salts used were chlorides in methanol: LiCl (Fluka, Microselect), CsCl (Fluka, purum), NaCl, KCl, RbCl, $MgCl_2 \cdot 6H_2O$, $CaCl_2$, $SrCl_2 \cdot 6H_2O$ and $BaCl_2$ (Merck, p.a.). In acetonitrile the following perchlorates and nitrate were used: $LiClO_4$, and $Ca(ClO_4)_2 \cdot 4H_2O$ (Fluka, purum), $KClO_4$ and $Ba(ClO_4)_2$ (Prolabo), $NaClO_4$ and $RbClO_4$ (Sigma), $CsClO_4$ and $Sr(ClO_4)_2 \cdot 6H_2O$ (Alfa Aesar), $Mg(NO_3)_2 \cdot 6H_2O$ (Merck, p.a.). All these salts were dried under vacuum for at least 24 h before use. The concentrations of the stock solutions of the cations (except alkali cations) were standardized by complexometry using the appropriate coloured indicators [39].

Proton NMR Titration Experiments

Several aliquots (up to 2–3 equiv) of the salt solutions (0.5 M) in CD_3OD were added to $CDCl_3$ solutions (1×10^{-2} M) of the ligands directly in the NMR tube. The salts used were thiocyanates (Na and K), Ba triflate and perchlorates (Li, Rb, Cs, Mg, Ca and Sr). Due to the low solubility of Rb and Cs perchlorates in MeOH, it was necessary to decrease the concentration of the ligands (2×10^{-4} M) and of the salts (1×10^{-3}–2×10^{-3} M). The spectra were recorded on a Varian Unity 300 Spectrometer after each addition of the salts. The temperature of the NMR probe was kept constant at 22°C. Job's method was performed for ketone **2b** and $Ca(ClO_4)_2$. The total concentration was maintained at 2×10^{-2} M in $CDCl_3$-CD_3OD (9:1).

Transport Experiments

The ion transport across a liquid membrane was done using an apparatus similar to that employed by Lamb *et al*. [35] The membrane phase (50 mL of a 7×10^{-5} M solution of the calixarene in CH_2Cl_2), the receiving phase (25 mL of doubly distilled and deionised water) and the source phase (7 mL of a 5×10^{-3} M aqueous solution of metal picrate), were placed in a thermostated vessel. The apparatus was maintained at 25°C and the phases stirred at 150 rpm. The experiments were repeated, at least, three times. The appearance of the picrate ion in the receiving phase was followed by UV spectrophotometry at regular time intervals. Experiments with no carrier present were performed, indicating no transport of metal picrates. The experimental procedure has already been described in detail elsewhere [18].

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References

[1] Gutsche, C. D. *Calixarenes Revisited*; The Royal Society of Chemistry: Cambridge, 1998.
[2] *Calixarenes 2001*; Asfari, Z., Böhmer, V., Harrowfield, J., Vicens, J., Eds.; Kluwer Academic Publishers: Dordrecht, 2001.
[3] *Calixarenes in Action*; Mandolini, L., Ungaro, R., Eds.; Imperial College: London, 2000.
[4] *Calixarenes for Separations*; ACS Symposium series 757; Lumetta, G. J., Rogers, R. D., Gopalan, A. S., Eds.; American Chemical Society: Washington, 2000.
[5] McKervey, M. A.; Schwing-Weill, M. J.; Arnaud-Neu, F. In *Comprehensive Supramolecular Chemistry*; Lehn, J. M., Gokel, G. W., Eds.; Elsevier: Oxford, 1996; Vol. 1, pp 537–603.
[6] Arnaud-Neu, F.; McKervey, M. A.; Schwing-Weill, M. J. In *Calixarenes 2001*; Asfari, Z., Böhmer, V., Harrowfield, J., Vicens, J., Eds.; Kluwer Academic Publishers: Dordrecht, 2001; pp 385–406.
[7] Ferguson, G.; Kaitner, B.; McKervey, M. A.; Seward, E. M. *J. Chem. Soc. Chem. Commun.* **1987**, 584.
[8] Schwing, M. J.; Arnaud, F.; Marques, E. *Pure. Appl. Chem.* **1989**, *61*, 1597.
[9] Arnaud-Neu, F.; Collins, E. M.; Deasy, M.; Ferguson, G.; Harris, S. J.; Kaitner, B.; Lough, A. J.; McKervey, M. A.; Marques, E.; Ruhl, B. L.; Schwing-Weill, M. J.; Seward, E. M. *J. Am. Chem. Soc.* **1989**, *111*, 8681.
[10] Deligöz, H.; Yilmaz, M. *Solv. Extr. Ion Exch.* **1995**, *13*, 19.
[11] Lamartine, R.; Meziani, H. *Supramol. Chem.* **2001**, *13*, 143.
[12] Danil de Namor, A.; Kowalska, D.; Castellano, E.; Piro, O.; Velarde, F. S.; Salas, J. V. *Phys. Chem. Chem. Phys.* **2001**, *3*, 4010.
[13] Danil de Namor, A.; Chahine, S.; Kowalska, D.; Castellano, E.; Piro, O. *J. Am. Chem. Soc.* **2002**, *124*, 12824.
[14] Bell, S.; Browne, J.; McKee, V.; McKervey, M. A.; Malone, J.; O'Leary, M.; Walker, A.; Arnaud-Neu, F.; Boulangeot, O.; Mauprivez, O.; Schwing-Weill, M. J. *J. Org. Chem.* **1998**, *63*, 489.
[15] Memon, S.; Yilmaz, M. *Sep. Sci. Technol.* **2000**, *35*, 457.
[16] Memon, S.; Yilmaz, M. *Sep. Sci. Technol.* **2001**, *36*, 473.
[17] Lamartine, R.; Bavoux, C.; Vocanson, F.; Martin, A.; Senlis, G.; Perrin, M. *Tetrahedron Lett.* **2001**, *42*, 1021.
[18] Marcos, P. M.; Ascenso, J. R.; Segurado, M. A. P.; Pereira, J. L. C. *J. Phys. Org. Chem.* **1999**, *12*, 695.
[19] Marcos, P. M.; Ascenso, J. R.; Segurado, M. A. P.; Pereira, J. L. C. *Tetrahedron* **2001**, *57*, 6977.
[20] Marcos, P. M.; Félix, S.; Ascenso, J. R.; Segurado, M. A. P.; Pereira, J. L. C.; Khazaeli-Parsa, P.; Hubscher-Bruder, V.; Arnaud-Neu, F.; New *J. Chem.* **2004**, *23*, 748.
[21] Pedersen, C. *J. Am. Chem. Soc.* **1970**, *92*, 391.
[22] Félix, S.; Ascenso, J. R.; Lamartine, R.; Pereira, J. L. C. *Tetrahedron* **1999**, *55*, 8539.
[23] Marcos, P. M.; Ascenso, J. R.; Lamartine, R.; Pereira, J. L. C. *Tetrahedron* **1997**, *53*, 11791.
[24] PC version by Havel, J. of Letagrop-Spefo from: Sillen G., Warnqvist, B, Ark. Kemi., **1968**, *31*, 377.
[25] Gampp, H.; Maeder, M.; Meyer, C. J.; Zuberbühler, A. D. *Talanta* **1985**, *32*, 257.
[26] Mellah, B.; Hubscher-Bruder, V.; Arnaud-Neu, F.;, unpublished results
[27] Perrin, D. D.; Dempsey, B.; Serjeant, E. P. *pKa Prediction for Organic Acids and Bases*; Chapman and Hall: London, 1981.
[28] Gutmann, V. *The Donor Acceptor Approach to Molecular Interactions*; Plenum Press: New York, 1978.
[29] Schwing-Weill, M. J.; Arnaud-Neu, F.; McKervey, M. A. *J. Phys. Org. Chem.* **1992**, *5*, 496.
[30] Bollender, S.; Arnaud-Neu, F.; *unpublished results*.

[31] Caldeira, M. M.; Ramos, M. L.; Oliveira, N. C.; Gil, V. M. S.; *Can J. Chem.* **1987**, *65*, 2434.

[32] Nomura, E.; Takagaki, M.; Nakaoka, C.; Uchida, M.; Taniguchi, H. *J. Org. Chem.* **1999**, *64*, 3151.

[33] Arduini, A.; Pochini, A.; Reverberi, S.; Ungaro, R.; Andreetti, G.; Ugozzoli, F. *Tetrahedron* **1986**, *42*, 2089.

[34] Gutsche, C. D. *Calixarenes*; The Royal Society of Chemistry: Cambridge, 1989.

[35] Lamb, J.; Christensen, J.; Izatt, S.; Bedke, K.; Astin, M.; Izatt, R. *J. Am. Chem. Soc.* **1980**, *102*, 3399.

[36] Kirch, M.; Lehn, J. M. *Angew. Chem. Int. Ed. Engl.* **1975**, *14*, 555.

[37] Lehn, J. M. *Pure Appl. Chem.* **1979**, *51*, 979.

[38] Arnaud-Neu, F.; Schwing-Weill, M. J.; Ziat, K.; Cremin, S.; Harris, S. J.; McKervey, M. A.; New *J. Chem.* **1991**, *15*, 33.

[39] *Méthodes d'Analyse Complexométriques avec le Titriplex*; Merck, E., Ed.;, 3 Grafis: Darmstadt, 1992.