Synthesis and extraction studies of 1,2- and 1,3-disubstituted butylcalix[4]arene amides with oxyions; geometric and conformational effects

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26,28-(Dibutylcarbamoyl)methoxy-5,11,17,23-*tert*-butylcalix[4]arene and two geometric isomers of 27,28-(dibutylcarbamoyl)methoxy-5,11,17,23-*tert*-butylcalix[4]arene have been used to extract U^{VI}, Mo^{VI}, Cr^{VI} and Se^{VI} from aqueous solution into toluene or isooctane.

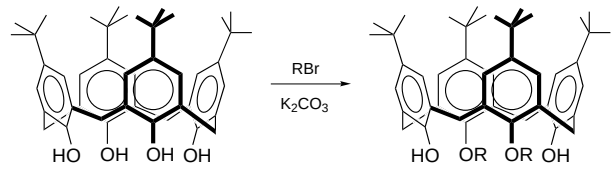
The selective extraction of metal cations and anions from aqueous solution into an organic phase is an important goal, especially if the particular ions are toxic and present in the environment in significant quantities.[1,2] Three such metals are uranium,[3] chromium[4–10] and selenium,[11] all of which exist primarily in their hexavalent forms. Although there is considerable diversity between these species there are also some similarities. The main difference is that whereas Se^{VI} and Cr^{VI} are anions in strongly acidic solution, U^{VI} is a cation. An important similarity, however, is that these species are high valent oxophiles, and an amide functionality can potentially act as a complexant for each of these species. This premise is based on the logic that such a functionality should not only coordinate as a hard N,O-donor ligand to such high-valent centers, but should also function as a neutral host to hydrogen bond with the protonated form of the oxyanion.

In developing extractants it is important to target specific solvent systems as well as complexants. Although in earlier work with calix[4]arenes we have used chloroform as the organic phase,[12–19] we have always been aware that it would be advantageous to use a less toxic organic such as an alkane. We have now prepared the geometrically isomeric 1,2- and 1,3-calix[4]arene amides having appended *n*-butyl substituents in order that they can be more compatible with such an alkane phase. In addition to solvent selectivity, the effect of both geometric and conformational properties of the complexant needs also to be considered. Since the 1,2 isomer has been obtained as a separable mixture of geometric isomers, the availability of such a pair of isomers affords us the opportunity to compare their relative extraction properties.

These three new calix[4]arene amides have been synthesized using the same general procedures.[20] The precursor compound *N*,*N*-dibutyl-2-bromoacetamide has been synthesized in 82% yield by stirring a mixture of bromoacetic acid and *N*,*N*-dibutylamine in dichloromethane with 1,3-dicyclohexylcarbodiimide for 12 h.

The synthetic route of the calix[4]arene amides involves reacting 5,11,17,23-*tert*-butylcalix[4]arene with *N*,*N*-dibutyl-2-bromoacetamide (2.2 equiv.) in the presence of a base. For the case of 26,28-(dibutylcarbamoyl)methoxy-5,11,17,23-*tert*-butylcalix[4]arene **1** the conditions use potassium carbonate in refluxing acetone for 18 h (Scheme 1), and for the two isomers of 27,28-(dibutylcarbamoyl)methoxy-5,11,17,23-*tert*-butylcalix[4]arene (**2**, **3**), sodium hydride in DMF at 60 °C for 26 h is used (Scheme 2). Compounds **2** and **3** were obtained in the same reaction mixture and separated by column chromatography.

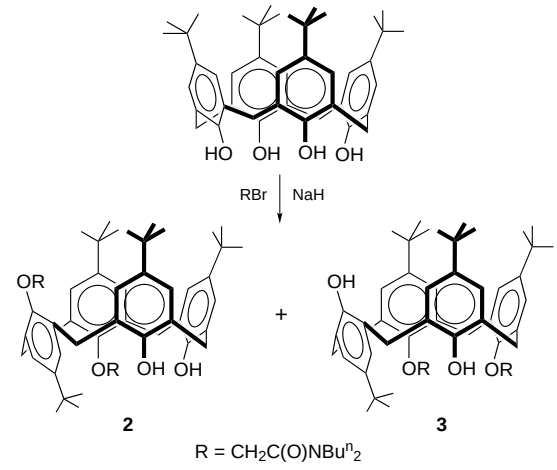
These compounds have been structurally characterized by NMR spectroscopy. Compound **1** (yield 65%; mp 130–132 °C) is characterized as being in the cone conformation by the presence of a single triplet resonance in the ^{1}H NMR spectrum



Scheme 1

due to the NCH_2 group at δ 3.36, a singlet at δ 4.81 due to $OCH_2C(O)$ and an AB pair for the bridging methylenes at δ 3.27 and 4.46 [^2J(HH) 13 Hz]. The $^{13}C\{^1H\}$ NMR spectrum shows the amide carbonyl resonance at δ 168.0. Compound **2** (yield 9.0%; mp 130 °C) is characterized as being in the partial cone conformation with the bis-(dibutylcarbamoyl)methoxy groups on opposite rims by the presence of a multiplet resonance due to NCH_2 groups at δ 3.21–3.42, two inequivalent singlets at δ 5.24 and 5.29 due to the pair of $OCH_2C(O)$ groups, and two sets of AB pairs for the inequivalent bridging methylenes at δ 4.34 and 4.96 [^2J(HH) 13 Hz], and at δ 4.68 and 4.70 [^2J(HH) 14 Hz]. The $^{13}C\{^1H\}$ NMR spectrum shows the amide carbonyl resonance at δ 170.0. Compound **3** (yield 9.6%; mp 174–175 °C) is characterized as being in the partial cone conformation with the bis-(dibutylcarbamoyl)methoxy groups on the same side of the upper rim by the presence of a multiplet resonance due to the NCH_2 group at δ 3.39–3.49, a singlet for $OCH_2C(O)$ at δ 4.98, along with two sets of AB pairs for the inequivalent bridging methylenes at δ 3.41 and 4.63 [^2J(HH) 13 Hz] and at δ 3.43 and 4.37 [^2J(HH) 14 Hz]. The OH resonances are found at δ 9.76 and 10.48. The $^{13}C\{^1H\}$ NMR spectrum shows the amide carbonyl resonance at δ 169.0. Both the ^{1}H NMR and ^{13}C NMR spectra show additional corresponding resonances for the other functional groups in these structures of **1**–**3**.

Extraction studies have been carried out with isooctane and toluene, along with the compounds **1**, **2** and **3** (1 mM solutions of each), and aqueous solutions of the metal salts (1 mM in



Scheme 2

Table 1 Extraction of oxyions by **1**, **2** and **3**

Compound	Solvent	Extraction (%)[a]			
		UO_2^{2+}	MoO_3(aq)	$Cr_2O_7^{2-}$	$HSeO_4^-$
1	Toluene	3	< 1	20(2)[b]	1
	Isooctane	31(3)	20(2)	< 1	< 1
2	Toluene	13(1)	7(1)	20(2)	11(1)
	Isooctane	25(2)	20(2)	< 1	< 1
3	Toluene	14(1)	< 1	32(3)	13(1)
	Isooctane	39(4)	40(4)	< 1	15(1)

[a] Extractions were carried out by vigorous shaking for 1 min with both the calix[4]arene and the metal salt as 1 mM solutions. The aqueous solution is at pH 0.85. [b] The initial and final metal concentrations were measured by ICP and the errors are estimated from multiple measurements.

0.14 M HNO_3). Equal volumes of the organic and aqueous solutions are then shaken for 1 min. The resultant aqueous layer is then separated and the remaining metal concentration in that layer analyzed by ICP. These data with estimated errors in parentheses are collected in Table 1. From these data it is apparent that the oxyions can be extracted into toluene or isooctane from an aqueous solution at pH 0.85 in the presence of these three hydrophobic calix[4]arene amides. These data also show differences between both these two solvents and the isomers of **1**, **2** and **3**. Although these data may not represent equilibrium conditions, they are viable because for an extractant to be useful the phase transfer of the species must be rapid, therefore these data reflect this property. From these preliminary data with these compounds it appears that both UO_2^{2+} and molybdenum trioxide have a slight preference for isooctane over toluene, with the reverse trend being observed for the two oxyanions. The differences between **1**, **2** and **3** are less apparent, but it does appear that there may be a preference of **3** being an extractant for transferring these oxyions into isooctane. Interestingly, this particular isomer is the one that has the amides in a potentially chelating geometry, with a hydrophobic *tert*-butyl group projecting into this lower rim binding cavity. Further use of these compounds as extractants will be reported in due course.

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Notes and References

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† Satisfactory elemental analyses have been obtained for these calix[4]arenes. The calix[4]arenes were purified on a silica column using the eluents dichloromethane and ethyl acetate for **1** and ethyl acetate and light petroleum (bp 40–50 °C) for **2** and **3**.

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