Synthesis of new calixcrowns and their anchoring to silica gel for the selective separation of Cs$^+$ and K$^+$

Giuseppe Arena,[a] Alessandro Casnati,[b] Annalinda Contino,[a] Leonardo Mirone,[a] Domenico Sciotto*[a] and Rocco Ungaro[b]

[a] *Dipartimento di Scienze Chimiche, Università di Catania, Viale A. Doria 8, 95125 Catania, Italy*
[b] *Dipartimento di Chimica Organica ed Industriale, Università di Parma, Viale delle Scienze, 43100 Parma, Italy*

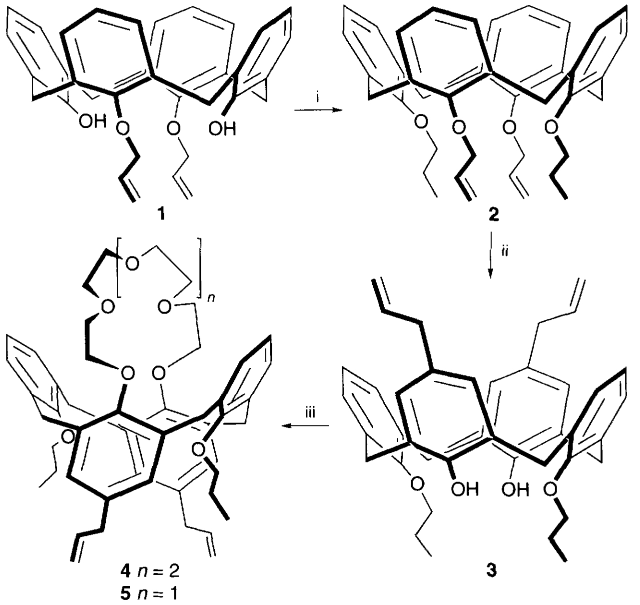
New 1,3-alternate calix[4]arenecrown-6 and calix[4]arenecrown-5, which are selective for caesium and potassium ions respectively, have been synthesized and linked covalently to silica gel *via* hydrosilanization and successfully employed for the chromatographic separation of Cs$^+$ and K$^+$ from alkali metal ions.

Macrocyclic ligands can be covalently attached to silica gel to separate or remove metal ions by chromatography in a selective fashion. Bradshaw *et al.* synthesized silica gel-bound crown ethers and aza macrocycles.[1,2] Glennon *et al.* succeeded in separating Na$^+$ from a mixture containing other ions by using a calixarene-bonded silica gel stationary phase.[3]

Calix[4]arenes[4] have been extensively used as molecular platforms for the construction of ionophores for alkali and alkaline earth metal ions and their conformational properties exploited to control efficiency and selectivity in metal ion recognition.[5] Very recently a series of calix[4]crown-6 fixed in 1,3-alternate conformations have been shown to be very selective towards caesium cations,[6] whereas the corresponding crown-5 derivatives are considered to be the most selective potassium ionophores known, showing a K$^+$/Na$^+$ selectivity higher than that obtained with valinomycin.[7]

For these reasons we have selected this class of ionophores and tried to modify their backbone in order both to link them covalently to silica gel and preserve their binding characteristics and selectivity. Here we report the successful synthesis of two new calixcrowns, **4** and **5**, in a 1,3-alternate conformation bearing two allyl groups on two opposite aromatic rings; this renders it possible to attach the calixcrowns to silica gel and to perform a chromatographic separation of some alkali metal ions.

Calixcrowns **4** and **5** were synthesized in three steps (Scheme 1) starting from the 1,3-diallylcalix[4]arene **1**.[8] The first step involved the alkylation of the free OH groups on the lower rim using a strong base, NaH (3.3 equiv.), and an alkylating agent, propyl iodide (2.5 equiv.), in anhydrous DMF. A Claisen rearrangement of compound **2** gave the upper rim diallyl derivative **3** which was transformed into the crowns **4** and **5** in the third step using Cs_2CO_3 as a base, with yields of 90 and 70%, respectively.† The silica gel-linked macrocycles (Fig. 1) were obtained by heating **4** or **5** with triethoxysilane and H_2PtCl_6 as a catalyst in anhydrous toluene and refluxing the heterogeneous mixture of the crude silanized products (yield 70%) and silica gel (1 : 10 w/w) for 30 h.‡ The solid was filtered and washed in sequence with toluene, hexane and dichloromethane. The stationary phases were characterized by elemental analysis, showing a macrocycle–silica gel ratio of 1 : 10 (w/w). Two columns were packed with the two stationary phases (i.d. 4 mm, *L* 18 and 15 cm, respectively). Both columns were tested using methanolic metal chloride solutions as analytes and alcoholic solutions as mobile phases. Separate injections of the metal salt solutions give the separation factors shown in Tables 1 and 2. The stationary phase containing **4** showed a good selectivity for caesium ions (Fig. 2). The same was observed for



Scheme 1 *Reagents and conditions*: i, NaH, C_3H_7I, DMF, ii, *N,N*-dimethylaniline, reflux; iii, $TsO(CH_2CH_2O)_{n+3}$ Ts, Cs_2CO_3, MeCN, reflux

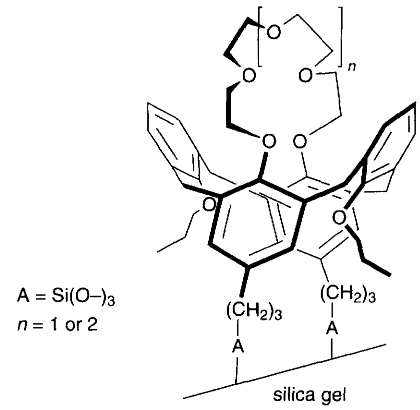


Fig. 1 Silica gel-linked calixcrowns

Table 1 Capacity and selectivity factors for the stationary phase containing **4**[a]

k_{Na^+}	k_{K^+}	k_{Cs^+}	α_{Cs^+/Na^+}	α_{Cs^+/K^+}
0.94	1.37	2.5	2.66	1.82

[a] Conditions: eluent MeOH, column (5 μm particle size) 18 × 0.4 cm I.D., conductivity detector, flow-rate 0.4 ml min^{-1}, room temp., t_0 = 3.0 min.

potassium (Table 2) when using the stationary phase containing calixcrown macrocycle **5**. These peaks became sharper when a small amount of water (10%) was added; in such cases the separation factors are lower. A much better separation of the metal ions is obtained when a less polar eluent (MeOH–Pr^{i}OH 9 : 1) is employed, although the solvent mixture causes a broadening of the peaks.

Table 2 Capacity and selectivity factors for the stationary phase containing **5**[a]

k_{Na^+}	k_{K^+}	k_{Cs^+}	α_{K^+/Na^+}	α_{K^+/Cs^+}
0.73	2.40	1.36	3.29	1.76

[a] Conditions: eluent MeOH, column (5 μm particle size) 15 × 0.4 cm I.D., conductivity detector, flow-rate 0.4 ml min^{-1}, room temp., t_0 = 2.6 min.

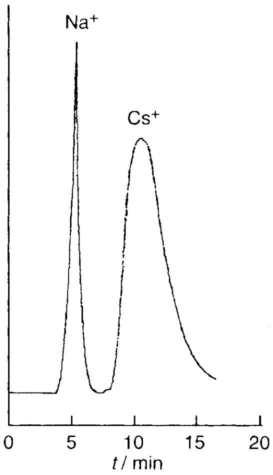


Fig. 2 Typical chromatogram for the Cs$^+$/Na$^+$ separation [eluent MeOH, stationary phase containing **4** (5 μm, 18 × 0.4 cm I.D.), conductivity detector, flow-rate 0.4 ml min^{-1}, room temp.]

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Footnotes

† All compounds were characterized by ^{1}H NMR, ^{13}C NMR, MS and elemental analysis techniques.

‡ The silica gel was activated by placing it in a refluxing HCl–H_2O mixture; the mixture was then filtered and washed with water until a pH of 4 was attained and then dried in a vacuum oven overnight.

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