

Selective Chromogenic Reagents based upon Phenolic Cryptands

Alastair F. Sholl and Ian O. Sutherland*

Department of Chemistry, University of Liverpool, PO Box 147, Liverpool L69 3BX, UK

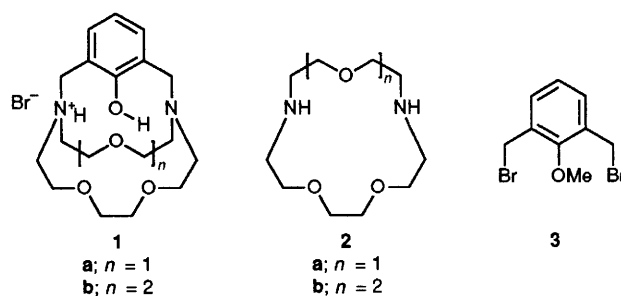
Chloroform solutions of the chromoionophore **4c**, which has been synthesised by a simple procedure from diaza-15-crown-5 **2a**, extract lithium cations from aqueous solutions in the pH range 7–8 with very high selectivity as compared with the extraction of sodium, potassium, magnesium and calcium; the related reagent **5** shows moderate selectivity for sodium.

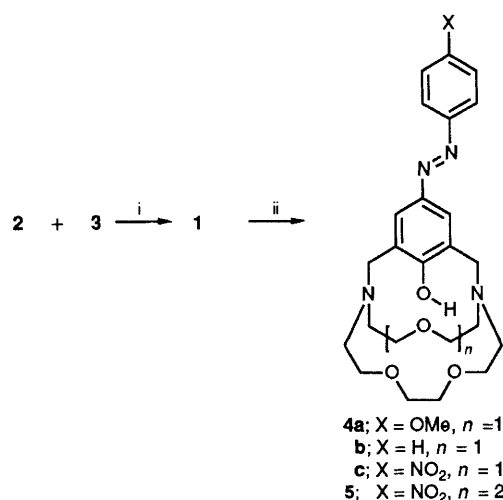
A number of highly selective ionophores for lithium have been reported, which have, for the most part, been based upon 14-crown-4 derivatives and some of which have provided the basis for lithium selective electrodes¹ with $\text{Li}^+ : \text{Na}^+$ selectivity ratios of up to 1500:1. Selective chromogenic reagents for lithium have been rather less successful although a number of examples have been reported² and in one case³ a high $\text{Li}^+ : \text{Na}^+$ selectivity ratio has been reported for complexation in methanol. Ion selective electrodes for sodium are well established, a number of chromogenic agents have been described and high $\text{Na}^+ : \text{K}^+$ selectivity^{4,5} has been reported for reagents based upon a spherand and a cryptahemisphere. In this communication we report a new chromogenic reagent that shows very high selectivity for lithium and a related reagent that shows moderate selectivity for sodium. Both compounds can be obtained by very simple procedures from commercially available diaza-crown ethers.

The ready availability⁶ of the phenolic cryptands **1** by the reaction of diaza-crown ethers **2** with the dihalide **3** suggested that chromogenic reagents based upon these cryptand structures should be investigated. Reaction of the phenols **1** with

aryldiazonium salts gave the azophenolic cryptands **4a–c** and **5** as outlined in Scheme 1. The products **4a–c** and **5** had spectroscopic properties (NMR, mass and absorption spectra) in accord with the assigned structures, although in aqueous solution there may be a proportion of the phenylhydrazone tautomer (*cf.* ref. 7).

Chloroform solutions of compounds **4a** and **4b** extract lithium from an aqueous solution of lithium chloride at pH 9





Scheme 1 Synthesis of azophenolic cryptands **4** and **5**. Reagents and conditions (yields): i, reflux in MeCN *ca.* 24 h (**1a** 86%, **1b** 82%); ii, ArN₂⁺ Cl⁻, 0 °C (**4a** 50%, **4b** 83%, **4c** 85%, **5** 80%)

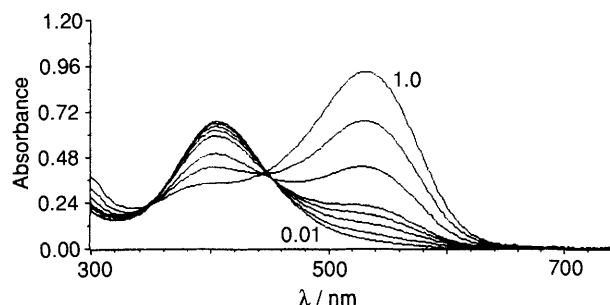


Fig. 1 Absorption spectrum (300–700 nm) of cryptand **4c** in CHCl₃ (8.14×10^{-5} mol dm⁻³) after equilibration with an equal volume of aqueous LiCl at pH 7.0 [tris(hydroxymethyl)methylamine–HCl buffer] at concentrations of 0.01, 0.025, 0.05, 0.075, 0.1, 0.25, 0.50 and 1.0 mol dm⁻³. The absorbance at 406 nm corresponds to the free cryptand and at 534 nm to the lithium complex.

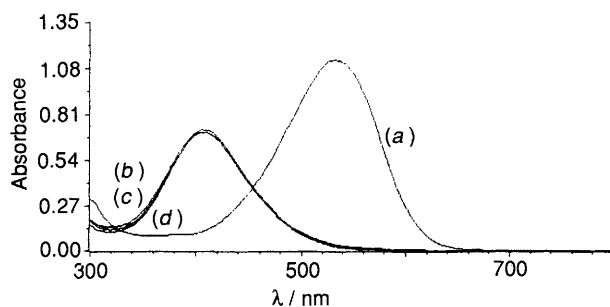


Fig. 2 Absorption spectrum (300–800 nm) of cryptand **4c** in CHCl₃ (5.15×10^{-5} mol dm⁻³) after equilibration with equal volumes of aqueous (a) LiCl (1.0 mol dm⁻³), (b) NaCl (1.0 mol dm⁻³) and (c) KCl (1.0 mol dm⁻³) at pH 9.0 [tris(hydroxymethyl)methylamine–HCl buffer]. Under these conditions there is no detectable response to either Na⁺ or K⁺ as indicated by (d) the absorbance of the free cryptand.

but they are not sufficiently acidic to function as useful chromogenic reagents in the pH range 7–8. The more acidic *p*-nitrophenylazophenol **4c** extracts lithium from aqueous solution in the pH range 7–9 with a considerable change in its absorption spectrum as shown in Fig. 1. It also shows very high selectivity for lithium as compared with sodium and potassium, neither of which gives a measurable response in this pH range even at concentrations as high as 1 mol dm⁻³ (see Fig. 2). Details of extraction coefficients are given in Table 1, the

Table 1 Extraction coefficients^a for chromoionophores **4c** and **5**

| Compound | pH/±0.1 | Cation | log ₁₀ K _e /±0.2 ^d |
|------------------------|---------|------------------|---|
| 4c ^b | 7.7 | Li ⁺ | -6.9 |
| | 8.2 | Li ⁺ | -7.0 |
| | 9.3 | Li ⁺ | -7.2 |
| 5 ^c | 6.9 | Na ⁺ | -6.5 |
| | 8.1 | Na ⁺ | -6.6 |
| | 9.3 | Na ⁺ | -6.7 |
| | 9.4 | K ⁺ | -9.3 |
| | 9.2 | Li ⁺ | -9.6 |
| | 9.1 | Ca ²⁺ | -7.9 |

^a For a solution of **4c** or **5** at *ca.* 10^{-5} to 10^{-4} mol dm⁻³ in CHCl₃ and solutions of M⁺ at 10^{-4} to 1 mol dm⁻³ in water using a tris(hydroxymethyl)methylamine–HCl buffer. K_e is based upon changes in absorption at 406 and 534 nm for **4c** and Li⁺, 402 and 554 nm for **5** and Li⁺, Na⁺ and K⁺, and 402 and 500 nm for **5** and Ca²⁺. ^b No measurable response for Na⁺, K⁺, Mg²⁺ and Ca²⁺ in the pH range 7–9 up to 1 mol dm⁻³ concentration of the metal salts. ^c No measurable response for Mg²⁺ in the pH range 7–9 up to 1 mol dm⁻³ concentration of the metal salts. ^d $K_e = \frac{[H^+]_{aq}[M^+Cl^-]_{org}}{[M^+]_{aq}[ClH]_{org}}$ (where the subscripts aq and org refer to the aqueous and organic phases, respectively and ClH refers to the ionisable chromoionophore).

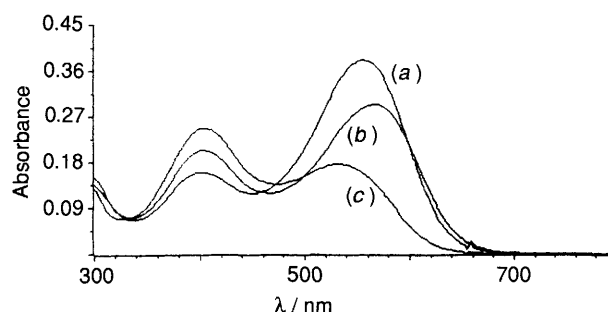
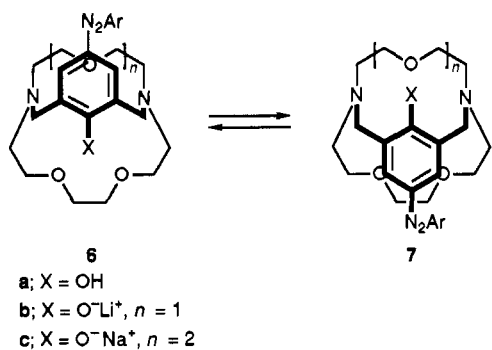


Fig. 3 Absorption spectrum (300–800 nm) of cryptand **5** in CHCl₃ (2.79×10^{-5} mol dm⁻³) after equilibration with equal volumes of aqueous (a) NaCl (0.005 mol dm⁻³), (b) KCl (1.0 mol dm⁻³) and (c) LiCl (1.0 mol dm⁻³) at pH 9.0 [tris(hydroxymethyl)methylamine–HCl buffer]

Li⁺:Na⁺ selectivity ratio is *ca.* 10⁴ or greater on the basis of the spectroscopic response at pH 9 (response to 10^{-4} mol dm⁻³ Li⁺ greater than response to 1 mol dm⁻³ Na⁺).

The larger cavity of the *p*-nitrophenylazophenol **5** is more appropriate for sodium complexation and within the pH range 7–8 this compound shows moderately high selectivity for sodium extraction as compared with lithium (ratio of K_es for Na⁺:Li⁺ *ca.* 800) and for sodium as compared with potassium (ratio of K_es for Na⁺:K⁺ *ca.* 400), the selectivity at pH 9 is illustrated in Fig. 3. The response of chromoionophore **5** to calcium is more significant (ratio of K_es for Na⁺:Ca²⁺ *ca.* 16), although in this case the absorption maximum of the Ca²⁺ complex is at a rather shorter wavelength (see data in Table 1). Although relatively modest, this selectivity compares well with that shown by chromogenic reagents based upon spherand systems.^{4,8} The lithium salt **6b** and the sodium salt **6c/7c** had spectroscopic properties (¹H and ¹³C NMR) in accord with the proposed structures, in particular the ¹H spectra (400 MHz) are in accord with the conformations shown diagrammatically in **6** and **7** in which the NCH₂CH₂O and OCH₂CH₂O units have a *gauche* relationship between the heteroatoms and the aromatic ring lies parallel to the macrocycle. Although the process **6a** ⇌ **7a** is fast on the NMR time scale for the free chromoionophore **5** this process is slow on the NMR time scale for the sodium salt **6c/7c**. On the other hand the chromoionophore **4c** appears to adopt only the conformation **6** for both the free chromoionophore **6a** and the lithium salt **6b**.

The chromoionophores **4c** and **5** are promising compounds for use in optical fibre sensors for Li⁺ and Na⁺ and structural modification to enhance lipophilicity and sensitivity should



improve their performance. They also show an interesting relationship to chromogenic cryptahemispherands⁵ and cryptands^{7,9} which, although highly selective for Na⁺ and K⁺, require more elaborate synthetic procedures. The advantage of using cryptand structures¹⁰ for cation recognition by chromoionophores is exemplified by these compounds and also by a bridged calixarene derivative which shows¹¹ very high selectivity for K⁺ (ratio of K_{es} for K⁺:Na⁺ ca. 1200).

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