

Barium-selective Chromoionophoric Properties of Nitro Derivative of Calix[4]arene-crown Ethers

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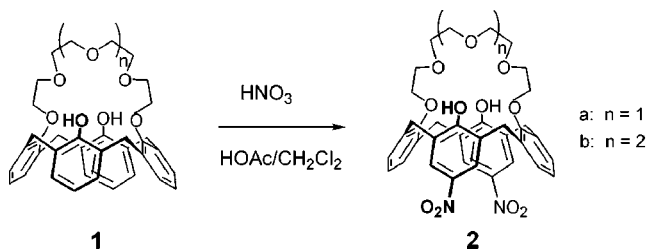
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There has been much interest for the development of efficient and selective chromogenic and fluorogenic ionophore systems.¹ Many compounds are based on the well-known molecular framework of crown ethers, calixarenes, and other EDTA type efficient chelating compounds.² Among them the ionophores derived from the calix[4]arenes are particularly attractive for their efficient ionophoric properties toward some of important guest ions.³ Particularly, the calix[4]arene-crown ethers are known to have unique binding properties toward alkali, alkaline earth metal ions, and organic amines.⁴ Many of spectroscopic sensing materials are developed by conjugating molecular framework of calix[4]arene-crown ethers with suitable signaling functions of azophenols, thiazoles, and aminoquinones.⁵ Quite unexpectedly, however, the ionophoric properties of simple nitro derivative of calix[4]arene-crown ethers were not reported, except for the closely related structure having ester-ether functions in crown moiety,⁶ in spite of their synthetically easy availability and efficient ionophoric properties. In this paper, we report the synthesis of dinitro derivative of calix[4]arene-crown ethers and their ionophoric properties toward representative alkali and alkaline earth metal ions aiming for the development of efficient and selective chromogenic sensing material for the barium ions.

Dinitro derivatives **2a** and **2b** were prepared by the selective nitration⁷ of calix[4]arene-crown-5 ether⁸ **1a** and calix[4]arene-crown-6 ether **1b** with HNO₃ (HOAc/CH₂Cl₂) on unsubstituted phenol groups in good yield (88-92%) (Scheme 1). The resonances for the bridging methylene protons are observed at δ 4.46 and 3.49 indicating that the nitro derivatives adopt a cone conformation in solution. Phenolic OH resonances were observed at relatively down field of δ 8.81-8.97, as expected from the presence of a nitro group on the phenol ring. In their IR spectrum, characteristic bands of a nitro group were observed at 1512 and 1337 cm⁻¹.



Scheme 1

The structure of calix[4]arene crown-5 ether is known to have high selectivity toward large alkaline earth metal ions of Ba²⁺.⁹ We have utilized the nitrophenol groups¹⁰ for the signaling unit which can be prepared easily by selective nitration of phenols and can also be used as electroactive functions.¹¹

The chromogenic ionophore properties of **2** were investigated by examining the UV-Vis absorption behaviors of the host in common organic solvents. Among the solvent system surveyed, CH₃CN-MeOH mixture was found to be most efficient and selective for the development of chromogenic responses. In CH₃CN-MeOH mixture ([**2a**] = 1 × 10⁻⁵ M, CH₃CN : MeOH = 1 : 9, v/v) the crown-5 ionophore **2a** showed a broad absorption band around 326 nm which is a characteristic of the *p*-nitrophenol moiety (Figure 1). Addition of 100 equiv of metal ions in perchlorate resulted in the appearance of a new band due to the formation of nitrophenoxide in the ionophore around 441 nm. The color of the solution turned from colorless to yellow. The Ba²⁺ ions showed most pronounced response that is in good agreement with previous reported selectivity and the induced absorbance intensity at 441 nm decreases in the order of Ba²⁺ >> Ca²⁺ > Mg²⁺ ≈ K⁺ ≈ Na⁺ ≈ Li⁺. The increase in the absorption band at 441 nm is around 300-fold with Ba²⁺ ions. With Ca²⁺ ion, the increase in the absorption band is less significant (around 70-fold) and somewhat blue shift

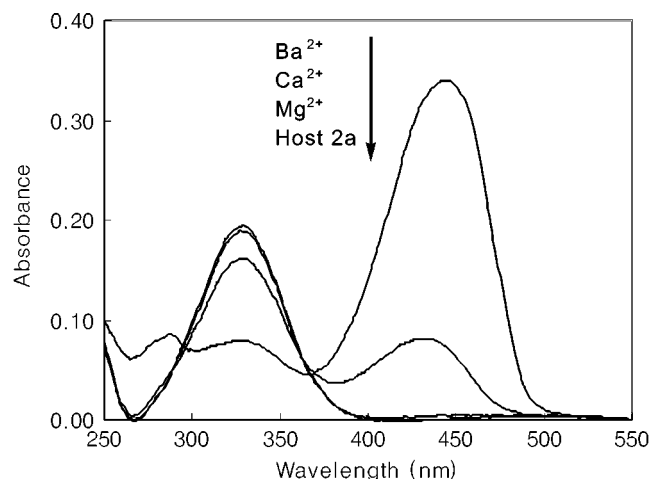


Figure 1. Absorption spectra of **2a** in the presence of metal ions. [**2a**] = 1.0 × 10⁻⁵ M, [M²⁺] = 1.0 × 10⁻³ M in CH₃CN-MeOH (1 : 9, v/v).

($\lambda_{\max} = 430$ nm) was also observed when compared with Ba^{2+} ions. Other metal ions (Li^+ , Na^+ , K^+ , and Mg^{2+}) induced no significant changes in the spectral behaviors of **2a**.

The chromogenic behavior of homologous calix[4]arene-crown-6 ether **2b** was also investigated. Under the same conditions, the ionophore itself showed somewhat residual absorbance at 430 nm without interaction with any metal ion in addition to the strong absorption band at 326 nm. Upon addition of Ba^{2+} ions, the absorption band at 448 nm increased markedly and the color of the solution also turned into yellow one exhibiting almost identical spectral changes of **2a**- Ba^{2+} system. On the other hand, with Ca^{2+} ions a strong absorption band at 430 nm was observed, which is about 77% of the absorption intensity induced by the interaction with Ba^{2+} ions. The enhanced response toward the Ca^{2+} ions significantly reduces the Ba^{2+} selectivity of the crown-6 ether **2b**.

To have a further insight into the chromogenic behavior of the ionophore **2a**, the absorption profile as a function of metal ion concentration was obtained (Figure 2). Ionophore **2a** exhibited a gradual increase in absorption intensity at the λ_{\max} of 441 nm upon addition of incremental barium ions up to 3 equiv then leveled off. From the plot of absorbance versus metal ion concentration for **2a**- Ba^{2+} system, the detection limit¹² of 2×10^{-6} M was found which is suitable for the analysis of barium ions in the micromolar concentration range. From the plot of the absorbance changes of **2a**- Ba^{2+} system the association constant was determined by nonlinear curve fitting procedure and found to be $2.4 \times 10^6 \text{ M}^{-1}$ in this solvent system of CH_3CN -MeOH (1 : 9, v/v). For Ca^{2+} ions, somewhat smaller value of $1.1 \times 10^4 \text{ M}^{-1}$ was obtained. Other metal ions induced too small changes in absorption spectra to estimate reliable association constants.

The selective response of nitro derivative toward barium ions was further evidenced by the experiments performed in the presence of background metal ions (100 equiv of Li^+ , Na^+ , K^+ , Mg^{2+} , and Ca^{2+}). Ionophore **2a** exhibited very

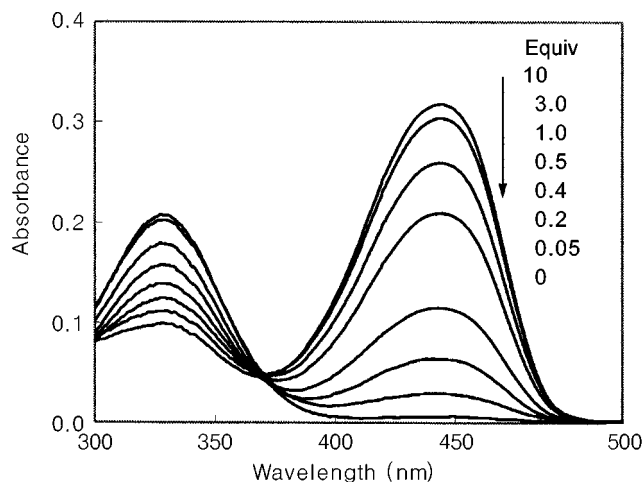


Figure 2. Changes in absorption spectra as a function of $[\text{Ba}^{2+}]$. $[\mathbf{2a}] = 1 \times 10^{-5}$ M in CH_3CN -MeOH (1 : 9, v/v).

similar Ba^{2+} -selective response profile as compared with the results obtained in the absence of any background metal ions except for somewhat increased residual absorbance due to the presence of large quantity of calcium ions. The Ba^{2+} selectivity of the ionophore can be utilized as a new sensor material for the determination of barium ions¹³ as well as the sulfate ions in mineral waters.¹⁴

In conclusion, simple nitro derivative of calix[4]arene-crown-5 ether showed a selective molecular recognition behavior toward barium ions over other alkali and alkaline earth metal ions. The prepared nitro derivatives can be used as a new and selective chromogenic probe for the sensing of barium ions in chemical systems.

Experimental Section

General. Calix[4]arene, tetra(ethylene glycol) di-*p*-tosylate, and penta(ethylene glycol) di-*p*-tosylate were purchased from Aldrich and used without further purification. NMR spectra were obtained with a Varian Gemini 2000 NMR spectrometer (300 MHz). UV-Vis absorption spectra were recorded with a Jasco V-550 UV spectrometer. FAB-MS spectra were measured with a Micromass Autospec mass spectrometer. Calix[4]arene-crown-5 ether and calix[4]arene-crown-6 ether were prepared by following the reported procedure.⁸

Preparation of nitro derivatives 2. Calix-crown ether **1a** (500 mg, 0.835 mmole) was dissolved in dichloromethane (10 mL) and subsequently added HNO_3 (0.4 mL) and HOAc (0.5 mL) solution. The solution was stirred at rt for 30 min until the reaction was completed (monitored by TLC). The reaction mixture was washed with water twice and the organic layer was evaporated under reduced pressure. The crude residue was purified by crystallization from CH_2Cl_2 /MeOH. Nitro-crown-5 ether **2a**. Yield: 92%; ^1H NMR (CDCl_3) δ 8.97 (s, 2H, ArOH), 8.06 (s, 4H, NO_2 -ArH), 6.95 (d, 4H, $J = 7.5$ Hz, ArH), 6.83 (t, 2H, $J = 7.6$ Hz, ArH), 4.46 and 3.49 (d, 4H each, $J = 13.3$ Hz, ArCH_2Ar), 4.14, 4.10, 3.89 and 3.82 (br m, 4H each, OCH_2); FAB-MS (*m*-NBA) calcd for $[\text{M}+\text{H}]^+ \text{C}_{36}\text{H}_{37}\text{N}_2\text{O}_{11}$ 673.2, found 673.16. Nitro-crown-6 ether **2b** was prepared similarly. Yield: 88%; ^1H NMR (CDCl_3) δ 8.81 (s, 2H, ArOH), 8.06 (s, 4H, NO_2 -ArH), 6.94 (d, 4H, $J = 7.5$ Hz, ArH), 6.81 (t, 2H, $J = 7.6$ Hz, ArH), 4.46 and 3.49 (d, 4H each, $J = 13.2$ Hz, ArCH_2Ar), 4.20, 4.00, 3.88, and 3.81 (br m, 4H each, OCH_2), 3.65 (s, 4H, OCH_2); FAB-MS (*m*-NBA) calcd for $[\text{M}+\text{H}]^+ \text{C}_{38}\text{H}_{41}\text{N}_2\text{O}_{12}$ 717.3, found 717.3.

UV measurements. Stock solutions of ionophore **2** (1×10^{-4} M, in CH_3CN) and metal perchlorate (1×10^{-2} M, in MeOH) were prepared. The metal solution was diluted 10 and 100 times to give 1×10^{-3} M and 1×10^{-4} M solutions. Aliquots of metal solution was added to the ionophore solution and the final concentration and composition of the solution were adjusted to the desired value by adding extra MeOH.

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