



## Chemical Chromogenic Sensors Based on Calixarenes: Syntheses and Recognition Properties for Alkylamines

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### Abstract

Nitration of 1,3-*distal* dialkylated calix[4]arenes was investigated in order to prepare chromogenic sensor compounds. There were three kinds of separable products, which came from the nitration and oxidation of the phenol moieties. The cone conformation of calix[4]arenes containing a quinone structure was first determined. And the effect of the structure of reactants for the nitration and oxidation is also discussed. Dinitrated calix[4]arenes possess recognition ability for the alkylamines, which can be as the chromogenic sensors for determining the alkylamines. The recognition behavior was due to the proton transfer between alkylamine and calix[4]arenes, and the resulting ammonium phenoxide was stabilized by the phenoxide oxygen atom and the carbonyl at the lower rim with hydrogen bonding.

### Introduction

Molecular recognition is the crucial process in biological systems such as enzymes, antibodies or genes, and is also the fundament of supramolecular chemistry. The complementarity of size, shape and interactions between receptors and substrates not only gives living organisms specific functions, but also makes the design of molecular or supramolecular devices possible [1]. Chemical sensing, which is accompanied by combining a recognition element with an optical or electronic transduction element, has received much attention as an efficient analytical technique for the detection of particular species, especially bio-molecules [2]. Among these sensing systems, chromogenic receptors give rise to a specific color change upon selective complexation with guest species, which are not only as spectrophotometric analytical reagents but also as the tools for the detailed understanding of receptor–substrate interaction because that molecular recognition process could be efficiently amplified as an optical signal. Therefore, the design of new and highly efficient chromogenic receptors is always a challenge for supramolecular chemistry and analytical techniques [3].

Calixarenes, which are cyclic oligomers of varying size derived from *para*-substituted phenols and formaldehyde [4], can be ideal frameworks or building blocks for the development of chromogenic receptors in molecular recognition since the incorporation of an appropriate sensory group into the calixarene having a preorganized substrate binding site results in a tailored chromogenic receptor. A variety of chromogenic calixarenes bearing quinone, nitrophenol, nitrophenylazophenol, indoaniline, indophenol and azophenol have been synthesized and show high selectivity in recog-

nitration for cations and organic molecules [5]. Especially, Kubo *et al.* have reported the colorimetric chiral recognition for amines with chromogenic calix[4]arenes, which was based on the transduction of chiral recognition process to optical signals [6]. We have also investigated that nitrated calix[4]crowns containing ester group at lower rim as chromogenic receptors recognize alkylamines [7]. Here, we wish to continue reporting the nitration of different 1,3-*distal* dialkylated calix[4]arenes, the effect of the structure of reactants for the nitration and oxidation, and the recognition ability of dinitrated calix[4]arenes for alkylamines.

### Experimental

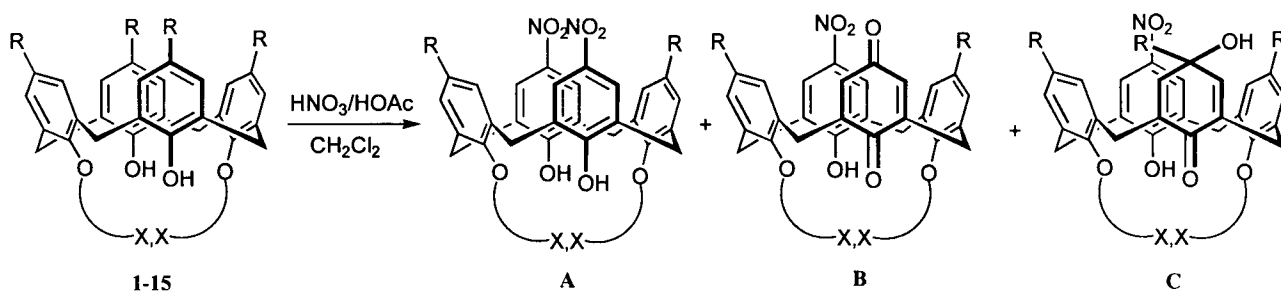
#### Material and methods

Melting points were uncorrected.  $^1\text{H}$  and  $^{13}\text{C}$  NMR spectra were recorded on a Varian Unity 200 spectrometer (chemical shifts in  $\delta$  units relative to TMS as internal standard,  $J$  in Hertz). Mass spectra (FAB) were recorded on a KYKY-ZHT-5 instrument. Infrared spectra were recorded on a Perkin-Elmer 782 spectrometer ( $\nu$   $\text{cm}^{-1}$ ). UV-VIS spectra were determined with a Uvikon 810 spectrometer. Elemental analyses were performed at the Analytical Laboratory of the Institute of Chemistry, CAS.

#### General procedure for the selective nitration or ipso-nitration of 1,3-*distal* dialkylated calix[4]arenes

To a solution of 0.5 mmol of 1,3-*distal* dialkylated calix[4]arenes **1–18** in a mixture of  $\text{CH}_2\text{Cl}_2$  and 36 equiv. (50 equiv. for *ipso*-nitration) of glacial acetic acid was added 50 equiv. (80 equiv. for *ipso*-nitration) of 65%  $\text{HNO}_3$  at

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	R	X,X
1	<i>tert</i> -butyl	CH <sub>3</sub> , CH <sub>3</sub>
2	H	CH <sub>3</sub> , CH <sub>3</sub>
3	<i>tert</i> -butyl	CH <sub>2</sub> COOEt, CH <sub>2</sub> COOEt
4	H	CH <sub>2</sub> COOEt, CH <sub>2</sub> COOEt
5	<i>tert</i> -butyl	(CH <sub>2</sub> CH <sub>2</sub> OCH <sub>2</sub> ) <sub>2</sub>
6	H	(CH <sub>2</sub> CH <sub>2</sub> OCH <sub>2</sub> ) <sub>2</sub>
7	<i>tert</i> -butyl	(CH <sub>2</sub> CO <sub>2</sub> CH <sub>2</sub> ) <sub>2</sub>
8	H	(CH <sub>2</sub> CO <sub>2</sub> CH <sub>2</sub> ) <sub>2</sub>
9	<i>tert</i> -butyl	(CH <sub>2</sub> CO <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> ) <sub>2</sub> O
10	H	(CH <sub>2</sub> CO <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> ) <sub>2</sub> O
11	<i>tert</i> -butyl	(CH <sub>2</sub> CO <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> OCH <sub>2</sub> ) <sub>2</sub>
12	H	(CH <sub>2</sub> CO <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> OCH <sub>2</sub> ) <sub>2</sub>
13	<i>tert</i> -butyl	(CH <sub>2</sub> CO <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> OCH <sub>2</sub> CH <sub>2</sub> ) <sub>2</sub> O
14	H	(CH <sub>2</sub> CO <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> OCH <sub>2</sub> CH <sub>2</sub> ) <sub>2</sub> O
15	<i>tert</i> -butyl	(CH <sub>2</sub> CONHCH <sub>2</sub> ) <sub>2</sub>
16	H	(CH <sub>2</sub> CONHCH <sub>2</sub> ) <sub>2</sub>
17	<i>tert</i> -butyl	(CH <sub>2</sub> CONH) <sub>2</sub> - <i>o</i> -C <sub>6</sub> H <sub>4</sub>
18	H	(CH <sub>2</sub> CONH) <sub>2</sub> - <i>o</i> -C <sub>6</sub> H <sub>4</sub>

Scheme 1.

0 °C (ambient temperature for *ipso*-nitration), the reaction mixture was stirred for 30 minutes at this temperature, then poured into water (50 ml). The organic phase was washed with water (2 × 50 ml) and brine (50 ml), dried with MgSO<sub>4</sub>, then chromatographed on a silica gel column using chloroform as eluent to afford a solid, which was recrystallized from CHCl<sub>3</sub>/CH<sub>3</sub>OH to give pure product **1–16A**, **6B**, **10B**, **15B**, **17–18B** or **17C**.

**Compound 6B**: yield: 34%; m.p. 240 °C (decomp.); – IR (KBr):  $\nu = 3170$  (OH), 1635 (CO), 1590, 1495 (NO<sub>2</sub>), 1320 (NO<sub>2</sub>). – <sup>1</sup>H NMR (200 MHz, CDCl<sub>3</sub>):  $\delta = 9.19$  (s, 1 H, OH), 8.03 (s, 2 H, ArH), 7.10–6.85 (m, 6 H, ArH), 6.75 (s, 2 H, C=CHCO), 4.22, 3.43 (AB,  $J_{AB} = 12.5$ , 4 H, ArCH<sub>2</sub>Ar), 4.26–4.13 (m, 2 H, OCH<sub>2</sub>CH<sub>2</sub>O), 4.07–3.90 (m, 2 H, OCH<sub>2</sub>CH<sub>2</sub>O), 3.88–3.72 (m, 4 H, OCH<sub>2</sub>CH<sub>2</sub>O), 3.79 (s, 4 H OCH<sub>2</sub>CH<sub>2</sub>O), 3.75, 3.56 (AB,  $J_{AB} = 15.0$ , 4 H, ArCH<sub>2</sub>Ar), – <sup>13</sup>C NMR (50.3 MHz, CDCl<sub>3</sub>):  $\delta = 186.27$ ,

188.42 (CO), 159.46, 153.54, 146.80, 139.91, 133.25, 132.42, 131.70, 129.94, 129.84, 128.96, 125.37, 124.05 (ArC), 72.45 (ArOCH<sub>2</sub>), 68.76, 68.53 (CH<sub>2</sub>OCH<sub>2</sub>), 35.40, 31.50 (ArCH<sub>2</sub>Ar). – MS (FAB, positive):  $m/z = 598$  [M + H]<sup>+</sup>. – C<sub>34</sub>H<sub>31</sub>NO<sub>9</sub> (597.60): calcd. C 68.33, H 5.23, N 2.34; found C 68.24, H 5.21, N 2.16.

**Compound 9A**: yield: 41%; m.p. > 300 °C; – IR (KBr):  $\nu = 3340$  (OH), 2960, 1745 (CO<sub>2</sub>), 1590, 1515 (NO<sub>2</sub>), 1335 (NO<sub>2</sub>). – <sup>1</sup>H NMR (200 MHz, CDCl<sub>3</sub>):  $\delta = 8.93$  (s, 2 H, OH), 7.93 (s, 4 H, ArH), 7.05 (s, 4 H, ArH), 4.90 (s, 4 H, OCH<sub>2</sub>CO), 4.56 (t,  $J = 8$ , 4 H, CO<sub>2</sub>CH<sub>2</sub>), 4.46, 3.48 (AB,  $J_{AB} = 13.0$ , 8 H, ArCH<sub>2</sub>Ar), 3.84 (t,  $J = 8$ , 4 H, CH<sub>2</sub>OCH<sub>2</sub>), 1.15 (s, 18 H, C(CH<sub>3</sub>)<sub>3</sub>). – <sup>13</sup>C NMR (50.3 MHz, CDCl<sub>3</sub>):  $\delta = 169.89$  (CO<sub>2</sub>), 158.44, 150.91, 149.05, 140.15, 131.84, 128.68, 126.57, 124.51 (ArC), 71.80 (ArOCH<sub>2</sub>), 69.33, 64.54 (CH<sub>2</sub>OCH<sub>2</sub>), 34.29 (C(CH<sub>3</sub>)<sub>3</sub>), 31.86 (ArCH<sub>2</sub>Ar), 31.19 (C(CH<sub>3</sub>)<sub>3</sub>). – MS

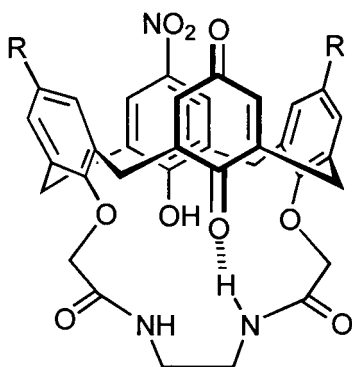


Figure 1. Intramolecular hydrogen-bonding in compound **15B**.

(FAB, negative):  $m/z = 811 [M - H]^-$ . -  $C_{44}H_{48}N_2O_{13}$  (812.84); calcd. C 65.01, H 5.95, N 3.45; found C 65.13, H 5.95, N 3.46.

**Compound 13A**: yield: 31%; m.p. 144–145 °C; – IR (KBr):  $\nu = 3390$  (OH), 2960, 1750 ( $CO_2$ ), 1590, 1515 ( $NO_2$ ), 1335 ( $NO_2$ ). –  $^1H$  NMR (200 MHz,  $CDCl_3$ ):  $\delta = 9.07$  (s, 2 H, OH), 7.96 (s, 4 H, ArH), 7.09 (s, 4 H, ArH), 4.89 (s, 4 H,  $OCH_2CO$ ), 4.51 (t,  $J = 8$ , 4 H,  $CO_2CH_2$ ), 4.50, 3.49 (AB,  $J_{AB} = 13.0$ , 8 H,  $ArCH_2Ar$ ), 3.89 (t,  $J = 8$ , 4 H,  $CO_2CH_2CH_2$ ), 3.75 ~ 3.60 (m, 8 H,  $OCH_2CH_2O$ ), 1.18 (s, 18 H,  $C(CH_3)_3$ ). –  $^{13}C$  NMR (50.3 MHz,  $CDCl_3$ ):  $\delta = 169.34$  ( $CO_2$ ), 158.60, 150.28, 149.21, 140.24, 131.93, 129.02, 126.61, 124.47 (ArC), 71.98 ( $ArOCH_2$ ), 71.10, 70.75, 68.80, 65.00 ( $OCH_2CH_2O$ ), 34.34 (C ( $CH_3$ )<sub>3</sub>), 31.81 ( $ArCH_2Ar$ ), 31.19 (C( $CH_3$ )<sub>3</sub>). – MS (FAB, negative):  $m/z = 899 [M - H]^-$ . -  $C_{48}G_{56}N_2O_{15} \cdot 0.5CHCl_3$  (960.64); calcd. C 60.63, H 5.89, N 2.92; found C 60.14, H 5.93, N 2.68.

## Results and discussion

### Synthesis of chromogenic receptors: Nitration of 1,3-distal dialkylated calix[4]arenes

The nitration of 1,3-distal dialkylated calix[4]arenes has been reported by Reinhoudt and ourselves [7–9]. Because the *para* positions of phenol rings are much more reactive than those of alkoxyphenyl rings in electrophilic aromatic substitution, the compounds whose two phenol rings were selectively nitrated or *ipso*-nitrated could be obtained as main products in mild conditions, for example, using nitric acid and glacial acetic acid as nitration reagents. However, even under this condition, we still obtained by-products, which were mainly the product of oxidation. Böhmer *et al.* have reported that the *ipso*-nitration of 1,3-distal dialkylated *tert*-butylcalix[4]arenes could provide the products with two 6-nitro-cyclohexa-2,4-dienone units by attacking the *ortho* position of the phenolic hydroxyl group exploiting concentrated nitric acid and glacial acetic acid as nitration reagents [10]. And we have also obtained the products with one nitrated phenol moiety and one quinone moiety or one cyclohexadienone moiety [9]. Here we investigate systematically the nitration of different kinds of 1,3-distal dialkylated calix[4]arenes, in order to find the effect of the structure of reactants for the nitration.

The calix[4]arenes were chosen as reactants, including 1,3-distal dialkylated calix[4]arenes with methyl (**1**, **2**), ethoxycarbonylmethyl (**3**, **4**), ethylene oxide chain (**5**, **6**), crown ether moiety containing two ester groups (**7–14**) and crown ether moiety containing two amide groups (**15–18**). To a solution of 1,3-distal dialkylated calix[4]arenes **1–18** in a mixture of  $CH_2Cl_2$  and glacial acetic acid, was added 65%  $HNO_3$  at 0 °C (ambient temperature for *ipso*-nitration), the reaction mixture was stirred for 30 minutes at this temperature, then quenched by adding water. After treatment, we obtained three kinds of products: **A**, **B**, and **C**. (Scheme 1)

All products have been characterized by  $^1H$  and  $^{13}C$  NMR, FAB-MS, IR and elemental analyses. Two very strong peaks of absorption at ca. 1500 and 1320  $cm^{-1}$  indicated the presence of a nitro group in all of their IR spectra. For the kind of dinitrated products **A**, the chemical shift of the aromatic protons of nitrated phenol rings were located at about  $\delta$  8 ppm in their  $^1H$  NMR spectra. For the kind of mono-nitrated and mono-oxidation products **B**, there were absorption of carbonyl groups at 1640  $cm^{-1}$  in their IR spectra. And two signals at  $\delta$  188 and 186 ppm in their  $^{13}C$  NMR spectra also indicated that this kind of product contained two carbonyl groups, which originated from the presence of quinone structure. For the kind of mono-nitrated and semi-oxidation products **C**, there were two kinds of signals for the protons of hydroxyl group in their  $^1H$  NMR spectra and only one signal for the carbonyl of cyclohexadienone moiety in  $^{13}C$  NMR spectra.

The conformation of these products is very interesting. The product **A** adopts cone conformation in  $CDCl_3$ , which could be deduced by only one AB system for the signal of protons of methylene between two aromatic rings in its  $^1H$  NMR spectrum, and the signal at about  $\delta$  31 ppm for the carbons of methylene between two aromatic rings in its  $^{13}C$  NMR [11]. This kind of conformation of products **A** could be stabilized by the hydrogen bonding between the OH group of nitrated phenol and the oxygen atom of alkoxyphenyl rings. Alternatively, the quinone moiety in products **6B** and **10B** could rotate freely without the hydrogen bonding in  $CDCl_3$ , which was confirmed with the signal at  $\delta$  35 ppm in the  $^{13}C$  NMR spectra of these compounds. And this conformation could also be confirmed in its  $^1H$  NMR by  $\Delta\delta$  0.2 ppm between the chemical shifts of protons of the methylene groups adjacent to the quinone moiety [4c]. However, if there were hydrogen bonding between the oxygen atom and NH of linkage between two alkylated aromatic rings, the products **15B**, **17B** and **18B** could be restricted as cone conformation in  $CDCl_3$  (Figure 1). And in our primary research, the 1,3-distal dialkylated calix[4]arenes containing two quinone moieties and NH groups in the molecule could adopt cone conformation under same situations [12]. To the best of our knowledge, this was the first example of the cone conformation for calix[4]quinones. Similarly, the compound **17C** was also in cone conformation.

The distribution and yields of different products of nitration were summarized in Table 1. From it, we could see that: (a) although there were different kinds of products in nitration, in most instances, the main products were still the

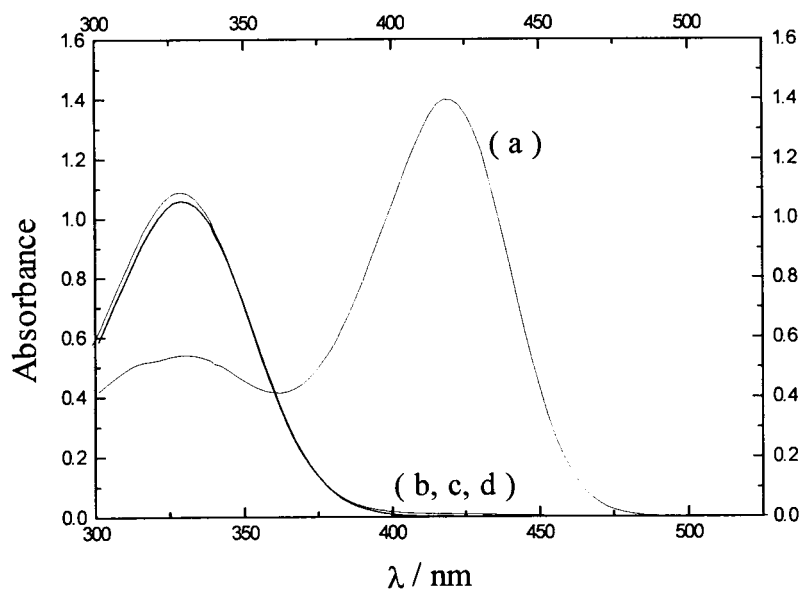


Figure 2. Spectral changes upon the addition of  $\text{Bu}^n\text{NH}_2$  to a chloroform solution of receptor (a)  $[\text{Bu}^n\text{NH}_2] = 5.0 \times 10^{-2} \text{ mol dm}^{-3}$ ,  $[\mathbf{4A}] = 5.0 \times 10^{-5} \text{ mol dm}^{-3}$ ; (b)  $[\text{Bu}^n\text{NH}_2] = 0 \text{ mol dm}^{-3}$ ,  $[\mathbf{4a}] = 5.0 \times 10^{-5} \text{ mol dm}^{-3}$ ; (c)  $[\text{Bu}^n\text{NH}_2] = 5.0 \times 10^{-2} \text{ mol dm}^{-3}$ ,  $[\mathbf{2A}] = 5.0 \times 10^{-5} \text{ mol dm}^{-3}$ ; (d)  $[\text{Bu}^n\text{NH}_2] = 0 \text{ mol dm}^{-3}$ ,  $[\mathbf{2A}] = 5.0 \times 10^{-5} \text{ mol dm}^{-3}$ ;  $T = 25^\circ\text{C}$ .

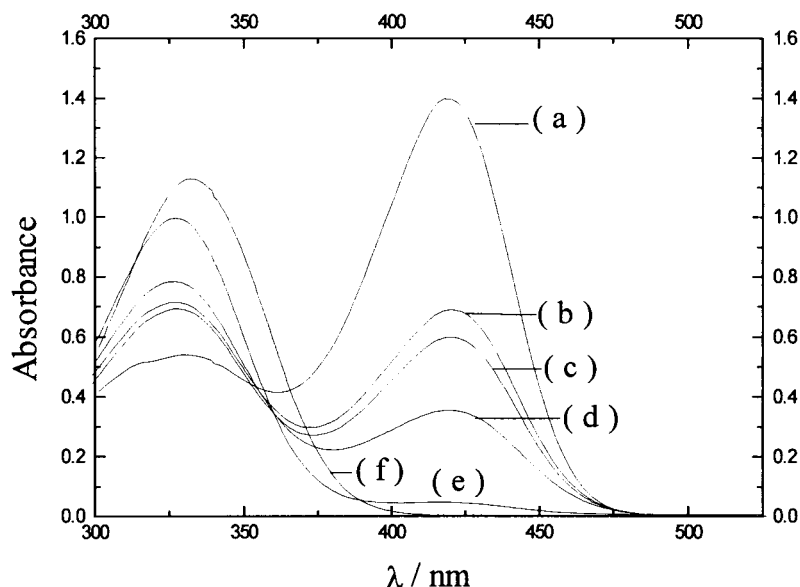


Figure 3. Spectral changes upon the addition of  $\text{Bu}^n\text{NH}_2$  ( $5.0 \times 10^{-2} \text{ mol dm}^{-3}$ ) to a chloroform solution of (a)  $\mathbf{4A}$ , (b)  $\mathbf{12A}$ , (c)  $\mathbf{10A}$ , (d)  $\mathbf{14A}$ , (e)  $\mathbf{8A}$ , (f)  $\mathbf{6A}$  ( $5.0 \times 10^{-2} \text{ mol dm}^{-3}$ );  $T = 25^\circ\text{C}$ .

phenol-dinitrated compounds, the kind of products **A**; (b) if there was *tert*-butyl in the *para* position of phenol hydroxyl group, this phenol was easier *ipso*-nitrated than oxidation; and (c) if there were secondary amide groups in linkage between two alkylated aromatic rings, after one phenol was nitrated, the other phenol was very easily oxidized. The compound **16** was exceptional, which was maybe due to the lower solubility of dinitrated product in  $\text{CH}_2\text{Cl}_2$ .

#### Recognition ability of dinitrated 1,3-distal alkylated calix[4]arenes for alkylamines

Many alkylamines were the degradation products of action of bacteria upon flesh. The detection of them could measure meat and fish freshness, which was important in food indus-

tries. Several methods are used to determine the freshness, for example, GC analysis [15], olfactory analysis [16], enzyme electrode [17], semiconductor gas sensors [18], and the measurement of volatile basic nitrogen in flesh [19], etc. However, most of these methods require a complicated operation or expensive instruments. Colorimetric sensor methods have been employed because they are handy and inexpensive. Dyer reported the application of colorimetric methods to distinguish between trimethylamine and dimethylamine, both of which are generated as the fish spoils [20]. Kaneda has given an excellent review about the amine-selective color complexation with crown ethers, which could be used as potential colorimetric sensory systems [21]. McCarrick *et al.* reported the first gas sensor for colorimetric determin-

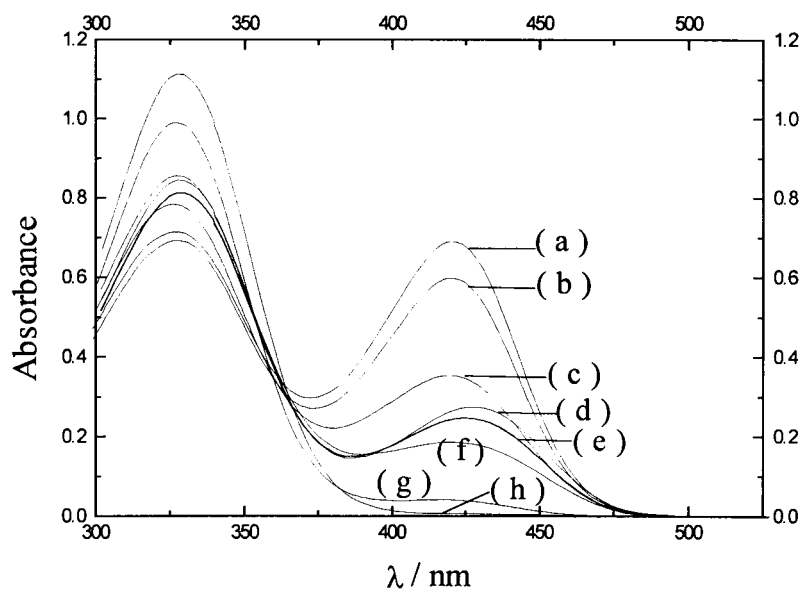


Figure 4. Spectral changes upon the addition of  $\text{Bu}^n\text{NH}_2$  ( $5.0 \times 10^{-2} \text{ mol dm}^{-3}$ ) to a chloroform solution of (a) **12A**, (b) **10A**, (c) **14A**, (d) **11A**, (e) **9A**, (f) **13A**, (g) **8A**, (h) **7A** ( $5.0 \times 10^{-2} \text{ mol dm}^{-5}$ );  $T = 25^\circ\text{C}$ .

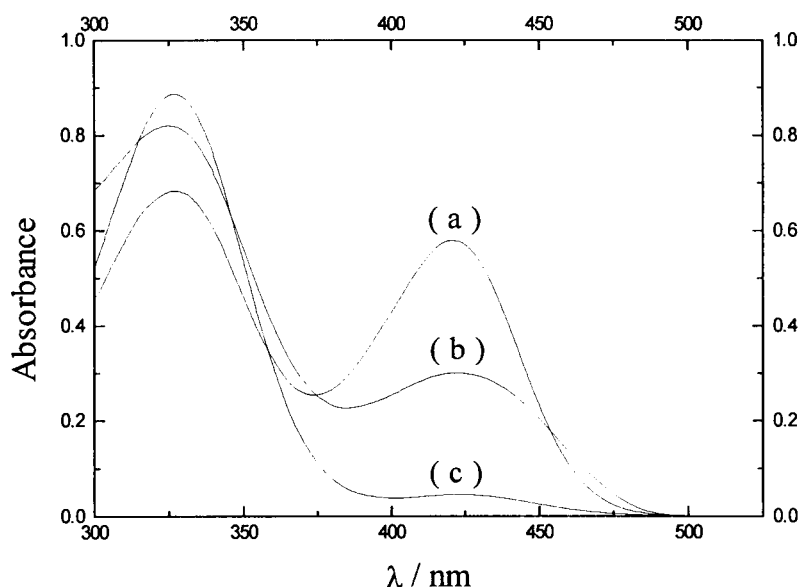


Figure 5. Spectral changes upon the addition of (a)  $\text{Bu}^n\text{NH}_2$ , (b)  $\text{Bu}^s\text{NH}_2$ , (c)  $\text{Bu}^t\text{NH}_2$  ( $5.0 \times 10^{-2} \text{ mol dm}^{-3}$ ) to a chloroform solution of **10A** ( $5.0 \times 10^{-5} \text{ mol dm}^{-3}$ );  $T = 25^\circ\text{C}$ .

ation of trimethylamine using a calix[4]arene bearing four nitrophenylazophenol residues, which may be applicable as a non-instrumental indicator system to the monitoring of fish freshness [22]. The complexed calixarene has been immobilized onto filter paper and found to undergo a dramatic colour change from yellow to red in the presence of gaseous trimethylamine at concentrations above 20 ppb in under 2 min. Herein, we wish to report the recognition ability of the nitrated calix[4]arenes for alkylamine.

#### Effect of the structure at lower rim of calixarene

There was no absorption in visible scope in the  $\text{CHCl}_3$  solution of dinitrated calix[4]arenes without the presence of alkylamine ( $\lambda_{\text{max}} = 329 \text{ nm}$ ,  $\log \epsilon = 4.33$ ) (Figure 2). Upon

adding  $\text{Bu}^n\text{NH}_2$  into the solution of **4A**, we could determine a new absorption at  $\lambda_{\text{max}} = 420 \text{ nm}$ , whose absorbance increased following the increased concentrate of the substrate, and the color of the solution changed to yellow. However, under the same conditions, for the solution of dinitrated dimethylated calix[4]arenes **2A**, these absorption spectra have no obvious changes. From Figure 3, we could also confirm that the ability of dinitrated calix[4]arenes containing ester groups at the lower rim were stronger than that without ester groups in binding alkylamines, and that the appropriate size of crown ring benefit for the recognition.

According to the modified Henesi–Hildebrand equation, we deduced that dinitrated calix[4]arenes formed a 1:2 complex with alkylamines [7]. The association constants of

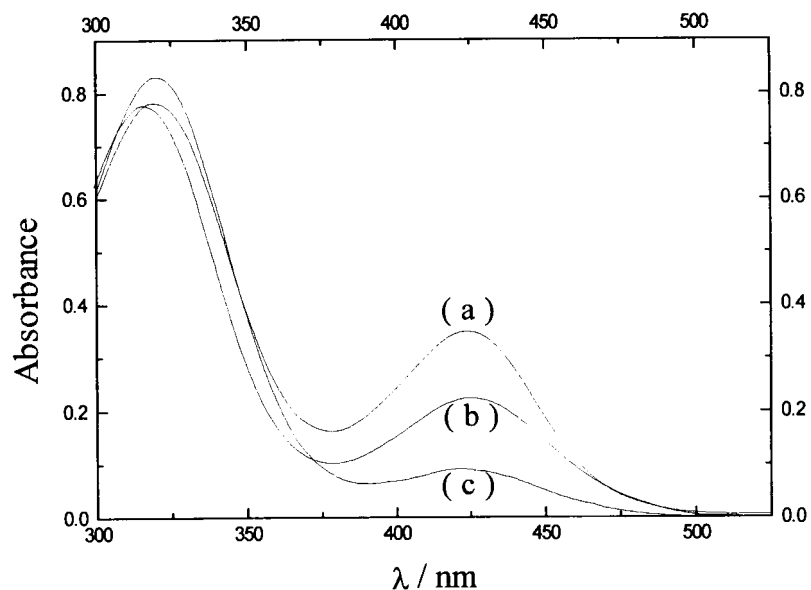


Figure 6. Spectral changes upon the addition of (a) 1,4-diaminobutane, (b) 1,3-diaminopropane, (c) 1,2-diaminoethane ( $5.0 \times 10^{-2} \text{ mol dm}^{-3}$ ) to a chloroform solution of **10A** ( $5.0 \times 10^{-5} \text{ mol dm}^{-3}$ );  $T = 25^\circ\text{C}$ .

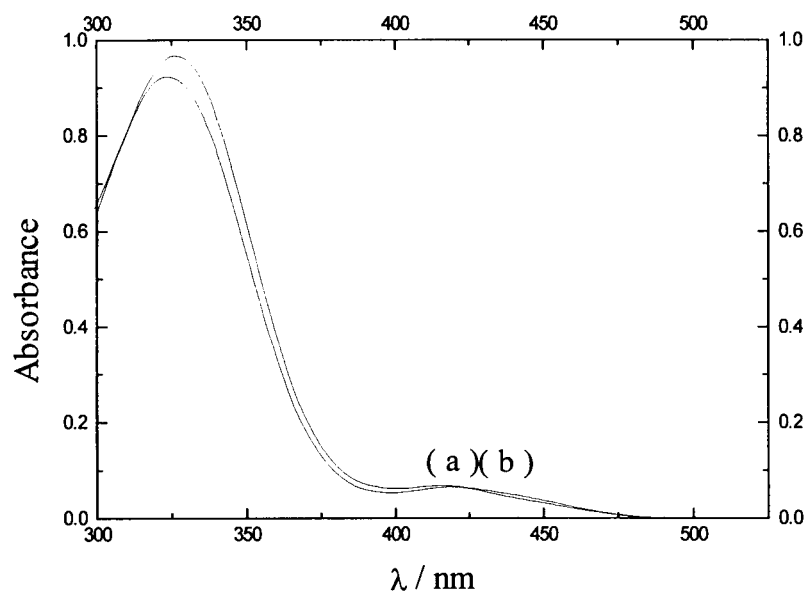


Figure 7. Spectral changes upon the addition of diethylamine ( $5.0 \times 10^{-2} \text{ mol dm}^{-3}$ ) to a chloroform solution of (a) **10A**, (b) **14A** ( $5.0 \times 10^{-5} \text{ mol dm}^{-3}$ );  $T = 25^\circ\text{C}$ .

some receptors with  $\text{Bu}^n\text{NH}_2$  were 326 (**4A**), 105 (**9A**), 251 (**10A**), 129 (**11A**) and  $59 \text{ mol}^{-2} \text{ dm}^6$  (**13A**), respectively.

*Recognition ability of dinitrated calix[4]crown containing ester groups at lower rim*

#### *Effect of the structure at upper rim of calixarene*

From Figure 4 we could find that the recognition ability of calix[4]arenes containing *tert*-butyl at upper rim was weaker than that of calix[4]arenes without *tert*-butyl. It maybe due to the difference of energy, which came from the conformational change of calix[4]arenes when they recognized substrates. In addition, although the crown ether ring is the smallest, compounds **8A** without *tert*-butyl give a weak absorption spectrum because their phenol groups can easily rotate to adapt the substrate's structure.

#### *(a) For primary alkylamine and alkylenediamine*

Figure 5 indicated that there was an obvious steric effect when chromogenic receptors recognized different isomeric butylamines. The recognition ability of **10C** for  $\text{Bu}^s\text{NH}_2$  and  $\text{Bu}^t\text{NH}_2$  was poorer than for  $\text{Bu}^n\text{NH}_2$ , which could be due to the interaction between the alkyl of amines and the substituents at lower rim of calixarene.

It was worth mentioning that dinitrated calix[4]arenes could also recognize alkylenediamine (Figure 6). And the recognition ability increased alongside the growth of length of diamine.

Table 1. Yields of nitration of 1,3-dialkylated calix[4]arenes

Reactant	Product			Reference
	A	B	C	
1	54%	–	–	[10]*
2	51%	–	–	[8b]*
3	60%	–	–	[8a]*
4	57%	–	–	[13]*
5	66%	–	–	[14]
6	43%	34%	–	[14]
7	64%	–	–	[14]
8	33%	–	–	[7]
9	41%	–	–	
10	37%	11%	–	[7]
11	40%	–	–	[7]
12	50%	–	–	[7]
13	31%	–	–	
14	20%	–	–	[7]
15	19%	20%	–	[9]
16	70%	–	–	[9]
17	–	25%	36%	[9]
18	–	68%	–	[9]

\* The nitration conditions have been modified according to our procedure.

#### (b) For secondary and tertiary alkylamine

As we mentioned above, the recognition ability was affected by the steric effect. Upon adding to diethylamine and triethylamine, there was a very small change for the absorbance of receptors (Figure 7). So the interaction between them was weak and it also indicated that the recognition has no linear relation with basicity of alkylamine because the basicity of them is triethylamine > diethylamine > Bu<sup>n</sup>NH<sub>2</sub> [23].

#### The recognition mechanism

In summary, dinitrated calix[4]arenes possess recognition ability for the alkylamines, as the chromogenic sensors for determining the alkylamines. The recognition ability was due to the proton transfer between alkylamine and calix[4]arenes. And the resulting ammonium phenoxide was stabilized by the phenoxide oxygen atom and the carbonyl at the lower rim with hydrogen bonding. The steric effect between the alkyl of amines with the substituents of calix[4]arenes at lower rim could be the key factor for improving the selectivity of recognition. Figure 8 displays the possible interaction of calix[4]arenes and alkylamines.

#### Conclusion

There were three kinds of separable products when 1,3-distal dialkylated calix[4]arenes were nitrated, which originated from the nitration and oxidation of the phenol moieties. The cone conformation of calix[4]arenes containing a quinone structure could be observed owing to hydrogen bonding between the oxygen atom of quinone and the NH group of

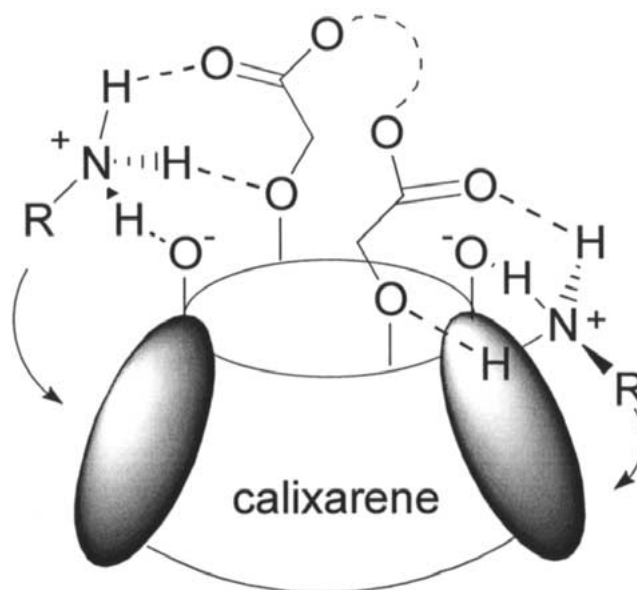


Figure 8. Possible structure for the complex of chromogenic receptors with two alkylamines.

the linkage at lower rim. The effect of the structure of reactants for the nitration and oxidation has been discussed. The main products of nitration were the phenol-dinitrated calix[4]arenes. If there was *tert*-butyl in the *para* position of the phenol hydroxyl group, this phenol was more easily *ipso*-nitrated than oxidation. If there were secondary amide groups in linkage between two alkylated aromatic rings, after one phenol was nitrated, another phenol was very easily oxidized. Dinitrated calix[4]arenes possess recognition ability for the alkylamines, as chromogenic sensors for determining the alkylamines. The recognition ability was due to the proton transfer between alkylamine and calix[4]arenes, and the resulting ammonium phenoxide was stabilized by the phenoxide oxygen atom and the carbonyl at the lower rim with hydrogen bonding.

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