

Pb²⁺ On-Off Switchable 1,3-Alternate Calix[4]arene Chemosensor Containing Urea and Pyrene Moieties

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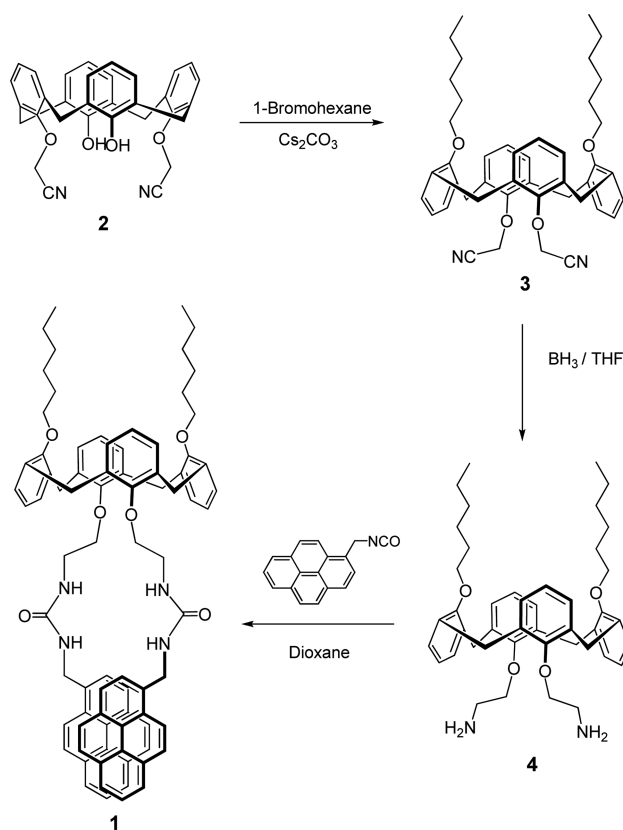
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Calix[4]arenes, well-known macrocyclic molecules with almost unlimited derivatization potential, possess a unique three-dimensional structure with outstanding shaping possibilities.¹ During last decade these compounds have been widely used in supramolecular chemistry as building blocks or molecular scaffolds for the construction of receptors towards ions or neutral molecules.² While the complexation of cations^{3,4} has been studied very intensively, the application of calixarenes for anion complexation remains relatively unused. Thus, several calix[4]arene derivatives bearing activated urea as hydrogen bonding units have been reported to interact with anions. Fluorescent chemosensors capable of selectively recognizing cations have potential analytical applications in many different fields, including chemistry, biology, and medicine. Most of the fluorescent chemosensors for cations are composed of a cation recognition unit (ionophore) together with a fluorogenic unit (fluorophore) and are called fluoroionophores.⁴ An effective fluorescence chemosensor must convert the event of cation recognition by the ionophore into an easily monitored and highly sensitive light signal from the fluorophore. Fluorescent moieties available to the scientist are typically aromatics such as substituted benzenes, anthracenes, naphthalenes, and pyrenes. Pyrenes are a particularly elegant basis for ratiometric based optical sensors, where the ratio of two emission wavelengths comprised the analytical signal. To date the pyrene excimer/monomer system has been exploited mainly for cation sensing⁵⁻¹⁶ and increasingly for anion sensing.¹⁷⁻²⁰ Dermont *et al.* reported²¹ that the excimer emission of 1,3-alternate tetrasubstituted calix[4]arene combined urea functional groups bridged with pyrene units is quenched, with a simultaneous rise in the monomer emission solely by the chloride anion. Sharp decrease in excimer emission is with a corresponding increase in monomer emission. Chloride anion appears to selectively coordinate with the urea protons in the cavity of 1,3-alternate tetrasubstituted calix[4]arene so as to “unstack” or lever apart, the facing π - π stacked pyrenes. Kim and co-workers reported²² two pyrene moieties linked to the cation recognition units in 1,3-alternate calix[4]arene composed of the amide groups form a strong excimer. Upon addition of Pb²⁺ ion to a solution, both monomer and excimer bands were strongly quenched because of reverse PET from the pyrene unit to the amide group and a geometrical change of the two pyrene amide

groups, respectively. Herein, we synthesized fluorogenic chemosensor, based on 1,3-alternate calix[4]arene urea derivative, which showed a unique fluorescent in the presence of various ions. For **1**, the excimer fluorescence is quenched by Pb²⁺, but revived by addition of F⁻ to the 1+ Pb²⁺ complexes.

Results and Discussion

Compound **2** was prepared by alkylation of calix[4]arene with bromoacetonitrile in the presence of K₂CO₃ in acetonitrile.²³ Treatment of **2** with 1-bromohexane in the presence of Cs₂CO₃ produced calix[4]arene **3** in the 1,3-alternate conformation in 61% yield. Subsequent reduction of **3** with borane-tetrahydrofuran complex gave quantitatively the corresponding diaminocalix[4]arene **4** which was fixed in



Scheme 1. Synthetic Route to Fluorescent Chemosensor **1**.

1,3-alternate conformation. Finally, reaction of **4** with 1-pyrenemethylisocyanate in dioxane gave the receptor **1** in 58% yield (Scheme 1). The ^1H NMR spectrum of **1** showed the chemical shifts corresponding to aromatic protons of calix[4]arene between δ 7.00-6.51 and bridge methylene protons as singlet at δ 3.67 respectively. The analysis of the ^1H NMR spectrum well confirms the 1,3-alternate conformation. Also the protons from N-H of the four urea units of **1** were observed as broad singlets at δ 5.51 and 5.14. The ^{13}C NMR spectrum of **1** also confirmed the 1,3-alternate conformation, which showed one peak at δ 38.0 for the bridge methylene carbons as an indication of all anti oriented²⁴ phenolic rings. We studied the binding properties of the 1,3-alternate calix[4]arene **1** using fluorescence titration. We first probed the anion binding abilities of **1** based on fluorescence changes of their acetone/ CHCl_3 (v/v = 7:3) solutions produced by addition of salts of the anions tetrabutylammonium F^- , Cl^- , Br^- , CH_3COO^- , H_2PO_4^- , HSO_4^- , ClO_4^- . In the absence of anions, the two pyrene units in **1** exhibit weak monomer ($\lambda_{\text{em}}=375$ nm) and strong excimer ($\lambda_{\text{em}}=475$ nm) bands. The strong excimer is attributed to two facing pyrene units in an intramolecular π - π stacked arrangement. The fluorescence titration of **1** showed that almost no

changes in the fluorescence emission intensities of the monomer and excimer bands of **1** occurred even when 100 equivalents anions were added. Due to the strong excimer complex of urea and oxygen pyrene fluorescence emission was not changed. However, fluorescence intensities of the monomer and excimer bands of **1** were quenched when Pb^{2+}

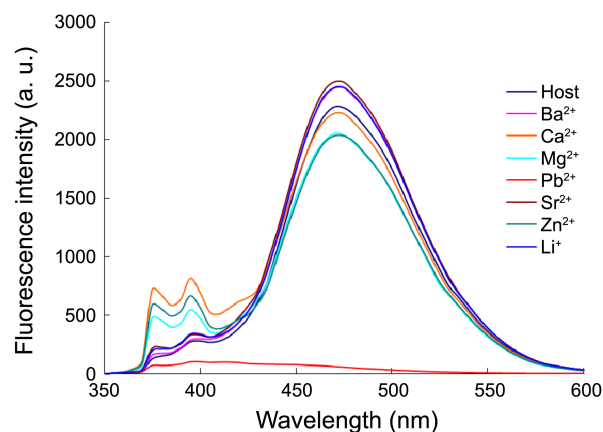


Figure 1. Emission spectra of **1** (1.0 μM) upon the addition of cations to 100 eq in acetone/ CHCl_3 (v/v = 7:3). (The excitation wavelength is 343 nm).

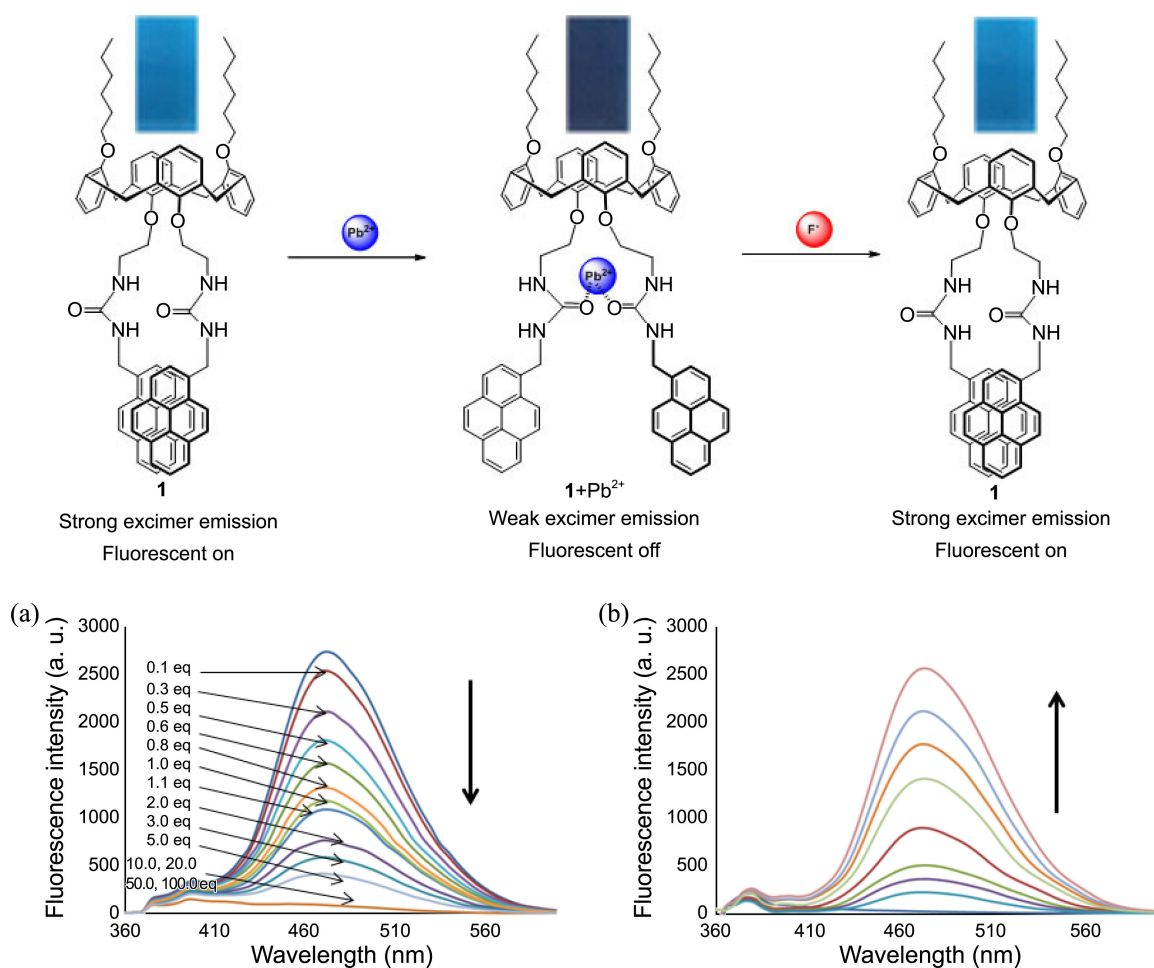


Figure 2. (a) Emission spectra of **1** (1.0 μM) upon the addition of Pb^{2+} from 0 eq to 100 eq in acetone/ CHCl_3 (v/v = 7:3). (b) Emission spectra of **1** + Pb^{2+} (1.0 μM) upon the addition of F^- from 0 eq to 100 eq in acetone/ CHCl_3 (v/v = 7:3). (The excitation wavelength is 343 nm). Association constant (K_a) = 5.0×10^5 by ENZFITTER.²⁵

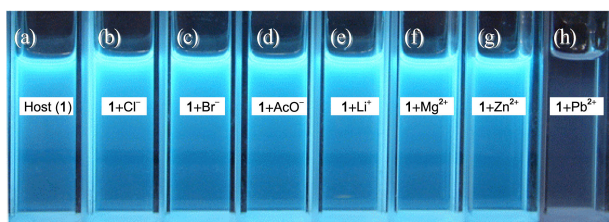


Figure 3. Photograph of the quenched emission of **1** in CHCl_3 , (a) Host **1** and in the presence of (b) Cl^- , (c) Br^- , (d) AcO^- , (e) Li^+ , (f) Mg^{2+} , (g) Zn^{2+} and (h) Pb^{2+} .

was added in acetone/ CHCl_3 ($v/v = 7:3$) as shown in Figure 1. Figures 2 shows the fluorescence changes for solutions of **1** in acetone/ CHCl_3 ($v/v = 7:3$) with increasing Pb^{2+} concentration. From the data, association constant for complexation of Pb^{2+} by **1** in acetone/ CHCl_3 ($v/v = 7:3$) were calculated to be $5.0 \times 10^5 \text{ M}^{-1}$. Also, addition of Pb^{2+} to a solution of **1** quenched the fluorescence intensities (Figure 3). The monomer fluorescence quenching can be explained as reverse PET when Pb^{2+} ion is bound to the two urea oxygen atoms with the pyrene unit behaving as a PET donor to the carbonyl group, as well as a heavy metal effect. Quenching of the excimer emission is rationalized as resulting from a conformational change caused by two outward-facing urea carbonyl groups turning inward to bind with Pb^{2+} . By the addition of fluoride ion into the Pb^{2+} and **1** complex, we observed an interesting on-off switching process. When F^- was added into a solution of **1**+ Pb^{2+} complex solution, both the excimer and monomer bands gradually revived and then became saturated upon addition of about 100 equiv of F^- as shown in Figure 2. It appears that fluoride ions could bind to the amide protons, which disrupt the metal complex.

In conclusion, a new chemosensor with urea binding site on lower rim of an 1,3-alternate calix[4]arene framework is synthesized. In the free ligand, two pyrene moieties linked to the cation recognition units composed of the urea groups form a strong excimer. The emission changes induced by the cations indicate that **1** shows high selectivity for only Pb^{2+} . Upon addition of Pb^{2+} ion to a solution of **1** in CHCl_3 , both monomer and excimer bands were quenched because of reverse PET from the pyrene units to the urea groups and a geometrical change of the two pyrene urea groups, respectively. For **1**, the excimer fluorescence was quenched by Pb^{2+} , but revived by the addition of F^- to the Pb^{2+} ligand complex, thus, producing an on-off switchable fluorescence.

Experimental

25,27-Bis[(N-pyrenemethylureido)ethyloxy]-26,28 dihexyloxy-calix[4]arene (1). To a 0.2 g (0.3 mmol) of **4** in 20 mL of dioxane, 0.155 g (0.6 mmol) of pyrenemethylisocyanate was added and the mixture was stirred for 3 h under the nitrogen atmosphere. After removing the solvent, the residue was triturated with MeOH, filtered and dried to give 0.20 g (57%) of **1**. $^1\text{H NMR}$ (CDCl_3) δ 7.77-7.30 (m, 18H, PyH), 6.98 and 6.88 (d, 4H, ArH, $J = 7.5$ Hz), 6.73 and

6.53 (t, 4H, ArH, $J = 7.2$ Hz), 5.51 and 5.14 (broad s, 4H, -NH), 3.98 (s, 4H, $-\text{CH}_2\text{Py}$), 3.67 (q, 8H, ArCH_2Ar , $J = 9.9$ Hz), 3.44 (t, 4H, $-\text{OCH}_2-$, $J = 7.5$ Hz), 2.85 (broad s, 4H, $-\text{OCH}_2-$), 2.64 (broad s, 4H, $-\text{NCH}_2-$), 1.3-1.15 (m, 16H, $-\text{OCH}_2\text{CH}_2\text{CH}_2\text{CH}_2-$), 0.92 (t, 6H, $-\text{CH}_3$, $J = 6.9$ Hz); $^{13}\text{C NMR}$ (CDCl_3) δ 158.1, 157.3, 155.7, 135.1, 134.2, 131.1, 130.6, 130.4, 129.7, 128.7, 127.5, 127.2, 126.6, 125.3, 124.7, 124.6, 124.3, 122.5 and 122.3 (Ar), 70.9, 31.9, 28.9, 25.4 and 22.7 ($-\text{OCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2-$), 42.5 ($-\text{CH}_2\text{N}-$), 38.0 (ArCH_2Ar), 14.1 ($-\text{CH}_3$).

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