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Fluorescent Sensing of Tetrahedral Anions with a Pyrene Urea Derivative of Calix[4]arene Chemosensor

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Considerable attention has been focused upon the design of supramolecules which have the ability to selectively recognized and sense analytes through the naked eye. electrochemical. and optical responses. On account of its simplicity and high sensitivity. fluorescence is becoming of increasing importance for chemical trace detection.[1-3]

Selective binding of ions is an important aspect of ion detection and ion transport. Selective complexation of anions is more demanding than that of cations due to low charge density and strong solvation. Furthermore. it has to be kept in mind that anions are subject to pH-dependent acid-base equilibria.[4-6] In nature sulfate and phosphate binding proteins are very important receptors for the active transport systems in the cell.[7] It is known that prokaryotic. periplasmic phosphate and sulfate binding proteins can bind anions with high selectivity. exclusively by the formation of hydrogen bonds. They exhibit selectivities of more than 10^5 for binding phosphate over sulfate and of sulfate over phosphate. respectively.[8,9] Incorporating of anion binding urea and fluorescence pyrene moieties into the calix[4]arene framework. we synthesized two urea derivatives[10,11] of calix[4]arene 4 and 5 studied the fluorescence emission behavior. This novel neutral anion receptor 5 binds anions through hydrogen bonding and shows high selectivity with HSO_4^- over $CH_3CO_2^-$, $H_2PO_4^-$. F⁻ and Cl⁻. To our knowledge, this is the first report of a fluorescence selective receptor for HSO_4^-.

Results and Discussion

Synthetic strategy from urea pyrene and calix[4]arene as
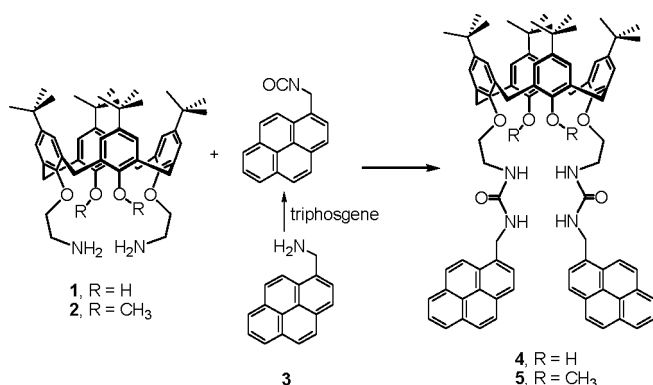
Scheme 1. Synthesis of fluorescent chemosensors 4 and 5.

reported[12] was not succeeded probably due to degradation of urea pyrene unit under the reaction conditions. Instead. the pyrene urea derivative calix[4]arene 4 and 5 was obtained successfully by the reaction of aminocalix[4]arene 1 and 2[13] with 1-pyrenylmethylisocyanate which was prepared by treating 1-aminomethylpyrene with triphosgene. ^{1}H. ^{13}C NMR. elemental analysis. and mass spectra are consistent with the proposed structure 4 and 5.

The excitation spectrum of 3. 4 and 5 revealed a λ_{max} of 340 nm as an ideal excitation wavelength. Figure 1 shows the emission spectrum of 3. 4 and 5 in acetonitrile. 3 reveals two monomer emission peaks at 376 nm and 398 nm (λ_{max}). There are no significant emission features > 430 nm. indicating that the absence of excimer formation. Host 4, 5 shows the monomer emissions as well as a much larger broad emission band at 472 nm (λ_{max}). characteristic of an intramolecular pyrene excimer emission. The pure 4 and 5. unlike the fluorescence spectra of 3 revealed pyrene excimer emission.

For 5. the ratio of excimer (472 nm) to monomer (398 nm) emission remained unchanged at 2.35 in the concentration range 1×10^{-6} to 1×10^{-5}. This further confirmed the presence of pyrene units interacting by an intramolecular mechanism. not an intermolecular one.

The changes in the emission spectrum of 5 were examined with five common anions. These spanned a comprehensive range of sizes and shapes. 5000 equivalents of the tetrabutyl-ammonium salt of each anion were added to 1×10^{-6} M
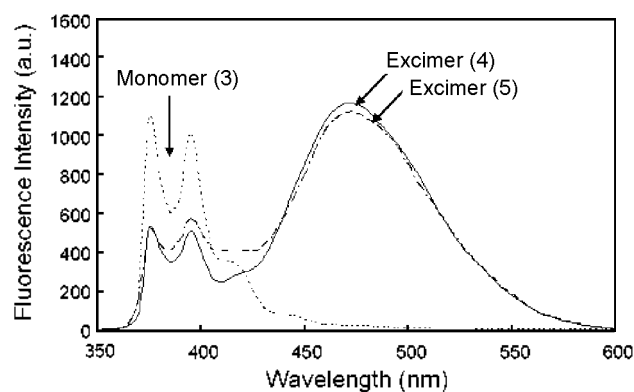

Figure 1. Emission spectra of 3, 4 and 5 (1×10^{-6}) in acetonitrile showing monomer maxima at 376 and 398 nm. The receptors 4 and 5 show an additional large band at 472 nm due to the excimer formation. (The excitation wavelength is 340 nm).
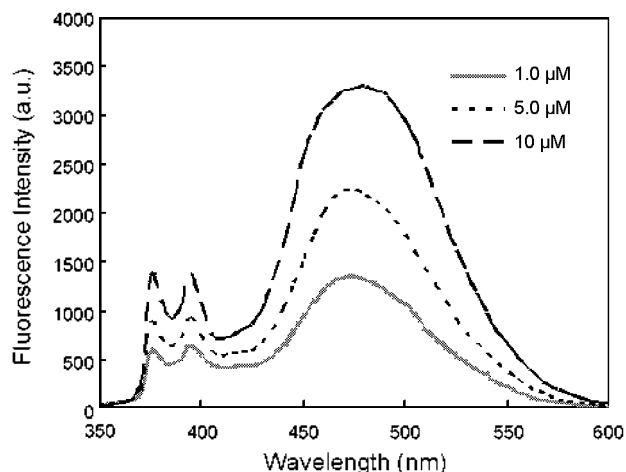
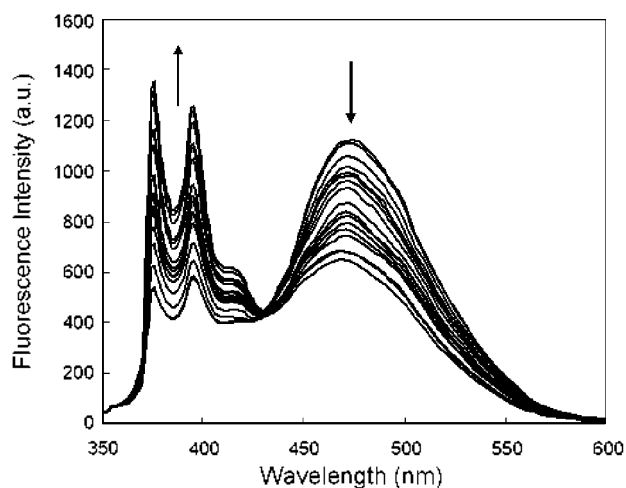**Figure 2.** Changes of the fluorescence spectrum of 5 depending on the concentration.

Figure 3. Emission spectra of 5 (1.0 μM) upon the addition of hydrogen sulfate from 0 eq to 5000 eq in acetonitrile. (The excitation wavelength is 343 nm).

solutions of 5 in acetonitrile. The change in excimer and monomer emission was monitored and remarkably only hydrogen sulfate caused the dramatic change in the emission spectrum of 5. There is a sharp decline in excimer emission with a corresponding increase in monomer emission as shown in Figure 3. There observations suggest that the hydrogen sulfate anion appears to selectively coordinate with the urea protons in the cavity of 5 so as to disrupt the facing π-π stacked pyrenes. No emission change was observed in ligand 4 in the presence of various anions including hydrogen sulfate, indicating that hydrogen bond between OH group in hydrogen sulfate and ether oxygen in ligand 5 played a crucial role for the selective binding of hydrogen sulfate ions with 5.

The excimer emission of 472 nm (λ_{max}) signifies a similar shift compared to other intramolecular pyrene excimer systems, which typically show a λ_{max} of 480 nm[14,15] The comparison of the pyrene excimer emission of sandwich-like systems (full overlap) with a partially overlapping system is normally explained in this way. Sandwich-like systems are described as

Table 1 The association constants (K_a) of receptors 5 with anions in CH₃CN.

Anion	K_a/dm³mol⁻¹
F⁻	6.0×10^2
Cl⁻	1.9×10^2
H₂PO₄⁻	1.1×10^4
HSO₄⁻	2.0×10^4
CH₃CO₂⁻	8.0×10^3

Conditions: (1.0 μM): Determined by fluorescence spectroscopy in CH₃CN; excitation at 343 nm; anions, 5000 equiv. The errors in the association constants were less than 10%.

dynamic excimers, in that pyrene moieties are free to fully overlap. Partially overlapping pyrenes are described as static because some force is inducing a partial overlap. In the case of free 5, there is a strong likelihood of H-bonding acting between urea groups in addition to steric factors, thereby offering a plausible explanation for the observed partially overlapping static excimer.

The association constants of the various anions to the receptors are obtained from the resulting titration curves using ENZFITTER program[16] and these values are presented in Table 1. The highest binding affinity for HSO₄⁻ was observed for the ligand 5 expected from the fluorescence spectra. The influence of the OH group in hydrogen sulfate with ether moieties in calixarene could affect the strong binding. Investigation of the ¹H NMR spectral characteristics of the ligand 5 in the presence of anions was carried out but failed due to the bad solubility in common NMR solvents such as CDCl₃ and acetonitrile-d_3.

Summary

Calix[4]arene pyrene urea derivatives 4 and 5 have been synthesized by the 1, 2 and their corresponding 1-pyrene-methylisocyanates. When hydrogen sulfate ion is bound, receptor 5 ratiometry of monomer (375 nm) increased and excimer (475 nm) decreased due to the intramolecular hydrogen bonding between receptor 5 and hydrogen sulfate ions causing the separation of pyrene π-π stacking.

Experimental

5,11,17,23-Tetra-*tert*-butyl-25,27-*bis*(methyl-2-pyreneu-reidoethyloxy)calix[4]arene (4) To a solution 0.17 g (0.2 mmol) of 5,11,17,23-tetra-*tert*-butyl-25,27-*bis*(2-amino-ethoxy)-26.28-dihydroxycalix[4]arene in 20 mL dioxane was added with 0.1 g (0.4 mmol) of 2-pyrenemethyl isocyanate which was prepared from reaction of 1-aminomethylpyrene and triphosgene and the reaction mixture was stirred for 4 hour under the nitrogen atmosphere. The precipitate was collected by filtration to give 0.24 g (89%) of 4: ¹H NMR (DMSO-d_6) δ 8.65 (s, 2H, -OH), 7.85-8.20 (m, 18H, ArH), 7.13 (s, 8H, ArH), 6.97 and 6.55 (two br s, 4H, -NH), 4.85 (d, 4H, ArCH₂N-), 4.24 and 3.38 (a pair of d, 8H, ArCH₂Ar), 4.02 (br t, 4H, -OCH₂-), 3.75 (br s, 4H, -CH₂N-), 1.19 and 1.13 (two s, 36H, -C(CH₃)₃). ¹³C NMR (DMSO-d_6) δ 158.18 (-CO-).

149.92, 149.37, 147.16, 141.48, 133.86, 133.24, 130.67, 130.14, 129.61, 127.61, 127.50, 127.17, 126.63, 125.94, 125.68, 125.31, 124.86, 124.52, 123.81, 122.67 and 122.80 (Ar), 75.88 (-OCH$_2$-), 41.10 (-CH$_2$N-), 33.99, 33.59, 31.37 and 29.22 (ArCH$_2$Ar. -NCH$_2$Ar and -C(CH$_3$)). EA calcd for C$_{84}$H$_{88}$N$_4$O$_6$: C, 80.74; H, 7.10; N, 4.48. Found: C, 81.91; H, 7.28; N, 4.37. MALDI MS calcd for [M]$^+$: 1248.67. Found: 1248.82.

5,11,17,23-Tetra-*tert*-butyl-25,27-*bis*(methyl-2-pyreneureidoethyloxy)-26,28-dimethoxycalix[4]arene (5). To a solution 0.18 g (0.2 mmol) of 5,11.17.23-tetra-*tert*-butyl-25.27-*bis*(2-aminoethoxy)-26.28-dimethoxycalix[4]arene in 10 mL THF was added with 0.1 g (0.4 mmol) of 2-pyrenemethyl isocyanate which was prepared from reaction of 1-aminomethylpyrene and triphosgene and the reaction mixture was stirred for 1 hour under the nitrogen atmosphere. After reaction mixture of removing the solvent, the residue was triturated with MeOH to give 0.2 g (72%) of 5; ^{1}H NMR (DMSO-d_6) δ 7.97-8.38 (m, 18H, ArH), 7.04 (s, 8H, ArH), 6.45 and 5.99 (two br s, 4H, -NH), 4.94 (br s, 4H, ArCH$_2$N-), 4.31 and 3.92 (a pair of d. 8H, ArCH$_2$Ar), 4.08 (br s, 4H, -OCH$_2$-). 3.78 (br s, 4H, -CH$_2$N-), 3.13(br s, -OCH$_3$). 1.28 and 0.98 (two s, 36H, -C(CH$_3$)$_3$). ^{13}C NMR (DMSO-d_6) δ 157.96 (-CO-), 143.01, 134.23, 130.79, 130.29, 129.90, 127.94, 127.37, 127.35, 126.85, 126.20, 126.18, 125.13, 125.04, 124.63, 124.02, 123.94 and 123.21 (Ar), 74.22 (-OCH$_2$-), 72.11 (-OCH$_3$), 41.19 (-CH$_2$N-), 33.70, 33.22, 31.46 and 30.96 (ArCH$_2$Ar, -NCH$_2$Ar and -C(CH$_3$)). EA calcd for C$_{86}$H$_{92}$N$_4$O$_6$: C, 80.84; H, 7.26; N, 4.39. Found: C, 81.76; H, 7.67; N, 4.15. MALDI MS calcd for [M + Na$^+$]$^-$: 1299.70 Found: 1299.59.

References

1. Bell, J. W.; Hext, N. M. *Chem. Soc. Rev.* **2004**, *33*, 589.
2. Epistein, J. R.; Walt, D. R. *Chem. Soc. Rev.* **2003**, *32*, 203.
3. Callan, J. F.; de Silva, A. P.; Magri, D. C. *Tetrahedron* **2005**, *61*, 8551.
4. Wang, Y. C.; Moses, S. S.; Zuo, Z. *J. Pharmaceutics* **2008**, *352*, 217.
5. Seneque, O.; Rager, M.; Giorgi, M.; Prange, T.; Tomas, A.; Reinaud, O. *J. Am. Chem. Soc.* **2005**, *127*, 14833.
6. Cerdan, E.; Campo, M. L.; Santiago, E.; Lopez-Moratalla, N. *Revista Espanola de Fisiologia.* **1987**, *43*, 281.
7. Moon, B. S.; Choi, Y. L.; Kim, J. H.; Ryu, J. W.; Lee, K. D. *Appl. Chem.* **2006**, *10*, 433.
8. Beer, P. D.; Gale, P. A. *Angew. Chem. Int. Ed.* **2001**, *40*, 486.
9. Na, S.; Meng, L.; Shi-Jie, Z.; Feng, Li.; Hui, L.; Qing-Wei, M. *Planta* **2007**, *226*, 1097.
10. Lee, C.; Kim, J.; Kim, D. W.; Lee, S. S.; Kim, J.; Kim, J. S. *Bull. Korean Chem. Soc.* **2007**, *28*, 2466.
11. Thiagarajan, V.; Ramamurthy, P.; Thirumalai, D.; Ramakrishnan, V. T. *Org. Lett.* **2005**, *7*, 657.
12. Benjamin, S.; Nameer, A.; Dermot, D. *J. Am. Chem. Soc.* **2006**, *128*, 8607.
13. Lee, H. K.; Yeo, H.; Park, D. H.; Jeon, S. *Bull. Korean Chem. Soc.* **2003**, *24*, 1737.
14. Forster, T.; Kasper, K. *Zeitschrift Fur Elektrochemie* **1955**, *59*, 976.
15. Lee, Y. O.; Choi, Y. H.; Kim, J. S. *Bull. Korean Chem. Soc.* **2007**, *28*, 151.
16. (a) Association constants were obtained using the computer program ENGFITTER available from Elsevier-BIOSOFT, 68 Hills Road, Cambridge CB2 1LA, U. K. (b) Connors, K. A. *Binding Constants*; Wiley: New York, 1987.