Discrimination among Octylamine Isomers by Polymeric Membrane Electrodes Based on Lipophilic Calix[6]arene Tetraester Derivatives

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Liquid membrane type ion-selective electrodes (ISEs) provide one of the most powerful sensing methods because they afford the ability to select various sensory elements according to the shape and size of the target ion. Liquid membrane type electrodes for inorganic cations, such as sodium, potassium and lithium based on the host-guest chemistry, have been developed using crown ethers and related macrocyclic hosts as well as acyclic ligands.[1-11] Many of these inorganic cation-selective electrodes exhibit excellent selectivity for analyte cations and are now commercially available.[12-16]

For organic cation-ISEs based on derivatives of crown ether or natural ionophore, as reported thus far, there are not many of these ISEs that respond strongly enough to discriminate among organic guests, and the selectivities of these electrodes are mostly controlled by the lipophilicity of the guest.[7-18]

Recently, calixarenes have received considerable attention as an interesting class of ionic and molecular binding hosts,[19,20] and studies show that various functionalized calixarenes are selective host molecules for cations as well as anions.[21-32] The well-defined structure of the calixarene cavity could also be investigated for inclusion of organic guests. Actually, calix[4]crowns, penta-*o*-alkylated calix[5]-arenes, calix[6]arene hexaesters, *para*-1-adamantyl calix[8]-arene and homooxacalix[3]arene triether have been shown to display selectivities for primary amines.[33-39] Calix[6]arene has a sufficiently large cavity so that it can accommodate organic guests, whereas the calix[4]arene cavity is too small for ordinary organic guests. In addition, the tetraester of calix[6]arene affords an excellent binding site for protonated primary amines, because the NH_3^+ moiety of these guests can bind strongly to the inward-directed ester carbonyl groups of the host by hydrogen bonds.[29] In the present study, synthesized lipophilic tetraesters of calix[6]arene and calix-[6]diquinone reported as cesium-selective ionophores[30] were exploited as the sensory element of a PVC matrix liquid membrane electrode for organic amines (protonated form). The potentiometric response properties were examined for octylamine, 1-methylheptylamine, 2-ethylhexylamine and *tert*-octylamine as octylamine isomers and phenethylamine.

Experimental Section

Reagents. Lipophilic tetraesters of calix[6]arene and calix[6]diquinone tested as octylamine ionophores are shown in Figure 1. They were prepared according to the procedures reported by our group.[32] High molecular weight PVC, dioctyl sebacate (DOS), potassium tetrakis(*p*-chlorophenyl)borate (KT*p*ClPB) and tetrahydrofuran (THF), which were obtained from Fluka (Buchs, Switzerland), were used to prepare the PVC membranes. As guests for the potentiometric measurements, the following amines were purchased: octylamine, 1-methylheptylamine, 2-ethylhexylamine, *tert*-octylamine and phenethylamine from Aldrich Chemical Co. (Milwaukee, WI USA). All guests were prepared with hydrochloric acid salts. The structures of all guests are shown in Figure 1. Doubly distilled water in a quartz apparatus was used to prepare all aqueous electrolyte solutions.

Fabrication of polymeric ion-selective membranes. Table 1 summarizes the compositions and electrochemical properties of amine-selective membranes employed in this study. The ionophore, plasticizer and PVC were dissolved in the appropriate volume of THF and mechanically stirred. All membrane cocktails were cast in glass rings placed on glass plates for conventional ion-selective electrodes. Solvent from PVC membrane was allowed to evaporate for at least 24 hours at room temperature. The thickness of the resulting membrane was about 0.3 mm.

Potentiometric measurements. The electrochemical properties of the amine-selective electrodes have been investigated in the conventional configuration. Small disks were punched from the cast membranes and mounted in Philips electrode bodies (IS-561). For all electrodes, 0.1 M KCl was used as an internal filling solution. The external reference electrode was an Orion sleeve-type double-junction Ag/AgCl reference electrode (Model 90-02). The electrochemical potential was measured using a home-made 16-channel potentiometer coupled to a computer. Before each set of measurements, the electrode was soaked overnight in 0.01 M octylamine aqueous solution. The dynamic response curves were produced by adding standard solutions of protonated amines to magnetically stirred buffer solution (0.05 M Tris-HCl, pH 7.2). The selectivity coefficients ($\log K_{i,j}$) were determined by the separate solution method (SSM), using 10^{-2} M amine. Detection limits were estimated according to the IUPAC recommendation. At least, three times measurement was performed, and the data were determined from the plot.
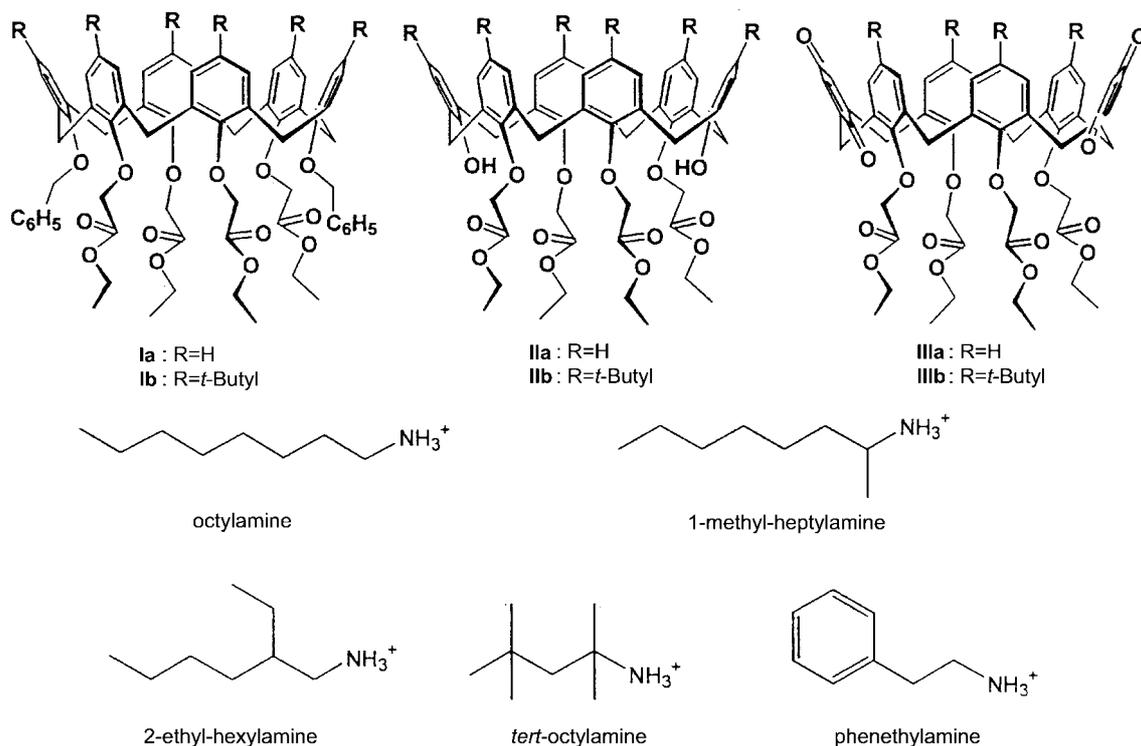
Figure 1. Six lipophilic tetraesters of calix[6]arene (**Ia-IIb**), calix[6]diquinone (**IIIa**, **IIIb**), and the organic amine guests.

Table 1. Composition and electrochemical properties of PVC-based octyl amine selective membranes[a]

Ionophore	Electrode No.	PVC	DOS	Ionophore	slope (mV/decade)	detection limit (log *a* octyl)	log $K^{pot}_{octyl,j}$			
							j = 1-methylheptyl	j = 2-ethylhexyl	j = *tert*-octyl	j = phenethyl
Ia	1	33	66	1	59.7 ± 1.0	-6.5	-1.54	-1.61	-2.48	-1.23
Ib	2	33	66	1	59.8 ± 1.1	-6.1	-0.48	-0.84	-1.69	-0.85
IIa	3	33	66	1	60.0 ± 1.5	-6.4	-1.21	-1.26	-2.30	-1.15
IIb	4	33	66	1	55.1 ± 1.5	-5.4	-0.38	-0.60	-1.37	-0.19
IIIa	5	33	66	1	60.9 ± 1.2	-5.0	-0.73	-0.85	-1.08	-0.91
IIIb	6	33	66	1	61.4 ± 1.0	-6.0	-0.67	-0.41	-1.18	-0.70
None[b]	7	33	66		58.5 ± 0.9	-6.3	0.02	-0.33	-0.53	0.31

[a]In wt%. [b]KT*p* CIPB 50 mol% relative to the Ionophore **Ia**.

Results and Discussion

The potentiometric discrimination among octylamine isomers by calix[6]arene and calix[6]diquinone tetraesters as specific ionophores has been studied on a PVC liquid membrane. The slope of the potentiometric response curve, detection limit and selectivity coefficient of each tested electrode are summarized in Table 1. Especially, the selectivity coefficients (log $K^{pot}_{octylamine,j}$) are illustrated in Figure 2. Electrode No. 7 without ionophore shows negligible discrimination of octylamine against interference guests,[29] although it shows near-nernstian slope and low detection limit, because the ionic exchanger enhances membrane conductivity, accelerates ionic exchange processes and diminishes anion transfer from the solution to the membrane phase. However, the electrodes No. 1 and 3 based on calix[6]arene tetraesteres without *para t*-butyl sub-

stituents (**Ia**, **IIa**) show noticeable properties compared with electrode No. 7. Those display higher selectivities (log $K^{pot}_{octyl,1-methylheptyl}$ = -1.54 and -1.21, respectively), where selectivities of the responses is in the order of octylamine >> 1-methylheptylamine > 2-ethylhexylamine >> *tert*-octyl, and low detection limits (log $a_{octylamine}$ = -6.5 and -6.4, respectively). Electrodes No. 1 and 3 exhibit efficient capability of discrimination between octylamine and phenethylamine (log $K^{pot}_{octyl,phenethyl}$ = -1.23 and -1.15, respectively), unlike electrode No. 7. Figure 3 illustrates potentiometric response curves for guests obtained in pH 7.2 (0.05 M Tris-HCl buffer solution) by electrode No. 1. Electrode No. 1 displays nearly a theoretical slope of the response curve, 59.7 mV per decade to octylamine in the range 10^{-6} M-10^{-2} M and the best detection limit among other electrodes (log $a_{octylamine}$ = -6.5). The strongest response is observed for octylamine with a detection limit below 10^{-6} M. Nernstian responses are

Notes
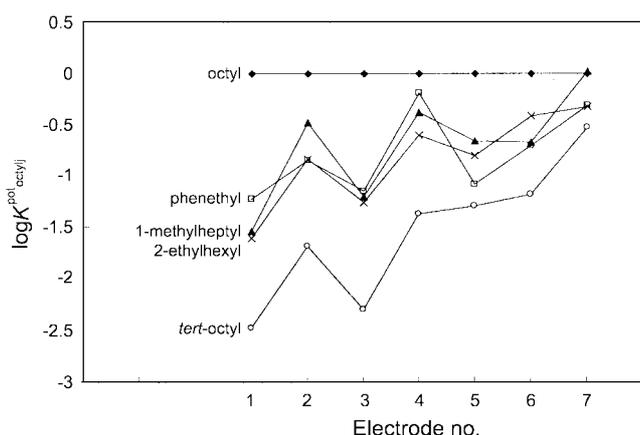
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Figure 2. Comparison of the selectivity coefficients determined by the separate solution method (SSM) using 10^{-2} M amine.
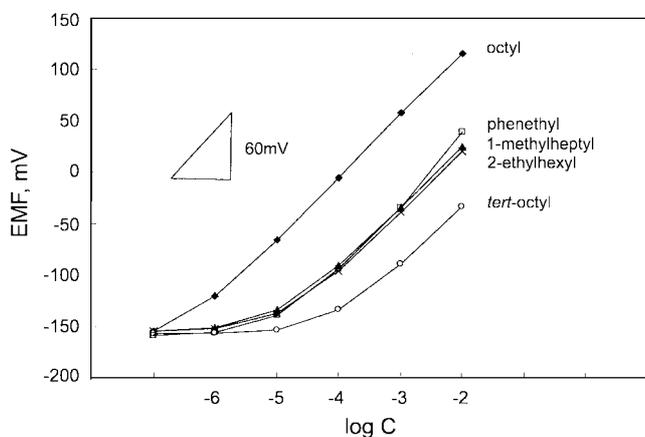

Figure 3. The potentiometric response curves of the electrode No. 1 based on calix[6]arene tetraester **Ia** to the concentration change of amine guests in pH 7.2 buffer solution.
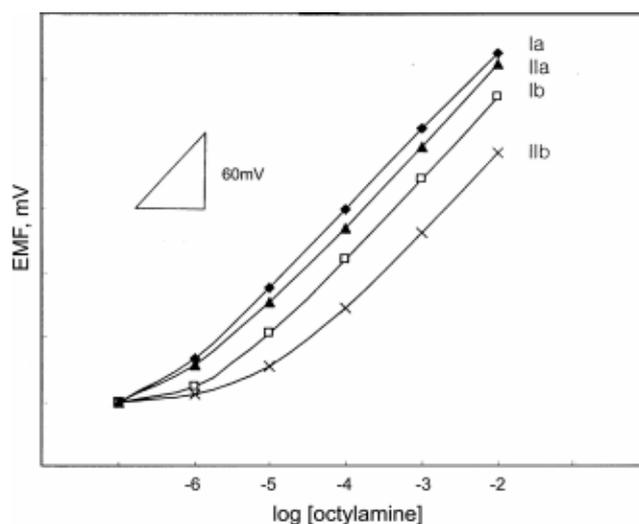

Figure 4. The potentiometric response curves of electrodes No. 1-4 to the concentration change of octylamine in pH 7.2 buffer solution.

also observed for 1-methylheptylamine and 2-ethylhexyl-amine, starting from *ca.* 10^{-5} M and for *tert*-octylamine, from *ca.* 10^{-4} M. Otherwise, electrodes No. 2 and 4 based on calix[6]arene tetraesters having *para t*-butyl substituents (**Ib**, **IIb**) show a different trend from No. 1 and 3. They demonstrate lower selectivity coefficients $K_{\text{octyl,1 – methylheptyl}}^{\text{pot}}$ = -0.48 and -0.38, respectively) and higher detection limits than those of No. 1 and 3 in Table 1 and Figure 2. The electrodes are easily compared with response curves of octylamine illustrated in Figure 4. In addition, electrodes No. 5 and 6 containing calix[6]diquinone tetraesters **IIIa** and **IIIb**, which have the ability of redox-switching or chromo-phore, are studied in this work. Comparing the electro-chemical properties of No. 5 with those of No. 6, we found that electrodes No. 5 and 6 show similar characteristics, except that electrode No. 6 displays lower detection limit ($\log a_{\text{octylamine}}$ = -6.0) than that of No. 5 ($\log a_{\text{octylamine}}$ = -5.0).

From the result of this work, the selectivity and sensitivity of the protonated octylamine against interference isomers can be explained by the following points. According to ^{1}H NMR studies,[32] in the compounds containing no *para* substituent, such as **Ia**, **IIa**, and **IIIa**, the ^{1}H NMR spectra

show a well resolved spectral pattern, indicating that they exist in flexible conformations. On the other hand, in compounds containing *p-t*-butyl group, such as **Ib**, **IIb**, and **IIIb**, the ^{1}H NMR spectra are in general featureless, showing several broad humps, which is chracteristic of many conformationally flexible derivatives of calix[6]arenes. The improved selectivity and sensitivity of non-*para* substituents (**Ia**, **IIa**) for the protonated octylamine against interference isomers attribute to the rapid complexation of ionophore and octylamine, compared with the slow complexation of octylamine and *p-t*-butyl substituents (**Ib**, **IIb**). Because the *p-t*-butyl substituents (**Ib**, **IIb**) give steric hindrance through the inclusion of amine to host, the complexation of octyl-amine and *p-t*-butyl substituents is difficult. Therefore, the high selectivity and sensitivity for the protonated octylamine are explained as an excellent geometric fit with the pseudo-cavity constructed by the four carbonyl oxygens in no *para* calix[6]arene tetraesters (**Ia**, **IIa**). The good selectivity of **Ia** compared with that of **IIa** is unclear, but the result could be ascribed to the acidity of the hydroxy group. The bad selectivities of **IIIa** and **IIIb** for the protonated octylamine against interference isomers can be attributed to the fact that the four *para* units in calix[6]diquinone tetraesters do not form a good pseudocavity, because the six *para* substituents exert a strong influence through deriving the geometric pseudocavity. the four *para* substituents do not affect that. In view of the results so far achieved, an examination of the selectivity data for the electrodes employed indicates that the ionophore structure is the major factor determining the selectivity.

In conclusion, the electrodes combined with non-*para* calix[6]arene tetraesters (**Ia**, **IIa**) show superior characteri-stics (selectivity, detection limit and response slope) to those combined with calix[6]arene tetraesters with *p-t*-butyl sub-stituents (**Ib**, **IIb**). Meanwhile, the electrodes combined with calix[6]diquinone tetraesters (**IIIa**, **IIIb**) show no remark-

able distinction. That is, the capability for discrimination of octylamine against its branched isomers and phenethylamine is dependent upon ionophore, which has excellent geometric pseudocavity suitable for the octylamine. All the electrodes respond rapidly to change in amine concentration with time constants on the order of a few seconds. The rate of response was limited only by the speed of stirring and the injection technique.

References

1. Jaramillo, A.; Lopez, S.; Justice, J. B. Jr.; Salamone, J. D.; Neil, D. B. *Anal. Chim. Acta* **1983**, *146*, 149.
2. Asfari, Z.; Wenger, S.; Vicens, J. *Incl. Phenom. Mol. Recogn. Chem*. **1994**, *19*, 137.
3. Asfari, Z.; Wenger, S.; Vicens, J. *Pure Appl. Chem*. **1995**, *67*, 1037.
4. Alfieri, C.; Dradi, E.; Pochini, A.; Ungaro, R.; Andreetti, G. D. *J. Chem. Soc., Chem. Commun*. **1993**, 1075.
5. Asfari, Z.; Wenger, S.; Vicens, J. *Supramol. Sci*. **1994**, *1*, 103.
6. Moody, G. J.; Owusu, R. K.; Thomas, J. D. *Analyst* **1987**, *112*, 121.
7. Hassan, S. S.; Elnemma, E. M. *Anal. Chem*. **1989**, *61*, 2189.
8. Shinbo, T.; Yamaguchi, T.; Nishimura, K.; Kikkawa, M.; Sugiura, M. *Anal. Chim. Acta* **1987**, *193*, 367.
9. Maruyama, K.; Sohmiya, H.; Tsukube, H. *J. Chem. Soc. Chem. Commun.* **1989**, 864.
10. Tsukube, H.; Sohmiya, H. *Tetrahedron Lett*. **1990**, *31*, 7027.
11. Tsukube, H.; Sohmiya, H. *J. Org. Chem*. **1991**, *56*, 875.
12. Maeda, T.; Ikeda, M.; Shibahara, M.; Haruta, T.; Satake, I. *Bull. Chem. Soc. Jpn*. **1981**, *54*, 94.
13. Shirahama, K.; Kamaya, H.; Ueda, I. *Anal. Lett*. **1983**, *16*(B19), 1485.
14. Boche ska, M.; Biernat, J. F. *Anal. Chim. Acta* **1984**, *162*, 369.
15. Thoma, A. P.; Viviani-Nauer, A.; Schellenberg, K. H.; Bedekovi, D.; Pretsch, E.; Prelog, V.; Simon, W. *Helv. Chim. Acta* **1979**, *62*, 2303.
16. Bussmann, W.; Lehn, J. M.; Oesch, U.; Plmmer, P.; Simon, W. *Helv. Chim. Acta* **1981**, *64*, 657.
17. Yasaka, Y.; Yammaguchi, T.; Kimura, K.; Shono, T. *Chem. Lett*. **1980**, 769.
18. Katsu, T.; Xu, D.; Tsuji, K.; Nagamatsu, T. *Anal. Chim. Acta* **1997**, *354*, 301.
19. Gutsche, C. D. *Calixarenes*.; Stoddart, J. F., Ed.; Monographs in Supramolecular Chemistry 1; Royal Society of Chemistry: Cambridge, 1989.
20. Vicens, J.; Bohmer, V. *Calixarenes, a Versatile Class of Macro-cyclic Compounds*; Kluwer, Dordrecht, The Netherlands, 1990.
21. Ikeda, A.; Shinkai, S. *Chem. Rev.* **1997**, *97*, 1713.
22. Diamond, D.; McKervey, M. A. *Chem. Rev.* **1996**, 15.
23. Shinkai, S. *Tetrahedron* **1993**, *40*, 8933.
24. Cadogan, A.; Diamond, D.; Smyth, M. R.; Deasy, M.; Mckervey, M. A.; Harris, S. J. *Analyst* **1989**, *114*, 1551.
25. Ikeda, A.; Shinkai, S. *J. Am. Chem. Soc.* **1994**, *116*, 3102.
26. Jeong, H.; Choi, E. M.; Kang, S. O.; Nam, K. C.; Jeon, S. *Bull. Korean Chem. Soc.* **1999**, *20*, 1232.
27. Nam, K. C.; Kang, S. O.; Jeong, H.; Jeon, S. *Tetrahedron Lett.* **1999**, *40*, 7343.
28. Jeong, H.; Choi, E. M.; Kang, S. O.; Nam, K. C.; Jeon, S. *J. Electroanal. Chem.* **2000**, *485*, 154.
29. Odashima, K.; Yagi, K.; Tohda, K.; Umezawa, Y. *Anal. Chem.* **1993**, *65*, 1074.
30. Oh, H.; Choi, E. M.; Jeong, H.; Nam, K. C.; Jeon, S. *Talanta* **2000**, *53*, 535.
31. Choi, E. M.; Oh, H.; Ko, S. W.; Choi, Y. K.; Nam, K. C.; Jeon, S. *Bull. Korean Chem. Soc.* **2001**, *22*, 1346.
32. Nam, K. C.; Kang, S. O.; Lee, H.; Jeon, S.; Cho, H. J.; Chang, S. K. *Bull. Korean Chem. Soc.* **1998**, *19*, 279.
33. Chan, W. H.; Shiu, K. K.; Gu, X. H. *Analyst* **1993**, *118*, 863.
34. Chan, W. H.; Lee, A. W. M. *Analyst* **1994**, *119*, 2809.
35. Zheng, Q. U.; Chen, C. F.; Huang, Z. T. *Tetrahedron* **1997**, *53*, 10345.
36. Giannetto, M.; Mori, G.; Notti, A.; Pappalardo, S.; Parisi, M. F. *Anal. Chem.* **1998**, *70*, 4631.
37. Shvedene, N. V.; Nemilova, M. Y.; Kovalev, V. V.; Shokova, E. A.; Rozov, A. K.; Pletnev, I. V. *Sensors and Actuators B* **1995**, *26-27*, 372.
38. Katsu, T.; Ido, K. *Anal. Sci.* **2002**, *18*, 473.
39. Odashima, K.; Yagi, K.; Tohda, K.; Umezawa, Y. *Bioorg. & Med. Chem. Lett.* **1999**, *9*, 2375.