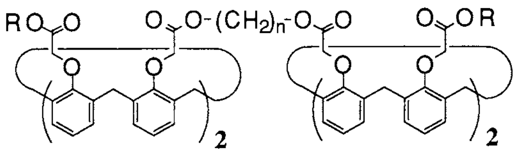
CHEMISTRY LETTERS, pp. 2045-2048, 1993.

Metal Vibration in an Ionophoric Biscalix[4]arene

Fumio OHSETO and Seiji SHINKAI*
Chemirecognics Project, ERATO, Research Development Corporation of Japan,
Aikawa 2432-3, Kurume, Fukuoka 830

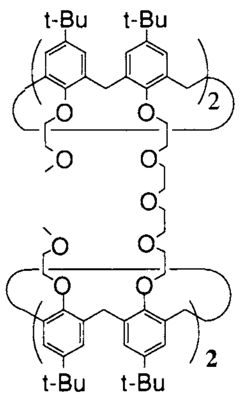
A biscalix[4]arene linked with two poly(oxyethylene) groups was synthesized. It was spectrometrically detected by temperature-dependent ^{1}H-NMR spectroscopy that alkali metal cations such as Na$^+$ or K$^+$ really "*vibrates*" between two metal-binding sites in the NMR time-scale.

The calix[n]arene skeletons provide new, fascinating platforms not only for metal recognition but also for molecular recognition.[1,2] Recently, a few groups have devoted their research effort towards the molecular design of higher-order supermolecules containing plural calix[n]arenes. For example, Böhmer *et al.*[3] synthesized a few biscalix[4]arenes in which the upper edges confront each other. McKervey *et al.*[4] synthesized a biscalix[4]arene in which two calix[4]arenes are linked by a single chain. On the other hand, Vicens *et al.*[5] synthesized a biscalix[4]arene with a 1,3-alternate conformation. It is unknown, however, whether or not these biscalix[4]arenes can provide some novel functions that conventional monocalix[4]arenes cannot. We also synthesized a series of biscalix[4]arenes (**1**$_n$) which possess two metal binding sites, each of which is composed of four ester groups.[6] Very interestingly, temperature-dependent ^{1}H-NMR spectroscopy showed that the metal exchange rates for **1**$_n$ are faster than those for the reference monocalix[4]arenes, suggesting that Na$^+$ may jump from one ionophoric site to another ionophoric site in the NMR time-scale.[6] If this is the case, the phenomenon is similar to a "*molecular shuttle*" proposed by Stoddart *et al.*[7] for a rotaxane system. To find unequivocal

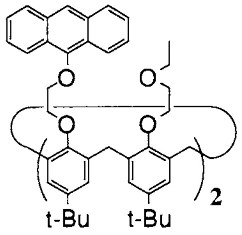


R = Et, t-Bu
n = 0, 1, 3, 8

1$_n$



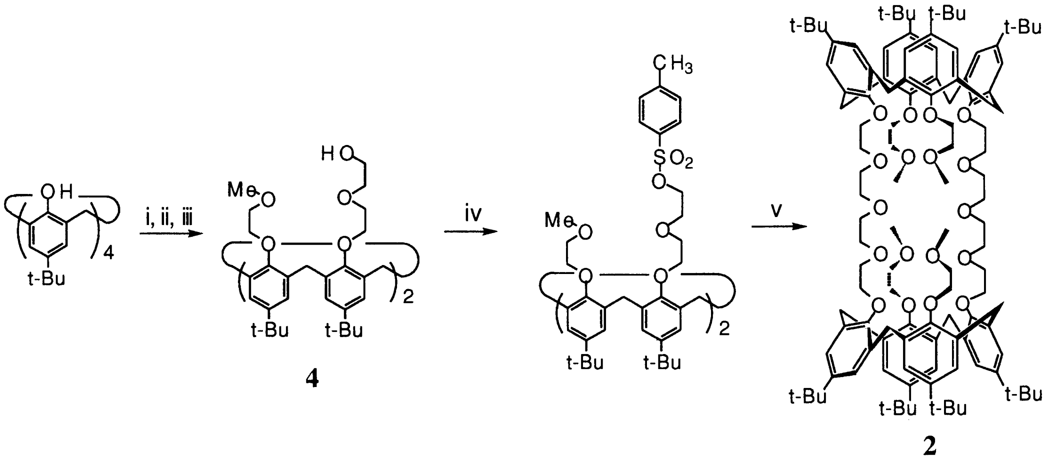
2



3

evidence for the reversible metal jump we newly synthesized a biscalix[4]arene (**2**) in which two calix[4]arenes are linked by two ionophoric poly(oxyethylene) chains. Based on the NMR spectral data, we have confirmed that Na^+ really "*vibrates*" between two metal-binding sites.

Compound **2** (mp 274 °C) was synthesized from 5,11,17,23-tetra-*tert*-butylcalix[4]arene-25,26,27,28-tetrol by the method in Scheme 1 and identified by IR, NMR and Mass ((M+Na^+)) spectroscopy and elemental analysis.



Scheme 1. Reagent: i, $ClCH_2CH_2OCH_2CH_2OTHP$, K_2CO_3, KI, acetone, reflux for two weeks; ii, bromoethylmethylether, NaH, THF; iii, MeOH-H_2SO_4; iv, p-toluenesulfonyl chloride, pyridine; v, **4**, NaH, $NaClO_4$, THF.

We first estimated the metal affinity and selectivity of **2** in two-phase solvent extraction. **3** was used as a reference compound which is known to show the Na^+ selectivity.[8] As illustrated in Fig. 1, **2** also shows the Na^+ selectivity and the extractabilities (Ex%) are much higher than those for **3**. In general, the Ex% values for $ROCH_2CH_2O$-modified calix[4]arenes are lower than those for $ROCOCH_2O$-modified calix[4]arenes.[8] The difference is attributed to the high freedom of the molecular motion remaining in the $ROCH_2CH_2O$ groups. In **2**, on the other hand, the molecular motion of two $ROCH_2CH_2O$ groups is suppressed because of the ring formation. This advantage would enhance Ex% for **2**. Figure 2 shows the partial ^1H NMR spectra of **2** in the absence and the presence of NaSCN. It is seen from Fig. 2 that in a 1.0:1.0 **2**/Na^+ molar ratio the ArH protons in one calix[4]arene shift to lower magnetic field whereas those in another calix[4]arene remains unaffected. In a 1.0:2.1 **2**/Na^+ molar ratio only the peaks assignable to the complex were observed. The results indicate that **2** can accept two Na^+ ions in the order $\mathbf{2} \rightarrow \mathbf{2}\bullet Na^+ \rightarrow \mathbf{2}\bullet(Na^+)_2$. The temperature-dependent ^1H NMR spectra (Fig. 3)

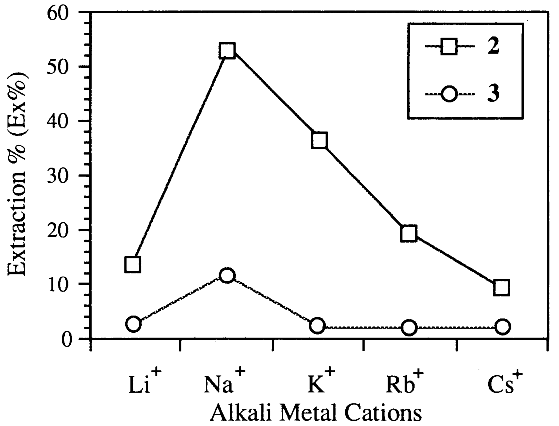


Fig. 1. Two phase solvent extraction of alkali metal picrates. Organic phase: CH_2Cl_2 (5 ml), [host] = 8.02×10^{-5} M. Aqueous phase: H_2O (5 ml), [MCl] = 0.5 M, [MOH] = 0.1 M, [picric acid] = 2.75×10^{-5} M.

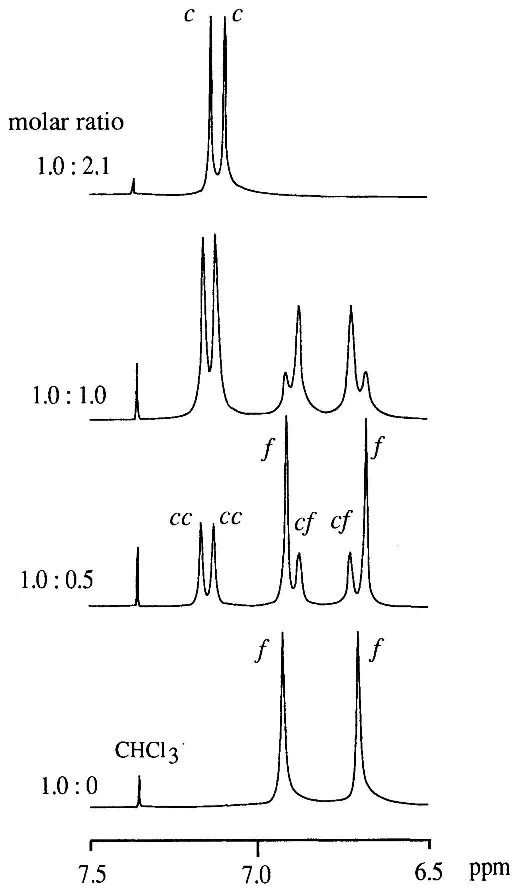


Fig. 2. NMR titration of **2** with NaSCN in $CDCl_3$. [**2**] = 2.1×10^{-2} M, temperature = -25 °C, (6.5 - 7.5 ppm). *cc*: ArH protons of the complex site in the complex species, *cf*: ArH protons of the free site in the complex species, *c*: ArH protons of the complex species, *f*: ArH protons of the free species.

disclosed an exciting phenomenon hidden in a biscalix[4]arene system. At -25 °C we can count three inequivalent ArH protons, which are assigned to two calix[4]arenes in free **2** (*f*), a free calix[4]arene in **2**•Na^+ (*cf*) and a complexed calix[4]arene in **2**•Na^+ (*cc*). With the rise in the temperature *cf* and *cc* coalesced at 0 °C and then *f* and *c* coalesced at 25 °C. The low-temperature coalescence is ascribed to the intramolecular metal-hopping process between two metal-binding sites (Fig. 4) and the high-temperature coalescence is ascribed to the intermolecular association-dissociation equilibrium. The similar spectral change was also observed for K^+. The low-temperature coalescence is -25 °C and the high-temperature coalescence is 25 °C: that is, in K^+ the intra-molecular metal-hopping process is faster but the inter-molecular association-dissociation equilibrium is unaffected. We also investigated the concentration dependence of these coalescence temperatures, holding the **2**/Na^+ ratio to 1.0:0.5. When the concentration of **2** was 2.0×10^{-2} M, the low-temperature coalescence and the high-temperature coalescence were 0 °C and 25 °C, respectively. The high-temperature coalescence rose with decreasing the concentration: 32 °C at 1.0×10^{-2} M and above 35 °C at 0.5×10^{-2} M. The low-temperature coalescence was, however, independent of the concentration change. As the concentration change should affect only the inter-molecular process, the high-temperature coalescence and the low-temperature coalescence are attributable to the intermolecular process and the intramolecular process, respectively.

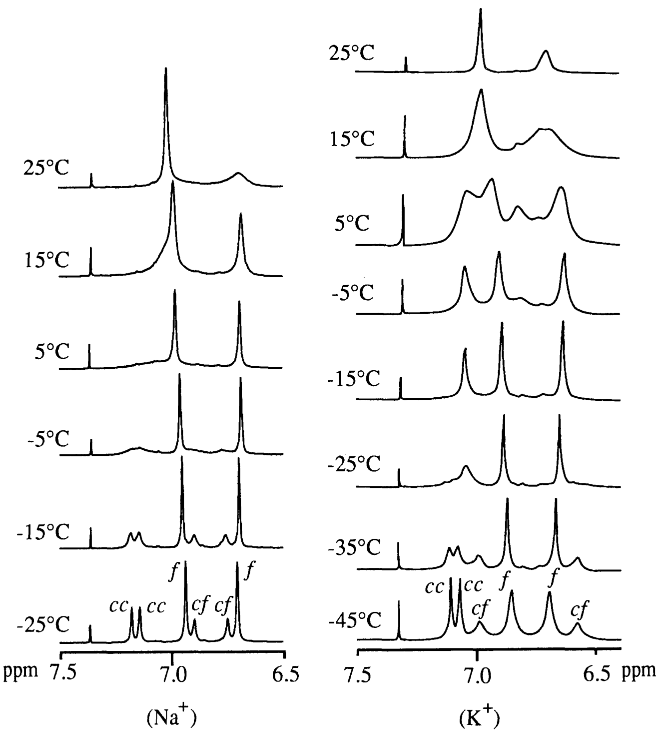


Fig. 3. Temperature dependent ^1H NMR spectra of **2** in the presence of alkali metals (Na^+ or K^+). [**2**] = 2.0×10^{-2} M, [alkali metal] = 1.0×10^{-2} M, CD_2Cl_2, 300 MHz.

The foregoing results clearly demonstrate that alkali metal cations "*vibrate*" between two ionophoric sites in a biscalix[4]arene (**2**) in the NMR time-scale.[9,10]

In conclusion, biscalix[4]arenes are interesting compounds for which the unique intramolecular metal-vibration is observed by an NMR spectral method.

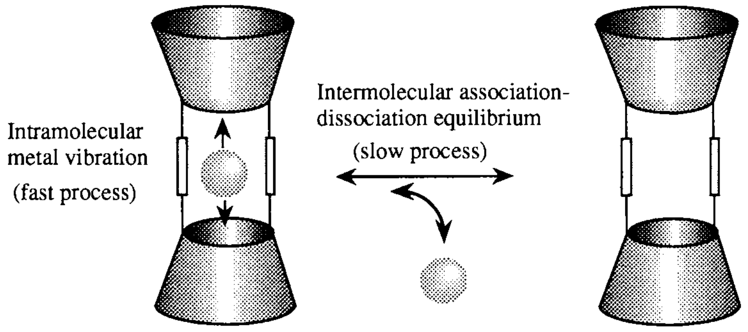


Fig. 4. Illustration of intra- and inter-molecular metal exchange processes.

References

1) C. D. Gutsche, "Calixarenes", Royal Society of Chemistry, Cambridge (1989).
2) J. Vicens and V. Böhmer , "Calixarenes", Kluwer Academic Press Pub., Dordrecht (1990).
3) V. Böhmer, H. Goldmann, W. Vogt, J. Vicens, and Z. Asfari, *Tetrahedron Lett.*, **30**, 1391 (1989).
4) M. A. McKervey, M. Owens, H.-R. Schulten, W. Vogt, and V. Böhmer, *Angew. Chem., Int. Ed. Engl.*, **29**, 280 (1990).
5) Z. Asfari, R. Abidi, F. Arnaud, and J. Vicens, *J. Inclusion Phenom.*, **13**, 163 (1992).
6) F. Ohseto, T. Sakaki, K. Araki, and S. Shinkai, *Tetrahedron Lett.*,**34**, 2149 (1993).
7) P. R. Ashton, D. Philp, N. Spencer, and J. F. Stoddart, *J. Chem. Soc., Chem. Commun.*, **1992**, 1124.
8) G. Deng, T. Sakaki, K. Nakashima, and S. Shinkai, *Chem. Lett.*, **1992**, 1287.
9) Unfortunately, we cannot yet determine the exchange rates because we have to take three species simultaneously into account.
10) The similar phenomenon was found for [3]cryptates: J.-M. Lehn and M. E. Stubbs, *J. Am. Chem. Soc.*, **96**, 4011 (1974). We thank Prof. J.-M. Lehn for his interest in and discussion on the present results.

(Received August 25, 1993)