

SYNTHESIS AND MERCUROPHILIC PROPERTIES OF 5,8,14,17-TETRAOXA-2,11,20-TRITHIABICYCLO[19.4.1]HEXACOSA-21,23,25-TRIEN-26-ONE

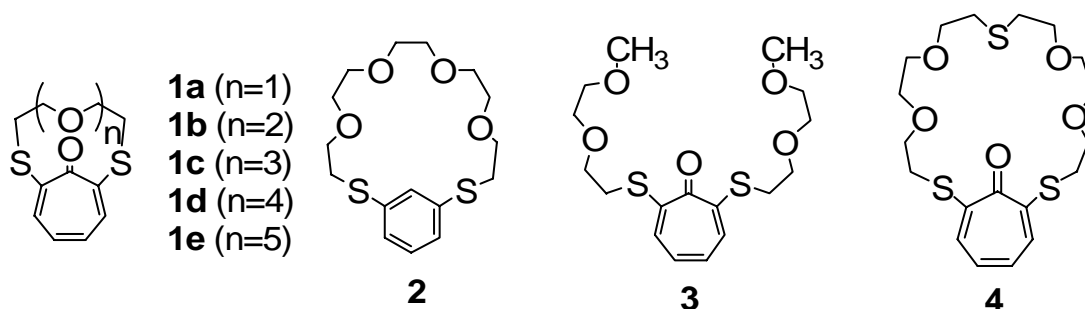
Kanji Kubo,* Akira Mori,* and Tatsuya Nishimura[†]

Institute for Materials Chemistry and Engineering, Kyushu University, Kasuga-koen, Kasuga, Fukuoka 816-8580, Japan

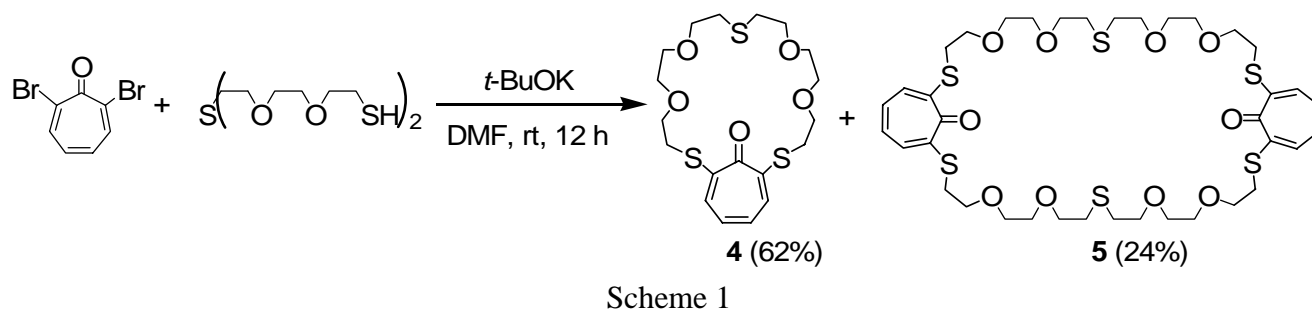
[†]*Graduate School of Engineering Sciences, 39, Kyushu University, Kasuga-koen, Kasuga, Fukuoka 816-8580, Japan*

Abstract—Base-mediated condensation reaction of 2,7-dibromotroponone with 3,6,12,15-tetraoxa-9-thiaheptadecane-1,17-dithiol afforded 1:1 and 2:2 condensates (**4** and **5**). Troponoid trithiocrown ether (**4**) was used as a carrier through a chloroform liquid membrane. However, the guest selectivity of **4** was lower than that of the corresponding dithiocrown ether derivative (**1e**).

The development of selective ion recognition systems has been of much concern because of a solution to environmental pollution. Macrocyclic ligands are of great interest because they serve as models for metal ion transport through a membrane.¹ We are currently interested in synthesizing metal ion-capturing ionophores having a troponone ring (**1**).² Particularly noteworthy are their reversible complexation behaviors with mercury(II) salts to enable transport of mercury(II) ions through a liquid membrane. As a matter of efficiency in transport of Hg²⁺ ion, transport rates of the troponoid dithiocrown derivatives (**1**) depended on the cavity size of the crown ethers. The order of Hg²⁺ transport rate of **1** was **1d**>**1e**>**1b**>**1a**>**1c**. The relationship between the transport rate and the structures of its Hg²⁺ complex was confirmed by the X-Ray analyses^{3,4} of the HgCl₂ complexes of **1a-d**; there are two kinds of coordination modes, one of which is a side-on complex³ and another is a normal penetrated one.⁴ The Hg²⁺ ions of **1a-c** are coordinated with both the troponone carbonyl group and one of the thioether sulfur atoms to form a side-on complex, whereas the Hg²⁺ ion of **1d-HgCl₂** is at the center of the thiocrown



ring to form a normal penetrated complex. The transport rate of **1d** for Hg^{2+} is faster than that of the corresponding benzenoid (**2**),⁵ suggesting that the troponone part participates in the liberation of Hg^{2+} . On the other hand, the transport rate of troponoid acyclic ether (**3**)⁶ was slower than that for troponoid dithiocrown ether (**1d**), suggesting that the dithiocrown ether part also plays an important role in the complexation. Indeed, it is interesting to investigate the selectivity on the mercuriphilicity of several troponoid ionophores. As an approach to the manipulation of sulfur-containing troponoid ionophores, we now report the synthesis and complexation behavior of trithiocrown ether (**4**) having a troponone pendant. At first, 2,7-dibromotroponone was condensed with 3,6,12,15-tetraoxa-9-thiaheptadecane-1,17-dithiol mediated by *t*-BuOK to give 1:1 and 2:2 condensates (**4** and **5**). Structures of **4** and **5** were clarified as depicted in Scheme 1 by NMR spectroscopy and FAB MS spectrometry.⁷



^1H NMR spectral screening experiments of **1e** and **4** suggested a complexation with metal ions (10 eq.). The complex formation of **1e** and **4** was examined with various metal salts, i.e., alkali metal ions (LiCl, NaCl, KCl, RbCl, and CsCl), alkaline earth metals (MgCl_2 , CaCl_2 , and BaCl_2), and some transition metal ions (NiCl_2 , CuCl_2 , and CdCl_2) showed no ^1H NMR spectral changes in CDCl_3 . The ^1H NMR spectra of **4**, however, changed by the complex formation of HgCl_2 and AgNO_3 although the selectivity of **4** was lower than **1**. Remarkable ^1H NMR spectral feature was observed in Figure 1.

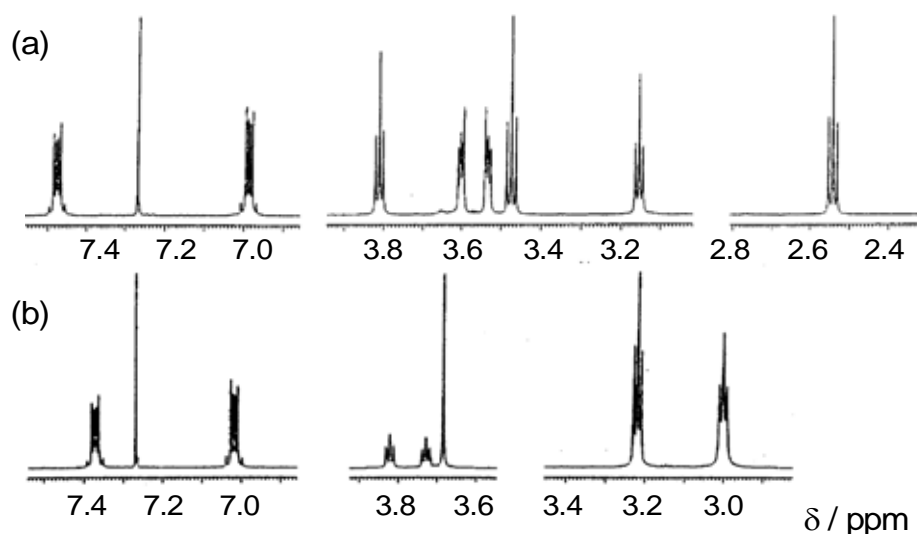


Figure 1. ^1H NMR spectrum of (a) **4** (6.0 mM) and (b) **4** (6.0 mM) in the presence of HgCl_2 (18 mM).

When HgCl_2 was added, the original proton signals of **4** changed depending on the guest concentrations. The ^1H NMR spectrum of the mercury complex is as follows: ^1H NMR (CDCl_3): $\delta=3.00$ (4H, t, $J=5.7$ Hz), 3.22 (4H, t, $J=5.7$ Hz), 3.69 (8H, s), 3.73 (4H, t, $J=5.7$ Hz), 3.82 (4H, t, $J=5.7$ Hz), 7.00-7.04 (2H, m), and 7.35-7.39 (2H, m). The methylene proton signals bearing the trithiocrown ether group shifted downfield and the aromatic proton signals shifted upfield or downfield. The spectral patterns are similar to those of **1d**, **1e**,² and 23-dicyanomethylene-5,8,11,14,17-pentaoxa-2,20-dithiabicyclo[19.4.1]-hexacosa-1(26),21,24-triene.⁸ This result means that the Hg^{2+} ion of **4**- HgCl_2 is at the center of the thiocrown ring to form a normal penetrated complex in pentagonal bipyramidal coordination.

The extraction experiment⁹ of the troponoid ionophores toward HgCl_2 was examined using a CHCl_3 -water system. The molar ratio of the extracted Hg^{2+} with **4** is 0.23, that is smaller than **1e** (0.30). Further transport experiments¹⁰ were performed using a liquid membrane system. When an aqueous solution of HgCl_2 (source phase) was brought into contact with a CHCl_3 solution of **1e** or **4**, stirring with a magnetic bar at 25 °C, the concentration of Hg^{2+} in the source phase decreased. The Hg^{2+} was transported to the CHCl_3 layer and could be extracted by aqueous 5 M HCl into the receiving phase. Figure 2 shows the results of transport experiments of Hg^{2+} with **1e** and **4**. It is also noteworthy that the transport rate for **4** was slower than **1e**. These results mean that the stability of **4**- HgCl_2 complex in pentagonal bipyramidal coordination is lower than that of **1e**. The additional sulfur atom of **4** inhibited the complexation with Hg^{2+} . Thus, the crown ether part in the dithiocrown ether (**1e**) played an important role in the complexation of Hg^{2+} .

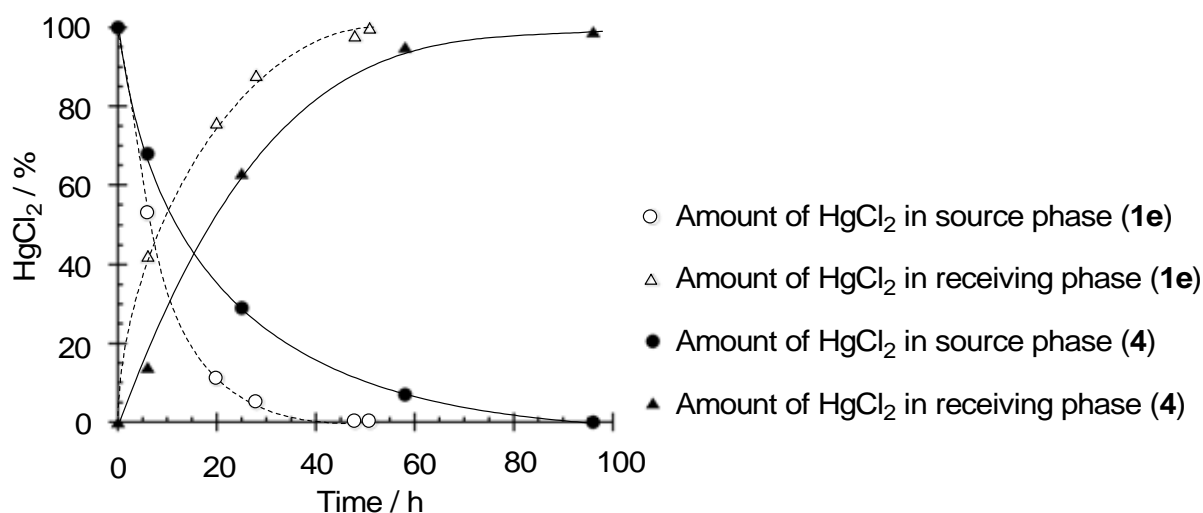


Figure 2. Transport of Hg^{2+} with **1e** and **4** using 5 M HCl.

In conclusion, a new carrier (**4**) was synthesized. But the extractability and transport rate for **4** were slower than those for the corresponding troponoid dithiocrown ether (**1e**). This result makes it possible to design more effective carriers for Hg^{2+} separation.

REFERENCES AND NOTES

1. H. E. Bacon and L. Jung, *J. Membrane Sci.*, 1985, **24**, 185; E. Bacon and M. Kirch, *ibid.*, 1987, **32**, 159; R. M. Izatt, G. A. Clark, and J. J. Christensen, *ibid.*, 1985, **24**, 1; R. M. Izatt, M. B. Jones, J. D. Lamb, J. S. Bradshaw, and J. J. Christensen, *ibid.*, 1986, **26**, 241; R. M. Izatt, R. L. Bruening, G. A. Clark, J. D. Lamb, and J. J. Christensen, *ibid.*, 1986, **28**, 77; J. C. Hernandez, J. E. Trafton, and G. W. Gokel, *Tetrahedron Lett.*, 1991, **32**, 6269; Y. Yamini, N. Alizadeh, and M. Shamsipur, *Anal. Chim. Acta*, 1997, **355**, 69; M. Shamsipur and F. Raoufi, *Sep. Sci. & Tech.*, 2002, **37**, 481.
2. A. Mori, K. Kubo, and H. Takeshita, *Bull. Chem. Soc. Jpn.*, 1994, **67**, 1094; A. Mori, K. Kubo, and H. Takeshita, *Coordination Chem. Rev.*, 1996, **148**, 71; N. Kato, K. Kubo, A. Mori, and H. Takeshita, *Heterocycles*, 1995, **41**, 1901; K. Kubo, A. Mori, N. Kato, and H. Takeshita, *Acta Cryst.*, 2000, **C56**, E396; A. Mori, K. Kubo, T. Nishimura, N. Kato, and H. Takeshita, *Chem. Lett.*, **2000**, 180.
3. A. Mori, K. Kubo, N. Kato, H. Takeshita, M. Shiono, and N. Achiwa, *Heterocycles*, 1998, **47**, 149; K. Kubo, N. Kato, A. Mori, and H. Takeshita, *ibid.*, 2000, **53**, 535.
4. K. Kubo, A. Mori, N. Kato, and H. Takeshita, *Acta Cryst.*, 1996, **C52**, 1656.
5. A. Mori, K. Kubo, and H. Takeshita, *Heterocycles*, 1997, **46**, 509.
6. K. Kubo and A. Mori, *Heterocycles*, 2001, **54**, 351.
7. Synthetic details and physical properties will be reported elsewhere. **4**: yellow oil, ^1H NMR (270 MHz, CDCl_3) δ =2.52 (4H, t, J=6.6 Hz), 3.14 (4H, t, J=5.9 Hz), 3.46 (4H, t, J=6.6 Hz), 3.50-3.60 (8H, m), 3.79 (4H, t, J=5.9 Hz), 6.92-7.02 (2H, m), and 7.41-7.51 (2H, m). ^{13}C NMR (67.9 MHz, CDCl_3) δ =31.7 (2C), 32.0 (2C), 69.9 (2C), 70.6 (2C), 70.8 (2C), 128.3 (2C), 129.3 (2C), 150.1 (2C), and 179.1. HR FAB MS. Found: 433.1175. Calcd for $\text{C}_{19}\text{H}_{28}\text{O}_5\text{S}_3$: 433.1177. **5**: yellow crystals (EtOAc-hexane), 87-88 °C, ^1H NMR (270 MHz, CDCl_3) δ =2.77 (8H, t, J=6.6 Hz), 3.09 (8H, t, J=5.9 Hz), 3.60-3.66 (16H, m), 3.67 (8H, t, J=6.6 Hz), 3.77 (8H, t, J=6.6 Hz), 6.96-7.00 (4H, m), and 7.23-7.27 (4H, m). ^{13}C NMR (67.9 MHz, CDCl_3) δ =31.6 (4C), 31.9 (4C), 68.8 (4C), 70.3 (4C), 70.6 (4C), 128.2 (4C), 128.4 (4C), 150.5 (4C), and 178.7 (2C). HR FAB MS. Found: 865.2284. Calcd for $\text{C}_{38}\text{H}_{56}\text{O}_{10}\text{S}_6$: 865.2276.
8. N. Kato, K. Kubo, A. Mori, and H. Takeshita, *Heterocycles*, 1995, **41**, 1901; K. Kubo, A. Mori, N. Kato, and H. Takeshita, *Chem. Lett.*, **1995**, 629; K. Kubo, A. Mori, N. Kato, and H. Takeshita, *Heterocycles*, 1998, **49**, 385; K. Kubo, N. Kato, A. Mori, and H. Takeshita, *Acta Cryst.*, 2000, **C56**, 644.
9. A standard aqueous solution (10 mL) containing HgCl_2 (13.6 mg, 50 μmol) was shaken with CHCl_3 solution (10 mL) of **1e** and **4** (each 50 μmol) for 5 min. Aqueous layer was titrated photometrically (490 or 610 nm) in phosphate buffer (10 cm^3 , pH=6.0) with added 1,5-diphenylthiocarbazone solution (5 mL, 0.0006%).
10. The apparatus is the same to one used in the previous study.² The metal ions dissolved in water (50 μmol , 10 mL, Aq. I) and 5 M HCl solution (10 mL, Aq. II) is connected with 20 mL of CHCl_3 layer containing **1e** and **4** (50 μmol) and stirred with a magnetic bar. Occasionally, aliquots of Aq I and Aq II were taken for the measurement of UV spectrophotometry.