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SYNTHESIS AND PROPERTIES OF 2-BROMO-7-(1,4,7,10-TETRAOXA-13-AZACYCLOPENTADEC-13-YL)-2,4,6-CYCLOHEPTATRIEN-1-ONE†

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Abstract – 2-Bromo-7-(1,4,7,10-tetraoxa-13-azacyclopentadec-13-yl)tropone (**1**) was found to display unique absorption spectral changes in the presence of guest cations. The compositions of **1** with guest salts were 1:1 for $Mg(SCN)_2$, $Ca(SCN)_2$, and $Ba(SCN)_2$, 1:2 for CdI_2 and 1:1.5 for $Zn(SCN)_2$, respectively. Azacrown ether (**1**) could be used as a carrier for transport of Hg^{2+} through a chloroform liquid membrane.

INTRODUCTION

Synthetic chromoionophores,[1-6] which give rise to a specific absorption spectral change upon selective complexation with cations, have attracted considerable attention as spectrophotometric analytical reagents for the detection of particular guest cations. There are extensive investigations toward the characterization of chromoionophores including azacrown ethers with azobenzene,[1,2] quinone imine,[3] naphthoquinone,[3] anthraquinone,[3] cyanine,[4] azulene,[5,6] and tropone.[7,8] While liquid membrane methods are useful for assessing the partitioning of metal into and out of organic phases and are of considerable importance in medicine, water purification, and metallurgy.[9,10] A liquid membrane, (which consists of an organic solvent placed at the bottom of a U-tube), has been widely used in order to study ion transport from one water compartment to the other, a process requiring, of course, passage through the chloroform barrier. Recently, we prepared several dithio-crown ethers and azamacrocycles having a tropone pendant. It is of particular interest to observe that the tropone part can be used as a chromophore. Furthermore the dithiocrown ethers having tropone pendant are used as a Hg(II) cation carrier through a liquid membrane. In this paper, we report on the synthesis and complexation behaviours of aza-15-crown-5 containing

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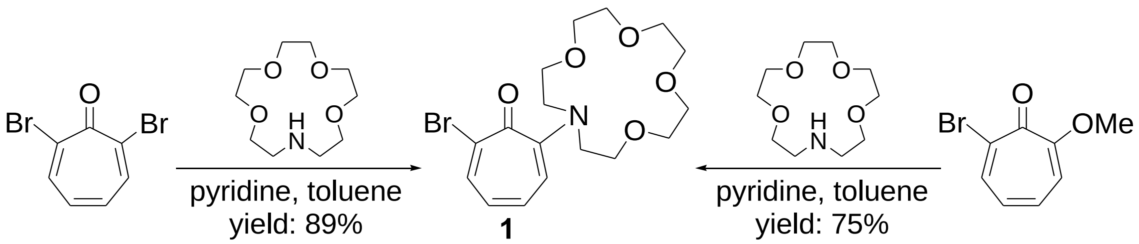
†Dedicated to Professor Emeritus Keiichiro Fukumoto on the occasion of his 75th birthday.

2-bromotropone pendant in order to elucidate the influence on the complex formation of bromo group substituted at the 2-position of tropone.

RESULTS AND DISCUSSION

2-Bromo-7-(1,4,7,10-tetraoxa-13-azacyclopentadec-13-yl)tropone (**1**) was prepared by the substitution reaction of 2,7-dibromotropone with aza-15-crown-5. The yield (89%) of **1** obtained from 2,7-dibromotropone was higher than that (75%)[8] from 2-bromo-7-methoxytropone. The structure and purity of **1** was ascertained by NMR spectroscopy and elemental analysis.



Scheme 1

Compound (**1**) had two strong absorption bands at 361 and 437 nm, which were longer wavelength region than those (352 and 410 nm) of 2-(1,4,7,10-tetraoxa-13-azacyclopentadec-13-yl)tropone. The complexation behaviors of **1** with various guest salts (LiSCN, NaSCN, KSCN, NH_4SCN, $Mg(SCN)_2$, $Ca(SCN)_2$, $Ba(SCN)_2$, $Zn(SCN)_2$, CdI_2, $Hg(SCN)_2$) were studied by UV spectroscopy. By the addition of guest salts, the UV spectra of **1** changed dramatically in MeCN as shown in Figure 1. Addition of metal salts except for Hg^{2+} to **1** caused the disappearance of two original absorption bands at 361 and 437 nm of **1** and a new absorption band similar to that of 2-bromotropone, which appeared around 340 nm, as shown in Figure 1.

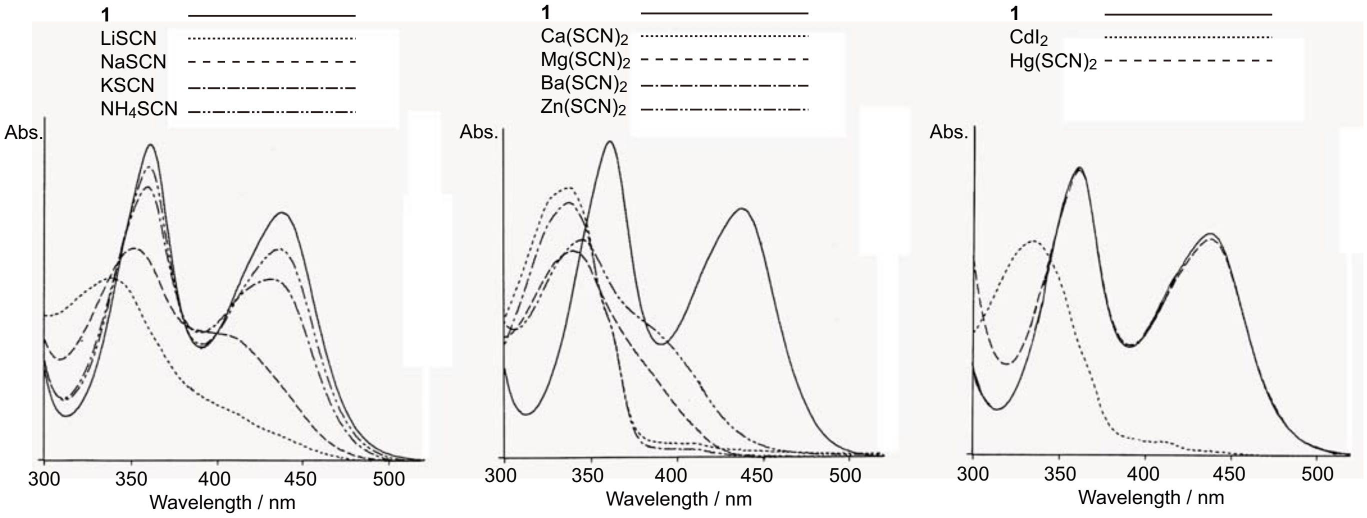


Figure 1. Absorption spectra of **1** (2×10^{-4} M) with and without guest salts (2×10^{-3} M) in MeCN

This means that the complexation of guest salts, except for the case of Hg^{2+}, gave rise to deconjugation between the tropone ring and the nonbonding electron pair of the nitrogen atom. The spectral changes depended on the concentration of guest salts.

The metal-cation concentration dependence of the absorbance allowed us to determine the composition of the complexes by a molar ratio method (Figure 2) and the association constants (*K*) by a nonlinear curve-fitting method (Table 1).

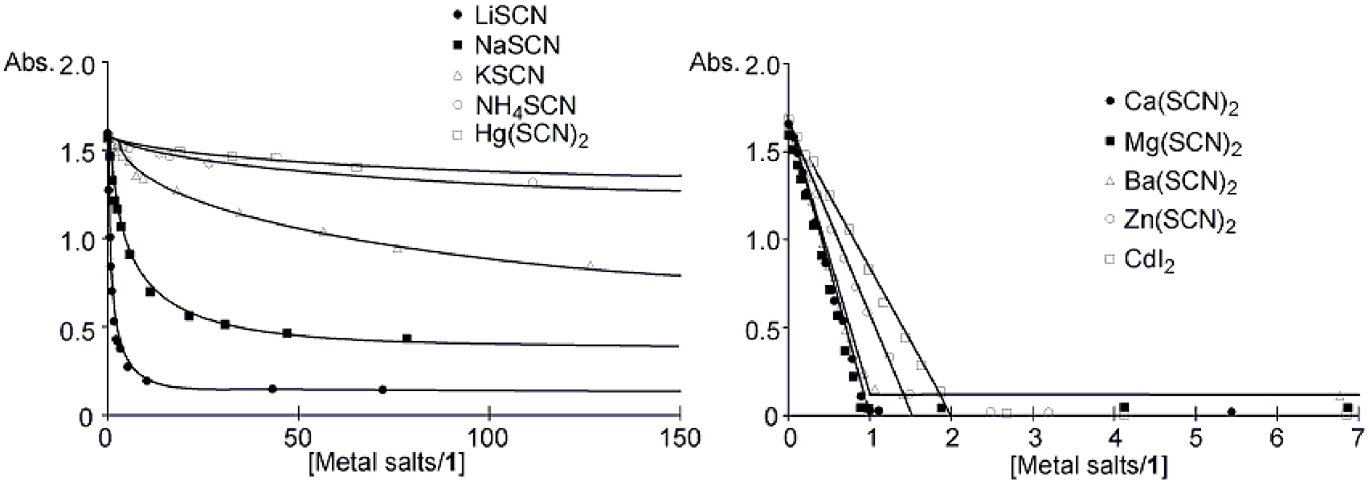


Figure 2. Absorbance dependence of **1** (2×10^{-4} M) on concentration of various guest salts in MeCN

Table 1. Association constants (log *K* / M^{-1}) of **1** and *N*-(tropon-2-yl)-15-azacrown-5[8] for various guest salts in MeCN and $CHCl_3$-MeOH (9:1 *v/v*)

Metal ions	Compound (**1**) MeCN	Compound (**1**) $CHCl_3$-MeOH (9:1 *v/v*)	*N*-(tropon-2-yl)-15-azacrown-5 MeCN	*N*-(tropon-2-yl)-15-azacrown-5 $CHCl_3$-MeOH (9:1 *v/v*)
Li^+	4.13 ± 0.01	1.20 ± 0.02	5.23 ± 0.03	
Na^+	3.12 ± 0.01		3.65 ± 0.02	
K^+	2.01 ± 0.02		2.68 ± 0.01	
NH_4^+	1.40 ± 0.01		2.30 ± 0.01	
Mg^{2+}		1.20 ± 0.11		1.18 ± 0.10
Ca^{2+}		2.38 ± 0.01		3.40 ± 0.01
Ba^{2+}		3.28 ± 0.02		4.20 ± 0.01
Zn^{2+}		3.07 ± 0.07		3.82 ± 0.08
Cd^{2+}		2.33 ± 0.10		3.51 ± 0.08
Hg^{2+}	1.82 ± 0.09		1.89 ± 0.09	

The composition of the complexes was determined as 1 (ligand):1 (metal) for **1**-LiSCN, **1**-$Mg(SCN)_2$, **1**-$Ca(SCN)_2$ and **1**-$Ba(SCN)_2$ systems, 1:2 for **1**-CdI_2 system and 1:1.5 for **1**-$Zn(SCN)_2$ system, respectively. Since the measurements in MeCN for alkali earth metal salts and CdI_2 were out of range, the solvent was changed to a mixture of MeOH and $CHCl_3$ (1:9 *v/v*). As shown in Table 1, the *K* values of **1** for various guest cations were smaller than those of *N*-(tropon-2-yl)-15-azacrown-5.[8] Compound (**1**) showed the following guest cation selectivity: Ba^{2+} > Zn^{2+} > Ca^{2+} >Cd^{2+} > Mg^{2+} > Li^+ > Na^+ > K^+ > Hg^{2+}> NH_4^+. It is interesting that the order of *K* of **1** with alkali ions was Li^+ > Na^+ > K^+. The selectivity pattern of **1** with alkali ions is distinct from that of 15-crown-5.[11] It is known that 15-crown-5 showed Na^+ selectivity. The selectivity pattern of **1** is similar to that (Li^+ > Na^+ > K^+) of *N*-(tropon-2-yl)-15-azacrown-5.[8] The UV spectral behavior of **1** indicated a change of conformation by complexation. Since the oxygen and nitrogen atoms of tropone carbonyl group and aza-15-crown-5 constitute the coordination form, the effective size of the crown cavity become smaller than the parent crown ether to decrease the mutual conjugation between the host system and the tropone moiety.

Transport experiments were performed using a liquid membrane system with a U-type cell (the same apparatus used in the previous study),[10] which was set to contain the source phase (Aq. I) (0.05 mmol of metal salts in 10 cm^3 of water), $CHCl_3$ (0.05 mmol of **1** in 20 cm^3), and the receiving phase (Aq. II) (10 cm^3 of 1 M HCl). Metal cation concentrations in the aqueous compartments were monitored as a function of time by means of the colorimetric method. No transport of metal cation through the $CHCl_3$ was observed unless a carrier was used. Although UV spectroscopy in MeCN and $CHCl_3$-MeOH (9:1 *v/v*) solvents indicated the complexation of **1** with Ca^{2+}, Ba^{2+}, Zn^{2+}, and Cd^{2+}, these metal cations could not be transported by **1**. When an aqueous solution of $HgCl_2$ (source phase) was brought into contact with a $CHCl_3$ solution of **1**, stirring with a magnetic bar, the concentration of Hg(II) ion in the source phase decreased. The Hg(II) ion was transported to the $CHCl_3$ layer and could be extracted by aqueous 1 M HCl into the receiving phase. It is noteworthy that Hg^{2+} ion was transported selectively with **1**. The transport rate of Hg^{2+} for **1** was slower than that of troponoid dithiocrown ether derivatives[10] and same as that of 1-(8,8-dicyanoheptafulven-3-yl)aza-15-crown-5.[12]

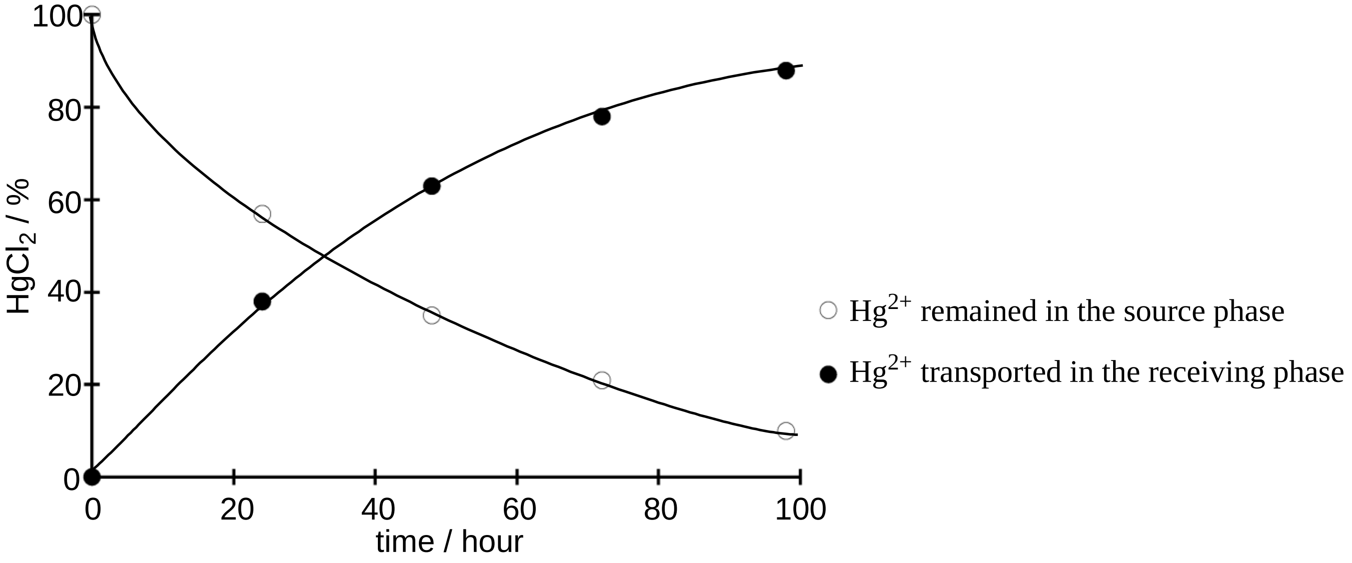


Figure 3. Transport of Hg(II) with **1** and **3** using 2 M HCl

In conclusion, a new chromoionophore for various metal cation was synthesized. The azacrown (**1**) also showed pronounced mercurophilic properties according to the transport experiments. And again, although the UV spectral changes of **1** with Ca^{2+}, Ba^{2+}, Zn^{2+}, and Cd^{2+} were observed, only Hg^{2+} ion was transported through the chloroform layer.

EXPERIMENTAL

Instruments

The elemental analyses were performed at the elemental analysis laboratory of Kyushu University. The melting points were measured with a Yanagimoto Micro Melting Point Apparatus and are uncorrected. The NMR spectra were measured by means of JEOL Lambda-400 Model spectrometers in $CDCl_3$; the chemical shifts are expressed in units of δ. The mass spectra were measured with a JEOL JMS-0ISG-2 spectrometer. The IR spectra were taken as KBr disks for crystalline compounds or as liquid films inserted between NaCl plates for oily compounds, using a JASCO IR-700 spectrometer. The UV spectra were measured using Hitachi U-3410 spectrophotometer. The stationary phase used in column chromatography was Wakogel C-300 and the eluent was a mixture of ethyl acetate and hexane.

Synthesis of 2-Bromo-7-(1,4,7,10-tetraoxa-13-azacyclopentadec-13-yl)tropone (1)

A pyridine-toluene solution (8 cm^3, 1:1 *v/v*) of 1-aza-15-crown-5 (87.6 mg, 0.40 mmol) and 2,7-dibromotropone (26.4 mg, 0.10 mmol) was stirred for 12 h. The solvent was evaporated and the residue was purified by column chromatography over silica gel using $CHCl_3$ as the eluent. Recrystallization from $CHCl_3$ gave 2-bromo-7-(1,4,7,10-tetraoxa-13-azacyclopentadec-13-yl)tropone (**1**) (36.0 mg, 89%). The physical and spectral data are given below.

2-Bromo-7-(1,4,7,10-tetraoxa-13-azacyclopentadec-13-yl)tropone (1): A yellow oil, Anal. Calcd for $C_{17}H_{24}BrNO_5$: C, 50.76; H, 6.01; N, 3.48. Found: C, 50.46; H, 6.16; N, 3.42. ^1H NMR ($CDCl_3$) δ=3.57-3.66 (12H, m), 3.80 (8H, s), 6.33 (1H, t, J=9.9 Hz), 6.71 (1H, d, J=10.6 Hz), 7.06 (1H, dd, J=10.6, 9.9 Hz), 7.88 (1H, d, J=9.9 Hz). ^{13}C NMR ($CDCl_3$) δ=54.6 (2C), 68.9 (2C), 70.2 (2C), 70.4 (2C), 71.0 (2C), 113.1, 119.6, 129.3, 133.9, 138.4, 154.2, 174.4. IR (NaCl) ν 713, 751, 931, 977, 1066, 1124, 1232, 1294, 1316, 1335, 1352, 1379, 1414, 1455, 1484, 1564, 1595, 2866, 3000 cm^{-1}. UV (MeCN) λ_{max} 263.9 (ε=12800), 361.2 (10300), 437.4 (8100) nm. MS *m/z* 404 (4), 403 (18), 402 (8), 401 (16), 225 (100), 227 (98), 212 (45), 322 (38), 210 (35), 105 (34), 226 (32), 228 (21).

Determination of Composition of Complex and Association Constants (*K*). The titrations were conducted by adding a crown-ether solution (2.0×10^{-4} M for **1** in acetonitrile or $CHCl_3$-MeOH (9:1 *v/v*)) progressively containing excess metal salts, using a 250 cm^3 syringe, to a cuvette containing 2 cm^3 of the crown ether solution (2.0×10^{-4} M for **1** in MeCN or $CHCl_3$-MeOH (9:1 *v/v*)). The solutions were homogenized by ultrasonic waves for 5 min. The spectrum was recorded after each addition. The added equivalents of the cation were then plotted against the absorption-intensity change around 420 nm, as shown in Figure 2. Even though the solvent takes part in the association interaction, the solvent concentration is virtually unaffected. The composition of complex with metal salts were determined by molar ratio method. A self-written nonlinear curve-fitting computer program was used to fit the experimental titration curves. The association constants were determined from the absorption-intensity changes around 420 nm using the equation given in Table 1.

Transport Experiment

The apparatus is the same as the U-type cell used in the previous study.[10] The metal salts (0.05 mmol) were dissolved in water (10 cm^3, aq I) and 1M HCl (10 cm^3, aq II) connected with $CHCl_3$ (20 cm^3) containing **1** (0.05 mmol) and stirred with magnetic bar. Occasionally, aliquots of Aq I and Aq II were taken for the UV spectrophotometry. 1,5-Diphenylthiocarbazone for $HgCl_2$, $ZnCl_2$, $CdCl_2$, sodium diethyldithiocarbamate for $CuCl_2$, glyoxal bis(2-hydroxyanil) for $CaCl_2$, dimethyl sulfonazo II for $BaCl_2$ were used as colorimetric reagents.

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