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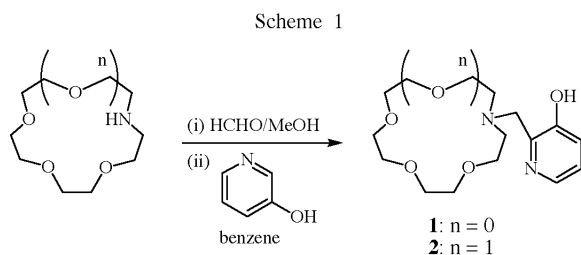
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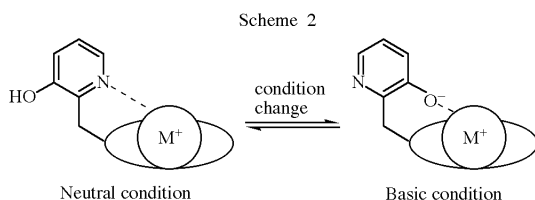
New armed-monoaza-12-crown-4 and armed-monoaza-15-crown-5 ethers having dual phenolic OH and pyridine nitrogen binding sites in a side arm were prepared by the Mannich reaction of *N*-methoxymethyl-monoazacrown ethers with 3-hydroxypyridine. Complexation studies of these new hydroxypyridine-armed ligands were carried out by liquid membrane transport, ¹H nmr titration experiments, thermodynamic values (log *K*, Δ*H* and TΔ*S*), and X-ray crystallography of two alkali-metal complexes. These results indicate that the oxygen atom of the phenolic OH group and pyridine nitrogen atom of the side arm are involved in complexation under basic and neutral conditions, respectively.

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Recently, we reported the synthesis of *p*-hydroxybenzyl-armed macrocycles, molecular structures of the polymer-like complexes formed from them and various salts [1-6]. In continuation, we designed macrocyclic ligands having hydroxypyridine as an additional binding site in the side arm (**1** and **2**, Scheme 1). We expected to



observe two phenomenon with these new ligands: (i) when one of the binding sites coordinates to a cation bound in the crown ether ring, the other coordination site may bind a cation incorporated in another ligand molecule to give a polymer-like complex, and (ii) since the armed-azacrown ethers have dual binding sites in the side arm, pyridine N atom and phenolic OH group, it may be possible to control the functional group involved in complexing by changing conditions (Scheme 2). We report here the synthesis and complexing abilities of two armed-azacrown ethers having dual binding sites.



N-(6'-Hydroxy-2'-pyridyl)monoazacrown ethers, **1** and **2**, were prepared by the Mannich reaction of a mixture of the *N*-methoxymethylcrown ether and 3-hydroxypyridine in benzene. Compounds **1** and **2** were obtained as hygroscopic oils in 74% and 89% yields, respectively. Structures of these compounds are confirmed by their ¹H nmr, mass spectral and elemental analyses.

Competitive alkali-metal ion transport by **1** and **2** were carried out using a double tube transport apparatus. Results of the transport experiments are summarized in Table 1. When **1** and **2** were used as carriers in bulk liquid membrane transport under basic-source phase/acidic-receiving phase conditions (using alkali-metal hydroxides), lithium and sodium cations were selectively transported, respectively. Under neutral-source phase/neutral-receiving phase conditions (using alkali-metal thiocyanates), ligand **2** also exhibited sodium cation selectivity, although the transport rate decreased. Under neutral conditions, ligand **1** did not transport any of the cations studied. The transport experiments show that the deprotonated phenolic OH group participates in complexation under basic conditions, whereas neither the phenolic OH group nor the nitrogen atom in the side arm act as capping sites under neutral conditions. Thus, ligands **1** and **2** transport size-matched alkali-metal cations under basic conditions and ligand **2** does under neutral conditions.

Table 1
Competitive Transport of Alkali Metal Cations with **1** and **2**

Carrier	Transport rate (μmol/hour) [a]					
	MOH			MSCN		
1	Li ⁺ 280	K ⁺ < 1	Cs ⁺ < 1	Li ⁺ < 1	K ⁺ < 1	Cs ⁺ < 1
2	Na ⁺ 610	K ⁺ 17	Cs ⁺ 3	Na ⁺ 14	K ⁺ < 1	Cs ⁺ < 1

[a] Reproducibility is ± 10 % or better.

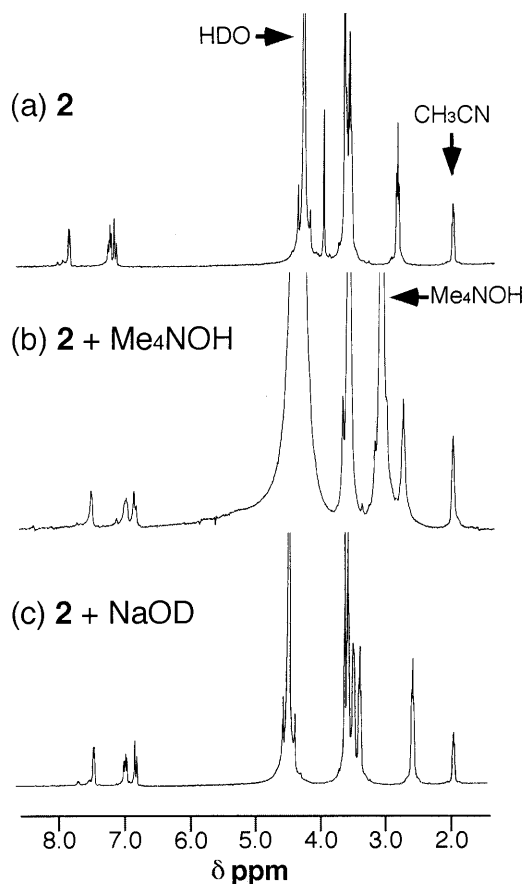


Figure 1. ^1H NMR spectra of (a) **2**, (b) **2**+ Me_4NOH , and (c) **2**+ NaOD .

Titration experiments using nmr are convenient for obtaining structural information about metal ion-ligand complexes. We carried out ^1H nmr titration experiments in an acetonitrile- d_3 /deuterium hydroxide (1:1) solution for ligand **2**. When 1.0 equivalent of tetramethylammonium hydroxide, which forms a salt with the phenolic OH group and would not bind inside the crown ether, was added to a solution of **2**, the aromatic protons next to the pyridine nitrogen atom and the OH group in the hydroxypyridine unit shifted to higher field by 0.31 and 0.35 ppm, respectively (Figure 1b). The methylene protons at the benzylic position also shifted to higher field by 0.29 ppm. Clearly, formation of a phenoxide salt causes significant chemical shifts of the signals of the aromatic hydrogens as expected. The NCH_2 and OCH_2 methylene protons of the crown ether ring shifted to higher field by only 0.09 and 0.02 ppm, respectively, showing little or no ring association with the cation. On the other hand, when 1 equivalent of sodium hydroxide- d_1 (40% solution in deuterium hydroxide) was added to a solution of **2**, significant chemical shift changes were observed not only for the aromatic protons, but also for the methylene protons of the crown ring (Figure 1c). The aromatic protons and the methylene protons at the

benzylic position shifted almost the same amount as in the **2**-tetramethylammonium hydroxide system suggesting that a sodium ion forms a salt with the phenoxide ion. In addition, the $\text{NCH}_2\text{CH}_2\text{O}$, $\text{NCH}_2\text{CH}_2\text{O}$, $\text{NCH}_2\text{CH}_2\text{OCH}_2$ methylene protons of the crown ring were shifted to higher field by 0.22, 0.14 and 0.09 ppm, respectively. The chemical shift changes of the crown ring protons when sodium hydroxide- d_1 was added clearly show that the sodium ion is interacting with the macrocycle. The chemical shift changes to the aromatic ring show that sodium ion is interacting with the phenoxide oxygen. Thus, the phenoxide O atom of the side arm binds the sodium ion incorporated in the crown ether part under basic conditions. No spectral changes were observed with the addition of 1.0 equivalent of sodium thiocyanate under neutral conditions. Structural information for the hydroxypyridine unit in the complexes of **2** with sodium thiocyanate was not obtained by the ^1H nmr titration experiments.

To investigate the complexation ability of **2**, thermodynamic values ($\log K$, ΔH and $T\Delta S$) were measured by titration calorimetry in methanol solution (Table 2) [7]. The $\log K$ values show that ligand **2** forms the most stable 1:1 complex with sodium ion ($\log K = 2.88$) followed by potassium ion ($\log K = 2.73$), rubidium ion ($\log K = 2.63$) and cesium ion ($\log K = 2.45$). It is well known that the slope (α) of the enthalpy-entropy compensation (plot of $T\Delta S$ versus ΔH) indicates conformational changes of host compounds on complex formation [8]. From the plot of $T\Delta S$ versus ΔH , the α value was calculated as 0.876 ($r^2 = 0.995$). This α value agrees with the average (0.87) of typical armed-crown ethers. This result suggests that ligand **2** forms complexes with alkali-metal cations by both the crown moiety and the side arm under neutral conditions.

Table 2
Log K , ΔH (kJ/mol), and $T\Delta S$ (kJ/mol) Values for the 1:1 Interaction of Compound **2** (L) with Metal Cations (M^+) in Methanol Solution at 25 °C.

Cation	$\log K$	ΔH	$T\Delta S$
Na^+	2.88 ± 0.02	-23.3 ± 0.2	-6.9
K^+	2.73 ± 0.04	-19.5 ± 0.3	-3.9
Rb^+	2.63 ± 0.05	-20.6 ± 0.4	-5.6
Cs^+	2.45 ± 0.08	-6.9 ± 0.5	7.1

It is easily estimated that the lone pair of the pyridine nitrogen atom has higher affinity to the positive charge (cation) than the oxygen of alcoholic and phenolic OH groups, while phenolate anion affinity is much stronger due to the large Coulomb term. To visualize and confirm the estimation, the electrostatic potential iso-surfaces (isopotential surfaces) [9] of 2-methyl-3-hydroxypyridine, a model compound of the side arm portion of the ligand, and its phenolate anion were calculated by the density functional calculation (Slater, Vosko, Wilk, Nusair (SVWN) which involves the local density approxima-

tion/numerical polarization basis sets (DN*) method [10]. The electrostatic potential is defined as the energy of interaction of a positive point charge located with the nuclei and electrons of a molecule, and the isopotential surfaces show the lone pairs on the nitrogen and oxygen atoms [9]. As shown in Figure 2, in 2-methyl-3-hydroxypyridine, the isopotential surface of the nitrogen atom is larger than that of the oxygen atom, while the isopotential surface of the oxygen atom is larger in the phenolate anion. The calculation results support that the armed-azacrown ethers having 3-hydroxypyridine could change their additional binding sites in response to the conditions (neutral and basic). Thus, the nitrogen atom of the hydroxypyridine unit has a greater binding ability than the oxygen atom of the phenolic OH group toward metal cations under the neutral condition. Conversely, the phenolate oxygen atom has a greater binding ability in basic conditions. There is a great difference in the energy of the isopotential surface between 2-methyl-3-hydroxypyridine (-30.0 kcal/mol) and its phenolate anion (-139.3 kcal/mol). Since a larger negative value of the isopotential surface means greater attracting effect, the values of the isopotential surface would also reflect the strength of interaction between cations and heteroatoms in the hydroxypyridine unit.

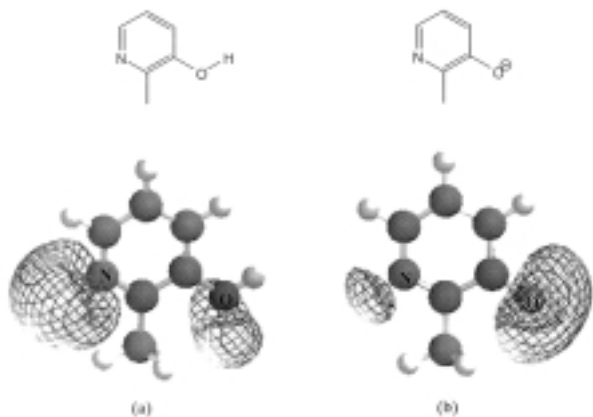


Figure 2. Isopotential surface of (a) 2-methyl-3-hydroxypyridine (Isopotential value = -30.0 kcal/mole) and its anion (Isopotential value = -139.3 kcal/mole) calculated by density functional calculation (SVWN/DN*) method.

Although we tried to make alkali-metal complexes of ligands **1** and **2** with alkali-metal hydroxide and alkali-metal thiocyanate salts, only the sodium thiocyanate complex with ligand **1** and the rubidium thiocyanate complex with ligand **2** were obtained as single crystals suitable for X-ray crystallography. Figure 3 shows the ORTEP views of the **1**-NaSCN and **2**-RbSCN complexes. The views indicate that sodium and rubidium cations are six-coordinated with the pyridine nitrogen atoms coordinated to the guest cations. The phenolic OH group is not involved in the complexation in these complexes. The

results clearly show that the pyridine nitrogen atom of the side arm is used for complexation under the neutral condition.

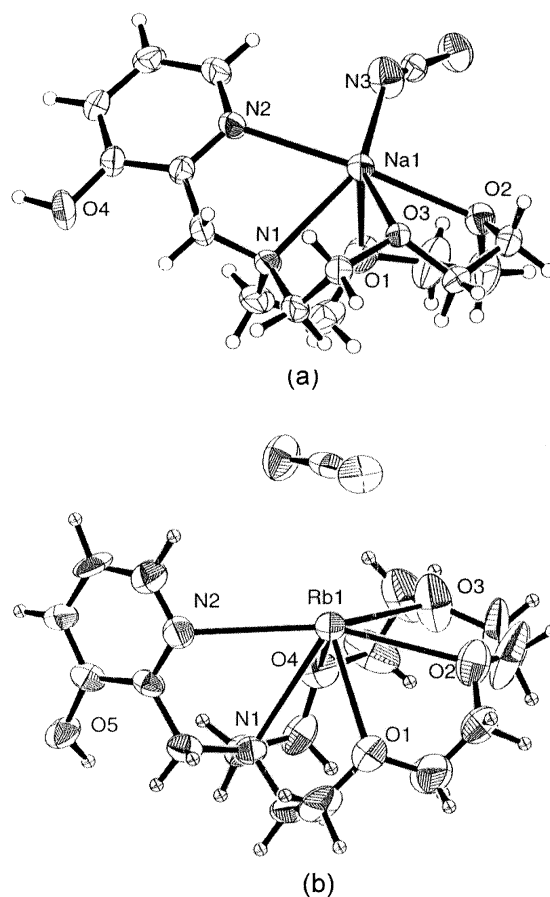


Figure 3. The ORTEP diagrams of (a) **1**-NaSCN and (b) **2**-RbSCN complexes.

In conclusion, armed-azacrown ethers having dual phenolic OH and pyridine nitrogen binding sites in a side arm were prepared. Complexation studies of these new hydroxypyridine-armed ligands show that the oxygen atom of the phenolic OH group and pyridine nitrogen atom of the side arm are used for complexation under basic and neutral conditions, respectively.

EXPERIMENTAL

The ^1H nmr spectra were measured in deuteriochloroform on a Bruker AC-250 (250 MHz) spectrometer. The ei-ms were performed using the Hitachi M-80 spectrometer.

General Procedure for the Reaction of 3-Hydroxypyridine with *N*-Methoxymethyl Crown Ethers.

A mixture of *N*-methoxymethylmonoazacrown ether [11] (1.0 mmole) and 3-hydroxypyridine (1.0 mmole) in absolute benzene (20 mL) was refluxed under a nitrogen atmosphere for 24 hours. The reaction mixture was cooled and then concentrated under

Table 3
Crystal and Selected Experimental Data for **1**-NaSCN and **2**-RbSCN

	1 -NaSCN	2 -RbSCN
Formula	C ₁₅ H ₂₂ N ₃ O ₄ Na	C ₁₇ H ₂₆ N ₃ O ₅ SRb
<i>M</i>	363.41	469.94
Crystal system	monoclinic	monoclinic
Space group	P2 ₁ /n	P2 ₁ /n
<i>a</i> /Å	11.263(4)	13.418(8)
<i>b</i> /Å	8.876(3)	9.053(8)
<i>c</i> /Å	18.625(3)	18.191(6)
β/°	103.65	102.43(4)
U/Å ³	1809.4(8)	2157(2)
<i>Z</i>	4	4
Dc/g cm ⁻³	1.334	1.446
<i>F</i> (000)	768.00	968.00
μ(Mo-Kα)/cm ⁻¹	2.26	24.17
Crystal dimensions/mm	0.50x0.50x0.50	0.10x0.10x0.50
No. of reflections for unit cell determination (2θ range)/°	25 (27.8-29.9)	25 (20.2-23.1)
Scan width/°	1.57+0.30tanθ	1.15+0.30tanθ
Limiting indices	0 ≤ <i>h</i> ≤ 14, 0 ≤ <i>k</i> ≤ 11, -24 ≤ <i>l</i> ≤ 23	0 ≤ <i>h</i> ≤ 14, 0 ≤ <i>k</i> ≤ 10, -21 ≤ <i>l</i> ≤ 21
No. reflections		
measured	4660	3803
unique (<i>R</i> _{int})	4441 (0.018)	3621 (0.095)
used[all data], <i>N</i> _o	1981	3377
<i>R</i>	0.081	0.184
<i>R</i> _w	0.142	0.0157
<i>R</i> 1 [<i>I</i> > 2.0σ(<i>I</i>)]	0.051	0.065
Goodness of fit	1.46	1.03
No. parameters, <i>N</i> _p	217	244
Maximum shift/error in final cycle	0.001	0.010
Maximum, minimum peaks in final difference map/e Å ⁻³	0.21, -0.25	0.95, -0.98

Details in common: ω-2θ scan; scan range 2θ 0-55°; $R_w = [\sum w(|F_o| - |F_c|)^2 / \sum w F_o^2]^{1/2}$, $R_1 = \sum ||F_o| - |F_c|| / \sum |F_o|$, goodness of fit $[\sum w(|F_o| - |F_c|)^2 / (N_o - N_p)]^{1/2}$.

reduced pressure. The residual yellow oil was separated and purified by gel-permeation column chromatography to give the following products.

N-(6'-Hydroxy-2'-pyridylmethyl)-1,4,7-trioxa-10-azacyclodecane (**1**).

Ligand **1** (74%) was isolated as an oil; ¹H-nmr: δ 7.99 (dd, *J* = 2.5 Hz, *J* = 3.7 Hz, 1H), 7.10-7.09 (m, 2H), 4.01 (s, 2H), 3.73-3.61 (m, 17H), 2.85 (t, *J* = 5.5 Hz, 4H); ms: ei (m/z) 283 (*M*⁺ + 1, 100 %).

Anal. Calcd. for C₁₄H₂₂N₂O₄•1/10H₂O: C, 59.18; H, 7.87; N, 9.86. Found: C, 59.02; H, 7.87; N, 9.89.

N-(6'-Hydroxy-2'-pyridylmethyl)-1,4,7,10-tetraoxa-13-azacyclopentadecane (**2**).

Ligand **2** (89%) was isolated as an oil; ¹H nmr: δ 7.97 (dd, *J* = 1.7 Hz, *J* = 3.7 Hz, 1H), 7.18-7.07 (m, 2H), 3.99 (s, 2H), 3.73-3.63 (m, 13H), 2.81 (t, *J* = 4.7 Hz, 4H); ms: ei (m/z) 327 (*M*⁺ + 1, 100 %).

Anal. Calcd. for C₁₆H₂₆N₂O₅1/10H₂O: C, 58.56; H, 8.05; N, 8.54. Found: C, 58.40; H, 8.18; N, 8.49.

Metal Ion Transport Experiments.

The transport experiments were carried out using a double tube (diameter of the inner and outer tubes are 10 mm and 20

mm, respectively) at 25±2 °C. Initial conditions of the competitive transport were as follows; [basic source phase] = aqueous solution containing a mixture of 0.1 mole/L of sodium hydroxide, potassium hydroxide and cesium hydroxide (4 mL) or aqueous solution containing a mixture of 0.1 mole/L of lithium hydroxide, potassium hydroxide and cesium hydroxide (4 mL): [membrane phase] = 2 mmoles/L of crown ether in chloroform (4 mL): [acidic receiving phase] = 0.1 mole/L of hydrochloric acid (1 mL). Neutral source and receiving phase conditions were as follows; [neutral source phase] = aqueous solution containing a mixture of 0.1 mole/L of sodium thiocyanate, potassium thiocyanate and cesium thiocyanate (4 mL) or aqueous solution containing a mixture of 0.1 mole/L of lithium thiocyanate, potassium thiocyanate and cesium thiocyanate (4 mL): [membrane phase] = 2 mmoles/L of crown ether in chloroform (4 mL): [neutral-receiving phase] = distilled water (1 mL). The concentration of the receiving phase was determined by ion chromatography. We used two sets of cations, because peaks for lithium and sodium cations overlapped in our analysis condition. The transport rate was calculated from the amounts of alkali-metal cations in the receiving phase. The aqueous and organic phases were stirred by a stirring bar (10 mm) at 500 rpm by a synchronous motor in order to avoid a stirring error. The amounts of metal ions in the receiving phases were measured by ion chromatography. The initial transport rate

Table 4
Atomic Coordinates and B_{iso}/B_{eq} for **1**-NaSCN

Atom	x	y	z	B_{eq}
S(1)	0.79081(9)	-0.4666(1)	0.35572(5)	6.49(2)
Na(1)	0.68229(9)	-0.0561(1)	0.50544(5)	4.05(2)
O(1)	0.8436(2)	0.0450(3)	0.4563(1)	6.84(7)
O(2)	0.6020(2)	0.0347(2)	0.37658(10)	4.81(5)
O(3)	0.5382(1)	0.1723(2)	0.49890(9)	3.65(4)
O(4)	1.0108(2)	0.0354(2)	0.7838(1)	6.88(6)
N(1)	0.7895(2)	0.1640(2)	0.5897(1)	4.35(5)
N(2)	0.8022(2)	-0.1454(3)	0.6328(1)	4.84(6)
N(3)	0.7153(3)	-0.3092(3)	0.4655(2)	7.24(9)
C(1)	0.9075(3)	0.1814(4)	0.5688(2)	6.26(9)
C(2)	0.8967(3)	0.1839(5)	0.4867(2)	7.7(1)
C(3)	0.8098(4)	0.0370(6)	0.3766(2)	9.1(1)
C(4)	0.6929(4)	0.1008(5)	0.3450(2)	8.0(1)
C(5)	0.4996(3)	0.1328(3)	0.3700(2)	5.01(7)
C(6)	0.5185(3)	0.2491(3)	0.4298(2)	4.70(7)
C(7)	0.5804(3)	0.2683(3)	0.5615(1)	4.46(7)
C(8)	0.7151(3)	0.3013(3)	0.5759(2)	5.25(7)
C(9)	0.8108(3)	0.1192(3)	0.6674(2)	5.15(7)
C(10)	0.8579(2)	-0.0410(3)	0.6801(1)	3.98(6)
C(11)	0.9557(2)	-0.0783(3)	0.7387(1)	4.22(6)
C(12)	0.9937(3)	-0.2248(3)	0.7485(1)	4.53(7)
C(13)	0.9360(3)	-0.3314(3)	0.6998(2)	5.15(8)
C(14)	0.8411(3)	-0.2874(3)	0.6430(2)	5.50(8)
C(15)	0.7476(3)	-0.3730(3)	0.4205(2)	4.53(7)
H(1)	0.9437	0.2737	0.5885	7.4024
H(2)	0.9594	0.1000	0.5893	7.4024
H(3)	0.9753	0.1930	0.4766	9.1286
H(4)	0.8464	0.2643	0.4646	9.1286
H(5)	0.8700	0.0932	0.3592	10.7330
H(6)	0.8119	-0.0642	0.3629	10.7330
H(7)	0.6742	0.0780	0.2933	9.6266
H(8)	0.6953	0.2047	0.3524	9.6266
H(9)	0.4868	0.1830	0.3236	5.9279
H(10)	0.4305	0.0741	0.3717	5.9279
H(11)	0.4479	0.3109	0.4235	5.6146
H(12)	0.5874	0.3098	0.4287	5.6146
H(13)	0.5371	0.3612	0.5519	5.1950
H(14)	0.5635	0.2217	0.6034	5.1950
H(15)	0.7374	0.3642	0.6182	6.1536
H(16)	0.7318	0.3516	0.5344	6.1536
H(17)	0.8692	0.1850	0.6962	6.0540
H(18)	0.7361	0.1259	0.6821	6.0540
H(19)	1.0597	-0.2516	0.7888	5.3738
H(20)	0.9602	-0.4339	0.7056	6.1092
H(21)	0.8014	-0.3616	0.6088	6.5340
H(22)	1.0759	-0.0070	0.8217	7.9969

$$B_{eq} = 8/3\pi^2(U_{11}(aa^*)^2 + U_{22}(bb^*)^2 + U_{33}(cc^*)^2 + 2U_{12}aa^*bb^* \cos\gamma + 2U_{13}aa^*cc^* \cos\beta + 2U_{23}bb^*cc^* \cos\alpha)$$

was calculated from the increase of the cation concentration in the receiving phase after a period of 6 hours.

Preparation of Alkali-metal Thiocyanate Complexes with Armed-azacrown Ethers, **1** and **2**.

Ligand **1** or **2** (0.01 mmole) in acetonitrile (1 mL) was reacted with alkali-metal thiocyanate (0.01 mmole) in methanol (1 mL). After the solvent had evaporated, the crystals were recrystallized from acetonitrile. The crystals were dried with an Abderhalden's

Table 5
Atomic Coordinates and B_{iso}/B_{eq} for **2**-RbSCN

Atom	x	y	z	B_{eq}
Rb(1)	0.31226(8)	0.4273(1)	0.53182(6)	6.21(3)
S(1)	0.1690(3)	0.0933(4)	0.5755(2)	9.7(1)
O(1)	0.4395(6)	0.6725(9)	0.4992(5)	7.1(3)
O(2)	0.4387(8)	0.608(1)	0.6548(5)	8.9(3)
O(3)	0.2403(8)	0.535(1)	0.6589(5)	12.0(4)
O(4)	0.1238(5)	0.6019(9)	0.5153(5)	7.6(2)
O(5)	0.0545(5)	0.4600(7)	0.2211(4)	7.0(2)
N(1)	0.2338(7)	0.6279(9)	0.3933(5)	5.0(2)
N(2)	0.2349(7)	0.298(1)	0.3758(5)	6.1(3)
N(3)	0.3749(8)	0.116(1)	0.6331(6)	9.0(4)
C(1)	0.2989(9)	0.760(1)	0.3982(6)	6.6(3)
C(2)	0.408(1)	0.731(1)	0.4249(9)	10.1(5)
C(3)	0.469(1)	0.770(2)	0.555(1)	12.9(6)
C(4)	0.4969(10)	0.715(2)	0.6278(9)	9.1(5)
C(5)	0.388(2)	0.656(3)	0.704(1)	16.7(8)
C(6)	0.296(2)	0.641(3)	0.7056(9)	15.4(7)
C(7)	0.134(1)	0.541(2)	0.6416(9)	13.4(7)
C(8)	0.092(1)	0.636(2)	0.582(1)	11.5(6)
C(9)	0.1057(8)	0.719(1)	0.4636(8)	7.2(4)
C(10)	0.1278(8)	0.670(1)	0.3914(6)	5.6(3)
C(11)	0.2373(7)	0.543(1)	0.3244(6)	5.8(3)
C(12)	0.1880(9)	0.394(1)	0.3240(6)	5.1(3)
C(13)	0.0960(9)	0.357(1)	0.2722(6)	5.3(3)
C(14)	0.0550(9)	0.219(1)	0.2760(6)	6.5(4)
C(15)	0.103(1)	0.122(1)	0.3300(8)	8.1(4)
C(16)	0.193(1)	0.169(2)	0.3766(7)	8.1(5)
C(17)	0.2898(10)	0.104(1)	0.6104(6)	6.6(4)
H(1)	0.2850	0.8146	0.3506	8.2073
H(2)	0.2769	0.8330	0.4338	8.2073
H(3)	0.4462	0.8232	0.4208	11.7708
H(4)	0.4270	0.6633	0.3904	11.7708
H(5)	0.5342	0.8261	0.5493	15.1283
H(6)	0.4233	0.8488	0.5591	15.1283
H(7)	0.5051	0.8025	0.6634	10.8788
H(8)	0.5679	0.6799	0.6346	10.8788
H(9)	0.4297	0.6393	0.7547	17.9437
H(10)	0.3966	0.7739	0.7023	17.9437
H(11)	0.2676	0.7395	0.6994	16.5828
H(12)	0.3019	0.6182	0.7598	16.5828
H(13)	0.1133	0.4306	0.6232	13.8818
H(14)	0.1061	0.5398	0.6876	13.8818
H(15)	0.1232	0.7326	0.6057	12.1862
H(16)	0.0219	0.6458	0.5806	12.1862
H(17)	0.0346	0.7542	0.4520	8.6911
H(18)	0.1475	0.8039	0.4771	8.6911
H(19)	0.1072	0.7470	0.3504	6.1223
H(20)	0.0824	0.5866	0.3707	6.1223
H(21)	0.2059	0.6002	0.2798	6.6733
H(22)	0.3106	0.5378	0.3214	6.6733
H(23)	-0.0086	0.1880	0.2418	7.4094
H(24)	0.0818	0.0186	0.3364	9.1500
H(25)	0.2295	0.0964	0.4187	10.0288
H(26)	0.0234	0.5628	0.2361	7.3499

$$B_{eq} = 8/3\pi^2(U_{11}(aa^*)^2 + U_{22}(bb^*)^2 + U_{33}(cc^*)^2 + 2U_{12}aa^*bb^* \cos\gamma + 2U_{13}aa^*cc^* \cos\beta + 2U_{23}bb^*cc^* \cos\alpha)$$

dryer (50 °C, 0.5 Torr). The elemental analyses of the **1**-NaSCN and **2**-RbSCN complexes, respectively, are given below.

Anal. Calcd. for $C_{15}H_{22}N_3O_4SNa$; C, 49.58; H, 6.10; N, 11.56. Found: C, 49.67; H, 6.07; N, 11.33.

Anal. Calcd. for $C_{17}H_{26}N_3O_5SRb$, 43.45; H, 5.58; N, 8.94. Found: C, 43.43; H, 5.59; N, 8.95.

1H NMR Titration Experiments.

Conditions of the 1H nmr titration experiments are as follows: [crown ether] = 0.05 mmole in acetonitrile- d_3 /deuterium hydroxide (1:1) 0.65 mL, [tetramethylammonium hydroxide] = 0.05 mmole (15% aqueous solution), [sodium hydroxide- d_7] = 0.05 mmole (40% solution in deuterium hydroxide), [sodium thiocyanate] = 0.05 mmole (0.05 mmole/10 μ L solution in acetonitrile- d_3 /deuterium hydroxide (1:1)).

Determination of Thermodynamic Values.

Log K , ΔH , and $T\Delta S$ were determined as described [7] in methanol at 25.0 ± 0.1 °C by titration calorimetry using a Tronac Model 450 calorimeter equipped with a 20 mL reaction vessel. The metal cation solutions (0.08-0.12 mole/L) were titrated into the armed-azacrown ether solutions (1.3×10^{-3} – 2.6×10^{-3} mole/L) and the titrations were carried out to a two-fold excess of the metal cations. Sodium bromide, potassium bromide, rubidium chloride, and cesium chloride were used to prepare each cation solution.

Crystallography.

The crystallographic and experimental data are listed in Table 3. Each of the single crystals was mounted in a glass capillary. All measurements were made at 298 K on a Rigaku AFC5S four-circle diffractometer with graphite-monochromated Mo $K\alpha$ radiation (0.71069 Å) and a 12kW rotating-anode generator. Cell contacts and an orientation matrix for data collection were obtained from a least-squares refinement. The data were collected using the 2- 2θ scan technique to an above maximum 2θ value of 55.0°. All intensities were corrected for Lorentz and polarization effects. The structure was solved by direct methods (SIR 92) [12]. The non-hydrogen atoms were refined anisotropically. The coordinates of all hydrogen atoms except the hydrogen atoms of the phenolic OH group were calculated at ideal positions and were refined (Table 5 and 6). Neutral atom scattering factors were taken from Cromer and Waber [13]. Anomalous dispersion effects were included in Fc [14]; the values for $\Delta f'$ and $\Delta f''$ were those of Creagh and McAuley [15]. The values for the mass attenuation coefficients are those of Creagh and Hubbel [16]. All calculations were using the teXsanTM crystallographic software package of Molecular Structure Corporation [17].

Calculation of Electrostatic Potential Iso-surfaces (Isopotential Surfaces).

The structures were optimized by an *ab-initio* method [10] and then use a density functional calculations (SVWN/DN*) [10]. All calculations were performed using PC Spartan *Pro* [18]. The volume of the isopotential surfaces displayed in 2-methyl-3-pyridinol and its phenolate anion were made equal (14.41 Å³ for 2-methyl-3-pyridinol and 14.38 Å³ for its phenolate anion) to compare their energy.

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