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# Studies on Synthetic Ionophores. VI.[1] Synthesis of Polyether Carboxylic Acids and Their Use as Carriers for Alkali Metal Ion Transport through Liquid Membrane

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ω-Hydroxy carboxylic acids (**3**, **5**, **6**, **7**, **10**, **12**, **14**, **17**, **18**, **20**, and **22**) bearing 2—6 ether oxygens and aromatic rings with or without a tetrahydrofuran ring and the ω-methoxy and ω-benzyloxy derivatives of **5** (**8** and **9**) were synthesized. These were employed as carriers for active and competitive transport of alkali metal ions through liquid membrane as well as for extraction of alkali metal ions to organic layers. Effect of hydrophobic group of aromatic and tetrahydrofuran rings, number of ether oxygens, and terminal hydroxyl group of the ionophores on the ion transport ability and selectivity were investigated. The hydrophobic groups increased total amount of transported ions as well as partition coefficients. The ionophore, **5**, which contains five ether oxygens, two aromatic rings, and *o*-toluic acid moiety transported $K^+$ selectively over $Na^+$ and $Li^+$ through 1,2-dichloroethane being consistent with the extraction experiments. The *m*- and *p*-substituted isomers, **6** and **7**, exhibited no transport ability through 1,2-dichloroethane. The ω-alkoxy derivatives of **5** (**8** and **9**) exhibited less selectivity for $K^+$ through 1,2-dichloroethane than **5** did. Through 1-hexanol, the ionophores, **5**—**9**, including linoleic acid with no ether linkage transported alkali metal ions. The ionophores (**3**, **12**, **20**, and **22**) containing 2—4 ether oxygens did not exhibit high transport ability.

Among naturally occurring compounds, there is a class of ionophores which form stable, lipophilic complexes with ions and are able to transport them across membranes.[2] The ionophores are classified based on their structures into two types. One is neutral ionophore which is cyclic and contains no ionizable functional group.[2a] Another is charged ionophore characterized by a carboxylic acid head group and a tail of a hydroxyl or an amino group capable of hydrogen-bonding interactions. The backbones are linear, containing heterocyclic rings with a variety of oxygen-containing functional groups. The carboxylic group is ionized at physiological pH and the complex with cation is neutral. Their complex formation and physiological activity have been investigated extensively.[3] A number of synthetic models for neutral ionophores, such as crown ethers, were reported in order to understand the mechanism of action of the naturally occurring ionophores as well as to dissolve reactive inorganic salts in organic solvents for organic synthesis.[4] However, synthetic analogues of natural carboxylic ionophores remain relatively unexplored.[5]

We have already reported transport of alkali metal ions across an organic liquid membrane mediated by synthetic carboxylic acid ionophores.[1] It was found that an ion was pumped against its concentration gradient by a coupled counterflow of proton and that formation of a pseudocyclic structure of the ionophore, with or without hydrogen bonding of the head and tail, was essential for lipophilization and transport of the cation similar to the case of natural ionophores.[1c,e]

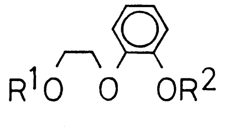
We describe here synthetic procedures for new carboxylic acid ionophores together with already reported ones and systematic studies on transport of alkali metal ions by these ionophores.

## Results and Discussion

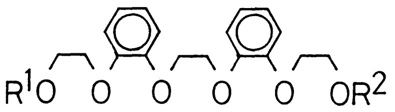
**Synthesis of Polyether Carboxylic Acids.** As ionophore, eleven carboxylic acids containing 2—6 ether oxygens and one terminal hydroxyl group were synthesized. Aromatic and tetrahydrofuran rings were employed as hydrophobic groups and acetic or toluic acid moieties serving as the carboxyl group. Two derivatives with terminal ether groups were also prepared to clarify a role of head-to-tail hydrogen bonding. The synthetic procedures are based mainly on the Williamson ether synthesis.

2-(2-Hydroxyethoxy)phenol (**1**) was obtained by conventional means using the reaction of sodium catecholate with ethylene chlorohydrin.[6] A better yield was obtained using the previously reported reaction of phenol with ethylene carbonate.[7] Heating a mixture of catechol and ethylene carbonate at 160 °C in the presence of tetrabutylammonium iodide gave a 77% yield of **1**.

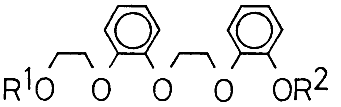
Coupling of ethylene glycol ditosylate with **1** gave the best result for synthesis of **4**.[8] Williamson coupling of **4** with methyl 2-(bromomethyl)benzoate and subsequent hydrolysis provided **5**. Similarly, *m*- and *p*-substituted isomers, **6** and **7** were afforded. ω-Alkoxy derivatives, **8** and **9**, were obtained by reaction of **5** with methyl iodide and benzyl chloride respectively and successive hydrolysis. Instead of methyl 2-(bromomethyl)benzoate, chloroacetic acid was employed for synthesis of **10**. Methyl 2-(bromomethyl)benzoate was allowed to react with **1** directly followed by hydrolysis to synthesize **3**. Treatment of **1** with tosyl chloride formed the ditosylate, **2**. Reaction of **2** with **1** and subsequent hydrolysis yielded **11**. Compound **12** was derived from **11**. Compound **14** was obtained similarly from **13** which was prepared by reaction of two equivalents of the sodium salt of **1** with bis(2-chloroethyl) ether. Coupling of tetrahydro-2,5-furandimethanol ditosylate (**15**)[9] with two equivalents of **1** afforded **16**. The reaction of **16** with methyl 2-(bromomethyl)benzoate formed **17**. The acetic acid derivative **18** was obtained from **16** and ethyl bromoacetate. Two equivalents of catechol and bis(2-hydroxyethyl) ether were employed to synthesize **19**[10] which was converted into **20** using methyl 2-(bromomethyl)benzoate. Compound **21**[11] obtained from catechol and two equivalents of ethylene chlorohydrin was allowed to react with methyl 2-(bromomethyl)benzoate to form lactone which was hydrolyzed to **22**.



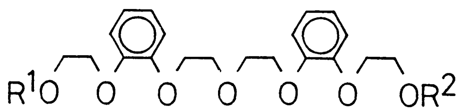
**1**; $R^1$=$R^2$=H
**2**; $R^1$=$R^2$=Ts
**3**; $R^1$=H, $R^2$=$o$-$CH_2$-$C_6H_4$-COOH



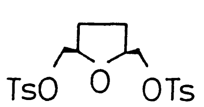
**4**; $R^1$=$R^2$=H
**5**; $R^1$=H, $R^2$=$o$-$CH_2$-$C_6H_4$-COOH
**6**; $R^1$=H, $R^2$=$m$-$CH_2$-$C_6H_4$-COOH
**7**; $R^1$=H, $R^2$=$p$-$CH_2$-$C_6H_4$-COOH
**8**; $R^1$=$CH_3$, $R^2$=$o$-$CH_2$-$C_6H_4$-COOH
**9**; $R^1$=$PhCH_2$, $R^2$=$o$-$CH_2$-$C_6H_4$-COOH
**10**; $R^1$=H, $R^2$=$CH_2COOH$



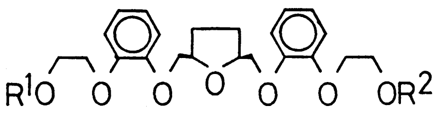
**11**; $R^1$=$R^2$=H
**12**; $R^1$=H, $R^2$=$o$-$CH_2$-$C_6H_4$-COOH



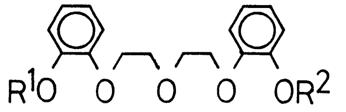
**13**; $R^1$=$R^2$=H
**14**; $R^1$=H, $R^2$=$o$-$CH_2$-$C_6H_4$-COOH



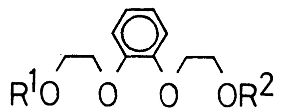
**15**



**16**; $R^1$=$R^2$=H
**17**; $R^1$=H, $R^2$=$o$-$CH_2$-$C_6H_4$-COOH
**18**; $R^1$=H, $R^2$=$CH_2COOH$



**19**; $R^1$=$R^2$=H
**20**; $R^1$=H, $R^2$=$o$-$CH_2$-$C_6H_4$-COOH



**21**; $R^1$=$R^2$=H
**22**; $R^1$=H, $R^2$=$o$-$CH_2$-$C_6H_4$-COOH

These ionophores are classified by the number of ether oxygens in Table 1. Cavity sizes of the pseudocyclic conformers which are formed by head-to-tail hydrogen bonding between carboxyl and hydroxyl groups were measured in their CPK models. The cavity size increases as the number of ether oxygens increases. Hydrophobicity parameters (log $P$) are also shown in Table 1 where $P$ is calculated value of partition coefficient to octanol obtained by the literature method.[12] Tetrahydrofuran compounds (**17**, **18**) have higher log $P$ than the analogues containing oxyethylene residue (**5**, **10**) do. Toluic acid derivatives (**5**, **17**) are more hydrophobic than the corresponding acetic acid ones (**10**, **18**). Ionophores become more lipophilic by alkylation of terminal hydroxyl group (**5** to **8** or **9**). The cavity sizes and log $P$'s will be correlated with the

Table 1. Synthetic Ionophores

| Compound | Cavity size/Å | Numbers of ethereal and hydroxyl oxygens | log $P$ |
|---|---|---|---|
| **3** | 1.4 | 3 | 4.4 |
| **22** | 1.6 | 4 | 4.4 |
| **12** | 2.1 | 5 | 7.5 |
| **20** | 2.2 | 5 | 7.1 |
| **10** | 2.5 | 6 | 5.0 |
| **5** | 2.5 | 6 | 7.6 |
| **6** | — | 6 | 7.6 |
| **7** | — | 6 | 7.6 |
| **8** | 2.5 | 6 | 8.2 |
| **9** | 2.5 | 6 | 10.4 |
| **18** | 2.8 | 7 | 5.8 |
| **17** | 3.0 | 7 | 8.4 |
| **14** | 3.2 | 7 | 7.6 |

Diameter of alkali metal ions(Å): $Li^+$; 1.56, $Na^+$; 1.96, $K^+$; 2.66, $Rb^+$; 2.98, $Cs^+$; 3.30.

Table 2. Partition Coefficient of Alkali Metal Salts of **5** to Organic Solvents

| Solvent | $\mu$ | $\varepsilon$ | Na$^+$ | K$^+$ | Rb$^+$ | Cs$^+$ |
|---|---|---|---|---|---|---|
| 1-Hexanol | 1.9 | 13.3 | 1.9 | 5.3 | 4.9 | 4.0 |
| 1-Hexanol/toluene | | | | | | |
| (5/5) | 1.13 | 7.84 | 0.79 | 4.0 | 4.0 | 3.8 |
| (3/7) | 0.82 | 5.66 | 0.43 | 2.8 | — | — |
| (2/8) | 0.67 | 4.56 | 0.22 | 1.6 | — | — |
| (1/9) | 0.51 | 3.47 | 0.064 | 0.52 | — | — |
| Toluene | 0.36 | 2.38 | 0 | 0 | — | — |
| 1,2-Dichloroethane | 1.44 | 10.65 | 0.042 | 0.54 | 0.27 | 0.11 |

Table 3. Partition Coefficient of Alkali Metal Salts of Synthetic Ionophores to Organic Solvents

| Compound | Solvent | Na$^+$ | K$^+$ | Rb$^+$ | Cs$^+$ |
|---|---|---|---|---|---|
| **10** | 1-Hexanol | 0.064 | 0.22 | 0.47 | 0.33 |
| **14** | | 1.7 | 8.1 | 4.9 | 3.5 |
| **17** | | 5.3 | 16.0 | 6.1 | 6.1 |
| **10** | 1-Hexanol-toluene | 0.10 | 0.18 | 0.30 | 0.35 |
| **14** | (1/1) | 0.82 | 4.0 | 3.3 | 2.8 |
| **17** | | 1.9 | 6.1 | 5.7 | 6.1 |
| **10** | 1,2-Dichloroethane | 0.14 | 0.12 | 0.042 | 0.053 |
| **14** | | 0.087 | 0.33 | 0.33 | 0.37 |
| **17** | | 0.18 | 1.2 | 1.4 | 1.7 |

ion transport ability and ion selectivity.

**Partition Coefficient of Alkali Metal Salts of Synthetic Ionophores.** In order to investigate the hydrophobicity of alkali metal salts of synthetic carboxylic ionophores the salts in water were extracted with organic solvents. Partition coefficients of alkali metal salts of **5** to organic solvents (such as 1-hexanol, toluene, 1-hexanol-toluene, and 1,2-dichloroethane) together with dipole moment ($\mu$) and dielectric constant ($\varepsilon$) are shown in Table 2. 1-Hexanol extracted more of the salts than 1,2-dichloroethane and none of the salts was extracted by toluene. With increased ratio of toluene in 1-hexanol-toluene (decrease in polarity), the amount of extracted salts decreased. The potassium salt was more extracted than the sodium salt. There was not much difference among the partition coefficients of the potassium, rubidium, and cesium salts.

Partition coefficients of alkali metal salts of synthetic ionophores **10**, **14**, **17** to organic solvents are shown in Table 3. The salts of **14** and **17** with toluic acid moiety as well as **5** (Table 2) have larger partition coefficients than that of **10** with acetic acid moiety. As can be seen in log *P*, the toluic acid derivatives are more hydrophobic, so that these salts are more soluble in organic solvents. K, Rb, and Cs salts of **14** and **17** were more extracted than that of the sodium salts in most cases.

Table 4. Active Ion Transport through Various Liquid Membrane by **5**

| Liquid membrane | Transported ion (%) | | | | |
|---|---|---|---|---|---|
| | **5** | | | None | |
| | Na$^+$ | K$^+$ | total | Na$^+$ | K$^+$ |
| 1-Hexanol | 31 | 54 | 85 | 13 | 10 |
| 1-Hexanol/toluene | | | | | |
| 5/5 | 22 | 66 | 88 | 8 | 5 |
| 3/7 | 22 | 69 | 91 | 5 | 9 |
| 2/8 | 20 | 70 | 90 | 2 | 4 |
| 1/9 | 15 | 68 | 83 | 1 | 4 |
| 1,2-Dichloroethane | 13 | 62 | 75 | 0 | 0 |

Table 5. Active Ion Transport through 1-Hexanol by Ionophores Containing 5—6 Ether Oxygens

| Compound | Transported ion (%) | | | | |
|---|---|---|---|---|---|
| | Na$^+$ | K$^+$ | Rb$^+$ | Cs$^+$ | Total |
| **5** | 31 | 54 | — | — | 85 |
| **17** | 34 | 52 | — | — | 86 |
| **18** | 31 | 51 | — | — | 82 |
| None | 13 | 10 | — | — | 23 |
| **5** | — | 41 | 44 | — | 85 |
| **17** | — | 47 | 48 | — | 95 |
| **18** | — | 30 | 31 | — | 61 |
| None | — | 17 | 10 | — | 27 |
| **5** | 26 | 42 | — | 21 | 89 |
| **10** | 20 | 25 | — | 18 | 63 |
| **14** | 24 | 41 | — | 25 | 90 |
| **17** | 25 | 42 | — | 22 | 89 |
| **18** | 29 | 42 | — | 17 | 88 |
| None | 12 | 11 | — | 9 | 32 |

**Active Transport of Alkali Metal Ions by Ionophores Containing 5—6 Ether Oxygens.** Competitive transport of Na$^+$ and K$^+$ through various liquid membranes was carried out by using **5** which was expected to exhibit high selectivity from partition coefficient experiments. The results are shown in Table 4. The ionophore exhibited high transport ability and K$^+$-selectivity through all the liquid membranes. 1,2-Dichloroethane gave the highest selectivity. Total transport was comparable at all ratios of 1-hexanol-toluene mixtures, and increase in toluene content enhanced K$^+$-selectivity. The ratio of 1/9 gave the highest selectivity comparable to that in 1,2-dichloroethane. Transport of Na$^+$ and K$^+$, by **5** exhibited preference for K$^+$ in all the liquid membranes consistent with the results of extraction experiments.

Competitive transport of alkali metal ions using **10**, **14**, **17**, and **18** as well as **5** was carried out. 1-Hexanol and 1,2-dichloroethane were employed as the liquid membrane and ion combinations of Na$^+$-K$^+$, Na$^+$-K$^+$-Cs$^+$, and K$^+$-Rb$^+$ were used. These results are shown in Tables 5 and 6.

Table 5 shows competitive ion transport through 1-hexanol. All the ionophores were K$^+$-selective in the transport of Na$^+$ and K$^+$. Although **17** and **18** with tetrahydrofuran ring have one more ether oxygen and the cavity sizes are larger than that of **5**, both had similar transport ability and selectivity to those of **5**. Results of competitive transport of Na$^+$, K$^+$, and Cs$^+$ by **5**. **10**, **14**, **17**, and **18** show that all the ionophores preferred K$^+$. The cavity size of **14** with six ether oxygens seems to fit diameter of Cs$^+$ better than that of K$^+$, whereas **14** had selectivity for K$^+$. No ionophore distinguished between K$^+$ and Rb$^+$ with similar diameter.

Table 6 shows the results of ion transport through 1,2-dichloroethane instead of 1-hexanol. In the transport of Na$^+$ and K$^+$, not only **5** but also **17** and **18** exhibited higher selectivity for K$^+$ than seen in 1-hexanol. Acetic acid derivative, **18** transported only 25% of the total salt. In the transport of Na$^+$, K$^+$, and Cs$^+$, the ionophores except for **10** displayed K$^+$-preference. Selective transport of Cs$^+$ was not achieved even by the compounds with six ether oxygens such as **14**, **17**, and **18**. Ionophores containing seven or more ether oxygens might fit for Cs$^+$. Poor transport ability of compounds bearing acetic acid moiety (**10** and **18**) is consistent with their partition coefficient experiments. Compounds **5** and **18** showed no preference between K$^+$ and Rb$^+$, but **17** exhibited a slight selectivity for Rb$^+$.

As mentioned above, it was found that the ionophores having five or six ether oxygens transported K$^+$ and Rb$^+$ in preference to the smaller Na$^+$ and the larger Cs$^+$. Since the cavity size of these ionophores in a pseudocyclic conformation formed by head-to-tail hydrogen bonding meets diameter of K$^+$ and Rb$^+$ rather than Na$^+$ and Cs$^+$, the hydrophobic conformations of the potassium and rubidium salts are more stable to diffuse into organic phase than those of the sodium and cesium salts resulting in the K$^+$- and Rb$^+$-preference.

Table 6. Active Ion Transport through 1,2-Dichloroethane by Ionophores Containing 5—6 Ether Oxygens

| Compound | Transported ion (%) | | | | |
|---|---|---|---|---|---|
| | Na$^+$ | K$^+$ | Rb$^+$ | Cs$^+$ | Total |
| **5** | 13 | 62 | — | — | 75 |
| **17** | 20 | 71 | — | — | 91 |
| **18** | 5 | 20 | — | — | 25 |
| None | 0 | 0 | — | — | 0 |
| **5** | — | 42 | 45 | — | 87 |
| **17** | — | 36 | 49 | — | 85 |
| **18** | — | 10 | 11 | — | 21 |
| None | — | 0 | 0 | — | 0 |
| **5** | 11 | 56 | — | 13 | 80 |
| **10** | 7 | 4 | — | 3 | 14 |
| **14** | 11 | 53 | — | 21 | 85 |
| **17** | 12 | 69 | — | 12 | 93 |
| **18** | 8 | 15 | — | 8 | 31 |
| None | 0 | 0 | — | 0 | 0 |

**Active Transport of Alkali Metal Ions by Derivatives of 5.** Table 7 illustrates competitive active transport of alkali metal ions by **5** and its analogues including linoleic acid through 1,2-dichloroethane liquid membrane. Compound **5** and its methyl and benzyl ethers (**8** and **9**) were able to transport alkali metal ions whereas *m*- and *p*-substituted isomers of **9** (**6** and **7**) and linoleic acid had almost no transport ability. Compound **5** exhibited high specificity for K$^+$ over Na$^+$ and Li$^+$, but the methyl ether was less selective and the benzyl ether had no selectivity. Compounds **5** and **8** showed less selectivity for K$^+$ over Rb$^+$ and Cs$^+$ than over Na$^+$ and Li$^+$ in 1,2-dichloroethane.

All the compounds react with cations to form the salts at water/1,2-dichloroethane interface. In the case of **5** and its derivatives subsequent replacement of water molecules out of the hydration sphere by ether oxygens affords a lipophilic complex soluble in the liquid membrane. On the contrary, the ether oxygens of *m*- and *p*-isomers of **5** are too far away to interact with from hydrated metal ions and linoleic acid had no ether oxygen to coordinate metal ion, so the salts stayed at the interface. Ion selectivity of **5** could be accounted for in a similar manner to naturally occurring carboxylic ionophores.[2] A metal ion is entrapped in a hydrophilic cavity made by head-to-tail hydrogen bonding between carboxylato and hydroxyl groups of ionophore. The diameter of a potassium ion (2.66 Å) meets the cavity size of **5** (2.6 Å by CPK model) result-

Table 7. Active Transport of Alkali Metal Ions through 1,2-Dichloroethane by 5 and Its Derivatives

| Compound | Transported ion (%) | | | | | |
|---|---|---|---|---|---|---|
| | Li$^+$ | Na$^+$ | K$^+$ | Rb$^+$ | Cs$^+$ | Total |
| **5** | 0 | 11 | — | — | — | 11 |
| | — | 13 | 62 | — | — | 75 |
| | — | — | 40 | 36 | 24 | 100 |
| **8** | 11 | 28 | — | — | — | 39 |
| | — | 28 | 41 | — | — | 69 |
| | — | — | 42 | 32 | 26 | 100 |
| **9** | 40 | 33 | — | — | — | 73 |
| | — | 35 | 35 | — | — | 70 |
| | — | — | 42 | 30 | 28 | 100 |
| **6** | 0 | 0 | — | — | — | 0 |
| | — | 0 | 0 | — | — | 0 |
| | — | — | 1 | 5 | 1 | 7 |
| **7** | 0 | 0 | — | — | — | 0 |
| | — | 0 | 0 | — | — | 0 |
| | — | — | 1 | 2 | 1 | 4 |
| Linoleic acid | 0 | 0 | — | — | — | 0 |
| | — | 0 | 0 | — | — | 0 |
| None | 0 | 0 | — | — | — | 0 |
| | — | 0 | 0 | — | — | 0 |
| | — | — | 0 | 0 | 0 | 0 |

Table 8. Active Ion Transport through 1-Hexanol by **5** and Its Derivatives

| Compound | Transported ion (%) | | | | | |
|---|---|---|---|---|---|---|
| | $Li^+$ | $Na^+$ | $K^+$ | $Rb^+$ | $Cs^+$ | Total |
| **5** | 44 | 26 | — | — | — | 70 |
| | — | 31 | 54 | — | — | 85 |
| | — | — | 34 | 30 | 26 | 89 |
| **8** | 56 | 28 | — | — | — | 84 |
| | — | 35 | 47 | — | — | 82 |
| | — | — | 26 | 26 | 21 | 73 |
| **9** | 36 | 13 | — | — | — | 49 |
| | — | 13 | 20 | — | — | 33 |
| **6** | 56 | 27 | — | — | — | 83 |
| | — | 34 | 41 | — | — | 75 |
| | — | — | 33 | 30 | 36 | 99 |
| **7** | 54 | 23 | — | — | — | 77 |
| | — | 32 | 32 | — | — | 64 |
| | — | — | 31 | 27 | 32 | 90 |
| Linoleic acid | 70 | 30 | — | — | — | 100 |
| | — | 47 | 43 | — | — | 90 |
| None | 15 | 13 | — | — | — | 28 |
| | — | 13 | 10 | — | — | 23 |
| | — | — | 17 | 16 | 15 | 48 |

Table 9. Active Ion Transport by Ionophores Containing 2—4 Ether Oxygens

| Compound | Liquid membrane | Transported ion (%) | | | |
|---|---|---|---|---|---|
| | | $Li^+$ | $Na^+$ | $K^+$ | Total |
| **3**[a)] | 1-Hexanol | 24 | 15 | 14 | 53 |
| **12** | | 36 | 24 | — | 60 |
| **20** | | 20 | 15 | — | 35 |
| **22** | | 29 | 24 | — | 53 |
| None | | 15 | 13 | — | 28 |
| None[a)] | | 20 | 17 | 19 | 56 |
| **3**[a)] | 1,2-Dichloroethane | 2 | 0 | 3 | 5 |
| **12** | | 4 | 16 | — | 20 |
| **20** | | 0 | 2 | — | 2 |
| None | | 0 | 0 | 0 | 0 |

a) Donor phase I contains an aqueous solution of 0.1 M $Li^+$ (1 M=1 mol $dm^{-3}$), 0.1 M $Na^+$, 0.1 M $K^+$, and 0.3 M $OH^-$. The other conditions are described in experimental section.

ing in the potassium selectivity. Since $Na^+$ and $Li^+$ are too small to fit in the cavity, these complexes are less stable than that of potassium salt of **5**. Smaller difference between the diameters of $K^+$ and $Rb^+$ ($Cs^+$) leads to less selectivity for $K^+$ over $Rb^+$ ($Cs^+$) by **5**. The methyl and benzyl ethers of **5**, **8**, and **9**, where the head-to-tail hydrogen bonding is impossible, could still adopt a pseudocyclic conformation fitting the size of $K^+$. However, the other conformations with smaller cavity sizes to meet $Na^+$ or $Li^+$ diameter would be also possible because of the enhanced hydrophobicities of **8** and **9**. This is responsible for less selectivity and increase in transported amount of $Na^+$ and $Li^+$. All the salts of the ionophores where cations are coordinated by all or some ether oxygens depending on the sizes of cations were hydrophobic enough to be extracted into organic membrane. There is not much difference between the stability of the complexes.

Behavior of these ionophores in 1-hexanol membrane is quite different from that in 1,2-dichloroethane as shown in Table 8. Not only *o*-substituted compounds **5**, **8**, and **9** but also *m*- and *p*-isomers **6** and **7** and linoleic acid served as a carrier. Compound **5** had still specificity for $K^+$ over $Li^+$ and $Na^+$, but $Li^+$ was more transported than $Na^+$. The other ionophores preferred $Li^+$. Any ionophore did not exhibit remarkable selectivity for $K^+$ over $Rb^+$ and $Cs^+$ regardless of the position of terminal carboxyl group or the structure of the other end.

Selectivity in the ion transport through 1-hexanol might be explained as follows: Water molecules of hydrated cations of linoleic acid salts formed at the interface were replaced by 1-hexanol molecules to solubilize in the organic membrane. The transport selectivity for $Li^+$ suggests that 1-hexanol can dehydrate more easily out of $Li^+$ with higher charge density. In the case of the synthetic ionophores containing ether oxygens, metal ions were coordinated by the ether oxygens of the ionophores and alcohol oxygens of the liquid membrane competitively. Compound **5** whose ether oxygens may be stronger ligands toward $K^+$ than 1-hexanol exhibited $K^+$ selectivity, but the complex coordinated by 1-hexanol oxygens was also produced resulting in lowering $K^+$-selectivity.

**Active Transport of Alkali Metal Ions by Ionophores Containing 2—4 Ether Oxygens.** The ionophores containing two to four ether oxygens were employed for ion transport as shown in Table 9. In 1-hexanol, the ionophores transported $Li^+$ more than $Na^+$ similar to the case of **5** and its derivatives as mentioned above. However, the total amount of transported ions was small. This could be accounted for by the small stability constant of the salt complexes solvated by 1-hexanol resulting from the low lipophilicity of these ionophores. Although the ionophores were expected to exhibit $Li^+$- or $Na^+$-selectivity through 1,2-dichloroethane from the cavity sizes, almost no ion was transported.[13)]

## Experimental

**Methods.** IR spectra were run with a Jasco IR-G spectrophotometer. $^1H$ NMR specta were recorded with a JEOL JNM-PMX 60 instrument using tetramethylsilane as internal standard. UV spectra were recorded on a Hitachi 124 spectrophotometer. Mass spectra were obtained on a Hitachi M-80 mass spectrometer operating at 30 eV. Elemental analyses were performed on a Yanaco Model MT-3. Flame spectrochemical analyses were performed with Hitachi 170-30 Atomic Absorption Spectrophotometer.

**Materials.** Unless stated otherwise reagent grade reactants and solvents were obtained from commercial suppliers and used without further purification. Dry ethanol and dry methanol were distilled in the presence of sodium alkoxides.

Dry *N,N*-dimethylformamide (DMF) and dry pyridine were distilled over NaH. Methyl 2-(bromomethyl)benzoate was prepared by photobromination of methyl 2-methylbenzoate with bromine according to the literature method[14] and the *m*- and *p*-isomers, methyl 3-(bromomethyl)benzoate and methyl 4-(bromomethyl)benzoate, were obtained similarly. Bis[2-(2-hydroxyphenoxy)ethyl] ether (**19**),[10] and 1,2-bis(2-hydroxyethoxy)benzene (**21**)[11] were prepared by Williamson synthesis from catechol and the appropriate halides according to the literatures. Ethylene glycol ditosylate[15] and tetrahydro-2,5-furandimethanol ditosylate (**15**)[9] were obtained according to the literature methods.

**2-(2-Hydroxyethoxy)phenol (1).** A mixture of catechol (22 g, 0.2 mol), ethylene carbonate (17.6 g, 0.2 mol), and tetrabutylammonium iodide (2.4 g, 6.5 mmol) was heated at 160 °C for about 1 h until evolution of $CO_2$ ceased. The mixture was distilled under reduced pressure (ca. 115 °C/0.1 mmHg(1 mmHg=133.322 Pa)) to get a solid. Recrystallization of this from water gave pure product (23.1 g, 77%). Mp 99—101 °C (lit,[6] mp 100—101 °C).

**1,2-Bis[2-(2-hydroxyethoxy)phenoxy]ethane (4).** A mixture of **1** (2 g, 13 mmol) and NaH (13 mmol) in dry DMF (8 ml) was stirred at room temperature for 30 min. To this was added dropwise ethylene glycol ditosylate[13] (2.4 g, 6.4 mmol) in dry DMF (25 ml) and the mixture was stirred at room temperature for 24 h. After removal of DMF in vacuo, water (40 ml) was added to the residue followed by reflux. After cooling, the precipitate was collected by suction. It was recrystallized from ethanol-water (1/1) to get **4** (1.71 g, 81%). Mp 88—89 °C (lit,[8] mp 99 °C). $^1$H NMR ($CDCl_3$) $\delta$=3.6—4.3 (8H, m, $OC\underline{H}_2C\underline{H}_2OH$), 4.3 (4H, s, $OC\underline{H}_2C\underline{H}_2$), 6.9 (8H, s, aromatic).

**2,5-Bis[[2-(2-hydroxyethoxy)phenoxy]methyl]tetrahydrofuran (16).** NaOH (2.1 g, 52 mmol) was dissolved in 1-butanol (100 ml) under reflux. After addition of **1** (8 g, 52 mmol) the mixture was refluxed for 1 h. To this was added dropwise a solution of **15**[14] (11 g, 25 mmol) in dry DMF (100 ml) and the mixture was heated under reflux for 16 h. After distillation of the solvents under reduced pressure the residue was dissolved in water (50 ml) with heating followed by acidification with 1 M HCl (1 M=1 mol dm$^{-3}$). The formed precipitate was collected by suction and was recrystallized from ethanol-water (1/1) to give **16** (4 g, 40%). Mp 99—101 °C. $^1$H NMR (DMSO-$d_6$) $\delta$=1.9 (4H, m, $CH_2$ of tetrahydrofuran), 3.1—4.7 (14H, m, OCH= and $OCH_2$), 6.9 (8H, s, aromatic). Found: C, 62.11; H, 7.31%. Calcd for $C_{22}H_{28}O_7\cdot H_2O$: C, 62.54; H, 7.16%.

**Bis[2-[2-(2-hydroxyethoxy)phenoxy]ethyl] Ether (13).** From **1** (10 g), NaOH (2.6 g), and bis(2-chloroethyl) ether (4.65 g), **13** was synthesized similar to **4**. Yield (11 g, 90%). Mp 84—86 °C (50% ethanol). $^1$H NMR ($CDCl_3$) $\delta$=3.7—4.3 (16H, m, $CH_2$), 6.9 (8H, s, aromatic). Found: C, 57.72; H, 7.38%. Calcd for $C_{20}H_{26}O_7\cdot 2H_2O$: C, 57.96; H, 7.30%.

**2-(2-Hydroxyethoxy)phenol Ditosylate (2).** To **1** (3.0 g, 20 mmol) in dry pyridine (20 ml) at 0 °C was added portionwise tosyl chloride (8.4 g, 44 mmol). The mixture was stirred at room temperature for 40 h and poured into ice water. The precipitate was filtered and washed with water. The solid dried in vacuo was recrystallized from ethanol-ethyl acetate to give white crystal of **2** (5.6 g, 61%); mp 125.5—126 °C. $^1$H NMR ($CDCl_3$) $\delta$=2.4 (6H, s, $CH_3$), 3.8—4.3 (4H, m, $CH_2$), 6.6—7.9 (12H, m, aromatic). Found: C, 57.23; H, 4.67; S, 13.96%. Calcd for $C_{22}H_{22}O_7S_2$: C, 57.13; H, 4.79; S, 13.87%.

**2-[2-[2-(2-Hydroxyethoxy)phenoxy]ethoxy]phenol (11).** A mixture of **1** (1.5 g, 10 mmol) and NaH (10 mmol) in dry DMF (70 ml) was stirred at 80—90 °C to form alkoxide. To this was added dropwise **2** (4.6 g, 10 mmol) in dry DMF (40 ml) at room temperature and the mixture was stirred at 80—90 °C for 18 h. DMF was removed in vacuo and the residue dissolved in chloroform was washed with water. The organic layer dried over sodium sulfate was evaporated and chromatographed over silica gel (chloroform/methanol=100/5) to separate the monotosylate roughly. To this was added KOH (8.4 g), $H_2O$ (14 ml), and ethanol (14 ml) followed by reflux for 1 h. This was acidified with HCl followed by extraction with chloroform. The organic layer dried over sodium sulfate was evaporated and applied to a silica-gel column (chloroform) to separate **11** (1.8 g, 62%). $^1$H NMR ($CDCl_3$) $\delta$=3.8—4.1 (4H, m, $OC\underline{H}_2C\underline{H}_2OH$), 4.2 (4H, s, $OC\underline{H}_2C\underline{H}_2$), 6.9 (8H, s, phenylene). Found: C, 66.16; H, 6.33%. Calcd for $C_{16}H_{18}O_5$: C, 66.20; H, 6.25%.

**[2-[2-[2-[2-(2-Hydroxyethoxy)phenoxy]ethoxy]phenoxy]ethoxy]acetic Acid (10).** To **4** (2.6 g, 7.4 mmol) dissolved in dry THF (80 ml) under gentle reflux was added portionwise small pieces of K (0.59 g, 15 mmol) and the mixture was stirred for 1 h to form precipitate of the alkoxide. Chloroacetic acid (0.7 g, 7.4 mmol) in dry DMF (20 ml) was added dropwise to the suspension and the mixture was refluxed for 9 h. After cooling, THF was removed in vacuo and to the residue was added appropriate amount of dil NaOH, then $H_2O$ was removed in vacuo. The residual oil was washed with dioxane to remove the starting material of **4**. To the resulting solid was added 2 M HCl and chloroform and it was shaken. The organic layer was separated, dried over magnesium sulfate, and evaporated. The solid was recrystallized from 50% ethanol to give **10** (1.8 g, 60%). Mp 73—76 °C. IR (KBr) 1740 cm$^{-1}$ (C=O); $^1$H NMR ($CDCl_3$) $\delta$=3.7—4.2 (10H, m, $CH_2O$), 4.3 (4H, s, $OCH_2CH_2O$), 6.9 (8H, s, aromatic). Found: C, 60.72; H, 6.34%. Calcd for $C_{20}H_{24}O_8$: C, 61.22; H, 6.17%.

**2-[[2-[2-[2-[2-(2-Hydroxyethoxy)phenoxy]ethoxy]phenoxy]ethoxy]methyl]benzoic Acid (5).** A mixture of **4** (3.34 g, 10 mmol) and NaH (10 mmol) in dry DMF (70 ml) was stirred at room temperature for 4 h. To the alkoxide was added dropwise methyl 2-(bromomethyl)benzoate (2.17 g, 10 mmol) in dry DMF (40 ml) and the mixture was stirred at room temperature for 4 h and at 80—90 °C for 24 h. DMF was removed in vacuo and to the residue was added 1 M NaOH followed by reflux for 2 h. It was acidified with dil HCl and the precipitate was collected by suction and washed with water thoroughly. To the solid dissolved in methanol was added anion-exchange resin (Amberlyst, OH$^-$, 5 g) and the mixture was stirred for 1 h. The resin was filtered, washed with methanol, and was poured into 1 M HCl. The resin was filtered off and washed with methanol. The combined filtrate and washing were evaporated in vacuo. The residue was recrystallized from 50% ethanol to give **5** (2.8 g, 59%). Mp 112—113 °C. IR (KBr) 1690 cm$^{-1}$ (C=O); $^1$H NMR ($CDCl_3$) $\delta$=3.8—4.4 (8H, m, $OCH_2$), 4.4 (4H, s, $OCH_2$), 4.9 (2H, s, benzyl), 6.9 (8H, s, aromatic), 7.3—8.1 (4H, m, aromatic). Found: C, 66.03; H, 6.02%. Calcd for $C_{26}H_{28}O_8$: C, 66.66; H, 6.02%.

Compounds **18**, **14**, and **17** were prepared from **16** and ethyl bromoacetate, **13** and methyl 2-(bromomethyl)benzoate and **16** and methyl 2-(bromomethyl)benzoate respectively by

Williamson synthesis similar to that for **5**.

**[2-[2-[[Tetrahydro-5-[[2-(2-hydroxyethoxy)phenoxy]methyl]-2-furanyl]methoxy]phenoxy]ethoxy]acetic Acid (18).** Yield (0.9 g, 20%). Mp 115—118 °C (50% ethanol). IR (KBr) 1730 cm$^{-1}$ (C=O); $^1$H NMR (DMSO-$d_6$) $\delta$=1.9—2.1 (4H, m, tetrahydrofuranyl $CH_2$), 3.5—4.5 (16H, m, all other $CH_2$ and tetrahydrofuranyl CH), 6.9 (8H, s, aromatic). Found: *m/z* 462.1901. Calcd for $C_{24}H_{30}O_9$: M, 462.1890.

**2-[[2-[2-[2-[2-[2-(2-Hydroxyethoxy)phenoxy]ethoxy]ethoxy]phenoxy]ethoxy]methyl]benzoic Acid (14).** Yield (0.51 g, 10%). Mp 82—84 °C (50% ethanol). IR (KBr) 1690 cm$^{-1}$ (C=O); $^1$H NMR (DMSO-$d_6$) $\delta$=3.5—4.3 (16H, m, $CH_2O$), 4.85 (2H, s, benzyl), 6.9 (8H, s, phenylene), 7.3—7.9 (4H, m, aromatic of toluic acid). Found: *m/z* 512.2081. Calcd for $C_{28}H_{32}O_9$: M, 512.2046.

**2-[[2-[2-[[Tetrahydro-5-[[2-(2-hydroxyethoxy)phenoxy]methyl]-2-furanyl]methoxy]phenoxy]ethoxy]methyl]benzoic Acid (17).** Yield (1.35 g, 30%). The crystal from 50% ethanol became oil on drying under vacuum. IR (neat) 1710 cm$^{-1}$ (C=O); $^1$H NMR ($CDCl_3$) $\delta$=1.9—2.2 (4H, m, tetrahydrofuranyl $CH_2$), 3.6—4.5 (14H, m, all other $CH_2$ and tetrahydrofuranyl CH), 6.9 (8H, s, aromatic), 7.3—8.1 (4H, m, aromatic of toluic acid). Found: *m/z* 538.2148. Calcd for $C_{30}H_{34}O_9$: M, 538.2203.

**2-[[2-(2-Hydroxyethoxy)phenoxy]methyl]benzoic Acid (3).** To sodium alkoxide prepared from **1** (0.87 g, 5.65 mmol) and NaH (5.68 mmol) in dry DMF (10 ml) was added dropwise methyl 2-(bromomethyl)benzoate (1.3 g, 5.68 mmol) in dry DMF (10 ml) and the reaction mixture was stirred at room temperature for 3 h and at 80 °C for 24 h. DMF was removed in vacuo and to the residue was added 1 M NaOH followed by reflux. It was acidified with 1 M HCl and extracted with chloroform. The organic layer was washed with water, dried over magnesium sulfate, and evaporated. The solid was recrystallized from $CCl_4$-$CHCl_3$-acetone (5/1/2) to give white crystals of **3** (0.42 g, 25%). Mp 138—139 °C. IR (KBr) 1690 cm$^{-1}$ (C=O); $^1$H NMR (acetone-$d_6$) $\delta$=3.7—4.3 (4H, m, $CH_2$), 5.5 (2H, s, benzyl), 6.9 (4H, s, aromatic), 7.3—8.1 (4H, m, aromatic). Found: C, 66.08; H, 5.61%. Calcd for $C_{16}H_{16}O_5$: C, 66.66; H, 5.59%.

**2-[[2-[2-(2-Hydroxyethoxy)phenoxy]ethoxy]methyl]benzoic Acid (22).** A mixture of **21**[11] (1.98 g, 10 mmol) and NaH (10 mmol) in dry DMF (30 ml) was stirred at 80—90 °C until evolution of hydrogen ceased. Methyl 2-(bromomethyl)benzoate (2.3 g, 10 mmol) in dry DMF (80 ml) was added dropwise and the mixture was stirred at 80—90 °C for 48 h. DMF was removed in vacuo and the residue dissolved in methanol was neutralized by addition of cation-exchange resin. The resin was filtered and the filtrate was evaporated. The residue was dissolved in hexane with heating and it was allowed to stand at room temperature to separate crystals of lactone (0.2 g, 6.4%). Mp 89—90 °C. IR (KBr) 1720 cm$^{-1}$ (C=O); $^1$H NMR ($CDCl_3$) $\delta$=3.7—4.0 (2H, m, $CH_2O$), 4.0—4.3 (4H, m, $CH_2O$), 4.5—4.7 (2H, m, $CH_2O$), 5.1 (2H, s, benzyl), 6.8 (4H, s, phenylene), 7.0—7.8 (4H, m, aromatic of toluic acid). Found: C, 68.46; H, 5.88%. Calcd for $C_{18}H_{18}O_5$: C, 68.77; H, 5.77%. The lactone (0.13 g, 0.4 mmol) in 1 M NaOH (25 ml) was refluxed for 1 h. It was neutralized with 1 M HCl and extracted with $CHCl_3$. The organic layer dried over sodium sulfate was evaporated to give **22** (0.13 g, 98%). Mp 105—107 °C. IR (KBr) 1690 cm$^{-1}$ (C=O); $^1$H NMR ($CDCl_3$) $\delta$=3.6—4.3 (8H, m, $CH_2O$), 4.9 (2H, s, benzyl), 6.8 (4H, s, phenylene), 7.0—7.9 (4H, m, aromatic of toluic acid). Found: C, 64.46; H, 6.26%. Calcd for $C_{18}H_{20}O_6$: C, 65.05; H, 6.07%.

**2-[[2-[2-[2-(2-Hydroxyethoxy)phenoxy]ethoxy]phenoxy]methyl]benzoic Acid (12).** A mixture of **11** (0.8 g, 2.8 mmol) and NaH (2.8 mmol) in dry DMF (30 ml) was stirred at room temperature to form alkoxide. To this was added dropwise methyl 2-(bromomethyl)benzoate (0.64 g, 2.8 mmol) in dry DMF (10 ml) and the mixture was stirred at room temperature for 18 h. DMF was removed in vacuo and to the residue was added 2 M NaOH followed by reflux for 2 h. It was acidified with 2 M HCl followed by extraction with chloroform. The organic layer dried over sodium sulfate was evaporated and applied to a silica-gel column (chloroform/methanol=100/1) to obtain **12** (0.34 g, 29%). IR (KBr) 1710 cm$^{-1}$ (C=O); $^1$H NMR ($CDCl_3$) $\delta$=3.3—4.4 (8H, m, $CH_2O$), 5.4 (2H, s, benzyl), 6.9 (8H, s, phenylene), 7.2—8.0 (4H, m, aromatic of toluic acid). Found: *m/z* 424.1457. Calcd for $C_{24}H_{24}O_7$: M, 424.1522.

Compound **20** was synthesized from **19** and methyl 2-(bromomethyl)benzoate similar to synthesis of **12**.

**2-[[2-[2-[2-(2-Hydroxyphenoxy)ethoxy]ethoxy]phenoxy]methyl]benzoic Acid (20).** Yield (0.5 g, 12%). Mp 111—114 °C. IR (KBr) 1710 cm$^{-1}$ (C=O); $^1$H NMR (acetone-$d_6$) $\delta$=3.5—4.3 (8H, m, $CH_2$), 5.5 (2H, s, benzyl), 6.7—7.0 (8H, m, phenylene), 7.2—8.1 (4H, m, aromatic of toluic acid). Found: *m/z* 424.1438. Calcd for $C_{24}H_{24}O_7$: M, 424.1522.

**4-[[2-[2-[2-[2-(2-Hydroxyethoxy)phenoxy]ethoxy]phenoxy]ethoxy]methyl]benzoic Acid (7).** A mixture of **4** (3.3 g, 10 mmol) and NaH (10 mmol) in dry DMF (70 ml) was stirred at 80—90 °C to form alkoxide. To this was added dropwise methyl 4-(bromomethyl)benzoate (2.3 g, 10 mmol) in dry DMF (40 ml) and the mixture was stirred at 80—90 °C for 18 h. DMF was removed in vacuo and to the residue was added 2 M NaOH followed by reflux for 2 h. It was acidified with 2 M HCl followed by extraction with chloroform. The organic layer dried over sodium sulfate was evaporated and was applied to a silica-gel column (chloroform/methanol=100/1) to obtain **7** (0.70 g, 15%). IR (KBr) 1690 cm$^{-1}$ (C=O); $^1$H NMR (DMSO-$d_6$) $\delta$=3.5—4.4 (12H, m, $CH_2$), 4.6 (2H, s, benzyl), 6.9 (8H, s, aromatic), 7.3—8.0 (4H, m, aromatic of toluic acid). Found: C, 66.18; H, 5.82%. Calcd for $C_{26}H_{28}O_8$: C, 66.02; H, 6.07%.

**3-[[2-[2-[2-[2-(2-Hydroxyethoxy)phenoxy]ethoxy]phenoxy]ethoxy]methyl]benzoic Acid (6).** Compound **6** was synthesized by the same procedure as that for **7** using methyl 3-(bromomethyl)benzoate instead of *p*-isomer. Yield (1.2 g, 26 %). IR (KBr) 1690 cm$^{-1}$ (C=O); $^1$H NMR ($CDCl_3$) $\delta$=3.6—4.4 (12H, m, $CH_2$), 4.6 (2H, s, benzyl), 7.0 (8H, s, aromatic), 7.4—8.1 (4H, m, aromatic of toluic acid). Found: C, 66.51; H, 5.96%. Calcd for $C_{26}H_{28}O_8$: C, 66.66; H, 6.02%.

**2-[[2-[2-[2-[2-(2-Methoxyethoxy)phenoxy]ethoxy]phenoxy]ethoxy]methyl]benzoic Acid (8).** A mixture of **5** (0.5 g, 1.1 mmol) and NaH (4 mmol) in dry DMF (10 ml) was stirred at room temperature to form alkoxide. To this was added dropwise methyl iodide (0.71 g, 5 mmol) in dry DMF (5 ml) and the mixture was stirred at room temperature for 48 h. DMF was removed in vacuo and to the residue was added a mixture of KOH (0.84 g, 5 mmol), $H_2O$ (5 ml), and ethanol (5 ml) followed by reflux for 2 h. It was acidified with HCl followed by extraction with chloroform. The organic layer dried over sodium sulfate was evaporated. The residue was applied to a silica-gel column (chloroform/methanol=100/1) to obtain **8** (0.38 g, 73%). IR (KBr) 1690 cm$^{-1}$ (C=O);

$^1$H NMR ($CDCl_3$) $\delta$=3.4 (3H, s, $OCH_3$), 3.6—4.4 (12H, m, $CH_2O$), 5.0 (2H, s, benzyl), 6.9 (8H, s, phenylene), 7.3—8.1 (4H, m, aromatic of toluic acid). Found: C, 67.28; H, 6.40%. Calcd for $C_{27}H_{30}O_8$: C, 67.21; H, 6.27%.

Compound **9** was prepared from **5** and benzyl chloride instead of methyl iodide by the same procedure as that for **8**.

**2-[[2-[2-[2-[2-(2-Benzyloxyethoxy)phenoxy]ethoxy]phenoxy]ethoxy]methyl]benzoic Acid (9).** Yield (0.54 g, 89%). IR (KBr) 1690 cm$^{-1}$ (C=O); $^1$H NMR ($CDCl_3$) $\delta$=3.6—4.4 (12H, m, $CH_2O$), 4.6 (2H, s, benzyl), 4.9 (2H, s, toluic benzyl), 6.9 (8H, s, phenylene), 7.3 (5H, s, aromatic of benzyl), 7.3—8.1 (4H, m, aromatic of toluic acid). Found: C, 71.07; H, 6.29%. Calcd for $C_{33}H_{34}O_8$: C, 70.95; H, 6.14%.

**Extraction of Alkali Metal Salts of Ionophores.** Ionophore ($10^{-4}$ mol) was dissolved in 0.1 M alkali metal hydroxide (10 ml) in 50 ml vial. To 10 ml was diluted 0.1 ml of the aqueous solution and the optical density of the diluted solution ($OD_0$) was measured at 273 nm. To the native aqueous solution was added an organic solvent (20 ml) and the mixture was vigorously shaken 60 times by hand. The vial was allowed to stand for 2 d to separate the aqueous layer from the organic layer. The aqueous solution (0.1 ml) was diluted to 10 ml and optical density of the diluted solution ($OD_1$) was measured at 273 nm. Partition coefficient of a salt of a carboxylic ionophore was calculated as follows: Partition coefficient=$(OD_0-OD_1)/2OD_1$.

**Ion Transport Experiment.** Ion transport was carried out in U-type or H-type cells[1b] at 35±1 °C for 5 d with stirring at 200 rpm. Donor phase I contains 10 ml aqueous solution of an alkali metal hydroxide (0.1 M) and other alkali metal chlorides (0.1 M). Acceptor phase II contains 10 ml aqueous solution of HCl (0.1 M) and all alkali metal cations with chloride anion (0.1 M). Organic phase III contains an organic solution of a $10^{-4}$ mol ionophore. An aqueous solution at acceptor phase was diluted to an appropriate volume. The concentration of alkali metal ions (10—100 ppm) was determined to be $c_0$ and $c_1$ before and after transport experiment by flame spectrochemical analysis. Transported ion (%) was calculated by $[(c_1-c_0)/c_0]\times 100$.

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