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Strong Binding Ability of Lipophilic Cyclodextrins for Alkali Metal and Alkaline Earth Metal Ions

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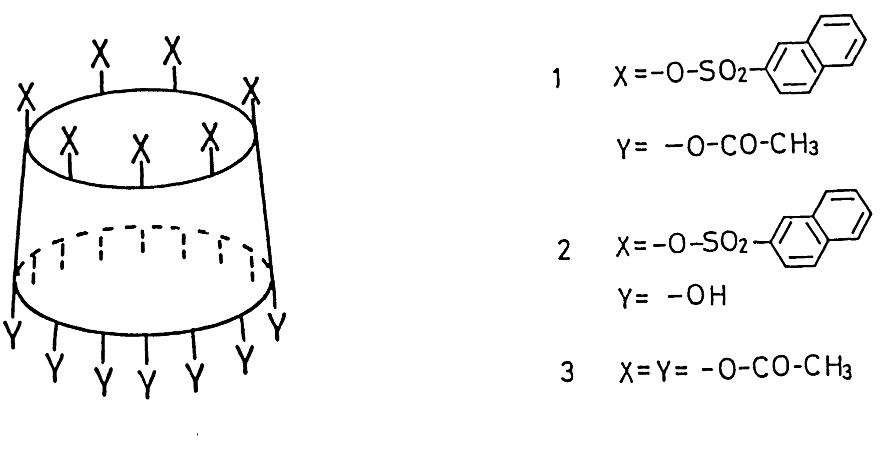
Lipophilic cyclodextrins bearing seven 2-naphthalenesulfonyl moieties at primary (C_6) side of β-cyclodextrin exhibited marked binding ability for alkali metal and alkaline earth metal ions in dichloromethane.

Cyclodextrins are torus-shaped oligosaccharides named as α, β, and γ for hexamer, heptamer, and octamer, respectively. Heretofore, cyclodextrins have been regarded, with a few limited exceptions,[1,2] as hosts which form inclusion complexes with a variety of guest molecules in aqueous solution and are very different from crown ethers capable of binding alkali metal ions in organic solvents. We report here that lipophilic β-cyclodextrin derivatives **1** and **2** strongly bind alkali metal and alkaline earth metal ions in dichloromethane, even more strongly than dibenzo-18-crown-6 (DB-18-Cr-6).



The host **2**, in which all primary hydroxyl groups of β-cyclodextrin are sulfonated, was prepared by the reaction of β-cyclodextrin with 2-naphthalenesulfonyl chloride in pyridine at room temperature for 30 h according to the method similar to the previously reported one for the synthesis of hepta(6-O-tosyl)-β-cyclodextrin; yield, 24%.[3)] The purified product obtained as white powder was identified by elemental analysis, NMR, UV, and TLC data.[4)] ^{13}C-NMR spectrum (DMSO-d_6) shows a peak of C-6 at 69.3 ppm which is markedly downfield shifted from that of β-cyclodextrin (59.8 ppm), indicating modification of primary hydroxyl groups of β-cyclodextrin.[5)] The host **1** was prepared by acetylation of all secondary hydroxyl groups of **2** with acetic anhydride at 50 °C for 16 h in pyridine. Silica-gel column chromatography of the crude product (pale brown powder) with ethyl acetate followed by recrystallization from ethyl acetate and hexane afforded white powder; yield, 5%. The ^{1}H-NMR spectrum ($CDCl_3$) of the purified **1** showed the expected area ratio for aromatic and methyl protons. The compound **3** was prepared by the reaction of β-cyclodextrin with acetic anhydride in pyridine.[6)] The cyclodextrin derivatives **1**, **2**, and **3** are lipophilic, being soluble in dichloromethane but insoluble in water.

The liquid-liquid extraction was carried out by vigorous shaking of a 2 ml aqueous solution containing alkali metal or alkaline earth metal picrate (0.01 mM (mM = mmol dm^{-3})) with the equal volume of dichloromethane solution containing **1**, **2**, **3**, or DB-18-Cr-6 at 25 °C. The picrate concentration in the aqueous layer was determined by the absorbance change at 354 nm. The results of the extraction experiments are shown in Table 1.

When the host concentration was 0.1 mM, the host showed different binding abilities for alkali metal ions, the magnitude of binding ability lying in the order of **1**>**2**>DB-18-Cr-6>**3**. It is noted that **3**, which was reported to be effective in dissolving alkali metal and alkaline earth metal ions into organic solvents[1)], is a poorer host than **1** and **2**. The binding ability of **2** is slightly smaller than that of **1**, but still better than that of DB-18-Cr-6 except for potassium ion. The ion selectivity of **1** and **2** is negligible while that of DB-18-Cr-6 is remarkable with the order of $Na^+<Cs^+<Rb^+<K^+$. Both **1** and **2** showed marked ability to bind alkaline earth metals which are hard to be extracted by **3** and DB-18-Cr-6. It is seen that the binding ability of **1** is better for alkaline earth metal ions as well as alkali metal ions than that of **2**. More distinct differences for **1** and **2** were observed when the host concentration was 0.01 mM, e.g. 6-fold and 8-fold larger amounts of picrates were extracted by **1**

Table 1. Extraction of Alkali Metal and Alkaline Earth Metal Picrates by Lipophilic Cyclodextrins[a)]

	Picrate extracted (%)							
Host	Na^+	K^+	Rb^+	Cs^+	Mg^{2+}	Ca^{2+}	Sr^{2+}	Ba^{2+}
1 (0.1 mM)	98	97	97	97	97	96	98	98
2 (0.1 mM)	82	73	75	73	66	51	43	41
3 (0.1 mM)	2	5	4	6	2	4	2	2
DB-18-Cr-6 (0.1 mM)	16	86	67	44	4	4	3	3
1 (0.01 mM)	72	71	70	71	51	56	49	47
2 (0.01 mM)	16	12	15	19	31	9	11	6
DB-18-Cr-6 (0.01 mM)	7	40	23	14	3	4	2	1

a) Organic phase (2 ml of dichloromethane) contains **1**, **2**, **3**, or DB-18-Cr-6 while aqueous phase (2 ml of water) contains picrate (0.01 mM) and chloride (1 M) of alkali metal or alkaline earth metal.

for potassium and barium ions, respectively.

Since **1** has no hydroxyl group while **2** has fourteen hydroxyl groups, the data suggest that more lipophilic nature of **1** resulted in better binding ability. It is noted that Tagaki et al. claimed that the presence of hydroxyl groups was needed for dissolving solid methyl orange into chloroform in the case of β-cyclodextrin derivatives bearing long alkyl chains.[2)] The marked binding ability of **1** probably owes to sulfonyl groups which are arranged along a circle on one side of cyclodextrin unit and may trap a metal ion cooperatively. The low ion selectivity may be explained in terms of the flexibility of the sulfonyl groups. Similar extraction data were obtained when methyl orange was used in place of picrate anion.

The present results have shown that appropriate modification of β-cyclodextrin enables it to bind metal ions in organic solvents. The metal ion binding by cooperation of flexible functional moieties arranged along a circle may be used as a basis for constructing new types of ionophores.

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References

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4) Data of **2**: R_f 0.61 (1-butanol,ethanol, water 5:4:3 by volume (plate, Kieselgel 60 F_{254} made by Merck Co.)); Found: C, 54.22; H, 4.39; S, 8.99%. Calcd for $C_{112}H_{112}S_7O_{49}$: C, 54.55; H, 4.55; S, 9.09%; ^{13}C-NMR (DMSO-d_6) δ = 69.3 (C_6 and C_5 overlapped peaks), 71.6, 72.4 (C_2, C_3), 81.3 (C_4), 101.9 (C_1), 122.0-134.7 (aromatic C).

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