CHEMISTRY LETTERS, pp. 1005-1008, 1988.

14,16-Bridged 16-Crown-5. Drastic Enhancement in Cation-Binding Ability[1)]

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14,16-Bridged 16-crown-5 derivatives possess unusually high cation-binding abilities for most cations, maintaining the original relative cation-selectivity for Na^+ and Ag^+, for which the fixed conformation is responsible.

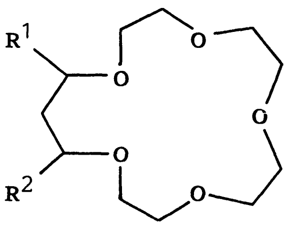
We have recently demonstrated that the 16-crown-5 derivatives, though formally less-symmetrical, possess much higher relative cation-selectivity for Na^+ and Ag^+ than common 15-crown-5.[2)] This specificity has been attributed to the slight ring-expansion induced by the extra methylene introduced, which affords such cavity size and donor orientation that are more suitable for complexing size-matched cations. In the work on the 16-crown-5 lariats,[2c,e)] it has been shown that the simple alkylation(s) of the parent 16-crown-5 (**1**) at 15-position lead to substantial, global decrease in the cation-binding abilities for all cations examined. This phenomenon appears to be general, since similar tendency has also been reported with 15-crown-5.[3)] In the present communication, we report unusual enhancement of cation-binding ability upon bridging substitution of 16-crown-5, which is in sharp contrast to the substantially decreased binding ability of simply methylated 16-crown-5 at the same positions.

The vinylene-bridged 16-crown-5 (**3**) was synthesized in 31% by the reaction of cis-2-cyclopentene-1,4-diol[4)] with tetraethylene glycol ditosylate in the presence of sodium hydroxide in tetrahydrofuran. Catalytic hydrogenation of **3** over Pd/C gave 14,16-ethylene-16-crown-5 (**4**) in 80% yield. For comparison purpose, 1:1

Table 1. Solvent extraction of aqueous metal picrates with some substituted 16-crown-5 and 17-crown-5 derivatives[a)]

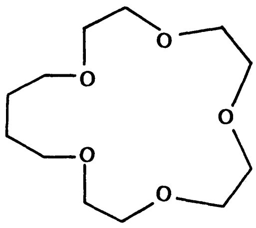
Ligand	% Extractability[b)]									
	Na^+	K^+	Rb^+	Cs^+	Ag^+	Tl^+	Mg^{2+}	Ca^{2+}	Sr^{2+}	Ba^{2+}
1	13.5	3.0	2.1	0.9	35.7	18.1	0.3	0.8	5.7	15.4
2[c)]	5.1	1.4	1.0	0.5	23.4	14.4	0.3	0.3	3.6	8.2
3	13.1	7.6	6.8	6.2	55.3	34.6	0.6	0.8	2.0	14.2
4	41.0	14.5	12.7	6.2	65.0	45.0	1.1	2.0	9.0	28.0
5	1.8	1.9	0.9	0.7	13.8	7.8	0.7	0.7	0.9	2.1
6	0.9	1.3	1.0	1.0	12.2	9.8	d)	d)	d)	d)

a) Temperature 25.0 ± 0.1 °C; aqueous phase (10 cm^3), [picrate] = 0.003 mol dm^{-3}; organic phase (CH_2Cl_2, 10 cm^3), [ligand] = 0.003 mol dm^{-3}. b) Defined as percent picrate extracted into the organic phase; average of two or three independent runs: error <0.7. c) A 1:1 mixture. d) Not determined.



	R^1	R^2
1	H	H
2*	CH_3	CH_3
3	CH=CH	
4	CH_2CH_2	

* A 1:1 mixture of cis- and trans-isomers.



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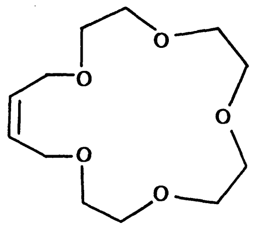

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mixture of cis- and trans-14,16-dimethyl-16-crown-5 (**2**), 17-crown-5 (**5**), and cis-17-crown-5-15-ene (**6**) were prepared in 45, 11, and 7% yields by analogous procedures from 2,4-pentanediol, 1,4-butanediol, and cis-2-butene-1,4-diol, respectively.[5)]

The cation-binding abilities of the 16- and 17-crown-5 derivatives (**1-6**) were evaluated by the conventional solvent extraction experiments under our standardized conditions.[2)] Aqueous solutions of alkali, alkaline earth, and some heavy metal picrates (0.003 mol dm^{-3}) were extracted with dichloromethane solutions of the respective crown ether (0.003 mol dm^{-3}) at 25 °C.

As can be seen from Table 1, 14,16-dimethyl-16-crown-5 (**2**) gave much lower extractabilities for all cations examined than those for the parent 16-crown-5 (**1**); similar effect has been observed in the case of 15-substituted 16-crown-5 derivatives.[2e] The effect may be ascribed to the conformational change induced by the methylation. The introduction of two methyl groups at 14- and 16-positions of **1** increases steric repulsion through 1,3-diaxial interaction, especially when the methyl is located at the axial-position. The resulting conformation would not be suitable for complexation owing to the less-favorable orientation and/or arrangement of the donor oxygen atoms.

By contrast vinylene-bridged 16-crown-5 (**3**) shows marked recovery in extractabilities for most cations, which are comparable to or even greater than those for the parent 16-crown-5 (**1**). This may be attributed to the reduced steric interaction of the substituents at 14-/16-positions and/or the conformational fixing by bridging substitution. The facile extraction of soft Ag^+ and Tl^+ would suggest possible interaction with π electrons of the double bond.

The introduction of an ethylene bridge to 16-crown-5 enormously enhances the binding ability of **4** for all cations. Indeed, **4** exhibited the highest extractabilities for the size-matched Na^+ and Ag^+, among the crown ether derivatives ever examined by us, which include common 3m-crown-m (m=4-12), some of their benzo- and stilbeno-derivatives, and the 16-crown-5 lariats.[2,6] It is also important that, despite the drastic enhancement in extractability, the original preference of **4** for Na^+ and Ag^+ is not impaired. As the ligand **4** does not contain a double bond, the enhancement cannot be rationalized by the reduced steric hindrance or the π interaction, but it should be attributed to the partial freezing of the flexible 16-crown-5 skeleton by introducing a rigid cyclopentane or cyclopentene framework.

Inability of a double bond as an effective π-donor was further demonstrated by the extraction with the structurally related 17-crown-5-15-ene (**6**). Carrying a double bond at the corresponding position but lacking a conformation-fixing bridge, **6** merely shows extremely low extractabilities for all cations including Ag^+ and Tl^+, which are comparable with those for the saturated 17-crown-5 (**5**).[2d]

It may be concluded that the structural freezing by introducing a rigid framework into a flexible crown ether ring can be used as a tool for enhancing cation-binding ability without changing original cation-selectivity.

This work was supported in part by Grant-in-Aid for Scientific Research Nos. 61550645 and 62303006 from the Ministry of Education, Science, and Culture, which is gratefully acknowledged.

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(Received March 5, 1988)