

tions on the transition states were done as follows. Approximate structures for Ts(1) and Ts(2) were constructed and crudely optimized. The force fields at the new approximations to the geometries of Ts(1) and Ts(2) were then determined. This Cartesian Hessian was used as the initial guess for the Hessian for the σ optimization. The transition states were determined by minimizing the sum of the squares of the gradient vector (σ

optimization) rather than minimizing the energy as is done in a geometry optimization.

Supplementary Material Available: Tables listing crystallographic details for **2a** and **2b**, final positional and thermal parameters, bond distances, bond angles, etc. (25 pages). Ordering information is given on any current masthead page.

Molecular Design of Crown Ethers. 4.^{1,2} Syntheses and Selective Cation Binding of 16-Crown-5 and 19-Crown-6 Lariats

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A number of new lariat 16-crown-5 and 19-crown-6 ethers possessing a variety of single or double side arm(s) were synthesized, and their cation-binding abilities were evaluated by solvent extraction technique. In general, the extractabilities of the 16-crown-5 lariats for most mono- and divalent cations increased gradually with extending oxyethylene side arm. However, sodium and silver ions, which are best size fitted to the crown cavity, showed peak extractability/selectivity at a specific length of the donating side arm. The complexation stoichiometry is 1:1 for all cations employed as confirmed by measurement of the extraction equilibrium constants for the single-armed 16-crown-5 (**3p**). The tetrasubstituted pivot carbon is shown to be a requirement for lariat 16-crown-5 to effect extra side-arm ligation, although the second side arm of lariat ether **3e** seems ineffective in extractability enhancement with reference to the single-armed analogue **3p**. By contrast, the corresponding 19-crown-6 lariats with potential donor side arms at an appropriate position did not show any enhancement in extractability for most cations, which may be attributed to its flexible framework.

Lariat ethers⁴ have been designed to enhance the cation-binding ability of common crown ethers by introducing a side arm carrying extra donor group(s) and also to partly mimic the dynamic complexation process shown by natural macrocyclic ligands. As has been demonstrated by several research groups,^{2,4-6} some carbon- and nitrogen-pivot lariat ethers indeed exhibit higher cation-binding abilities than the parent crown ethers probably through further ligation of side-arm donors. From the standpoint of synthetic feasibility, the usual lariat ethers are predominantly based on common 3*m*-crown-*m* ethers or their aza analogues. On the other hand, they may not necessarily be the best choice in respect of cation selectivity.

We have recently reported that less symmetrical (3*m*+*n*)-crown-*m* ethers show lower extractabilities in general but exhibit drastically different and, in some cases, higher selectivities for specific cations.⁷ 16-Crown-5, in particular,

shows much higher cation selectivity for Na⁺ and Ag⁺ than any other crown-5. This behavior prompted us to use the 16-crown-5 framework for the design of lariat ethers with enhanced cation-binding ability and selectivity. We now report the syntheses of a variety of lariat 16-crown-5 and, for comparison purpose, 19-crown-6 ethers with different single and double side arms. They are composed of long alkyl and/or oxyethylene chains attached through a carbon pivot. The cation-binding ability of the new lariat ethers evaluated from solvent extraction of aqueous alkali, alkaline-earth, and some heavy-metal picrates is discussed (Chart I).

Results

Syntheses. Double-armed 16-crown-5 ethers **3e-3j** were synthesized in 60-78% yields by reaction of the corresponding oligoethylene glycol monomethyl ether tosylates **6a-6f** with 15,15-bis(hydroxymethyl)-16-crown-5 (**3d**)^{7a,10} in the presence of NaOH (or NaH) as a base in THF. The acyclic ligand **5c** was obtained from 2,2-dimethyl-1,3-propanediol and **6d** in 79% yield.

The 16-crown-5 derivative **3m** with a single oxyethylene chain was synthesized analogously from (hydroxymethyl)-16-crown-5 (**3l**) and **6a**. **3l** was prepared by hydroboration of 15-methylene-16-crown-5 (**3k**)⁸ in 83% yield.

For the single-armed lariat ethers with a methyl group at the pivot, i.e. **3p**, **3q**, **4f**, and **4g**, two different routes were applied. The first reaction path involves the synthesis of **8b** by reaction of 5-(hydroxymethyl)-2,2,5-trimethyl-1,3-dioxane (**8a**)^{2b} with **6a**. **8a** was obtained from 2-(hydroxymethyl)-2-methyl-1,3-propanediol by treatment with

(1) Part 3: Inoue, Y.; Ouchi, M.; Hakushi, T. *Bull. Chem. Soc. Jpn.* **1985**, *58*, 525.

(2) Preliminary reports: (a) Ouchi, M.; Inoue, Y.; Wada, K.; Hakushi, T. *Chem. Lett.* **1984**, 1137. (b) Weber, E. *Liebigs Ann. Chem.* **1983**, 770. (c) Offermann, W.; Weber, E. *Chem. Ber.* **1984**, *117*, 234.

(3) (a) Himeji Institute of Technology. (b) Universität Bonn.

(4) (a) Dishong, D. M.; Diamond, C. J.; Cinaman, M. I.; Gokel, G. W. *J. Am. Chem. Soc.* **1983**, *105*, 586. (b) Schultz, R. A.; White, B. D.; Arnold, K. A.; Gokel, G. W. *Ibid.* **1985**, *107*, 6659.

(5) (a) Ikeda, I.; Emura, H.; Okahara, M. *Bull. Chem. Soc. Jpn.* **1985**, *57*, 1612. (b) Nakatsuji, Y.; Nakamura, T.; Okahara, M.; Dishong, D. M.; Gokel, G. W. *J. Org. Chem.* **1983**, *48*, 1237. (c) Nakatsuji, Y.; Nakamura, T.; Okahara, M. *Chem. Lett.* **1982**, 1207.

(6) Tsukube, H.; Takagi, K.; Higashiyama, T.; Hayama, N. *J. Chem. Soc., Perkin Trans. 1* **1986**, 1033.

(7) (a) Ouchi, M.; Inoue, Y.; Sakamoto, H.; Yamahira, A.; Yoshinaga, M.; Hakushi, T. *J. Org. Chem.* **1983**, *48*, 3168. (b) Ouchi, M.; Inoue, Y.; Kanzaki, T.; Hakushi, T. *Ibid.* **1984**, *49*, 1408. (c) Inoue, Y.; Ouchi, M.; Hakushi, T. *Bull. Chem. Soc. Jpn.* **1985**, *58*, 525. The K_{ex} values for divalent cations were reported erroneously and should read as reported here.

(8) Tomoi, M.; Abe, O.; Ikeda, M.; Kihara, K.; Kakiuchi, H. *Tetrahedron Lett.* **1978**, 3031.

(9) Blicke, F. F.; Zienty, M. F. *J. Am. Chem. Soc.* **1941**, *63*, 2779.

(10) (a) Weber, E. *Angew. Chem.* **1979**, *91*, 230; *Angew. Chem., Int. Ed. Engl.* **1979**, *18*, 219. (b) Weber, E. *J. Org. Chem.* **1982**, *47*, 3478.

Table I. Solvent Extraction of Metal Picrates with Some Ligands^a

entry	ligand	% extractability ^b									
		Na ⁺	K ⁺	Rb ⁺	Cs ⁺	Ag ⁺	Tl ⁺	Mg ²⁺	Ca ²⁺	Sr ²⁺	Ba ²⁺
1	1a	13.2	14.3	9.6	3.3	26.7	29.2	0.7	1.5	8.0	25.3
2	1b	14.9	9.6	7.6	2.6	27.2	35.2	0.3	2.0	6.8	50.3
3	2a	6.3	69.0	57.6	36.7	31.3	73.2	2.5	26.2	69.0	75.8
4	3a	13.5	3.0	2.1	0.9	35.7	18.1	0.3	0.8	4.5	15.4
5	3b	10.2	2.2	2.1	1.6	25.9	11.4	1.2	1.1	1.9	3.9
6	3c	9.8	2.7	2.5	2.1	24.7	11.1	1.6	1.6	3.1	9.3
7	3e	19.2	2.6	1.5	0.9	33.7	13.8	0.7	1.0	4.0	19.2
8	3f	15.0	4.8	2.4	1.2	29.4	15.7	1.2	1.4	3.9	26.2
9	3g	15.2	5.8	4.3	2.4	30.6	18.5	0.6	1.3	5.6	35.0
10	3h	15.8	6.4	5.2	3.6	30.2	21.6	0.7	1.6	5.1	32.5
11	3i	14.1	2.5	1.5	0.9	29.3	14.7	0.4	0.6	2.4	6.6
12	3j	11.4	2.7	1.7	1.0	26.9	13.4	0.6	1.0	3.1	9.1
13	3m	10.2	1.9	1.3	0.9	21.0	10.8	0.7	0.8	3.2	10.7
14	3r	9.8	1.7	1.6	0.9	23.3	10.5	0.7	0.6	1.9	3.6
15	3p	18.2	2.3	1.7	1.1	32.2	12.4	1.8	0.9	3.3	10.3
16	3q	14.4	3.9	2.3	1.3	27.8	13.7	0.6	1.0	2.5	15.9
17	3y	17.4	2.6	2.5	1.5	28.7	12.6	0.8	1.1	2.8	9.6
18	3z	16.3	5.0	3.0	1.5	31.4	17.0	0.7	1.0	2.7	18.5
19	4a	2.5	22.4	17.0	7.4	8.5	35.8	0.6	1.6	52.4	68.1
20	4b	2.8	21.8	18.1	7.4	9.5	40.2	0.3	2.1	55.2	73.3
21	4c	7.6	18.4	14.5	5.6	15.9	36.7	0.4	6.2	53.0	68.0
22	4f	2.2	18.9	12.9	4.9	6.2	40.1	0.7	3.2	57.0	71.3
23	4g	4.8	21.4	16.8	6.1	11.8	42.8	0.5	2.8	56.6	73.9
24	4h	1.8	20.1	15.6	6.0	7.3	41.0	0.3	2.6	48.5	63.6
25	4m	2.2	20.6	c	c	6.4	c	c	3.2	c	62.7
26	5a	0.1	0.1	0.1	0.1	0.1	1.0	0.1	0.1	0.2	1.3
27	5b	0.2	0.7	0.6	0.5	0.5	3.3	0.1	0.1	3.1	36.4
28	5c	0.3	1.3	1.4	1.2	1.2	12.0	0.2	0.2	1.4	16.7

^a Temperature 25.0 ± 0.1 °C; aqueous phase (10 mL), [picrate] = 3.0 mM; organic phase (CH₂Cl₂, 10 mL), [ligand] = 3.0 mM. ^b Defined as percent picrate extracted into the organic phase. Average of two independent runs; error < 0.7. ^c Extractability not determined.

Table II. Extraction Equilibrium Constants (K_{ex})^a for 1:1 Cation-Ligand Complexes

compd	log K_{ex}							
	Na ⁺	K ⁺	Rb ⁺	Cs ⁺	Ag ⁺	Tl ⁺	Sr ²⁺	Ba ²⁺
1a	4.52 ^b	4.40 ^b	4.29 ^b	3.74 ^b	5.00 ^c	5.08 ^c	6.07	6.80
3a	4.55 ^b	3.65 ^b	3.52 ^b	3.14 ^b	5.25 ^c	4.63 ^c	5.85	6.33
3p	4.57	3.39	3.24	2.86	4.91	4.26	5.48	6.04

^a Dichloromethane-water system; temperature 25.0 ± 0.1 °C; K_{ex} value in M²⁻ for monovalent and in M³⁻ for divalent cations. ^b Reference 7a. ^c Reference 7c.

acetone. Intermediate **8b** was hydrolyzed to diol **8c** in 90% yield. Reaction of **8c** with **6g** gave **3p** in 57% yield. The second path involves reaction of diol **8e**^{2b} with **6g** or **6h** in the presence of NaH in THF to yield (benzyloxy)methyl crown ethers **3n** or **4d**^{2b} in 45 and 48% yields, respectively. Hydrogenolysis of **3n** or **4d**^{2b} gave hydroxymethyl crown ethers **3o** and **4e** in 90 and 97% yields, respectively. Compounds **3q**, **4f**, and **4g** were obtained from **3o** or **4e** with the chlorides **7a** and **7b**,⁹ respectively, in 60–68% yield.

The crown ethers with a (dodecyloxy)methyl side chain **3r** and **4h** were synthesized by reaction of **3o** or **4e** with 1-bromodecane in 61 and 74% yields.

Double-armed crown ethers carrying both oxyethylene and (dodecyloxy)methyl side chains **3y**, **3z**, and **4m** were synthesized in four steps. The spiro crown ethers **3s** and **4i**^{7a,10} were reduced by LiAlH₄/AlCl₃ in diethyl ether to afford **3t** and **4j** in 90 and 92% yields.¹¹ Compounds **3t** and **4j** were then reacted with **7a,b** to give the crown ether derivatives with an oxyethylene chain and a (benzyloxy)methyl group **3u**, **3v**, and **4k** in 39–47% yields. Hydrogenolysis yielded the corresponding hydroxymethyl crown ethers **3w**, **3x**, and **4l** in 89–95% yields. They were then reacted with 1-bromodecane to give **3y**, **3z**, and **4m** in 51–55% yields.

Extraction. The cation-binding abilities of the crown ethers 1–4 and the acyclic ligands 5 were assessed by solvent extraction of alkali, alkaline-earth, and heavy-metal picrates (3.0 mM) at 25 °C with dichloromethane solutions of the ligands (3.0 mM). The percent extractabilities (% Ex), defined as percent picrate extracted into the organic phase, were measured twice, and the average values are shown in Table I.

In order to discuss the interaction of the lariat 16-crown-5 **3p** with cations from a quantitative point of view, extraction studies were carried out at different ligand concentrations between 2 and 7 mM to determine the extraction equilibrium constant (K_{ex}) and the complex stoichiometry.

As we reported previously,¹ the solvent extraction of a metal picrate MA_m ($m = 1$ or 2) with n molecules of crown ether (CE) is expressed by eq 1, where D_M represents the

$$\log (D_M/[A^-]^m) = n \log [CE]_{org} + \log K_{ex} \quad (1)$$

distribution ratio of the metal ion between the two phases: $D_M = [M(CE)_n A_m]_{org} / [M^{m+}]_{aq}$. The plots of $\log (D_M/[A^-]^m)$ as functions of $\log [CE]_{org}$, shown in Figure 1, give straight lines with a slope of unity for all cations employed, indicating 1:1 complex stoichiometry. The K_{ex} values are calculated from the intercepts; see Table II for the results.

Discussion

Lariat Effect (entries 5–10 in Table I). How the cation-binding ability of the double-armed 16-crown-5

(11) Cf.: De Jong, F.; van Zon, A.; Reinhoudt, D. N.; Torny, G. J.; Tomassen, H. P. M. *Recl. Trav. Chim. Pays-Bas* 1983, 102, 164.

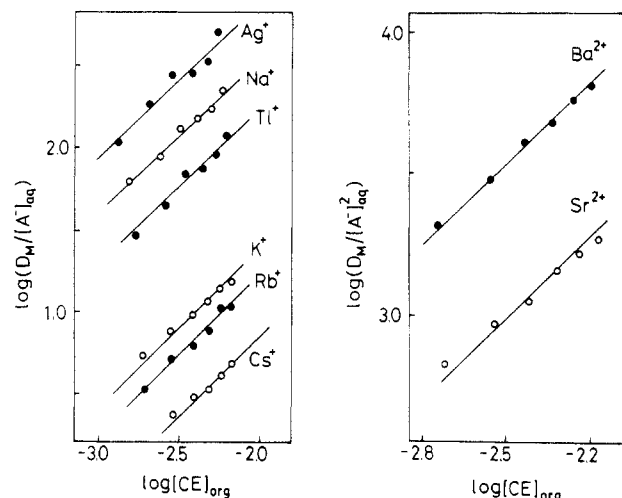


Figure 1. Plots of $\log(D_M/[A^-]^m)$ vs. $\log[CE]_{org}$ for solvent extraction of some metal picrates with lariat ether **3p**.

ethers **3e–3h**, **3b**, and **3c** depends on the number (N) of oxygens in a side arm will first be discussed. It is shown that extractabilities for most cations increase gradually with extension of the oxyethylene side arms (Table I). The profile of the extractability change with increasing N depends substantially upon the cation extracted and may be classified into three categories: (1) an optimum extractability is obtained at $N = 2$ or **3e**; (2) extractability increases monotonically with increasing N ; (3) extractability is not enhanced by the introduction of additional binding sites.

Na^+ and Ag^+ fall under category (1). This is probably indicative of the so-called size-fit concept. The cavity of the 16-crown-5 ring is more easily adjustable to these cation sizes than any others, smaller or larger ones. The size relationship obviously applies in the present case, although some contrary observations have been reported in solid and homogeneous phases.¹² The fact that crown ether **3e** with two oxygens in each side arm gives the maximum extractabilities for Na^+ and Ag^+ suggests that the terminal side-arm oxygen is placed at the most favorable position to access the cation accommodated in the crown ether cavity (Figure 2a). The extractability drop at $N = 3$ and the subsequent steady extractabilities at $N > 3$ are attributable to steric hindrance of the extra oxyethylene units interacting with the transannular ring oxygen, illustrated in Figure 2a (dashed line). Details of steric effects will be discussed below.

Category (2) may involve K^+ , Rb^+ , Cs^+ , Tl^+ , Sr^{2+} , and Ba^{2+} , which are too large to fit in the cavity of the 16-crown-5 derivatives and hence lie above the hole of the

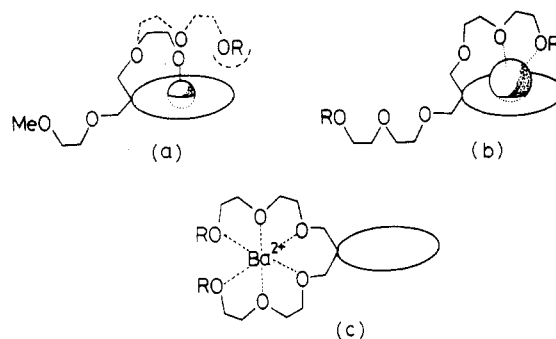


Figure 2. Schematic drawings of interaction between cation (ball) and crown ether (tray) with double side arms.

crown ether just like a ball on a tray. In this situation, the donor oxygens of the side arm may stabilize the weak crown ether-cation complex via wrapping of the cation by more than one side-arm oxygen (Figure 2b), which rationalizes the gradual increase in extractability with increasing N .

Category (3) may involve Mg^{2+} and Ca^{2+} . The extractabilities of the lariat 16-crown-5 derivatives both with and without oxyethylene side arms are very low, and no evident improvement is achieved by introducing side arms. We have previously shown¹ that in case of small divalent cations, like Mg^{2+} and Ca^{2+} , not the size but the hydration energy of the cation becomes the dominant factor controlling the extractability. The present result indicates that dehydration powers of the lariat ethers with additional binding sites are still unsatisfactory to overcome the high hydration energies of these small divalent cations.

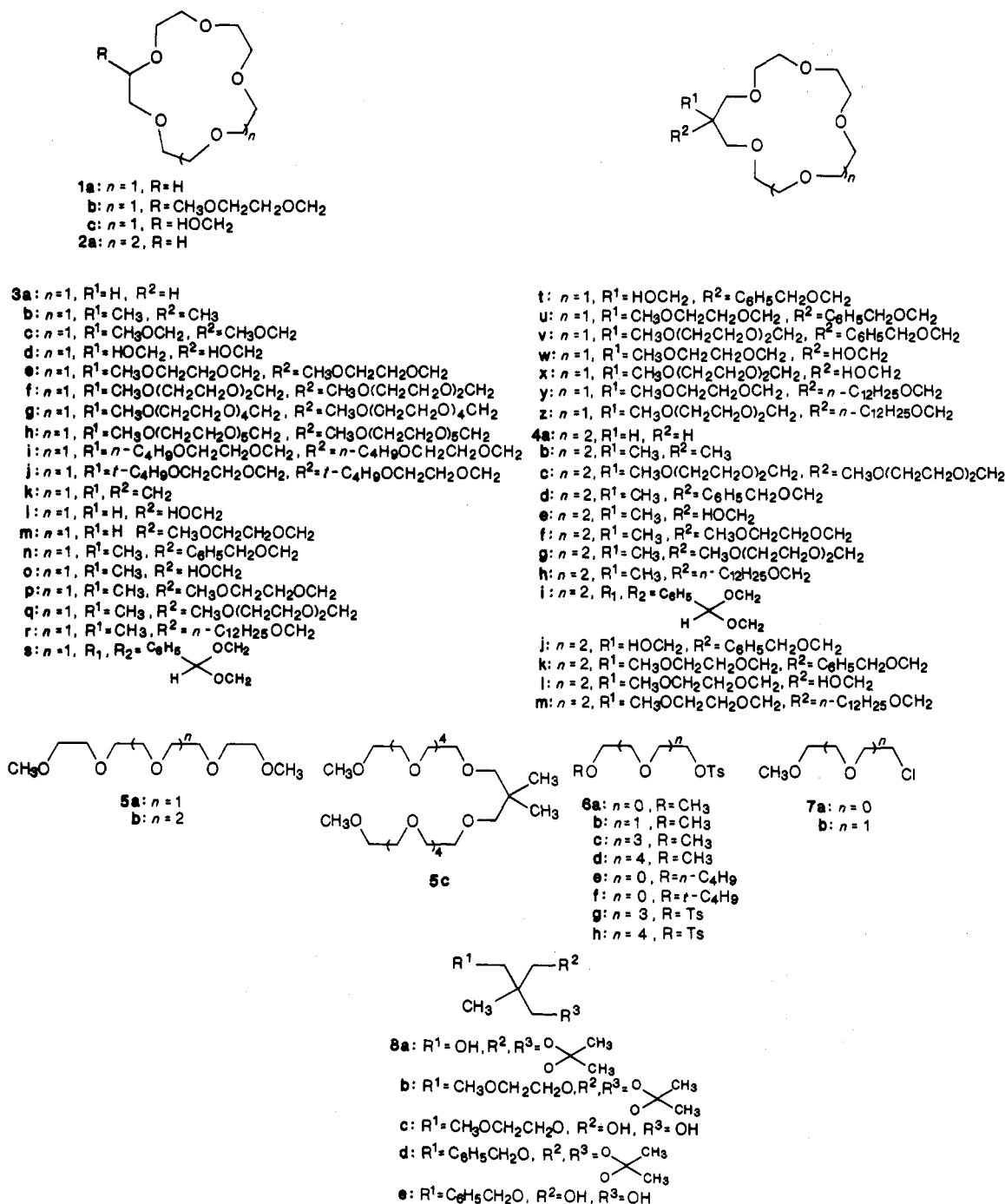
Effective Donor Atoms and Steric Effects (Entries 7–12). It was suggested that the extractability drop of double-armed 16-crown-5 ethers for Na^+ and Ag^+ at $N = 3$ originates from steric hindrance caused by unnecessarily long oxyethylene chains. In order to furnish proof, the third oxygen atoms in the side arms of lariat ether **3f** were replaced by methylene groups to give **3i**. Both lariat ethers **3f** and **3i** show comparable extractabilities (Table I) for size fitting Na^+ and Ag^+ , but **3f** possessing three donor atoms in each side arm yields higher extractabilities for the larger cations K^+ , Rb^+ , Cs^+ , Tl^+ , Sr^{2+} , and Ba^{2+} than **3i**. This result clearly indicates that the third oxygen in **3f** and probably also in **3g** and **3h** is not an effective donor site for Na^+ and Ag^+ in contrast to the larger cations, especially Ba^{2+} .

In the same nexus, **3e** with terminal methyl groups was modified to lariat ether **3j** having bulky *tert*-butyl groups attached directly to the donating oxygen. Interestingly, the diminishing effect of the voluminous substituents upon extractability was significant only for the size-matching cations Na^+ and Ag^+ but almost negligible for most larger cations. This along with the previous observation may be interpreted reasonably in the framework of our original idea that Na^+ and Ag^+ penetrate so deeply into the cavity of 16-crown-5 that any substituent larger than a methyl group at the second side-arm oxygen causes steric hindrance resulting in diminished interaction between cation and oxygen atom. On the other hand, the larger cations merely perch on the crown cavity. Hence, they enjoy wrapping complexation by the "unnecessary" long oxyethylene side arm to give gradual increase of extractability with N , and the extractabilities are relatively insensitive to steric hindrance.

Side Arms as an Independent Ligand Site (Entries 8, 10, 15, 18, 20). In the double-armed lariat ether series, the extractabilities for Tl^+ and Ba^{2+} show steady growth with increasing N in sharp contrast with the other cations

(12) As has been demonstrated by an X-ray crystallographic study of several N -pivot lariat ethers [Gandour, R. D.; Fronczek, F. R.; Gatto, V. J.; Minganti, C.; Schultz, R. A.; White, B. D.; Arnold, K. A.; Mazzocchi, D.; Miller, S. R.; Gokel, G. W. *J. Am. Chem. Soc.* **1986**, *108*, 4078], the conformation and size of the crown ring vary substantially depending upon the ligand topography, the complexed cation, and the coordination number around it. The same group and others have also shown from binding studies in homogeneous solutions that the hole-size relationship fails to explain cation selectivity in flexible macrocycles and lariat ethers. For recent papers, see: Schultz, R. A.; White, B. D.; Dishong, D. M.; Arnold, K. A.; Gokel, G. W. *J. Am. Chem. Soc.* **1985**, *107*, 6659. Michaux, G.; Reisse, J. *Ibid.* **1982**, *104*, 6895. On the other hand, the cation selectivity in the present case can be rationalized in terms of the size-fit concept, indicating that the concept still holds at least in the solvent extraction experiment. This may be attributed to the fairly rigid framework of 16-crown-5 as compared with larger macrocycles or to the use of solvent extraction in evaluating cation-binding ability. Alternatively, the complexation behavior of the carbon-pivot lariats might differ from that of the nitrogen-pivot lariats. A study to measure the complex stability constants in homogeneous phase is in progress using our own lariat ethers and the related crown ethers.

Chart I



(Table I). The double-armed crown ether **3f** with three oxygens in a side arm yields higher extractability for Ba^{2+} than the corresponding single-armed crown ethers **3q** and **3z**, while no significant difference was found in the extractabilities of other cations. These results suggest possible involvement of double side arms as an independent acyclic ligand site according to Figure 2c. Evidence is given by the fact that the side-arm mimic **5c** (podand) exhibits unusually high extractabilities only for Tl^+ and Ba^{2+} , which amount half the extractabilities produced by the corresponding lariat ether **3h**.

It is also interesting to note that, despite the failure of tetraglyme to extract any cations in significant yield, pentaglyme **5b** exhibits unexpectedly high extractability, in particular for Ba^{2+} (Table I). We suggest potentiality for a highly efficient Ba^{2+} selector based on the acyclic polyether **5b**.

Single vs. Double Side Arms (Entries 7, 8, 15, 16, 18). Our original intention to introduce two side arms to 16-crown-5 was enhancement of the cation-binding ability and selectivity through supporting side-arm ligation from both open faces of the cation embedded in the macrocycle. However, there is no significant difference in extractability between the single- and double-armed lariat ethers with two or three oxygens in a side arm (Table I). This is obvious by comparing the extractabilities for **3e** with **3p** or **3y** and **3f** with **3q** or **3z**; Ba^{2+} behaves differently due to the independent ligation of the double side arms shown above. An examination of CPK molecular models also indicates that only one side arm appears to have access to the complexed cation.

Highly Lipophilic Crown Ethers (Entries 14, 15, 17, 18, 24, 25). Since most unsubstituted 3m-crown-m ethers are fairly soluble in water, a considerable amount of the

ligand initially dissolved in the organic phase is distributed into the aqueous phase during solvent extraction. For example, the distribution ratios K_D (between water and dichloromethane) for 15- and 16-crown-5 are 0.31 and 0.18, respectively,^{7a} which may diminish the apparent cation-binding ability evaluated by percent extractability. As shown above, the second side arm in a double-armed lariat ether provides no effective donor properties. Hence we introduced a lipophilic alkyl chain to the 16-crown-5 and 19-crown-6 lariats instead (cf. **3y**, **3z**, **4m**). However these and comparable highly lipophilic crown ethers (**3r**, **4h**) did not show any significant improvement in ion extractability; actually almost identical percent extractabilities were obtained for the respective methyl- and (dodecyl-oxy)methyl-substituted crown ethers (cf. **3p** vs. **3y** and **3q** vs. **3z**). This turned out to be quite reasonable since the distribution ratio for the methyl lariat ether **3p** was found to be as low as 0.02; thus, we deal already with a lipophilic species. It is interesting however to note that the introduction of a long alkyl chain at C-15 of 16-crown-5 lariats does not affect the ligation power of the donating side arm. This finding is in sharp contrast to the diminishing effect of a bulky group introduced at the second oxygen of the donating side arm.

Extraction Equilibrium. All plots in Figures 1 give straight lines with the same slope of unity, indicating that the lariat ether **3p** forms 1:1 complexes for all cations over the entire concentration range employed. This is quite reasonable since the parent 16-crown-5 also forms only 1:1 complexes.⁷ Confirmation of the 1:1 stoichiometry is essential when discussing the relative cation selectivity of the lariat ethers with reference to the distribution ratio (D_M) of metal ions between the organic and aqueous phases.

The extraction equilibrium constant data listed in Table II suggest that introduction of a donating side arm at 16-crown-5 (**3a**) to give lariat ether **3p** does not remarkably enhance the K_{ex} values for the size-fitting cations but lowers the values for the larger cations, thus yielding higher selectivities for size-fitting cations in the case of **3p** compared to the parent **3a**. This is analogously true for **1a** and **1b**. But there is a trick in the present case. It is evident from Table I that the introduction of nondonating substituents at the 15-position of 16-crown-5 results in a general decrease of the extractability for all cations (compare **3a** with **3b**, **3c**, or **3r**). The conclusion therefore is that lariat modification of **3b** does enhance both cation-binding ability and relative cation selectivity without changing the complex stoichiometry.

Substitution Effect (Entries 4, 13, 15). Although simple 15,15-dialkylation of 16-crown-5 (**3a**) is disadvantageous with regard to the cation-binding ability as mentioned above, substitution at C-15 has a different effect on the extraction behavior of single-armed lariat ethers **3m** and **3p**. Possessing the same side arm with a donor oxygen at an appropriate position but lacking the methyl group at the pivot, **3m** exhibits much lower extractabilities for all cations examined than the methyl lariat ether **3p**. A similar effect has been observed for lariat 15-crown-5 ethers.^{5b} The origins of the substitution effects are not necessarily the same in both cases, but the steric hindrance of the pivot methyl may play an important role since the framework of the crown-5 structure is fairly rigid. As shown in Figure 3a, the pivot methyl may cause repulsion with the methylenes adjacent to the pivot, locking the side arm in an appropriate conformation for better ligation. Lack of lariat effect in **3m** would indicate that, in such a conformation, the pivot hydrogen of lariat ether **3m** does

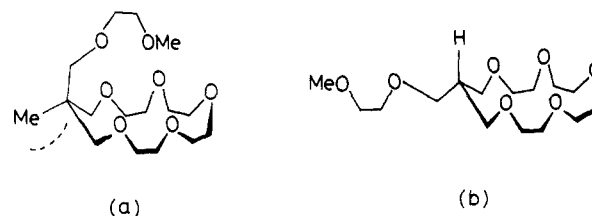


Figure 3. Schematic drawings of lariat effect.

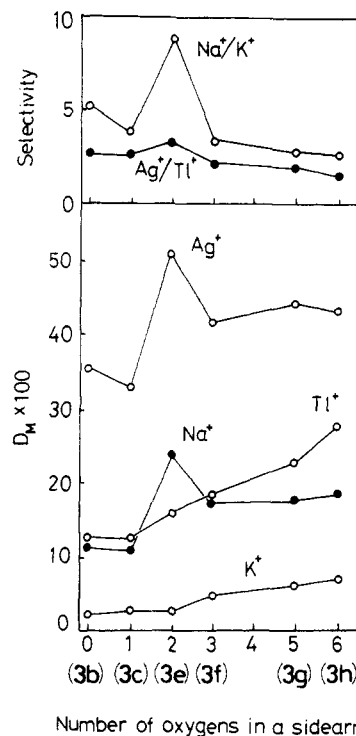


Figure 4. Plots of D_M and of ion selectivity (Na^+/K^+ and Ag^+/Tl^+) as a function of the number of oxygens (N) in a side arm of double-armed 16-crown-5 ethers **3b**, **3c**, and **3e-3h**.

not greatly contribute to push up the side arm and lock it there. However, the complete absence of enhancement in extractability may rather suggest that **3m** takes a different conformation illustrated in Figure 3b, which is probably more relaxed but evidently inadequate for further ligation by the side arm.

Cation Selectivity. In order to discuss cation selectivity more quantitatively, the distribution ratios (D_M) for selected cations and the relative selectivities for Na^+/K^+ and Ag^+/Tl^+ are plotted in Figure 4 as a function of N for the double-armed crown ethers **3b**, **3c**, and **3e-3h**. As is the case for extractability, the D_M plot for Na^+ shows a peak at $N = 2$ but the value for K^+ stays constant over $N = 0-2$. We thus found the lariat ethers **3e** and **3p** of highest Na^+/K^+ selectivity in the crown-5 series. On the other hand, the relative selectivity of Ag^+/Tl^+ exhibits just a small peak at $N = 2$ owing to the simultaneous, but still Ag^+ -favorable, increases in D_M for both cations. It should be noted that the introduction of an appropriate donating side arm not only enhances the cation-binding ability but also improves the cation selectivity of the original crown ether. Work is in progress to further improve the cation selectivity on this basis.

Lariat 16-Crown-5 vs. Lariat 15-Crown-5. It is an interesting problem to compare lariat 16-crown-5 **3m** with lariat 15-crown-5 **1b**, although we have only limited extraction data for lariat 15-crown-5. Both lariat ethers are derived by introducing the same donor side arm to the parent crown ethers, but the extraction behavior is sub-

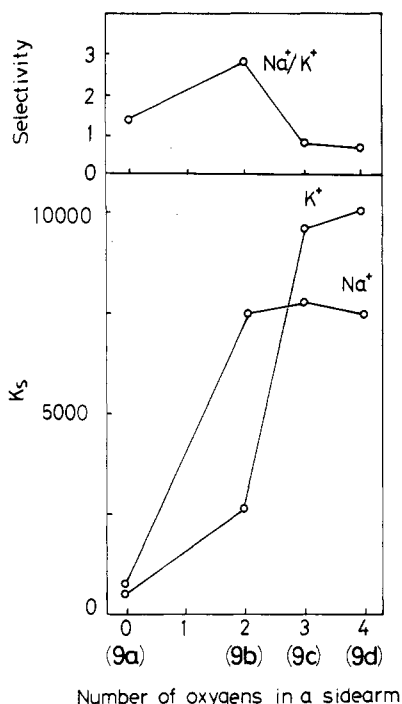
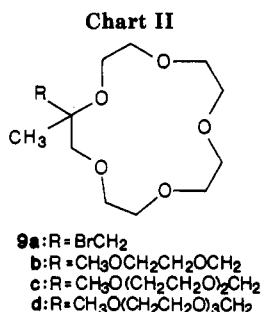


Figure 5. Plots of K_s for Na^+ and K^+ and of Na^+/K^+ selectivity as a function of the number of oxygens (N) in a side arm of lariat 15-crown-5 ethers **9a-9d**.



stantially different. In contrast with the negative lariat effect in **3m**, **1b** without a locking substituent at the pivot exhibits higher extractabilities for some cations compared to the parent **1a**, suggesting that in the 15-crown-5 series the lariat effect works to some extent in the absence of a pronounced gearing effect⁵ caused by pivot substitution.

Another interesting comparison between **1b** and **3m** is the change of cation-binding ability with increasing number (N) of side-arm oxygens. Complex stability constants (K_s) of single-armed 15-crown-5 lariats **9** for Na^+ and K^+ in methanol have been reported of a series^{5b} (Chart II). The K_s values and Na^+/K^+ selectivities were plotted as functions of N in Figure 5. The shape of the resulting plot is completely different from that for the lariat 16-crown-5 series shown in Figure 4. The K_s value for Na^+ increases distinctly to $N = 2$, and the value for K^+ , to $N = 3$. Both values appear to reach plateaus at larger N . As a result, the Na^+/K^+ selectivity shows a small peak at $N = 2$ but is reversed at $N > 2$. That no peak is found for K_s is closely related to the complex geometry of the lariat 15-crown-5 series. This result supports our previous suggestion⁷ that Na^+ , like K^+ , does not nest in but only perches on the cavity of 15-crown-5, so that the "unnecessarily" long oxyethylene chain of **9c** and **9d** does not interact repulsively with the transannular oxygen, affording K_s plateaus for Na^+ and K^+ instead of the peak for Na^+ with lariat 16-crown-5.

Lariat 19-Crown-6 (Entries 3, 18-25). For comparison

purpose, some single- and double-armed 19-crown-6 lariats were synthesized as higher homologues. The parent 19-crown-6 (**4a**) itself possesses fairly low extractabilities for most cations and slightly shifted cation selectivity to large cations,^{7b} as compared with 18-crown-6 (**2a**). Unexpectedly, the extraction behavior of the lariat 19-crown-6 series was distinctly different from that of the lariat 16-crown-5 series in at least two aspects: (1) no evident enhancement occurs in extractability for both size-matching and larger cations by introduction of additional binding sites; (2) the lariat effect works instead with the less size-fitting small cations Na^+ , Ag^+ , and Ca^{2+} .

One might suppose that the oxyethylene chain with up to three oxygens in a side arm is not long enough to reach the cation accommodated in the cavity. CPK model examinations show, however, that the third oxygen in a side arm can be located above the complexed cation by adjusting the ring conformation. Also revealed is that 19-crown-6 is structurally much more flexible and feasible to flip-flop than 16-crown-5. It is likely that in such a flexible system the pivot methyl, which causes a dramatic substitution effect in the 16-crown-5 system, does not function as a conformational locking group and the system takes a more relaxed conformation, which is inadequate for lariat ligation.

At present the reason is not necessarily clear why only the small cations enjoy considerable lariat enhancement in extractability, although the encapsulating complexation, which reduces flexibility, must be responsible to some extent. Without the presence of a rigid molecular framework, little or no substitution effect as well as lariat effect is to be expected.

Experimental Section

General Procedures. Infrared spectra were obtained on a Jasco A-100 grating spectrophotometer. Melting points were measured with a Yanaco micro melting points apparatus and are uncorrected. Mass spectra were obtained at 20 or 70 eV on a Hitachi RM-50GC, RMU-6E, or AEI MS-50 instrument. ¹H NMR spectra were recorded on a Jeol PMX-60 (60-MHz), Varian EM-360 (60-MHz), or Bruker WH-90 (90-MHz) spectrometer in CDCl_3 solution containing tetramethylsilane as an internal standard. UV-vis spectra were recorded on a Shimadzu UV-300 spectrophotometer. Preparative chromatography columns were packed with activated Al_2O_3 (Brockmann, grade II-III). Precoated sheets (Al_2O_3 60 F-254 neutral type E or SiO_2 60 F-254, Merck) were used for TLC analyses. Spectroscopic data (IR, MS, ¹H NMR) of the new compounds are given in the supplementary material. Satisfactory elemental analytical data ($\pm 0.3\%$ for C, H) were obtained for all new compounds.

Materials. Tetrahydrofuran (THF) was dried over CaCl_2 and then distilled from NaH or LiAlH_4 . The other commercially available reagents were used without further purification.

Synthesis. Pentaglyme (**5b**),^{7b} tetra- and pentaethylene glycol ditosylates (**6g**, **6h**),^{7b} 4-chloro-2-oxabutane (**7a**), and 6-chloro-2,5-dioxahexane (**7b**)⁹ were obtained as reported.

Oligoethylene glycol monomethyl ether tosylates (6a-6f) were prepared from *p*-toluenesulfonyl chloride and the corresponding oligoethylene glycol monomethyl ethers in the presence of NaOH in water/THF with reference to the reported procedure.^{7b} Purification by column chromatography (SiO_2 , eluent CH_2Cl_2) gave the tosylates **6a-6f** as colorless viscous oils in 88, 90, 68, 63, 87, and 90% yields, respectively.

5-(Hydroxymethyl)-2,2,5-trimethyl-1,3-dioxane (8a). 2-(Hydroxymethyl)-2-methyl-1,3-propanediol (200.0 g, 1.67 mol) and *p*-toluenesulfonic acid (200 mg) were dissolved in acetone (2 L, dried over CaCl_2), and the mixture was stirred for 2 days at room temperature. The solution was neutralized by adding 5 g of K_2CO_3 , filtrated, and evaporated to give the product **8a** (256 g, 96%) of satisfactory purity by ¹H NMR and IR spectra; the sample may be further purified by distillation; bp 75 °C (0.4 torr).

5-(2,5-Dioxaheptyl)-2,2,5-trimethyl-1,3-dioxane (8b) was prepared in almost quantitative yield from **8a** (160.0 g, 1.0 mol) and **6a** (197.0 g, 0.86 mol) in the presence of NaOH (80.0 g, 2.0 mol) in THF (1.5 L) according to procedure A shown below; bp 105 °C (0.4 torr). Usually the product was subjected directly to the subsequent hydrolysis.

2-(2,5-Dioxaheptyl)-2-methyl-1,3-propanediol (8c). Ketal **8b** (185.0 g, 0.86 mol) was dissolved in 10% aqueous HCl (400 mL). After being stirred for 20 h at room temperature, the resultant mixture was evaporated and the residue was distilled to give diol **8c**: 137.0 g, 90%; bp 135–137 °C (2.0 torr).

5-[(Benzyloxy)methyl]-2,2,5-trimethyl-1,3-dioxane (8d) was prepared by reaction of **8a** (160 g, 1.0 mol) with benzyl chloride (132.8 g, 1.05 mol) in the presence of Na metal (24.0 g, 1.05 mol) in xylene at 100 °C for 2 h with reference to the reported procedure.^{2b} Distillation gave 146.7 g (59%) of **8d**, bp 94–116 °C (0.25 torr).

2-Methyl-2-[(benzyloxy)methyl]-1,3-propanediol (8e) was prepared by hydrolysis (7% HCl solution) of **8d** (82.5 g, 0.31 mol) in 91% yield, mp 48–49 °C.^{2b}

Crown compounds 1c, 3a–3d, 3k, 3l, 3s, 4c–4e, 4g, and 4i were synthesized according to the methods reported.^{2b,c,3a,7a,8,10}

Alkylation Reaction (NaOH in THF). Procedure A. To a stirred suspension of finely ground NaOH (1.20 g, 30 mmol) in THF (100 mL) at reflux temperature (66 °C) under N₂ was added the respective hydroxy compound (12 mmol) in THF (100 mL). Stirring was continued for 1 h at 66 °C. The corresponding tosylate (12.5 or 25 mmol, respectively) in THF (100 mL) was then added dropwise to the stirred mixture over 1 h. Stirring was continued for 24 h at 66 °C under N₂. The solvent was distilled off, and the residue was extracted with CHCl₃. The extract was dried (MgSO₄) and evaporated to give an oily product. Purification by column chromatography (SiO₂, eluent CHCl₃/acetone) or by distillation under reduced pressure gave the product. Specific details for each compound synthesized according to this method are given below.

1b: from **1c** with **6a**; yield 58%; bp 145–151 °C (0.6 torr) [lit.^{4a} bp 150–155 °C (0.15 torr)]. **3e**: from **3d** with **6a**; 75%; bp 185 °C (0.07 torr). **3f**: from **3d** with **6b**; 75%. **3g**: from **3d** with **6c**; 78%. **3h**: from **3d** with **6d**; 75%. **3i**: from **3d** with **6e**; 72%; bp 190 °C (0.4 torr). **3j**: from **3d** with **6f**; 60%; bp 165–170 °C (0.4 torr). **3m**: from **3l** with **6a**; 85%; bp 145 °C (0.15 torr). **3p**: from **8c** with **6g**; 57%; bp 155 °C (0.3 torr). **4b**: from 2,2-dimethyl-1,3-propanediol with **6h**; 19% (lit.^{2b} 58%); bp 100–107 °C (0.4 torr). **5c**: from 2,2-dimethyl-1,3-propanediol with **6d**; 79%.

Crown Compound 3n. Solutions of **8e** (10.5 g, 50 mmol) and **6g** (25.1 g, 50 mmol) in 250 mL of THF each were simultaneously added over a period of 8 h to a vigorously stirred refluxing suspension of NaH (3.0 g, 125 mmol) in THF (1 L) under N₂ (high-dilution conditions). After being refluxed for additional 12 h, the mixture was allowed to cool to room temperature and was quenched with methanol. The solvent was evaporated, and the residue was extracted with hot Et₂O (3 × 500 mL). The combined extracts were evaporated and chromatographed over an SiO₂ column. First 1 L of petroleum ether (40–60 °C) was passed through the column to remove mineral oil (NaH suspension). The product **3n** was eluted with Et₂O: yield 45%; bp 175–178 °C (0.3 torr).

Catalytic Hydrogenolysis. Procedure B. A suspension of the respective benzyl-blocked crown compound in EtOH was hydrogenated in a Parr apparatus at a hydrogen pressure of 3 atm H₂ at room temperature for 4 h. The catalyst was filtered off, and the filtrate was evaporated to give the pure product. Specific details for the compounds obtained by this procedure are given below.

3o: from **3n**; yield 90%. **3w**: from **3u**; 95%. **3x**: from **3v**; 93%. **4l**: from **4k**; 89%.

Alkylation Reaction (NaH in THF). Procedure C. To a suspension of NaH (0.25 g, 10 mmol) in 25 mL of THF was added the respective crown alcohol (5 mmol) under N₂. After being stirred for 1 h at room temperature, the mixture was heated to reflux and the corresponding halo compound (5 mmol) dissolved in THF (5 mL) was dropped in. Refluxing was continued for additional 18 h. The mixture was cooled to room temperature and quenched with MeOH. Specific details for the compounds synthesized by this procedure are given below.

3q: from **3o** with **7b**; 60%. **3r**: from **3o** with 1-bromodecane (9); 61%. **3u**: from **3t** with **7a**; 44%. **3v**: from **3t** with **7b**; 39%. **3y**: from **3w** with **9**; 55%. **3z**: from **3x** with **9**; 52%. **4f**: from **4e** with **7b**; 64%. **4m**: from **4l** with **9**; 51%. **4k**: from **4j** with **7b**; 47%.

Reductive Cleavage. Procedure D.¹¹ LiAlH₄ (1.0 g, 25 mmol) was added to a cooled (0 °C) solution of AlCl₃ (13.3 g, 100 mmol) in 150 mL of dry Et₂O. The mixture was stirred at the same temperature for 30 min. The benzylidene-blocked crown ether **3s** or **4i** (25 mmol) was added, and the mixture was refluxed for 8 h. The mixture was cooled to room temperature and was quenched with H₂O. The ether layer was washed with H₂O, dried over MgSO₄, and evaporated to yield a colorless viscous oil. Yield: **3t**, 90%; **4j**, 92%.

Metal Picrates. Picric acid (containing 12–15% H₂O) was recrystallized from H₂O and dried in vacuo at room temperature in the dark. Sodium, potassium, rubidium, and cesium picrates were prepared from picric acid and the corresponding metal hydroxide according to the reported method.¹³ Sodium picrate was a monohydrate, and potassium, rubidium, and cesium picrates were anhydrous salts. Silver and thallium picrates (anhydrous salts) were prepared from picric acid and the corresponding metal oxide as reported.¹ Magnesium, calcium, strontium, and barium picrates were prepared from picric acid and the corresponding metal carbonates as reported.¹ Magnesium, calcium, and strontium picrates were pentahydrates. Barium picrate was an anhydrous salt.

Extraction. The general procedures employed are similar to those described in previous papers.^{1,7b} Distilled CH₂Cl₂ and demineralized H₂O were used. The solvents were saturated with each other before use in order to prevent volume changes of the phases during extraction. Equal volumes (10 mL) of a CH₂Cl₂ solution of the respective crown ether (3.0 mM) and of an aqueous solution of the corresponding metal picrate (3.0 mM) were introduced into a stoppered Erlenmeyer flask and shaken for 10 min at 25.0 ± 0.1 °C in a Taiyo M100L incubator. The mixture was then allowed to stand for at least 2 h at that temperature in order to complete phase separation. The organic phase was separated by filtration (Toyo filter paper No. 2s). The concentration of alkali- and heavy-metal picrate in the organic phase was determined from absorbance at 375 nm in a 1:1 mixture of CH₂Cl₂ and acetonitrile. The molar extinction coefficients at the absorption maximum of 375 nm for sodium, potassium, rubidium, cesium, silver, and thallium picrates are 18 600, 19 000, 18 800, 18 500, 18 800, and 18 900 M⁻¹ cm⁻¹, respectively. The concentration of alkaline-earth-metal picrate in the organic phase was determined as reported.¹ After phase separation, 5 mL of the CH₂Cl₂ phase was taken and evaporated to dryness; 5 mL of acetonitrile was then added. After further dilution with acetonitrile, if necessary, the picrate concentration in acetonitrile was determined from its absorbance at 375 nm. The molar extinction coefficients at the absorption maximum of 375 nm for magnesium, calcium, strontium, and barium picrates are 29 400, 29 700, 29 500, and 29 000 M⁻¹ cm⁻¹, respectively.

In the experiments determining extraction equilibrium constants (K_{ex}), CH₂Cl₂ solutions of a crown ether of various concentrations (2.0–7.0 mM) and aqueous solutions of various metal picrates (3.0 mM) were brought to equilibrium at 25.0 ± 0.1 °C by the same procedure.

The free crown ether concentration in the organic phase, [CE]_{org}, was calculated according to eq 2. [CE]_i is the initial concentration

$$[CE]_{org} = ([CE]_i - n[M(CE)_nA]_{org}) / (1 + K_D) \quad (2)$$

of crown ether dissolved in the organic phase, and K_D is the distribution coefficient of crown ether between the aqueous and organic phases ($K_D = [CE]_{aq} / [CE]_{org}$).

In control runs, no detectable amounts of any picrates were extracted into the organic phase in the absence of ligand.

Distribution of Crown Ether 3p. Equal volumes (25 mL) of CH₂Cl₂ solutions of **3p** (48 and 46 mM) and demineralized H₂O were brought to equilibrium at 25.0 °C under the conditions used in the extraction experiments. After the phase separation, the CH₂Cl₂ phase was evaporated and dried in vacuo (<0.5 torr) for

24 h. The aqueous phase was extracted with CH_2Cl_2 (25 mL \times 3), and the combined extracts were evaporated and dried in vacuo. The K_D value ($[\text{CE}]_{\text{aq}}/[\text{CE}]_{\text{org}}$) was determined as 0.02.

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Supplementary Material Available: Spectroscopic and analytical data for the new compounds (3 pages). Ordering information is given on any current masthead page.

Silyl-Substituted Cyanoamines as Reagents for Heterocyclic Synthesis

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Attempts to silylate the anion derived from several (dialkylamino)acetonitriles with chlorotrimethylsilane gave self-condensation products. Slow addition of chlorotrimethylsilane to (benzylmethylamino)acetonitrile followed by treatment of the resulting ammonium salt with LDA gave the α -silylated cyanoamine in excellent yield. This material on treatment with silver fluoride produced the desilylated cyanoamine rather than an aminocarbene. Treatment of benzyl[(trimethylsilyl)methyl]amino nitrile with silver fluoride in the presence of several trapping agents afforded 1,3-dipolar cycloadducts in good yield. The cycloadditions are believed to proceed via the intermediacy of a cyano-substituted azomethine ylide intermediate. Alkylation of the carbanion derived from (*N,N*-dimethylamino)acetonitrile with 5-iodo-1-(trimethylsilyl)-1-pentene proceeded in high yield. The reaction of this material with silver fluoride in aqueous ethanol gave rise to ethyl 6-(trimethylsilyl)-5-hexenoate in good yield without any detectable signs of a cyclized cyanoamine.

In previous papers in this series we outlined a strategy for the synthesis of pyrrolidines wherein the heterocyclic compound was prepared by a 1,3-dipolar cycloaddition of an azomethine ylide.¹ Studies conducted in these^{1,2} and other laboratories³⁻⁸ have shown that the desilylation of α -(trimethylsilyl)ammonium salts represent a convenient method for azomethine ylide generation. More recently we described the use of α -cyanomethylaminosilanes as

(1) Padwa, A.; Chen, Y. Y. *Tetrahedron Lett.* **1983**, 3447. Padwa, A.; Chen, Y. Y.; Dent, W.; Nimmesgern, H. *J. Org. Chem.* **1985**, *50*, 4006. Padwa, A.; Dent, W.; Parker, K. A.; Cohen, I. D. *Tetrahedron Lett.* **1984**, 4917. Padwa, A.; Chen, Y. Y.; Chiacchio, U.; Dent, W. *Tetrahedron* **1985**, *41*, 3529. Padwa, A.; Dent, W.; Tomas, M.; Chen, Y. Y.; Chiacchio, U. *J. Heterocycl. Chem.* **1985**, *22*, 21. Padwa, A.; Gasdaska, J. R. *J. Am. Chem. Soc.* **1986**, *108*, 1104.

(2) Padwa, A.; Chen, Y. Y.; Koehler, K. F.; Tomas, M. *Bull. Soc. Chim. Belg.* **1983**, *92*, 811. Padwa, A.; Haffmanns, G.; Tomas, M. *Tetrahedron Lett.* **1983**, 4303. Padwa, A.; Haffmanns, G.; Tomas, M. *J. Org. Chem.* **1984**, *49*, 3314. Padwa, A.; Chiacchio, U.; Venkatramanan, M. K. *J. Chem. Soc., Chem. Commun.* **1985**, 1108.

(3) Vedejs, E.; Martinez, G. R. *J. Am. Chem. Soc.* **1979**, *101*, 6452. Vedejs, E.; West, F. G. *J. Org. Chem.* **1983**, *48*, 4773. Vedejs, E.; Martinez, G. R. *J. Am. Chem. Soc.* **1980**, *102*, 7993. Vedejs, E.; Larsen, S.; West, F. G. *J. Org. Chem.* **1985**, *50*, 2170.

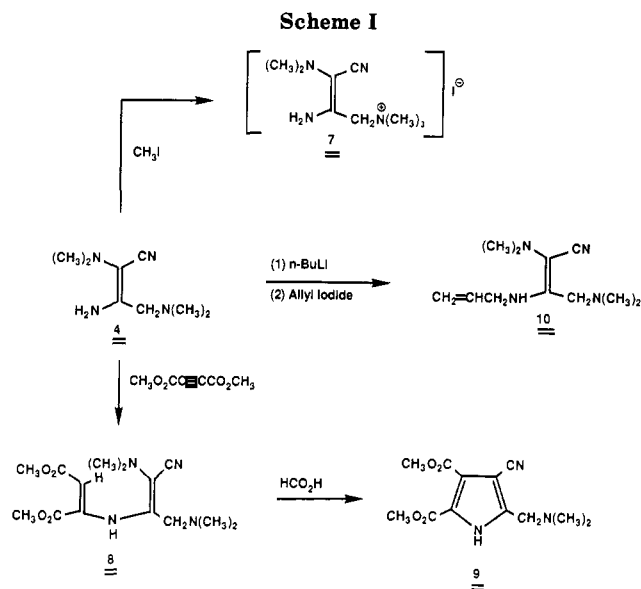
(4) Smith, R.; Livinghouse, T. *J. Org. Chem.* **1983**, *48*, 1554; *J. Chem. Soc., Chem. Commun.* **1983**, 210.

(5) Chen, S. F.; Ullrich, J. W.; Mariano, P. S. *J. Am. Chem. Soc.* **1983**, *105*, 6160.

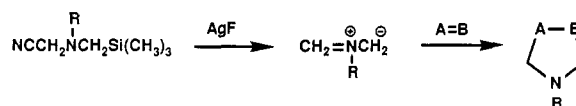
(6) Tsuge, O.; Kanemasa, S.; Kuraoka, S.; Tanenaka, S. *Chem. Lett.* **1984**, 279. Tsuge, O.; Kanemasa, S.; Kuraoka, S. *Bull. Chem. Soc. Jpn.* **1985**, *58*, 1570. Tsuge, O.; Kanemasa, S.; Kuraoka, S.; Tanenaka, S. *Chem. Lett.* **1984**, 281. Tsuge, O.; Kanemasa, S.; Matsuda, K. *Chem. Lett.* **1985**, 1411. Tsuge, O.; Kanemasa, S.; Hatada, A.; Matsuda, K. *Chem. Lett.* **1984**, 801. Tsuge, O.; Kanemasa, S.; Yamada, T.; Matsuda, K. *Heterocycles* **1985**, *23*, 2489.

(7) Terao, Y.; Imai, N.; Achiwa, K.; Sekiya, M. *Chem. Pharm. Bull.* **1982**, *30*, 3167. Achiwa, K.; Sekiya, M. *Chem. Lett.* **1981**, 1213. Achiwa, K.; Motoyama, T.; Sekiya, M. *Chem. Pharm. Bull.* **1983**, *31*, 3939. Achiwa, K.; Sekiya, M. *Heterocycles* **1983**, *20*, 167. Achiwa, K.; Imai, N.; Inaoka, T.; Sekiya, M. *Chem. Pharm. Bull.* **1984**, *32*, 2878. Imai, N.; Terao, Y.; Achiwa, K. *Heterocycles* **1985**, *23*, 1107. Achiwa, K.; Sekiya, M. *Tetrahedron Lett.* **1982**, *23*, 2589. Achiwa, K.; Imai, N.; Motoyama, T.; Sekiya, M. *Chem. Lett.* **1984**, 2041. Imai, N.; Terao, Y.; Achiwa, K.; Sekiya, M. *Tetrahedron Lett.* **1984**, 1579.

(8) Miki, Y.; Hachiken, H.; Takemura, S.; Ikeda, M. *Heterocycles* **1984**, *22*, 701.



valuable azomethine ylide precursors.¹ Exposure of these compounds to silver fluoride promotes a metal-assisted decyanation to an iminium salt^{9,10} and a concomitant desilylation¹¹ to give the unsubstituted 1,3-dipole.



From a synthetic standpoint, we were struck by the ease with which this reaction allowed the preparation of a

(9) Grierson, D. S.; Harris, M.; Husson, H. P. *J. Am. Chem. Soc.* **1980**, *102*, 1064.

(10) Overman, L. E.; Jacobsen, E. J. *Tetrahedron Lett.* **1982**, 2741.

(11) Colvin, E. W. *Chem. Soc. Rev.* **1978**, *7*, 15. Chan, T. H.; Fleming, I. *Synthesis* **1979**, 761.