Polytopic Cation Receptors. 2.[1] Synthesis and Selective Complex Formation of Spiro-Linked "Multiloop Crown Compounds"

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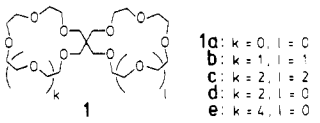
A new type of crown compound (**1–10**) featuring a spiro-linked assembly of two to four individual macrorings differing in ring size, rigidity, and donor characteristics is synthesized. Syntheses were achieved by means of high-dilution techniques and blocking/deblocking procedures beginning with pentaerythritol as the basic building block. The ability of the new ligands ("multiloop crown compounds") to selectively form crystalline polyhomonuclear/heteronuclear complexes is studied. It is found that the symmetrically looped molecules (**1a-c**, **4a**, **6**, **7d**) can incorporate two or three identical metal cations well matched in their diameter (Li^+, Na^+, K^+, Ca^{2+}, Ba^{2+}). Cations which are too large to fit into the crown rings of **1a–c** complex in a sandwich-like manner; those which are too small effect a high hydration in their complexes. Asymmetrical **1d** and **9** allow the common uptake of different metal ions, e.g., a combination of Li^+ and Ba^{2+} or of $2K^+$ and Co^{2+}. The specific occupation of the different subrings is discussed. Ligand **1b** is shown to discriminate Ca^{2+} from Na^+; **1c** and **6** preferentially complex Ba^{2+} from a Ba^{2+}/K^+ mixture. Thus, the new ligands act as manifold selective cation receptors, corresponding to the specification of their binding compartments.

Since 1970, when binuclear complexes of organic macrocyclic ligands were first reported,[2] this area of coordination chemistry has seen intensive growth.[3] Stimulations proceeded from interest in metalloenzymes, homogeneous catalysis, electical conductance, and magnetic-exchange processes.[4] As a result, most of the research was focussed on transition-metal coordination.[3,4] Multisite ligands which make possible a close neighborhood of more than one alkali or alkaline earth metal ion are still rather rare.[5-8] Although new practical applications are imaginable,[9] mixed systems for the common complexation of alkali *and* transition-metal ions are almost unknown.[10]

We recently outlined a concept for the synthesis of a novel type of multisite receptors by which *any* number and type of macrocyclic binding compartment can be linked together via a spiro skeleton.[1] The multiplicity and variability in ring aggregation is demonstrated by the ligands described here and represented by formulas **1–10**. Within the series ring sizes vary from 13 to 25 ring atoms (cf. **1a–e**), and donor sites vary from exclusively oxygen to



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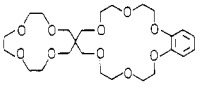

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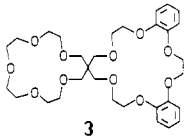

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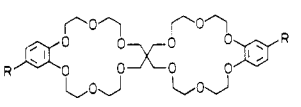

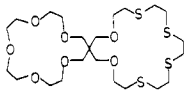

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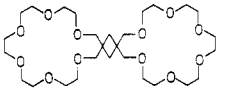

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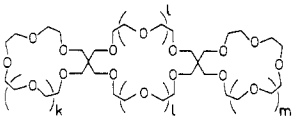
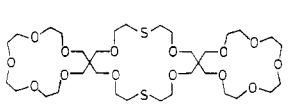
combinations of oxygen/sulfur (cf. **5** and **8**) oxygen/nitrogen donor atoms (**9**), thus providing specific binding characteristics for different cations. Variability in the





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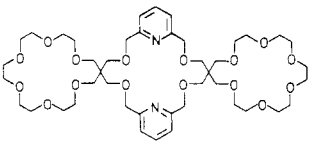

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(1) Part I: Weber, E. *Angew. Chem.* **1979**, *91*, 230; *Angew. Chem., Int. Ed. Engl.* **1979**, *18*, 219.

(2) Travis, K.; Busch, D. H. *J. Chem. Soc., Chem. Commun.* **1970**, 1041. Stotz, R. W.; Stoufer, R. C. *Ibid.* **1970**, 1682. Pilkington, N. H.; Robson, R. *Aust. J. Chem.* **1970**, *23*, 2225.

(3) Groh, S. E. *Isr. J. Chem.* **1976**, *15*, 277. Casellato, U.; Vigato, P. A.; Vidali, M. *Chem. Soc. Rev.* **1979**, *8*, 199.

(4) Casellato, U.; Vigato, P. A.; Vidali, M. *Coord. Chem. Rev.* **1977**, *23*, 31. Lehn, J. M. *Pure Appl. Chem.* **1980**, *52*, 2441.

(5) For binucleating large ring crown compounds and polydentate linear analogues, see: Dalley, N. K. In "Synthetic Multidentate Macrocyclic Compounds"; Izatt, R. M., Christensen, J. J., Eds.; Academic Press: New York, 1978; p 207. Vögtle, F.; Weber, E. In "The Chemistry of Functional Groups"; Patai, S., Ed. Wiley: New York, 1980; Supplement E, p 59. Hilgenfeld, R.; Saenger, W. *Top. Curr. Chem.* **1982**, *101*, 1.

(6) Ligand systems composed of two individual crown rings: Helgeson, R. C.; Tarnowski, T. L.; Timko, J. M.; Cram, D. J. *J. Am. Chem. Soc.* **1977**, *99*, 6411. Helgeson, R. C.; Tarnowski, T. L.; Cram, D. J. *J. Org. Chem* **1979**, *44*, 2538. Helgeson, R. C.; Weisman, G. R.; Toner, J. L.; Tarnowski, T. L.; Chao, Y.; Mayer, J. M.; Cram, D. J. *J. Am. Chem. Soc.* **1979**, *101*, 4928. Johnson, M. R.; Sutherland, I. O.; Newton, R. F. *J. Chem. Soc., Chem.* Commun. **1979**, 306. Shinkai, S.; Ogawa, T.; Kusano, Y.; Manabe, O. *Chem. Lett.* **1980**, 283; Rebek, J., Jr.; Wattley, R. V.; Costello. I.; Gadwood, R.; Marshall, L. *J. Am. Chem. Soc.* **1980**, *102*, 7398. Wada, F.; Arata, R.; Goto, T.; Kikukawa, K.; Matsuda, T. *Bull. Chem. Soc. Jpn.* **1980**, *53*, 2061.

(7) Molecular assemblies of three crown ring subunits: Dix, J. P.; Vögtle, F. *Angew. Chem.* **1978**, *90*, 893; *Angew. Chem., Int. Ed. Engl.* **1978**, *17*, 857. Frensch, K.; Vögtle, F. *Liebigs Ann. Chem.* **1979**, 2121.

(8) Crown ether polymers: Smid, J. In "Progress in Macrocyclic Chemistry"; Izatt, R. M., Christensen, J. J., Eds.; Wiley: New York, 1981; Vol. 2, p 91.

(9) Kimura, K.; Tamura, H.; Tsuchida, T.; Shono, T. *Chem. Lett.* **1979**, 611. Shinkai, S.; Nakaji, T.; Ogawa, T.; Shigematsu, K.; Manabe, O. *J. Am. Chem. Soc.* **1981**, *103*, 111.

(10) Chang, C. K. *J. Am. Chem. Soc.* **1977**, *99*, 2819. Rebek, J., Jr.; Trend, J. E.; Wattley, R. V.; Chakravorti, S. *Ibid.* **1979**, *101*, 4333. Kruse, R.; Breitmaier, E. *Chem. Ber.* **1981**, *14*, 832. See also ref 3.

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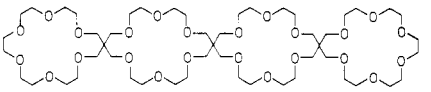
ligand framework is also derived by alteration of the succession of binding compartments (e.g., **3** and **4a**, **5** and **8**) and by ring stiffening via benzoannelation (**2–4**) as well as by a specific expansion of the centers of adjacent crown ring subunits (cf. **1c** and **6**).

The number of the ring subunits ranges from two to four, defining, e.g., **1a–c**, **4**, and **6** as *di-*, **7d** as *tri-*, and **10**



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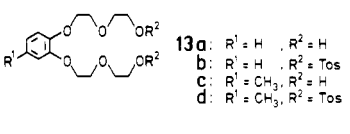
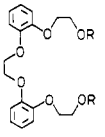
as *tetrahomotopic* molecular receptors. Ligand systems (oligocoronands[11]) including more than three individual and defined crown ether subunits have not been described so far. The ligands **1d,e**, **2**, **3**, and **5** represent *diheterotopic* and **7e**, **8**, and **9** *triheterotopic* receptor molecules, respectively. They may successively bind different substrates yielding cascade complexes.[12] In general, the ligands act in a manner corresponding to the specification of the binding compartments used in forming *polyhomonuclear/heteronuclear* complexes with suited cations. However, there is also observed cooperativity in complexation behavior which originates from an interaction of adjacent binding sites. We report here the syntheses and the specific coordination properties of this new type of ligand which we have designated as "multiloop" cation receptors for obvious reasons.

Results and Discussion

Synthetic Strategy and Ligand Synthesis. The synthetic strategy to multiloop ligands is characterized by stepwise cyclization making use of blocking/deblocking techniques (Schemes I and II). Ring closures were performed under high-dilution conditions[13] by using NaH in boiling THF as the base system. Monobenzalpentaerythitol (**12**), which was obtained from pentaerythritol (**11**) and benzaldehyde in the usual way,[14] represents the starting compound for each ligand synthesis. The cyclization of **12** with appropriate ditosylates (tri- to heptaethylene glycol ditosylate, **13b,d**) afforded the monoloop crown ethers **15a–e**. The yields for these reactions ranged from 31% to 54%, being highest for the 16- and for the 19-membered rings **15b,c** but lower for larger ring sizes (**15d,e**) and especially low for the small 13-membered cycle **15a**. In the latter case a dimeric cyclization product, **16**, was also isolated in 33% yield.[15] The ditosylates **13b** and **13d**, needed for the preparation of macrocycles **17a**



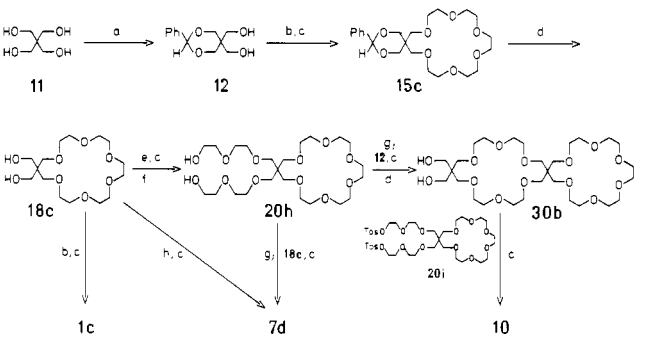
13a: R^1 = H, R^2 = H; **b**: R^1 = H, R^2 = Tos; **c**: R^1 = CH_3, R^2 = H; **d**: R^1 = CH_3, R^2 = Tos



14a: R = CH_2Ph; **b**: R = H; **c**: R = Tos

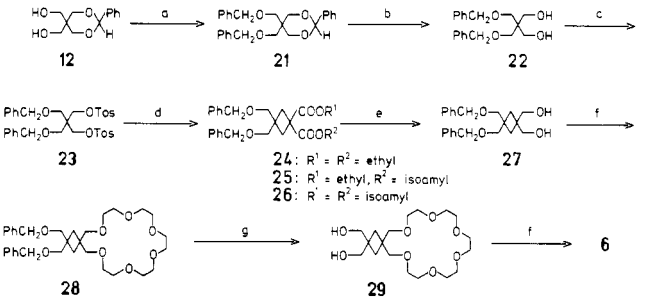
and **17b**, were obtained from diols **13a** and **13c** by common tosylation.[16] The diols **13a** and **13c** were prepared in 65% and 58% yields, respectively, from catechol, 4-methylcatechol (Aldrich Chemical Co.), and 2-(2-chloroethoxy)ethanol,[17] respectively. The latter was directly applied for

Scheme I. Synthesis of 1c, 7d, and 10, Representative for Pentaerythrityl-Linked Multiloop Crown Compounds



a: PhCHO, HCl; b: TosO(CH$_2$CH$_2$O)$_6$CH$_2$CH$_2$OTos; c: NaH, THF; d: H_2, Pd/C, EtOH, 3 atm; e: Cl(CH$_2$CH$_2$O)$_2$THP; f: HCl, EtOH; g: TosCl, pyridine; h: TosO(CH$_2$CH$_2$O)$_4$CH$_2$CH$_2$OTos.

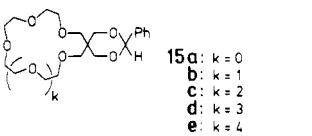
Scheme II. Synthesis of the Cyclobutane-Linked Diloop Crown Ether 6



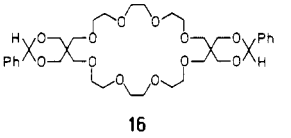
a: $PhCH_2Cl$, KOH, benzene; b: HCl, MeOH/H_2O; c: TosCl, pyridine; d: $CH_2(COOEt)_2$, isoamylalcohol; e: $LiAlH_4$, THF; f: TosO(CH$_2$CH$_2$O)$_6$CH$_2$CH$_2$OTos, NaH, THF; g: H_2, Pd/C, EtOH, 3 atm.

the reaction, i.e., without the temporary protection of the appropriate THP–ether.[18]

Functionalities for a further ring closure were liberated by hydrogenolysis of the benzylidene blocked monocycles **15a–e** and **17a,b** to afford the bis(hydroxymethyl) crown



15a: k = 0; **b**: k = 1; **c**: k = 2; **d**: k = 3; **e**: k = 4



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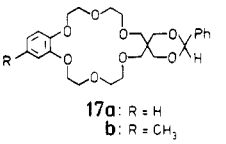
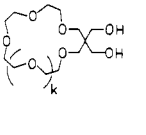
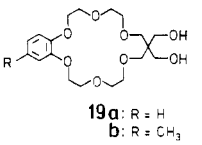


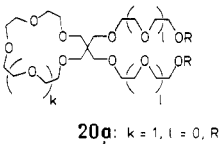
17a: R = H; **b**: R = CH_3



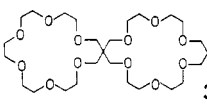
18a: k = 0; **b**: k = 1; **c**: k = 2; **d**: k = 3; **e**: k = 4



19a: R = H; **b**: R = CH_3



20a: k = 1, l = 0, R = THP; **b**: k = 1, l = 0, R = H; **c**: k = 1, l = 0, R = Tos; **d**: k = 1, l = 1, R = THP; **e**: k = 1, l = 1, R = H; **f**: k = 1, l = 1, R = Tos; **g**: k = 2, l = 1, R = THP; **h**: k = 2, l = 1, R = H; **i**: k = 2, l = 1, R = Tos



30a: R^1, R^2 =  **b**: R^1, R^2 = H

ethers **18a–e** and **19a,b** in nearly quantitative yield.[15] These diols serve as key intermediates for the synthesis of di- as well as triloop compounds. The *symmetric* double crown ethers **1a–c** and **4a,b** were obtained under high-

(11) For a new classification and notation system of organic neutral ligands, see: Weber, E.; Vögtle, F. *Inorg. Chim. Acta* **1980**, *45*, L65.
(12) Cf.: Lehn, J. M. *Pure Appl. Chem.* **1978**, *50*, 871.
(13) Cf.: Weber, E.; Vögtle, F. *Chem. Ber*, **1976**, *109*, 1803.
(14) Issidorides, C. H.; Gulen, R. *Org. Synth.* **1958**, *38*, 65.
(15) Cf.: Coxon, A. C.; Stoddart, J. F. *J. Chem. Soc., Perkin Trans. 1* **1977**, 767.
(16) Marvel, C. S.; Sekera, V. C. *Org. Synth.* **1940**, *20*, 50.
(17) Kopolow, S.; Hogen Esch, T. E.; Smid, J. *Macromolecules* **1973**, *6*, 133.
(18) Kyba, E. P.; Helgeson, R. C.; Madan, K.; Gokel, G. W.; Tarnowski, T. L.; Moore, S. S.; Cram, D. J. *J. Am. Chem. Soc.* **1977**, *99*, 2564.

Table I. Data of the Crystalline Complexes

ligand			complex[d]			
no.	compartmental sequence	salt	ligand/salt ratio (amt of H_2O)	yield, %	mp, °C	characteristic IR, cm^{-1}
1a	$O_4 \cdot O_4$	LiI	1:2 (2 H_2O)	68[a]	>300 dec	3450, 3390, 2920, 2875, 1070
1b	$O_5 \cdot O_5$	NaSCN	1:2	75[b]	204-206	2905, 2880, 2054, 1080
		KSCN	1:1	73[b]	193-195	2890, 2870, 2050, 1103, 1085
		$Ca(SCN)_2$	1:2	74[a]	>300 dec	2940, 2880, 2030, 1070, 1045
		$Ba(SCN)_2$	3:4	46[b]	234 (sinters at 229)	2930, 2880, 2045, 1078, 1062
1c	$O_6 \cdot O_6$	LiI	1:2 (4 H_2O)	71[c]	72-74	3410, 2900, 1085
		KSCN	1:2	76[b]	224-226	2905, 2070, 1100
		BaI_2	1:2 (1 H_2O)	69[b]	>350 dec	3390, 2920, 2875, 1067
		$Ba(SCN)_2$	1:2 (1 H_2O)	74[b]	275-276	3350, 2927, 2880, 2060, 1075
1d	$O_6 \cdot O_4$	LiI, BaI_2	1:1:1 (1 H_2O)	72[b]	280 dec	3410, 2915, 2875, 1070
		LiI	1:2	56[c]	196-198	2880, 1090, 1065
		BaI_2	1:1 (2 H_2O)	46[b]	225 (sinters at 95)	3400, 2920, 2875, 1073
4a	$BO_6 \cdot BO_6$	KSCN	1:1	81[b]	268-270	2905, 2880, 2060, 1595, 1505, 1250, 1085
6	$O_5 \cdot O_6$	$Ba(SCN)_2$	1:2 (3 H_2O)	42[b]	>300 dec	3390, 2920, 2880, 2850, 2076, 1070
7d	$O_6 \cdot O_6 \cdot O_6$	KSCN	1:3	45[b]	273-275	2890, 2054, 1085
9	$O_6 \cdot Py_2O_4 \cdot O_6$	KSCN, $Co(SCN)_2$	1:2:1	95[a]	106-108	2890, 2060, 1587, 1570, 1090

[a] Solvent acetone/ether. [b] Solvent acetone. [c] Solvent acetone/ethyl acetate. [d] Satisfactory analytical data for C, H, and N, where applicable, were obtained. For compound **1d** with LiI + BaI_2 satisfactory analytical data were also found for Li and Ba.

dilution conditions on employing the same ditosylates as for the first ring closure. *Asymmetric* diloops **1d,e**, **2**, and **3** clearly result from different ditosylate building blocks. The yields are comparable with that of the initial ring closure, if the same ring sizes are considered. For the double-loop crown ether **1a** which is composed of two 13-membered rings, the yield obtained was only 15%, indicating steric restrictions of the system. This might also be true of the corresponding triloop compound **7a** which could be isolated as a second fraction from the reaction mixture in 5% yield. The asymmetric diloop **5**, having a $O_5 \cdot O_2S_4$ donor-site sequence in its binding compartments, was synthesized by high-dilution cyclization from crown ditosylate **20c** and 3,6-dithia-1,8-octanedithiol;[19] ditosylate **20c** itself was synthesized from diol **18b** and 2-chloroethyl 2-tetrahydropyranyl ether,[20] followed by an acid hydrolysis/tosylation sequence. The homologous ditosylates **20f** and **20i** were prepared in the same way by beginning with diols **20e** or **20h** and 2-(2-chloroethoxy)ethyl 2-tetrahydropyranyl ether.[18]

The *cyclobutane-linked* diloop **6** was synthesized according to Scheme II. In the initial step of this sequence, monobenzalpentaerythritol (**12**)[14] was reacted with benzyl chloride to give the asymmetrically blocked pentaerythritol derivative **21**. Selective acid-induced cleavage of the benzylidene group[21] of **21** afforded the diol **22** which, after tosylation (**23**), was changed by reaction with diethyl malonate in isoamyl alcohol[22] into a mixture of the cyclobutane diesters **24–26**. The latter, originating from a transesterification with the solvent,[22] was isolated and reduced to the corresponding diol **27**. Ring closure with pentaethylene glycol ditosylate to form the monoloop **28**, deblocking of the benzyl ether group in **28**, and subsequent formation of the second crown ether ring completes the sequence.

Triloop crown compounds **7–9** were synthesized either by a two- or a four-component high-dilution cyclization, consistant with the molecular symmetry of the ligand, e.g.: **7e** (asymmetric compartments) from diol **18e** and ditosylate **20e**; **9** (identical terminal compartments) from diol **18c** and 2,6-bis(chloromethyl)pyridine[23] (see Experimental Section). The *tetraloop* crown ether **10** was obtained via ring closure of diol **30b** with diosylate **20i**; diol **30b** was cyclized from monobenzalpentaerythritol[11] and ditosylate **20i** with subsequent hydrogenolysis of the benzylidene blocking group. All assigned structures are consistent with the data derived from IR, ^1H NMR, and mass spectra. The new compounds also gave correct elemental analysis.[24]

Complexation. The ligands were shown to be general suitable hosts for the common incorporation of several cations, and they can complex identical or different metal ions (*homo-* or *heteronuclear complexes*, respectively), corresponding to the specific binding characterization of the individual coordination compartments combined in the ligand skeleton (Table I). The *symmetrical* double-loop compounds **1a–c** as well as **4a** and **6**, which have oxygen donor sites only but which, however, gradually exhibit larger rings and donor numbers, readily form homobinuclear complexes with alkali/alkaline earth metal ions suitable in their size (*homodifunctional cation receptors*); e.g., on going from **1a** to **1c**, one finds Li^+, Na^+, and K^+ to be incorporated in pairs in the given order. Ligand **1b** also complexes two Ca^{2+} ions and **1c** and **6** two Ba^{2+} ions. Complexes of **1b** with NaSCN and $Ca(SCN)_2$ and of **1c** and **4a** with KSCN are not hydrated. IR spectra confirm the thiocyanate ions[25] to be N-terminally coordinated here. LiI and BaI_2 complexes of **1a,c** were isolated in a di- or monohydrated form, respectively. A monohydrate was also obtained in case of the **1c** complex with $Ba(SCN)_2$, and

(19) Rosen, W.; Busch, D. H. *J. Am. Chem. Soc.* **1969**, *91*, 4694. Bradshaw, J. S.; Hui, J. J.; Chan, Y.; Haymore, B. L.; Izatt, R. M.; Christensen, J. J. *J. Heterocycl. Chem.* **1974**, *11*, 45.

(20) Buzas, A.; Egnell, C.; Moczar, M. *Bull. Chim. Soc. Fr.* **1962**, 267.

(21) Cf.: Baggett, N.; Brimacombe, J. S.; Foster, A. B.; Stacey, M.; Whiffen, D. H. *J. Chem. Soc.* **1960**, 2574.

(22) Cf.: Sharts, C. M.; McLeod, A. H. *J. Org. Chem* **1965**, *30*, 3308.

(23) Baker, W.; Buggle, K. M.; McOmie, J. F. W.; Watkins, D. A. M. *J. Chem. Soc.* **1958**, 3594.

(24) Except for the sulfur-containing macrocycles **5** and **8** and for the tosylates **20c,f,i** which could not be brought to analytical purity by chromatographic methods (slight decomposition). However, ^1H NMR data indicate the compounds to be practically pure.

(25) Bailey, R. A.; Kozak, S. L.; Michelson, T. W.; Mills, W. N. *Coord. Chem. Rev.* **1971**, *6*, 407.

the $Ba(SCN)_2$ complex of **6** was determined as a trihydrate which demonstrates that Ba^{2+} is not saturated by the coordination of the crown ether rings alone.[26] Another explanation might be derived from a stabilizing effect proceeding from the insertion of a separating molecule of H_2O into the space of the two adjacent Ba^{2+} ions[27] with a possible electrostatic replusion. The crown subunits of the ligand **1a** make four oxygen donor sites available. The coordination number 5, predicted as optimal for Li^+,[28] accordingly is filled up in the 2:1 (ligand/salt) **1a**–LiI complex by a pair of water molecules.

The isolation of the 2:1 LiI complex of the bis(hexaether) **1c**, which was analysed as a tetrahydrate, can hardly be explained by the previous argumentation. The X-ray crystal structure was determined,[29] and it shows that only three (adjacent to the spiro linkage) of the available six oxygen atoms of each subring are used for the coordination of the Li^+ ion. One water molecule of the solvation bridges via strong hydrogen bonds two opposite ether oxygens of the 19-membered ring and acts simultaneously as a donor toward Li^+, thus contracting the ring to a 13-crown-4 analogous size. A second water molecule traditionally binds to Li^+ and completes the coordination sphere of the metal ion.

Other examples where the complexed cation is not matched with the ring size of the ligand are revealed by the isolated 1:1 (ligand/salt) KSCN or 3:4 $Ba(SCN)_2$ complexes of **1b**. The former stoichiometry squares with the accepted complexation behavior of the 15-crown-5 system,[5] and the latter indicates a more complicated structure, possibly of the "club sandwich" type.[30]

In general, the alkaline earth ion complexes compared with alkali metal ion complexes distinguish themselves by a remarkable IR splitting in the region of the CH stretching frequency which points to a basic difference in the ligand geometry which is dependent on the charge of the complexed cation.

Selectivity in the crystalline complex formation of the double-loop **1b** is demonstrated as follows. The addition of a 1:1 mixture of NaSCN and $Ca(SCN)_2$ into a solution of **1b** in acetone/ethyl acetate leads to the precipitation of the already mentioned 1:2 Na^+ complex exclusively. In contrast, 15-crown-5 yields a 1:1 complex with $Ca(SCN)_2$ under identical conditions. The double loop **1b** was also added into a solution of KSCN and $Ba(SCN)_2$ in acetone, whereupon the same Ba^{2+} complex was formed as in the absence of K^+ ions. The systems **6**/KSCN/$Ba(SCN)_2$ or **6**/NaSCN/$Ba(SCN)_2$ are analogous. In both cases only the corresponding $Ba(SCN)_2$ complex precipitates. These statements might be interpreted with regard to a cation separation according to the charge for alkaline earth vs. alkali metal ions.

The *asymmetrical* diloop compounds **1d,e**, **2**, **3**, and **5** should be able to incorporate several cations of various types (*heterofunctional cation receptors*). Whereas a compartmental discrimination by the cation size was desired with the bis(crown ethers) **1d,e**, **2**, and **3**, the diloop **5** was assigned to also control the cation nature (oxophilic vs. thiophilic cations). A charge-differentiating effect of the binding compartments, e.g., alkali vs. alkaline earth metal ions, may be expected of the asymmetrically benzoannelated bis(crown ethers) **2** and **3** (thickness of the ligand shell as a selectivity control[28]). For determination of the assumed compartmental preferences, a series of alkali, alkaline earth, and transition-metal ion salt combinations were brought together with the given ligands. In most cases the complexes did not separate in a crystalline form or were identified to be inhomogeneous. However, an analytically pure crystaline complex of **1d** with LiI and BaI_2, which contains the components in a 1:1:1 ratio, could be isolated from an acetone/ethyl acetate solution. As the compartmental distribution of the two cations could not be elucidated unambiguously by spectroscopic means, individual complexation studies of **1d** with both cations were undertaken. In a metal complexation reaction of such a ligand the metal ion is presented with a choice between the two different compartments, which can lead to the availability of both mononuclear positional isomers and dinuclear species. In the reaction of **1d** with only BaI_2 a dihydrated 1:1 complex was isolated. A supposed occupation of the O_6 chamber of Ba^{2+} is confirmed by two facts: O_4O_4 diloop **1a** does not form a crystalline complex with BaI_2 under the same conditions, whereas O_6O_6 diloop **1c** readily precipitates a 1:2 complex (see above). The molecules of water present in **1d**–BaI_2 may effect a coordinative saturation at the metal ion or they may be taken up by the O_4 compartment coordinatively.[31] On the other hand, the reaction of **1d** with only LiI results in a crystalline, highly hygroscopic, but stoichiometric 1:2 (ligand/salt) complex. Efforts to prepare a mononuclear LiI complex of **1d** have been unsuccessful up to now.

Thus, the compartmental discrimination ability of **1d** with regard to the crystalline complex formation is demonstrated to proceed via O_6/O_4 differentiation for Ba^{2+}. Attempts to exploit the different ring sizes of **1d** for the preparation of mixed complexes exclusively with alkali metal ion salts, e.g., LiI/KI, unexpectedly resulted in a defined 1:2 LiI complex (see above) being obtained from acetone solution. Obviously, an unequal occupation of the **1d** compartments seems to require differences in size as well as differences in charge for the metal ions.

The triloop compounds **7**–**10** provide an additional receptor site for cations (*trifunctional cation receptors*) as revealed by **6d** which, in its crystalline KSCN complex, incorporates three K^+ ions altogether. Corresponding mixed complexes of the asymmetrical ligands **7e** and **8** could not be obtained in an analytically pure crystalline state from salt solutions containing LiI, KI, and RbI or NaSCN and $Co(SCN)_2$, respectively. A mixed alkali/transition metal ion complex from **9** with KSCN and $Co(SCN)_2$, however, was isolated. They found an exact 1:2:1 (ligand/K^+/Co^{2+}) stoichiometry. An X-ray crystal structure was attempted, but it could not be performed because of twinning.[32] Although not evidence, the Co^{2+} is likely to be encircled by the pyridine-containing central compartment and the K^+ ions by the terminal rings. Attempts to isolate a corresponding tetranuclear crystalline complex of compound **10** (*homotetrafunctional cation receptor*) have been unsuccessful so far.

(26) Coordination numbers for Ba^{2+} observed in crown ether complexes range from 9 to 11, 10 being preferred. Frequently, anions and molecules of water are found to participate in complexation in order to fill up the coordination polyhedron: Poonia, N. S.; Bajaj, A. V. *Chem. Rev.* **1979**, *79*, 389.

(27) Similar facts are obvious for the alkali vs. alkaline earth metal salt complexes of dibenzo-24 crown-8: dinuclear complexes are formed only in case of the singly charged alkali metal ions. See: Hughes, D. L. *J. Chem. Soc., Dalton Trans.* **1975**, 2374. Hughes, D. L.; Wingfield, J. N. *J. Chem. Soc., Chem. Commun.* **1977**, 804. Mercer, M.; Truter, M. R. *J. Chem. Soc., Dalton Trans.* **1978**, 1418. Hughes, D. L.; Mortimer, C. L.; Truter, M. R. *Acta Crystallogr., Sect. B* **1978**, *B34*, 800.

(28) Lehn, J. M. *Struct. Bonding (Berlin)* **1973**, *16*, 1.

(29) Czugler, M.; Weber, E. *J. Chem. Soc., Chem. Commun* **1981**, 472.

(30) Pederesen, C. J. *J. Am. Chem. Soc.* **1970**, *92*, 386.

(31) Cf. encircling of a complexed H_2O molecule by a crown ether ring: Goldberg, I. *Acta Crystallogr., Sect. B* **1978**, *B34*, 3387. See also: Weber, G.; Saenger W. *Ibid.* **1980**, *B36*, 207. Weber, G.; Sheldrick, G. M. *Ibid.* **1980**, *B36*, 1978.

(32) Czugler, M., private communication.

They also intended to form crystalline *mononuclear dihapto/oligohapto* complexes[33] of the multiloop crown compounds, e.g., with di/oligo ammonium ions or analogous cations. However, no analytically defined complexes of this type could be obtained, even when the geometrical factors (distance with regard to the host compartments and distance between the charges in the guest particle) seemed to be well adjusted in model studies, e.g., in the case of ligand **1c** and the octamethylene diammonium cation.

All the ligands show a high efficiency in solid-to-liquid ($Na/KMnO_4,CH_2Cl_2$) and liquid-to-liquid (Na/K picrate, CH_2Cl_2/H_2O) phase-transfer experiments. Thermodynamic and kinetic data of the complexation which was obtained by ^{23}Na NMR spectroscopic investigations are published in other studies.[34]

Experimental Section

General Methods. All infra-red (IR) spectra were obtained on a Pye-Unicam SP-1100 spectrometer and were taken in chloroform solution unless otherwise specified. The proton nuclear magnetic resonance (^1H NMR) spectra were run on a Varian EM-360 (60 MHz) spectrometer in deuteriochloroform with tetramethylsilane as an internal standard. Mass spectra were recorded on an MS-50 (AEI, Manchester, England). The elemental analyses were performed by the Microanalytical laboratory of the Institut für Organische Chemie and Biochemie, Bonn. Melting points were determined on a Kofler apparatus (Reichert, Wien) and are uncorrected. For column chromatography aluminium oxide (Brockmann, grade II-II; Woelm, Eschwege, West Germany) was used.

Materials. Tetrahydrofurane (THF) was purified by fresh distillation from $LiAlH_4$ under nitrogen. NaH was applied as a 80% suspension in mineral oil. A 10% Pd/C catalyst of type E10N (Degussa, West Germany) was used in catalytic hydrogenations.

Glycols and Their Tosylates. Di-, tri-, and tetraethylene glycol were purchased from Aldrich Chemical Co. and were used without further purification. Penta-, hexa-, and heptaethylene glycol were synthesized as described earlier.[35] The corresponding ditosylates were prepared in the usual way.[16,36] **Heptaethylene glycol ditosylate**, which is not completely characterized in the literature,[37] was obtained in 63% yield as a clear, viscous oil: IR 1594 (Ar), 1353, 1173 cm^{-1} (SO_2); ^1H NMR δ 2.42 (s, 6 H, CH_3), 3.48–3.76 (m, 24 H, OCH_2), 4.01–4.25 (m, 4 H, $TosOCH_2$), 7.15–7.83 (AB, J = 8 Hz, 8 ArH).

Anal. Calcd for $C_{28}H_{42}O_{12}S_2$: C, 52.98; H, 6.67; mol wt 634.2. Found: C, 52.98; H, 6.85; mol wt 634 (m/e value, M^+).

2,2′-[1,2-Phenylenebis(oxyethyleneoxy)]diethanol (13a) and 2,2′-[1,2-phenylenebis(oxyethyleneoxy)]diethanol bis(*p*-toluenesulfonate) (13b) were prepared according to literature procedures.[17,18]

2,2′-[4-Methyl-1,2-phenylenebis(oxyethyleneoxy)]diethanol (13c) and 2,2′-[4-methyl-1,2-phenylenebis(oxyethyleneoxy)]diethanol bis(*p*-toluenesulfonate) (13d) were synthesized analogously to **13a**[18] and **13b**[18] from 4-methylcatechol and 2-(2-chloroethoxy)ethyl 2-tetrahydropyranyl ether[18] with subsequent tosylation.

13c: distillation of the crude product affforded 58% of a colorless viscous oil; bp 196–198 °C (0.5 torr); IR 3380 (br, OH), 1580, 1490 cm^{-1} (Ar); ^1HNMR δ 2.27 (s, 3 H, CH_3), 3.36 (s, br, 2 H, OH), 3.68 (s, 8 H, CH_2CH_2OH), 3.70–3.95 (m, 4 H, $ArOCH_2CH_2$), 4.00–4.25 (m, 4 H, $ArOCH_2CH_2$), 6.61–6.73 (m, 3 Ar H).

Anal. Calcd for $C_{15}H_{24}O_6$: C, 59.98; H, 8.05; mol wt 300.4. Found: C, 59.75; H, 8.26; mol wt 300 (m/e value, M^+).

13d: yield 75% of a clear viscous oil: IR 1590, 1490 (Ar), 1350, 1170 cm^{-1} (SO_2); ^1H NMR δ 2.26 (s, 3 H, CH_3), 2.40 (s, 6 H, tosyl CH_3), 3.52–4.27 (2 m, 16 H, OCH_2), 6.58–6.72 (m, 3 H, Ar H), 7.08–7.81 (AB, J = 8 Hz, 8 H, tosyl H).

Anal. Calcd for $C_{29}H_{36}O_{10}S_2$: C, 57.22; H, 5.96; mol wt 608.2. Found: C, 57.26; H, 6.01; mol wt 608 (m/e value, M^+).

2,2′-Ethylenebis(oxy-*o*-phenyleneoxy)diethyl Dibenzyl Ether (14a). To a stirred solution of KOH (5.84 g, 104 mmol) in 200 mL of ethanol were added under N_2 2,2′-(ethylenedioxy)diphenol[38] (12.30 g, 50 mmol). The resulting suspension was heated to reflux, and a solution of 2-(benzyloxy)ethyl *p*-toluenesulfonate[39] (30.60 g, 100 mmol) in 100 mL of ethanol was added dropwise. After being boiled for 6 h, the mixture was cooled to room temperature and filtrated. Evaporation of the solution left a colorless solid which was recrystallized from ethanol to give 16.98 g (66%) of colorless crystals: mp 81–83 °C; IR (KBr) 1590, 1505 cm^{-1} (Ar); ^1H NMR δ 3.68–3.94 (m, 4 H, $PhCH_2OCH_2$), 4.05–4.30 (m, 4 H, $PhCH_2OCH_2CH_2$), 4.37 (s, 4 H, $ArOCH_2CH_2OAr$), 4.64 (s, 4 benzyl H), 6.98 (s, 8 ArH), 7.38 (s, 10 Ar H, benzyl).

Anal. Calcd for $C_{32}H_{34}O_6$: C, 74.69; H, 6.66; mol wt 514.6. Found: C, 74.83; H, 6.59; mol wt 514 (m/e value, M^+).

2,2′-[Ethylenebis(oxy-*o*-phenyleneoxy)]diethanol (14b). Procedure 1. A suspension of dibenzyl ether **14a** (15.44 g, 30 mmol) and of 10% Pd/C (2.00 g) in 100 mL of ethyl acetate was hydrogenated in a Parr apparatus at 3 atm H_2 and at room temperature for 4 h. The filtrate after evaporation solidified and was recrystallized from ethyl acetate to afford 8.10 g (81%) of colorless crystals: mp 66–68 °C; IR (KBr) 3390 (br, OH), 3080, 3070, 1595, 1510 cm^{-1} (Ar); ^1H NMR δ 3.57–4.18 (2 m, 8 H, CH_2CH_2OH), 4.31 (s, 4 H, $ArOCH_2CH_2OAr$), 4.50 (br, 2 H, OH), 6.94 (s, 8 ArH).

Anal. Calcd for $C_{18}H_{22}O_6$: C, 64.66; H, 6.63; mol wt 334.4. Found: C, 64.53; H, 6.72; mol wt 334 (m/e value, M^+).

2,2′-[Ethylenebis(oxy-*o*-phenyleneoxy)]ethanol Bis(*p*-toluenesulfonate) (14c). Diol **14b** (8.02 g, 24 mmol) and tosyl chloride (9.52 g, 50 mmol) were reacted under standard conditions[16] to give a clear viscous oil which solidified. Recrystallization from methanol yielded 3.32 g (43%) of colorless crystals: mp 97–99 °C; IR (KBr) 3080, 3050, 1595, 1505 (Ar), 1360, 1175 cm^{-1} (SO_2); ^1H NMR δ 2.38 (s, 6 H, CH_3), 4.10 (m, 12 H, OCH_2), 6.76–7.08 (m, 8 Ar H), 7.10–7.87 (AB, J = 8 Hz, 8 H, tosyl H).

Anal. Calcd for $C_{32}H_{34}O_{10}S_2$: C, 59.80; H, 5.33; mol wt 642.7. Found: C, 59.86; H, 5.39; mol wt 642 (m/e value, M^+).

General Procedure for the Synthesis of the Dioxolane-Blocked Crown Ethers 15a–e, 16, and 17a,b. Procedure 2. Monobenzalpentaerythritol[14] (11.2 g, 50 mmol) and 50 mmol of the corresponding ditosylate (see below) in separate 250-mL portions of THF were simultaneously added over a period of 8 h to a vigorously stirred refluxing suspension of NaH (3.00 g, 125 mmol) in 1 L of THF (high-dilution conditions[13]). After being boiled for additional 12 h, the mixture was allowed to cool to room temperature and was quenched with methanol. The solvent was removed under reduced pressure, and the resulting residue was extracted with hot ether (3 × 500 mL). The combined extracts were evaporated and chromatographed on an Al_2O_3 column. First 1 L of petroleum ether (40–60 °C) was passed through the column to remove the mineral oil (NaH suspension). The products were eluted with ether. Specific details are given for each compound.

3-Phenyl-2,4,8,11,14,17-hexaoxaspiro[5.12]octadecane (15a) and 3,22-Diphenyl-2,4,8,11,14,17,21,23,26,29,32,35-dodecaoxadispiro[5.12.5.12]hexatriacontane (16). Triethylene glycol ditosylate (22.9 g, 50 mmol) was reacted by using procedure 2. Two major fractions were eluted from the column.

Fraction 1: 5.30 g (31% yield) of **15a** as a colorless viscous oil; IR 1595 cm^{-1} (w, Ar); ^1H NMR δ 3.30 (s, 2 H, CH_2, equatorial), 3.48–4.34 (AB, J = 12 Hz, 4H, dioxane CH_2), 3.55–3.75 (m, 12 H, OCH_2CH_2O), 3.87 (s, 2 H, CH_2, axial), 5.38 (s, 1 H, PhCH), 7.18–7.50 (m, 5 ArH).

(33) Goldberg, I. *Acta Crystallogr. Sect. B* **1977**, *B33*, 472. Kotzyba-Hilbert, F.; Lehn, J. M.; Vierling, P. *Tetrahedron Lett.* **1980**, *21*, 941. Johnson, M. R.; Sutherland, I. O.; Newton, R. F. *J. Chem. Soc., Perkin Trans. 1* **1980**, 586.

(34) Bouquant, J.; Delville, A.; Grandjean, J.; Laszlo, P. *J. Am. Chem. Soc.*, **1982**, *104*, 686.

(35) Newcomb, M.; Moore, S. S.; Cram, D. J. *J. Am. Chem. Soc.* **1977**, *99*, 6405. Bradshaw, J. F.; Reeder, R. A.; Thompson, M. D.; Flanders, E. D.; Carruth, R. L.; Izatt, R. M.; Christensen, J. J. *J. Org. Chem.* **1976**, *41*, 134.

(36) Dale, J.; Kristiansen, P. O. *Acta Chem. Scand.* **1972**, *26*, 1471.

(37) Reinhoudt, D. N.; de Jong, F.; Tomassen, H. P. M. *Tetrahedron Lett.* **1979**, 2067.

(38) Vögtle, F.; Müller, W. M.; Weber, E. *Chem. Ber.* **1980**, *113*, 1130.

(39) Clapp, M. A.; Tipson, R. S. *J. Am. Chem. Soc.* **1946**, *68*, 1332.

Anal. Calcd for $C_{18}H_{26}O_6$: C, 63.89; H, 7.74; mol wt 338.4. Found: C, 63.97; H, 7.68; mol wt 337 (m/e value $M^+ - 1$).

Fraction 2: 5.55 g (33% yield) of dimer **16** as a colorless viscous oil; IR 1595 cm^{-1} (w, Ar); ^1H NMR δ 3.32 (s, 4 H, CH_2, equatorial), 3.65 (mc, 24 H, OCH_2CH_2O), 3.67–4.25 (AB, J = 12 Hz, 8 H, dioxane CH_2), 3.78 (s, 4 H, CH_2, axial), 5.38 (s, 2 H, PhCH), 7.19–7.54 (m, 10 ArH).

Anal. Calcd for $C_{36}H_{52}O_{12}$: C, 63.89; H, 7.74; mol wt 676.8. Found: C, 63.71; H, 7.71; mol wt 675 (m/e value, $M^+ - 1$).

3-Phenyl-2,4,8,11,14,17,20-heptaoxaspiro[5.15]heneicosane (15b). Tetraethylene glycol ditosylate (25.1 g, 50 mmol) was reacted: yield 10.3 g (54%) of a colorless viscous oil; IR 1600 cm^{-1} (w, Ar); ^1H NMR δ 3.43 (s, 2 H, CH_2, equatorial), 3.64 (mc, 16 H, OCH_2CH_2O), 3.67–4.28 (AB, J = 12 Hz, 4 H, dioxane CH_2), 3.78 (s, 2 H, CH_2, axial), 5.38 (s, 1 H, PhCH), 7.18–7.50 (m, 5 Ar H).

Anal. Calcd for $C_{20}H_{30}O_7$: C, 62.81; H, 7.91; mol wt 382.5. Found: C, 62.51; H, 7.88; mol wt 381 (m/e value, $M^+ - 1$).

3-Phenyl-2,4,8,11,14,17,20,23-octaoxaspiro[5.18]tetracosane (15c). Pentaethylene glycol ditosylate (27.4 g, 50 mmol) was reacted: yield 11.1 g (52%) of a colorless viscous oil; IR 1590 cm^{-1} (w, Ar); ^1H NMR δ 3.40 (s, 2 H, CH_2, equatorial), 3.67 (mc, 20 H, OCH_2CH_2O), 3.69–4.23 (AB, J = 12 Hz, 4 H, dioxane CH_2), 3.78 (s, 2 H, CH_2, axial), 5.38 (s, 1 H, PhCH), 7.16–7.50 (m, 5 Ar H).

Anal. Calcd for $C_{22}H_{34}O_8$: C, 61.95; H, 8.03; mol wt 426.5. Found: C, 61.83; H, 7.98; mol wt 425 (m/e value, $M^+ - 1$).

3-Phenyl-2,4,8,11,14,17,20,23,26-nonaoxaspiro[5.21]heptacosane (15d). Hexaethylene glycol ditosylate (29.6 g, 50 mmol) was reacted: yield 9.14 g (39%) of a colorless viscous oil; IR 1595 cm^{-1} (w, Ar); ^1H NMR δ 3.33 (s, 2H, CH_2, equatorial), 3.65 (mc, 24 H, OCH_2CH_2O), 3.60–4.24 (AB, J = 12 Hz, 4 H, dioxane CH_2), 3.78 (s, 2 H, CH_2, axial), 5.37 (s, 1 H, PhCH), 7.17–7.48 (m, 5 ArH).

Anal. Calcd for $C_{24}H_{38}O_9$: C, 61.26; H, 8.14; mol wt 470.6. Found: C, 61.31; H, 8.39; mol wt 469 (m/e value, $M^+ - 1$).

3-Phenyl-2,4,8,11,14,17,20,23,26,29-decaoxaspiro[5.24]triacontane (15e). Heptaethylene glycol ditosylate (31.7 g, 50 mmol) was reacted: yield 10.7 g (42%) of a colorless viscous oil; IR 1590 cm^{-1} (w, Ar); ^1H NMR δ 3.32 (s, 2 H, CH_2, equatorial), 3.64 (mc, 28 H, OCH_2CH_2O), 3.67–4.23 (AB, J = 12 Hz, 4H, dioxane CH_2), 3.78 (s, 2 H, CH_2, axial), 5.37 (s, 1 H, PhCH), 7.17–7.48 (m, 5 ArH).

Anal. Calcd for $C_{28}H_{42}O_{10}$: C, 60.68; H, 8.23; mol wt 514.6. Found: C, 60.47; H, 8.36; mol wt 513 (m/e value, $M^+ - 1$).

1,4,7,11,14,17-Hexaoxa[17](1,2)benzenophane-9-spiro-5′-(2′-phenyl-1′,3′-dioxane) (17a). Ditosylate **13b** (29.7 g, 50 mmol) was reacted: yield 9.50 g (40%) of a colorless viscous oil; IR 1590 cm^{-1} (Ar); ^1H NMR δ 3.33 (s, 2 H, CH_2, equatorial), 3.58–4.30 (m, 22 H, OCH_2CH_2O, dioxane CH_2, CH_2, axial), 5.37 (s, 1 H, PhCH), 6.85 (s, 4 H, phenylene), 7.17–7.50 (m, 5 H, phenyl).

Anal. Calcd for $C_{26}H_{34}O_8$: C, 65.80; H, 7.22; mol wt 474.6. Found: C, 65.46; H, 7.13; mol wt 473 (m/e value, $M^+ - 1$).

20-Methyl-1,4,7,11,14,17-hexaoxa[17](1,2)benzenophane-9-spiro-5′-(2′-phenyl-1′,3′-dioxane) (17b). Ditosylate **13d** (30.4 g, 50 mmol) was reacted: yield 10.5 g (43%) of a colorless viscous oil; IR 1580, 1498 cm^{-1} (Ar); ^1H NMR δ 2.26 (s, 3 H, CH_3), 3.32 (s, 2 H, CH_2, equatorial), 3.57–4.26 (m, 22 H, OCH_2CH_2O, dioxane CH_2, CH_2, axial), 5.34 (s, 1 H, PhCH), 6.66 (mc, 3 H, tolylene), 7.17–7.50 (m, 5 H, phenyl).

Anal. Calcd for $C_{27}H_{36}O_8$: C, 66.37; H, 7.43; mol wt 488.6. Found: C, 66.13; H, 7.38; mol wt 487 (m/e value, $M^+ - 1$).

Catalytic Hydrogenation to the Crown Ether Alcohols 18a–e and 19a,b. Procedure 1 was applied. Details and data for the individual compounds are given below.

12,12-Bis(hydroxymethyl)-1,4,7,10-tetraoxacyclotridecane (18a). Hydrogenolysis of **15a** in ethanol afforded a 89% yield of colorless needles (recrystallized from n-heptane): mp 85–86 °C; IR (KBr) 3410 cm^{-1} (br, OH); ^1H NMR δ 2.98 (s, br, 2 H, OH), 3.49–3.79 (m, 20 H, OCH_2).

Anal. Calcd for $C_{11}H_{22}O_6$: C, 52.78; H, 8.86; mol wt 250.3. Found: C, 52.74; H, 8.83, mol wt 251 (m/e value, $M^+ + 1$).

15,15-Bis(hydroxymethyl)-1,4,7,10,13-pentaoxacyclohexadecane (18b). Hydrogenolysis of **15b** in ethanol afforded a 95% yield of colorless crystals (recrystallized from n-heptane): mp 48–50 °C; IR (KBr) 3450 cm^{-1} (br, OH); ^1H NMR δ 3.01 (s, br, 2 H, OH), 3.48–3.77 (m, 24 H, OCH_2).

Anal. Calcd for $C_{13}H_{26}O_7$: C, 53.05; H, 8.90; mol wt 294.3. Found: C, 52.96; H, 9.03; mol wt 295 (m/e value, $M^+ + 1$).

18,18-Bis(hydroxymethyl)-1,4,7,10,13,16-hexaoxacyclononadecane (18c). Hydrogenolysis of **15c** in ethanol afforded 96% of a colorless viscous oil: IR 3460 cm^{-1} (br, OH); ^1H NMR δ 2.92 (s, br, 2H, OH), 3.52–3.77 (m, 28 H, OCH_2).

Anal. Calcd for $C_{15}H_{30}O_8$: C, 53.24; H, 8.94; mol wt 338.4. Found: C, 53.20; H, 8.81; mol wt 339 (m/e value, $M^+ + 1$).

21,21-Bis(hydroxymethyl)-1,4,7,10,13,16,19-heptaoxacyclodocosane (18d). Hydrogenolysis of **15d** in ethanol afforded 97% of a colorless viscous oil: IR 3470 cm^{-1} (br, OH); ^1H NMR δ 2.82 (s, br, 2 H, OH), 3.50–3.75 (m, 32 H, OCH_2).

Anal. Calcd for $C_{17}H_{34}O_9$: C, 53.39; H, 8.96; mol wt 382.5. Found: C, 53.29; H, 9.18; mol wt 382 (m/e value, M^+).

24,24-Bis(hydroxymethyl)-1,4,7,10,13,16,19,22-octaoxacyclopentacosane (18e). Hydrogenolysis of **15e** in ethanol afforded 90% of a colorless viscous oil: IR 3475 cm^{-1} (br, OH); ^1H NMR δ 2.87 (s, br, 2 H, OH), 3.50–3.77 (m, 36 H, OCH_2).

Anal. Calcd for $C_{19}H_{38}O_{10}$: C, 53.50; H, 8.98; mol wt 426.5. Found: C, 53.58; H, 9.27; mol wt 426 (m/e value, M^+).

9,9-Bis(hydroxymethyl)-1,4,7,11,14,17-hexaoxa[17](1,2)-benzenophane (19a). Hydrogenolysis of **17a** in ethyl acetate afforded a 96% yield of colorless crystals (recrystallized from n-heptane): mp 72–74 °C; IR (KBr) 3350 (br, OH), 1585, 1495 cm^{-1} (Ar); ^1H NMR δ 3.06 (s, br, 2 H, OH), 3.50–4.30 (m, 24 H, OCH_2), 6.83 (s, 4 ArH).

Anal. Calcd for $C_{19}H_{30}O_8$: C, 59.05; H, 7.82; mol wt 386.5. Found: C, 59.25; H, 7.67; mol wt 386 (m/e value, M^+).

9,9-Bis(hydroxymethyl)-20-methyl-1,4,7,11,14,17-hexaoxa-[17](1,2)benzenophane (19b). Hydrogenolysis of **17b** in ethyl acetate afforded a 92% yield of colorless crystals (recrystallized from n-heptane): mp 84–85 °C; IR (KBr) 3340 (br, OH), 1590, 1500 cm^{-1} (Ar); ^1H NMR δ 2.26 (s, 3 H, CH_3), 2.87 (s, br, 2 H, OH), 3:45–4.30 (m, 24 H, OCH_2), 6.58–6.73 (m, 3 ArH).

Anal. Calcd for $C_{20}H_{32}O_8$: C, 59.98; H, 8.05; mol wt 400.5. Found: C, 59.72; H, 7.99; mol wt 400 (m/e value M^+).

Monospiro Bis(crown ethers) 1a–e, 2,3, and 4a,b. The experimental procedure (high-dilution reaction) parallels that described for the synthesis of the dioxolanes **15a–e**, and **17a,b** (procedure 2). NaH (0.80 g, 33.3 mmol) in 1 L of boiling THF was used in each case. Both the diol and the ditosylate components were dissolved separately in 250 mL of THF. The purification of the compounds was accomplished by column chromatography (see procedure 2). Specific details are given for each compound.

2,5,8,11,15,18,21,24-Octaoxaspiro[12.12]pentacosane (1a). Diol **18a** (2.50 g, 10 mmol) and triethylene glycol ditosylate (4.58 g, 10 mmol) were reacted. Chromatographic workup afforded two major fractions.

Fraction 1: 0.54 g (15% yield) of pure **1a** as colorless platelets (from n-heptane); mp 78–79 °C; ^1H NMR δ 3.44–3.74 (m, all OCH_2).

Anal. Calcd for $C_{17}H_{32}O_8$: C, 56.03; H, 8.85; mol wt 364.4. Found: C, 55.99; H, 8.90; mol wt 364 (m/e value, M^+).

Fraction 2 was identified as the dispiro crown compound **7a** which is detailed in the corresponding section (see below).

2,5,8,11,14,18,21,24,27,30-Decaoxaspiro[15.15]hentriacontane (1b). Diol **15b** (2.94 g, 10 mmol) and tetraethylene glycol ditosylate (5.03 g, 10 mmol) were reacted: yield 2.35 g (52%) of a colorless viscous oil; ^1H NMR δ 3.47–3.73 (m, all OCH_2).

Anal. Calcd for $C_{21}H_{40}O_{10}$: C, 55.73; H, 8.91; mol wt 452.5. Found: C, 55.61; H, 8.69; mol wt 452 (m/e value, M^+).

2,5,8,11,14,17,21,24,27,30,33,36-Dodecaoxaspiro[18.18]heptatriacontane (1c). Diol **15c** (3.38 g, 10 mmol) and pentaethylene glycol ditosylate (5.47 g, 10 mmol) were reacted: yielded 2.75 g (51%) of a colorless viscous oil; ^1H NMR δ 3.42–3.70 (m, all OCH_2).

Anal. Calcd for $C_{25}H_{48}O_{12}$: C, 55.54; H, 8.95; mol wt 540.7. Found: C, 55.38; H, 9.01; mol wt 540 (m/e value, M^+).

2,5,8,11,15,18,21,24,27,30-Decaoxaspiro[12.18]hentriacontane (1d). Diol **8c** (3.38 g, 10 mmol) and triethylene glycol ditosylate (4.58 g, 10 mmol) were reacted: yield 1.18 g (26%) of a colorless viscous oil; ^1H NMR δ 3.43–3.72 (m, all OCH_2).

Anal. Calcd for $C_{21}H_{40}O_{10}$: C, 55.73; H, 8.91; mol wt 452.5. Found: C, 55.91; H, 9.03; mol wt 452 (m/e value, M^+).

2,5,8,11,15,18,21,24,27,30,33,36-Dodecaoxaspiro[12.24]heptatriacontane (1e). Diol **15e** (4.26 g, 10 mmol) and triethylene

glycol ditosylate (4.58 g, 10 mmol) were reacted: yield 1.51 g (28%) of a colorless viscous oil; ^{1}H NMR δ 3.42–3.72 (m, all OCH_2).

Anal. Calcd for $C_{25}H_{48}O_{12}$: C, 55.54; H, 8.95; mol wt 540.7. Found: C, 55.43; H, 9.09; mol wt 540 (*m/e* value, M^+).

1,4,7,11,14,17-Hexaoxa[17](1,2)benzenophane-9-spiro-12′-(1′,4′,7′,10′-tetraoxacyclotridecane) (2). Diol **19a** (3.86 g, 10 mmol) and triethylene glycol ditosylate (4.58 g, 10 mmol) were reacted: yield 1.48 g (30%) of a colorless viscous oil; IR 1595, 1505 cm^{-1} (Ar); ^{1}H NMR δ 3.40–4.28 (m, 36 H, OCH_2), 6.85 (s, 4 Ar H).

Anal. Calcd for $C_{25}H_{40}O_{10}$: C, 59.98; H, 8.05; mol wt 500.6. Found: C, 60.18; H, 7.89; mol wt 500 (*m/e* value, M^+).

1,4,8,11,14,17-Hexaoxa[11.4](1,2)benzenophane-6-spiro-15′-(1′,4′,7′,10′,13-pentaoxacyclohexadecane) (3). Diol **18b** (2.94 g, 10 mmol) and ditosylate **14c** (6.42 g, 10 mmol) were reacted to yield 2.19 g (37%) of colorless crystals: mp 85–87 °C (from *n*-heptane); IR (KBr) 1600, 1505 cm^{-1} (Ar); ^{1}H NMR δ 3.40–4.29 (m, 32 H, OCH_2), 4.40 (s, 4 H, $ArOCH_2CH_2OAr$), 6.90 (s, 8 Ar H).

Anal. Calcd for $C_{31}H_{44}O_{11}$: C, 62.82; H, 7.48; mol wt 592.7. Found: C, 62.75; H, 7.40; mol wt 592 (*m/e* value, M^+).

9,9′-Spirobi[1,4,7,11,14,17-hexaoxa[17](1,2)benzenophane] (4a). Diol **19a** (3.86 g, 10 mmol) and ditosylate **13b** (5.94 g, 10 mmol) were reacted to yield 2.99 g (47%) of colorless crystals: mp 77–78 °C (from ethanol); IR (KBr) 3080 (w), 1590, 1520 cm^{-1} (Ar); ^{1}H NMR δ 3.35–4.24 (m, 40 H, OCH_2), 6.85 (s, 8 Ar H).

Anal. Calcd for $C_{33}H_{48}O_{12}$: C, 62.25; H, 7.60; mol wt 636.7. Found: C,62.36; H, 7.61; mol wt 636 (*m/e* value, M^+).

20,20′-Dimethyl-9,9′-spirobi[1,4,7,11,14,17-hexaoxa[17]-(1,2)benzenophane] (4b). Diol **19b** (4.76 g, 10 mmol) and ditosylate **13d** (6.08 g, 10 mmol) were reacted to yield 2.93 g (44%) of colorless crystals: mp 55–57 °C (from ethanol); IR (KBr) 3060 (w), 1590, 1545 cm^{-1} (Ar); ^{1}H NMR δ 2.26 (s, 6 H, CH_3), 3.33–4.23 (m, 40 H, OCH_2), 6.62–6.74 (m, 6 Ar H).

Anal. Calcd for $C_{35}H_{52}O_{12}$: C, 63.23; H, 7.88; mol wt 664.8. Found: C, 63.41; H, 7.94; mol wt 664 (*m/e* value, M^+).

15,15-Bis(4-hydroxy-2-oxabutyl)-1,4,7,10,13-pentaoxacyclohexadecane (20b). Procedure 3. A solution of diol **18b** (7.35 g, 25 mmol) in 50 mL of THF was added dropwise within 15 min into a stirred suspendion of NaH (1.80 g, 75 mmol) in 50 mL of THF under N_2. The mixture was stirred for 30 min and heated to reflux, and a solution of 2-chloroethyl 2-tetrahydropyranyl ether[20] (4.11 g, 50 mmol) in 50 mL of THF was dropped in over a period of 30 min. Refluxing was continued for 6 h. The mixture then was cooled to room temperture and quenched with methanol. The solvent was removed under reduced pressure to leave crude bis(tetrahydropyranyl) ether **20a** as a brownish oily residue which was immediately used for the liberation of **20b**. The deblocking of the tetrahydropyranyl groups was effected by acidic hydrolysis.[40] For that purpose, the oil obtained was dissolved in 25 mL of ethanol, brought to pH 2.5 with concentrated HCl, and refluxed for 3 h. After cooling, the mixture was neutralized with saturated $NaHCO_3$ solution and evaporated under reduced pressure. Water was removed by coevaporation with three 100-mL portions of ethanol. The residue was triturated with chloroform, filtered from the salt, and evaporated to give 8.32 g (87%) of **20b** as a pale yellow, viscous oil. An analytical pure sample was obtained by chromatography on a SiO_2 column [elution with ethyl acetate/methanol (95:5)] and was a colorless viscous oil: IR 3410 cm^{-1} (br, OH); ^{1}H NMR δ 3.05 (br, 2 H, OH), 3.40–3.70 (m, 32 H, OCH_2).

Anal. Calcd for $C_{17}H_{34}O_9$: C, 53.39; H, 8.96; mol wt 382.5. Found: C, 52.97; H, 9.11; mol wt 383 (*m/e* value, $M^+ + 1$).

15,15-Bis(7-hydroxy-2,5-dioxaheptyl)-1,4,7,10,13-pentaoxacyclohexadecane (20e) and 18,18-Bis(7-hydroxy-2,5-dioxaheptyl)-1,4,7,10,13,16-hexaoxacyclononane (20h). Diol **18b** (14.7 g, 50 mmol) and **18c** (16.9 g, 50 mmol) were respectively allowed to react with NaH (3.00 g, 125 mmol) and 2-(2-chloroethoxy)ethyl 2-tetrahydropyranyl ether[18] (20.9 g, 100 mmol) in a manner analogous to procedure 3. The same operations were performed for the purification of the compounds.

20e: yield 18.6 g (79%) of a colorless viscous oil; IR 3430 cm^{-1} (br, OH); ^{1}H NMR δ 3.00 (br, 2 H, OH), 3.45–3.77 (m, 40 H, OCH_2).

Anal. Calcd for $C_{21}H_{42}O_{11}$: C, 53.60; H, 9.00; mol wt 470.6. Found: C, 54.01; H, 9.03; mol wt 471 (*m/e* value, $M^+ + 1$).

20h: yield 19.5 g (76%) of a colorless oil; IR 3440 cm^{-1} (br, OH); ^{1}H NMR δ 2.88 (br, 2 H, OH), 3.37–3.76 (m, 44 H, OCH_2).

Anal. Calcd for $C_{23}H_{46}O_{12}$: C, 53.68; H, 9.01; mol wt 514.6. Found: C, 53.03; H, 9.09; mol wt 515 (*m/e* value, $M^+ + 1$).

15,15-Bis[4-(*p*-toluenesulfonyloxy)-2-oxabutyl]-1,4,7,10,13-pentaoxacyclohexadecane (20c), 15,15-Bis[7-(*p*-toluenesulfonyloxy)-2,5-dioxyheptyl]-1,4,7,10,13-pentaoxacyclohexadecane (20f), and 18,18-Bis[7-(*p*-toluenesulfonyloxy)-2,5-dioxaheptyl]-1,4,7,10,13,16-hexaoxacyclononadecane (20i). The corresponding diols **20b**, **20e**, and **20h** were tosylated in the usual way.[16]

20c: yield 68% of a pale yellow viscous oil; IR 1590 (Ar), 1350, 1170 cm^{-1} (SO_2); ^{1}H NMR δ 2.43 (s, 6 H, CH_3), 3.28–3.76 (m, 28 H, OCH_2), 3.93–4.16 (m, 4 H, CH_2OTos), 7.15–7.86 (AB, J = 8 Hz, 8 H, tosyl H); high-resolution mass spectrum, calcd for $C_{31}H_{46}O_{13}S_2$ (M^+) *m/e* 690.2367, found *m/e* 690.2361.

20f: yield 72% of a pale yellow viscous oil; IR 1595 (Ar), 1350, 1170 cm^{-1} (SO_2); ^{1}H NMR δ 2.47 (s, 6 H, CH_3), 3.37–3.86 (m, 36 H, OCH_2), 4.10–4.33 (m, 4 H, CH_2OTos), 7.28–7.98 (AB, J = 8 Hz, 8 H, tosyl H); high-resolution mass spectrum, calcd for $C_{35}H_{54}O_{15}S_2$ (M^+) *m/e* 778.2889, found *m/e* 778.2881.

20i: yield 77% of a pale yellow viscous oil; IR 1595 (Ar), 1350, 1170 cm^{-1} (SO_2); ^{1}H NMR δ 2.42 (s, 6 H, CH_3), 3.30–3.80 (m, 40 H, OCH_2), 4.02–4.27 (m, 4 H, CH_2OTos), 7.20–7.90 (AB, J = 8 Hz, 8 H, tosyl H); high-resolution mass spectrum, calcd for $C_{37}H_{58}O_{16}S_2$ (M^+) *m/e* 822.3150, found *m/e* 822.3149.

2,5,8,11,14,18,33-Heptaoxa-21,24,27,30-tetrathiaspiro-[15.18]tetratriacontane (Monospiro Hetero Crown Compound) (5). Ditosylate **20c** (6.91 g, 10 mmol) in 250 mL of ethanol, 3,6-dithia-1,8-octanedithiol[19] (2.15 g, 10 mmol) in 250 mL of DMF, and KOH (1.15 g, 20.5 mmol) in 250 mL of ethanol/H_2O (99:1) were placed into a three-component high-dilution-principle setup[13] and then simultaneously added to 1 L of boiling ethanol over a 10-h period under vigorous stirring. The mixture was refluxed for additional 5 h and then evaporated under reduced pressure. The residue was washed thoroughly with water, extracted into chloroform, and dried over $MgSO_4$. Evaporation left a brownish syrup which was chromatographed on an Al_2O_3 column (Woelm, basic, grade I, chloroform as eluent) to afford 1.18 g (21%) of **5** as a clear viscous oil: ^{1}H NMR δ 2.67–2.85 (m, 16 H, SCH_2), 3.34–3.70 (m, 28 H, OCH_2; high-resolution mass spectrum, calcd for $C_{23}H_{44}O_7S_4$ (M^+) *m/e* 560.1959, found *m/e* 560.1966.

2-Phenyl-5,5-bis[(benzyloxy)methyl]-1,3-dioxane (21). A mixture of monobenzalpentaerythritol (**12**);[14] 112.0 g, 0.50 mol), benzylchloride (260.0 g, 2.06 mol), powdered KOH (116.3 g, 2.07 mol), and 700 mL of dry benzene was heated in a Dean–Stark apparatus until the separation of water was complete (16 h).[41] The obtained solution was cooled to room temperature, washed subsequently with H_2O, 0.1 N HCl, H_2O; and 2.5% aqueous K_2CO_3 (200 mL each), and dried ($NaSO_4$). Evaporation of the solvent left an oily residue which was distilled in vacuo to give 179.0 g (89% yield) of a pale yellow viscous oil: bp 246–248 °C (0.2 torr); solidifies to colorless crystals. Recrystallization from ethanol afforded colorless platelets: mp 72.5–73 °C; IR (KBr) 3105, 3080, 3050, 1610, 1590, 1500 cm^{-1} (Ar); ^{1}H NMR δ 3.33 (s, 2 H, CH_2, equatorial), 3.73–4.33 (AB, J = 12 Hz, 4 H, dioxane CH_2), 3.84 (s, 2 H, CH_2, axial), 4.43, 4.55 (2 s, 4 benzyl H), 5.38 (s, 1 H, PhCH), 7.08–7.39 (m, 15 Ar H).

Anal. Calcd for $C_{26}H_{28}O_4$: C, 77.23; H, 6.93; mol wt 404.5. Found: C, 77.20; H, 7.01; mol wt 403 (*m/e* value, $M^+ - 1$).

2,2-Bis[(benzyloxy)methyl]-1,3-propanediol (22). Benzylidene compound **21** (40.4 g, 100 mmol) in a mixture of 320 mL of methanol, 60 mL of H_2O, and 40 mL of concentrated HCl was heated to reflux for 5 h. The formed benzaldehyde was distilled off from the reaction mixture by steam. After the mixture cooled, an organic phase separated. The water layer was decanted and the oily residue evaporated with two 150-mL portions of ethanol to complete the removal of water and to effect the crystallization of the crude compound. Recrystallization from *n*-heptane yielded

(40) Reese, C. B. In "Protective Groups in Organic Chemistry"; McOmie, J. F., Ed.; Plenum Press: London, 1973; p 95.

(41) Cf.: Kates, M.; Chan, T. H.; Stanacev, N. Z. *Biochemistry* **1963**, *2*, 394.

22.3 g (70.5%) of pure **22** as colorless needles: mp 72–73 °C (lit.[42] mp 72–74 °C); IR (KBr) 3300 (br, OH), 1500 cm^{-1} (Ar); ^1H NMR δ 2.70 (br s, 2 H, OH), 3.55 (s, 4 H, $PhCH_2OCH_2$), 3.69 (s, 4 H, CH_2OH), 4.50 (s, 4 benzyl H), 7.32 (s, 10 Ar H).

2,2-Bis[(benzyloxy)methyl]-1,3-propanediyl Bis(*p*-toluenesulfonate) (23). Diol **22** (19.0 g, 60 mmol) and tosyl chloride (25.0 g, 130 mmol) were allowed to react under standard conditions.[16] The crude product was recrystallized from ethanol to yield 35.5 g (95%) of pure **23**: colorless needles; mp 116–117.5 °C; IR (KBr) 3078, 3050, 1600, 1500, 1495 (Ar), 1360, 1185 cm^{-1} (SO_2); ^1H NMR δ 2.37 (s, 6 H, CH_3), 3.38 (s, 4 H, $PhCH_2OCH_2$), 4.02 (s, 4 H, CH_2OTos), 4.30 (s, 4 benzyl H), 6.99–7.87 (m, 18 Ar H).

Anal. Calcd for $C_{33}H_{36}O_8S_2$: C, 63.44; H, 5.81; mol wt 624.8. Found: C, 63.68; H, 5.86; mol wt 624 (*m/e* value, M^+).

Diisoamyl 3,3-Bis[(benzyloxy)methyl]cyclobutane-1,1-dicarboxylate (26). Sodium metal (1.70 g, 75 mmol) was added in small pieces under stirring and under an atmosphere of nitrogen to diethyl malonate (16.0 g, 100 mmol). A suspension of ditosylate **23** (21.0 g, 33.6 mmol) in 70 mL of isoamyl alcohol was brought in, and the stirred mixture was refluxed for 19 h.[22] After the mixture was cooled, 60 mL of chloroform were added and the precipitated sodium tosylate removed by suction filtration. The filtrate was evaporated in vacuo and distilled. Several fractions within the boiling range 110–239 °C (0.4 torr) were collected and indicated (NMR) to be mixtures of the corresponding diethyl, ethyl isoamyl, and diisoamyl esters **24–26**. A high-boiling fraction (bp 230–239 °C) (0.4 torr) was identified as the practically pure diisoamyl ester **26**: yield 9.20 g (52%) of a tan viscous oil which was used without further purification; ^1H NMR δ 0.88 (d, J = 6 Hz, 6 H, CH_3), 1.20–1.70 (m, 6 H, amyl CH_2), 2.48 (s, 4 H, cyclobutyl CH_2), 3.45 (s, 4 H, $PhCH_2OCH_2$), 4.06 (t, J = 6 Hz, 4 H, $COOCH_2$), 4.47 (s, 4 benzyl H), 7.25 (s, 10 Ar H).

[3,3-Bis[(benzyloxy)methyl]-1,1-cyclobutanediyl]dimethanol (27). A solution of diester **26** (9.20 g, 17.5 mmol) in 50 mL of THF was dropped into a stirred suspension of $LiAlH_4$ (2.00 g, 53 mmol) in 50 mL of THF under nitrogen and under cooling. The mixture was refluxed for 16 h, cooled, and quenched with ice–water, followed by the addition of 15% aqueous NaOH and H_2O. The precipitated aluminium hydroxide was separated by suction filtration and extracted with THF (2 × 100 mL). The combined organic filtrates were evaporated in vacuo and the residue reevaporated with two 100-mL portions of toluene and then ethanol to remove traces of isoamyl alcohol. A pale brownish syrup was obtained which solidified. Recrystallization from *n*-heptane yielded 3.50 g (56%) of pure **27**: colorless needles; mp 87–89 °C; IR (KBr) 3310 (br, OH), 1500 cm^{-1} (Ar); ^1H NMR δ 1.88 (s, 4 H, cyclobutyl CH_2), 2.77 (br, 2 H, OH), 3.38 (s, 4 H, $PhCH_2OCH_2$), 3.61 (s, br, 4 H, CH_2OH), 4.47 (s, 4 benzyl H), 7.24 (s, 10 Ar H).

Anal. Calcd for $C_{22}H_{28}O_4$: C, 74.12; H, 7.92; mol wt 356.5. Found: C, 74.19; H, 7.85; mol wt 357 (*m/e* value, $M^+ + 1$).

2,2-Bis[(benzyloxy)methyl]-6,9,12,15,18,21-hexaoxaspiro[3.18]docosane (28). Diol **27** (7.70 g, 23.5 mmol, in 250 mL of THF), pentaethylene glycol ditosylate (12.8 g, 23.5 mmol, in 250 mL of THF, and NaH (1.80 g, 75 mmol, suspensed in 1 L of THF) were allowed to react under high-dilution conditions as described in procedure 2. An analogous workup and purification (chromatography) afforded 5.65 g (43%) of pure **28** as a colorless viscous oil: IR 1598 cm^{-1} (w, Ar); ^1H NMR δ 1.70 (s, 4 H, cyclobutyl CH_2), 3.40–3.73 (m, 28 H, CH_2O), 4.48 (s, 4 benzyl H), 7.24 (s, 10 Ar H).

Anal. Calcd for $C_{32}H_{46}O_8$: C, 68.79; H, 8.30; mol wt 558.7. Found: C, 68.55; H, 8.58; mol wt 558 (*m/e* value, M^+).

2,2-Bis(hydroxymethyl)-6,9,12,15,18,21-hexaoxaspiro[3.18]docosane (29). The experimental procedure parallels that for the hydrogenolysis of dibenzyl ether **14b**. **28** (5.00 g, 8.90 mmol) in 25 mL of ethanol and 10% Pd/C (0.50 g) was used to yield 3.27 g (97%) of a colorless syrup: IR 3450 cm^{-1} (br, OH); ^1H NMR δ 1.70 (s, 4 H, cyclobutyl CH_2), 3.07 (s, br, 2 H, OH), 3.42–3.77 (m, 28 H, OCH_2).

Anal. Calcd for $C_{18}H_{34}O_8$: C, 57.12; H, 9.05; mol wt 378.5. Found: C, 56.87; H, 9.00; mol wt 379 (*m/e* value, $M^+ + 1$).

2,5,8,11,14,17,23,26,29,32,35,38-Dodecaoxadispiro[18.1.18.1]tetracontane (6). A high-dilution reaction (procedure 2) of diol **29** (2.84 g, 7.50 mmol, in 250 mL THF), pentaethylene glycol ditosylate (4.10 g, 7.50 mmol, in 250 mL THF), and NaH (0.50 g, 20.8 mmol, in 1 L of THF) was performed. Chromatographic purification (see procedure 2) afforded 2.36 g (54% yield) of **6** as a colorless viscous oil: ^1H NMR δ 1.65 (s, 4 H, cyclobutyl CH_2), 3.41–3.77 (m, 48 H, OCH_2).

Anal. Calcd for $C_{28}H_{52}O_{12}$: C, 57.91; H, 9.03; mol wt 580.7. Found: C, 57.68; H, 9.25; mol wt 580 (*m/e* value, M^+).

Dispiro Crown Compounds 7a–e, 8, and 9. The high-dilution conditions and workup of procedure 2 apply. For the two-component cyclizations (compounds **7c,e**) 0.50 g (21 mmol) of NaH in 1 L of boiling THF was used; four-component cyclizations (compounds **7b,d**, **8**, and **9**) were performed with 0.80 g (33.3 mmol) of NaH. Both the diol and the ditosylate components were used as separate solutions in 250 mL of THF. Specific details and data for each compound are given below.

2,5,8,11,15,18,21,24,28,31,34,37,40,43,46,49-Hexadecaoxadispiro[12.12.12.12]pentacontane (7a). This compound was isolated by column chromatography in 5% yield as a second fraction in the synthesis of spiro crown ether **1a** (for preparative details see there); ^1H NMR δ 3.43–3.75 (m, all OCH_2).

Anal. Calcd for $C_{34}H_{64}O_{16}$: C, 56.03; H, 8.85; mol wt 728.9. Found: C, 55.71; H, 8.93; mol wt 728 (*m/e* value, M^+).

2,5,8,11,14,18,21,24,28,31,34,37,40,43,46,49-Hexadecaoxadispiro[15.9.15.9]pentacontane (7b). Diol **18b** (2.94 g, 10 mmol) and diethylene glycol ditosylate (4.15 g, 10 mmol) were reacted to yield 1.24 g (34%) of a colorless viscous oil; ^1H NMR δ 3.42–3.73 (m, all OCH_2).

Anal. Calcd for $C_{34}H_{64}O_{16}$: C, 56.03; H, 8.85; mol wt 728.9. Found: C, 56.24; H, 8.80; mol wt 728 (*m/e* value, M^+).

2,5,8,11,14,18,21,24,27,31,34,37,40,43,46,49,52,55-Octadecaoxadispiro[15.12.15.12]hexapentacontane (7c). Diol **20b** (1.91 g, 5 mmol) and ditosylate **20f** (3.89 g, 5 mmol) were reacted to yield 1.51 g (37%) of a colorless viscous oil, ^1H NMR δ 3.43–3.74 (m, all OCH_2).

Anal. Calcd for $C_{38}H_{72}O_{18}$: C, 55.86; H, 8.88; mol wt 817.0. Found: C, 56.03; H, 8.73; mol wt 816 (*m/e* value, M^+).

2,5,8,11,14,17,21,24,27,31,34,37,40,43,46,49,52,55-Octadecaoxadispiro[18.9.18.9]hexapentacontane (7d). Diol **18c** (3.38 g, 10 mmol) and diethylene glycol ditosylate (4.15 g, 10 mmol) were reacted to yield 1.47 g (36%) of a colorless viscous oil: ^1H NMR δ 3.40–3.74 (m, all OCH_2).

Anal. Calcd for $C_{38}H_{72}O_{18}$: C, 55.86; H, 8.88; mol wt 817.0. Found: C, 56.06; H, 8.91; mol wt 816 (*m/e* value, M^+).

2,5,8,11,14,18,21,24,28,31,34,37,40,43,46,49,52,55-Octadecaoxadispiro[15.9.21.9]hexapentacontane (7e). Diol **18d** (1.91 g, 5 mmol) and ditosylate **20f** (3.89 g, 5 mmol) were reacted to afford 2.16 g (53%) of a colorless viscous oil: ^1H NMR δ 3.46–4.70 (m, all OCH_2).

Anal. Calcd for $C_{38}H_{72}O_{18}$: C, 55.86; H, 8.88; mol wt 817.0. Found: C, 56.03; H, 9.12; mol wt 816 (*m/e* value, M^+).

2,5,8,11,14,18,24,28,31,34,37,40,43,49-Tetradecaoxa-21,46-dithiadispiro[15.9.15.9]pentacontane (8). Diol **18b** (2.94 g, 10 mmol) and 1,5-dibromo-3-thiapentane[43] (2.48 g, 10 mmol) were reacted to afford 0.32 g (8.4%) of a clear viscous oil: ^1H NMR δ 2.79 (t, J = 7 Hz, 8 H, SCH_2), 3.50–3.76 (m, 56 H, OCH_2); high-resolution mass spectrum, calcd for $C_{34}H_{64}O_{14}S_2$ (M^+) *m/e* 760.3720, found *m/e* 760.3712.

1,4,7,10,13,16-Hexaoxacyclononadecane-18-spiro-4′-[2′,6′,15′,19′-tetraoxa[7.7](2,6)pyridinophane]-17′-spiro-18″-[1″,4″,7″,10″,13″,16″-hexaoxacyclononadecane] (9). Diol **18c** (3.38 g,10 mmol) and 2,6-bis(chloromethyl)pyridine (1.76 g, 10 mmol) were reacted to afford 1.02 g (23%) of colorless needles: mp 123–125 °C; IR (KBr) 1590, 1565 cm^{-1} (Ar); ^1H NMR δ 3.40–3.73 (m, 56 H, OCH_2), 4.36 (s, 8 H, Py-CH_2), 6.74–7.40 (m, 6 H, pyridyl H).

Anal. Calcd for $C_{44}H_{70}N_2O_{16}$: C, 59.85; H, 7.99; N 3.17; mol wt 883.1. Found: C, 60.13; H, 8.09; N, 3.19; mol wt 882 (*m/e* value, M^+).

3-Phenyl-2,4,8,11,14,18,21,24,27,30,33,36,39,42-tetradecaoxadispiro[5.9.18.9]tritetracontane (30a). Monobenzal-

(42) Abdun-Nur, A. R.; Issidorides, C. H. *J. Org. Chem.* **1962**, *27*, 67.

(43) Steinkopf, W.; Herold, J.; Stöhr, J. *Ber. Dtsch. Chem. Ges.* **1920**, *53*, 1007.

pentaerythritol (12;[14] 5.60 g, 25 mmol, in 250 mL of THF), ditosylate **20i** (20.6 g, 25 mmol, in 250 mL of THF), and NaH (1.80 g, 75 mmol, in 1 L of THF) were allowed to react according to procedure 2 (high-dilution conditions). Purification of the crude product by chromatography (twice on an Al_2O_3 column, ether as the eluent) yielded 7.40 g (42%) of a colorless viscous oil: IR 1500 cm^{-1} (w, Ar); ^1H NMR δ 3.36 (s, 2 H, CH_2, equatorial), 3.40–3.74 (m, 48 H, OCH_2), 3.61–4.30 (AB, J = 12 Hz, 4 H, dioxane CH_2), 3.83 (s, 2 H, CH_2, axial), 5.41 (s, 1 H, PhCH), 7.31–7.62 (m, 5 Ar H).

Anal. Calcd for $C_{35}H_{58}O_{14}$: C, 59.81; H, 8.32; mol wt 702.8. Found: C, 59.54; H, 8.48; mol wt 701 (m/e value, $M^+ - 1$).

29,29-Bis(hydroxymethyl)-2,5,8,11,14,17,21,24,27,31,34,37-dodecaoxaspiro[18.19]octatriacontane (30b). Catalytic hydrogenation of benzylidene compound **30a** (7.03 g, 10 mmol) by following procedure 1 (ethanol as solvent) gave 5.83 g (95%) of a colorless viscous oil: IR 3440 cm^{-1} (OH); ^1H NMR δ 3.27–3.80 (m, CH_2O, OH).

Anal. Calcd for $C_{28}H_{54}O_{14}$: C, 54.71; H, 8.85; mol wt 614.7. Found: C, 54.98; H, 8.82; mol wt 614 (m/e value, M^+).

2,5,8,11,14,17,21,24,27,31,34,37,41,44,47,50,53,56,59,62,65,68,71,74-Tetracosaoxatrispiro[18.9.9.18.9.9]pentaheptacontane (Trispiro Crown Compound) (10). Bis(crown ether) diol **30b** (4.71 g, 7.5 mmol, in 250 mL of THF), crown ether ditosylate **20i** (6.19 g, 7.5 mmol, in 250 mL of THF), and NaH (0.50 g, 20.8 mmol, in 1 L of THF) were cyclized under high-dilution conditions (procedure 2). Column chromatography (Al_2O_3, ether) afforded 3.12 g (38%) of a colorless viscous oil, ^1H NMR δ 3.38–3.75 (m, all OCH_2).

Anal. Calcd for $C_{51}H_{96}O_{24}$: C, 56.03; H, 8.85; mol wt 1093.3. Found: C, 56.17; H, 9.01; mol wt 1092 (m/e value, M^+).

Preparation of the Complexes. General Procedure. The corresponding ligand (0.25 mmol) and the calculated amount of the appropriate salt (1 equiv/individual crown ether ring) were combined under stirring in 2 mL of acetone. Already at this stage the precipitation of a crystalline complex can occur. The mixture was gently refluxed for 2 h and then allowed to cool to room temperature. In those cases where the complexes did not precipitate, the crystallization was initiated by addition of ether or ethyl acetate to the start of cloudiness of the solution. After storage for 12 h at 5 °C the complexes were collected by suction filtration, washed with a few milliliters of acetone/ethyl acetate (1:1), and dried under vacuum (5 h, 15 mm, 50 °C). The used solvents, yields, and properties of the synthesized complexes are listed in Table I.

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Registry No. **1a**, 69502-43-8; **1a**·LiI, 69508-09-4; **1b**, 69502-44-9; **1b**·NaSCN, 69508-11-8; **1b**·KSCN, 69508-15-2; **1b**·$Ca(SCN)_2$, 69508-13-0; **1b**·$Ba(SCN)_2$, 82293-64-9; **1c**, 69502-15-4; **1c**·LiI, 69508-19-6; **1c**·KSCN, 82265-21-2; **1c**·BaI_2, 69508-16-3; **1c**·$Ba(SCN)_2$, 69508-18-5; **1d**, 69502-16-5; **1d**·LiI·BaI_2, 69508-20-9; **1d**·LiI, 69508-21-0; **1d**·BaI_2, 82265-22-3; **1e**, 69502-17-6; **2**, 82264-90-2; **3**, 82280-74-8; **4a**, 69502-24-5; **4a**·KSCN, 82265-24-5; **4b**, 69502-25-6; **5**, 69502-22-3; **6**, 82264-91-3; **6**·$Ba(SCN)_2$, 82265-26-7; **7a**, 69502-21-2; **7b**, 82264-92-4; **7c**, 69502-18-7; **7d**, 69502-19-8; **7d**·KSCN, 82265-27-8; **7e**, 69502-20-1; **8**, 82264-93-5; **9**, 69502-23-4; **9**·KSCN·$Co(SCN)_2$, 69508-29-8; **10**, 82264-94-6; **11**, 115-77-5; **12**, 2425-41-4; **13a**, 41757-99-7; **13b**, 41024-87-7; **13c**, 41758-02-5; **13d**, 82264-95-7; **14a**, 82264-96-8; **14b**, 68380-65-4; **14c**, 82264-97-9; **15a**, 69502-28-9; **15b**, 82264-98-0; **15c**, 69502-29-0; **15d**, 82264-99-1; **15e**, 69502-30-3; **16**, 82265-00-7; **17a**, 82265-01-8; **17b**, 82265-02-9; **18a**, 55067-00-0; **18b**, 55063-81-5; **18c**, 55063-79-1; **18d**, 69502-42-7; **18e**, 69502-31-4; **19a**, 82265-03-0; **19b**, 82265-04-1; **20a**, 82265-05-2; **20b**, 82265-06-3; **20c**, 82265-07-4; **20d**, 69502-35-8; **20e**, 82265-08-5; **20f**, 69502-39-2; **20g**, 69502-34-7; **20h**, 82265-09-6; **20i**, 69502-38-1; **21**, 82265-10-9; **22**, 2997-97-9; **23**, 82265-11-0; **24**, 82265-12-1; **25**, 82265-13-2; **26**, 82265-14-3; **27**, 82265-15-4; **28**, 82265-16-5; **29**, 82265-17-6; **30a**, 82265-18-7; **30b**, 82265-19-8; heptaethylene glycol ditosylate, 69502-27-8; 2,2-(ethylenedioxy)diphenol, 20115-81-5; 2-(benzyloxy)ethyl *p*-toluenesulfonate, 4981-83-3; triethylene glycol ditosylate, 19249-03-7; tetraethylene glycol ditosylate, 37860-51-8; pentaethylene glycol ditosylate, 41024-91-3; hexaethylene glycol ditosylate, 42749-27-9; 2-(2-chloroethoxy)ethyl 2-tetrahydropyranyl ether, 54533-84-5; diethylene glycol ditosylate, 7460-82-4.

Adducts of Anthrahydroquinone and Anthranol with Lignin Model Quinone Methides. 1. Synthesis and Characterization

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Adduct formation of anthrahydroquinone (9,10-dihydroxyanthracene, AHQ) or anthranol (9-hydroxyanthracene) with lignin model quinone methides (4-methylenecyclohexa-2,5-dienones) was established. This reaction is thought to be the key step in AHQ-catalyzed delignification of wood under alkaline pulping conditions. Numerous quinone methides derived from both 1-aryl-2-*O*-arylethyl and 1-aryl-2-*O*-arylpropyl lignin models were used. A typical example is the reaction of the quinone methide derived from 1-(3-methoxy-4-hydroxyphenyl)-2-(2-methoxyphenoxy)propane-1,3-diol with AHQ to give the adduct *threo*-1-(3-methoxy-4-hydroxyphenyl)-1-(10-hydroxy-9-oxoanthracen-10-yl)-2-(2-methoxyphenoxy)propan-3-ol. ^1H NMR spectra of the adducts revealed large diamagnetic shifts of the protons in the 1-aryl substituent due to its close approach to the shielding regions of the anthracenyl moiety. This effect dimished with increasing size of the 10-substituent (H to OH to OAc). In AHQ adducts, intense hydrogen bonding between the 10-OH and the ether oxygen of the 2-aryl ether substituent was indicated by a large paramagnetic shift of the hydroxyl proton. The unusually large diamagnetic and paramagnetic shifts reflect a distinct rigidity of the adduct conformation that is more pronounced in the adducts containing a propyl side chain.

The significant rate increase in alkaline delignification of wood induced by catalytic quantities of anthraquinone (AQ) has generated worldwide interest in the pulp and paper industry.[1-5] In a model investigation of the catalysis mechanism utilizing **1a** as a lignin model (Scheme I), a

† Maintained at Madison, WI, in cooperation with the University of Wisconsin.

(1) H. H. Holton, U.S. Patent 4 012 280 (1977).
(2) K. L. Ghosh, V. Venkatesh, W. J. Chin, and J. S. Gratzl, *Tappi*, **60** (11), 127 (1977).