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Synthesis and Crystal Structure of a Unique Linear Homoditopic Ligand Bifacially Complexed to Lithium Picrate

Leo A. Paquette,* Jinsung Tae, and Judith C. Gallucci

Evans Chemical Laboratories, The Ohio State University, Columbus, Ohio 43210

paquette.1@osu.edu

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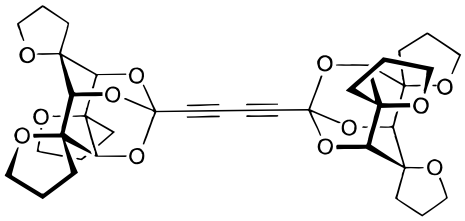
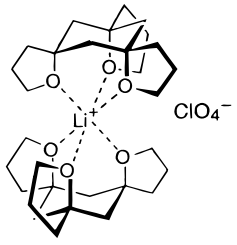
ABSTRACT



Preparation of the first rigid homoditopic tris(tetrahydrofuranyl) ligand with a pair of exotopic binding sites specifically tailored for effective coordination to lithium ions is described. The crystallographically defined structural parameters of the monomeric building block and a 1:2 complex of the dimer with lithium picrate reveal the unique features of these materials.

Self-assembly, that capacity of select molecules to form well-oriented oligomeric networks, plays an important role in supramolecular chemistry.[1] In general, ligand association develops as a direct consequence of hydrogen bonding, π-stacking, or interactions involving transition metals. Up to now, the application of group IA metal ions (Li^+, Na^+, etc.) to the formation of ionic supramolecules has not been accorded meaningful consideration. In earlier reports, we have described the readiness with which the sandwich complexes **1** and **2** can be generated.[2,3] The unique 2:1 binding feature exhibited by the two neutral ionophores and particularly the high binding selectivity for Li^+ observed in the latter instance have prompted us to consider the linkage



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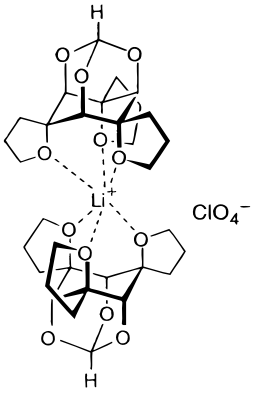

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of two inositol-based scaffolds as in **3**, exposure of which to Li^+ can be expected to result in formation of a lithium ion−ionophore coordination polymer having the generic formula **4**.[4] Beyond this, methodology has presently been developed for arresting the polymerization in a way that leads to the first linear homoditopic complex involving a pair of lithium ions.

(1) (a) Lehn, J.-M. *Supramolecular Chemistry*; VCH: Weinheim, 1995; p 138. (b) Philp, D.; Stoddart, J. F. *Angew. Chem., Int. Ed. Engl.* **1996**, *35*, 1154; *Angew. Chem.* **1996**, *108*, 1242. (c) Conn, M. M.; Rebek, J., Jr. *Chem. Rev.* **1997**, 16477. (d) de Mendoza, J. *Chem. Eur. J.* **1998**, *4*, 1373. (e) Stang, P. J. *Chem. Eur. J.* **1998**, *4*, 19.

(2) Paquette, L. A.; Tae, J.; Hickey, E. R.; Rogers, R. D. *Angew Chem., Int. Ed.* **1999**, *38*, 1409; *Angew. Chem.* **1999**, *111*, 1502.

(3) Tae, J.; Rogers, R. D.; Paquette, L. A. *Org. Lett.* **2000**, *2*, 139.

(4) After completion of this work, the preparation of rodlike ruthenium(II) coordination polymers was reported: Kelch, S.; Rehahn, M. *Chem. Commun.* **1999**, 1123.

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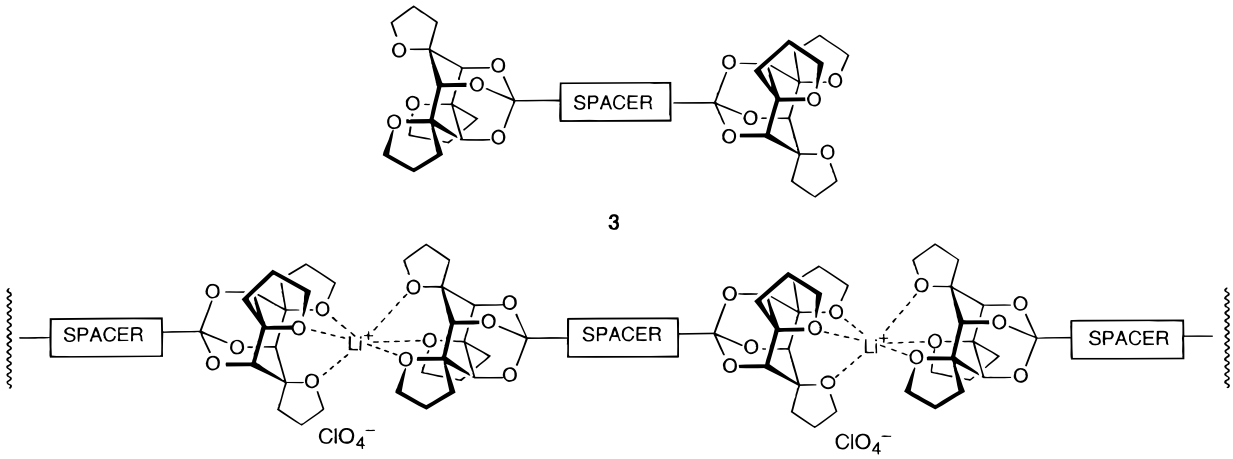
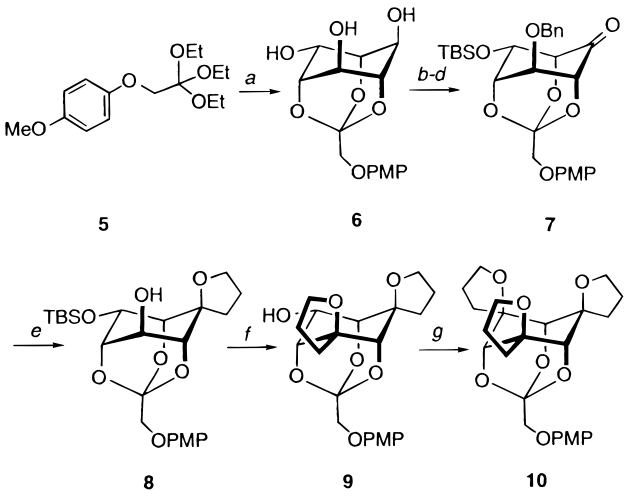


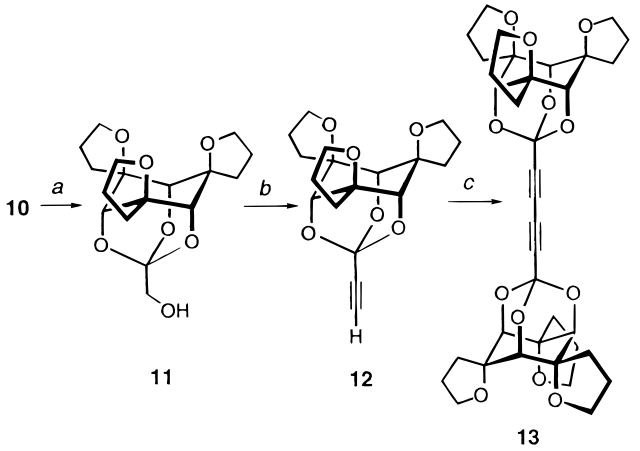
The first important consideration involves the orthoester substituent to be carried through the synthesis. The decision was made in favor of **5** because of its ready availability[5] and the robustness of the *p*-methoxyphenyl (PMP) group. Acid-promoted coupling of **5** to *myo*-inositol furnished **6** in satisfactory yield (Scheme 1). The conversion of **6** to **10** via **7**−**9** follows precedent[3] and is not detailed here. Successful arrival at this aryloxy orthoacetate-protected trispiro ether allowed us to examine the feasibility of the key dimerization reaction. Deprotection of the PMP group with ceric ammonium nitrate in aqueous acetonitrile was completed in 10 min at 0 °C (Scheme 2). Oxidation of primary alcohol **11** with the Dess−Martin periodinane or tetra-*n*-propylammonium perruthenate proved unworkable. The highly polar nature of the alcohol and the aldehyde precluded the use of oxidants that require significant purification during workup. The Swern process worked best, although efficiency was still sacrificed (<50% of crude product). Direct reaction of the unpurified aldehyde with dimethyl 1-diazo-2-oxopropylphosphonate[6] and K_2CO_3 in methanol solution gave the targeted **12** in 33% yield over two steps. This alkyne is a powdery

Scheme 1. Synthesis of the Trispiro Ligand **10**



[a] *myo*-Inositol, DMF, TsOH, 100 °C, 24 h (57%, 95% based on recovered starting material). [b] 1.0 equiv of TBSCl, imidazole, DMF (55%, 82% based on recovered starting material). [c] NaH, BnBr (56%, 86% based on recovered starting material). [d] Dess−Martin periodinane, CH_2Cl_2 (87%). [e] $ClMg(CH_2)_3OMgCl$; TsCl, Et_3N, CH_2Cl_2, 10% Pd/C, H_2 (40−50 psi), EtOAc (55% over three steps). [f] Dess−Martin periodinane; $ClMg(CH_2)_3OMgCl$; TsCl, Et_3N, CH_2Cl_2; TBAF, THF (79% over four steps). [g] Swern oxidation; $LiClO_4$, THF, rt, 2 h; $ClMg(CH_2)_3OMgCl$; TsCl, Et_3N, CH_2Cl_2 (78% over three steps).

Scheme 2. Synthesis of the Bifacial Dimeric Ionophore **13**



[a] Ceric ammonium nitrate, CH_3CN-H_2O (4:1) (69%). [b] Swern oxidation; $CH_3COC(=N_2)P(O)(OMe)_2$, K_2CO_3, MeOH (33% over two steps). [c] CuCl, TMEDA, air, CH_2Cl_2 (100%).

(5) Voss, G.; Gerlach, H. *Helv. Chim. Acta* **1983**, *66*, 2294.
(6) Muller, S.; Liepold, B.; Roth, G. R.; Bestmann, H. J. *Synlett* **1996**, 521.
(7) (a) Hamilton, D. J.; Prodi, L.; Feeder, N.; Sanders, J. K. M. *J. Chem. Soc., Perkin Trans. 1* **1999**, 1057. (b) Hay, A. S. *J. Org. Chem.* **1962**, *27*, 3320.
(8) The authors thank Dr. A. Daniel Jones (Pennsylvania State University) for the electrospray ionization mass spectrometric measurements and the interpretation thereof and Prof. Robin Rogers (University of Alabama) for the X-ray analysis of **12**.

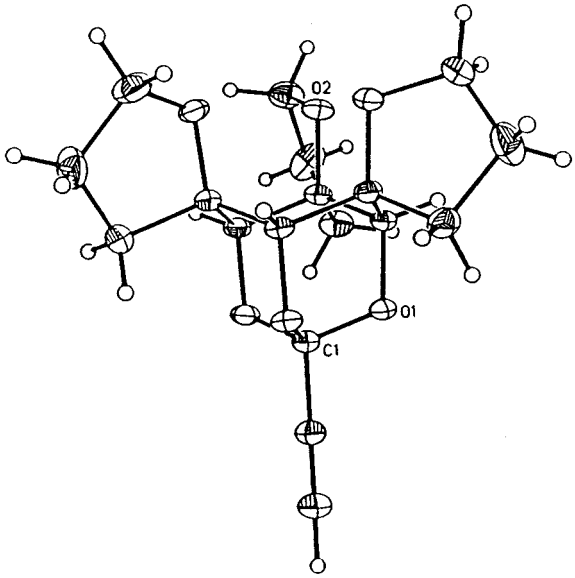


Figure 1. Perspective plot of **12** in the solid state.

white solid that has only limited solubility in CH_2Cl_2. Nevertheless, crystals of **12** suitable for X-ray diffraction have been obtained (Figure 1).

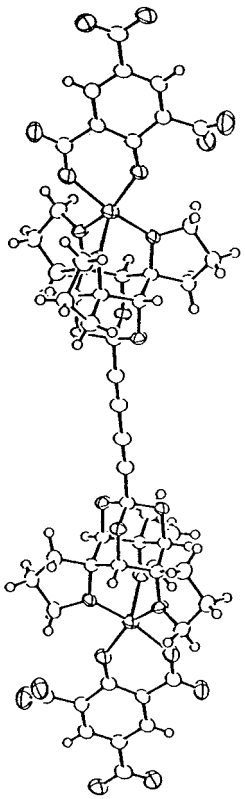
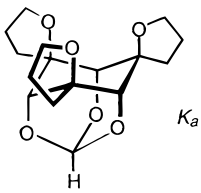
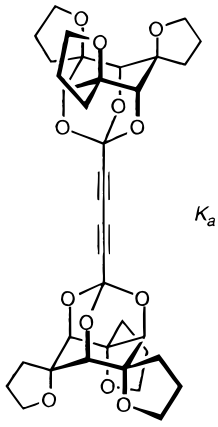


Figure 2. Crystallographically determined molecular structure of **15** drawn with 50% probability displacement ellipsoids for the non-hydrogen atoms. The hydrogen atoms are drawn with circles of arbitrary radii.

Modified Glaser coupling[7] of **12** with CuCl in the presence of TMEDA under a dry air atmosphere led to the formation of dimer **13** in quantitative yield. This highly polar colorless substance does not melt below 280 °C but is freely soluble in CH_2Cl_2 from which it is deposited as feathery crystals that turn cloudy on drying. The binding constants for **13** involving Li^+, Na^+, and K^+ picrate expectedly demonstrate the closely comparable capacities of **13** and **14** for coordination to all three guest ions (Table 1). Once again for the

Table 1. Association Constants (K_a, M^{-1}) Determined by Picrate Extraction into Chloroform at 20 °C

$$[M^+]_{aq} + [Pic^-]_{aq} + [host]_{org} \underset{}{\overset{K_a}{\rightleftharpoons}} [M^+Pic^- host]_{org}$$

	Li^+	Na^+	K^+
 **14**	1.1×10^7	2.5×10^4	5.1×10^3
	$K_a(Li^+)/K_a(Na^+) = 440$		
 **13**	1.1×10^7	4.2×10^4	1.9×10^3
	$K_a(Li^+)/K_a(Na^+) = 262$		

sake of uniformity, the K_a values have been calculated on the assumption that 1:1 complexation is operative. Although the precise degree of complexation is not known with certainty, precipitation of a colorless solid as expected for 2:1 complexation was not observed.

When solutions of **13** in $CH_3CN-CH_2Cl_2$ were treated with 1 equiv of $LiClO_4$, a white precipitate was rapidly deposited that proved sparsely soluble in most solvents. Electrospray mass spectral analysis of these samples in the positive ion mode gave spectra consisting of broad humps of low intensity over the range of m/z 2000−6000. The lack of resolution of individual peaks is taken as an indication that the substance is a much higher mass polymer (of unknown charge states) with a bit of heterogeneity likely arising from counterion association.[8] Consequently, oligomeric networks of type **4** with "spacers" consisting of 1,3-butadiyne subunits are amenable to ready production.

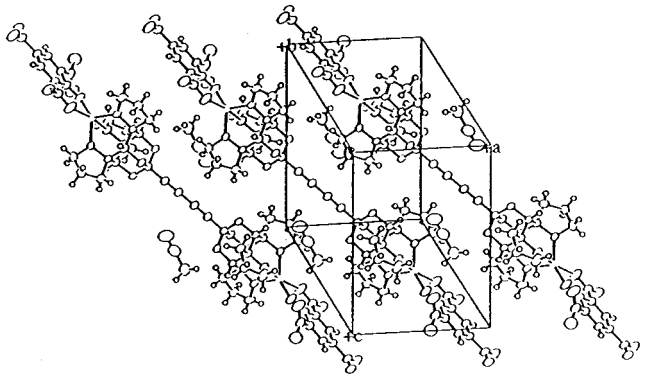


Figure 3. Packing diagram for **15**.

As anticipated, purposeful control over the unbridled formation of **4** proved to be tricky. Ultimately, it was recognized that the utilization of an internally chelated Li^+ salt such as lithium picrate can serve effectively to deliver metal atoms to the binding sites of **13** without disruption of the preexisting coordination. Thus, admixture of **13** dissolved in CH_2Cl_2 with 2 equiv of lithium picrate in CH_3CN solution resulted in the deposition of yellow crystals that proved insoluble in most solvents (CH_3CN, CH_2Cl_2, CH_3OH, H_2O, DMF). These crystals are fragile and turn cloudy on drying. X-ray crystallographic analysis defined this substance to be the bifacially capped complex **15** (Figures 2 and 3). Interestingly, the O- - -O distance in **15** (2.831 Å) is unchanged relative to that in **12** (2.830 Å).

In summary, an optimized method has been developed for the synthesis of a rigid homoditopic ligand system having exotopic tris(tetrahydrofuranyl) binding sites that share a strong affinity to bind lithium ion in a highly selective manner. The structural features of **13** are such that it can serve as a key template in the formation of alternating ionic polymers. The realization of a reliable means for harnessing the high ligating potential of **13** so as to generate well-defined bifacially capped systems typified by **15** will hopefully open this field to further fundamental exploration.

Acknowledgment. This work was financially supported by the Paquette Research Fund.

Supporting Information Available: Full characterization data for **12** and **13** and X-ray crystallographic data for **12** and **15**. This information is available free of charge via the Internet at http://pubs.acs.org.

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