4,17-Dibenzoyl-1,7,14,20-tetrakis(*p*-tolylsulfonyl)-1,4,7,14,17,20-hexaazacyclohexacosane (2e): isolated as a white solid from the second mobile band on silica with 0.1% MeOH/$CHCl_3$, 17% ^1H NMR δ 7.44 (m, 26 H), 3.65 (br, 8 H), 3.14 (br, 16 H), 2.41 (s, 12 H), 1.35 (m, 16 H); IR 3000-2860 (s), 1645 (s), 1350 (s), 1158 (s).

General Procedure for Deprotection of Selectively Protected Macrocycles. The crude reaction mixture (**1c** and **2e**, n = 6; 0.895 mequiv of benzoyl) was dissolved in THF (60 mL; distilled under N_2 from Na/benzophenone). To this was added H_2O (3.6 mmol) and sublimed potassium *tert*-butoxide (1.23 g, 11.0 mmol). The brown slurry was refluxed under a N_2 atmosphere until TLC analysis on silica showed the reaction was complete (several hours). Addition of ice caused the precipitation of the crude product, a tan solid. The rings were separated by column chromatography on silica gel with $CHCl_3$/MeOH.

1,7-Bis(*p*-tolylsulfonyl)-1,4,7-triazacyclotridecane (1d, *n* = 6): eluted as the first mobile band, using 0.5% MeOH/$CHCl_3$; isolated as a white solid in 91% yield (based on **1c**); mp 162-164 °C; ^1H NMR δ 7.49 (dd, 8 H), 3.00 (m, 12 H), 2.41 (s, 6 H), 1.55 (br, 9 H); IR 3345 (w), 1597 (sh), 1330 (s), 1145 (s); mol wt calcd 494, found 478. Anal. Calcd for $C_{24}H_{35}N_3O_4S_2$: C, 58.39; H, 7.15. Found: C, 58.00 H, 7.06.

1,7,14,20-Tetrakis(*p*-tolylsulfonyl)-1,4,7,14,17,20-hexaazacyclohexacosane (2f, *n* = 6): eluted from the column by increasing the MeOH to 2%; isolated as a white solid in 85% yield (based on **2e**); mp 145-147 °C; ^1H NMR δ 7.53 (dd, 16 H), 3.02 (m, 24 H), 2.42 (s, 12 H), 1.42 (br, 18 H); IR 3310 (w), 1598 (sh), 1340 (s), 1154 (s); mol wt calcd 987, found 1024. Anal. Calcd for $C_{48}H_{70}N_6O_8S_4$: C, 58.39; H, 7.15. Found: C, 57.83; H, 6.95.

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Registry No. **1c** (n = 2), 77429-90-4; **1c** (n = 4), 77429-91-5; **1c** (n = 6), 77429-92-6; **1d** (n = 6), 77450-07-8; **2e** (n = 4), 77429-93-7; **2e** (n = 6), 77429-94-8; **2f** (n = 6), 77429-95-9; **5**, 77429-96-0; **6** (n = 2), 6315-52-2; **6** (n = 4), 4724-56-5; **6** (n = 6), 4672-50-8; **7**, 14316-16-6; **8**, 6367-75-5; **9**, 3634-89-7; **10**, 77429-97-1; **11**, 77429-98-2.

General Synthetic Route to Hexaamine Macrocycles

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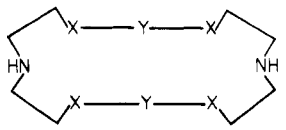
A general synthetic route has been developed for the preparation of hexaamine macrocycles containing two diethylenetriamine units joined by aliphatic hydrocarbon bridges of varying length. By use of this method, the new 20-, 22-, and 24-membered polyamines 1,4,7,11,14,17-hexaazacycloeicosane, 1,4,7,12,15,18-hexaazacyclodocosane, and 1,4,7,13,16,19-hexaazacyclotetracosane were prepared and isolated as crystalline solids. The synthetic details are described, and the characterization of the macrocycles is reported.

Macromonocycles 1 containing two distinct sets of donor atoms are of current interest due to their ability to form bimetallic complexes with transition-metal ions. The resulting binuclear compounds have the two metals positioned within a single ligand cavity and rely on the macrocylic framework rather than directly bridging groups between the metals to maintain structural integrity. Recent work with such macrocycles[1-3] has shown that discrete bimetallic complexes of this type do have unique structural, chemical, and physical properties. For macrocycle **1a**, an imidazolate-bridged dicopper complex was spontaneously formed upon addition of imidazolate to 1:1 mixtures of **1a** and Cu(II).[1] Additionally, this complex showed marked hydrolytic stability of the bridge compared to similar imidazolate-bridged complexes where the metals were not girdled by a macrocyclic ligand. In the case of **1c**, a dicopper(I) complex has been prepared[3] which has unusual reactivity with CO and O_2. A dicopper(II) complex of this same ligand which possessed two azide bridges between the metals was found to be completely diamagnetic at room temperature. Comparison of the structural data for this bridged dicopper compound with those for a nonbridged analogue indicated that the macrocycle is capable of accommodating intermetal distances spanning from ca. 5 to 7 Å[3]. Further studies of these and similar binuclear systems offer great promise for elucidating the reactivity of two metal sites, metal-exchange interactions, and multielectron redox phenomena, especially if the nature of the donor atoms and the intermetal separations can be systematically varied by synthetic control of the macrocyclic ligands.



1a, X = NH; Y = $(CH_2)_5$
b, X = NH; Y = $(CH_2CH_2)_2O$
c, X = S; Y = $(CH_2)_5$

To date, the macrocycles 1 capable of coordinating two metals have been reported only with five-atom bridges between the two diethylene tridonor units. The 18-membered homologues where Y is an ethylene bridge have been of little value in forming bimetallic complexes since they tend to encapsulate a single metal atom, yielding stable mononuclear complexes.[4,5] The reported synthetic routes to **1b**[6] and **1c**[7] are inconvenient for synthesis of large

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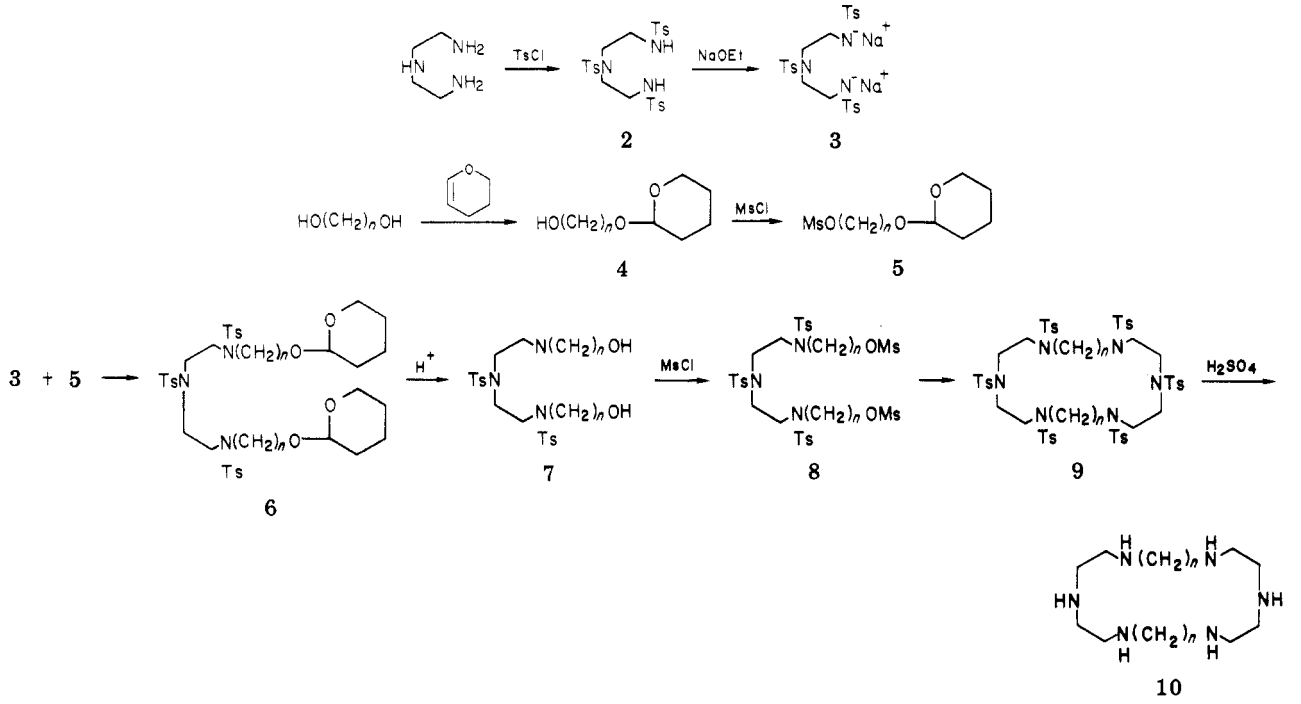
Scheme I



quantities of these macrocycles since they involve the use of high-dilution techniques in the crucial cyclization step. We wished to develop a synthetic scheme leading to these macrocycles which would eliminate the need for high-dilution conditions and, at the same time, permit the incorporation of different chain lengths Y into the macrocycle in order to systematically vary the distance between the sets of donor atoms and, ultimately, the coordinated metals.

Our approach was designed to take advantage of a reported procedure[8] for efficiently effecting ring closures at high reactant concentrations by condensing disulfonamide sodium salts of tritosylated diethylenetriamine with disulfonate esters. By use of this method, high yields of 1:1 cyclization products were obtained when equimolar mixtures of the two reactants were condensed directly with 1,*n*-diols (*n* = 2 and 3). For diols of greater length (*n* = 5 and 6), the 1:1 cyclization was less efficient, and the 2:2 cyclization byproducts were obtained in 10–15%[8] yields. Similar results were found[9] for the reaction of a selectively protected diethylenetriamine disulfonamide salt and disulfonate esters of diols. A modification of this ring-closure procedure has been detailed[10] which gives the 18-membered 1,4,7,10,13,16-hexaazacyclooctadecane (**10**, *n* = 2) in ca. 70% yields in the cyclization step. Since our interest is in the 20-, 22-, and 24-membered hexaamine macrocycles as binucleating ligands, we wanted to synthesize them free of triamine species which could interfere in subsequent studies on properties such as magnetism and reactivity due to contamination by monometallic compounds formed in the metalation reactions. We report here the results of this effort which provides a convenient synthetic method for the exclusive synthesis of the new 1,4,7,11,14,17-hexaazacycloeicosane (**10**, *n* = 3), 1,4,7,12,15,18-hexaazacyclodocosane (**10**, *n* = 4), and 1,4,7,13,16,19-hexaazacyclotetracosane (**10**, *n* = 5).

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Results and Discussion

Hexaamine macromonocycles **10** (*n* = 3–5) are easily prepared without high-dilution techniques by the sequence of reactions indicated in Scheme I. By use of this general procedure, the 20-, 22-, and 24-membered rings containing three-, four-, and five-carbon bridges linking two diethylenetriamine units are synthesized from readily available starting materials. The crucial cyclization step proceeds in yields of 20–40%. Since the reaction can be carried out on a large scale and the desired macrocycles are easily separated from the crude product mixture by simple column filtration techniques, the heretofore unavailable hexaamine macrocycles **10** can be conveniently obtained in gram quantities free of other macrocyclic impurities. This procedure represents an improvement over previous methods[8,9] in which the hexaamines are formed as byproducts in reactions where cyclic triamines are normally produced as the principal ring-closure products.

In this procedure, diols were used to form the bridges. They were first monoprotected with dihydropyran to generate **4** which was then reacted with mesyl chloride to provide the bridge precursors **5**. These mesylate derivatives were thermally unstable, and no attempt was made to completely purify them. Condensation of the crude mesylates **5** with the disodium salt of tritosylated diethylenetriamine **3** gave 80–90% yields of the stable ring precursor **6** after purification by chromatography. Mild acid hydrolysis of **6** gave the diol **7** which was reacted with mesyl chloride to form the mesylated derivative **8**. Condensation of **8** with the disodium salt **3** at 95 °C in dry dimethylformamide proceeded to give the hexatosylated macrocycles **9** in 40% (*n* = 3), 25% (*n* = 4), and 20% (*n* = 5) yields, respectively, after separation from the crude product mixture by column filtration with chloroform on silica. This isolation procedure is conveniently carried out with large quantities of crude product obtained directly by precipitation from the reaction mixture, since the macrocyclic product is the only major mobile component. Thus, short columns of wide diameter can be heavily loaded with the crude product mixture to effect the separation. A small amount of a very mobile unidentified

component is sometimes observed in the first portions of eluent but is eluted well before the macrocycle is collected.

The tosyl groups were removed from **9** by sulfuric acid hydrolysis[10] to give the free cyclic amines **10**. Progress of this reaction was conveniently followed by periodically testing small aliquots for solubility in aqueous base. The macrocycles were isolated as the hydrosulfate salts as soon as the test indicated complete removal of the tosyl groups (i.e., no insoluble residue observed during the test). Further unnecessary heating under these severe conditions resulted in product decomposition and significantly lower conversion yields. The free amines were isolated from aqueous solutions of the hydrosulfate salts either by continuous liquid–liquid extraction after basifying the solutions or by ion-exchange chromatography. Since the free amines are appreciably soluble in the aqueous base, extraction with organic solvents was inefficient. However, passage of the aqueous hydrosulfate salt solutions over a strong base ion-exchange resin, followed by evaporation of the water and extraction of the solid residue directly with organic solvents, proved to be an effective means of readily obtaining the white, hygroscopic, free amines.

Proton-decoupled ^{13}C NMR and chemical-ionization mass spectroscopic techniques were found to be particularly valuable for characterizing the hexaamines. The ^{13}C NMR spectra were simplified by the high symmetry of the macrocycles, with each spectrum having sharp and distinct absorptions consistent with the expected structures. Carbons adjacent to ring nitrogens appeared as three peaks with δ in the range of 47–50 ppm (relative to Me_4Si); peaks due to the bridge carbons were also sharp and well-separated and were found in the range of 25–30 ppm. ^1H NMR spectra, although consistent with the amine structures, were broadened and showed little fine structure. The chemical ionization mass spectra showed intense parent ions with minimal fragmentation; normal ionization mass spectral methods usually did not show the parents but consisted of highly complex patterns of fragmented amine species.

In conclusion, a synthetic route has been developed which provides a versatile means of obtaining large hexaamine macrocycles as the exclusive ring product. This scheme is currently being modified to also allow for the preparation of similar macrocycles possessing bridge substituents and other heteroatom donors. Now that they are readily available, these binucleating macrocycles and their analogues should be particularly useful in further studies of the properties of bimetallic coordination compounds of transition metals.

Experimental Section

All reagents (Aldrich, Fisher) were used as received, except where noted. Diethylenetriamine, 1,3-propanediol, 1,4-butanediol, and 1,5-pentanediol were vacuum distilled prior to use. Triethylamine was distilled under N_2 from phenyl isocyanate (2%). Dimethylformamide (DMF) and CH_2Cl_2 were dried over 4-A molecular sieves. Benzene was distilled from CaH_2 under N_2. Nitrogen gas (Linde) was passed through a column of $CaSO_4$ before use.

Melting points were determined with a Laboratory Devices Mel-Temp and are uncorrected. ^1H NMR spectra were obtained with a Perkin-Elmer R-12 magnetic resonance spectrometer. Proton-decoupled ^{13}C NMR spectra were recorded on a Bruker WP250 magnetic resonance spectrometer. All NMR samples were in $CDCl_3$, and spectra were referenced to Me_4Si. Infrared (IR) spectra were obtained as KBr pellets, except where noted, by using a Unicam SP1100 infrared spectrometer. Molecular weight determinations were made with a Hitachi Perkin-Elmer 115 vapor pressure osmometer, using CH_2Cl_2 solutions. Chemical ionization mass spectra (isobutane or methane reagent gas) were obtained in the mass spectrometry lab of the University of Delaware. Analyses were performed by MicroAnalysis, Inc.

***N,N',N''*-Tris(*p*-tolylsulfonyl)diethylenetriamine (2).** By use of the procedure of Koyama and Yoshino,[11] **2** was obtained after recrystallization from ethanol as a white solid: 60% yield; mp 175.5–177.0 °C (lit.[11] mp 173 °C); ^1H NMR δ 7.58 (dd, 12 H), 5.22 (t, 2 H), 3.18 (br, 8 H), 2.42 (s, 9 H); IR 3290 (s), 1601 (sh), 1330 (s), 1155 cm^{-1} (s).

***N,N',N''*-Tris(*p*-tolylsulfonyl)diethylenetriamine *N,N''*-Disodium Salt (3).** Compound **3** was prepared from **2** by treatment with NaOEt[8,10] to give the product as a white solid: ca. 95% yield; IR 1600 (sh), 1335 (s), 1152 (s). Compound **3** was not purified further and could be stored dry under N_2 for several months.

Procedure for Synthesis of Monotetrahydropyranyloxy Derivatives of Diols (4). On the basis of a reported procedure,[12] the diol (5.25 mol) was treated dropwise with 2,3-dihydropyran (1.75 mol) in the presence of a few drops of concentrated HCl. The solution was stirred for several hours, and the mono- and disubstituted products were separated from the unreacted diol by extraction into benzene. The benzene layer was washed with H_2O, dried with K_2CO_3, and evaporated. Fractional vacuum distillation of the residue provided the product, a colorless liquid, in 30–50% yield.

3-[(Tetrahydropyran-2-yl)oxy]propan-1-ol (4, *n* = 3): bp 70 °C (2 mmHg); ^1H NMR δ 4.60 (br, 1 H), 3.77 (m, 6 H), 2.58 (t, 1 H), 1.75 (m, 8 H); IR (neat) 3460 (br), 2960–2850 (s), 1450 (m), 1030 cm^{-1} (m).

4-[(Tetrahydropyran-2-yl)oxy]butan-1-ol (4, *n* = 4): bp 99 °C (2.5 mmHg); ^1H NMR δ 4.74 (br, 1 H), 3.76 (m, 7 H), 1.70 (br, 10 H); IR (neat) 3380 (br), 2960–2860 (s), 1442 (m), 1030 cm^{-1} (s).

5-[(Tetrahydropyran-2-yl)oxy]pentan-1-ol (4, *n* = 5): bp 100 °C (2 mmHg); ^1H NMR δ 4.60 (br, 1 H), 3.73 (s, 1 H), 3.68 (m, 6 H), 1.60 (br, 12 H); IR (neat) 3420 (br), 2960–2840 (s), 1450 (m), 1070–1030 cm^{-1} (s).

Procedure for Mesylation of Monotetrahydropyranyloxy Derivatives of Diols. By use of the procedure of Crossland and Servis,[13] **4** (0.300 m) and NEt_3 (63.0 mL, 0.450 m) were dissolved in 300 mL of dry CH_2Cl_2 and chilled to −5 °C. Dropwise addition of mesyl chloride (26.1 mL, 0.330 mol) was regulated to keep the temperature below 0 °C. After 0.5 h, the mixture was washed successively with ice–water, cold 10% aqueous HCl, saturated aqueous $NaHCO_3$, and brine. The CH_2Cl_2 layer was dried with K_2CO_3 and evaporated to give the product, a thermally unstable oil, in 80–90% yield. These compounds were used in subsequent steps without additional purification.

1-(Methanesulfonoxy)-3-[(tetrahydropyran-2-yl)oxy]propane (5, *n* = 3): ^1H NMR δ 4.57 (br, 1 H), 3.66 (m, 6 H), 3.01 (s, 3 H), 1.65 (br, 8 H); IR (neat) 3040–2840 (s), 1460 (m), 1370 (s), 1165 cm^{-1} (s).

1-(Methanesulfonoxy)-4-[(tetrahydropyran-2-yl)oxy]butane (5, *n* = 4): ^1H NMR δ 4.75 (br, 1 H), 4.45 (t, 2 H), 3.70 (m, 4 H), 3.10 (s, 3 H), 1.68 (br, 10 H); IR (neat) 3030–2860 (s), 1450 (m), 1350 (s), 1175 cm^{-1} (s).

1-(Methanesulfonoxy)-5-[(tetrahydropyran-2-yl)oxy]pentane (5, *n* = 5): ^1H NMR δ 4.62 (br, 1 H), 4.30 (t, 2 H), 3.63 (m, 4 H), 3.03 (s, 3 H), 1.65 (br, 12 H); IR (neat) 2960–2840 (s), 1460 (m), 1360 (s), 1168 cm^{-1} (s).

Procedure for the Preparation of the Bis(tetrahydropyranyloxy)alkane Derivatives of Tritosylated Diethylenetriamine (6). Compounds **3** (70.0 g, 0.115 mol) and **5** (0.259 mol) in 1 L of dry DMF under N_2 were heated to 95 °C for 2 h. The mixture was then cooled to room temperature and the volume reduced to ca. 100 mL. Upon addition of 1.5 L of H_2O, a white oil separated. The supernatant was decanted, and the oil was taken up in CH_2Cl_2, washed with H_2O, and dried with K_2CO_3. Evaporation of the CH_2Cl_2 left an oil, which was eluted on a silica column with $CHCl_3$. The product, the only mobile

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component under these conditions, was a pale yellowish oil, obtained in 80–90% yield.

4,7,10-Tris(*p*-tolylsulfonyl)-4,7,10-triaza-1,13-bis[(tetrahydropyran-2-yl)oxy]tridecane (6, *n* = 3): ^{1}H NMR δ 7.50 (dd, 12 H), 4.55 (br, 2 H), 3.67–3.29 (m, 20 H), 2.42 (s, 9 H), 1.62 (br, 16 H); IR (neat) 3000–2850 (s), 1600 (sh), 1460 (m), 1355 (s), 1160 cm^{-1} (s).

5,8,11-Tris(*p*-tolylsulfonyl)-5,8,11-triaza-1,15-bis[(tetrahydropyran-2-yl)oxy]pentadecane (6, *n* = 4): ^{1}H NMR δ 7.61 (dd, 12 H), 4.63 (br, 2 H), 3.66–3.17 (m, 20 H), 2.43 (s, 9 H), 1.63 (br, 20 H); IR (neat) 2960–2860 (s), 1600 (sh), 1455 (m), 1350 (s), 1155 cm^{-1} (s).

6,9,12-Tris(*p*-tolylsulfonyl)-6,9,12-triaza-1,17-bis[(tetrahydropyran-2-yl)oxy]heptadecane (6, *n* = 5): ^{1}H NMR δ 7.60 (dd, 12 H), 4.61 (br, 2 H), 3.65–3.33 (m, 20 H), 2.43 (s, 9 H), 1.62 (br, 24 H); IR (neat) 2980–2850 (s), 1598 (sh), 1455 (m), 1350 (s), 1160 cm^{-1} (s).

Procedure for the Removal of the Tetrahydropyranyl Groups[14] from Compound 6. Compound 6 (0.080 M) and *p*-toluenesulfonic acid (15 g, 0.080 mol) were refluxed in 95% EtOH (525 mL) for ca. 5 h, until TLC analysis (silica plate eluted with $CHCl_3$) showed the reaction was complete. The volume was reduced to ca. 100 mL, H_2O (500 mL) was added, and the resulting oil was taken up in CH_2Cl_2, washed with H_2O, and dried over K_2CO_3. After evaporation of the CH_2Cl_2, the oil was adsorbed on silica and the product eluted with $CHCl_3$ to give a pale yellowish oil in 75–90% yield.

4,7,10-Tris(*p*-tolylsulfonyl)-4,7,10-triazatridecane-1,13-diol (7, *n* = 3): ^{1}H NMR δ 7.55 (dd, 12 H), 3.70–3.33 (br, 16 H), 2.47 (s, 11 H), 1.68 (br, 4 H); IR (neat) 3500 (br), 2960–2850 (m), 1598 (sh), 1465 (m), 1345 (s), 1150 cm^{-1} (s).

5,8,11-Tris(*p*-tolylsulfonyl)-5,8,11-triazapentadecane-1,15-diol (7, *n* = 4): ^{1}H NMR δ 7.59 (dd, 12 H), 3.67–3.20 (br, 18 H), 2.43 (s, 9 H), 1.65 (br, 8 H); IR (neat) 3500 (br), 2960–2860 (m), 1600 (sh), 1465 (m), 1340 (s), 1155 cm^{-1} (s).

6,9,12-Tris(*p*-tolylsulfonyl)-6,9,12-triazaheptadecane-1,17-diol (7, *n* = 5): ^{1}H NMR δ 7.55 (dd, 12 H), 3.65–3.33 (br, 16 H), 2.43 (s, 9 H), 1.85 (br, 2 H), 1.50 (br, 12 H); IR (neat) 3400 (br), 2960–2840 (s), 1600 (sh), 1465 (m), 1343 (s), 1150 cm^{-1} (s).

Procedure for Conversion of Diols 7 to Dimesylates 8. The procedure described previously for preparation of compound 5 was followed, resulting in an 80–90% yield of a pale yellow, thermally unstable oil.

1,13-Bis(methanesulfonoxy)-4,7,10-tris(*p*-tolylsulfonyl)-4,7,10-triazatridecane (8, *n* = 3): ^{1}H NMR δ 7.51 (dd, 12 H), 4.27 (t, 4 H), 3.28 (m, 12 H), 3.01 (s, 6 H), 2.38 (s, 9 H), 1.55 (br, 4 H); IR (neat) 2960–2840 (m), 1598 (sh), 1350 (s), 1150 cm^{-1} (s).

1,15-Bis(methanesulfonoxy)-5,8,11-tris(*p*-tolylsulfonyl)-5,8,11-triazapentadecane (8, *n* = 4): ^{1}H NMR δ 7.66 (dd, 12 H), 4.34 (br, 4 H), 3.38 (m, 12 H), 3.06 (s, 6 H), 2.46 (s, 9 H), 1.80 (br, 8 H); IR (neat) 3030–2800 (s), 1598 (sh), 1465 (m), 1350 (s), 1170 cm^{-1} (s).

1,17-Bis(methanesulfonoxy)-6,9,12-tris(*p*-tolylsulfonyl)-6,9,12-triazaheptadecane (8, *n* = 5): ^{1}H NMR δ 7.56 (dd, 12 H), 4.23 (t, 4 H), 3.33 (m, 12 H), 2.99 (s, 6 H), 2.43 (s, 9 H), 1.55 (br, 12 H); IR (neat) 2980–2850 (s), 1600 (sh), 1455 (m), 1350 (s), 1165 cm^{-1} (s).

Preparation of Hexatosylhexaazamacrocycles (9). Compound 2 (11.7 g, 0.0192 mol) was dissolved in dry DMF (800 mL, 0.025 M) at 95 °C under N_2, and compound 8 (0.0192 mol) in DMF (400 mL, 0.048 M) was added dropwise. After 2 h, the mixture was cooled and evaporated to ca. 200 mL. Addition of H_2O (2 L) precipitated the crude product, a tan solid. This was purified by being dissolved in CH_2Cl_2, washed with H_2O, and dried over K_2CO_3. The CH_2Cl_2 was evaporated to about 50 mL and the mixture eluted with $CHCl_3$ on a large column (10 × 15 cm) of dry silica gel. The product was obtained as the most mobile component and was recrystallized from CH_2Cl_2/hexane.

1,4,7,11,14,17-Hexakis(*p*-tolylsulfonyl)-1,4,7,11,14,17-hexaazacycloeicosane (9, *n* = 3) was obtained as a white solid: mp 279–282 °C dec; 40% yield; ^{1}H NMR δ 7.48 (dd, 24 H), 3.22 (m, 24 H), 2.40 (s, 18 H), 1.88 (br, 4 H); IR 1596 (sh), 1334 (s), 1154 cm^{-1} (s).

1,4,7,12,15,18-Hexakis(*p*-tolylsulfonyl)-1,4,7,12,15,18-hexaazacyclodocosane (9, *n* = 4) was obtained as a white solid: mp 245–250 °C; 25% yield; ^{1}H NMR δ 7.65 (dd, 24 H), 3.36 (m, 24 H), 2.46 (s, 18 H), 1.69 (br, 8 H); IR 2980–2850 (m), 1600 (sh), 1465 (m), 1350 (s), 1157 cm^{-1} (s).

1,4,7,13,16,19-Hexakis(*p*-tolylsulfonyl)-1,4,7,13,16,19-hexaazacyclotetracosane (9, *n* = 5) was obtained as a white solid: mp 203–205 °C; 20% yield; ^{1}H NMR δ 7.47 (dd, 24 H), 3.28–3.07 (m, 24 H), 2.40 (s, 18 H), 1.46 (br, 12 H); IR 2960–2860 (m), 1598 (sh), 1460 (m), 1345 (s), 1155 cm^{-1} (s).

Removal of Tosyl Group To Give Cyclic Hexaamines 10. The cleavage of the tosyl groups was effected by treatment with H_2SO_4.[10] Compound 9 (6.45 mmol) was placed in 40 mL of concentrated H_2SO_4 (purged with N_2 gas). A N_2 atmosphere was maintained as the mixture was heated to 95 °C. The reaction was tested at intervals by withdrawing a small aliquot and basifying it with 10% aqueous NaOH. The absence of cloudiness signified that the reaction was complete, usually within 8–10 h. The mixture was then cooled on an ice–salt bath to −5 °C, and anhydrous diethyl ether (200 mL) was added slowly, so that the temperature remained below 10 °C. The tan solid (hygroscopic) was filtered under N_2, washed with ether, dissolved in H_2O, and treated with Darco at 80 °C for ca. 0.5 h. This mixture was filtered through Celite, and the free amine was isolated by one of two methods. (A) The volume was reduced to a minimum, and KOH pellets were added until the pH was ≥10. Continuous liquid–liquid extraction into benzene provided the macrocycle (n = 5) upon removal of the solvent. (B) The volume was reduced, and the mixture was then passed through an ion-exchange column (Bio-rad AG-1-X8, strongly basic, OH^- form). The eluent was periodically tested for presence of the product by addition of a few drops to an aqueous solution of $Cu(NO_3)_2$; a deep blue color indicated a positive test. Evaporation of the H_2O and extraction of the residue into benzene yielded the product upon removal of the solvent.

1,4,7,11,14,17-Hexaazacycloeicosane (10, *n* = 3): white, hygroscopic solid; mp 35.5–36.5 °C; 77% yield; ^{1}H NMR δ 2.70 (m, 24 H), 1.60 (m, 10 H); ^{13}C NMR (relative to Me_4Si) δ 49.2 (C-3,5,13,15), 48.6 (C-2,6,12,16), 48.0 (C-8,10,18,20), 30.2 (C-9,19); IR 3275 (s), 2940–2820 (s), 1465 cm^{-1} (s); CI mass spectrum, m/e 287$^+$ [(M + 1)$^+$]. Anal. Calcd for $C_{14}H_{34}H_6 \cdot 0.5H_2O$: C, 56.91; H, 11.94; N, 28.44. Found: C, 57.09; H, 11.78; N, 28.60.

1,4,7,12,15,18-Hexaazacyclodocosane (10, *n* = 4): white hygroscopic solid; mp 110.0–111.0 °C; 61% yield; ^{1}H NMR δ 2.73 (m, 24 H), 1.55 (br, 8 H), 1.34 (s, 6 H); ^{13}C NMR δ 49.4 (C-3,5,14,16), 49.0 (C-2,6,13,17), 48.5 (C-8,11,19,22), 27.8 (C-9,10,20,21); IR 3450 (m), 2940–2860 (s), 1480 (m), 1110 (m); CI mass spectrum, m/e 315$^+$ [(M + 1)$^+$]. Anal. Calcd for $C_{16}H_{38}N_6$: C, 61.10; H, 12.18; N, 26.72. Found: C, 61.80; H, 12.37; N, 26.46.

1,4,7,13,16,19-Hexaazacyclotetracosane (10, *n* = 5): white hygroscopic solid; mp 65.5–66.5 °C; 56% yield; ^{1}H NMR δ 2.71–2.61 (m, 24 H), 1.77 (s, 6 H), 1.46 (br, 12 H); ^{13}C NMR δ 49.0 (C-3,5,15,17), 48.8 (C-2,6,14,18), 48.2 (C-8,12,20,24), 29.9 (C-9,11,21,23), 24.6 (C-10,22); IR 3280 (s), 2950–2800 (s), 1470 (s), 1140–1100 (s); CI mass spectrum, m/e 343$^+$ [(M + 1)$^+$]; mol wt (vapor pressure osmometry) calcd 343, found 335. Anal. Calcd for $C_{18}H_{42}N_6 \cdot H_2O$: C, 59.96; H, 12.30; N, 23.30. Found: C, 60.21; H, 12.27; N, 23.23.

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