145.8 (aromatic C_1 and C_p); mass spectrum, m/e (relative intensity) 267 (10, $M^{+\cdot}$), 211 (50, $M^{+\cdot} - Me_2C{=}CH_2$), 155 (33, Ts^+), 91 (45, $C_7H_7^+$), 57 (100). Anal. Calcd for $C_{12}H_{17}O_2N_3S$ (mol wt 267): C, 53.91; H, 6.41; N, 15.72. Found: C, 53.89; H, 6.29; N, 15.83.

Thermolysis of **2b** (0.3 g) in 0.5 mL of toluene at 110 °C was completed within 15 h. The solvent was removed, and the residue was crystallized from ether–petroleum ether to give **3b** in 77% yield: mp 147–148 °C; IR (KBr) 3120 (s, NH), 2200 cm^{-1} (s, CN); ^1H NMR ($CDCl_3$) δ 1.15 (s, 9 H), 7.1–7.4 (m, NH and 10 aromatic H); ^{13}C NMR ($CDCl_3$) δ 26.3 (CH_3), 61.0 (d, CMe_3, $^3J_{CP}$ = 4.5 Hz), 115.2 (C≡N), 120.6 and 130.1 (aromatic CH), 150.9 (aromatic C_1); mass spectrum, m/e (relative intensity) 345 (6, $M^{+\cdot}$), 289 (100, $M^{+\cdot} - Me_2C{=}CH_2$), 105 (12), 94 (35, $PhOH^{+\cdot}$), 77 (24, $C_6H_5^+$). Anal. Calcd for $C_{17}H_{20}N_3O_3P$ (mol wt 345): C, 59.13; H, 5.80; N, 12.17. Found: C, 58.95; H, 5.85; N, 12.14.

A toluene solution of **10a** (0.28 g in 1 mL) was heated in an NMR tube at 100 °C for 3 h. Then, the solvent was removed in vacuo, and the residue was subjected to preparative TLC on silica gel, giving di-*tert*-butylcarbodiimide in 18% yield.

Acknowledgment. T. M. (Kyushu Institute of Technology, Japan) is indebted to the Katholieke Universiteit Leuven for a research fellowship. Financial support from the "Ministerie voor Wetenschapsbeleid" and from the FKFO is gratefully acknowledged.

Registry No. 1a, 739-31-1; **1b**, 78822-71-6; **1c**, 78822-72-7; **2a**, 70406-90-5; **2b**, 78822-73-8; **2c**, 78822-74-9; **3a**, 70388-51-1; **3b**, 78822-75-0; **8a**, 78822-76-1; **8b**, 78822-77-2; **10a**, 78822-78-3; **13a**, 78822-79-4; **13b**, 78822-80-7; **15a**, 78822-81-8; **15a** picrate, 78822-83-0; **15b**, 78822-82-9; *N,N'*-diisopropylcarbodiimide, 693-13-0; diisopropylurea, 4128-37-4; di-*tert*-butylcarbodiimide, 691-24-7.

Synthesis of Sulfur-Containing Macrocycles Using Cesium Thiolates

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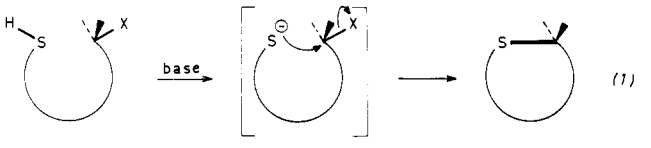
In dimethylformamide (DMF) solution 1,ω-dithiols are deprotonated by cesium carbonate. Reaction with 1,ω-dibromide in the same solvent leads to excellent yields of the corresponding macrocyclic (di)sulfides. The reaction is normally carried out by adding the dithiol (4×10^{-2} M in DMF) and dibromide (4×10^{-2} M in DMF) simultaneously to a 10% excess of cesium carbonate (8.8×10^{-3} M suspended in DMF) at 45–50 °C over a period of 12–15 h. In this fashion there was obtained, for example, 1,12-dithiacyclododocosane (**1d**) in 85% yield from the reaction of decane-1,10-dithiol with 1,10-dibromodecane. Other compounds obtained from the combination $HS(CH_2)_mSH$ and $Br(CH_2)_nBr$ are **1a** (m = 3, n = 4), **1b** ($m = n$ = 5), **1c** (m = 5, n = 10), **1e** (m = 10, n = 16), **1f** ($m = n$ = 10), and **1g** (m = 16, n = 18) in yields ranging from 45 to 90%. By means of the same approach using various 1,ω-dithiols and *o*-xylene α,α'-dibromide, a series of macrocycles was prepared in yields ranging from 64–88%. Various thia crown ether compounds have been prepared as well as ligands like 1,4,8,11-tetrathiacyclotetradecane (**15**), prepared from 3,7-dithianonane-1,9-dithiol and 1,3-dibromopropane in 76% yield as compared to the literature yield of 7.5%. This ability of cesium to promote ring closure appears to be unique certainly in cases where long chains devoid of heteroatoms are involved. This method makes available a variety of sulfur-containing ligands and the potential for scaling up the reaction has also been demonstrated.

Examples of macrocycles containing one or more sulfide linkages[1] include thia crown ethers[2] and cryptates,[3] sulfur-containing cyclophanes,[4] ligands of defined shape and bonding properties for complexing metal ions,[2,3,5] or compounds useful for examination of, for example, sulfur–sulfur bonding or electron transfer between sulfur atoms.[6] The sulfide linkage occurs also in some macrocyclic natural products.[7] There are broad aspects of interest for macrocyclic sulfur compounds, and the potential applications, although many, are relatively unexplored.

The limitation in studying such compounds is in many cases a synthetic one. Acute difficulties can be encountered if the ring closure must be accomplished by the logical synthetic route of S_N2 ring closure by means of a thiolate anion attacking an activated carbon (usually primary) as shown in the generalized formula of eq 1.



(1)

A rough generalization is that syntheses involving as final step ring closure as depicted in eq 1 can be carried

(1) Reviews of this and related topics: (a) Bradshaw, J. S.; Hui, J. Y. K. *J. Heterocycl. Chem.* **1974**, *11*, 649. (b) Newkome, G. R.; Sauer, J. D.; Roper, J. M.; Hager, D. C. *Chem. Rev.* **1977**, *77*, 513; (c) Bradshaw, J. S.; Stott, P. E. *Tetrahedron* **1980**, *36*, 461.

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(4) For a representative reference, see: Vögtle, F.; Neumann, P. *Synthesis* **1978**, 85. See also ref 1.

(5) (a) Rosen, W.; Busch, D. H. *J. Am. Chem. Soc.* **1969**, *91*, 4694. (b) Frensdorff, H. K.; *Ibid.* **1971**, *93*, 600. (c) Jones, T. E.; Zimmer, L. L.; Diaddario, L. L.; Rorabacher, D. B.; Ochrymowycz, L. A. *Ibid.* **1975**, *97*, 7163. (d) Jones, T. E.; Rorabacher, D. B.; Ochrymowycz, L. A. *Ibid.* **1975**, *97*, 7485. (e) Dockal, E. R.; Jones, T. E.; Sockol, W. F.; Engener, R. L.; Rorabacher, D. B.; Ochrymowycz, L. A. *Ibid.* **1976**, *98*, 4324. (f) Ferris, N. S.; Woodruff, W. H.; Rorabacher, D. B.; Jones, T. E.; Ochrymowycz, L. A. *Ibid.* **1978**, *100*, 5939. (g) Black, D. St. C.; McLean, I. A. *Tetrahedron Lett.* **1969**, 3961; *Aust. J. Chem.* **1971**, *24*, 1401; *J. Chem. Soc., Chem. Commun.* **1968**, 1004. (h) Rosen, W.; Busch, D. M. *Ibid.* **1969**, 148. (g) Travis, K.; Busch, D. M. *Ibid.* **1970**, 1041. (j) Rosen, W.; Busch, D. M. *Inorg. Chem.* **1970**, *9*, 262. (k) Weber, E.; Vögtle, F. *Justus Liebigs Ann. Chem.* **1976**, 891.

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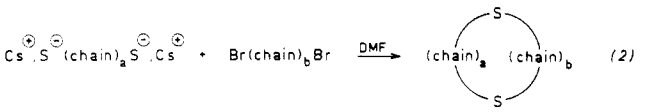
(7) See, for example: (a) Munekata, E.; Faulstich, H.; Wieland, T. *J. Am. Chem. Soc.* **1977**, *99*, 6151; *Justus Liebigs Ann. Chem.* **1978**, 776. (b) Waring, M. J.; Wakelin, L. P. G. *Nature (London)* **1974**, *10*, 346. (c) Dell, A.; Williams, D. H.; Morris, H. R.; Smith, G. A.; Feeney, J.; Roberts, G. C. K. *J. Am. Chem. Soc.* **1975**, *97*, 2497.

0022-3263/81/1946-4481$01.25/0

out in excellent yield if a combination is made of high-dilution techniques and the incorporation of a "rigid group"[8] like an ortho-substituted phenyl derivative in the ring. Such methods have been developed to a high degree of perfection by Vögtle.[5k] Cyclization when the components are polyethylene glycol chains can also proceed in acceptable yields owing probably to the operation of a template effect; such syntheses have been extensively investigated by Bradshaw.[9] More problems are encountered, however, for conformationally flexible macrocycles containing a number of sulfide linkages; Ochrymowycz[10] in painstaking work has developed purification methods for sulfides of general structure 1, which are generally formed only in low yields by following the route of eq 1. Many of these compounds are of much interest and the difficulties of synthesis and purification have clearly been a roadblock to further study.

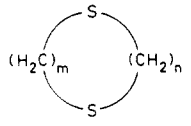
We had previously observed that macrocycle formation following the principle of eq 1 but with carboxylate or phenolate instead of thiolate often proceeds in remarkably good yields when *cesium* is used as the counterion for the nucleophile and dimethylformamide (DMF) as solvent. Thiols were found to be deprotonated readily by Cs_2CO_3 and $CsHCO_3$ in DMF to form cesium thiolates, which are reasonably soluble. With this background knowledge the synthesis of medium-ring and macrocyclic sulfides was undertaken by using the approach outlined in eq 2. In



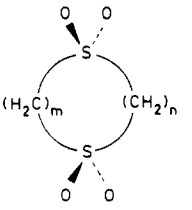
(2)

most cases conditions of moderate dilution were achieved by adding the thiol and bromide reactants simultaneously to the DMF solution. Details are given in the Experimental Section.

Several types of compounds have been prepared. The simplest examples are compounds 1, which contain only aliphatic chains. For purposes of characterization the corresponding sulfones (**2c–e**) were prepared by oxidation of (**1c–e**) with excess *m*-chloroperbenzoic acid (MCPBA).



1

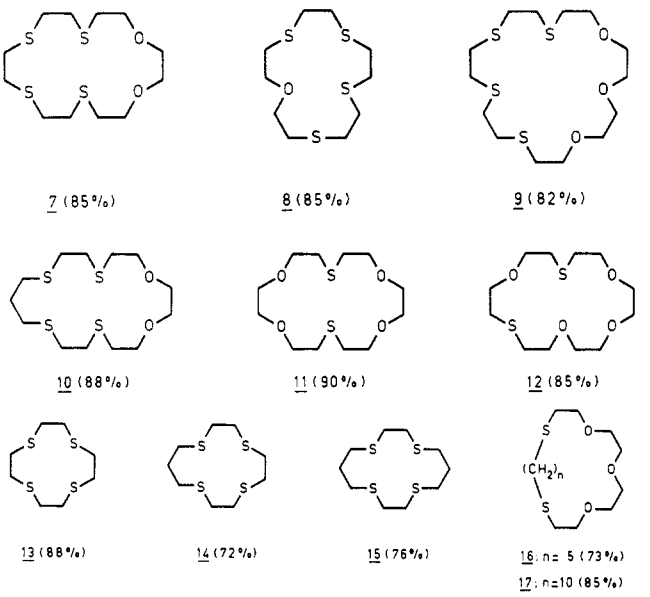


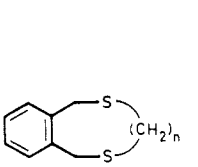
2c–e

a) m = 3, n = 4 (45%)
b) m = n = 5 (80%)
c) m = 5, n = 10 (90%)
d) m = n = 10 (85%)
e) m = 10, n = 16 (80%)
f) m = n = 16 (50%)
g) m = 16, n = 18 (90%)

Starting from *o*-xylene α,α'-dibromide together with the requisite cesium dithiolates we prepared the benzo derivatives 3 and 4. From the di-cesium salt of benzene-1,3-dithiol the meta-bridged compound 5 was prepared as well as its sulfone 6 by oxidation.

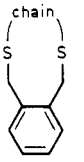
Chart I





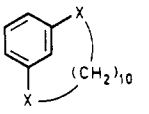
3

a) n = 5 (64%)
b) n = 10 (73%)



4

a) chain = $-(CH_2)_2S(CH_2)_3S(CH_2)_2-$ (85%)
b) chain = $-(CH_2)_2S(CH_2)_2S(CH_2)_2-$ (69%)
c) chain = $-(CH_2)_2O(CH_2)_2O(CH_2)_2O(CH_2)_2-$ (88%)



5; X = S (95%)
6; X = SO_2

Various thia crown compounds (**7–16**, Chart I; note also the benzothia crown compounds **4b,c**) were also prepared. These compounds are described in the Experimental Section. Satisfactory syntheses of the tetrathia compounds **13–15** and of "mixed" compounds **16** and **17** were also carried out.

The yields reported in parentheses for each cyclic sulfide are those for purified material having a ^1H NMR spectrum in accord with that expected and an acceptable melting point if solid; in all cases chromatography on thin-layer plates (TLC) or medium-pressure liquid chromatography (MPLC) revealed only one component. Although such criteria give a good indication of the purity of the obtained materials, and the purity is certainly acceptable for subsequent synthetic transformations, the obtainment of analytically pure material in some cases required additional purification by chromatography or by recrystallization for solids. This leads, of course, to loss of material. The removal of the last small traces of impurities, which have nearly the same polarity as the products, is a particularly acute problem for the very large ring compounds **1e–g** (28-, 34-, and 36-membered rings, respectively!), which also tenaciously hold on to small amounts of DMF. This hin-

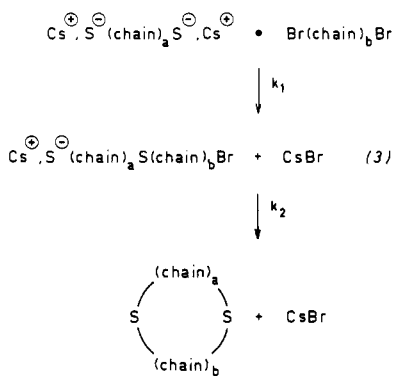
(8) (a) Baker, W.; Banks, R.; Lyons, D. R.; Mann, F. G. *J. Chem. Soc.* **1945**, 27. (b) Baker, W.; McOmie, J. F. W.; Ollis, W. D. *Ibid.* **1951**, 200.
(9) See, for example: Bradshaw, J. S.; Hui, J. Y.; Chan, Y.; Haymore, B. L.; Izatt, R. M.; Christensen, J. J. *J. Heterocycl. Chem.* **1974**, *11*, 45.
(10) For example: Ochrymowycz, L. A.; Mak, C.; Michna, J. D. *J. Org. Chem.* **1974**, *39*, 2079.

dered purification of these compounds greatly and is the cause of osmometric molecular weights about 10% too high.

The yields of cyclic sulfides of remarkably diverse structure obtained by the present technique are good. This point becomes more cogent on considering the literature yields, for example, for the ligands **13–15**, which are respectively 4%[5j] and 6.3%[10] for **13**, 16%[5j] for **14**, and 7.5%[5a] for **15**. These ligands have found use as metal complexing agents (see ref 5). The cyclic (di)sulfides **1a** and **1b**, which are of use in studies of sulfur–sulfur interaction (see ref 6), have been obtained in 5.8%[6a] and 0.8% yields, respectively. In all these cases tedious purification procedures must be followed for isolation of the low yields of desired cyclization products.

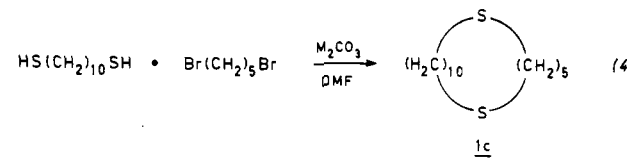
The yields reported here are for reactions run usually on a 4-mmol scale. In the Experimental Section a method in which limited amounts of DMF solvent are used is described for the preparation on a several gram scale of **3a** and **13**. These compounds were obtained in these scaled-up experiments in respectively 54% and 64% yields without a determined effort to find the optimal experimental conditions.

No mechanistic work has been undertaken so far on these cyclizations; hence all suggestions regarding this remarkable effect of cesium are at this time speculative. As a working model it is assumed that cyclization occurs in two steps as illustrated in eq 3. The effect of cesium



in promoting intramolecular cyclization is therefore assumed to lie in the second step with the rate constant k_2. We have previously advanced a simple hypothesis for the explanation of the effect of cesium ions in promoting intramolecular cyclizations of ω-halo carboxylates.[11] In short, this hypothesis is based on the idea that cesium salts of carboxylates (and other weak acids) in DMF are tight ion pairs owing to the poor solvation of the large cesium ion[12,13] but that the anion is nevertheless highly reactive.[14] The S_N2 reaction leading to intramolecular cyclization is thought to occur on the "surface" of the highly polarizable cesium ion.[15] These qualitative ideas[11] can be extrapolated directly to the thiolate cyclizations. Detailed mechanistic work will be necessary, however, to establish the validity of this interpretation.

That cesium is required for successful ring-closure is unambiguously underscored for the formation of **1c**, prepared as shown in eq 4 (this is the only compound investigated in detail). The smaller cations clearly give more oligomeric products at the cost of cyclization.



1c

M_2CO_3	yield (%)
Cs_2CO_3	90%
Rb_2CO_3	84% (glpc)
K_2CO_3	48% (glpc)
Na_2CO_3	33% (glpc)
Li_2CO_3	0% (glpc)

Conclusions

The methodology described herein should provide an acceptable synthetic basis for the preparation of a large variety of sulfur-containing compounds otherwise difficultly accessible. A wide range of structural types has been prepared, all in good to excellent yields. The causes of this remarkable effect of cesium ions are at this time still speculative.[16]

Experimental Section

General Methods. Melting points were recorded on a Mettler automatic FP-2 apparatus. ^1H NMR spectra (Me_4Si internal standard) were recorded on 60-MHz Varian or JEOL instruments or on a 100-MHz Varian XL-100 instrument; ^{13}C NMR (Me_4Si internal standard) were also obtained on the latter instrument. Mass spectra were measured on an MS-9 mass spectrometer. Medium-pressure liquid chromatographic separations were carried out on an instrument built in these laboratories. Elemental analyses were done by the analytical division of these laboratories.

Compounds cited without references were either in stock or were prepared by unexceptional literature procedures. The dibromides used were prepared by treatment of the corresponding dialcohols with PBr_3. The dithiols were all prepared by treatment of the corresponding dibromides with excess thiourea in alcohol followed by hydrolysis with base. Care must be taken that the dithiols do not oxidize to disulfides.

General Procedure for Preparation of Macrocyclic Sulfides. A 2-L three-necked flask was equipped with two addition funnels that could be regulated for slow addition, a stirrer, and a gas line to maintain a nitrogen atmosphere. Cs_2CO_3 (4.4 mmol) was suspended in 500 mL dry DMF. To this well-stirred solution held at 45–50 °C were added simultaneously and slowly a solution of dithiol (4 mmol) in 100 mL of DMF and a solution of dibromide (4 mmol) in 100 mL of DMF. For success of the reaction it is *very important* that both the dithiol and dibromide be pure. The total time for addition was 12–15 h.

The DMF was removed under vacuum, and the residue was taken up in CH_2Cl_2, washed with H_2O, and dried over $MgSO_4$. Purification was carried out as indicated by the entries below for the separate compounds. Unless otherwise indicated all syntheses were carried on the scale described above.

General Procedure for Larger Scale Reactions. The following procedure is designed to use a minimum quantity of DMF. Cs_2CO_3 (3.6 g, 11 mmol) was suspended in 1.7 L of well-stirred dry DMF solution at 45–50 °C under N_2. A solution containing dithiol (10 mmol) and dibromide (10 mmol) in 200 mL of DMF (the dithiol and dibromide do not react spontaneously with each other under these conditions) is added over 12–15 h. Another 11 mmol of Cs_2CO_3 is added at once followed by addition of 10 mmol dithiol and 10 mmol dibromide in 200 mL of DMF over 12–15 h. The entire procedure is repeated once more before stopping the reaction. The entire reaction time is about 40 h. The workup procedure was carried out as described above.

(11) Kruizinga, W. H.; Kellogg, R. M. *J. Am. Chem. Soc.*, in press.
(12) Hogen-Esch, T. E.; Smid, J. *J. Am. Chem. Soc.* **1966**, *88*, 318.
(13) Olmstead, W. N.; Bordwell, F. G. *J. Org. Chem.* **1980**, *45*, 3299.
(14) Solovyanov, A. A.; Beletskaya, I. P. *Russ. Chem. Rev.* (*Engl. Transl.*) **1978**, *47*, 425.
(15) See, for example, the arguments given by: Lehn, J. M. *Pure Appl. Chem.* **1980**, *52*, 2303.
(16) A portion of the present results appeared as a preliminary communication: Buter, J.; Kellogg, R. M. *J. Chem. Soc., Chem. Commun.* **1980**, 466.

1,5-Dithiacyclononane (1a) was prepared from propane-1,3-dithiol and 1,4-dibromobutane. The crude product was distilled in a Kugelrohr apparatus at 0.6 torr (bp 78–80 °C) to give **1a**: 45% yield; mp 56.5–58 °C (lit.[6a] mp 58.5–60 °C, yield[6a] 5.8%). About 20% of the material is lost during the distillation.

1,7-Dithiacyclododecane (1b) was prepared from pentane-1,5-dithiol and 1,5-dibromopentane and was isolated in 87.5% yield in a form pure by ^{1}H NMR criteria. After recrystallization from CH_3OH analytically pure **1b** [mp 78.5–80 °C (lit.[10] mp 81–82.5 °C)] was obtained in 63% yield. The yield reported in the literature[10] for this compound is 0.8%.

1,7-Dithiacycloheptadecane (1c). This was prepared from decane-1,10-dithiol and 1,5-dibromopentane or from 1,5-pentanedithiol and 1,10-dibromodecane with essentially equivalent results. The product (**1c**) was obtained pure as determined by ^{1}H NMR and TLC in 90% yield. An analytical sample was obtained by MPLC using *n*-hexane/CH_2Cl_2 (86:14): mp 71.5–72 °C; mol wt (osmometry in $CHCl_3$) 268, 277 (theory 274); ^{1}H NMR ($CDCl_3$) δ 1.37 and 1.58 (br, 22 H), 2.47 (br, t, 8 H, CH_2S); mass spectrum *m/e* 274 (theory 274).

Anal. Calcd for $C_{15}H_{30}S_2$: C, 65.62; H, 11.02; S, 23.36. Found: C, 65.48; H, 10.99; S, 23.22.

A portion of the ^{1}H NMR pure material above was oxidized in quantitative yield with 4 equiv of *m*-chloroperbenzoic acid in $CHCl_3$ to the disulfone **2c**: mp 132 °C; mol wt (osmometry in $CHCl_3$) 349, 338 (theory 338.5); IR (KBr) 1110–1150, 1240–1340 cm^{-1} (SO_2); ^{1}H NMR ($CDCl_3$) δ 1.32 and 1.75 (br, 22 H), 2.90 (br t, 8 H, CH_2SO_2).

Anal. Calcd for $C_{15}H_{30}S_2O_4$: C, 53.22; H, 8.93; S, 18.94. Found: C, 53.29; H, 8.88; S, 18.90.

1,12-Dithiacyclodocosane (1d) was prepared from decane-1,10-dithiol and 1,10-dibromodecane and was isolated in ^{1}H NMR and chromatographically pure form in 85% yield. An analytical sample of **1d** was obtained by MPLC using *n*-hexane/CH_2Cl_2 (86:14): mp 48–49 °C; mol wt (osmometry in $CHCl_3$) 357, 358 (theory 344.7); ^{1}H NMR ($CDCl_3$) δ 1.33 and 1.52 (br, 32 H), 2.42 (br t, 8 H, CH_2S).

Anal. Calcd for $C_{20}H_{40}S_2$: C, 69.70; H, 11.70; S, 18.60. Found: C, 68.95; H, 11.54; S, 18.35. The analysis for carbon could not be improved.

The disulfone was prepared in 60% yield as described above: mp 189–191 °C; IR (KBr) 1140, 1280–1340 cm^{-1} (SO_2); mol wt (osmometry in $CHCl_3$) 425, 421 (theory 408); ^{1}H NMR ($CDCl_3$) δ 1.29 and 1.65 (br, 32 H), 2.86 (br, t, 8 H, CH_2SO_2).

Anal. Calcd for $C_{20}H_{40}S_2O_4$: C, 58.79; H, 9.87; S, 15.68. Found: C, 58.31; H, 9.79; S, 15.31.

1,11-Dithiacyclooctacosane (1e) was prepared from hexadecane-1,16-dithiol and 1,10-dibromodecane. The product (**1e**) was obtained as a slightly yellow solid: mp 47–49 °C (from CH_3OH); 80–90% crude yield; ^{1}H NMR ($CDCl_3$) δ 1.24 (s plus shoulder, 44 H, CH_2), 2.43 (t, 8 H, CH_2S). Oxidation with excess *m*-chloroperbenzoic acid proceeded in 89% crude yield to give the disulfone **2e**: mp 120–121 °C (after recrystallization from CH_3OH/CH_2Cl_2); IR (KBr) 1310 and 1480 cm^{-1} (SO_2); ^{1}H NMR ($CDCl_3$) δ 1.30 (s plus shoulder, 44 H, CH_2), 2.97 (t, 8 H, CH_2SO_2); mol wt (osmometry in $CHCl_3$) 543 (theory 492); mass spectrum, *m/e* 492 (theory 492). The parent peak was too weak for an exact mass determination.

1,18-Dithiacyclotetratriacontane (1f) was prepared from hexadecane-1,16-dithiol and 1,16-dibromohexadecane. The product (**1f**) was obtained in 50% yield as white crystals: mp 75–77 °C (from $CH_3OH/CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 1.28 (br s, 56 H, CH_2), 2.52 (t, 8 H, CH_2S); mol wt (osmometry in $CHCl_3$) 578, 588 (theory 512); mass spectrum, *m/e* 512 (theory 512). The parent peak was too weak for an exact mass determination. In the IR spectrum an extraneous weak carbonyl absorption was observed due to residual DMF, which could also be detected in the ^{1}H NMR spectrum. It was not present in a stoichiometric amount.

A portion of the above material was oxidized in 55% yield to the disulfone **2e**: mp 158.5–159.5 °C; IR (KBr) 1270–1320 (br), 1470 cm^{-1} (SO_2); ^{1}H NMR ($CDCl_3$) δ 1.28 (br s, 56 H, CH_2), 2.97 (t, 8 H, CH_2SO_2); mass spectrum, *m/e* 576 (theory 576). The parent peak was too weak for an exact mass determination.

1,18-Dithiacyclohexatriacontane (1g) was prepared from hexadecane-1,16-dithiol and 1,18-dibromooctadecane in 90% crude yield and was obtained as a heavy oil: ^{1}H NMR ($CDCl_3$) δ 1.24 (br s, 60 H, CH_2), 2.40 (t, 8 H, CH_2S); mass spectrum, *m/e* 476 (theory 476). The parent peak was too weak for an exact mass determination.

A portion of the above material was oxidized in 50% yield to the disulfone **2g**: mp 118–123 °C (after recrystallization from $MeOH/CH_2Cl_2$); waxy solid; ^{1}H NMR ($CDCl_3$) δ 1.28 (s plus shoulder, 60 H, CH_2), 2.97 (t, 8 H, CH_2SO_2); mol wt (osmometry in $CHCl_3$) 657 (theory 604); mass spectrum, *m/e* 604 (theory 604). The parent peak was too weak for an exact mass determination. In the IR and ^{1}H NMR absorptions for a nonstoichiometric amount of DMF could be observed.

9,10-Benzo-1,7-dithiacycloundecane (3a) was obtained from pentane-1,5-dithiol and *o*-xylene α,α'-dibromide. The crude product was recrystallized from C_2H_5OH to give in 64% yield **3a** as a colorless solid: mp 93–95 °C; ^{1}H NMR ($CDCl_3$) δ 1.52 (br s, 6 H, $(CH_2)_3$), 2.53 (t, 4 H, CH_2S), 3.97 (s, 4 H, CH_2S, arom), 7.42 (m 4 H, arom).

Anal. Calcd for $C_{13}H_{18}S_2$: C, 65.50; H, 7.60; S, 26.90. Found: C, 65.26; H, 7.73; S, 26.96.

When run on a 20-mmol scale as described in the general procedure, **3a** was obtained in 54% isolated yield.

14,15-Benzo-1,12-dithiacyclohexadecane (3b) was obtained from decane-1,10-dithiol and *o*-xylene α,α'-dibromide. The product (**3b**) was purified by chromatography over SiO_2 with *n*-hexane/ethyl acetate (90:10) as eluant followed by recrystallization from C_2H_5OH to afford **3b** in 73% yield as a white solid: mp 61–63 °C; ^{1}H NMR ($CDCl_3$) δ 1.36 (br s, 16 H, $(CH_2)_8$), 2.60 (t, 4 H, CH_2S), δ 3.87 (s, 4 H, CH_2S, arom), 7.30 (m, 4 H, arom).

Anal. Calcd for $C_{18}H_{28}S_2$: C, 70.08; H, 9.14; S, 20.78. Found: C, 69.74; H, 9.07; S, 20.74.

13,14-Benzo-1,4,8,11-tetrathiacyclopentadecane (4a) was prepared from 3,7-dithianonane-1,9-dithiol and *o*-xylene α,α'-dibromide. The product (**4a**), after recrystallization from $C_2H_5OH/CHCl_3$ [mp 83–85 °C [(lit.[5a] mp 84–86 °C)] was obtained in 85% yield. The yield reported in the literature[5a] is 38%. The spectra for **4a** agreed with those reported.[5a]

12,13-Benzo-1,4,7,10-tetrathiacyclotetradecane (4b) was prepared from 3,6-dithiaoctane-1,8-dithiol and *o*-xylene α,α'-dibromide and was obtained, after chromatography over SiO_2 with *n*-hexane/ethylacetate (67:33) as eluant, in 69% yield as a white solid: mp 47.5–49.5 °C; ^{1}H NMR ($CDCl_3$) δ 2.67 (s, 4 H, CH_2S), δ 2.79 (s, 8 H, CH_2S) δ 3.95 (s, 4 H, CH_2S, arom), δ 7.38 (m, 4 H, arom).

Anal. Calcd for $C_{14}H_{20}S_4$: C, 53.12; H, 6.37; S, 40.51. Found: C, 53.05; H, 6.44; S, 40.40.

15,16-Benzo-1,13-dithia-4,7,10-trioxacycloheptadecane (4c) was prepared from 3,6,9-trioxaundecane-1,11-dithiol and *o*-xylene $\alpha,\alpha,'$-dibromide. The product was obtained by chromatography over SiO_2 with *n*-hexane/ethyl acetate (80:20) as eluant in 88% yield as thick colorless oil: ^{1}H NMR ($CDCl_3$) δ 2.71 (t, 4 H, CH_2S), 3.67 (s, 8 H, CH_2O), 3.80 (t, 4 H, CH_2O), 4.25 (s, 4 H, CH_2S), 7.30 (br s, 4 H, arom); mol wt (osmometry in $CHCl_3$) 322, 313 (theory 328); exact mass *m/e* 328.117 (theory 328.117).

Anal. Calcd for $C_{16}H_{24}O_3S_2$: C, 58.50; H, 7.37; S, 19.52. Found: C, 57.84; H, 7.34; S, 19.19. The elemental analysis for carbon could not be improved.

2,4-Benzo-1,5-dithiacyclopentadec-2-ene (5) was prepared from benzene-1,3-dithiol and 1,10-dibromodecane. ^{1}H NMR pure material was isolated in 95% yield. A small sample was recrystallized with some difficulty from CH_3OH to give **5**: mp 103–105 °C; IR (neat) 780, 1100, 1260, 1470, 1570, 2950, 3050 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.25 and 1.42 (br, 16 H), 2.83 (br t, 4 H, CH_2S), 7.10 (m, 3 H, arom); exact mass *m/e* 280.133 (theory 280.132).

A portion was oxidized in 57% yield to the disulfone **6**: mp 190–192 °C; ^{1}H NMR ($CDCl_3$) δ 1.23 and 1.50 (br, 16 H), 3.21 (br t, 4 H, CH_2SO_2), 8.23 (m, 3 H, arom); mass spectrum, *m/e* 344 (theory 344). An exact molecular weight determination was not done.

1,3,6,9-Tetrathia-18-crown-6 (7) was prepared from 3,6-dithiaoctane-1,8-dithiol and 1,8-dibromo-3,6-dioxaoctane. The crude product (**7**) was purified by chromatography over SiO_2 with *n*-hexane/ethyl acetate (60:40) as eluant and was obtained in 85% yield as a solid: mp 34–36 °C; ^{1}H NMR ($CDCl_3$) δ 2.68 (t, 4 H, CH_2S), 2.78 (s, 12 H, CH_2S), 3.57 (s, 4 H, CH_2O), 3.65 (t, 4 H, CH_2O); mass spectrum, exact mass *m/e* 328.066 (theory 328.066).

Anal. Calcd for $C_{12}H_{24}O_2S_4$: C, 43.86; H, 7.36; S, 39.04. Found: C, 43.80; H, 7.36; S, 38.63.

1,4,7,10-Tetrathia-13-oxacyclopentadecane (8) was prepared from 1,5-dibromo-3-oxapentane and 3,6-dithiaoctane-1,8-dithiol. The crude product was chromatographed over silica gel with *n*-hexane/ethyl acetate (60:40) as eluant to give in 85% yield 8 as a heavy oil that slowly solidified: mp 40–42 °C; ^{1}H NMR ($CDCl_3$) δ 2.75 (t, 4 H, CH_2S), 2.80 and 2.82 (br, 12 H, CH_2S), 3.75 (t, 4 H, CH_2O); mol wt (osmometry in $CHCl_3$) 287, 284 (theory 284); exact mass *m/e* 284.043 (theory for $C_{10}H_{20}S_4O$ 284.040).

Anal. Calcd for $C_{10}H_{20}S_4O$: C, 43.86; H, 7.36; S, 39.04. Found: C, 43.80; H, 7.36; S, 38.63.

1,3,6,9-Tetrathia-21-crown-7 (9) was prepared from 3,6-dithiaoctane-1,8-dithiol and 1,11-dibromo-3,6,9-trioxaundecane. The crude material was purified by chromatography over SiO_2 with *n*-hexane/ethyl acetate (75:25). The product 9 was obtained in 82% yield as a thick colorless oil: ^{1}H NMR ($CDCl_3$) δ 2.74 (t, 4 H, CH_2S), 2.83 (s, 12 H, CH_2S), 3.66 (s, 8 H, CH_2O), 3.74 (t, 4 H, CH_2O); exact mass *m/e* 372.095 (theory 372.092). An acceptable elemental analysis for C and S could not be obtained.

1,4,8,11-Tetrathia-14,17-dioxacyclononadecane (10) was prepared from 3,7-dithianonane-1,9-dithiol and 1,8-dibromo-3,6-dioxaoctane. The crude product was purified by chromatography over SiO_2 with *n*-hexane/ethyl acetate (67:33). The product (10) was obtained in 88% yield as slightly yellow thick oil: ^{1}H NMR ($CDCl_3$) δ 1.90 (quintet, 2 H, CH_2), 2.69 (t, 4 H, CH_2S), 2.77 (t, 4 H, CH_2S), 2.82 (s, 8 H, CH_2S), 3.65 (s, 4 H, CH_2O), 3.71 (t, 4 H, CH_2O); exact mass *m/e* 342.081 (theory 342.082).

Anal. Calcd for $C_{13}H_{26}O_2S_4$: C, 45.58; H, 7.65; S, 7.43. Found: C, 45.43; H, 7.63; S, 37.49.

1,13-Dithia-24-crown-8 (11) was prepared from 3,6,9-trioxaundecane-1,11-dithiol and 1,11-dibromo-3,6,9-trioxadecane. The product obtained after the workup (90% crude yield) was pure as determined by ^{1}H NMR spectroscopy. This material has been previously reported to be formed in 16% yield.[2a] A portion was oxidized by *m*-chloroperbenzoic acid in 69% yield to the disulfone: mp 87.5–89.5 °C; IR (Nujol) 710, 890, 960, 1070 (s), 1110 (s), 1140 (s), 1260 (s), 1300 (s), 1330 (s), 2950 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 3.32 (t, 8 H, CH_2SO_2), 3.60 (s, 16 H, CH_2O), 3.88 (t, 8 H, CH_2O); mass spectrum *m/e* 448 (theory 448).

Anal. Calcd for $C_{16}H_{32}S_2O_{10}$: C, 42.84; H, 7.19; S, 14.31. Found: C, 42.67; H, 7.24; S, 13.76. The analysis for sulfur could not be improved.

1,7-Dithia-18-crown-6 (12) was prepared from 3,6,9-trioxaundecane-1,11-dithiol and 1,5-dibromo-3-oxapentane in 65% crude yield after distillation [bp 170–175 °C (0.6 torr)] and in 58% crude yield from 1,11-dibromo-3,6,9-trioxaundecane and 3-oxapentane-1,5-dithiol: IR (Nujol) 1090–1150 (br), 1300, 1360, 2950 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.72 (t, 8 H, SCH_2CH_2O), 3.55 (8 H, OCH_2CH_2O), 3.65 (t, 8 H, OCH_2CH_2S). The literature yield is 29%.[2c]

1,4,7,10-Tetrathiacyclododecane (13) was prepared from 3,6-dithiaoctane-1,8-dithiol and 1,2-dibromoethane. The crude product (13) was purified by recrystallization from C_2H_5OH and was obtained in 88% yield as white crystals, mp 214–216 °C (lit.[10] mp 215–217 °C). The spectral characteristics were identical with those reported in the literature.[5j,10] The yields reported in the literature are 6.3% and 4%.[5j] When the reaction was run on a 30-mmol scale as described in the general procedure, 13 was obtained pure in 64% yield.

1,4,7,10-Tetrathiacyclodecane (14) was prepared from 3,6-dithiaoctane-1,8-dithiol and 1,3-dibromopropane. The crude product was recrystallized from $C_2H_5OH/CHCl_3$ to afford in 72% yield white crystals of 14, mp 131–133 °C (lit.[5a] mp 134–135). The spectral characteristics were identical with those reported in the literature.[5j] The reported yield of 14 is 16%.[5j]

Anal. Calcd for $C_8H_{18}S_4$: C, 42.88; H, 7.13; S, 50.39. Found: C, 42.44; H, 7.16; S, 50.05.

1,4,8,11-Tetrathiacyclotetradecane (15) was prepared from 3,7-dithianonane-1,9-dithiol and 1,3-dibromopropane. The crude product was purified by recrystallization from C_2H_5OH to afford in 76% yield as white crystals 15, mp 116–118 °C (lit.[5] mp 119–120 °C). The spectral characteristics were identical with those reported in the literature.[5a] The reported yield of 15 is 7.5%.[5a]

1,13-Dithia-4,7,10-trioxacyclooctadecane (16) was prepared from 1,5-pentane-dithiol and 1,11-dibromo-3,6,9-trioxaundecane. ^{1}H NMR pure material was isolated by kugelrohr distillation at 0.3 torr in 73–85% yield (depending on the experimental run). An analytical sample was obtained by MPLC with ethyl acetate as eluant. The product (16) was obtained as a heavy oil: IR (neat) 1110, 1290, 1360, 1480, 3000 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.57 (br, 6 H, $(CH_2)_3$), 2.56 (t, 4 H, CH_2S), 2.64 (t, 4 H, CH_2S), 3.54 (s, 8 H, OCH_2), 3.62 (t, 4 H, CH_2O); mass spectrum, *m/e* 294 (theory 294).

Oxidation of 16 with *m*-chloroperbenzoic acid gave in 62% yield the disulfone: mp 110–111 °C; IR (KBr), 1080, 1130, 1260, 1295, 1320 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.75 (br, 6 H, $(CH_2)_3$), 3.02 (t, 4 H, CH_2SO_2), 3.18 (t, 4 H, CH_2SO_2), 3.58 (s, 8 H, CH_2O), 3.85 (t, 4 H, CH_2SO_2); mass spectrum, *m/e* 358 (theory 358).

Anal. Calcd for $C_{13}H_{26}O_7$: C, 43.56; H, 7.31; S, 17.89. Found: C, 43.56; H, 7.25; S, 17.44.

1,13-Dithia-4,7,10-trioxacyclotricosane (17) was prepared from 3,6,9-trioxaundecane-1,11-dithiol and 1,10-dibromodecane or from 1,11-dibromo-3,6,9-trioxaundecane in 85% crude yield; this material is pure as determined by ^{1}H NMR. An analytical sample was obtained by MPLC with ethyl acetate/5% CH_3OH as eluant. The product 17 is a heavy oil: IR nearly identical with that of 15; ^{1}H NMR ($CDCl_3$) δ 1.30 (br, 16 H, $(CH_2)_8$), 2.50 (t, 4 H, CH_2S), 2.56 (t, 4 H, CH_2S), 3.51 (s, 8 H, CH_2O), 3.56 (t, 4 H, CH_2O); mass spectrum, *m/e* 364 (theory 364).

Oxidation of 17 gave in 48% yield the disulfone: mp 75–78 °C; IR (KBr) 1130, 1260, 1295, 1320, 3000 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.30 and 1.82 (br, 16 H, $(CH_2)_8$), 3.05 (t, 4 H, CH_2SO_2), 3.12 (t, 4 H, CH_2SO_2), 3.60 (s, 8 H, CH_2O), 3.86 (t, 4 H, CH_2O); mass spectrum *m/e* 428 (theory 428).

Anal. Calcd for $C_{18}H_{36}S_2O_7$; C, 50.44; H, 8.47; S, 14.95. Found: C, 50.59; H, 8.23. An acceptable analysis for sulfur could not be obtained.

Registry No. **1a**, 6573-48-4; **1b**, 51472-67-4; **1c**, 75703-90-1; **1d**, 296-90-2; **1e**, 79028-34-5; **1f**, 79028-35-6; **1g**, 79028-36-7; **2c**, 75703-97-8; **2d**, 75703-98-9; **2e**, 79028-37-8; **2f**, 79043-19-9; **2g**, 79028-38-9; **3a**, 79028-39-0; **3b**, 79028-40-3; **4a**, 25676-64-6; **4b**, 79028-41-4; **4c**, 59945-53-8; **5**, 75703-91-2; **6**, 75703-96-7; **7**, 79028-42-5; **8**, 52559-78-1; **9**, 79028-43-6; **10**, 79028-44-7; **11**, 297-13-2; **11** disulfone, 75703-95-6; **12**, 52559-81-6; **13**, 25423-56-7; **14**, 25423-54-5; **15**, 24194-61-4; **16**, 75703-92-3; **16** disulfone, 75703-99-0; **17**, 75703-93-4; **17** disulfone, 75703-94-5; propane-1,3-dithiol, 109-80-8; 1,4-dibromobutane, 110-52-1; pentane-1,5-dithiol, 928-98-3; 1,5-dibromopentane, 111-24-0; decane-1,10-dithiol, 1191-67-9; 1,10-dibromodecane, 4101-68-2; hexadecane-1,16-dithiol, 79028-45-8; 1,16-dibromohexadecane, 45223-18-5; 1,18-dibromooctadecane, 31772-06-2; 3,7-dithianonane-1,9-dithiol, 25676-62-4; 3,6-dithiaoctane-1,8-dithiol, 25423-55-6; 3,6,9-trioxaundecane-1,11-dithiol, 2781-02-4; benzene-1,3-dithiol, 626-04-0; 1,8-dibromo-3,6-dioxaoctane, 31255-10-4; 1,5-dibromo-3-oxapentane, 5414-19-7; 1,11-dibromo-3,6,9-trioxaundecane, 31255-26-2; 3-oxapentane-1,5-dithiol, 2150-02-9; 1,2-dibromoethane, 106-93-4; 1,3-dibromopropane, 109-64-8; *o*-xylene-α,α'-dibromo, 91-13-4.