Macrocyclic Sulfide Syntheses: A Review (1)

Jerald S. Bradshaw (2) and Joseph Y. K. Hui

Department of Chemistry and Contribution No. 61 from the Center for Thermochemical Studies, Brigham Young University, Provo, Utah 84602

Received April 29, 1974

The syntheses of various macrocyclic sulfides are reviewed. Tables containing information on hundreds of compounds are included. The types of cyclic compounds reviewed include: macrocyclic aliphatic dithioethers, macrocyclic mercaptals and mercaptoles, macrocyclic polysulfides, dithiacyclophanes, tris-bridged polythiacyclophanes, dithia[2,6]pyridinophanes, thiophene macrocycles, and macrocyclic polyether sulfides.

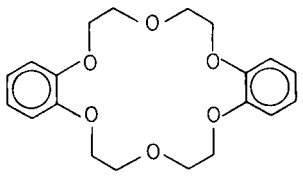
Introduction.

Since 1967, Pedersen has reported the synthesis of over sixty macrocyclic polyethers similar to compound **1** (3,4). He also discovered that these compounds formed complexes with many cations (mostly group I and II). Because of these unusual complexation properties, many alkali salts can be dissolved in organic solvents by forming complexes with these macrocyclic polyethers. Due to the appearance of its molecular model and its ability to crown the cations, these cyclic polyethers were named "crown compounds" (3). Generally, the alkali metal ions are regarded as poor complexing cations, and complexing of alkali cations by neutral molecules is an uncommon phenomenon. No stability constants of complexes of alkali cations with neutral molecules are listed in the most comprehensive collection which covers the literature through 1960 (5).

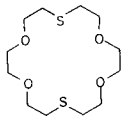
After this discovery, crown compounds and their complexes have been extensively investigated. At the same time "hetero-crown compounds" such as cyclic polyamines and their complexes have also been prepared and studied. Excellent reviews of the crown and hetero-crown compounds and their interaction with metal cations have recently been published (6-8).

Crown compounds have been studied as model systems in cation transport through cellular membranes (9-12). They have found use in organic chemistry to study certain chemical reactions including the catalysis of ionic organic reactions by solvolyzing cationic species (13-22).

Few thermodynamic or chemical reaction studies have been carried out on macrocyclic ether sulfide compounds. 1,10-Dithia-(18-crown-6) **2** (23) has been shown to have a



1



2

greater affinity for silver ions than for potassium ions (24). Lehn and co-workers have also studied the physical properties of macro heterobicyclic diamines containing oxygen and sulfur atoms **3** and **4** (6). They also found that these compounds had a great affinity for silver ions although **3** still had a relatively high attraction for the alkali metals (6).

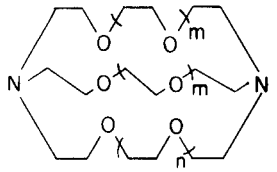
Other workers have studied metal complexation of certain macrocyclic thioethers (25) and macrocyclic thioether amines (26).

Because of the interest in macrocyclic compounds for metal complexation work and the general lack of specific information about macrocyclic sulfides, we decided to gather information on the synthesis of many different types of macrocyclic sulfur compounds. This review covers general synthetic methods as well as specific details for macrocyclic aliphatic dithioethers, mercaptal and mercaptoles, polysulfides, dithiacyclophanes, tris-bridged polythiacyclophanes, dithia(2,6)pyridinophanes, thiophene macrocycles and polyether sulfides.

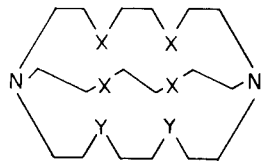
General Synthetic Methods.

Macrocyclic compounds possess a large ring which usually contains 12 or more atoms (27). Macrocyclic chemistry began in 1926 as the perfume component, muscone was isolated and identified as a large ring structure (28). The first large rings were ketones and were synthe-

sized through pyrolysis of heavy metal salts of long-chain dicarboxylic acids (29). Subsequently, numerous methods have been applied to prepare the macrocyclic compounds. Some of the methods include the acyloin cyclization reaction of long chain α,ω-diesters (30), the oxidative coupling of terminal diacetylenes (31) and use of the Wittig reaction (32).



3



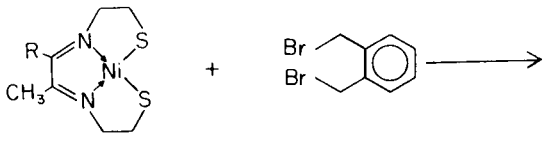
4

		Yield	m.p.
(a)	X = O, Y = S	25%	78-80
(b)	X = S, Y = O	20%	86-87
(c)	X = Y = S	7%	172

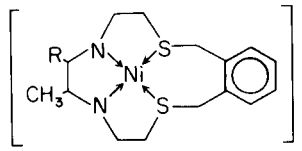
A number of ring enlargement reactions have been devised to prepare macrocyclic compounds from medium rings. These methods include enamine-acetylene condensation (33,34), intramolecular acyloin condensation (35), photo cleavage of bicyclic ketones (36) and 1,2-cycloaddition reactions (37). In 1968, Busch and Story reported on the ketone peroxide fragmentation synthesis of macrocyclic compounds. This method is generally applicable and carbocyclic compounds from C_8 through C_{33} have been prepared (38,39).

One of the most interesting methods for the preparation of organic ring compounds is the metal template syntheses of macrocycles. This subject has been reviewed separately by Busch (40) and Black (41). The metal template reactions have been defined as those ligand reactions which are dependent on or can be significantly enhanced by a particular geometrical orientation imposed by metal coordination. The metal ion may serve as a template to organize the course of complex multistep reactions. This method has found extensive use for metal porphyrins from suitably substituted pyrroles (40,41).

A few sulfur containing macrocycles have been synthesized using metal template syntheses. In 1964, Busch and Thompson reacted the planar Schiff base quadridentates **5** (42) derived from mercaptoethylamine and α-diketones, with α,α′-dibromo-*o*-xylene and obtained the macrocyclic chelates **6** (equation 1) (43). 1,2-Dibromoethane and 1,3-dibromopropane did not react, presumably because these rings cannot be planar due to the geometry of the sulfur atom. The formation of the bis-Schiff bases **5** can seldom be achieved without the intervention of the metal ion.

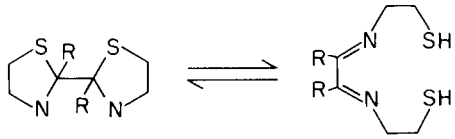


5



Eq. 1

6

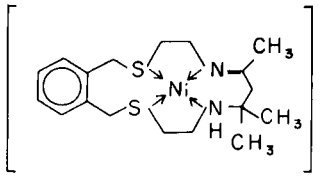


7 8

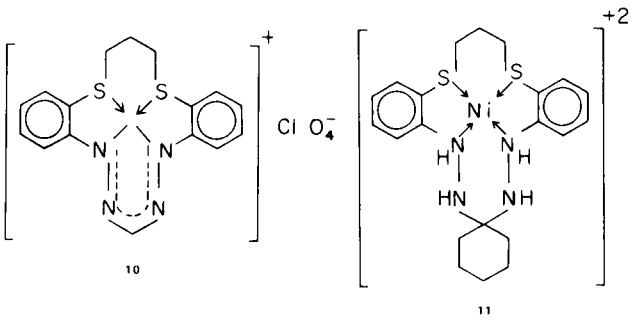
β-Mercapto amines usually react with α-diketones to form thiazolidines **7** which are in equalibrium with the Schiff base **8** (equation 2). In the presence of nickel ion, 70% of the Schiff base complex **5** was obtained (42,43). Recently, this research group has prepared the macrocyclic metal complex, 2,4,4-trimethyl-10,11-benzo-1,5-diaza-8,13-dithiacyclopentadecane-1,10-diene **9** by the reaction of Ni(II) complex of 1,10-diamino-3,8-dithia-5,6-benzodecene with acetone in methanol (44). Other chemists (45) have obtained a nickel complex of a novel monoanionic macrocyclic ligand **10** by reaction (o-NH_2 NH $C_6H_4SCH_2)_2$ CH_2, HCHO, and $Ni(ClO_4)_2$ in tetrahydrofuran. Compound **10** was determined to be planar by x-ray studies. A similar reaction with cyclohexanone gave complex **11** (45). No physical properties were given for these complexes.

Schrauzer and co-workers have prepared a 14-membered macrocyclic sulfur chelated **13** by refluxing the nickel complex **12** with α,α′-dibromo-*o*-xylene (equation 3) (46, 47). The crystals of **13** decomposed on dissolution in methanol to give the free macrocyclic ligand. Compound **12** may be prepared by reacting nickel bisdiphenyl ethanedithiol complex with norbornadiene. New chelates of type **14** have been obtained by the reaction of the dianion $NiS_4C_4Ph_4^{-2}$ with α,ω-dibromoalkanes at high dilution (46,47). No physical properties were reported.

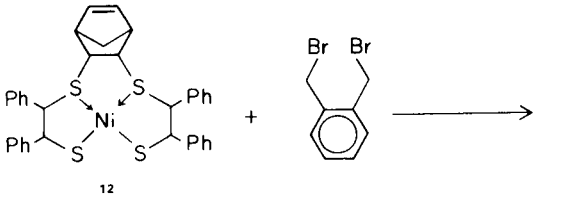
Another example of metal template synthesis is the formation of the iron (II) complex of the macrocyclic quinquedentate ligand **16** (48). The dialdehyde **15** was prepared by reacting the disodium salt of 3-thiapentane-1,5-dithiol with 2-chloro-5-nitrobenzaldehyde. A strainless configuration of the iron (II) complex with **15** presumably allowed the template formation of the macrocyclic complex **16** (equation 4). However, aldehyde **17** did not form cyclic products with ethylenediamine under similar conditions.



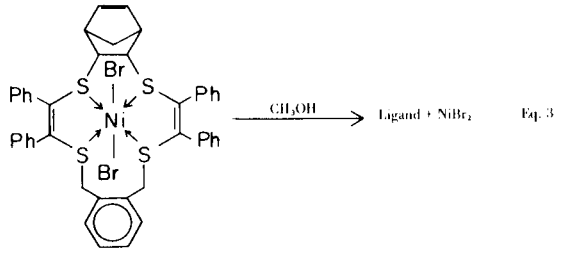
9



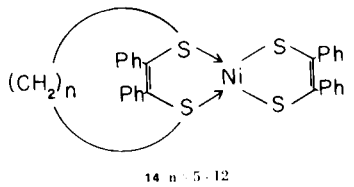
10 11



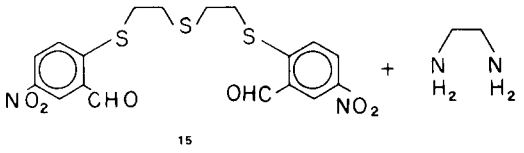
12



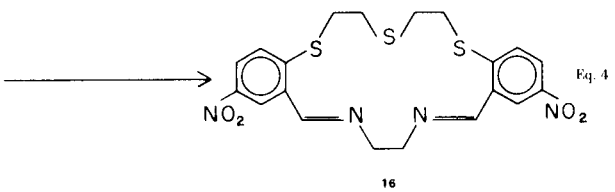
13
m.p. 290° d



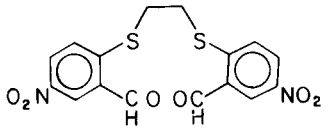
14 n = 5 - 12



15



16



17

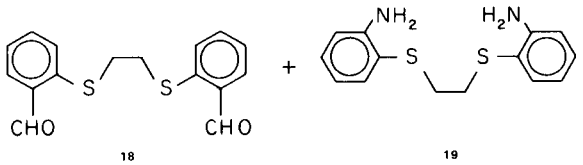
Presumably the aldehyde groups of **17** are *trans* to each other when coordinated with an octahedral metal ion and, thus, cyclization is not favored (48).

A series of macrocyclic sexadentate ligands **20** and **22** has been prepared (26,49). Although no "template" studies were performed in this synthesis, the common feature is that the cyclization occurred in the presence of transition metals. It is possible that the metal ions undertook a similar role in these reactions. The condensation of 1,4-bis(2-formylphenyl)-1,4-dithiabutane **18** and 1,2-bis(2-aminophenylthio)ethane **19** with nickel perchlorate hexahydrate in hot acetone gave 12,13,26,27-tetrahydrotetrabenzo[*e,i,o,s*][1,4,11,14]tetrathia[7,18]diazacycloeicosine nickel (II) perchlorate **20** (equation 5) (26,49). The free ligand precipitated when the complex was heated in dimethylformamide. Similarly, the reaction of **19** with 4,7-diaza-2,3,8,9-dibenzodecane-1,10-dial **21** in a methanolic solution of zinc (II) perchlorate (or chromium (III) perchlorate) gave the free ligand **22** (equation 6) in addition to the zinc complex $[Zn(N_4S_2)](ClO_4)_2 \cdot CH_3OH$. The free ligand was isolated by treating the complex with pyridine (26). No physical properties were given.

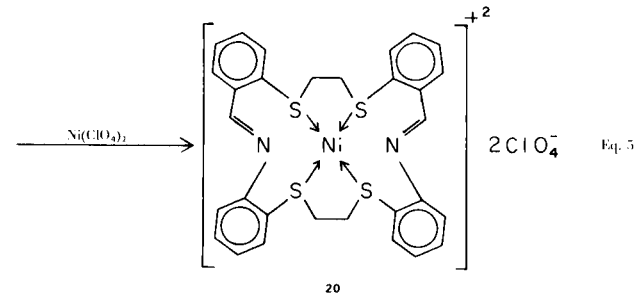
One of the most prevalent synthetic methods for macrocyclic sulfides is the reaction of dihalides with dimercaptans at high dilution in basic media. This and other synthetic methods will be discussed in the following sections for specific macrocyclic compounds.

Macrocyclic Aliphatic Dithioethers.

The reaction of an alkyl halide with a mercaptide produces a sulfide in a reaction similar to the Williamsen synthesis. The reaction of an alkyl dihalide with a dimer-

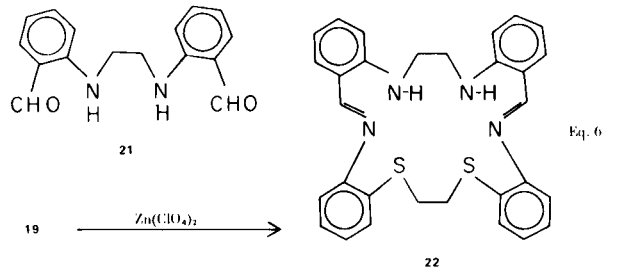


18 19

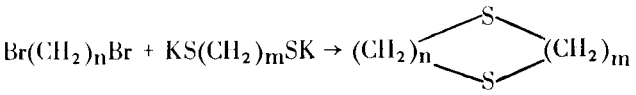


20

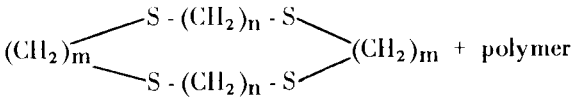
captide may produce a cyclic dithioether **23**, a cyclic dimer (tetrathioether) **24** or a linear polymer (equation 7) (50). The ratio of the products depends on the number of chain members and reaction conditions. The results of the reaction of various dihalides, dimercaptans, and sodium ethoxide in alcohol solution are given in Table I (50).



Eq. 6



23 (Eq. 7)



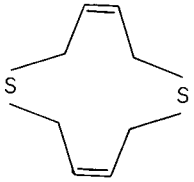
24

As in other cases of cyclization, certain ring sizes were more readily formed, especially the five and six member rings. The formation of rings of eight to eleven (51) members appears to be difficult. Dimers were generally the only products in these cases (see Table I). Unfortunately, the yield of macrocyclic sulfides (more than nine-membered rings) obtained from this method was bery low (less than 2%). In 1960, Stetter and Wirth improved this method by using a "Cyclization apparatus." The yields of the macrocyclic compounds ranged from 34 to 69% (see Table II) (52). No dimerization was mentioned. The successful synthesis of these five sulfur-containing macrocycles may extend the generality of this improved method to other large ring compounds (Table II).

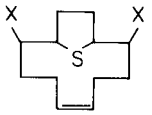
Lehn and co-workers have recently reported the synthesis of 4,9-dithia-1,6-cyclodecadiene **25** and its tetradeuterio isomer (53) by reacting 1,4-dibromo-2-butene with the corresponding dimercaptan (54). Lautenschlaeger, prepared *cis*-2,9-dichoro-13-thiabicyclo[8.2.1]-5-tridecene **26** and the *trans* isomer **27** as well as the dicyano derivative of **26** by reacting *trans, trans, cis*-cyclododecatriene with sulfur dichloride (55). Noritskaya, *et al.*, recently have prepared the acetate and diol derivatives (56).

Macrocyclic Mercaptals and Mercaptoles.

Thiols add readily and reversibly to carbonyl compounds to form hemimercaptals which are unstable (equation 8). Under acid catalysis they usually react with a second molecule of RSH to form the mecaptal or mercaptole (equation 9). These reactions are similar to the addition of alcohols

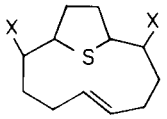


25



26

X	% Yield	m.p.	ref.
Cl	69	139.5-141.5	(55)
CN	87	153-155.5	(55)
OAc	90	146-148	(56)
OH	10	98-100	(56)



27

X	% Yield	m.p.	ref.
Cl	41	108-109	(55)
OAc	80	104-106	(55)

Table I

Yields of Rings of Different Sizes (a)

Dimercaptan	Dihalide	Monomer **23** Size	Monomer **23** Yield (%)	Dimer **24** Size	Dimer **24** Yield (%)
$HS(CH_2)_2SH$	CH_2Cl_2	5	26	10	0.2
"	$Br(CH_2)_2Br$	6	46	12	----
"	$Br(CH_2)_3Br$	7	9	14	1.0
"	$Br(CH_2)_4Br$	8	----	16	0.2
"	$Br(CH_2)_5Br$	9	----	18	0.15
"	$Br(CH_2)_6Br$	10	0.06	20	----
"	$O(CH_2CH_2Cl)_2$	9	----	18	1.4
$HS(CH_2)_3SH$	CH_2Cl_2	6	15	12	----
"	$Br(CH_2)_2Br$	7	8.2	14	----
"	$Br(CH_2)_3Br$	8	4	16	1.0
"	$Br(CH_2)_4Br$	9	0.6	18	1.8
"	$Br(CH_2)_6Br$	11	----	22	1.1
$S(CH_2CH_2SH)_2$	$Br(CH_2)_2Br$	9	----	18	1.7

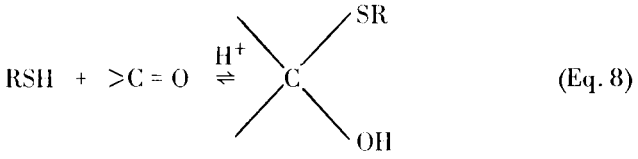
(a) Reference (50)

Table II

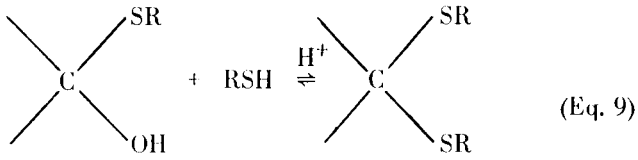
Yields of Macrocyclic Sulfides (by Cyclisation Apparatus) (a)

Dimercaptan	Dihalide	Size of Ring	Yield (%)
$HS(CH_2)_6SH$	$Br(CH_2)_2Br$	10	34
$HS(CH_2)_6SH$	$Br(CH_2)_6Br$	14	56
$HS(CH_2)_8SH$	$Br(CH_2)_6Br$	16	41
$HS(CH_2)_{10}SH$	$Br(CH_2)_6Br$	18	53
$HS(CH)_{10}SH$	$Br(CH_2)_{10}Br$	22	69

(a) Reference (52).

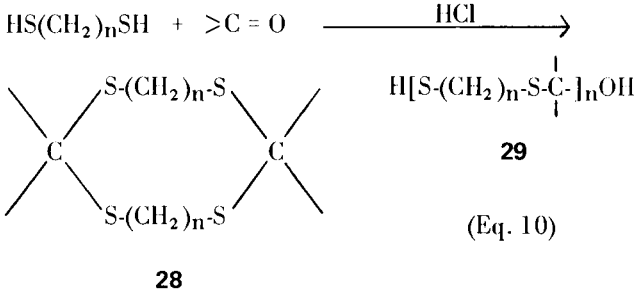


(Eq. 8)



(Eq. 9)

to aldehydes to form hemiacetals. But the reaction of thiols and aldehydes is faster and the mercaptals are more stable. Marvel has prepared several large ring mercaptals containing four atoms of sulfur by this method (57,58). The long chain dimercaptans, such as decamethylene dithiol, react with an aldehyde or ketone to produce a cyclic dimercaptal or dimercaptole **28** or a linear polymer **29** (equation 10). Macrocyclic compounds of structure **28**, containing from 20 to 26-members have been synthesized



(Eq. 10)

in this way. The results of some typical experiments are collected in Table III. When decamethylene dithiol (n = 10) was used, the major product was generally the cyclic dimercaptal with only minor amounts of linear polymers. Both heptamethylene dithiol and nonamethylene dithiol gave good yields of the cyclic dimercaptoles with acetone. However, heptamethylene dithiol gave a low molecular weight linear product with vanillin. It was found that the cyclic product prepared from decamethylene dithiol and vanillin was converted to a polymer on heating above its melting point, whereas the cyclic product from decamethylene dithiol and acetone was not changed even though it was heated with acidic catalysts.

This macrocyclic mercaptal synthesis was also reported by Autenrieth in 1908 and 1909 (59,60) to prepare aliphatic and aromatic cyclic mercaptals. The 16-membered aliphatic cyclic mercaptals were prepared from pentamethylene dithiol and acetone or diethyl ketone (Table III), whereas the aromatic cyclic mercaptals **30** and **31** were prepared from *p*-xylyl dimercaptan and aryl aldehydes and from *m*-xylyl dimercaptan and acetone. In this reaction, a mixture of carbonyl compound and the thiol was treated with hydrogen chloride gas in the absence of solvent, and

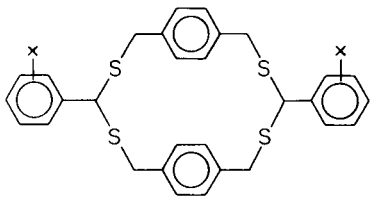
Table III

Reactions of Dimercaptans and Carbonyl Compounds (or Acetals) (a)

Dimercaptan	Carbonyl Compounds (or Acetals)	Ring Size	**28** Yield (%)	**28** M.p. °C	**29** Yield (%)
$HS(CH_2)_{10}SH$	Benzaldehyde	26	50	133-134	----
"	Vanillin	26	98.9	163-163	0
"	Acetone	26	83.9	120-121	0
"	Diethylacetal of benzaldehyde	26	29.9	133-134	69.5
"	Diethylacetal of *p*-chlorobenzaldehyde	26	39.4	144-145	60
"	*m*-Nitrobenzaldehyde	26	77	142-143	----
$HS(CH_2)_7SH$	Acetone	20	~89	129-129.5	~2
$HS(CH_2)_9SH$	Acetone	24	48	128-129	----
$HS(CH_2)_7SH$	Vanillin	20	----	----	----
$HS(CH_2)_5SH$	Acetone	16	52 (b)	117-118	
$HS(CH_2)_5SH$	Diethyl ketone	16	good (c)	113	

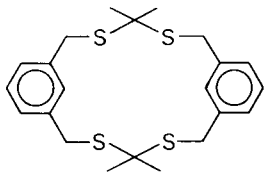
(a) References (57) and (58). (b) Reference (59). (c) Reference (60).

the yields were not reproducible. After more than sixty years Busby and Huckle further studied this reaction in 1972 (61). They found that the reaction was better when carried out in ether, and that boron triflouride-ether or methanolic sulfuric acid were more effective catalysts than hydrogen chloride. In this work, the oligothiacyclophanes, **32** and **33** [n > 1], were also isolated as crystalline solid oligomers from the by-products (resinous polymers). The reactions of pentane-1,5-dithiol with carbonyl compounds to form **34** were performed for comparison. Their work is summarized in Table IV. Alkylation of *m*-xylene-α,α'-dithiol with *gem*-dihalides was studied as an alternative method but the yields were low even under high dilution conditions. The results in Table IV show that most of the carbonyl compounds formed dimers (n = 1) except formaldehyde and acetaldehyde, and if $R^1 = R^2$ = Me or Et the best yields were obtained. The authors explained these results in terms of "conformational randomness" of the monothiohemiacetal dimer intermediates, and the *gem*-dialkyl effect (the alkyl groups force the chain together). The results also show that the formation of 18-membered paracyclophanes is easier than that of 16-membered metacyclophanes when the dithiols reacted with benzaldehyde. When the carbonyl compounds were reacted with pentane-1,5-dithiol, only acetone gave a 16-membered thiacycloalkane. This was reasonable because of the mobility of the pentamethylene chains relative to the cyclophanes (61).



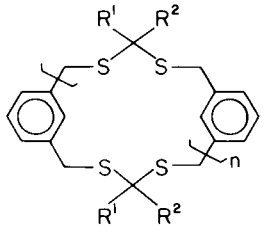
30

X	m.p.
H	248-249
p-CH_3	266
m-CH_3	219-220
p-OH	262-264
p-C_6H_5COO	233
m-OH	251-252
m-C_6H_5COO	169

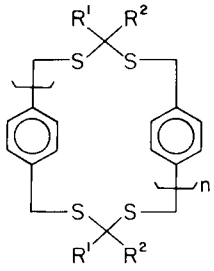


31

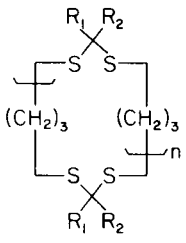
m.p. 254



32



33



34

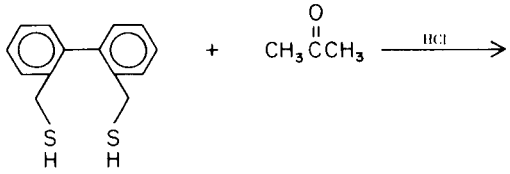
Millar and co-workers have prepared the 9-membered ring mercaptal **36** by condensing 2,2-bis(mercaptomethyl)-biphenyl **35** with acetone (equation 11), but no dimer was mentioned (62). [In the paper, a molecular weight determination for compound **36** was not reported, and there is a possibility that **36** is a dimer.] A series of 9-membered dioxy disulfide cyclic compounds of the type **37** was synthesized in good yields by Abdullaev, *et al.*, (63-65). They were prepared by treating saturated aqueous hyposulfite solution with the α,α'-dichlodimethyl ether of ethylene glycol. The ethylene glycol bis(bromomethyl) ether can be prepared according to the following reaction (66):

$$3C_2H_4(OH)_2 + 2P + 2(CH_2O)_3 + 2H_2O + 5Br_2 \rightarrow 3C_2H_4(OCH_2Br)_2 + 2H_3PO_4 + 4HBr$$

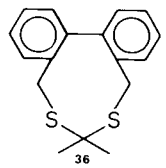
The resulting mixture was then reacted with the corresponding carbonyl compound in alcoholic hydrogen chloride solution. Compound **37b** was also prepared by reacting the Grignard reagent R'MgBr with **37a** (65).

Macrocyclic Polysulfides.

There are many synthetic methods to prepare polysulfides. Reid has written a chapter on this subject (67). Since sodium sulfide is an equilbrium mixture of Na_2S, Na_2S_4 and possibly Na_2S_5 and Na_2S_6, its reaction with alkyl halides gave a mixture of sulfide, disulfide, trisulfide and



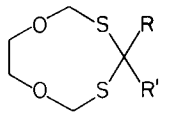
35



36

63%

Eq. 11



37

(a) R = CH_3 or C_2H_5, R' = OC_2H_5

(b) R = CH_3 or C_2H_5, R' = iso-C_3H_7, *n*-C_4H_9, iso-C_4H_{11}, *n*-C_5H_{10}, *n*-$C_{10}H_{21}$

Table IV

Reaction of Carbonyl Compounds with Dithiols (a)

	R^1	R^2	Yield (%) (M.p.) n = 1	other
Compound **32**	H	H		33 (n = 5) (–)
Thia[5,5^n]-metacyclophanes	H	CH_3		90 (n = n) (–)
				31 (n = 6) (53-57)
	H	C_6H_5	5 (209-211)	23 (n = ~34) (93-95)
	H	*o*-$CH_3C_6H_4$		13 (n = ~13) (100-102)
	CH_3	CH_3	35 (249-250)	3 (n = n) (–)
	CH_3	C_2H_5	28 (177-180)	5 (n = n) (203-205)
	CH_3	C_6H_5	25 (218-220)	18 (n = ~11) (103-105)
	C_2H_5	C_2H_5	69 (206-207)	
				18 (n = ~12) (118-120)
Compound **33**	H	C_6H_5	65 (239-240)	1 (n = 3) (192.5-193)
Thia[5,5^n]-paracyclophanes	CH_3	CH_3		60 (n = 7) (123-124)
				75 (n = n) (–)
				75 (n = n) (–)
	CH_3	C_2H_5		
	CH_3	C_6H_5		64 (n = ~20) (–)
Compound **34**	H	C_6H_5		58 (n = n) (–)
Thiacycloalkanes	CH_3	CH_3	52 (119-120)	75 (n = n) (–)
	CH_3	C_2H_5		(–)
	CH_3	C_6H_5		
	C_2H_5	C_2H_5	good (---)	

(a) Reference (61).

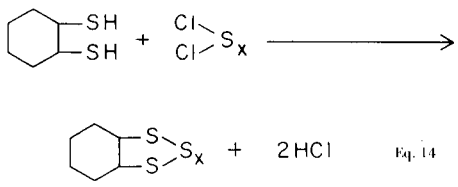
higher polysulfides. Heating various organic compounds with sulfur also produces monosulfides, disulfides, trisulfides and other products. The best way to obtain a pure disulfide is by oxidation of the corresponding mercaptan. The reaction of sulfur chlorides with mercaptans gave the polysulfides. This method has been used extensively with fair results (equations 12 and 13).

$$2\,EtSH + SCl_2 \longrightarrow Et_2S_3 + 2\,HCl \qquad \text{(Eq. 12)}$$

$$2\,EtSH + S_2Cl_2 \longrightarrow Et_2S_4 + 2\,HCl \qquad \text{(Eq. 13)}$$

Feher has synthesized several sulfur heterocycles by reacting chlorosulfanes, S_XCl_2 (X = 2...8) with dimercaptans (68-71). He was the first to obtain the macrocycles **38** and **39** containing a 7-membered sulfur chain (X = 5) (equations 14 and 15). An interesting bicyclopentathiepin **40** was also prepared by these workers. A 10-membered cyclopolysulfide, perhydrodibenzo-1,2,3,6,7,8-hexathiecin **41** was obtained by reacting *trans*-1,2-cyclohexadithiol with dichloromonosulfane in dilute solution (equation 16). When the dimercaptan was oxidized with iodine, an 8-membered cyclopolysulfide **42** was formed in good yield (equation 17) (71).

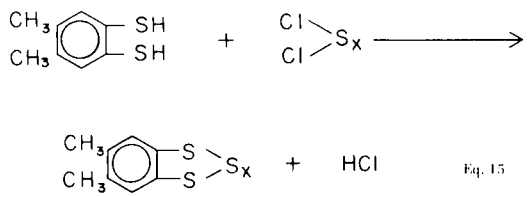
Three isomeric and one dimethyl substituted hexathia-[3.3]cyclophanes **44** have been prepared by reacting aromatic dithiols with bis(chlorodithio)benzene **43** in high dilution (equation 18). The reaction of benzenedithiols with an excess of dichloromonosulfane yields **43** (70,72).



Eq. 14

38

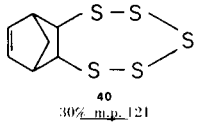
X	% Yield	m.p.
2	74	88.5-89
3	75	66.5-67
4	9	81-82
5	7.5	128-129



Eq. 15

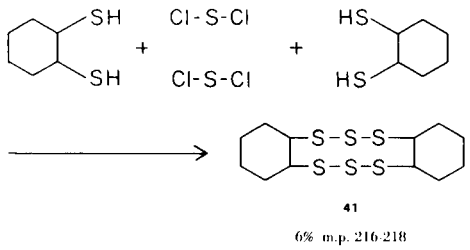
39

X	% Yield	m.p.
2	35	104
3	75	133
5	65	138



40

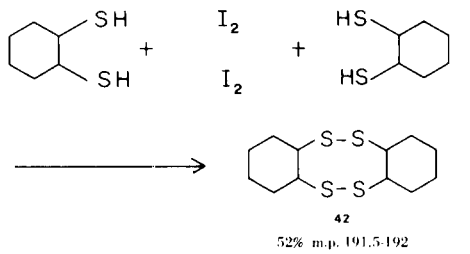
30% m.p. 121



Eq. 16

41

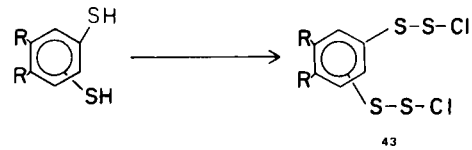
6% m.p. 216-218



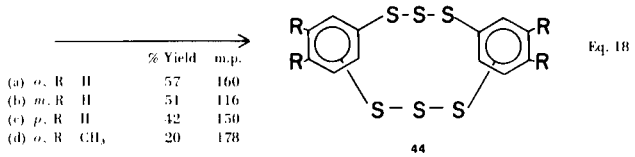
Eq. 17

42

52% m.p. 191.5-192



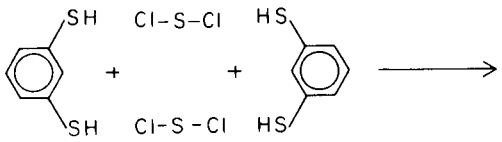
43

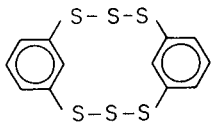


	% Yield	m.p.
(a) *o*-, R = H	57	160
(b) *m*-, R = H	51	116
(c) *p*-, R = H	42	150
(d) *o*-, R = CH_3	20	178

Eq. 18

44





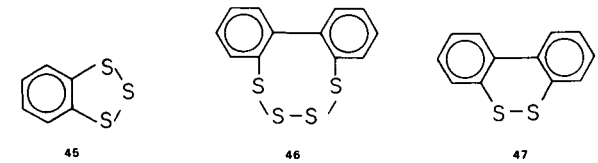
Eq. 19

44b

Compounds **44b** and **c** (*m*- and *p*-) have also been obtained in poor yields by the reaction of equimolar amounts of *meta* or *para* benzenedithiol with SCl_2 (equation 19). The corresponding reaction of *ortho*-benzenedithiol did not give the expected product **44a**; instead a viscous oil with a molecular weight of 172 was obtained. It was probably the monomer, trithia[3]orthocyclophane **45**. Compound **45** would be expected to have a more favorable conformation than the *m*- and *p*-monomers. Allen and co-workers (62) have prepared biphenyl tetra and disulfides in a similar manner (compounds **46** and **47**).

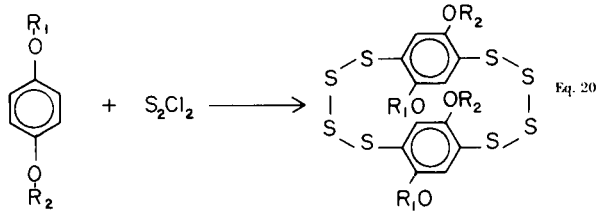
The discovery of the synthesis of an octathiaparacyclophane system was accidental. When Ariyan and Martin reacted *para*-dialkoxybenzene with dichlordisulfane (S_2Cl_2) in the presence of anhydrous aluminum chloride or an acid-clay catalyst in carbon disulfide or chloroform, they got large-ring crystalline products **48** (equation 20), 7,15,17,19-tetraalkoxy-2,3,4,5,10-11,12,13-octathiatricyclo[12.2.2.$2^{6,9}$]eicosa-6,8,14,16,17,19-hexaene (73-75). These compounds showed transmission of aromatic character (delocalization of electrons) across the polysulfide bridge. Attempts to prepare the unsubstituted parent compound were unsuccessful. It seems possible that the electron donating groups, in particular the *para*-alkoxy groups, play an important role in the synthesis. If the *ortho*-substituted dialkoxybenzenes were reacted with sulfur monochloride under similar catalytic conditions, tetra-substituted thianthrenes were obtained; however, uncatalysted reactions of the same starting materials gave linear sulfides (73-75).

A macrocyclic nickel (II) complex containing a tetrasulfide chelated ring **50** has been prepared (but not isolated) *via* a template mechanism by the reaction of **49** with excess dichlorodisulfane (S_2Cl_2) (equation 21) (76). Boekelheide has prepared two macrocyclic disulfides **51** by the addition of the dimercaptan to diethyl azodicarboxylate in the course of studying metacyclophane chemistry (see later) (77). Several 9-membered rings containing vicinal disulfides **52** have been synthesized by Eckhardt (78). In the cyclo-



45 46 47

70% m.p. 200 45% m.p. 110-112



Eq. 20

48

$R_1 = R_2 = C_2H_5$ 60% m.p. 185

$R_1, R_2 = CH_3$ and C_2H_5

phane series, 4,5,12,13-dibenzo,1,2,9,10-tetrathia[2.2]paracyclophane **53** was prepared by adding potassium ferrocyanide to 1,4-dimercaptonaphthalene (79). Luttringhaus and co-workers have prepared a number of macrocyclic disulfides **55** by cyclo oxidizing the long-chain dithiols of the benzene series **54** with air, using copper (II) chloride as catalyst (equation 22) (80,81). High dilution techniques were employed with 90% ethanol or aqueous dioxane as solvent. The yields increased as the chain length decreased. The dithiols **54** were prepared from hydroquinone and the dibromides followed by thiourea to convert the halide to

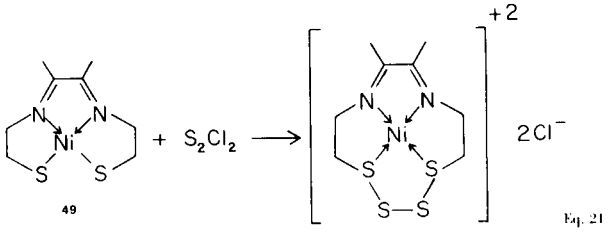
the mercaptan. A larger macrocyclic disulfide **56** was also synthesized in a similar manner by these workers (80,81).

Asinger and co-workers have prepared some interesting 8-alkylamino-8-aryl-1,2,3,4,5,6-hexathiocan-7-thiones **57** (82,83). For example by reacting cyclohexylamine and acetophenone with sulfur, they obtained the 8-cyclohexylamino-8-phenyl derivative. When *p*-acetylacetophenone was used, a bis-hexathiocan **58** was obtained (83). Their results are listed in Table V.

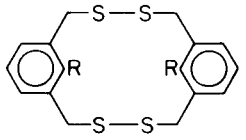
Dithiacyclophanes.

The name cyclophane is used as a general family name for a compound containing any number of benzene rings joined by chains in the *para*, *meta* and/or *ortho* positions (84). The title compounds refer to the cyclic dithioethers with at least one benzene ring. Dithia*ortho*-, *meta*- and *para*cyclophanes are all known.

Early in 1903, German chemists prepared a ten-membered heterocyclic dibenzodithiecin **59** by the reaction of dibromo-*o*-xylene with the corresponding dimercaptide

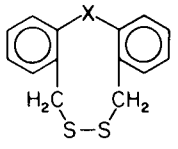


49 50 Eq. 21



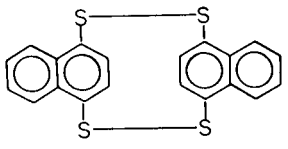
51

R = H, 50% m.p. 171.5-172.5
R = CH_3, 10% m.p. 178-180

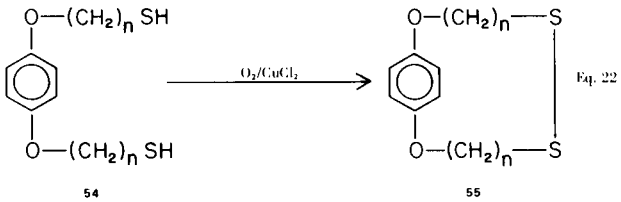


52

X = O, CH_2, S, SO_2

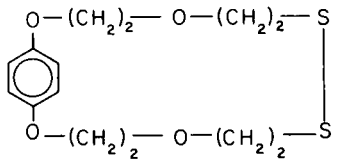


53



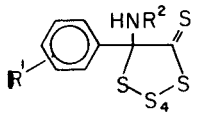
54 55 Eq. 22

n	% Yield	m.p.
6	...	98-99
8	5-7	95-96
10	2-3	110-112

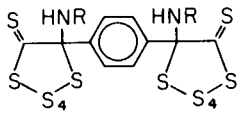


56

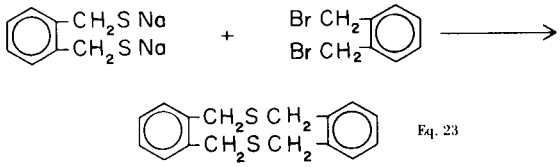
15% m.p. 115



57



58



59

m.p. 234-236 Eq. 23

Table V

Results of the Preparation of **57** and **58** (a)

57

R^1	R^2	Yield (%)	M.p. (°C)
H	$C_6H_5CH_2CH_2$-	63	127.5-128
H	C_6H_{11}	76	147.5-148
H	$(C_2H_5)_2NCH_2CH_2$-	66	94.5-95
H	$(CH_3)_2N(CH_2)_3$-	56	132.0-133
H	$(C_2H_5)_2N(CH_2)_3$-	23	75.5-76
H	$CH_3OCH_2CH_2$-	59	92.0-93
4-Cl	*n*-C_3H_7	38	82.0-83
4-CH_3O	*n*-C_3H_7	50	84.5-85.5

58

R		
n-C_3H_7	42	159.5-160.5
n-C_4H_9	25	156.0-156.5

(a) References (82) and (83).

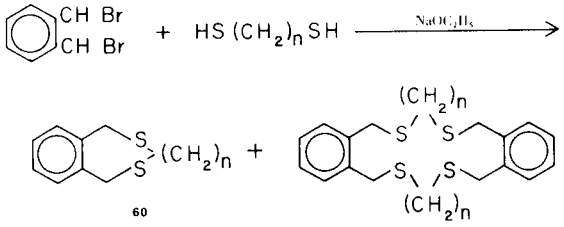
(equation 23) (85). Compounds **60** (n = 1 and 2) have also been reported separately (86,87).

In 1971, Millar and co-workers synthesized a series of aromatic macrocyclic sulfides (62). The reaction of the dihalide with dimercaptide yielded both the monomeric **60** and dimeric **61** cyclic products (see equation 24). When biphenyl-2,2'-dithiol or 2,2'-bis(mercaptomethyl)biphenyl was reacted with the dihalides, compounds **62-66** were formed. Table VI summarizes the experimental results. It appears that there is a maximum yield as the ring size approaches ten and eleven in this system. If α,α'-dibromo-

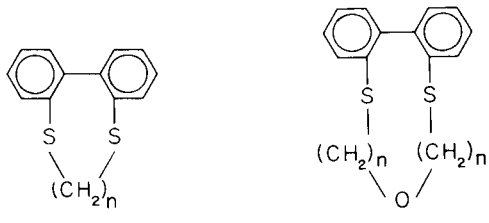
p-xylene was reacted with the thiol, only the 24-membered dimeric compound **67** was found. The formation of only dimer is not unreasonable for this kind of compound, because there would be too much strain in the monomer. In preparing some of the macrocyclic dithia-cyclophanes or mercaptals, the dimers were often the only products isolated.

Recently Tanaka and co-workers (88) have prepared some azathiaorthocyclophanes **68** and **69** by the reaction of bis(2-bromomethylphenyl)sulfide with various amines (equation 25). Their results are given in Table VII. These workers also prepared the corresponding sulfoxides and sulfones (89).

Dithiametacyclophanes have been prepared and studied intensively by Vögtle and co-workers (90-103). Over one hundred of these compounds have been synthesized and identified. In most cases the corresponding sulfones have also been prepared. These will not be discussed. Compounds **70**, (2,n+3)-dithia[n+4]metacyclophane, were prepared by reacting equal moles of α,ω-dimercaptan with the corresponding α,ω-dibromo-*m*-xylene in base. The yield ranged from 3% to 90%. Table VIII summarizes the



Eq. 24

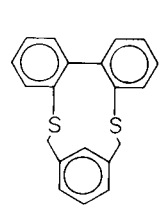


60

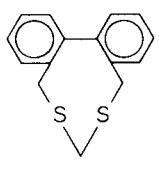
61

62

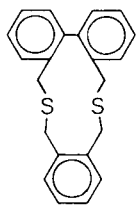
63



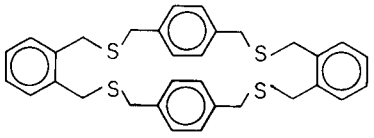
64



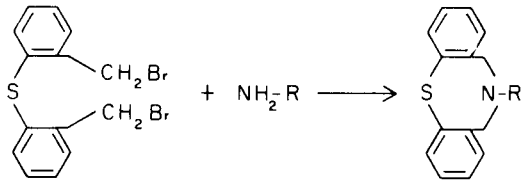
65



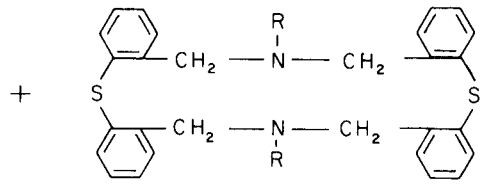
66



67



68



69

Eq. 25

experimental results (90,94,95,96,101). When n = 2, most of the cyclic monomers **70** were not formed, but instead the 18-membered dimers **71** were isolated. When n = 3, both monomers and dimers were formed (95). It is interesting to note that the melting points of the dithiametacyclophanes decrease as the ring size increases above twelve members (Table VIII). This is a result of the larger rings becoming more flexible and therefore they have a high entropy of fusion (see later discussion) (104,105).

Many 2,11-dithia[3.3]metacyclophanes **72** with different substituent groups have also been prepared (91,94, 102,106,107). Symmetrical compounds were prepared by the reaction of the corresponding α,ω-dibromo-*m*-xylenes with sodium sulfide; the unsymmetrical compounds were obtained from the disodium salts of the two-substituted α,ω-dimercapto-*m*-xylenes and the corresponding α,ω-dibromo-*m*-xylenes. All were reacted at high dilutions. The compounds are listed in Table IX. In the preparation of compound **72** (X = Y = CH_3), it is of interest to note that a trimer **73** was also isolated although the yield was only 2%. It was found that when the internal groups, X and Y, were large (*e.g.* X = CH_3), *syn*- and *anti*-isomers were isolated (94,108). An unusual result was observed by Boekelheide and Anderson in that the difluoro compound (**72**, X = Y = F) was formed only in the *syn* form (106). Many of these compounds are of interest because they can readily be converted to the [2.2]metacyclophanes by a Stevens rearrangement (109).

An alternate method to prepare compound **72** has been reported by Boekelheide (77). It involved the addition of a mercaptan to diethyl azodicarboxylate followed by reaction with a second mercaptan to give the disulfide which was converted to monosulfide by tri(diethylamino)phosphine (equation 26). Two dithia[3.3]metacyclophanes (**72**, X = Y = H and CH_3) have been prepared by this method. The dimethyl compound proved to be a mixture

Table VI

Syntheses of Dithiacyclophanes (a)
(Compounds **60-67**)

Dimercaptan	Dihalide	*Monomer* Ring Size	*Monomer* Yield (%)	*Monomer* M.p. (°C)	*Dimer* Ring Size	*Dimer* Yield (%)	*Dimer* M.p. (°C)
o-$C_6H_4(CH_2SH)_2$	CH_2I_2	7	15	157-159	14	3	198-200
$HS(CH_2)_2SH$	o-$C_6H_4(CH_2Br)_2$	8	40	94-96	16	5	142-144
$HS(CH_2)_3SH$	o-$C_6H_4(CH_2Br)_2$	9	40	85	18	5	208-210
o-$C_6H_4(CH_2SH)_2$	o-$C_6H_4(CH_2Br)_2$	10	50	234-236	----	----	----
o-$C_6H_4(CH_2SH)_2$	p-$C_6H_4(CH_2Br)_2$	----	----	----	24	10	183-184
Biphenyl-2,2′-dithiol	CH_2I_2	7	39	95-96			
same	$Br(CH_2)_2Br$	8	41	179-180			
same	$Br(CH_2)_3Br$	9	36	69-70			
same	$Br(CH_2)_4Br$	10	66	143-144			
same	$Br(CH_2)_5Br$	11	81	121-122			
same	$(ClCH_2)_2O$	9	59	150-152			
same	$[Br(CH_2)_2]_2O$	11	67	129			
same	o-$C_6H_4(CH_2Br)_2$	10	69	102-103			
same	m-$C_6H_4(CH_2Br)_2$	11	57	164-165			
same	p-$C_6H_4(CH_2Br)_2$	----	----	----			
2,2′-bis(mercaptomethyl)biphenyl	CH_2I_2	9	46	95-97			
same	m-$C_6H_4(CH_2Br)_2$	13	50	150-152			

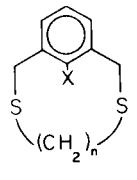
(a) Reference (62).

Table VII

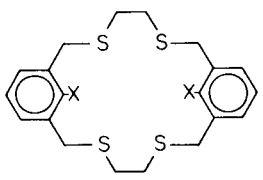
The Preparation of Azathiaorthocyclophanes (a)

R	**68** Yield (%)	**68** M.p. (°C)	**69** Yield (%)	**69** M.p. (°C)
$-CH_2CH_2CH_2OH$	46	103-104	27	238-240
$-CH_2CH_2OH$	21	96-97	4	224-226
$-CH_2C_6H_5$	15	92-93	3	170-172
$-CH_3$	17	68-69	25	290-291
$-CH_2CH_3$	31	69-70	8	234-236
$-CH_2CH_2CH_3$	15	55-56	9	232-234
$-CH_2CH{=}CH_2$	34	84-85	11	234-236

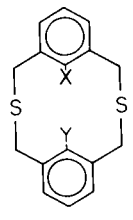
(a) Reference (88).



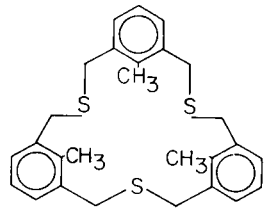
70



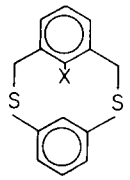
71



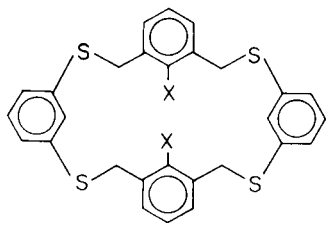
72



73



74



75

Table VIII

Synthesis of (2,n+3)-Dithia[n+4]metacyclophane **70**

n	Ring Size	Substituent, X, % Yield (M.p. below)						
		H	F	Cl	Br	CH_3	CH_3O	CN
2	9	7 (a) (85-86)	-----	----	-----	12 (a) (–)	60 (a) (–)	-----
2	18 (dimer)	15 (a) (170-171)	24 (a) (154-155)	30 (a) (160-161)	20 (a) (176-177)	-----	-----	-----
3	10	40 (a) (100-101)	16 (a) (71-72)	11 (a,b) (76-77)	14 (a,b) (117-118)	90 (c) (71-72)	66 (c) (134-135)	16 (d) (114)
3	20 (dimer)	19 (a) (116-117)	13 (a) (142-143)	(b) -----	(b) -----	-----	-----	-----
4	11	21 (e) (83-84)	16 (e) (59-60)	9 (e) (76-77)	12 (e) (117-118)	65 (c) (48-49)	36 (c) (100-102)	18 (d) (108)
5	12	36 (a) (59-60)	41 (a) (96-97)	35 (a) (99-100)	47 (a) (86-87)	82 (c) (70-71)	74 (c) (99)	34 (d) (166)
6	13	32 (a) (63-64)	29 (a) (81-82)	37 (a) (111-112)	39 (a) (97-98)	81 (c) (93-94)	65 (c) (106)	11 (d) (163)
7	14	(f,g) (51-52)	(f,g) (49-50)	(f,g) (83-84)	(f,g) (75-76)	75 (c) (93-95)	58 (c) (45-47)	5 (d) (112)
8	15	(f,g) (28-30)	(f,g) (<20)	(f,g) (53-54)	(f,g) (47-48)	96 (c) (74-76)	80 (c) (35-36)	24 (d) (84)
9	16	(f,g) (25)	(f,g) (58-59)	(f,g) (38-40)	(f,g) (28-30)	68 (c) (36-38)	85 (c) (23-24)	12.5 (d) (68)
10	17	-----	-----	-----	-----	72 (c) (liq)	71 (c) (liq)	3 (d) (46)

(a) Reference (95). (b) Mixture of monomer (**70**) and dimer (**71**). (c) Reference (94). (d) Reference (101). (e) Reference (90). (f) The compound has been prepared and identified, but the yield was not shown. (g) Reference (96).

Table IX

Syntheses of 8,16-Disubstituted-2,11-dithia[3.3]metacyclophane **72**

X	Y	Yield (%)	M.p.	Remarks
H	H	41 (a)	120-121	
H	F	(b,c)	149-150	
H	Cl	(b,c)	144-145	
H	Br	(b,c)	169-171	
H	CN	7 (d)	176-177	
H	CH_3	64 (e)	100-102	
H	OCH_3	51 (e)	157-158	
F	F	37 (f)	199-200	
Cl	Cl	(b,c)	270-274	
Br	Br	(b,c)	259-262	
Cl	F	(b,c)	196-220	
CN	CN	4 (d)	>260	
CH_3	F	17 (e)	196-198	25% (m.p. 200-205) (g)
CH_3	Cl	8 (e)	274-277	
CH_3	Br	8 (e)	232-236	
CH_3	CH_3	12 (e)	240-250	trimer also formed
CH_3	OCH_3	32 (e)	229-231	
OCH_3	F	29 (e)	213-214	
OCH_3	Cl	4 (e)	254-261	
OCH_3	Br	2 (e)	274-279	
OCH_3	OCH_3	8 (e)	248-250	

(a) Reference (77). (b) The yield was not given. (c) Reference (91). (d) Reference (102). (e) Reference (94). (f) Reference (106). (g) Reference (107).

$$RSH + C_2H_5O_2CN = NCO_2C_2H_5 \rightarrow RSNNHCO_2C_2H_5 \quad (CO_2C_2H_5)$$

$$\xrightarrow{R'SH} RSSR' \xrightarrow{[(C_2H_5)_2N]_3P} RSR' \quad \text{(Eq. 26)}$$

of the *anti* (14%, m.p. 250-255°) and the *syn* (2%, m.p. 238-240°) forms (77).

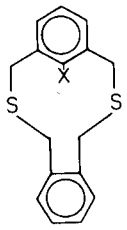
A smaller size compound of this family, 1,10-dithia-[2.2]metacyclophane (**74**, X = H), and its dimer **75** were prepared early in 1924 (110) and later isolated and identified by Vögtle (99). The compound was obtained by condensing *m*-xylene dibromide with the sodium salt of dithioresorcinol. A series of these compounds with substituents of one ring was prepared in the same manner (94, 96,99,102) (see Table X). Three other series of similar compounds, the 11-membered 2,11-dithia[3.3]orthometacyclophanes **76**, the 13-membered 2,11-dithia[3.3]metaparacyclophanes **77**, and the 15-membered 2,11-dithia-[3.3.0]metaparaparacyclophanes **78**, have also been synthesized under similar conditions. Table X includes all these compounds (92,94,95,96,102,107). Dithiacyclophanes like **79**, **80** and **81** have also been reported (90,93,98,111). Compound **81** was further reacted to give compounds **82** and thiacoronene **83** (111). The Vögtle research group has also prepared some 12-membered metacyclophanes containing four sulfur atoms **84** by reacting the *gem*-dihalides with the sodium salt of dithioresorcinol (112). A similar naphthialino-2-phane **85** was also prepared (113).

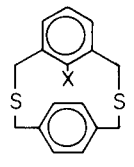
Table X

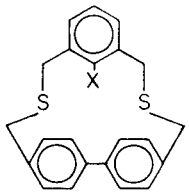
Syntheses of Dithiametacyclophanes

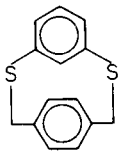
X	Compound Yield, % (M.p. below) **74**	**76**	**77**	**78**
H	21 (a) (145-146)	18 (a) (157-158)	13 (b) (172-173)	(c,d) (125-126)
F	19 (a) (142-143)	14 (a) (172-173)	22 (b) (131-132)	(c,d) (114-115)
Cl	15 (a) (176-177)	(c,d) (232-233)	18 (b) (115-116)	(c,d) (124-125)
Br	30 (a) (217-218)	(c,d) (225-226)		(c,d) (141-142)
CN	24 (e) (216-217)	---	10 (b) (104-105)	---
CH_3	81 (f) (140)	59 (f,g) (202)	65 (f) (112)	41 (d) (107-109)
OCH_3	53 (f) (182)	---	44 (f) (148)	---

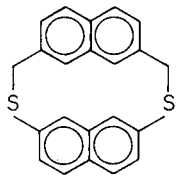
(a) Reference (92). (b) Reference (95). (c) Yield not given. (d) Reference (96). (e) Reference (102). (f) Reference (94). (g) Also 44%, m.p. 204-205°, Reference (107).

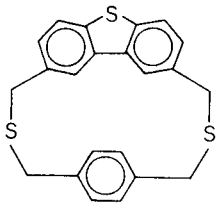

76

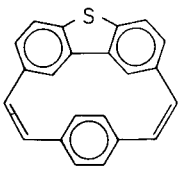

77

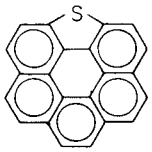

78

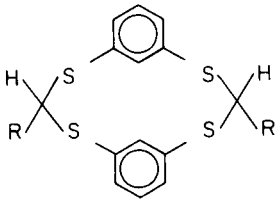

79


80
40% m.p. 228-230

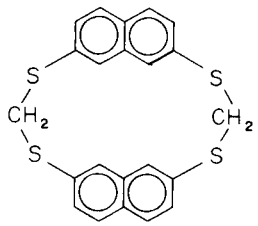

81
88% m.p. 260-261

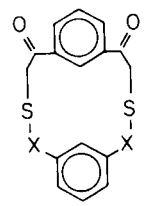

82


83

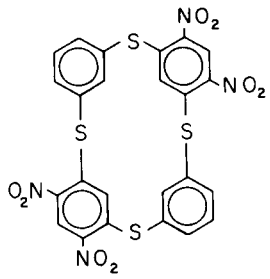

84

R	% Yield	m.p.
H	30	145-147
CH_3	12	183-188
C_6H_5	45	224-226


85


86

X	% Yield	m.p.
direct bond	21	218-219
$-CH_2-$	10	181-182
$-COCH_2-$	5	258-260

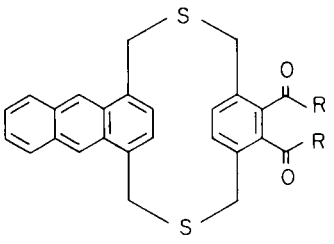

87
70% m.p. > 350

Other substituted metacyclophanes **86** (X = direct bond, CH_2, CH_2CO) were obtained by treating *m*-$(BrCH_2CO)_2C_6H_4$ with *m*-$(NaS)_2C_6H_4$, *m*-$(NaSCH_2)_2C_6H_4$ or two moles of sodium sulfide respectively in high dilution using *t*-butyl alcohol as the solvent (114). By reacting a dilute alkaline ethanol solution of 1,3-dichloro-4,6-dinitrobenzene with 1,3-benzenedithiol and 1,4-benzendithiol respectively, Montaudo has recently obtained the dimers **87** and **88** (115).

Gundermann and Roker (116) have prepared dithiaparacyclophanes **89** and **90** by reacting the dihalides with the dimercaptides. The corresponding sulfones were also prepared. Similar compounds **91** and **92** were prepared by Staab and co-workers (117). Kannen, Umemoto, Otsubo and Misumi have prepared some novel dithia triple-layered cyclophane compounds including the metaparaparacyclophane **93**, the metaparametacyclophane **94**, the metametametacyclophane **95** and the parametaparacyclophane **96** (117a). These compounds were converted to the corresponding cyclophanes by the Boekelheide procedure (109).

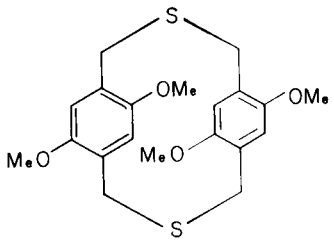
Tris-Bridged Polythiacyclophanes.

Of particular interest is the synthesis of tris-bridged cyclophanes (also called "caged" compounds). Only a few caged compounds containing sulfur as bridging members have been reported. Applying the high dilution principle, F. Vögtle treated 1,3,5-*tris*(bromoacetyl)benzene with 1,3,5-tris(mercaptomethyl)benzene in *t*-butyl alcohol as solvent and obtained the [4.4.4](1,3,5)cyclophane **97** in a reproducible yield of 10%. Similarly, cyclophane **98** was obtained in 0.16% yield by reacting the tris-bromide with sodium sulfide and the cyclophane **99** (n = 1) was obtained in a 10% yield by reacting 1,3,5-tris(mercaptomethyl)benzene with methylene bromide in the molar ratio 2:3 (118). The larger [6.6.6] and [7.7.7](1,3,5)cyclophanes (**99**, n = 2 and 3) were obtained from ethylene and propylene bromide, respectively (119). Boekelheide has also prepared a caged compound, 2,11,20-trithia[3.3.3](1,3,5)cyclophane **100** by condensing 1,3,5-tris(bromomethyl)benzene with sodium sulfide in ethanol (109). Compound **100** was further reacted to yield the *tris*-metacyclophane (120). A hexathia[3.3.3](1,3,5)cyclophane **101** was recently pre-

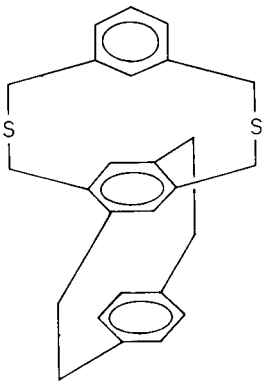


90
R = OCH_3 31% m.p. 230

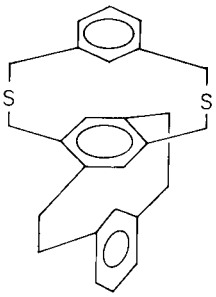
91
m.p. 211-213



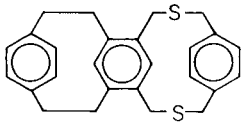
92
m.p. 243-246



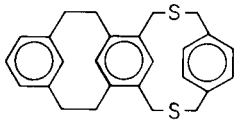
93
56%



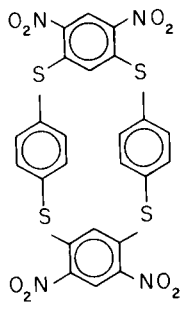
94
31%



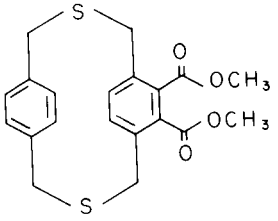
95
34%



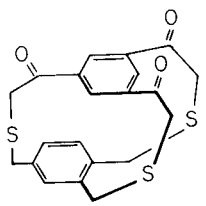
96
35%



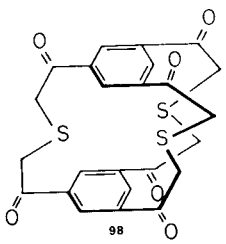
88
70% m.p. > 350



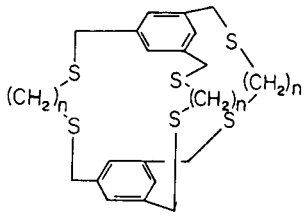
89
30% m.p. 174



97
10% m.p. > 360

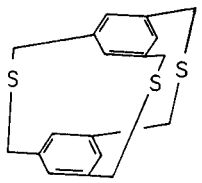


98
0.16% m.p. > 360



99

n	% Yield	m.p.
1	10	>380
2	8	269-271
3	0.5	>290



100

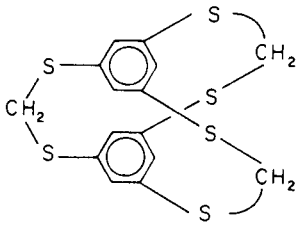
12% m.p. 254-255

pared in a 25% yield by Vögtle and co-workers (113).

Some novel thiabiphenylophanes have been prepared in Vögtle laboratory (121). By reacting 1,3,5-tris[(*p*-bromomethyl)phenyl]benzene with 1,3,5-tris[(*p*-mercaptomethyl)phenyl]benzene, they obtained a 31% yield of compound **102**. By using a high dilution technique, 1,3,5-tris[(*p*-bromomethyl)phenyl]benzene reacted with various α,ω-dimercaptoalkanes to yield compound **103**. These workers were even able to prepare the tetrakis caged compound **104** (8%) by reacting the corresponding tetrakis bromomethyl biphenyl compounds (121).

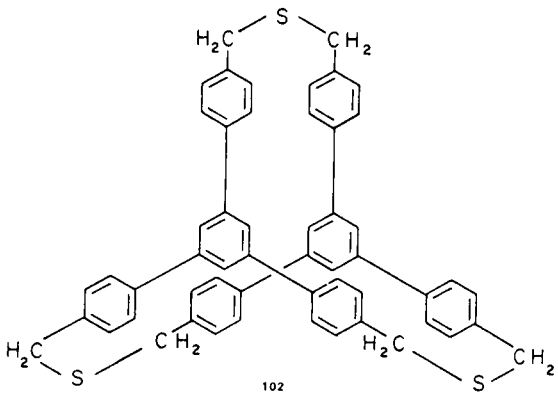
Dithia(2,6)pyridinophanes.

The dithia(2,6)pyridinophane is similar to dithiametacyclophane except that a benzene ring is replaced by a pyridine ring. Vögtle has prepared a number of these compounds by using the same techniques as that used for the dithiametacyclophanes. Compounds **105-110** have thus far been prepared (91,92,94,95,97). In the preparation of 2,11-dithia[3.3](2,6)pyridinophane **109** from 2,6-dichloromethylpyridine and sodium sulfide, a trimer **111** (3%) was also isolated by Martel (122). The intermolecular condensation of 6-chloropyridine-2-thione gave a 12-membered heterocyclic trimer **112** which by X-ray analysis has been found to have a nonplanar configuration (123). Boekelheide and co-workers have recently prepared a dithia[2.2](2,6)pyridinoparacyclophane **113** by the reaction of the corresponding 2,6-bis(mercaptomethyl)pyridine and *p*-xylylene dibromide (124). They found that the sulfur atoms could be extruded photochemically to give the [2.2](2,6)pyridinoparacyclophane (114). Jenny and co-workers have recently reported the preparation of other thiapyridionphanes **115-118** by similar reactions (125,126).



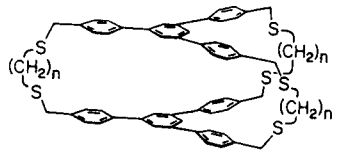
101

25% m.p. >360



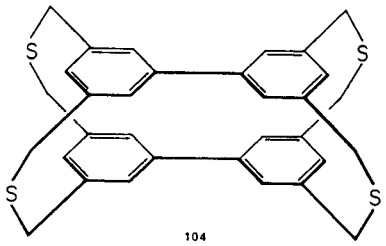
102

31% m.p. >450



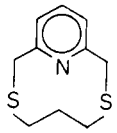
103

n	% Yield	dec. p.
2	4	280
3	5	280
4	5	280
5	5	270



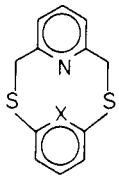
104

8% dec. p. 290



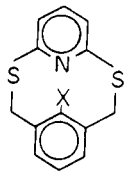
105

36% m.p. 78-79



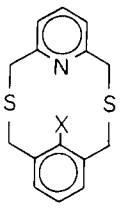
106

X	% Yield	m.p.
CH	29	172-173
N	30	228-229



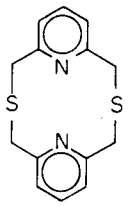
107

X	% Yield	m.p.
H	28	195-196
F	14	142-144
CH_3	61	129-131
OCH_3	15	206-208



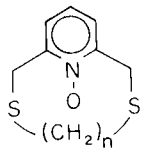
108

X	% Yield	m.p.
H	–	173-175
F	–	174-175
CH_3	34	135-136



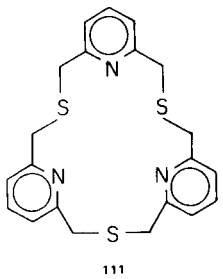
109

19% m.p. 220-222

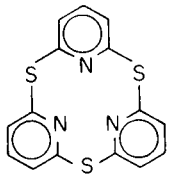


110

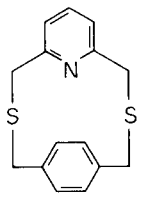
n	% Yield	m.p.
2	8	152-154
3	7	107-109
4	30	98-99
5	50	147-148
6	32	138-140
7	7	89
8	24	73-75
9	18	117-120
10	31	54-55



111

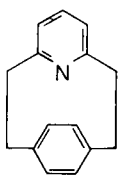


112

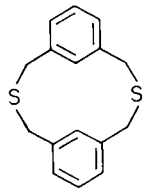


113

48% m.p. 117-118

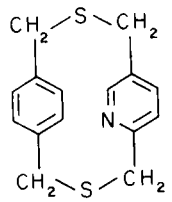


114



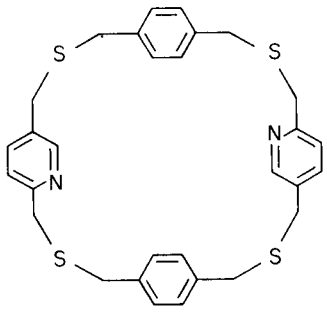
115

66% m.p. 177-178



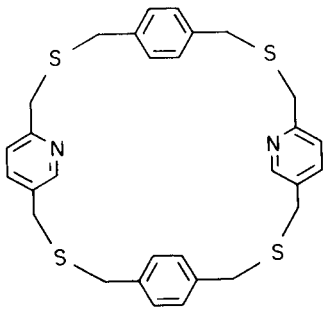
116

45% m.p. 204-205



117

4% (mixture of **117** and **118**) m.p. 217-218

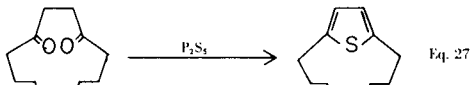


118

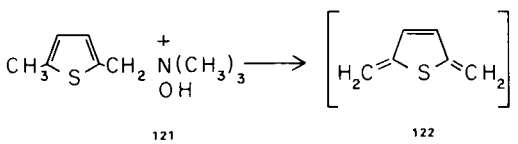
Thiophene Macrocycles (127).

The 11-membered thiophenophane **120** was prepared from the β-diketone **119** using phosphorus pentasulfide (equation 27) (128). The 2,2-thiophenophane **123** has been prepared by an 1,5-Hoffmann elimination process across compound **121** to yield the highly reactive intermediate **122** which readily polymerized. The dimer **123** was isolated in a 19% yield (equation 28) (129).

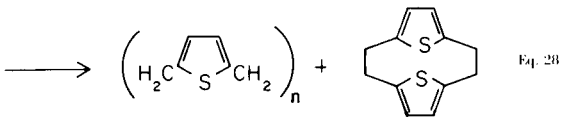
Goldfarb, *et al.*, has used an intra or intermolecular acylation of ω-(2-thienyl)alkanoyl chlorides in the presence of a catalyst to give several possible macrocycles (Scheme I and Table XI). The catalysts were polyphosphoric acid, Friedel-Crafts catalysts, silica or alumina gel of coarse pore size, or partially hydrolyzed aluminum chloride etherate. The chain length of the acid chloride played an important role in determining what type of products were formed (130-132). With m = 3 - 5, intramolecular acylation to the 3-position was the most significant reaction (**124** → **125**). Nevertheless, with m = 5, there were also some intermolecular reactions which gave both the dimer **127** and trimer **126** in low yields. With intermediate chain length (m = 5 - 9), more dimer **127** was isolated. At m = 8, cyclization to the 5-position **128** was first noticed, and good yields occurred with m = 9. Other methods of making these types of compounds included the acyloin reaction to give α,ω-dicarboxylic esters **129** (133) and cyclization of ω-halo-β-ketoester **130** with potassium carbonate in methyl ethyl ketone to form **131** and dimer **132** in excellent yields (equation 29) (133-137). Compounds **131** and **132** were hydrolyzed and decarboxylated to give **133** and **134**.



119 120 50% Eq. 27



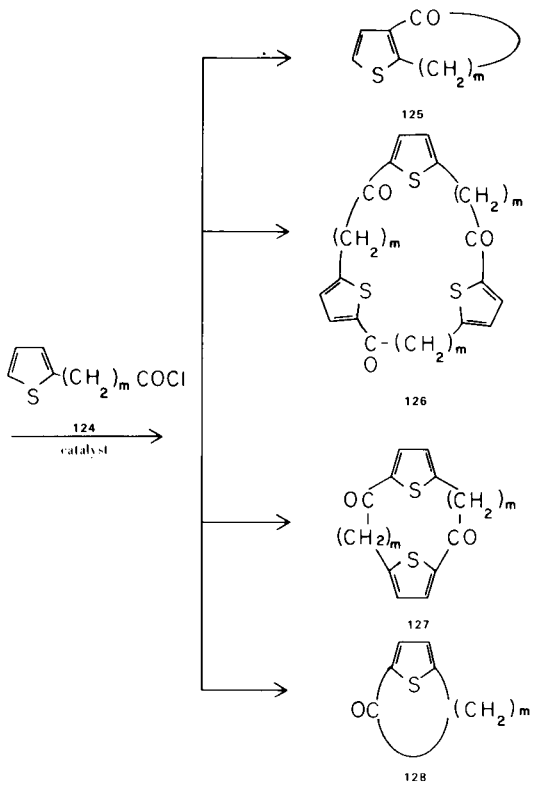
121 122



123

19% m.p. 194.5-196 Eq. 28

SCHEME I



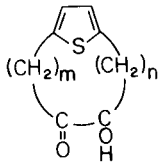
Another series of macrocyclic systems containing the thiophene ring has been extensively investigated by Badger and co-workers (138-141). They are the analogues **135** of the [18]annulene system **136**. The general synthetic method for the preparation of the trisulfide **135a** involved a Perkin condensation of thiophene-2,5-diacetic acid **137** with dialdehyde **138**, followed by hydrolysis and decarboxylation of the product **139** (equation 30). However, considerable preliminary work was necessary to prepare the starting materials **137** and **138**.

Similar compounds **140** and **141** were prepared by Cresp and Sargent (142) using a Wittig reaction. The seventeen membered ring **140** was formed in the greatest yield.

The porphyrinogen analogues **144**, **145** have been synthesized by Meth-Cohn and his co-workers (127,143). It was found that by reacting the dilithium compound **142** with the diketone or dialdehyde (**143**, R = CH_3 or H) cyclization failed when the two reactants did not have the dimethyl groups (equation 31 and 32) (143). An interesting sila analog **146** has also been prepared (144).

Macrocyclic Polyether Sulfides.

Early in 1920, Ray reported the isolation of the triethylene trisulfide, 1,4,7-trithia(9-crown-3) **147**, during the preparation of ethylene mercaptan by the interaction of ethylene dibromide and alcoholic potassium hydrogen sulfide (145). The trival naming system for these compounds is an extension of the trivial crown nomenclature (23). A thia prefix is used to show that sulfur atoms have replaced the oxygen atoms in the polyether ring (146). In



129

m = n = 4 41% m.p. 69.5-70
m = 4, n = 5 40% m.p. 62-64
m = n = 4 (3,4-dimethyl substitution) 43% m.p. 117-119

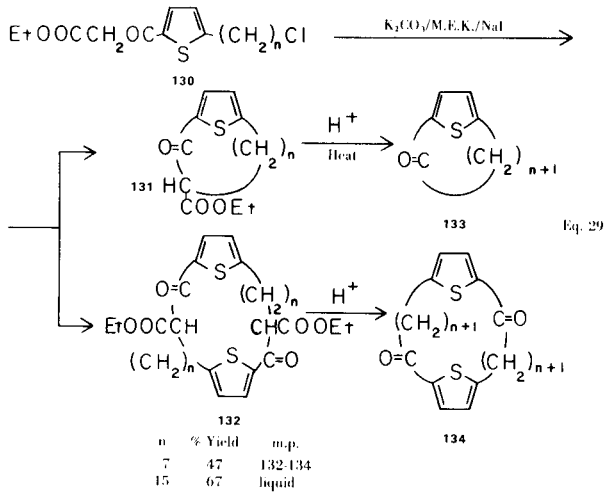
1934, the 18-membered macrocyclic compounds 1,4,7,10,13,16-hexathia(18-crown-6) **148** and 1,4,10,13-tetrathia-(18-crown-6) **149** were prepared by Meadow and Reid by the reaction of dimercaptans and dihalides in base (147). They expected to obtain crown-3 compounds but rather obtained the reported crown-6 compounds **148-149**. They

Table XI

Yields and Melting Points for Macrocyclic Thiophenes in Scheme I (a)

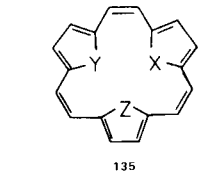
Compound m =	3	4	5	6	7	8	9	10	11	12
125	92 (34-35)	88 —	9 (46-47)							
126			*unk* (89-90)							
127			2 (141-143)	5 (108-109)	13 (97-98)	4 (81-83)	12 (102-104)			
128						8 (*unk*)	54 (40-41)	64 (44-46)	63 (31-32)	60 —

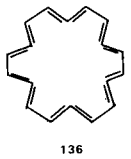
(a) References (130-133).



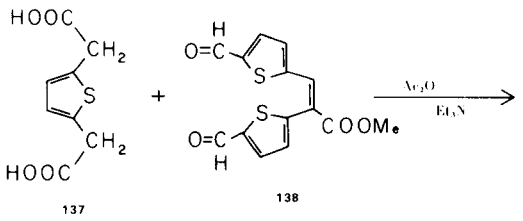
n	% Yield	m.p.
7	47	132-134
15	67	liquid

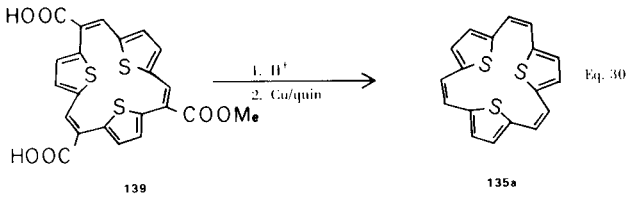
Eq. 29



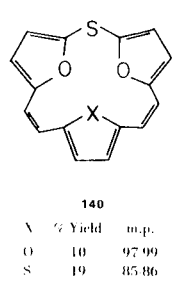


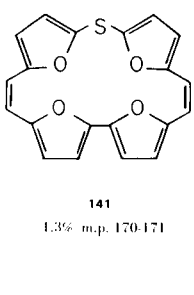
	X	Y	Z	% Yield	m.p.
a.	S	S	S	30	74.4-75.5
b.	S	S	O	39	103-103.5
c.	S	O	O	19	250-251 d
d.	S	S	NH		129-130
e.	O	O	O	11	215-216 d

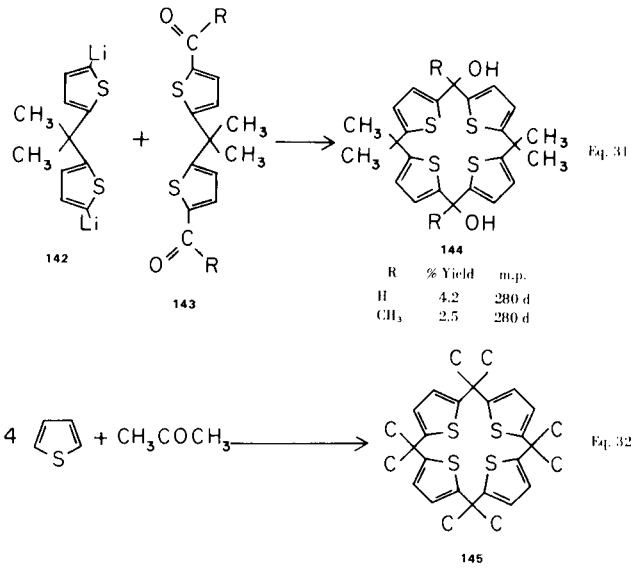




Eq. 30



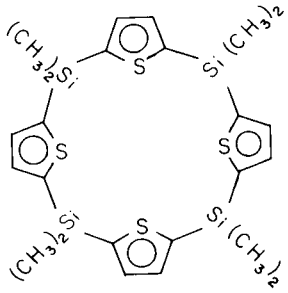


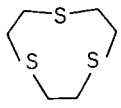


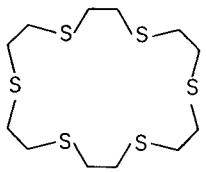
R	% Yield	m.p.
H	4.2	280 d
CH_3	2.5	280 d

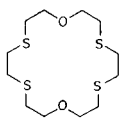
Eq. 31

Eq. 32







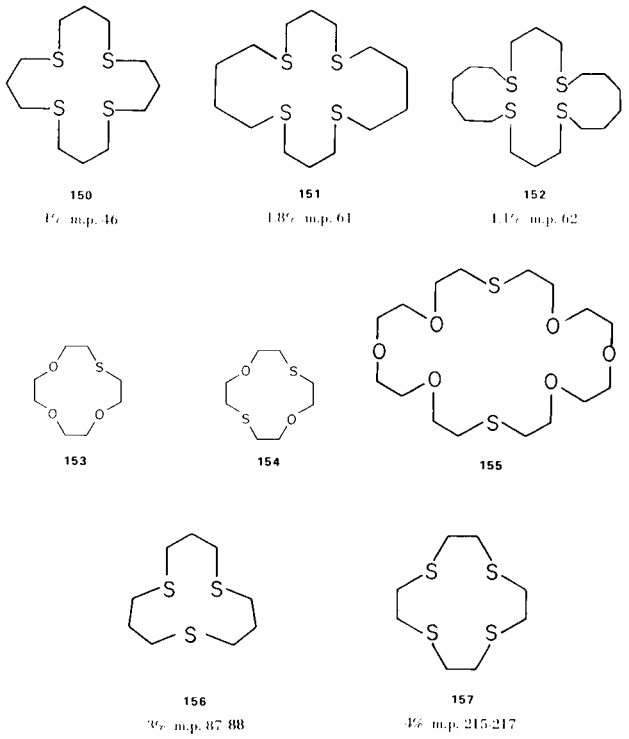


have also prepared other thia-crown-4 compounds **150**, **151**, and **152** from reaction of the corresponding dimercaptans and dihalides.

In 1961, Dann and co-workers at the Kodak Research Laboratories prepared some crown-4,6, and 8 polyether sulfides **153**, **154**, **2**, and **155** by the reaction of the dibromides and the dimercaptans or sodium sulfide (148).

Since 1968, several new "thia-crown" compounds have been prepared and studied as metal-ion complexing agents. Busch and co-workers synthesized perthia-12-crown-3 **156**, and perthia-crown-4 compounds **157-161**, from the dimercaptans and the dibromides (Scheme 2) (25,149,150). A dimer of **159**, perthia-28-crown-8 **160**, was also isolated, It is interesting to note that the perthia-crown-3 and 4 macrocycles are all white sublimable solids. Black and

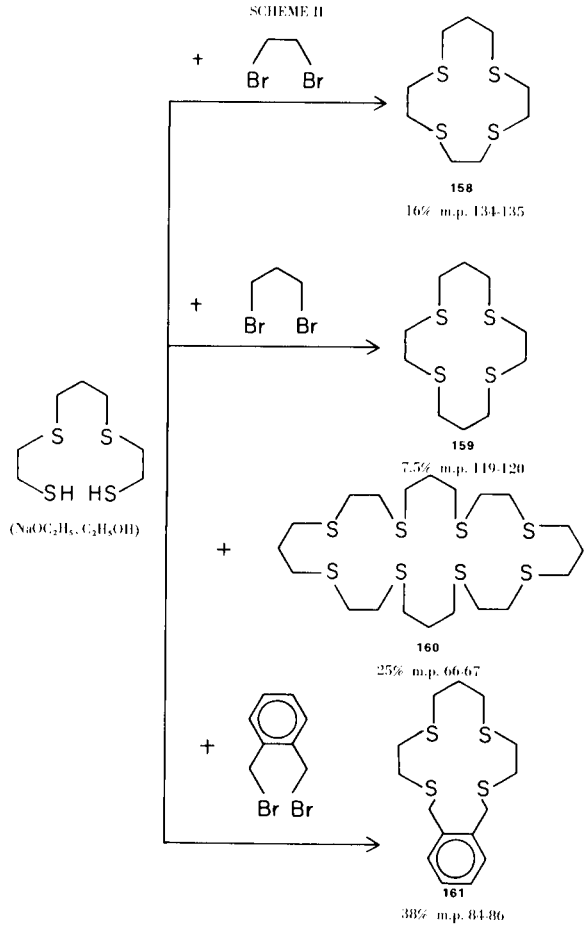
McLean following the same procedure described by Reid, prepared the thia-18-crown-6 macrocycles **148** and **149** in ethanol at high dilution. The yield of **148** was surprisingly high (31%) compared with **149** (7%) (151,152). A 10-membered macrocycle **162**, 1,3,5,7,9-pentathiacyclodecane, has been prepared by the reaction of sodium sulfide and dichloromethane (153). However, in addition to the cyclic pentamer of thioformaldehyde **162**, other cyclic compounds formed including the trimer and the tetramer.



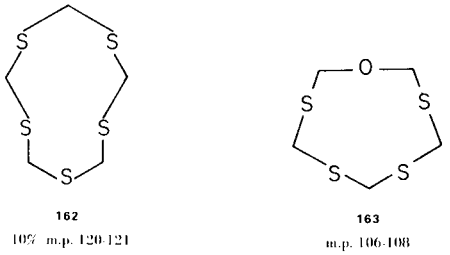
Other cyclic oligomers with both oxygen and sulfur heteroatoms have been prepared (154). The reaction of sodium sulfide nonahydrate and bischloromethyl ether in methanol gave polymers and the cyclic compounds 1-oxa-3,5,7,9-tetrathiacyclodecane **163** and 1-oxa-3,5,7,9,11-pentathiacyclododecane **164** (154). This latter reaction should have yielded polymers and cyclic oligomers with alternate formaldehydethioformaldehyde units. However, no products of this kind were obtained, and even the polymers had CH_2S/CH_2O ratios between 1 and 4. The explanation of this discrepancy and the mechanism of this reaction are still unknown.

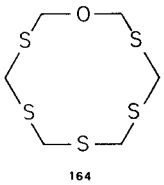
In 1955, a mixed amino-thia crown compound **165** was first prepared (155). In 1968, Black and McLean followed the same procedure and obtained **165** and **166** (151,152). These compounds were prepared by condensing bis-(2-bromoethyl)amine with ethane-1,2-dithiol and 3-oxapentane-1,5-dithiol respectively. Lehn and co-workers have also prepared **165** and **167** as well as the cryptate **4** (**a**, **b** and **c**) by a different synthetic path (similar to the following method) (6,156). More recently, four mixed crown-5 compounds **168**, **169** and **170** have been synthesized from the cycloaddition of α,ω-diamines to α,ω-dicarboxylic acid dichlorides. The cyclic diamides were then reduced to the products (equation 33) (157).

SCHEME II



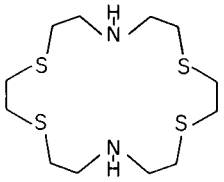
Pederson in 1971 synthesized nine aromatic thia-crown compounds **171-179** which contained two to four oxygen atoms and two to four sulfur atoms. The compounds were prepared by refluxing cyclic vicinal mercaptophenol or dithiols with equivalent portions of terminally substituted oligoethylene glycol dichlorides and sodium hydroxide in 1-butanol under nitrogen. Table XII summarizes the experimental results. It is of interest to point out that **175** and **176** are structural isomers and were prepared from identical





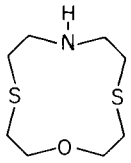
164

m.p. 163-165



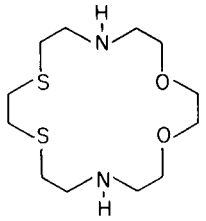
165

45% m.p. 125



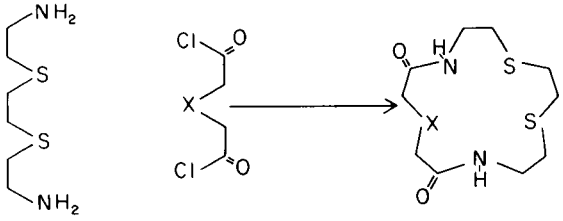
166

18% m.p. 64

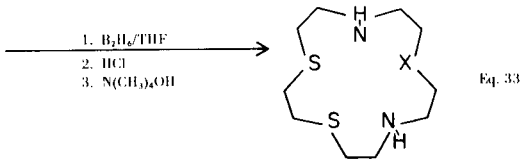


167

55% m.p. 125



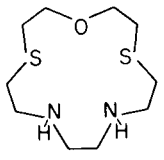
X = S 57% m.p. 190
X = O 45% m.p. 158



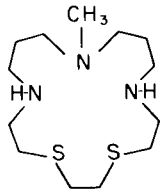
Eq. 33

168

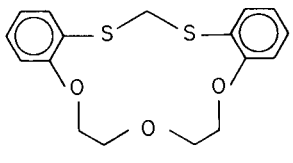
X = S m.p. 31
X = O liquid



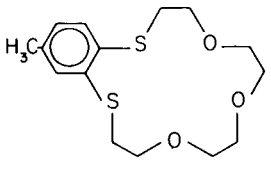
169



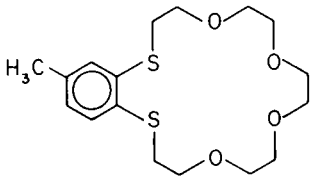
170



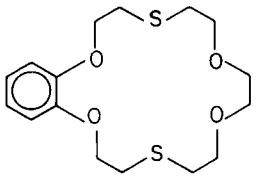
171



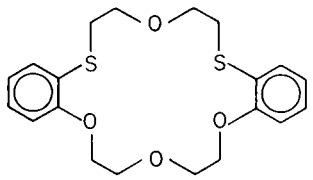
172



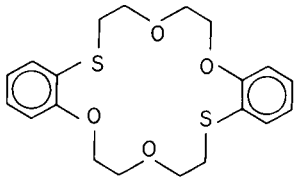
173



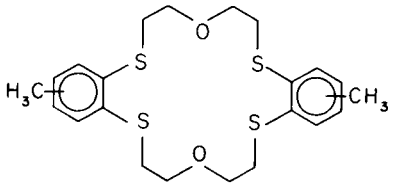
174



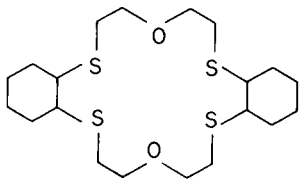
175



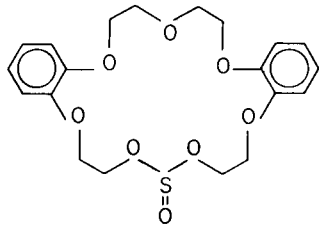
176



177



178



179

reactants. By varying the mole ratio of the starting materials different intermediates may by obtained, which lead to different products (158).

Recently, Bradshaw and co-workers have prepared a series of 9,12,15,18 and 21-membered macrocyclic polyether sulfides rings (105,146). Although these compounds could be prepared by a number of different methods, the most convenient was the reactions of a dimercaptan or sodium sulfide and an oligoethylene glycol dichloride in base. Thus, process C of Scheme 3 was the method used to give 1-thia(18-crown-6) **180**. This method was first used by Dann and co-workers to prepare, 1,10-dithia(18-crown-6) **2** (148). Compounds prepared include **180-195**. Table XIII lists the yields and melting points of these and related compounds.

Table XII

Synthesis of Thia-crown Compounds **171-179** (a)

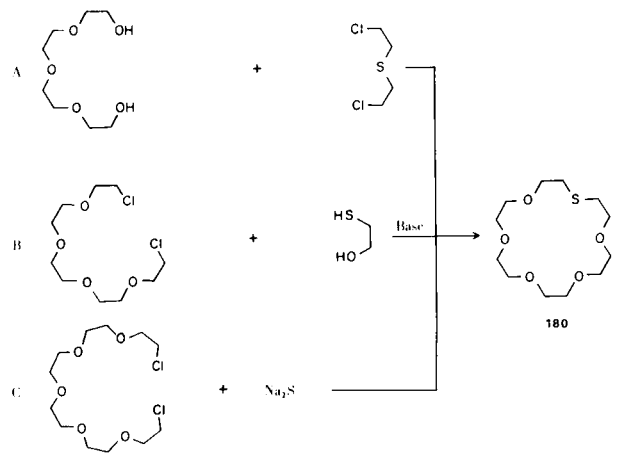
Compound	Reactants: Dithiol	Reactants: Dichlorides	Ring Size	Yield %	M.p. °C
171	bis(*o*-hydroxyphenylmercapto) methane	bis(2-chloroethyl) ether	14	3	150-153
172	toluene-3,4-dithiol	1,11-dichloro-3,6,9-trioxaundecane	15	30	oil
173	toluene-3,4-dithiol	1,14-dichloro-3,6,9,12-tetraoxatetradecane	18	56	oil
174	1,2-bis(β-mercaptoethoxy)ethane	1,2-bis(β-chloroethoxy)benzene	18	1	91
175	*o*-mercaptophenol	bis(2-chloroethyl)ether	18	15	143-144
176	as **175**	as **175**	18	5	114-115
177	toluene-3,4-dithiol	bis(2-chloroethyl)ether	18	6	147
178	*trans*-1,2-cyclohexanedithiol	bis(2-chloroethyl)ether	18	24	oil
179	1,17-dihydroxy-4,5,13,14-dibenzo-3,6,9,12,15-pentaoxaheptadeca-4,13-diene	thionyl chloride	20	33	133

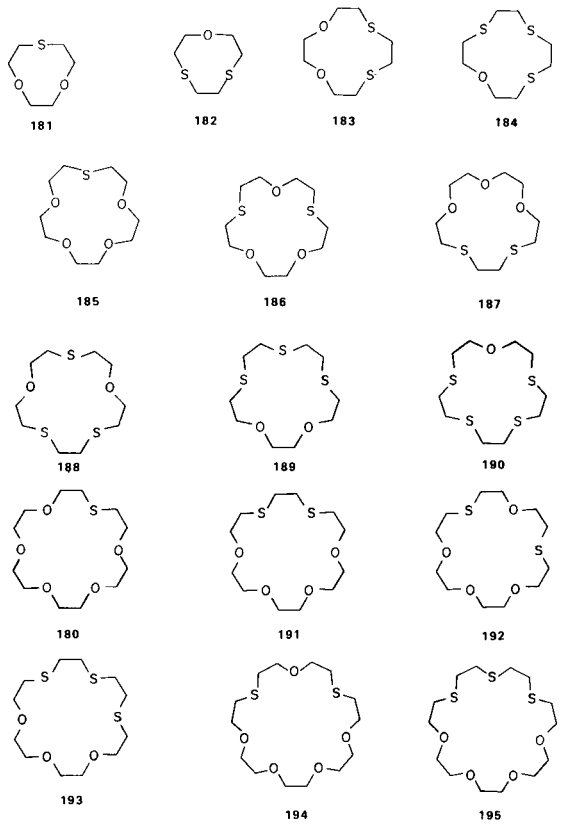
(a) Reference (158).

Dale has pointed out that melting points of macrocyclic compounds are related to their conformations (104). The melting point can be expressed as $T_m = \Delta H_m/\Delta S_m$. Since the heat of fusion will probably be constant (or nearly so) for all compounds of a particular series, a large entropy of fusion will mean a low melting point or *vice versa* (104). If a compound has a unique conformation which persists in the liquid state, it will have a low entropy change and therefore a high melting point. Large flexible rings have many equivalent conformations in the liquid state and therefore have high entropy of fusion and thus a low melting point (104).

The melting points of various related thia-crown compounds prepared by Bradshaw and others are listed in Table XIII. A number of interesting correlations are observed (105). In general, the melting point increases as the number of sulfur atoms is increased for each similar series. The larger sulfur atoms cause these rings to become

SCHEME III





less flexible and reduces the number of possible conformations in the liquid state. The perthia(15-crown-5) compound has not been reported. When prepared, it should have a melting point in excess of 100°.

Also, the more symmetrical compounds have higher melting points. 1,10-Dithia(18-crown-6) **2** is the most symmetrical of the eighteen-membered rings containing two sulfur atoms, while the 1,7-dithia compound **192**, is probably the least symmetrical. Compound **2** also has the

Table XIII

Yields and Melting Points of Thia-Crown Compounds

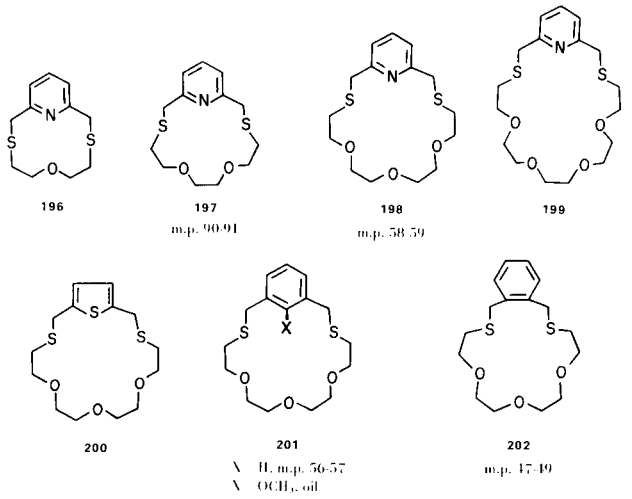
Crown-3	Yield (%)	M.p. (°C)	References
Trithia (**147**)	low	113°	(145)
Dithia (**182**)	6	liquid	(146)
Thia (**181**)	5	liquid	(146)
Crown-4			
Tetratha (**157**)	4	215-217	(25)
Trithia (**184**)	26	89-90	(146)
Dithia (**183**)	19	20-24	(146)
Dithia (**154**)	12	liquid	(146,148)
Thia (**153**)	14	liquid	(146,148)
Crown-5			
Tetrathia (**190**)	13	93-95	(105)
Trithia (**189**)	41	43-44	(105)
Trithia (**188**)	5	liquid	(105)
Dithia (**187**)	20	51-52	(146)
Dithia (**186**)	27	liquid	(146)
Thia (**185**)	29	liquid	(146)
Crown-6			
Hexathia (**148**)	1.4	145	(147)
Tetrathia (**149**)	1.7	125	(147)
Trithia (**193**)	11	liquid	(105)
Dithia (**2**)	12	90-91	(146,148)
Dithia (**191**)	28	54-56	(105)
Dithia (**192**)	29	liquid	(105)
Thia (**180**)	36	liquid	(105)
Crown-7			
Trithia (**195**)	11	liquid	(105)
Dithia (**194**)	25	liquid	(105)

highest melting point. Also in the twelve and fifteen-membered rings, the 1,4-dithia compounds **183** and **187** have higher melting points than the less symmetrical 1,7-dithia compounds **154** and **186**.

The effect of ring size on melting point can be seen by comparing compounds **157**, **158**, **159**, **150**, **151**, **152** and **160**. The first six compounds have the same number of sulfur atoms but an increasing number of ring members. The melting point decreases in a regular fashion as the ring size increases except for compounds **151** and **152**. As the ring size becomes larger, the ring becomes more flexible and the melting point decreases. In fact, very large rings (over 20 atoms) resemble two parallel chains connected by methylene bridges or heteroatoms at each end. This would be the case for compound **160** which is a dimer of **159**.

Adendum.

We attempted to cover the literature through 1973. Since that time new papers dealing with macrocyclic sulfur compounds have been published. Bockelheide and co-workers have now published complete data for the synthesis of metacyclophanes through sulfur intermediates (such as compounds **72-77**) (159-162). Vögtle and Weber have recently reported the preparation of macrocyclic compounds containing oxygen, sulfur and nitrogen heteroatoms (163). These compounds (**196-202**) were prepared to complex alkali metals. The amine oxides of some of these were also prepared.



REFERENCES

(1) Supported by the National Science Foundation Grant No. GP 33536-X and National Institute of Health Grant GM 18811.

(2) Department of Chemistry. To whom iniquiries should be sent.

(3) C. J. Pedersen, *J. Am. Chem. Soc.*, 89, 7071 (1967).

(4) C. J. Pedersen, *ibid.*, 92, 391 (1970).

(5) L. G. Sillen and A. E. Martell, *Chem. Soc. Spec. Publ.*, No. 17 (1964).

(6) J.-M. Lehn, *Structure and Bonding*, 16, 1 (1973).

(7) R. M. Izatt, D. J. Eatough and J. J. Christensen, *ibid.*, 16, 161 (1973).

(8) J. J. Christensen, D. J. Eatough and R. M. Izatt, *Chem. Rev.*, 74, 351 (1974).

(9) D. C. Tosteson, *Fed. Proc. Fed. Amer. Soc. Exp. Bio.*, 27, 1269 (1968).

(10) H. Lardy, *ibid.*, 27, 1278 (1968).

(11) G. Eisenman, S. M. Ciani and G. Szabo, *ibid.*, 27, 1289 (1968).

(12) S. Ciani, G. Eisenman, and G. Szabo, *J. Membrane Biol.*, 1, 294 (1969).

(13) K. H. Wong, G. Knoizer and J. Smid, *J. Am. Chem. Soc.*, 92, 666 (1970).

(14) J. Almy, D. C. Garwood, and D. J. Cram, *ibid.*, 92, 4321 (1970).

(15) J. N. Roitmann and D. J. Cram, *ibid.*, 93, 2231 (1971).

(16) M. J. Maskornick, *Tetrahedron Letters*, 1797 (1972).

(17) J. Zavada, M. Svoboda and M. Pankova, *ibid.*, 711 (1972).

(18) S. G. Smith and M. P. Hanson, *J. Org. Chem.*, 36, 1931 (1971).

(19) A. H. Haines and K. C. Symes, *J. Chem. Soc., (C),* 2331 (1971).
(20) C. J. Pedersen, *Chem. Eng. News,* March 2, 26 (1970).
(21) D. J. Sam and H. E. Simmons, *J. Am. Chem. Soc.,* **94**, 4024 (1972).
(22) L. M. Thomassen, T. Ellingsen, and J. Ugelstad, *Acta Chem. Scand.,* 25, 3024 (1971).
(23) The nomenclature for the "crown" compounds is fully discussed in reference (3). The 18 is the ring members and 6 is the number of oxygens. The thia (or oligothia) prefix is used to show that one (or more) or the ether oxygen atoms have been replaced by one (or more) sulfur atoms.
(24) H. K. Frendsdorff, *J. Am. Chem. Soc.,* **93**, 600 (1971).
(25) See for example, W. Rosen and D. H. Busch, *Inorg. Chem.,* 9, 262 (1970).
(26) See for example, F. B. Fleisher and P. A. Tasker, *Inorg. Nucl. Chem. Letters,* **6**, 349 (1970).
(27) For coverage of the litarature of macrocyclic compounds, see "Advances in Organic Chemistry," Vol. 8, Wiley-Interscience Publishers, New York, 1972, pp. 67-96.
(28) L. Ruzicka, *Helv. Chim. Acta,* **9**, 715, 1008 (1926).
(29) See L. Ruzicka, M. Stoll, and H. Schinz, *ibid.,* **11**, 496, 670 (1928) and other papers by these authors.
(30) V. Prelog, L. Frenkiel, N. Kobelt, and P. Barman, *ibid.,* **30**, 1741 (1947).
(31) See for example, F. Sondheimer and Y. Amiel, *J. Am. Chem. Soc.,* **81**, 4600 (1959).
(32) H. O. House and H. Babad, *J. Org. Chem.,* **28**, 90 (1963).
(33) G. A. Berchtold and G. F. Uhlig, *ibid.,* **28**, 1459 (1963).
(34) K. C. Brannock, R. D. Burpitt, and V. W. Goodlett, *ibid.,* 28, 1480 (1963).
(35) T. Mori, T. Nakahara, and H. Nozaki, *Can. J. Chem.,* **47**, 3266 (1969).
(36) H. Nozaki, T. Mori, and R. Noyori, *Tetrahedron Letters,* 779 (1967).
(37) G. Natta, G. F. Dall Asta, I. W. Bass, G. Carella, *Makromol. Chem.,* **91**, 87 (1966).
(38) P. R. Story, B. Lee, C. E. Bishop, D. D. Denson, and P. Busch, *J. Org. Chem.,* **35**, 3059 (1970).
(39) P. Busch and P. R. Story, *Synthesis,* 181 (1970).
(40) D. H. Busch, *Record Chem. Progr.,* **25**, 107 (1964).
(41) D. St. Black, *Rev. Pure and Appl. Chem.,* **15**, 109 (1965).
(42) M. C. Thompson and D. H. Busch, *J. Am. Chem. Soc.,* **84**, 1762 (1962).
(43) M. C. Thompson and D. H. Busch, *ibid.,* **86**, 213, 3651 (1964).
(44) F. L. Urback and D. H. Busch, *Inorg. Chem.,* **12**, 408 (1973).
(45) N. W. Alcock and P. A. Tasker, *Chem. Commun.,* 1239 (1972).
(46) G. N. Schrauzer, R. K. Y. Ho, and R. P. Murillo, *J. Am. Chem. Soc.,* **92**, 3508 (1970).
(47) G. N. Schrauzer in "Sulfur Research Trends," *Adv. Chemistry Series,* **110**, Edited by D. J. Miller and T. K. Wiewiorowski, American Chemical Society, 1972.
(48) D. St. C. Black and I. A. McLean, *Inorg. Nucl, Chem. Letters.,* **6**, 675 (1970).
(49) L. F. Lindoy and D. H. Busch, *J. Am. Chem. Soc.,* **91**, 4690 (1969).
(50) E. E. Reid, "Organic Chemistry of Bivalent Sulfur," Vol. III, Chemical Publishing Co., Inc., New York, 1960, pp. 11-12.
(51) *Ibid.,* p. 12.
(52) H. Steller and W. Wirth, *Ann. Chem.,* **631** 144 (1960).
(53) A. Feigenbaum and J.-M. Lehn, *Bull. Chim. Soc. France,* 198 (1973).
(54) See also G. Eglington, I. A. Lardy, R. A. Raphael and G. A. Sim, *J. Chem. Soc.,* 1154 (1964).
(55) F. Lautenschlaeger, *J. Org. Chem.,* **33**, 2627 (1968).
(56) N. N. Noritskaya, R. V. Kunakova, G. K. Samirhanova, and G. A. Tolstikov, *Zh. Org. Khim,* **9**, 636 (1973).
(57) C. S. Marvel and R. C. Farrar, Jr., *J. Am. Chem. Soc.,* 79, 986 (1957).
(58) C. S. Marvel, E. A. Sienick, M. Passer and C. N. Robinson, *ibid.,* **76**, 933 (1954).
(59) W. Autenrieth and F. Beutell, *Ber.,* **42**, 4346, 4357 (1909).
(60) W. Autenrieth and A. Geyer, *ibid.,* **41**, 4249 (1908).
(61) R. E. Busby and D. Huckle, *J. Chem. Soc. Perkin Trans. I,* 1705 (1972).
(62) D. W. Allen, P. N. Braunton, I. T. Millar, and J. C. Tabby, *J. Chem. Soc., (C),* 3454 (1971).
(63) A. I. Abdullaev, I. G. Ali-Zade and G. A. Agaev, USSR Patent, 177,881 of Jan. 8, 1966; [*Chem. Abstr.,* **64**, 19446g (1966)].
(64) A. I. Abdullaev, M. M. Dadasheva and I. G. Ali-Zade, *Uchenye Zapiski Azerbaidzhanskogo Gosudarstuennogo Universitete, Seriya Khimicheskikh Nauk,* No. 4, 89 (1966); [*Chem. Abstr.,* 70, 4086a (1969)].
(65) A. I. Abdullaev, I. G. Ali-Zade and M. M. Dadasheva, *ibid.,* No. 4, 89 (1970); [*Chem. Abstr.,* 77, 61975h (1972)].
(66) I. B. Ali-Zade and A. I. Abdullaev, *ibid.,* No. 4, 27 (1963); [*Chem. Abstr.,* **62**, 11677b (1965)].
(67) E. E. Reid, "Organic Chemistry of Bivalent Sulfur," Vol. 3, Chap. 7, Chemical Publishing Co., Inc., New York, 1960.
(68) F. Feher, J. Goebell and F. R. Minz, *Z. Anorg. Allgem. Chem.,* **342**, 146 (1966).
(69) F. Feher and B. Degen, *Angew. Chem. Intern. Edit. Engl.,* **6**, 703 (1967).
(70) F. Feher and M. Langer, *Tetrahedron Letters,* 2125 (1971).
(71) F. Feher, M. Langer, and R. Volkert, *Z. Naturforsch,* 27B, 1006 (1972).
(72) F. Feher, K. Glinka, and F. Malcharek, *Angew, Chem. Intern. Edit., Engl.,* **10**, 413 (1971).
(73) Z. S. Ariyan and R. L. Martin, *Chem. Commun.,* 847 (1969).
(74) Z. S. Ariyan and R. L. Martin, *Chem. Eng. News,* Nov. 17, 40 (1969).
(75) Z. S. Ariyan and R. L. Martin, *J. Chem. Soc. Perkin Trans.,* I, 1687 (1972).
(76) N. B. Egen and R. A. Krause, *J. Inorg. Nuclear Chem.,* **31**, 127 (1969).
(77) V. Boekelheide and J. L. Mondt, *Tetrahedron Letters,* 1203 (1970).
(78) P. Eckhardt, dissertation, University of Freiburg, 1968.
(79) D. Marschalk and J. P. Niederhauser, *Bull. Soc. Chim. France,* 147 (1952).
(80) A. Luttringhaus, F. Cramer, and H. Prinzback, *Angew, Chem.,* **69**, 137 (1957).
(81) A. Luttringhaus, F. Cramer, H. Prinzbach, and F. M. Henglein, *Ann. Chem.,* **613**, 185 (1958).
(82) F. Ansinger, *ibid.,* **723**, 119 (1969).
(83) F. Ansinger, D. Neuray, E.-Chr. Witte and J. Hartig, *Monatsh. Chem.,* **103**, **1661** (1972).
(84) B. H. Smith, "Bridged Aromatic Compounds," Academic Press, New York, 1964.
(85) W. Authenrieth and A. Bruning, *Ber.,* **36**, 183 (1903).
(86) W. Authenrieth and R. Hennings, *ibid.,* 35, 1388 (1902).
(87) W. Kiesslig, J. Peschel, W. Schmidt, and W. Schroth, *Z. Chem.,* **4**, 302 (1964).

(88) S. Tanaka, K. Hashimoto and H. Watanabe, *J. Pharm. Jap. (Yakugaku Zaashi)*, **93**, 991 (1973).
(89) S. Tanaka, H. Watanabe and Y. Ogata, *ibid.*, **93**, 997 (1973).
(90) F. Vögtle, *Chem. Ber.*, **102**, 1784 (1969).
(91) F. Vögtle, and L. Schunder, *ibid.*, **102**, 2677 (1969).
(92) F. Vögtle and A. H. Effler, *ibid.*, **102**, 3071 (1969).
(93) F. Vögtle, *ibid.*, **102**, 3077 (1969).
(94) F. Vögtle and P. Neumann, *Tetrahedron*, **26**, 5299 (1970).
(95) F. Vögtle, *ibid.*, **25**, 3231 (1969).
(96) F. Vögtle, *Tetrahedron Letters*, 3193 (1969).
(97) F. Vögtle and H. Risler, *Angew. Chem. Intern. Edit, Engl.*, **11**, 727 (1972).
(98) F. Vögtle and P. Neumann, *Tetrahedron Letters*, 5329 (1969).
(99) F. Vögtle, *ibid.*, 3623 (1968).
(100) F. Vögtle, *Angew. Chem. Intern. Edit. Engl.*, **8**, 274 (1969).
(101) F. Vögtle, P. Neumann and M. Zuber, *Chem. Ber.*, **105**, 2955 (1972).
(102) F. Vögtle, M. Zuber and P. Neumann, *Z. Naturforsch*, **26B**, 707 (1971).
(103) F. Vögtle and Peter Neumann, *Tetrahydron Letters*, 5329 (1969).
(104) J. Dale, *J. Chem. Soc.*, 93 (1963).
(105) J. S. Bradshaw, J. Y. Hui, J. Y. Chan, B. L. Haymore, J. J. Christensen and R. M. Izatt, *J. Heterocyclic Chem.*, **11**, 45 (1974).
(106) V. Boekelheide and P. H. Anderson, *J. Org. Chem.*, **38**, 3928 (1973).
(107) V. Boekelheide and C. H. Tsai, *ibid.*, **38**, 3931 (1973).
(108) R. H. Mitchell and V. Boekelheide, *Tetrahedron Letters*, 1197 (1970).
(109) V. Boekelheide and R. A. Hollins, *J. Am. Chem. Soc.*, **92**, 3512 (1970).
(110) F. Reindel and L. Schuberth, *Ber.*, **57B**, 369 (1924).
(111) J. Lawson, R. Du Vernet and V. Boekelheide, *J. Am. Chem. Soc.*, **95**, 956 (1973).
(112) F. Vögtle and R. Lichtenthaler, *Z. Naturforsch.*, **26B**, 872 (1971).
(113) F. Vögtle and R. G. Lichtenthaler, *Tetrahedron Letters*, 1905 (1972).
(114) F. Vögtle and R. B. Lichtenthaler, *Synthesis*, 480 (1972); *Chem. Abstr.*, **77**, 16450c (1972).
(115) G. Montaudo, F. Bottino, and E. Trivellone, *J. Org. Chem.*, **37**, 504 (1972).
(116) K.-D. Gundermann and K.-D. Roker, *Angew. Chem.*, **85**, 451 (1973).
(117) W. Rebafka and H. A. Staab, *ibid.*, **85**, 831 (1973).
(117a) N. Kannen, T. Umemoto, T. Otsubo and S. Misumi, *Tetrahedron Letters*, 4537 (1973).
(118) F. Vögtle and R. G. Lichtenthalaer, *Angew. Chem. Intern. Edit. Engl.*, **11**, 535 (1972).
(119) R. G. Lichtenthaler and F. Vögtle, *Chem. Ber.*, **106**, 1319 (1973).
(120) See V. Boekelheide and R. A. Hollins, *J. Am. Chem. Soc.*, **95**, 3201 (1973) for other interesting reactions of these compounds and their derivatives.
(121) F. Vögtle, G. Hohner and E. Weber, *J. Chem. Soc., Chem. Commun.*, **366** (1973).
(122) H. J. Martel and M. Rasmussen, *Tetrahedron Letters*, 3843 (1971).
(123) K. R. Reistad, P. Groth, R. Lie and K. Undheim, *J. Chem. Soc., Chem. Commun.*, 1059 (1972).
(124) V. Boekelheide, I. D. Reingold and M. Tuttle, *ibid.*, 406 (1973).
(125) J. Bruhin, W. Kneubuhler and W. Jenny, *Chimia*, **27**, 277 (1973).
(126) J. Bruhin and W. Jenny, *Tetrahedron Letters*, 1215 (1973).
(127) Most of the material in this section was taken from the review by O. Meth-Cohn, *Quart, Rep. Sulfur. Chem.*, **5**, 129 (1970).
(128) H. Nozaki, T. Koyama, T. Mori, and R. Noyori, *Tetrahedron Letters*, 2181 (1968).
(129) H. E. Winberg, F. S. Fawcett, W. E. Mochel and C. W. Theobald, *J. Am. Chem. Soc.*, **82**, 1428 (1960).
(130) L. I. Belenkii, S. Z. Taits and Ya. L. Goldfarb, *Dokl. Akad. Nauk SSSR*, 139, 1356 (1961); [*Proc. Acad. Sci. USSR, Chem. Sect.*, 139, 1338 (1961)].
(131) Ya. L. Goldfarb, S. Z. Taits and L. I. Belenkii, *Izvest. Akad. Nauk. SSSR, Otdel Khim. Nauk*, 1262 (1957); [*Bull Acad. Sci. USSR, Div. Chem. Sci.*, 1287 (1957)].
(132) Ya. L. Goldfarb, S. Z. Taits and L. I. Belenkii, *Zh. Obshch. Khim.*, **29**, 3564 (1959); [*J. Gen. Chem. USSR*, **29**, 3526 (1959)].
(133) Ya. L. Goldfarb, S. Z. Taits and L. I. Belenkii, *Tetrahedron*, **19**, 1851 (1963).
(134) Ya. L. Goldfarb, S. Z. Taits and V. N. Bulgakova, *Izvest. Akad. Nauk SSSR, Odel Khim. Nauk*, **1299** (1963); [*Bull Acad. Sci. USSR, Div. Chem. Sci.*, 1181 (1962)].
(135) E. A. Krasmyanskaya and Ya. L. Goldfarb, *Izvest. Akad. Nauk SSSR, Otdel Khim. Nauk*, 745 (1968).
(136) S. Z. Taits and Ya. L. Goldfarb, *Izvest, Akad. Nauk SSSR, Otdel Khim. Nauk*, 1968 (1960); [*Bull Acad. Sci. USSR, Div. Chem. Sci.*, 1574 (1960)].
(137) S. Z. Taits, V. N. Bulgakova and Ya. L. Goldfarb, *Khim Geterotsikl. Soedin*, 16 (1973).
(138) G. M. Badger, J. A. Elix and G. F. Wright, *Aust. J. Chem.*, **18**, 70 (1965).
(139) G. M. Badger, J. A. Elix and G. E. Lewis, *ibid.*, **19**, 1221 (1966).
(140) G. M. Badger, G. E. Lewis and U. P. Singh, *ibid.*, **19**, 257, 1461 (1966).
(141) G. M. Badger, G. E. Lewis and U. P. Singh, *ibid.*, **20**, 1635 (1967).
(142) T. M. Cresp and M. V. Sargent, *J. Chem. Soc., Perkin I*, 1786 (1973).
(143) M. Ahmed and O. Meth-Cohn, *J. Chem. Soc., C.*, 2104 (1971).
(144) T. Kauffmann and H.-H. Kniese, *Tetrahedron Letters*, 4043 (1973).
(145) P. C. Ray, *J. Chem. Soc.*, 1090 (1920).
(146) J. S. Bradshaw, J. Y. Hui, B. L. Haymore, R. M. Izatt and J. J. Christensen, *J. Heterocyclic Chem.*, **10**, 1 (1973).
(147) J. R. Meadow and E. E. Reid, *J. Am. Chem. Soc.*, **56**, 2177 (1934).
(148) J. R. Dann, P. P. Chiesa, and J. W. Gates, Jr., *J. Org. Chem.*, **26**, 1991 (1961).
(149) W. Rosen and D. H. Busch, *J. Am. Chem. Soc.*, **91**, 4694 (1969).
(150) K. Travis and D. H. Busch, *Chem. Commun.*, 1041 (1970).
(151) D. St. C. Black, and I. A. MaLean, *Tetrahedron Letters*, 3961 (1969).
(152) D. St. C. Black and I. A. MaLean, *Chem. Commun.*, 1004 (1968).
(153) R. Russo, L. Mortillaro, L. Credali, and Carlo De Checchi, *J. Polymer Sci., Part B, Polymer Letters*, **3**, 455 (1965).
(154) L. Mortillaro, M. Russo, L. Credali, and C. De Checchi, *J. Chem. Soc., C*, 428 (1966).
(155) B. Bobranski, T. Jakobiec, and D. Prelicz, *Acta Polon, Pharm.*, **12**, 195 (1955).

(156) B. Dietrich, J. M. Lehn, and J. P. Sauvage, *Chem. Commun.*, 1055 (1970).
(157) D. Pelissard and R. Louis, *Tetrahedron Letters*, 4589 (1972).
(158) C. J. Pedersen, *J. Org. Chem.*, **36**, 254 (1971).
(159) R. H. Mitchell and V. Boekelheide, *J. Am. Chem. Soc.*, **96**, 1547 (1974).
(160) V. Boekelheide, P. H. Anderson and T. A. Hylton, *ibid.*, **96**, 1558 (1974).
(161) S. A. Sherrod, R. L. da Costa, R. A. Barnes and V. Boekelheide, *ibid.*, **96**, 1565 (1974).
(162) V. Boekelheide, K. Galuszko and K. S. Szeto, *ibid.*, **96**, 1578 (1974).
(163) F. Vögtle and E. Weber, *Angew. Chem.*, **86**, 126 (1974).