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Two new dithia-crowns containing a hydroxy group and 1,4,7,10-tetrathia-18-crown-6 containing an allyloxymethyl substituent were prepared in good yields. Two of these crowns were covalently attached to silica gel. The silica gel-bound thia-crowns were used to separate gold(III), palladium(II), silver(I) and mercury(II) ions from an aqueous 0.1 M nitric acid solution which also contained 1.0 M ferric chloride.

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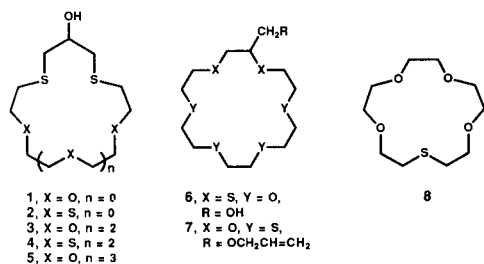
Introduction.

The chemistry of the thia-crowns has not developed as much as the chemistry of the crown ethers, aza-crowns or cyclans, although there has been some recent work [2,3]. Hexathia-18-crown-6 was first prepared by Meadow and Reid in a 1.7% yield in 1934 [4]. The same compound was prepared in 1974 by Ochrymowycz and co-workers in a 32.8% yield [5] and in 1989 by Ochrymowycz, Cooper and co-workers in a 64% yield [6]. Recent high yields for the synthesis of the thia-crowns are a result of the use of cesium ions in the cyclization step as reported by Buter and Kellogg [7-9]. The thia-crown compounds are of interest because they strongly complex with many soft cations such as nickel, silver, gold and platinum [3,10].

Very few functionalized thia-crown compounds have been prepared. Thia-crowns with the hydroxy functional group (**1-5**, Figure 1) have been reported [11-13]. The hydroxy group was used to bind some of these thia-crowns to functionalized polystyrene and some metal ion separations were observed [12,13]. Lavery also suggested that these types of ligands could be attached to silica gel although specific details were not given [3].

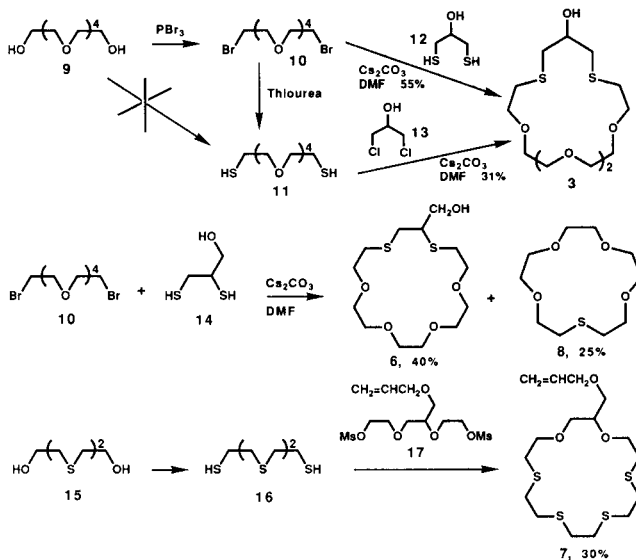
macrocyclic ligands have about the same affinity for metal ions as do the unbound ligands for the same metal cations in aqueous solutions. We herein report an improved synthesis of hydroxy-substituted dithia-19-crown-6 (**3**), the synthesis of hydroxymethyl-substituted dithia-18-crown-6 (**6**) and allyloxymethyl-substituted tetrathia-18-crown-6 (**7**) compounds. Metal cation separations by silica gel-bound **3** and **6** ligands are also reported in this paper. It should be mentioned here that some polyfunctionalized thia-crowns such as 1,5,9,13,17,21-hexathiacyclotetraicosane-3,11,19-triol, 1,5,9,13-tetrathiacyclohexadecane-3,11-diol and 1,4,7,13-tetrathia-7,16-diazacyclooctadecane are commercially available. Our new functionalized polythia-crowns are of the crown-6 variety and they have only one functional group.

Figure 1. Polythia-Crown Compounds



Crown ethers, diaza-crowns and crowns containing the pyridine subcyclic unit have been covalently attached to silica gel [14-16]. It was found that these silica gel-bound

Scheme I. Preparation of Polythia-Crowns



Results and Discussion.

Macrocycle **3** was prepared previously in our laboratory in an 8% yield by reacting the dichloro derivative of pentaethylene glycol with 2-hydroxy-1,3-propanedithol [11]. As shown in Scheme I, we have prepared **3** by two methods, each providing much higher yields than that seen earlier. In the first pathway, the dibromo derivative of pentaethylene glycol (**10**) [17] was reacted with dimercaptan **12** using cesium carbonate as the base. The seven-fold higher yield than in the previous synthesis [11] can be attributed both to the use of the more reactive dibromide and the use of the cesium base which has been reported to give much higher cyclization yields [7-9]. In the second pathway, dimercaptan **11** [18] was first prepared from dibromide **10**. Compound **11** was then reacted with 1,3-dichloro-2-hydroxypropane (**13**) in the presence of cesium carbonate to give a 31% yield of **3**. A more direct reaction sequence *via* the conversion of diol **9** to dimercaptan **11** by treatment with thiourea and hydrochloric acid [19-21], gave only poor yields of the dimercaptan product.

Hydroxymethyl-substituted macrocycle **6** was obtained in a 40% yield by the reaction of **10** with commercially available hydroxydimercaptan **14** (Scheme I). Again, cesium carbonate was used as the base in the cyclization reaction. Unexpectedly, thia-15-crown-5 (**8**) was also isolated in a 25% yield. Macrocycle **8** was originally prepared from the dichloride analog of **10** and disodium sulfide [22]. It is possible that in this base catalyzed reaction, some of the starting **14** eliminated a mercaptide ion which reacted with **10** to form macrocycle **8**.

Macrocycle **7** was obtained in a 30% yield by reacting dimesylate **17** [23] with dimercaptan **16** [20, 21 and 24] (Scheme I). This latter compound was prepared from diol **15** using thiourea. The resulting tetrathia-18-crown-6 ligand contains the allyloxymethyl substituent which, when attached to crown ethers and aza-crowns, has been hydrosilylated with triethoxysilane to form a crown-substituted triethoxysilane capable of bonding to silica gel [14-16].

Compounds **3** and **7** have been attached to silica gel [25]. Silica gel-bound ligands **3** and **7** were used to selectively separate and concentrate gold(III), palladium(II), silver(I) or mercury(II) ions from a 0.1 M nitric acid-1 M ferric chloride solution. For example, a liter of solution containing 20 ppb of gold(III) in the nitric acid-ferric nitrate matrix was passed through a column of 2.0 g of silica gel-bound macrocycle. The gold(III) ion complexed with the bound ligand. The complexed gold(III)-silica gel was washed with water to remove acid and ferric ion and then with 10 ml of ammonia buffer (pH below 10.5) to quantitatively recover the gold(III) ions. An analysis of the recovery solution showed that there were 20 ± 1 ppb gold-

(III) in the original solution. Thus, these new silica gel-bound thia-crowns can be used to quantitatively remove, concentrate, recover and analyze these important metal ions.

EXPERIMENTAL

Infrared (ir) spectra were obtained on a Perkin-Elmer 1600 series FTIR spectrometer. The proton nuclear magnetic resonance (^1H nmr) spectra were obtained on a Varian Gemini 200 spectrometer using deuteriochloroform. Elemental analyses were performed by MHW Laboratories, Phoenix, Arizona. Molecular weights were determined by the electron impact method on a Finnegan 8430 High Resolution Mass Spectrometer. Starting materials were purchased from Aldrich Chemical Co. when available.

1,14-Dibromo-3,6,9,12-tetraoxatetradecane (**10**) (Scheme I).

Phosphorus tribromide (9 g, 0.033 mole) was slowly added to a stirred mixture of 10 g (0.042 mole) of pentaethylene glycol and 2 g of pyridine at -5° to 5° . The resulting mixture was stirred at room temperature for 16 hours. The mixture was poured into 10 ml of water and the resulting solution was extracted three times with 40 ml portions of carbon tetrachloride. The combined organic extracts were washed successively with 25 ml portions of aqueous 10% sodium carbonate, saturated brine, 5% sulfuric acid and distilled water. After drying over anhydrous magnesium sulfate, the solvents were removed and the residue distilled to give 7.6 g (50%) of **10** as an oil, bp 140° - $144^\circ/0.085$ mm; ^1H nmr (δ): 3.45 (t, 4H), 3.65 (m, 12H), 3.8 (t, 4H).

3,6,9,12-Tetraoxa-1,15-dithiol (**11**) (Scheme I).

Thiourea (5.0 g, 0.066 mole) was dissolved in 45 ml of refluxing ethanol. Compound **10** (8.5 g, 0.012 mole) was slowly dripped into this solution and the resulting mixture was refluxed for 5 hours. The solvent was removed under reduced pressure, 100 ml of 20% aqueous sodium hydroxide was added and the resulting mixture was refluxed for 3 hours. After cooling, 10% aqueous hydrochloric acid was slowly added until the solution was slightly acidic (pH = about 2). This mixture was extracted with three 250 ml portions of ether. The combined ether extracts were dried over anhydrous magnesium sulfate and the solvent was removed under vacuum. The residue was distilled to give 4 g (63%) of **11** as an oil, bp 137° - $138^\circ/0.1$ mm; ^1H nmr (δ): 1.55 (t, 2H), 2.7 (m, 4H), 3.6 (m, 16H); ir (neat): 2555, 1100 cm^{-1} .

3-Hydroxymethyl-8,11,14,17-tetraoxa-1,5-dithiacyclononadecane (**3**) (Scheme I).

Procedure A.

A mixture of 1.82 g (5 mmoles) of **10** and 0.62 g (5 mmoles) of **12** in 100 ml of anhydrous DMF was slowly dripped into a stirred solution of 1.63 g (5 mmoles) of cesium carbonate in 350 ml of anhydrous DMF over a 5-hour period under an Argon atmosphere at 55° - 60° . The mixture was cooled and the DMF was evaporated under high vacuum keeping the water bath temperature at or below 55° . The residue was thoroughly mixed with 150 ml of methylene chloride and 25 ml of water. The organic layer was separated and dried over anhydrous magnesium sulfate. The mixture was filtered, the solvent removed under vacuum and the residue was chromatographed on neutral alumina using chloroform/hexane:1/1, chloroform and then ethyl acetate as eluents.

Compound **3** (0.88 g, 55%) gave the same physical properties as reported [11].

Procedure B.

The above procedure was used with 1.63 g (5 mmoles) of cesium carbonate, 1.35 g (5 mmoles) of **11** and 0.65 g (5 mmole) of **13**. The yield was 0.5 g (31%) of **3** which gave the same physical properties as reported [11].

2-Hydroxymethyl-1,4-dithia-7,10,13,16-tetraoxacyclooctadecane (**6**) and 1-Thia-4,7,10,13-tetraoxacyclopentadecane (**8**) (Scheme I).

A mixture of 1.24 g (10 mmoles) of **14** and 3.64 g (10 mmoles) of **10** in 100 ml of anhydrous DMF was slowly dripped into 3.25 g (10 mmoles) of cesium carbonate in 500 ml of anhydrous DMF over a 5-hour period under an Argon atmosphere at 55°-60°. This material was treated as above. The residue was chromatographed on neutral alumina using chloroform/hexane:2/1, chloroform, ethyl acetate and THF/ethyl acetate:5/1 as eluants to give 0.6 g (25%) of **8** [22] and 1.16 g (40%) of **6**; ¹H nmr (δ): 2.9 (m, 8H), 3.7 (m, 18H); ir (neat) 3400, 2950, 1100 cm⁻¹; ms [m/e (%): 117 (60), 326 (100)].

Anal. Calcd. for C₁₃H₂₆S₂O₅: C, 47.83; H, 8.03. Found: C, 47.69; H, 8.17.

14-Allyloxymethyl-1,4,7,10-tetrathia-13,16-dioxacyclooctadecane (**7**) (Scheme I).

Macrocycle **7** was prepared as above for **3** from 3.25 g (10 mmoles) of cesium carbonate, 2.14 g (10 mmoles) of **16** and 3.76 g (10 mmoles) of **17**. The reaction mixture was stirred at 60°-65° for 16 hours. The product was purified on a neutral alumina column using chloroform/ethyl acetate: 70/1 as eluant to give 1.2 g (30%) of **7** as an oil; ¹H nmr (δ): 2.8 (m, 16H), 3.6 (m, 9H), 4.0 (d, 2H), 5.2 (m, 2H), 5.8 (m, 1H); ir (neat): 2950, 1100 cm⁻¹; ms [m/e (%): 82 (96), 120 (100), 305 (60), 398 (36)].

Anal. Calcd. for C₁₆H₃₀S₄O₃: C, 48.20; H, 7.58. Found: C, 48.16; H, 7.61.

Selective Analytical Separation and Concentration of Gold(III), Palladium(II), Silver(I) and Mercury(II) Ions.

An acidic matrix of 0.1 M nitric acid and 1 M ferric chloride was prepared and spiked with 20 ppb of the desired metal ion using volumetric finnpipettes and atomic absorption spectroscopic standards of those elements. The separation experiment was carried out by passing one liter of the prepared solution through a 2.0 g (19 mm diameter) column of the silica gel material at a constant flow rate of about 50 ml/minute using an adjustable vacuum pump. The silica gel material was washed with 10 ml of distilled water and then with 10 ml of ammonia buffer solution (pH below 10.5). The 10 ml of buffer was collected and analyzed using atomic absorption spectroscopy.

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