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SYNTHESIS AND EXTRACTION PROPERTIES OF OXATHIACROWN COMPOUNDS CONTAINING BENZYL GROUPS

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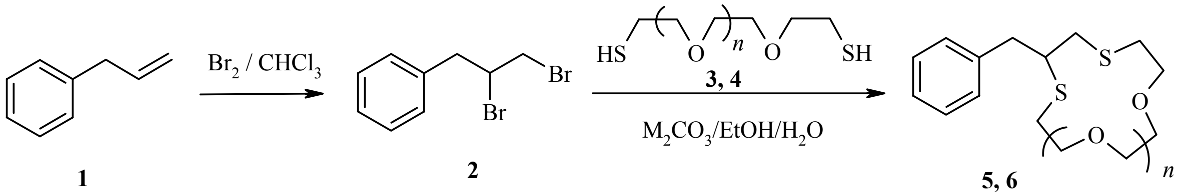
8-Benzyl-1.4-dioxa-7,10-dithiacyclododecane and 11-benzyl-1,4,7-trioxa-10,13-dithiacyclopentadecane were obtained by the interaction of (2,3-dibromo-1-propyl)benzene with 1,8-dimercapto-3,6-dioxaoctane and 1,11-dimercapto-3,6,9-trioxaundecane. The extracting ability of the obtained compounds has been studied in relation to Sr^{2+} and Pb^{2+} ions from aqueous solutions in the presence of anions of various degrees of hardness with determination of the metal content by a radiometric method.

Keywords: dithia-12(15)-crown-4(5) ethers, Sr^{2+} and Pb^{2+} ions, complex-formation, extraction.

The ability of thiacrown ethers to form complexes with the ions of heavy and transition metals stimulated the search for new efficient and selective ligands of this class [1]. In recent years oxathiacrown ethers containing various substituents have been studied intensively [2-9]. However the extracting ability of similar compounds is practically unstudied. The present work is devoted to the development of a method of synthesis of new oxathiacrown compounds linked with aromatic fragments through a methylene bridge, and to the study of their extracting properties. Benzooxathia and other annelated crown ethers are not considered. The essence of the method consists of electrophilic addition of bromine at the double bond of an allyl group with subsequent macrocyclization of the compounds obtained with various dithiols.

Since one of the most convenient methods of obtaining thiacrowns is the interaction of the appropriate dihalides or ditosylates with dithiols [10, 11], allylbenzene (**1**), was selected as the starting material, and was converted into (2,3-dibromo-1-propyl)benzene (**2**) [12]. 1,8-Dimercapto-3,6-dioxaoctane (**3**) and 1,11-dimercapto-3,6,9-trioxaundecane (**4**), synthesized by the method of [13], were used as nucleophiles.



3, **5** n = 1; **4**, **6** n = 2; M = Li, Cs

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8-Benzyl-1,4-dioxa-7,10-dithiacyclododecane (**5**) and 11-benzyl-1,4,7-trioxa-10,13-dithiacyclopentadecane (**6**) were obtained under high dilution conditions in the presence of template reagents Li_2CO_3 and Cs_2CO_3 by the method of [14]. A detailed study of the NMR spectra of compounds **5** and **6** was of particular interest since this is important for subsequent conformational investigations. In the ^{13}C NMR spectra of macrocycles **5** and **6** the number of signals in the aliphatic region was 9 and 11, which clearly confirms the proposed structures. Integration of the chemical shifts of signals was made on the basis of HETCOR and COSY two-dimensional experiments. Systematic analysis of the structure of multiplets in the ^1H NMR spectra together with information on cross peaks in the correlation pictures enabled an unequivocal assignment to be made of all the signals in the ^{13}C NMR and of the multiplets in the ^1H NMR spectra (see EXPERIMENTAL). Key information for assigning was the heteronuclear ^{13}C-^1H links in the SESE experiments (spin echo with selective excitation) [15]. The starting point was the assignment of the benzylic CH_2 group signals where the spin of the carbon atom is linked with the *ortho* protons of the phenyl groups in both compounds **5** and **6** [16, 17]. The multiplets in the ^1H NMR spectra of compound **5** are well resolved with the exception of a single very broad multiplet for the remote H-2 and H-3 protons. The structures of the multiplets in the spectra of compound **6** are more complex. Nevertheless the majority of the signals were assigned apart from the remote protons H-2, H-3, H-5, and H-6. The chemical shifts of the protons of the cyclic CH_2 groups linked to oxygen and sulfur lie at 3.50-3.86 and 2.40-3.36 ppm respectively. The range of shielding of the remote protons was significantly less than for protons of CH_2 groups linked to sulfur, which is in good agreement with data previously obtained for 12-membered thiacrown ethers [18]. It is remarkable that in both macrocycles shielding is observed for the pseudo-axial H-6 (compound **5**) and H-9 (compound **6**) protons, which are subject to more or less the same anisotropic influence of the neighboring phenyl substituents and sulfur, as our preliminary investigations showed (see, for example [19]). On the whole our observations for compounds **5** and **6** showed that the greater the distance of the protons of the macrocyclic ligand from a substituent then the less is its effect on their chemical shifts. This has been noted previously for thiacrown [18], crown [19], and azacrown ethers [20].

Concerning the study of complex formation using dithia-12(15)-crown-4(5) ethers, it is known that an unsubstituted 15-membered macrocyle forms stable complexes with Ag(I) [21] and with ions of metals of the platinum group [22]. In the first case coordination of the metal ion is effected both with sulfur atoms and with oxygen, and in the second, only with the sulfur atoms. It has also been reported [22] that a 12-membered macrocycle immobilized on SiO_2 through an ester group is an efficient complex-forming adsorbent for Ag(I), Au(III), and Hg(II) ions [8]. The extracting ability of compounds **5** and **6** synthesized in the present work was studied using the example of a soft cation Sr(II) and an intermediate cation Pb(II). Extraction was carried out from solutions of nitric acid and lithium picrate (LiPi). As was shown previously in [23, 24], lithium does not compete with strontium and lead under these conditions, but the use of salts and not picric acid is preferable, since the salt is practically completely dissociated in aqueous solution, picrate anion acting as counter ion.

From the data obtained it is evident that the investigated oxathiacrown ethers **5** and **6** preferentially extract lead cation from picrate solutions. This may indicate that the presence of sulfur atoms in the heterocycle aids the extraction of intermediate and, probably, soft metal cations. This, to a first approximation, corresponds to the concept of Pearson and the experimental data obtained previously in our laboratory [25, 26]. Another interesting fact must be mentioned. A concentration dependence is observed for the distribution coefficients of the metal cations in all the extraction systems investigated. This phenomenon is known in the literature [27, 28] and is linked with dissociation in polar solvents, to which dichloroethane belongs, of the compounds being extracted. The dissociation of complexes in the organic phase may lead to a mutual influence of metal cations on the extraction of one another [27, 28], and then the selectivity of isolating a radionuclide will depend on several factors, varying which will possibly determine the optimum conditions for separating radioactive isotopes.

TABLE 1. Conditions for Synthesizing Compounds **5** and **6**

Crown ether	Method	Template reagent, g (mmol)	**2**, g (mmol)	Dithiol, g (mmol)		Volume EtOH–H_2O, ml
				3	**4**	
5	1	Li_2CO_3, 0.19 (2.5)	0.14 (0.5)	0.1 (0.55)		200
	2	Cs_2CO_3, 1.63 (5)	0.28 (1)	0.2 (1.1)		400
		Cs_2CO_3, 1.63 (5)	1.4 (5)		1.2 (5.3)	400

TABLE 2. Distribution Coefficients of Sr(II) and Pb(II) on Extraction with a 1.5 × 10^{-2} M Solution of 8-Benzyl-1,4-dioxa-7,10-dithiacyclododecane in Dichloroethane

Aqueous phase	Concentration of $M(NO_3)_2$, mol/l									
	10^{-2}		5×10^{-3}		2×10^{-3}		10^{-3}		10^{-4}	
	Sr^{2}	Pb^{2+}	Sr^{2}	Pb^{2+}	Sr^{2}	Pb^{2+}	Sr^{2}	Pb^{2+}	Sr^{2}	Pb^{2+}
H_2O	0.12	—	0.15	—	0.2	—	0.26	—	0.3	—
3 mol/l HNO_3	0.2	4×10^{-3}	0.4	6×10^{-3}	0.5	8×10^{-3}	0.55	9×10^{-3}	0.6	0.01
4×10^{-3} mol/l LiPi	0.3	0.8	0.8	1.2	1	1.6	1.2	1.8	1.5	2.2

TABLE 3. Distribution Coefficients of Sr(II) and Pb(II) on Extraction with a 1.5 × 10^{-2} M solution of 11-Benzyl-1,4,7-trioxa-10,13-dithiacyclopentadecane in Dichloroethane

Aqueous phase	Concentrtion $M(NO_3)_2$, mol/l							
	5×10^{-3}		2×10^{-3}		10^{-3}		10^{-4}	
	Sr^{2}	Pb^{2+}	Sr^{2}	Pb^{2+}	Sr^{2}	Pb^{2+}	Sr^{2}	Pb^{2+}
H_2O	0.2	—	0.25	—	0.27	—	0.42	—
3 mol/l HNO_3	0.8	6×10^{-3}	1.2	7×10^{-3}	1.5	9×10^{-3}	2.2	15×10^{-3}
4×10^{-3} mol/l LiPi	0.6	0.45	1	0.68	1.5	0.95	2	1.35

EXPERIMENTAL

The ^{1}H and ^{13}C NMR spectra were recorded on a Varian XR 400 spectrometer (400 and 100 MHz respectively). Solutions (25%) of samples in $CDCl_3$ were used, internal standard was HMDS (δ 0.05 ppm) for ^{1}H, and solutions (30-50%) in $CDCl_3$ for ^{13}C. The spectra of the oxathiacrown ethers were identified by COSY and HETCOR methods. Mass spectra were obtained on a Finnigan MAT 112S instrument with direct insertion of samples into the ion source, ionizing voltage was 70 eV. A check on the progress of reactions and the purity of compounds was carried out by TLC on Silufol UV 254 plates in the systems ether–hexane, 1:1, and ethyl acetate–petroleum ether, 1:1.

(2,3-Dibromo-1-propyl)benzene (2). Bromine (28 g, 0.175 mol) was added dropwise with stirring at 0-5°C to a solution of allylbenzene (20 g, 0.17 mol) in $CHCl_3$ (125 ml). After distilling off the solvent, the residue was distilled in vacuum. Compound **2** (44.2 g) was obtained; bp 126-128°C (4 mm Hg). Lit. bp 137-138°C (8 mm Hg) [12]. Yield 94%. Mass spectrum: *m/z* (I_{rel}, %): 278 (3) $[M]^+$, 199 (12), 118 (11), 91 (100), 65 (3.5), 58 (2). ^{1}H NMR spectrum, δ, ppm: 3.09 (1H, dd, *J* = 13.21, *J* = 5.43, CH_2); 3.45 (1H, dd, *J* = 13.23, *J* = 5.52, CH_2); 3.58 (1H, dd, *J* = 11.44, *J* = 9.11, CH_2Br); 3.77 (1H, dd, *J* = 11.44, *J* = 3.08, CH_2Br); 4.31 (1H, m, CHBr); 7.25 (5H, m, C_6H_5).

1,11-Dimercapto-3,6,9-trioxaundecane (4). A mixture of 1,11-dibromo-trioxaundecane (17.9 g, 0.056 mol), thiourea (8.9 g, 0.12 mol), and EtOH (40 ml) was boiled for 12 h. The solution was cooled, and 20% KOH solution (96 ml) was carefully added dropwise. The mixture was boiled for 4 h. At the end of the reaction the mixture was acidified with dilute HCl to pH 2-3, then NaCl (25 g) was dissolved in it. An oily film was formed. The substance was extracted with ether, and the ether extract dried over $CaCl_2$. After distilling off the solvent the residue was distilled in vacuum. A colorless liquid (4.5 g) was isolated; bp 142-143°C (2 mm Hg). Yield 36%. Mass spectrum: *m/z* (I_{rel}, %): 167 (2), 133 (1), 107 (34), 61 (100), 45 (30). ^{1}H NMR spectrum, δ, ppm (*J*, Hz): 1.60 (1H, t, *J* = 7.26, SH); 2.68 (4H, dd, *J* = 10.23, *J* = 7.26, $C\underline{H}_2SH$); 3.62 (12H, m, CH_2O).

8-Benzyl-1,4-dioxa-7,10-dithiacyclododecane (5) and 11-Benzyl-1,4,7-trioxa-10,13-dithiacyclopentadecane (6) (General Procedure). Solutions of dibromide **2** and dithiol **3** or **4** each in ethanol (10 ml) were added simultaneously with stirring in a stream of argon to a boiling solution of Li_2CO_3 or Cs_2CO_3 in 1:1 aqueous alcohol. The quantities and molar ratios of reactants are given in Table 1. The reaction mixture was boiled for 50 h, evaporated, and the residue extracted with hot ethyl acetate. The extract was dried over $CaCl_2$. The solvent was removed, and the residue chromatographed on silica gel in the system EtOAc–petroleum ether, 1:1.

Compound 5. Method 1: yield 15%. Method 2: yield <1%. Mass spectrum: *m/z* (I_{rel}, %): 298 (47) $[M]^+$, 265 (2), 238 (14), 207 (22), 176 (14), 148 (41), 117 (100), 91 (52), 61 (47), 45 (37). ^{1}H NMR spectrum, δ, ppm (*J*, Hz): 2.40 (1H, ddd, *J* = 15.17, *J* = 8.24, *J* = 3.24, H-6_a); 2.61 (1H, dd, *J* = 13.50, *J* = 10.55, H-9_{cis}); 2.64 [1H, dd, *J* = 14.02, *J* = 9.04, $C\underline{H}_2(a)C_6H_5$]; 2.66 (1H, ddd, *J* = 15.19, *J* = 5.68, *J* = 2.95, H-6b); 2.71 (2H, m, H-11); 3.27 [1H, dd, *J* = 13.98, *J* = 4.07, $CH_2(b)C_6H_5$]; 3.36 (1H, dd, *J* = 13.55, *J* = 4.17, H-9_{trans}); 3.50-3.60 (6H, m, H-2, H-3, H-5a, H-8); 3.70 (1H, dt, J_o = 10.55, J_m = 5.30, H-12_a); 3.74 (1H, ddd, *J* = 10.48, *J* = 5.68, *J* = 3.27, H-5b); 3.87 (1H, dt, *J* = 10.52, *J* = 4.76, H-12b); 7.20-7.28 (5H, m, C_6H_5). ^{13}C NMR spectrum, δ, ppm: 31.11 ($C_{(6)}$), 31.55 ($C_{(11)}$), 38.13 ($C_{(9)}$), 39.63 ($CH_2C_6H_5$), 47.24 ($C_{(8)}$), 70.27 and 70.47 ($C_{(2)}$, $C_{(3)}$), 73.41 ($C_{(12)}$), 73.51 ($C_{(5)}$), 126.07 (*p*-C_6H_5), 127.95 (*m*-C_6H_5), 129.60 (*o*-C_6H_5), 139.34 (*ipso*-C_6H_5). Found, %: C 60.15; H 7.45. $C_{15}H_{22}O_2S_2$. Calculated, %: C 60.36; H 7.43.

Compound 6. Yield 16%. Mass spectrum: *m/z* (I_{rel}, %): 342 (52) $[M]^+$, 282 (5), 251 (10), 225 (7), 176 (31), 148 (38), 117 (100), 91 (35), 45 (35). ^{1}H NMR spectrum, δ, ppm (*J*, Hz): 2.53 (1H, d t, *J* = 14.47, *J* = 6.4, H-9a); 2.63-2.82 [5H, m, H-9b, H-12_{trans}, H-14, $CH_2(a)C_6H_5$]; 3.11 (1H, dd, *J* = 13.68, *J* = 4.33, H-12_{cis}); 3.24 [1H, dd, *J* = 15.04, *J* = 4.55, $CH_2(b)C_6H_5$]; 3.27 (1H, m, H-11); 3.56-3.71 (10H, m, H-2, 3, 5, 6, 8); 3.74 (2H, t, *J* = 6.30, H-15); 7.26 (5H, m, C_6H_5). ^{13}C NMR spectrum, δ, ppm: 30.92 ($C_{(9)}$), 32.11 ($C_{(14)}$), 38.22 ($C_{(12)}$), 39.34 ($CH_2C_6H_5$), 47.20 ($C_{(11)}$), 70.12 and 70.24 ($C_{(2)}$, $C_{(6)}$), 71.05 and 71.06 ($C_{(3)}$, $C_{(5)}$), 72.20 ($C_{(8)}$), 72.26 ($C_{(15)}$), 126.21 (*p*-C_6H_5), 128.01 (*m*-C_6H_5), 129.49 (*o*-C_6H_5), 139.01 (*ipso*-C_6H_5). Found, %: C 59.79; H 7.63. $C_{17}H_{26}O_3S_2$. Calculated, %: C 59.61; H 7.63.

Extraction of Sr(II) and Pb(II) Cations. Determination of the distribution coefficients of Sr(II) and Pb(II) was carried out radiometrically with a Canberra-Packard 2700 liquid scintillation counter, using the isotopes ^{89}Sr ($T_{1/2}$ = 50.5 days, $E_{\beta^-\,\max}$ = 1.492 MeV) and ^{210}Pb ($T_{1/2}$ = 22.3 years, $E_{\beta^-\,\max}$ 0.063 MeV) [16]. Since the maximum energy of the β particle from ^{210}Pb is low, counting of it was carried out using its daughter element ^{210}Bi ($T_{1/2}$ = 5 days, $E_{\beta^-\,\max}$ = 1.16 MeV). To establish radioactive equilibrium between the mother ^{210}Pb and daughter ^{210}Bi, samples for recording activity were stored for approximately 25 days from the time of preparation to the beginning of counting.

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