Scientific paper

Synthesis of Novel Macrocyclic Lactam Based Receptors for Alkali or Transition Metal Cations and $Cr_2O_7^{2-}$ Anions

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Abstract

The article describes the syntheses and extraction properties of new lactam ionophores. These lactam derivatives were easily synthesized via aminolysis of 2,2'-methylenebis(4-chlorophenol) dimethylester or its corresponding acyl chloride with corresponding diamine compounds in THF or methanol-dichloromethane solvent systems in one step, respectively. The extraction studies of lactam ionophores were performed toward dichromate anion and alkaline and transition metal cations such as Li^+, Na^+, K^+, Co^{2+}, Hg^{2+} and Pb^{2+}. All the structures of the ionophores were confirmed by spectroscopic techniques and elemental analysis.

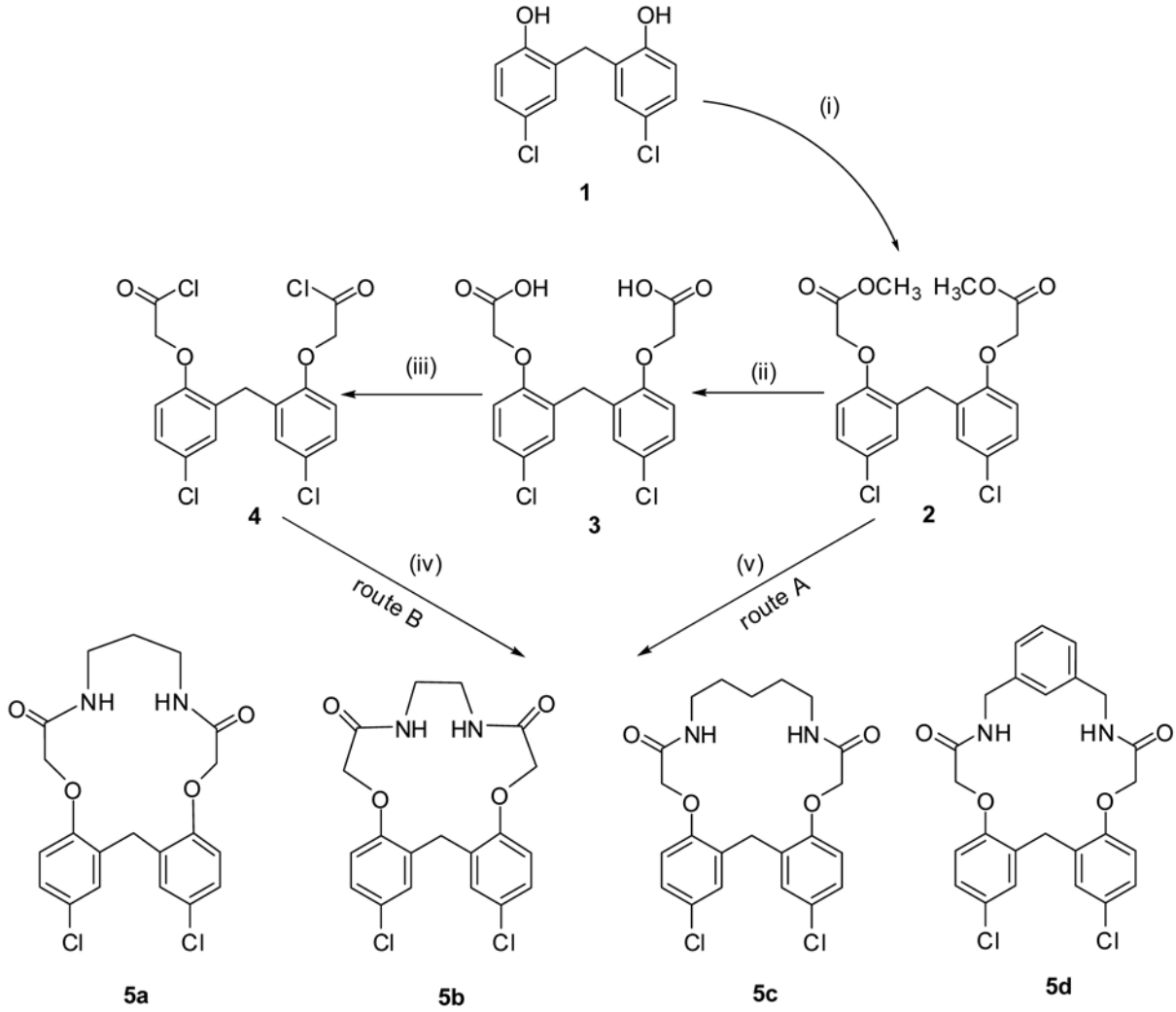
Keywords: Lactam, chromate extraction, picrate extraction, liquid-liquid extraction

1. Introduction

Polyoxalactone, polyazalactone and polyether compounds have received very much attention after quite a number of reports on macrocyclic ethers as multidendate ligands binding most cations were published. Because they form stable complexes both in solution and in the crystalline form, with salts of alkali and other metals[1] their role in studies on bioprocesses, catalysis, material science, and transport and separation phenomena is of exquisite imporatance.[2–4] Polyoxalactones, polyazalactones and polyethers containing hydrophobic exteriors are lipophilic hosts, which can incorporate cations (especially alkali and alkaline earth metal ions for polyethers and transition metals for polyoxalactones and polyazalactones) into their cavities via an ion-dipole interaction.[5–6] Macrocyclic polyoxalactones, polyazalactones and polyethers are cyclic compounds in which four to twenty heteroatoms are linked through ethylene or propylene moieties. Oxygen,[7–9] nitrogen,[10–11] and sulfur[12–13] may be heteroatoms. A macroring can contain either the same or different heteroatoms. Metal-cyclic polyether or amide complexes can be dissolved effectively in many organic solvents, so they can be easily extracted from their aqueous solutions by organic solvents. Because of this property, macrocyclic ligands are used as catalysts in phase-transfer reactions.[14–17] Macrocyclic compounds were also used for optical resolution of racemates.[18–19] Though enormous number of lactone and crown ether derivatives and their complexes have already been described, many more interesting systems of this type surely await discovery.

The main focus of this work is the design of new lactam derivatives-based ionophores that effectively bind alkali and heavy metals and anions. These ionophores can be useful for multiple applications such as laboratory, clinical, environmental and industrial process analysis. In our previous work,[20–21] we have extended the field of research of designing structures based on a polyoxalactone platform for the extraction of alkali (Li^+, Na^+ and K^+), transition metal cations (Hg^{2+}, Co^{2+} and Pb^{2+}). Herein, we report synthesis and extraction studies of newly designed lactam ionophores (**5a**-**d**) via aminolysis of dimethylester (**2**) or acyl chloride (**4**) of corresponding dihidroxy compound (**1**) with appropriate alkyl diamine derivatives. The bridging of two hydroxy groups at adjacent aromatic rings

by diamine units is favored over the bridging of two hydroxy groups at opposite aromatic rings. The synthesis of compounds **2**-**3** is based on previously published procedures,[22–23] compounds **4** and **5a**-**d** are reported for the first time, following the strategy outlined in Scheme 1.



Scheme 1. (i) Methylbromoacetate, K_2CO_3, acetone, reflux; (ii) NaOH, ethanol, reflux; (iii) thionyl chloride, THF, rt; (iv) alkyl diamine, THF, rt; (v) alkyl diamine, dichloromethane/methanol, rt.

2. Experimental

2. 1. General Methods

^{1}H and ^{13}C NMR spectra were recorded on a Varian 400 MHz spectrometer in $CDCl_3$. Melting points were determined on an Electrothermal 9100 apparatus in a sealed capillary and are uncorrected. IR spectra were obtained on a Perkin Elmer 1605 FTIR spectrometer using KBr pellets. UV-Vis spectra were obtained on a Shimadzu 160A UV-Vis spectrophotometer. Elemental analyses were performed using a Leco CHNS-932 analyzer. A Crison MicropH 2002 digital pH meter was used for the pH measurements. Analytical TLC was performed using Merck plates (silica gel 60 F254 on aluminum). All reactions, unless otherwise noted, were conducted under a nitrogen atmosphere. All reagents and starting material used were of standard analytical grade from Fluka, Merck and Aldrich and used without prior purification, except for THF that was dried with sodium/benzophenone; dichloromethane that was distilled from $CaCl_2$ and stored over molecular sieves and methanol that was distilled over CaO and stored over molecular sieves. Other commercial grade solvents were distilled and then stored over molecular sieves. Anions were used as their sodium salts. The drying agent employed was anhydrous $MgSO_4$. All aqueous solutions were prepared with deionized water that has been passed through a Millipore milli-Q Plus water purification system. Compounds **2**-**4** and lactam ionophores **5a**-**d** were

synthesized according to previously described methods.[21,24–26] All of the reactions were monitored with thin layer chromatography.

Methyl {4-chloro-2-[5-chloro-2-(2-methoxy-2-oxoethoxy)benzyl]phenoxy}acetate (2)

To a suspension of K_2CO_3 (11 mmol) in dry acetone (250 mL) was added compound **1** (2 mmol) under a nitrogen atmosphere, and stirred for 0.5 h at rt. Methyl bromoacetate (4.8 mmol) was added dropwise into the mixture by syringe and refluxed for 24 h. Reaction mixture was filtered and excess solvent was evaporated under reduced pressure and the residue dried in vacuo. The crude product was recrystallized from CH_2Cl_2/MeOH to give light white product **2** (0.66 g, 80%). Mp 125 °C; IR (KBr), ν_{max}/cm^{-1}: 3010–3000 (C–H_{aryl}), 2875–2870 (CH_2), 1760 (CO), 1585–1500 (C=C), 1260 (CO_{aryl}), 1170 (CO_{alkyl}), 720 (C–Cl_{arom}); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.31 (d, 2H, $ArH_{meta.}$), 7.10 (s, 2H, $ArH_{meta.}$), 6.83 (d, 2H, ArH_{orto}), 4.80 (s, 4H, OCH_2CO), 4.02 (s, 2H, Ar–CH_2–Ar), 3.55 (s, 6H, OMe); ^{13}C NMR (400 MHz, $CDCl_3$): δ 167.1, 151.4, 136.6, 133.3, 130.9, 128.2, 114.8, 66.3, 60.1, 33.5. Elemental Anal. Calcd. for $C_{19}H_{18}Cl_2O_6$: C, 55.21; H, 4.39. Found: C, 55.16; H, 4.46.

{2-[2-(Carboxymethoxy)-5-chlorobenzyl]-4-chlorophenoxy}acetic acid (3)

A mixture of compound **2** (2.45 mmol) and 15% aqueous NaOH (10 mL) in EtOH (150 mL) was stirred and heated under reflux for 24 h after which most of the ethanol was distilled off. The residue was taken in $CHCl_3$, acidified with 1M HCl until pH = 1 and washed with water and then with brine. The organic phase was dried over anhydrous magnesium sulfate and concentrated to give the crude product. Recrystallization of the crude product from ethanol/acetone furnished **6** as white solid (0.8 g, 85%). Mp 142 °C; IR (KBr), ν_{max}/cm^{-1}: 3360–3330 (COOH), 3010–3000 (C–H_{aryl}), 2875–2870 (CH_2), 1760 (CO), 1585–1500 (C=C), 1260 (CO_{aryl}), 1170 (CO_{alkyl}), 720 (C–$Cl_{arom.}$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.92 (br, 2H, CO_2H), 7.32 (d, 2H, $ArH_{meta.}$), 7.15 (s, 2H, $ArH_{meta.}$), 6.80 (d, 2H, ArH_{orto}), 4.81 (s, 4H, OCH_2CO), 4.05 (s, 2H, Ar–CH_2–Ar); ^{13}C NMR (400 MHz, $CDCl_3$): δ 165.7, 150.9, 134.7, 133.0, 131.2, 127.6, 113.8, 65.1, 31.5. Elemental Anal. Calcd. for $C_{17}H_{14}Cl_2O_6$: C, 53.01; H, 3.65. Found: C, 52.11; H, 3.72.

{4-Chloro-2-[5-chloro-2-(2-chloro-2-oxoethoxy)benzyl]phenoxy}acetyl chloride (4)

A mixture of compound **3** (2.48 mmol) and thionyl chloride (1.25 mL) in dry THF was stirred under a nitrogen atmosphere for 4 h. Removal of solvent and unreacted thionyl chloride gave acyl chloride **4** in quantitative yield, which was used in the subsequent reaction without purification.

3. General Procedure for Synthesis of Lactam Ionophores

Route A

To a solution of the dimethyl ester compound **2** (1.5 mmol) in dichloromethane (10 mL) was added drop by drop for 3 h methanol (20 mL) solution of 1,3-diaminopropane (9 mmol) for compound **5a**, 1,2-diaminoethane (9 mmol) for compound **5b**, 1,5-diaminopentane (9 mmol) for compound **5c** and *m*-xylylenediamine (9 mmol) for compound **5d**. The mixture was stirred at room temperature for 24 h under a nitrogen atmosphere and concentrated under reduced pressure. Excess of unreacted alkyldiamine derivative was distilled under reduced pressure and removed from reaction mixture. The residue was precipitated with methanol. Recrystallization of the crude product from dichloromethane/ethanol (3:1) furnished compounds **5a** (white solid, 85%), **5b** (white solid, 88%), **5c** (white solid, 88%) and **5d** (white solid, 90%).

Route B

To a solution of the acyl chloride compound **4** (1.5 mmol) in THF (10 mL) was added drop by drop for 3 h THF (10 mL) solution of 1,3-diaminopropane (2 mmol) for compound **5a**, 1,2-diaminoethane (2 mmol) for compound **5b**, 1,5-diaminopentane (2 mmol) for compound **5c** and *m*-xylylenediamine (2 mmol) for compound **5d**. The mixture was stirred at room temperature for 7 h under a nitrogen atmosphere and then concentrated under reduced pressure. Excess of unreacted alkyldiamine derivative was distilled under reduced pressure and removed from reaction mixture. The residue was precipitated with methanol. Recrystallization of the crude product from dichloromethane furnished compounds **5a** (white solid, 52%), **5b** (white solid, 58%), **5c** (white solid, 55%) and **5d** (white solid, 60%).

2,18-Dichloro-9,10,11,12-tetrahydro-6*H*,20*H*-dibenzo[*l*,*o*][1,11,4,8]dioxadiazacyclohexadecine-7,13(8*H*,14*H*)-dione (5a)

Mp 300–303 °C; IR (KBr), ν_{max}/cm^{-1}: 3010–3000 (C–H_{aryl}), 2875–2870 (CH_2), 1700 (CONH), 1585–1500 (C=C), 1260 (CO_{aryl}), 700 (C–$Cl_{arom.}$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.23 (d, 2H, ArH_{meta}), 7.01 (s, 2H, ArH_{meta}), 6.76 (d, 2H, ArH_{orto}), 5.84 (br s, 2H, 2 × CONH), 4.62 (s, 4H, 2 × OCH_2CO), 4.05 (s, 2H, Ar–C*H*$_2$–Ar), 3.10 (t, 4H, C*H*$_2$–CH_2–C*H*$_2$), 1.35 (p, 2H, CH_2–C*H*$_2$–CH_2); ^{13}C NMR (400 MHz, $CDCl_3$): δ 166.0, 155.4, 134.1, 132.9, 129.6, 128.7, 123.8, 71.3, 40.1, 30.5, 29.7. Elemental Anal. Calcd. for $C_{20}H_{20}Cl_2N_2O_4$: C, 56.75; H, 4.76; N, 6.62, Found: C, 56.76; H, 4.86; N, 6.59.

2,17-Dichloro-8,9,10,11-tetrahydro-19*H*-dibenzo[*k*,*n*][1,10,4,7]dioxadiazacyclopentadecine-7,12(6*H*,13*H*)-dione (5b)

Mp 270 °C; IR (KBr), ν_{max}/cm^{-1}: 3010–3000 (C–H_{aryl}), 2875–2870 (CH_2), 1710 (CO), 1585–1500

(C=C), 1260 (CO_{aryl}), 720 (C–$Cl_{arom.}$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.40 (d, 2H, ArH_{meta}), 7.15 (s, 2H, ArH_{meta}), 6.72 (d, 2H, ArH_{orto}), 5.65 (br s, 2H, 2 × CONH), 4.85 (s, 4H, 2 × OCH_2CO), 4.02 (s, 2H, Ar–C*H*$_2$–Ar), 3.42 (s, 4H, CH_2–CH_2); ^{13}C NMR (400 MHz, $CDCl_3$): δ 171.0, 148.4, 133.7, 130.3, 127.6, 126.2, 111.8, 63.7, 59.1, 30.5. Elemental Anal. Calcd. for $C_{19}H_{18}Cl_2N_2O_4$: C, 55.76; H, 4.43; N, 6.84 Found: C, 55.69; H, 4.44; N, 6.81.

2,20-Dichloro-9,10,11,12,13,14-hexahydro-6*H*,22*H*-dibenzo[*n*,*q*][1,13,4,10]dioxadiazacyclooctadecine-7,15(8*H*,16*H*)-dione (5c)

Mp 295-297 °C (with decomposition); IR (KBr), ν_{max}/cm^{-1}: 3010–3000 (C–H_{aryl}), 2875–2870 (CH_2), 1700 (CO), 1585–1500 (C=C), 1260 (CO_{aryl}), 720 (C–$Cl_{arom.}$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.31 (d, 2H, ArH_{meta}), 7.05 (s, 2H, ArH_{meta}), 6.70 (d, 2H, ArH_{orto}), 5.81 (br s, 2H, 2 × CONH), 5.03 (s, 4H, 2 × OCH_2CO), 4.21 (s, 2H, Ar–C*H*$_2$–Ar), 3.23 (t, 4H, 2 × NH–C*H*$_2$), 1.50 (m, 2H, $[CH_2]_2$–C*H*$_2$–$[CH_2]_2$), 1.31 (t, 4H, 2 × NH–CH_2–C*H*$_2$); ^{13}C NMR (400 MHz, $CDCl_3$): δ 167.1, 151.4, 136.6, 133.3, 130.9, 128.2, 114.8, 70.3, 48.1, 41.4, 35.1, 30.5. Elemental Anal. Calcd. for $C_{22}H_{24}Cl_2N_2O_4$: C, 58.54; H, 5.36; N, 6.21. Found: C, 58.46; H, 5.41; N, 6.13.

2,20-Dichloro-9,10,11,12,13,14-hexahydro-6*H*,22*H*-dibenzo[*n*,*q*][1,13,4,10]dioxadiaza-*meta*-xylyl-7,15(8*H*,16*H*)-dione (5d)

Mp 315–317 °C; IR (KBr), ν_{max}/cm^{-1}: 3010–3000 (C–H_{aryl}), 2875–2870 (CH_2), 1700 (CO), 1585–1500 (C=C), 1260 (CO_{aryl}), 720 (C–$Cl_{arom.}$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.70–7.35 (m, 8H, ArH), 7.04 (s, 2H, Ar-H_{meta}), 5.51 (br s, 2H, 2 × CONH), 4.83 (s, 4H, 2 × OCH_2CO), 4.40 (s, 4H, 2 × NH–C*H*$_2$), 3.88 (s, 2H, Ar–CH_2–Ar); ^{13}C NMR (400 MHz, $CDCl_3$): δ 170.0, 157.8, 137.9, 133.6, 130.9, 129.2, 128.1, 126.6, 121.9, 112.8, 69.1, 62.5, 34.1 (one signal is hidden). Elemental Anal. Calcd. for $C_{25}H_{22}Cl_2N_2O_4$: C, 61.87; H, 4.57; N, 5.77. Found: C, 61.80; H, 4.61; N, 5.70.

3. 1. Liquid-Liquid Extraction

Picrate and dichromate extraction experiments were performed following Pedersen's procedure.[27] 10 mL of a $2.5 \cdot 10^{-5}$ M aqueous picrate solution, 1×10^{-4} M dichromate solution (pH of dichromate solution was maintained by 0.01 M KOH/HCl solution) and 10 mL of 1×10^{-3} M solution of compounds **2** and **5a**-**d** in CH_2Cl_2 were vigorously agitated in a stoppered glass tube with a mechanical shaker for 2 min, then magnetically stirred in a thermostated water-bath at 25 °C for 1 h, and finally left standing for an additional 30 min. The concentration of picrate/dichromate ion remaining in the aqueous phase was then determined spectrophotometrically as previously described.[28] Blank experiments showed that no picrate extraction occurred in the absence of lactam ionophores **5a**-**d**. The alkali picrates were prepared as described[29] elsewhere by stepwise addition of a 2.5×10^{-2} M aqueous picric acid solution to a 0.14 M aqueous solution of metal hydroxide, until neutralization which was checked by pH control with a glass electrode. They were then rapidly washed with ethanol and ether before being dried in vacuo for 24 h. Transition metal picrates were prepared by stepwise addition of a 1×10^{-2} M of metal nitrate solution to a 2.5×10^{-5} M aqueous picric acid solution and shaken at 25 °C for 1 h.

The percent extraction (*E*%) has been calculated as:

$$E\% = \frac{A_0 - A}{A_0} \times 100$$

where A_0 and A are the initial and final concentrations of the metal picrate/dichromate before and after the extraction, respectively.

3. 2. Log-Log Plot Analysis

To characterize the extraction ability the dependence of the distribution coefficient *D* of the cation between the two phases upon the lactam concentration was examined.

$$M^{n+}_{(aq)} + n\text{Pic}^-_{(aq)} + x[L]_{(org)} \rightleftharpoons [M(\text{Pic})_n(L)_x]_{(org)} \quad (1)$$

If the general extraction equilibrium is assumed to be given by Eq. (1) the overall extraction equilibrium constant is expressed as Eq. (2)

$$K_{ex} = \frac{[M(\text{Pic})_n(L)_x]}{[M^{n+}][\text{Pic}^-]^n[L]^x} \quad (2)$$

and the distribution ratio *D* would be defined by Eq. (3).

$$D = \frac{[M(\text{Pic})_n(L)_x]}{[M^{n+}]} \quad (3)$$

one obtains Eq. (4). By introduction it in Eq. (2) and taking log of both sides.

$$\log D = \log(K_{ex}[\text{Pic}^-] + x \log[D]$$

With these assumptions a plot of the log *D* vs. log [L] should be linear and its slope should be equal to the number of ligand molecules per cation in the extraction species.

4. Results and Discussion

Synthesis of novel lactam ionophores **5a**-**d** was performed by treatment of compound **2** or its corresponding acyl chloride **4** with an excess of 1,2-diaminoetha-

ne, 1,3-diaminopropane, 1,5-diaminopentane and *m*-xylylenediamine in THF or dichloromethane/methanol solutions at room temperature under a nitrogen atmosphere (Scheme 1). All of the hosts **5a**-**d** were characterized by IR, NMR spectroscopy and elemental analysis. Spectroscopic data were in complete agreement with those expected. Route A and B were used for synthesis of related compounds **5a**-**d**. In the route A, compound **2** was directly treated with appropriate diamine compounds in dichloromethane/methanol (1:2) mixture to synthesize ligands **5a**-**d** at room temperature under a nitrogen atmosphere in 85–90% yield. In the route B, first compound **2** was hydrolyzed with 15% aqueous NaOH solution in ethanol to remove methyl groups of the compound **2**. Synthetically, the usefulness of acyl chloride is well known. Thus, the compound **3** was treated with thionyl chloride, in the presence of pyridine in THF, and provided the acyl chloride **4** in a quantitative yield. No attempts were made to purify the crude product and it was used in subsequent preparation without purification. Compound **4** was then treated with the corresponding diamine compounds to obtain related ligands **5a**-**d** in THF at room temperature under a nitrogen atmosphere in 52–60% yield. In the IR spectra of the synthesized compounds, diester compound **2** showed characteristic ester peaks at 1750–1760 cm^{-1}, while no absorption assignable to hydroxy groups in starting material **1** was observed in the region 3300–3500 cm^{-1}. These data can be used to monitor the esterification reaction progress. Furthermore, in the IR spectra of the lactam derivatives **5a**-**d**, corresponding amide peaks were seen around 1700–1710 cm^{-1}. At the same time characteristic IR band of the C–Cl bond stretching was also observed around 690–710 cm^{-1}. Phenolic hydroxy groups in starting material **1** usually give a sharp peak at δ 4.00–7.50 ppm in the ^{1}H NMR spectra, so that the absence of signals in the region δ 4.00–7.50 ppm and appearing of new singlet peaks around 3.50 ppm attributable OMe and 4.80 ppm attributable OCH_2CO counts in favor of the completion of the esterification reaction. Furtmermore, in the ^{1}H NMR spectrum of lactam derivatives **5a**-**d**, the singlet peak of OMe group of compound **2** around 3.50 ppm disappeared as expected and new broad singlet peak attributable to NH amide protons appeared around 5.50–5.80 ppm. These were also observed in their IR spectrum, confirming the formation of lactam ionophores **5a**-**d**. On the other hand, methylene protons in the polyalkyl fragments of **5a**-**d** were located at δ 1.30–3.40 ppm, and methyl bridge protons between phenyl ring were seen around 4.00 ppm. In the ^{13}C NMR spectra of ligands **5a**-**d**, it is obvious that compounds **5a**-**d** posses certain symmetry elements and therefore the number of signals observed in the ^{13}C NMR is lesser than the number of C atoms in the ligands **5a**-**d**. But in the ^{13}C NMR for compound **5d**, one signal is hidden because of the overlapped peaks.

4. 1. Liquid-Liquid Extraction Studies

4. 1. 1. Metal Cations

From the extraction data shown in Table 1, neither alkali nor transition metal cations were extracted by the starting material **1** from aqueous to organic phase. Upon the introduction of amide groups in lactam ionophore compounds **5a**-**d** to the two hydroxy groups in starting material **1**, all of these compounds **5a**-**d** showed a higher affinity towards transition metals such as Co^{2+}, Pb^{+2} and Hg^{2+}. However, acyclic compund **2** containing ester groups extracted only Hg^{2+}. It was not possible to significantly extract alkali metal cations, neither by lactam ionophores **5a**–**d** nor by the diester compound **2**. From these observations we conclude that the size of the macro ring alone does not play a major role in the complexation phenomenon, but the nature and ionic diameter of the metal ions and the effectiveness and aggregation of functional groups are factors in complexation. In the case of ligands **5a-d,** the increased affinity in complexation can be explained by the fact that there is an important role played by the carbonyl groups having π-electron system and electron-donor nitrogen atoms at the water -dichloromethane interface. Moreover, these phenomena may reflect the "hard and soft acids and bases" concept introduced by Pearson.[30] As this environment exists due to the presence of π-bonds containing functionalities, where cation-π interactions favor the complexation with the more polarizable transition metal ions especially Hg^{2+} and Pb^{2+} which are known as soft metal cations. Fig. 1 shows the extraction into dichloromethane at different concentrations of the ligand **5a** and **5b** for Hg^{2+}. A linear relationship between log *D* versus –log [L] is observed with the slope of lines for Hg^{2+} by the ligands **5a**,**b** which is roughly equal to 0.99, suggesting that the ligands **5a**,**b** form a 1:1 complex with Hg^{2+}.

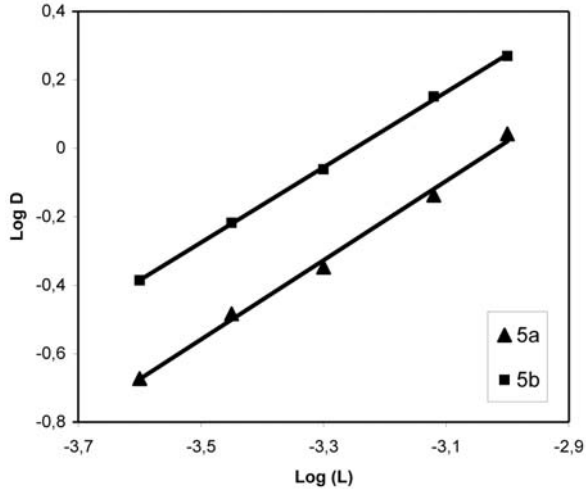


Fig. 1 Log *D* versus log [L] for the extraction of Hg picrate by the ligands **5a** and **5b** from an aqueous phase into dichloromethane at 25 °C.

Table 1. Percentage extraction of alkali and transition metal ions by ionophores[a,b]

Compound	Li^+	Na^+	K^+	Co^{2+}	Hg^{2+}	Pb^{2+}
2	2.2 ± 0.1	5.9 ± 0.1	4.2 ± 0.1	6.1 ± 0.1	64.1 ± 0.1	8.4 ± 0.1
5a	11.1 ± 0.2	14.8 ± 0.1	9.4 ±0.3	69.3 ± 0.1	68.5 ± 0.1	12.0 ± 0.2
5b	29.6 ± 0.2	58.5 ± 0.2	34.3 ± 0.2	46.4 ± 0.1	69.8 ± 0.3	43.4 ± 0.1
5c	14.5 ± 0.3	10.6 ± 0.1	9.7 ± 0.1	40.6 ± 0.3	77.9 ± 0.2	55.3 ± 0.1
5d	12.2 ± 0.1	16.6 ± 0.2	7.9 ± 0.1	43.1 ± 0.2	67.3 ± 0.3	45.5 ± 0.1

[a] Averages and standard deviations calculated for data obtained from three independent extraction experiments.
[b] Aqueous phase: [metal nitrate]: $1 \cdot 10^{-2}$ M; [picric acid]: 2.5×10^{-5} M; organic phase: dichloromethane, [ligand]: 1×10^{-3} M; at 25 °C, for 1 h.

4. 1. 2. Chromate Anion

The removal of the dichromate anions from water sources gained high attention because of their high toxic effect. Anion recognition and sensing is an increasingly important research topic in supramolecular chemistry due to the importance of various anions in biological and environmental locations. Chromate and dichromate anions are important because of their high toxicity[31] and their presence in soils and waters. The dichromate ions ($Cr_2O_7^{2-}$/$HCr_2O_7^-$) are anions where the periphery of the anion has oxide moieties. For a molecule to be effective as a host, it is necessary that its structural features are compatible with those of the guest anions. We performed some preliminary evaluations to investigate binding efficiencies of the selected extractants **5a**-**d** for $Na_2Cr_2O_7$ by using solvent extraction. The results are summarized in Table 2 and Fig 2.

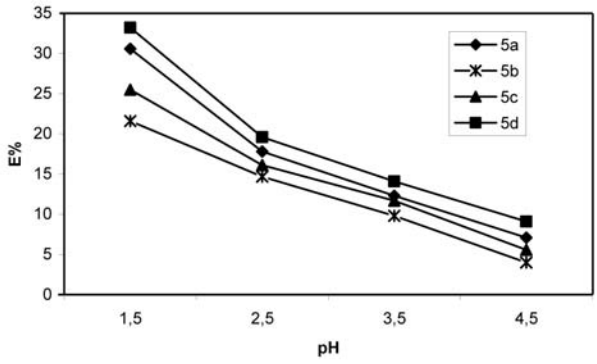


Fig. 2. Plots of extraction (*E*%) versus pH following the two-phase solvent extraction of dichromate anion with compounds **5a**-**d**.

Table 2. Percentage extraction of dichromate ion by ionophores at different pH.[a,b]

Compound	pH			
	1.5	**2.5**	**3.5**	**4.5**
2	<1.0	<1.0	<1.0	<1.0
5a	30.6 ± 0.1	17.8 ± 0.1	12.3 ± 0.1	7.1 ± 0.1
5b	21.6 ± 0.1	14.7 ± 0.1	9.8 ± 0.1	4.0 ± 0.1
5c	25.5 ± 0.1	16.1 ± 0.1	11.7 ± 0.1	5.6 ± 0.1
5d	33.2 ± 0.1	19.6 ± 0.1	14.1 ± 0.1	9.1 ± 0.1

[a] Averages and standard deviations calculated for data obtained from three independent extraction experiments.
[b] Aqueous phase, [metal dichromate]: 1×10^{-4} M; organic phase, dichloromethane, [ligand]: 1×10^{-3} M at 25 °C, for 1 h.

The results showed that $Na_2Cr_2O_7$ could be extracted from aqueous solution into dichloromethane at low pH values. Blank experiments showed that no dichromate anion extraction occurred in the absence of lactam ionophores **5a**-**d**. According to our knowledge the data obtained in extraction of **5a**-**d** can be attributed to a number of reasons. Compounds **5a**-**d** possess an amide nitrogen and carbonyl, facilitating hydrogen bonding with the dichromate anion. The next reason is that compounds **5a**-**d** have a more stable structure because of the bridging of the two amide moieties by alkyl chain. The acidic conditions facilitate the protonation of dichromate anion $Cr_2O_7^{2-}$ which in turn interacts with the receptors **5a**-**d**. Moreover, from the extraction phenomenon it could be concluded that the complexation of dichromate anion does not depend upon the pH of solution, but depends upon the conformation and size of the cyclic receptor, and also upon the nature of the aggregations of the ions around the receptor.

In the Fig. 3, a linear relationship between log *D* versus –log [L] is observed with the slope of lines for dichromate anion by the ligands **5a**-**b** which is roughly equal

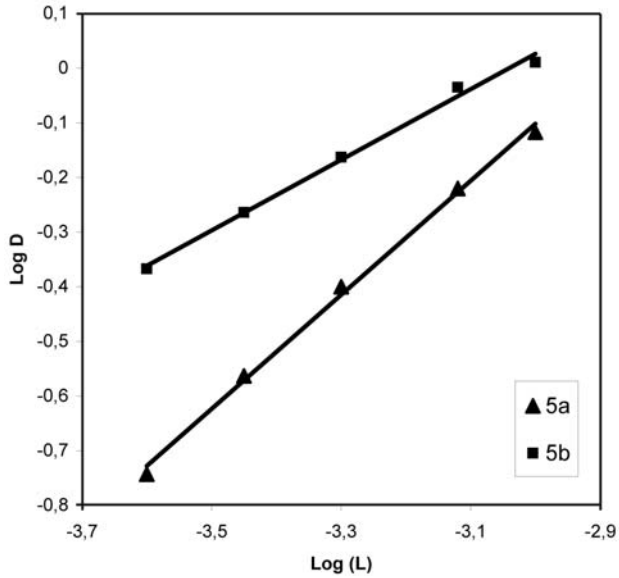


Fig. 3 Log *D* versus log [L] for the extraction of dichromate anion by the ligands **5a** and **5b** from an aqueous phase into dichloromethane at 25 °C.

to 0.99, suggesting that the ligands **5a**-**b** form a 1:1 complex with dichromate anion. However, it is well known that at more acidic conditions $Na_2Cr_2O_7$ is converted into $H_2Cr_2O_7$ and after ionization in an aqueous solution it exists in the $HCr_2O_7^-/Cr_2O_7^{2-}$ form. At higher acidic conditions $HCr_2O_7^-$ and $Cr_2O_7^{2-}$ dimers become the dominant Cr^{6+} form and pK_{a1} and pK_{a2} values of these equations are 0.74 and 6.49, respectively.

5. Conclusions

In conclusion, the synthesis and ion extraction abilities of lactam ionophores were studied. The studies of the complexation of toxic metal cations and anions showed that compounds **5a**-**d** were effective receptors. It could be concluded that the complexation of toxic anions and cations depends on the structural properties of the receptor such as hydrogen binding ability, stability or rigidity, and protonation ability. The lactam derivatives based receptors could be proved to find remarkable applications in the design of chemical sensors, using electrochemical transduction, as conventional ion selective electrodes and solid-state sensors.

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7. References

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Povzetek

Članek predstavlja sinteze in ekstrakcijske lastnosti novih laktamskih ionoforov. Te laktamske derivate smo pripravili z enostavno sintezo preko 2,2'-metilenbis(4-klorofenol) dimetilestrov ali ustreznih acil kloridov s primernimi diamini v THF ali v zmesi metanola in diklorometana kot topila. Študije ekstrakcijskih lastnosti laktamskih ionoforov smo izvedli z dikromatnimi anioni ter s kationi alkalijskih in prehodnih kovin, npr. Li^+, Na^+, K^+, Co^{2+}, Hg^{2+} in Pb^{2+}. Strukture pripravljenih ionoforov so bile potrjene s spektroskopskimi tehnikami in z elementno analizo.