SYNTHESIS OF PYRIDINOCROWNOPHANES EXHIBITING HIGH Ag+-AFFINITY

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Abstract-Crownophanes possessing a pyridine moiety were prepared by means of intramolecular [2 + 2] photocycloaddition of the styrene derivatives. The crown compounds having six to ten ethereal oxygens selectively extracted Ag+ with high efficiency in the liquid-liquid extraction. The high extractability and efficiency were maintained even at low pH region of the extraction system. From ESI-MS analysis, it was found that the crownophanes formed some kinds of complexes having 1:1 and 2:1 stoichiometry (host/guest) with Ag+ and Pb^{2+} in MeCN-H$_2$O homogeneous system.

Nitrogen atom has been found to show high affinity toward heavy metal cations such as Ag+ and Pb^{2+} ions when it is employed as dentate(s) of a crown ether or ligating site(s) of its in side chain(s).[1,2] In particular, pyridine ring(s) arranged in an appropriate position of host molecules have been found to exhibit interesting complexing behavior.[3-7] Recently, we have conveniently and efficiently prepared crownophanes bridged by cyclobutane ring by means of intramolecular [2 + 2] photocycloaddition of styrene derivatives with oligo(oxyethylene) linkage.[8] We have also prepared lariat crownophanes having pyridine residues in the side chains by the photocycloaddition, followed by attachment of side arms, and clarified some interesting complexation behavior with heavy metal cations.[9,10] For example, one of the lariat crownophanes showed high extractability toward Ag+ ion even at high proton concentration (pH<1).[9] In this paper, we would like to describe the synthesis and complexing properties of crownophanes possessing pyridine moiety in the polyether linkage (pyridinocrownophanes).

EXPERIMENTAL

Apparatus. IR spectra were obtained on a Hitachi 270-50 spectrophotometer. ^{1}H NMR spectra were taken at 500 MHz using tetramethysilane as an internal standard. Elemental analysis was carried out in Technical Research Center for Instrumental Analysis, Gunma University. Electrospray ionization mass spectra (ESI-MS) were obtained on a following conditions: A sample solution was sprayed at a flow rate of 2 μL min^{-1} at the tip of needle biased by a voltage of 4.5 kV higher than that of a counter electrode.

Reagents. Toluene and THF were purified by distillation over Na after prolonged reflux under a nitrogen atmosphere. Guaranteed reagent grade CH$_2$Cl$_2$ was distilled before use. 2,6-Bis[(tosyloxy)methyl)]pyri-dine was prepared by reported method.[11] Reagent grade dibenzopyridino-18-crown-6 (**5**) was used without further purification. Paracrownophane (**6**) was prepared by the method reported previousy.[8] AgNO$_3$, Pb(NO$_3$)$_2$, Cu(NO$_3$)$_2$, Mn(NO$_3$)$_2$, Zn(NO$_3$)$_2$, Ni(NO$_3$)$_2$, Co(NO$_3$)$_2$, and Fe(NO$_3$)$_3$ were of commercially available highest grade and used after vacuum drying. All aqueous solutions were prepared with distilled, deionized water.

Preparation of oligoethyleneglycol mono(*p*-bromophenyl) ethers. 2-(*p*-Bromo-   phenoxy)ethanol (**1a**) was prepared as follows: A mixture of *p*-bromophenol (25.0 g, 0.145 mol) and 2-chloroethanol (116.3 g, 1.45 mol) in 10% aqueous NaOH solution (600 mL) was stirred under a nitrogen atmosphere at rt. After 24 h, the mixture was extracted with CH$_2$Cl$_2$ (3 x 300 mL). The CH$_2$Cl$_2$ extracts were combined, washed with 10% aqueous NaOH (2 x 500 mL) and with water (3 x 500 mL), dried over anhydrous MgSO$_4$. After the solvent was evaporated, the residue was recrystallized from hexane-ethanol to give **1a** as white crystals (30.1 g, 96%). mp 52.0-53.0 ^{o}C. ^{1}H NMR (CDCl$_3$) δ=7.39 (2H, <u>A</u>Bq, *J*=6.7 Hz), 6.82(2H, A<u>B</u>q, *J*=6.7 Hz), 4.06 (2H, m), 3.96 (2H, m).
Oligoethylene glycol mono(*p*-bromophenyl) ether was prepared in a following manner: A mixture of 4-bromophenol (20.00 g, 0.115 mol), oligoethylene glycol monotosylate (0.058 mol), pulverized K$_2$CO$_3$ (23.91 g, 0.173 mol), and DMF (250 mL) was stirred under a nitrogen atmosphere at 50 ^{o}C for 24 h. The

mixture was cooled and poured into a separatory funnel together with 800 mL of water. The aqueous solution was extracted with CH_2Cl_2. The CH_2Cl_2 layer was washed with water (500 mL), 10% aqueous NaOH (500 mL), and again water (500 mL). The CH_2Cl_2 layer dried over anhydrous $MgSO_4$ was filtered and evaporated *in vacuo*. The residue was flash chromatographed (SiO_2, toluene-ethyl acetate(1:1)) to give **1b-d** as transparent viscous liquid. **1b** (95%). ^1H NMR ($CDCl_3$) δ=7.37 (2H, A<u>B</u>q, *J*=6.5 Hz), 6.81(2H, A<u>B</u>q, *J*=6.5 Hz), 4.11 (2H, m), 3.86 (2H, m), 3.77 (2H, m), 3.67 (2H, m). **1c** (94%). ^1H NMR ($CDCl_3$) δ=7.37 (2H, A<u>B</u>q, *J*=6.5 Hz), 6.81(2H, A<u>B</u>q, *J*=6.5 Hz), 4.11 (2H, m), 3.85 (2H, m), 3.65 (8H, m). **1d** (95% yield). ^1H NMR ($CDCl_3$) δ=7.37 (2H, A<u>B</u>q, *J*=6.5 Hz), 6.81(2H, A<u>B</u>q, *J*=6.5 Hz), 4.11 (2H, m), 3.84 (2H, m), 3.64 (12H, m).

Preparation of oligoethyleneglycol mono(*p*-vinylphenyl) ethers (2a-d). A solution of oligoethyleneglycol mono(*p*-bromophenyl) ethers (46.0 mmol), tributylvinylstannane (17.5 g, 55.0 mmol), $Pd(PPh_3)_4$ (1.33 g, 1.15 mmol), and 2,6-di-*tert*-butyl-4-methylphenol (15 mg) in toluene (120 mL) was heated to reflux for 20 h. After the mixture was cooled to ambient temperature, a large excess of 2 mol dm^{-3} aqueous KF solution was added, and the resulting mixture was stirred overnight at the same temperature. The organic layer was separated from the sludge and aqueous layer and then dried over $MgSO_4$. The concentrated crude material was purified by column chromatography (SiO_2, a gradient mixed solution of toluene and acetone) to afford the vinyl derivatives. **2a** (50%). White solid (mp 59.5-60.2 ^{o}C, hexane-ethanol). ^1H NMR ($CDCl_3$) δ=7.35 (2H, A<u>B</u>q, *J*=6.7 Hz), 6.88(2H, A<u>B</u>q, *J*=6.7 Hz), 6.66 (1H, dd, *J*=20.0 and 10.0), 5.62 (1H, d, *J*=20.0), 5.14 (1H, d, *J*=10.0), 4.09 (2H, m), 3.96 (2H, m). **2b** (31%). Transparent viscous liquid. ^1H NMR ($CDCl_3$) δ=7.31 (2H, A<u>B</u>q, *J*=6.7 Hz), 6.86(2H, A<u>B</u>q, *J*=6.7 Hz), 6.64 (1H, dd, *J*=17.5 and 10.0), 5.58 (1H, d, *J*=17.5), 5.12 (1H, d, *J*=10), 4.12 (2H, m), 3.85 (2H, m), 3.74 (2H, m), 3.66 (2H, m). **2c** (48%). Transparent viscous liquid. ^1H NMR ($CDCl_3$) δ=7.31 (2H, A<u>B</u>q, *J*=6.7 Hz), 6.86(2H, A<u>B</u>q, *J*=6.7 Hz), 6.65 (1H, dd, *J*=17.5 and 10.0), 5.61 (1H, d, *J*=17.5), 5.13 (1H, d, *J*=10.0), 4.13 (2H, m), 3.87 (2H, m), 3.73 (6H, m), 3.63 (2H, m). **2d** (67%). Transparent viscous liquid. ^1H NMR ($CDCl_3$) δ=7.31 (2H, A<u>B</u>q, *J*=8.9 Hz), 6.86(2H, A<u>B</u>q, *J*=8.9 Hz), 6.65 (1H, dd, *J*=17.5 and 8.0), 5.60 (1H, d, *J*=17.5), 5.12 (1H, d, *J*=8.0), 4.13 (2H, m), 3.85 (2H, m), 3.69 (10 H, m), 3.60 (2H, m).

Preparation of 2,6-bis[˜ (*p*-vinylphenyl)oligo(oxyethylenoxy)methyl]pyridine (3a-d). A THF solution (50 mL) of alcohol (**2**) (5.36 mmol) was added to a suspension of NaH (60% in mineral oil, 0.29 g, 7.15 mmol, washed with hexane) with stirring at ambient temperature over a period of 1 h. The reaction mixture was allowed to reflux and stirred for 1 h. After the mixture was cooled to -70 ^{o}C, 2,6-bis[(tosyloxy)methyl)]pyridine (0.80 g, 1.79 mmol) dissolved in 35 mL of THF was added dropwise in it in 2 h. The mixture was stirred at -70 ^{o}C for 1 h and then at ambient temperature for 24 h. A small amount of water was carefully added to destroy excess NaH. The solid material was filtered off. The filtrate was evaporated in vacuo and the residue was purified by column chromatography (SiO_2, a gradient solution of toluene and ethyl acetate) to give **3**. **3a** (86% yield). White solid (mp 67.5-68.5 ^{o}C, hexane-ethanol). ^1H NMR ($CDCl_3$) δ=7.70 (1H, br.), 7.38 (2H, d, *J*=9.1), 7.34 (4H, A<u>B</u>q, *J*=8.5 Hz), 6.88(4H, A<u>B</u>q, *J*=8.5 Hz), 6.66 (2H, dd, *J*=17.5 and 12.5), 5.61 (2H, d, *J*=17.5), 5.13 (2H, d, *J*=12.5), 4.97 (4H, m), 4.21 (4H, m), 3.99 (4H, m). **3b** (65% yield). Transparent viscous liquid. ^1H NMR ($CDCl_3$) δ=7.65 (1H, t, *J*=7.5), 7.35 (2H, d, *J*=7.5), 7.32 (4H, A<u>B</u>q, *J*=8.8 Hz), 6.87(4H, A<u>B</u>q, *J*=8.8 Hz), 6.64 (2H, dd, *J*=17.5 and 10.8), 5.60 (2H, d, *J*=17.5), 5.12 (2H, d, *J*=10.8), 4.67 (4H, s), 4.15 (4H, m), 3.88 (4H, m), 3.76 (8H, m). **3c** (67% yield). Transparent viscous liquid. ^1H NMR ($CDCl_3$) δ=7.66 (1H, t, *J*=7.5), 7.36 (2H, d, *J*=7.5), 7.32 (4H, A<u>B</u>q, *J*=10.0 Hz), 6.86(4H, A<u>B</u>q, *J*=10.0 Hz), 6.65 (2H, dd, *J*=15.5 and 12.5), 5.60 (2H, d, *J*=15.0), 5.12 (2H, d, *J*=12.5), 4.66 (4H, s), 4.13 (4H, m), 3.86 (4H, m), 3.72 (16H, m). **3d** (63% yield). Transparent viscous liquid. ^1H NMR ($CDCl_3$) δ=7.66 (1H, t, *J*=7.5), 7.35 (2H, d, *J*=7.5), 7.29 (4H, A<u>B</u>q, *J*=10.0 Hz), 6.84(4H, A<u>B</u>q, *J*=10.0 Hz), 6.62 (2H, dd, *J*=15.0 and 10.0), 5.58 (2H, d, *J*=15.0), 5.12 (2H, d, *J*=10.0), 4.08 (4H, m), 3.81 (4H, m), 3.66 (24 H, m).

Preparation of pyridinocrownophanes (4). Into a 1000-mL flask with a magnetic stirring and N_2 inlet was placed 2.0 mmol of olefin (**3**) dissolved in acetonitrile (800 mL), and nitrogen gas was bubbled in it for 20 min. The solution was irradiated by a 400-W high-pressure mercury lamp through a Pyrex filter. The progress of the reaction was followed by HPLC. After the disappearance of the olefin (*ca*.1.5h),the reaction mixture was evaporated. The crude reaction product was purified by column chromatography (SiO_2, a gradient solution of toluene and ethyl acetate) to afford **4**. **4a** (23% yield). White solid (mp

97.8~98.6 °C, hexane-ethanol). IR (KBr) 3054, 3026, 2924, 2894, 2849, 1613, 1598, 1593, 1510, 1480, 1261, 1211, 1103, 903, 827 cm^{-1}. ^{1}H NMR (CDCl$_3$) δ=7.41 (1H, t, J=7.3), 7.31 (2H, d, J=7.3), 6.78 (4H, A̲Bq, J=8.7 Hz), 6.56(4H, AB̲q, J=8.7 Hz), 4.68 (4H, s), 4.05 (4H, m), 3.86 (2H, m), 3.82 (4H, m), 2.37 (4H, m). ESI-MS m/z 431 (M^{+}). Anal. Calcd for C$_{27}$H$_{29}$NO$_4$: C, 75.15; H, 6.77; N,3.25, Found: C, 75.24; H, 6.68; N, 3.28. **4b** (38% yield). Pale yellow viscous liquid. IR (neat) 3056, 3036, 2936, 2914,1725, 1687, 1600, 1505, 1480, 1365, 1248, 1108, 930, 830 cm^{-1}. ^{1}H NMR (CDCl$_3$) δ=7.62 (1H, , J=7.6), 7.38 (2H, d, J=7.6), 6.82 (4H, A̲Bq, J=8.0 Hz), 6.65 (4H, A̲Bq, J=8.0 Hz), 4.67 (4H, s), 4.21 (4H, m), 4.00(4H, t, J=4.8), 3.89 (2H, m), 3.81 (4H, t, J=2.4), 3.73 (8H, m), 2.42 (4H, m). ESI-MS m/z 519 (M^{+}). Anal. Calcd for C$_{31}$H$_{37}$NO$_6$: C, 71.65; H, 7.18; N, 2.70, Found: C, 71.82; H, 7.13; N, 2.63. **4c** (38% yield). Pale yellow viscous liquid. IR (neat) 3056, 3028, 2916, 2876,1732, 1687, 1601, 1598, 1507, 1482, 1357, 1252, 1103, 940, 825 cm^{-1}. ^{1}H NMR (CDCl$_3$) δ=7.62 (1H, t, J=7.6), 7.39 (2H, d, J=7.6), 6.81 (4H, A̲Bq, J=8.5 Hz), 6.65(4H, AB̲q, J=8.5 Hz), 4.67 (4H, s), 3.99 (4H, t, J=4.9), 3.88 (2H, m), 3.82 (4H, t, J=4.7), 3.70 (12H, m), 2.40 (2H, m), 2.33 (2H, m). ESI-MS m/z 607 ([M^{+}). Anal. Calcd for C$_{35}$H$_{45}$NO$_8$: C, 69.17; H, 7.46; N, 2.30, Found: C, 69.02; H, 7.42; N, 2.48. **4d** (49% yield). Pale yellow viscous liquid. IR (neat) 3056, 3028, 2914, 2874, 1732, 1687, 1602, 1505, 1480, 1355, 1248, 1103, 950, 830 cm^{-1}. ^{1}H NMR (CDCl$_3$) δ=7.77 (1H, t, J=7.6), 7.45 (2H, d, J=7.6), 6.81 (4H, A̲Bq, J=8.5 Hz), 6.64 (4H, AB̲q, J=8.5 Hz), 4.75 (4H, s), 3.99 (4H, t, J=4.7), 3.90 (2H, m), 3.78 (4H, t, J=4.9), 3.64 (24H, m), 2.41 (2H, m), 2.33 (2H, m). ESI-MS m/z 695 (M^{+}). Anal. Calcd for C$_{39}$H$_{53}$O$_{10}$: C, 67.32; H, 7.68; N, 2.01, Found: C, 67.26; H, 7.58; N, 2.08.

Solvent extraction of heavy metal nitrates. A CH$_2$Cl$_2$ solution of pyridinocrownophane (1 x 10^{-4} mol dm^{-3}, 5.0 mL) and an aqueous metal nitrate solution (0.1 mol dm^{-3}, 5.0 mL), whose pH value was adjusted as high as possible not to precipitate the hydroxides, were shaken in a 20-mL test tube with a ground-glass stopper at an ambient temperature (18-20 °C) for 2 h. Two liquid phases were separated and evaporated *in vacuo*. The residue was dissolved in 0.1 mol dm^{-3} HNO$_3$ for analysis by atomic absorption spectrometry. Then the extracted cation into the organic phase was measured by the same manner as described above.

^{13}C NMR titration of crownophane (4b) with silver perchlorate or lead perchlorate. An acetonitrile–d$_3$ solution of **4b** (2.5 x 10^{-2} mol dm^{-3}) was prepared, and its 500 μL portions was placed in an NMR tube, and the solvent level was marked. A second solution was made in acetonitrile–d$_3$ with AgClO$_4$. An initial spectrum was recorded, then an appropriate volume of the salt solution was added to the NMR tube and the solvent level was reduced by evaporation to the mark. The spectrum was then recorded again. This procedure was repeated until the salt concentration is reached three equivalent of that of the crownophane.

Continuous variation method by using the liquid-liquid extraction of Ag^{+}. To clarify the stoichiometry of **4b**-Ag^{+} complex, Job's method was employed at the liquid-liquid extraction under the conditions shown in Figure 1.
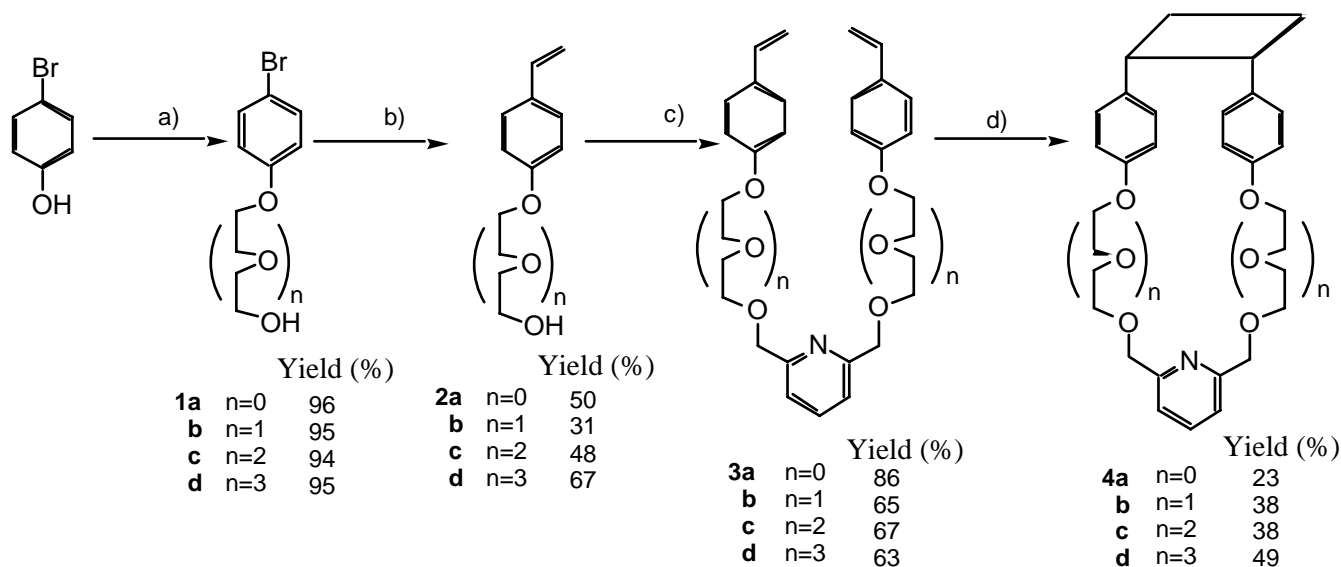
ESI-MS measurement of pyridinocrownophanes (4a-d) in the presence of AgNO$_3$ or Pb(NO$_3$)$_2$. The sample solution was 1:1 (v/v) MeCN-H$_2$O containing of the same concentration of crownophane and the salt (1 x 10^{-4} mol dm^{-3} in each).

RESULTS AND DISCUSSION

Synthesis of pyridinocrownophanes. Photocycloaddition of **3a-d** was carried out by using a 400-W high-pressure mercury lamp through Pyrex filter in MeCN. The yields of pyridinocrownophanes (**4a-d**) were 23-49% after chromatographic separation. All pyridinocrownophanes were of cis-configuration which was proved by the specific methine proton signals at δ=3.86-3.90.[12]

Complexing behavior of pyridinocrownophanes. Pyridinocrownophanes obtained were used as extractants for heavy metal cations in a liquid-liquid system. Results are summarized in Table 1 with reference dibenzopyridino-18-crown-6 (**5**) and paracrownophane (**6**). Paracrownophane (**6**) without soft heteroatom hardly extracted any heavy metal cation examined. Pyridinocrownophane (**4a**) exclusively extracted Ag^{+}, however, the extraction efficiency was not so high most likely due to formation of a perching complex, which is less stable than nesting complex.[13] From the frame work investigation using space-filling model, the cavity of the crownophane is a little small to incorporate the cation. The low

extractability can be improved by increasing lipophilicity of the complex.   In fact, the extractability was increased to 48% by addition of 3×10^{-4} mol dm^{-3} picric acid in the aqueous phase.   This increment is thought to result from a ternary complex formed from the crownophane, Ag$^+$, and picrate anion, which is more lipophilic than that formed from the crownophane, Ag$^+$, and nitrate anion. Compound (**4b**) showed high affinity toward Ag$^+$, which is closed to that of dibenzopyridino-18-crown-6 (**5**). Although the cavity size of compound (**4c-d**) seemed too large to fit the cation, they showed high affinity toward Ag$^+$.   In these cases, the host compounds formed special kind of complexes due to their conformational change, just like a three- dimensional tennis-ball-seam fashion observed for the complexation between valinomycin and K$^+$.[14]


	Yield (%)			Yield (%)			Yield (%)			Yield (%)
1a	n=0	96	**2a**	n=0	50	**3a**	n=0	86	**4a**	n=0	23
b	n=1	95	**b**	n=1	31	**b**	n=1	65	**b**	n=1	38
c	n=2	94	**c**	n=2	48	**c**	n=2	67	**c**	n=2	38
d	n=3	95	**d**	n=3	67	**d**	n=3	63	**d**	n=3	49

a) n=0: ClC$_2$H$_4$OH/aq. NaOH.   n=1-3: TsO(C$_2$H$_4$O)$_{n+1}$H, K$_2$CO$_3$/DMF.   b) CH$_2$=CHSn(n-Bu)$_3$, Pd(PPh$_3$)$_4$, 2,6-di-*tert*-butyl-4-methylphenol/toluene.   c) 2,6-bis[(tosyloxy)methyl]pyridine, NaH/THF. d) hv (>280 nm)/MeCN.

Scheme 1.   Preparation of pyridinocrownophanes.

Table 1.   Extraction of heavy metal cations with ligands

Ligand	Extractability (%)[a]							
	Ag$^+$	Pb^{2+}	Cu^{2+}	Mn^{2+}	Zn^{2+}	Ni^{2+}	Co^{2+}	Fe^{3+}
4a	10(6.2)	0(5.1)	0(4.7)	0(6.5)	0(6.5)	0(4.2)	0(6.4)	0(2.0)
4b	42(5.4)	14(5.4)	0(5.0)	0(6.3)	0(6.4)	0(6.6)	0(7.3)	0(2.0)
4c	53(5.6)	18(5.3)	0(4.9)	0(6.4)	2(5.8)	0(4.4)	0(6.9)	0(1.9)
4d	58(5.5)	16(4.6)	0(4.2)	0(6.3)	2(5.9)	0(6.3)	0(7.0)	0(1.5)
5	59(5.5)	10(5.6)	0(4.1)	0(6.3)	2(6.2)	0(6.7)	0(6.9)	0(1.6)
6	2(4.1)	0(5.0)	0(4.3)	0(6.2)	0(5.5)	0(6.9)	0(7.0)	0(1.7)

a) Extraction conditions: Aq. phase (5 mL), [metal nitrate]= 1.0×10^{-1} mol dm^{-3}; Org. phase, CH$_2$Cl$_2$ (5 mL), [ligand]= 1.0×10^{-4} mol dm^{-4}; ca. 20 $^{\circ}$C, shaken for 1 h.   The values were based on the concentration of the crown compounds.   Values in parentheses were equilibrium pH of aqueous phase.   Reproducibility was not more than $\pm$ 15% which was the average value obtained from three independent runs.
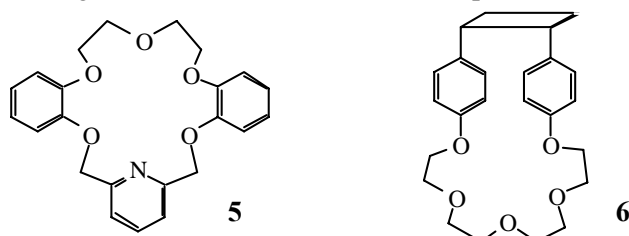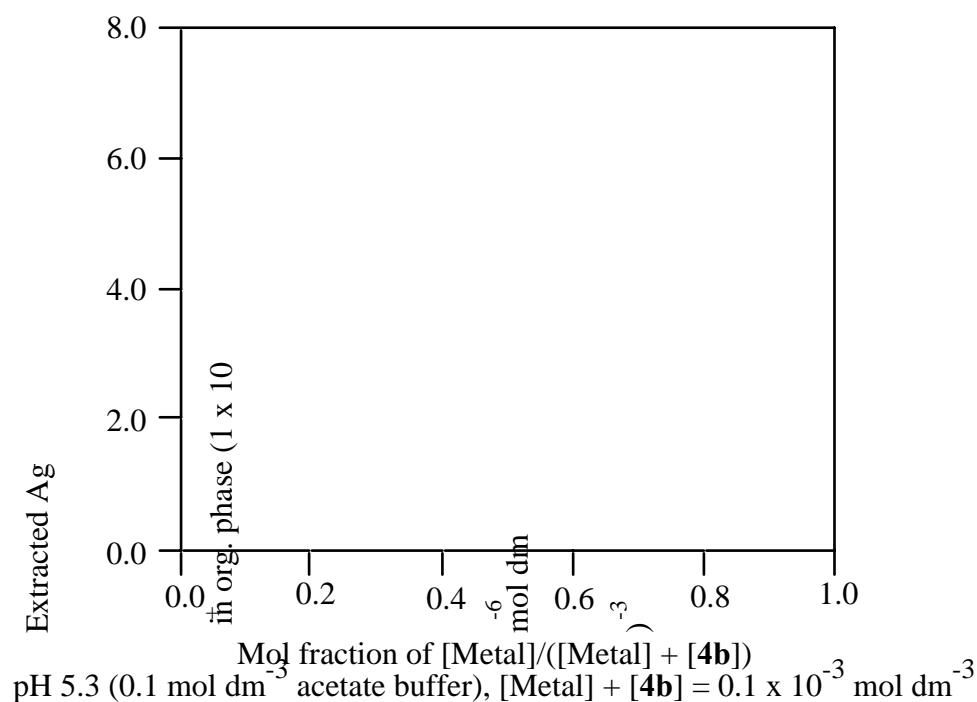
Figure 1.   Job's plots of the extraction of Ag^{+} by pyrinocrownophane (**4b**).

The binding behavior of Ag^{+} ion to **4b** was studied by the continuous variation method (Figure 1) in a similar manner as described previously.[10]   The clear maximum is not seen at any molar fraction. Consequently, the ratios are not determined by this method.
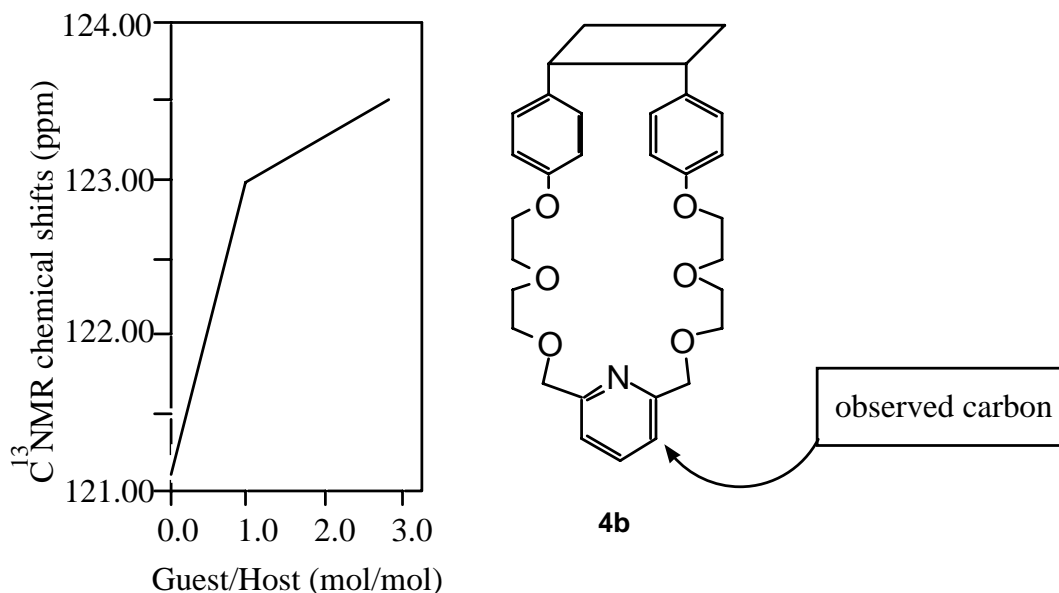

Figure 2.   Ag^{+}-induced changes of an aromatic carbon of pyridinocrownophane (**4b**) in ^{13}C NMR chemical shifts in CD$_3$CN.

In order to make the complexing behavior of **4b** to Ag^{+} in homogeneous system, we spectroscopically investigated the interaction in CH$_3$CN by using ^{13}C NMR titration method.   As shown in Figure 2, the chemical shift of its β-carbon of pyridine moiety considerably changed with increasing the amount of AgClO$_4$ added to the host solution, but the titration curve was not reached to a plateau within the observation, indicating a variety of complexes were produced.
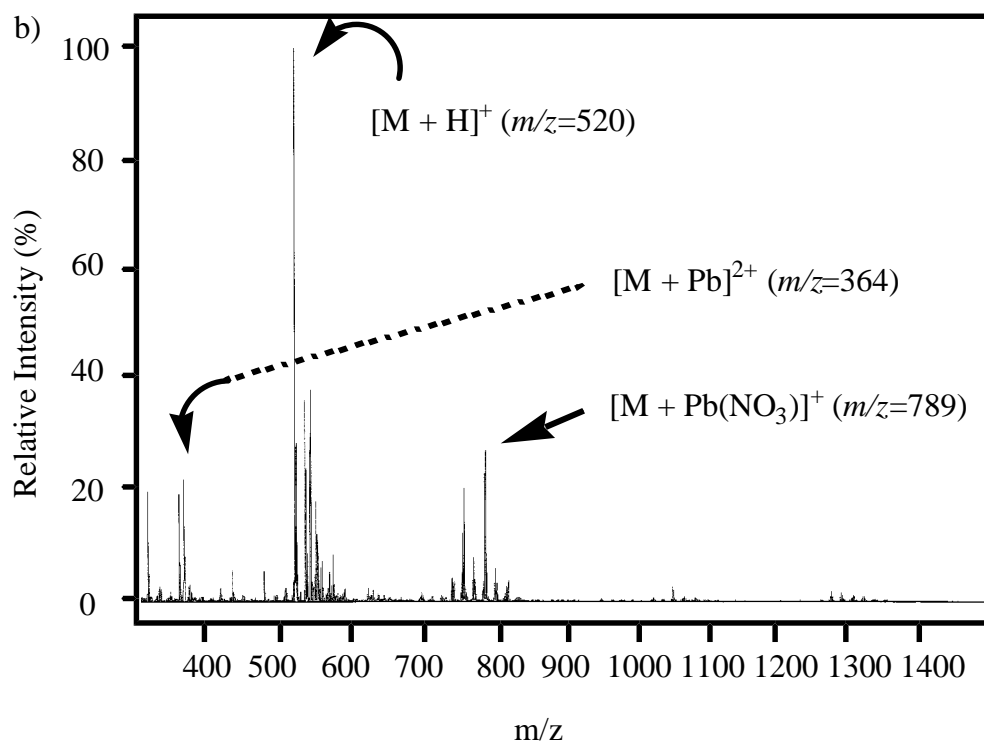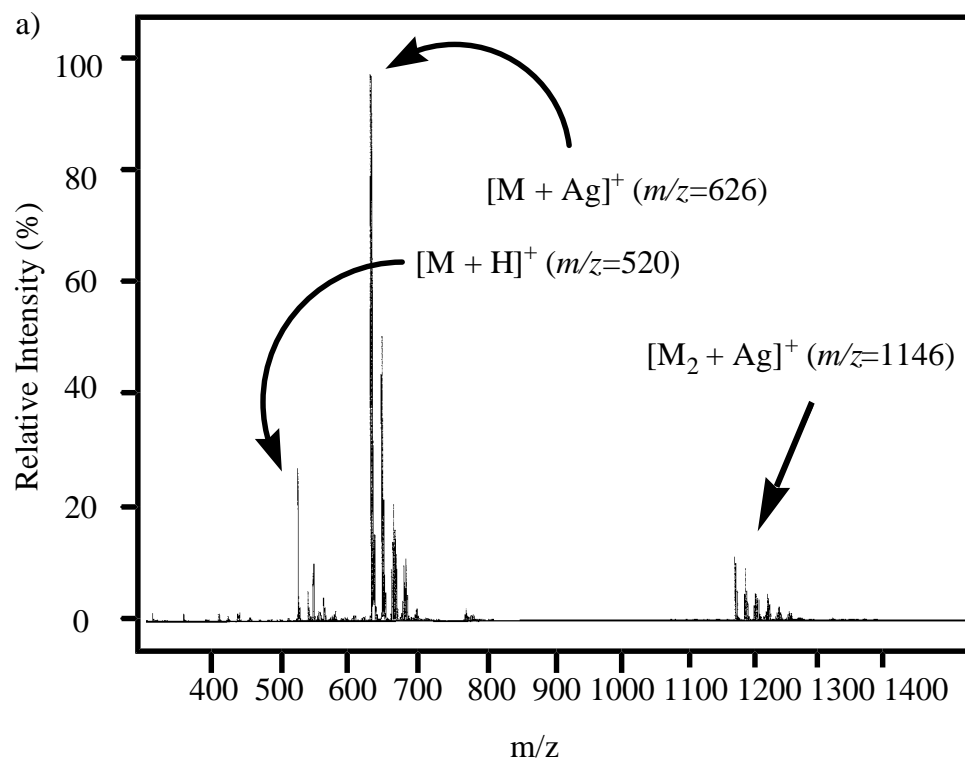
a)

[M + Ag]⁺ (*m/z*=626)

[M + H]⁺ (*m/z*=520)

[M₂ + Ag]⁺ (*m/z*=1146)

b)

[M + H]⁺ (*m/z*=520)

[M + Pb]²⁺ (*m/z*=364)

[M + Pb(NO₃)]⁺ (*m/z*=789)

Figure 3. ESI-MS spectra of pyridinocrownophane (**4b**) in 1:1 (v/v) CH₃CN-H₂O containing AgNO₃ (a) and Pb(NO₃)₂.

Furthermore, to make the behavior of complex formation between **4** and Ag⁺ ion more clear and to solve a question of why the complexing ability is considerably different between silver and lead in spite of almost the same ionic diameter to each other, we investigated the interaction between **4a-d** and Ag⁺ or Pb²⁺ ion in CH₃CN-H₂O (1:1) by employing ESI-MS. The behavior of representative **4b**-Ag⁺ complex was first disclosed as shown in Figure 3. It was clarified that **4b** formed large amount of 1:1 and 2:1 (host/guest) complexes with Ag⁺. This is the reason why the stoichiometry was not simply determined by both continuous variation method and ¹³C NMR titration method as mentioned above. Host (**4b**) was formed two kinds of 1:1 complexes with Pb²⁺ in contrast with Ag⁺ complexation (Figure 3b). As shown in Table

2, the extraction efficiency of **4a** for Ag^+ was not so high, while large amount of **4a** existed in Ag^+-complex with 1:1 stoichiometry. Although Pb^{2+} was not extracted by **4a**, similar spectrum of Pb^{2+}-complexes to that of Ag^+-complexes was obtained in the system. Host (**4c**) behaved similarly to **4b** at the complexation with the both cations.   In the case of complex formation of Ag^+ with **4d**, over 90% of the host molecule was converted to the 1:1 complex.   On the Ag^+ extraction, the high hydrophilicity of **4d**, which possess ten ethereal oxygens, is thought to be compensated by extraordinarily high complexing ability of **4d** toward silver. Very high complexing ability of **4d** toward Pb^{2+} was observed in this method, however, the extraction percent of the metal by **4d** was low as mentioned above. This low extractability is most likely due to the high hydrophilicity of the complex formed from high hydrophilic host (**4d**), the cation, and two nitrate anions.[15]

Thus, different equilibrium complexing abilities were observed for these metals due to different polarity of solvents and different phase systems, and the compositions and the stoichiometry of the complexes in CH_3CN-H_2O phase were detailedly clarified.

Table 2   Peak intensity data for ESI-MS analysis for complexation of pyridinocrownophanes (**4a-d**) with Ag^+ or Pb^{2+}.

| Compound	Salt added	Species (relative intensity/%)
4a	$AgNO_3$	$[M + H]^+$ (13, m/z=432), $[M + Ag]^+$ (100, m/z=538), $[M_2 + Ag]^+$ (14, m/z=970)
4b	$AgNO_3$	$[M + H]^+$ (27, m/z=520), $[M + Ag]^+$ (100, m/z=626), $[M_2 + Ag]^+$ (6, m/z=1146)
4c	$AgNO_3$	$[M + H]^+$ (34, m/z=608), $[M + Ag]^+$ (100, m/z=714), $[M_2 + Ag]^+$ (20, m/z=1322)
4d	$AgNO_3$	$[M + H]^+$ (8, m/z=696), $[M + Ag]^+$ (100, m/z=802)
4a	$Pb(NO_3)_2$	$[M + Pb]^{2+}$ (34, m/z=320), $[M + H]^+$ (100, m/z=432), $[M +Pb(NO_3)]^+$ (80, m/z=701)
4b	$Pb(NO_3)_2$	$[M + Pb]^{2+}$ (22, m/z=364), $[M + H]^+$ (100, m/z=520), $[M + Pb(NO_3)]^+$ (27, m/z=789)
4c	$Pb(NO_3)_2$	$[M + Pb]^{2+}$ (71, m/z=408), $[M + H]^+$ (100, m/z=608), $[M + Pb(NO_3)]^+$ (68, m/z=878)
4d	$Pb(NO_3)_2$	$[M + Pb]^{2+}$ (100, m/z=452), $[M + H]^+$ (26, m/z=696), $[M + Pb(NO_3)]^+$ (64, m/z=965)
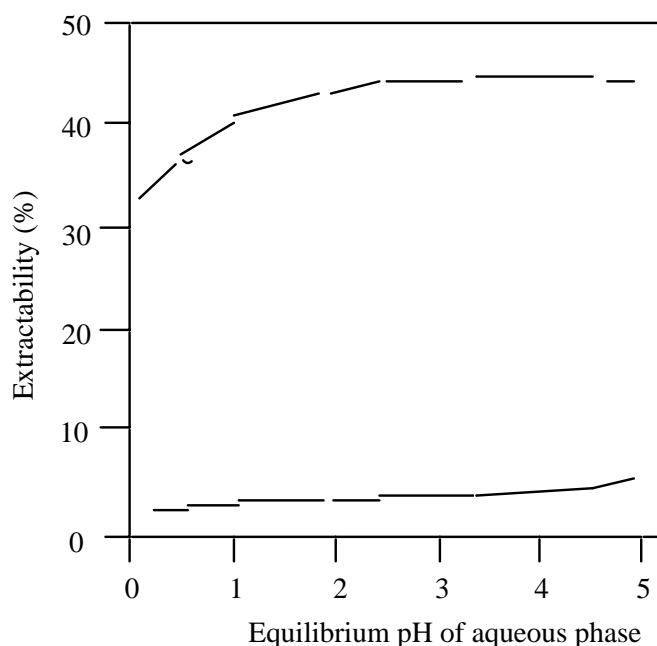
Figure 4.   Effect of pH on the extraction of Ag^+ and Pb^{2+} ions by pyridinocrownophane (**4b**).

Table 1 showed the extractability observed in the single system at the equilibrium pH of the aqueous solution which was adjusted as high as possible without precipitating the hydroxide. In a practical point of view, the extraction ability of crownophane (**4b**) was evaluated in the various pH region by the competitive extraction experiments as shown in Figure 4.   The complexing ability and high Ag^+-selectivity over Pb^{2+} were maintained in all pH region examined. This high complexing ability toward Ag^+ in acidic region is required to recovery of the cation from the waste stream[16] since the stream is generally shows low pH values.

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