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First Synthesis and Structure of β-Ketoimine Calix[4]arenes: Complexation and Extraction Studies

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Received March 19, 2004

The synthesis of a new series of β-ketoimine calix[4]arene derivatives is described. The reaction of calix[4]arene or *p-tert*-butylcalix[4]arene with bromoacetonitrile or bromobutyronitrile afforded di-, tri-, and tetranitrile calixarene derivatives (**3**−**8**, **3a**), which were then reduced into the corresponding amine (**9**−**13**, **3b**). The condensation of these aminocalixarenes with acetylacetone led to six β-ketoimine calix[4]arene derivatives (**14**−**18**, **3c**) as a class of selective receptors toward transition metals. Molecular structures of **4**, **7**, and **17** have been determined by X-ray diffraction. The packing of **17** revealed a network of intramolecular and intermolecular hydrogen bonds. The complexation properties of receptors **15**, **17**, and **3c** toward different metal ions have been investigated by UV−vis titrations in organic media. The stoichiometries of complexes with **17** were determined by both the mole ratio method and Job plots. These novel receptors selectively complex Cu^{2+}, Hg^{2+}, and Ag^{+}. Moreover, the extraction properties of **17** toward cations have been studied by liquid−liquid extraction and atomic absorption spectrometry. Compound **17** has good affinity and selectivity toward Pb^{2+}.

Introduction

Selective signaling of heavy metal ions is a very important topic for the detection and treatment of the toxic metal ions in various chemical systems including living systems. In this field, calixarenes are currently the subjects of study as chemical sensors[1,2] and selective receptors[3] as a result of their important functionalization possibilities. In recent papers, we have reported the synthesis and extraction properties of derivatized azocalix[4]arenes bearing ester,[4] amide,[5] bipyridyl,[6] and bithiazoyl[7] moieties. It was shown that the amide calixarene derivatives are able to complex akali metal cations, whereas bipyridyl analogue are able to complex soft cations such as zinc. However, there are only few examples in the literature of calixarenes being used as ligands for the heavy[8] and precious metal ions[9] in comparison with the variety of compounds for the alkali and alkaline earth metal ions.[10] One study reports[11] that a series of Schiff base *p-tert*-butylcalix[4]arenes are good extractants for Cu^{2+} and Pb^{2+}. However, most of the other alkali, alkaline earth, and first row transition metals are also extracted in significant amounts by these derivatives. Then, to obtain more efficiency and selectivity in metal extraction properties of calixarenes, we have introduced hybrid ligands between β-diketone and amide, β-ketoimine on the lower rim of calixarenes. Indeed β-ketoimine ligands are among the most fundamental chelating systems in coordination chemistry.[12] The geometry of such ligands is amenable to fine-tuning to give close control of the coordination environment of the

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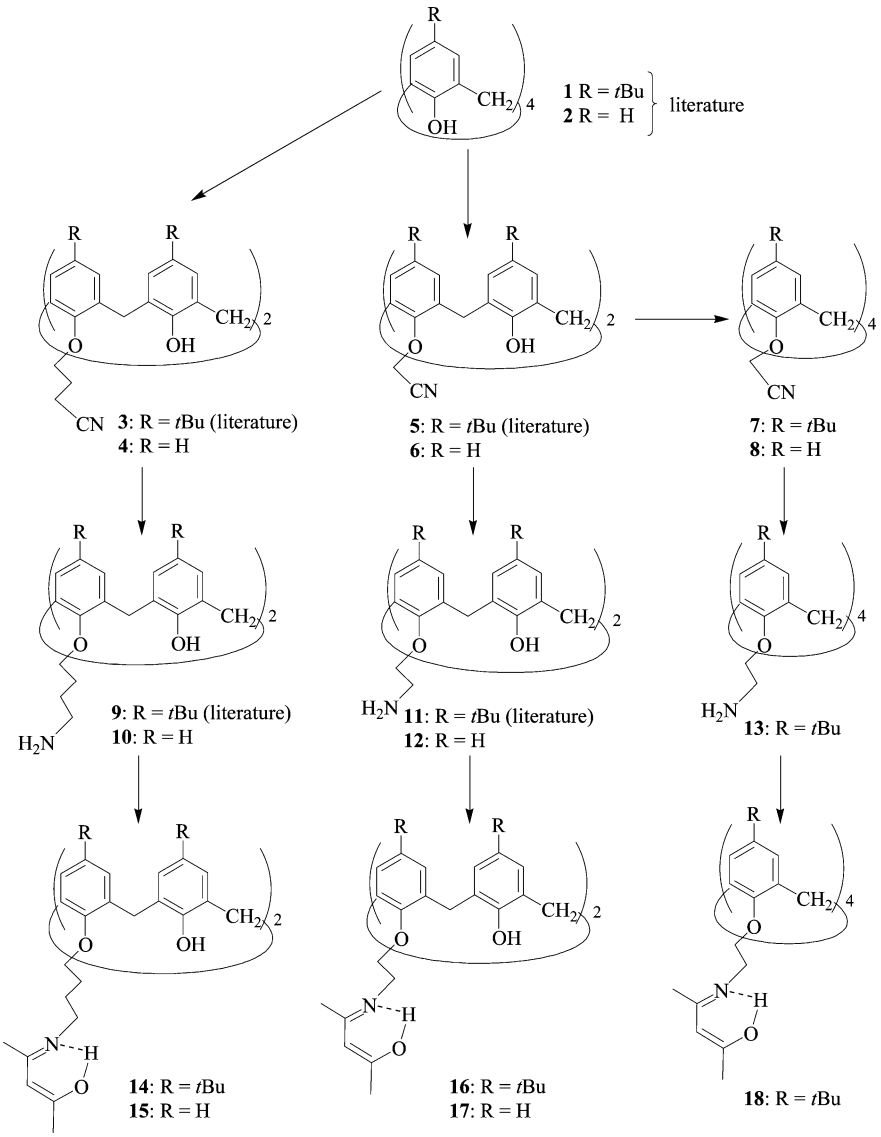
10.1021/jo0495485 CCC: $27.50 © 2004 American Chemical Society
Published on Web 09/02/2004

SCHEME 1. Synthtetic Patways of *β*-Ketoimine Calix[4]arene Derivatives



metal.[13] Moreover, *β*-ketoimine have been appended to numerous transition elements,[12a] used in enantioselective reactions[14] and as catalysts for a-olefin polymerization.[15]

Here we report the syntheses of a number of *β*-ketoimine-substituted calixarene derivatives: **14** and **15** bearing two (*β*-ketoimine)butoxy groups at the lower rim of *p-tert*-butylcalix[4]arene and calix[4]arene, respectively, **16** and **17** with two (*β*-ketoimine)ethoxy groups, **3c** with both (*β*-ketoimine)butoxy and (*β*-ketoimine)ethoxy groups, and **18** with four. Their conformations were studied by ^{1}H and ^{13}C NMR spectroscopy and X-ray diffraction analysis in the case of compounds **4**, **7**, and **17**. The complexation properties of receptors **15**, **17**, and **3c** toward various metal cations have been investigated by UV−vis titrations. Additionally, the extraction properties of compound **17** toward cations have been studied.

Results and Discussion

Syntheses and Caracterization of Ligands. *β*-Ketoimine calix[4]arene derivatives have been prepared in three steps by the reaction sequence depicted in Scheme 1. First, nitrile functions were incorporated by O-alkylation on the lower rim of calix[4]arene and *p-tert*-butylcalix[4]arene[16] in a distal position. Disubstituted compounds were obtained by similar procedures: treatment of **2** with the corresponding bromoalkylnitrile and K_2CO_3 in dry acetonitrile gave compounds **4** and **6** (76%, 59%). The tri- and tetrasubstituted compounds cannot

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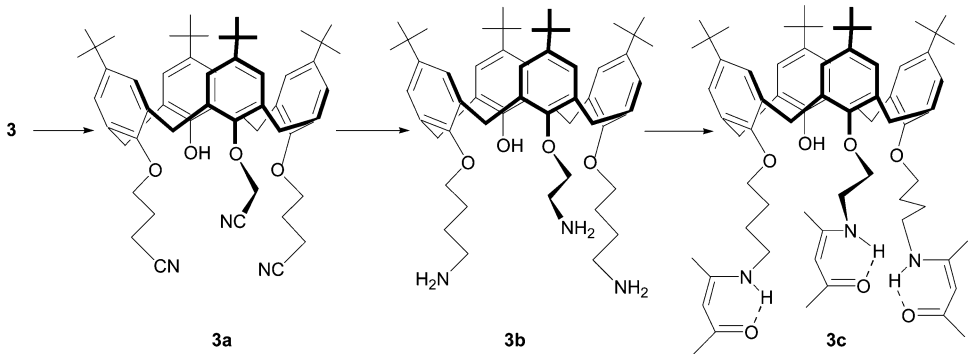
SCHEME 2. Synthesis of Trisubstituted *β*-Ketoimine *p-tert*-Butylcalix[4]arene



be obtained directly from **1** or **2** but from the disubstituted nitrile calixarene derivatives.[17] Compounds **7** and **8** were synthesized from **5** and **6** in dry DMF (58%, 16%). In the second step, compounds **3**−**7** and **3a** were reduced into the corresponding amines by classic procedure.[18] Then, the amine calixarene derivatives **9**−**13** and **3b** were condensated with pentan-2,4-dione in a mixture of ethanol/dichloromethane. Molecular sieves were used in order to trap water molecules. These reactions lead us to the desired *β*-ketoimine calix[4]arene derivatives **14**−**18** and **3c**.

All of the compounds are in cone conformation in solution. This is confirmed by the ^{1}H NMR spectra: two characteristic AB systems for the Ar-CH_2-Ar groups (J = 13−14 Hz) are observed. The *β*-ketoimine functions are characterized by the presence of two singlets (δ = 1.9 and 2.1 ppm) for the methyl groups, one singlet (δ = 5 ppm) for the proton in the α-position of carbonyl group, and one triplet (δ = 11 ppm) for the NH group. This last chemical shift of the N*H* proton is deshielded probably as the result of the formation of an intramolecular hydrogen bond. The ^{13}C NMR spectra showed peaks at around 19, 29, 96, 163, and 196 for *C*H_3, *C*H_α, *C*-NH, and *C*O groups, respectively, all of which describe the *β*-ketoimine function.

Single-Crystal X-ray Structures. Single crystals suitable for X-ray analysis were obtained for **7** (from dichloromethane), **4** (from acetonitrile), and **17** (from dichloromethane/ethanol). The skeleton of calix[4]arene is numbered conventionally (C1−C28, O25−O28) and the different substituants as depicted for the compound **4**. These free compounds adopt a distorted cone conformation in the solid state. Intramolecular hydrogen bonds between the protons of phenolic oxygen atoms and the oxygen atoms of the adjacent ether bridges are observed for **4** and **17**.

The X-ray structure of **7**, which is tetrasubstituted with four nitrile groups, confirms a cone conformation in the solid state in accordance with the results in the liquid state, presumably due to the use of NaH as base for the functionalization of the two free phenolic units. The dihedral angles between mean planes of the phenyl rings have values near 90° for two of them and near 135° for the two others. No particular interactions are observed. The parallel packing underlines the presence of dichloromethane in a disordered position between the macrocycles.

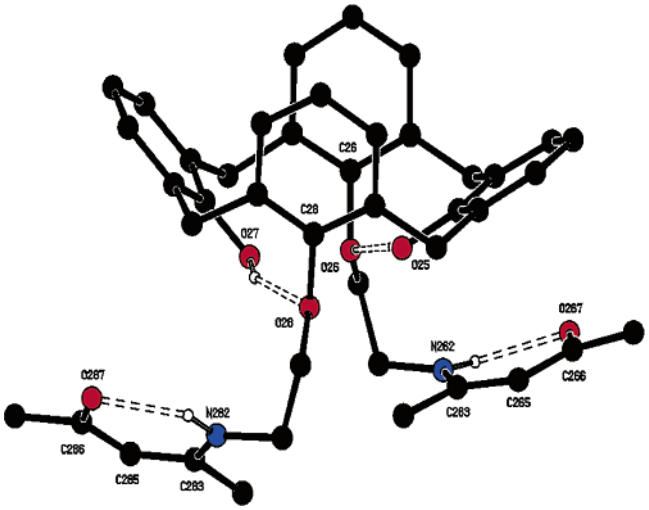


FIGURE 1. Numbered scheme of compound **17**.

TABLE 1. Hydrogen Bonds of *β*-Ketoimine Groups of Compound 17

	N−H [Å]	N···H [Å]	N···O [Å]	N−H···O [deg]	interactions
N262−H262···O267	0.82	2.05	2.70	136	intramolecular
N262−H262···O287	0.82	2.42	3.05	133	intermolecular
N282−H282···O267	1.00	2.44	3.02	126	intermolecular
N282−H282···O287	1.00	2.01	2.69	134	intramolecular

From X-ray analysis of **4** corresponding to the disubstituted cyanopropyl calix[4]arene, a distorted cone conformation is shown as indicated by the values of inclination angles: 127.1(1)°, 111.3(1)°, 130.5(1)°, and 109.6(1)°. Intramolecular hydrogen bonds are observed between the protons of free OH with the adjacent ether bridges. The packing of **4** shows that one acetonitrile molecule is present as a guest in the structure, but it is disordered with occupation factors of 0.58 and 0.42.

Like **4**, the structure of compound **17** (Figure 1) shows the intramolecular bonds concerning the phenolic proton. Moreover the *β*-ketoimine group shows two kinds of interactions: the two NH groups form intramolecular and intermolecular hydrogen bonds with the CO group of the same macrocycle and one CO group of the neighboring one (Table 1).

So, this structure shows a very interesting packing with strong intermolecular interactions along the *a* axis "polymeric" chain (Figure 2).

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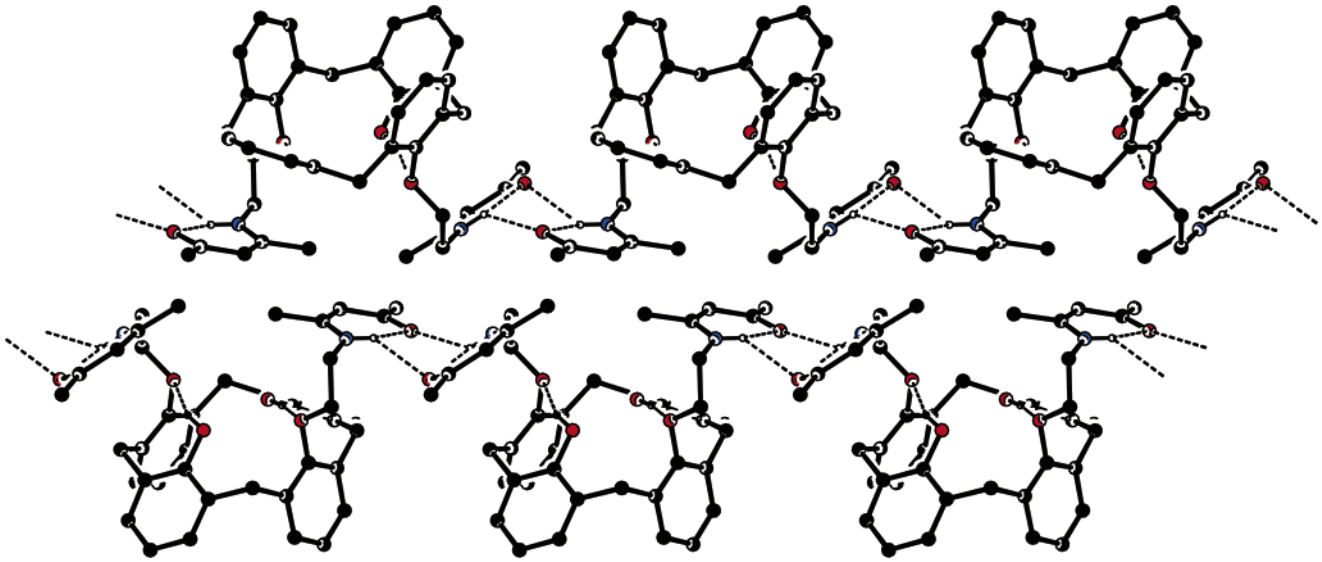

FIGURE 2. Packing of compound **17** with intra- and intermolecular interactions.

Spectrophotometric Titrations. Complexation properties of **15**, **17**, and **3c** were studied toward various metal cations (Ni^{2+}, Cr^{2+}, Pb^{2+}, Cd^{2+}, Cu^{+}, Cu^{2+}, Zn^{2+}, Co^{2+}, Ag^{+} , Hg^{2+}) by UV−vis titrations. β-Ketoimine calixarene derivatives **15** and **17** show one absorption band centered at 305 nm with a shoulder at 280 nm corresponding to, respectively, the absorption of β-ketoimine groups and aromatic rings. Upon addition of Ni^{2+}, Cr^{2+}, Pb^{2+}, Cd^{2+}, Zn^{2+}, Co^{2+}, or Cu^{+} solutions to compounds **15**, **17**, and **3c**, the ligand spectra remain practically unchanged, thus indicating that these compounds do not complex these cations.

On the other hand, upon addition of Hg^{2+}, Cu^{2+}, and Ag^{+} solutions, the UV−vis ligand spectra undergo clear changes that indicate the formation of at least one metal complex species. The addition of aliquots of Cu^{2+} (from 0.1 to 1 equiv) to a solution of **17** leads to an hypochromic effect and bathochromic shift (2.5 nm) of the band at 305 nm and the apparition of a new absorption band centered at 430 nm that is characteristic of a MLCT (metal−ligand charge transfer) band between Cu^{+} and the nitrogen, oxygen atoms of the β-ketoimine function. This phenomenon corresponds to a spontaneous autoreduction[19] of the Cu^{2+} into Cu^{+}, which was already observed in the case of complexation of $CuCl_2$ with the 6,6′-dimethyl-2,2′-bipyridine.[20] Upon addition of Ag^{+} solution (up to 1 equiv) to **17**, we can observe a hypochromic effect and a bathochromic shift (10.5 nm) of the band at 305 nm. In the case of addition of Hg^{2+} to **17**, a hypochromic effect of the band at 305 nm is observed. Moreover, in these three cases, the spectra show two isobestic points for Cu^{2+}, Ag^{+}, and Hg^{2+} complexations, respectively, at 265, 332 nm; 263, 318 nm; and 270, 331 nm indicating the existence of new species. For the compound **15**, the same results were observed. This point seems to confirm that the cations are complexed by the β-ketoimine groups and that the length of the alkyl chain does not influence the complexation. The UV−vis spectrum of **3c** shows only one broad band centered at 304 nm. Similar effects as previously were observed upon addition of Ag^{+} and Hg^{2+}, but upon addition of Cu^{2+} to a solution of **3c**, the MLCT band was not observed, indicating that there is not an autoreduction phenomena, probably because of a steric obstruction.

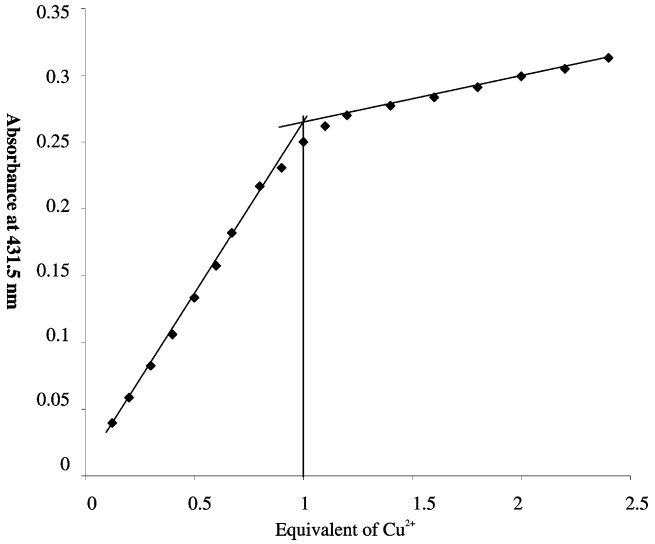

FIGURE 3. Mole ratio method of Cu-**17** mixture.

The stoichiometry of Cu-**17**, Hg-**17**, and Ag-**17** complexes was initially determined by both the mole ratio[21] and the Job plot[22] methods. The results indicate a 1:1 stoichiometry (Figure 3) for the three cases. The stability constants, log K_{11}, were extracted from the Benesi−Hildebrand plots.[23] Values for log K of 4.1, 3.9, and 4.4 for Cu-**17**, Hg-**17**, and Ag-**17**, respectively, indicate the good efficiency[11,24] of this ligand toward the target cations.

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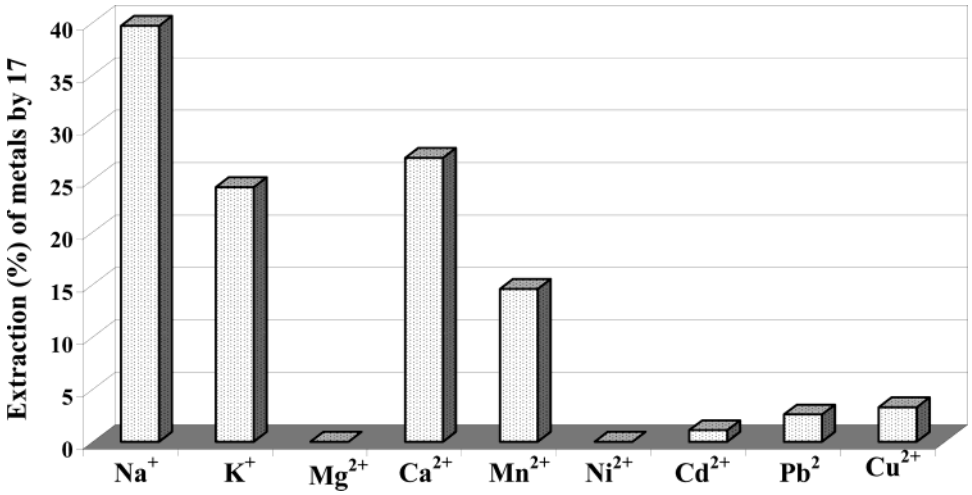

FIGURE 4. Extraction percentages of cations by **17** at pH = 4.8.

Metal Extractabilities. The extraction data with (β-ketoimine)ethoxy calix[4]arene derivative **17** has been investigated for various cations into chloroform from water. The extractabilities data have been collected in Figure 4.

The results of extraction show that this podand presents a good affinity for Na^+ (39.7%), K^+ (24.3%), and Ca^{2+} (27.1%). This is probably due to the electrostatic interaction between the cations and the cavity formed by the β-ketoimine groups. This compound does not extract the transition metals at pH = 4.8 and 2.2 and does not exceed 5% of extraction, except for Mn^{2+} (14.6%) at pH = 4.8.

On the other hand, in a basic media (pH = 8) in the presence of pyridine as catalyst, the compound **17** is an effective extractant for Pb^{2+} (86.7%) but is ineffective for Cu^{2+}, Ni^{2+}, and Cd^{2+}. These extractabilities seem to correlate with size effects of cations. Indeed, lead has the largest ionic radius of the three metals tested. These results encouraged us to study the selectivity of Pb^{2+} toward Ni^{2+}, Cd^{2+}, and Cu^{2+} in the same experimental conditions: A solution of four metals (Pb^{2+}, Ni^{2+}, Cd^{2+}, and Cu^{2+}) at the same concentration (10^{-4} mol L^{-1}) has been prepared. Our data show that **17** presents a very good selectivity of Pb^{2+} (84.8%) in comparison with Ni^{2+} (2.4%), Cd^{2+} (3.8%), and Cu^{2+} (2.8%) (Figure 5). The presence of hydrogen substituants introduces the possibility of both intramolecular and intermolecular hydrogen bonding, which might influence the behavior of extraction.

At our state of knowledge of calix[4]arene complexation with heavy metals, it is difficult to make any statements about the reasons for this observed selectivity. The receptor **17** exhibits a selectivity for Pb^{2+}.

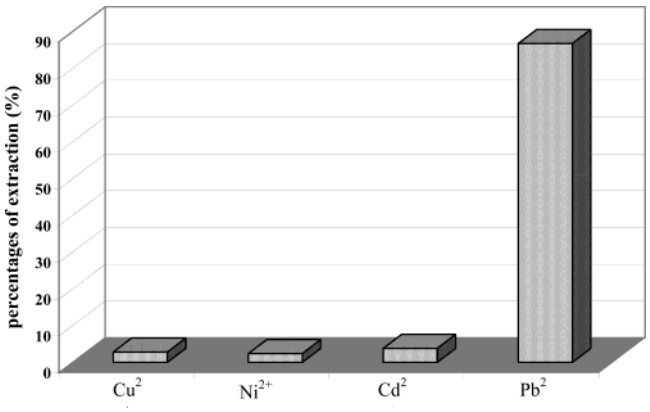

FIGURE 5. Extraction selective of Pb^{2+} by compound **17** at pH = 8.

Conclusion

For the first time, β-ketoimine groups have been grafted on calixarenes. These hosts adopt a cone conformation in solution. In the solid state, a "polymeric linear chain" is observed as a result of the intermolecular interactions between β-ketoimine groups. These functions permit to complex Hg^{2+}, Cu^{2+}, and Ag^+ and extract for compound **17** effectively Na^+, K^+ and Ca^{2+}. This receptor exhibits a very good selectivity for Pb^{2+}. This class of receptors opens new possibilities for selective extraction of heavy metals.

Experimental Section

Compounds **1**,[25] **2**,[26] **3**,[16] **5**,[27] **9**,[18] and **11**[18] were prepared according to literature procedures.

25,27-Di(cyanopropoxy)-26,28-dihydroxycalix[4]-arene (4). Calix[4]arene (5 g, 11.78 mmol), K_2CO_3 (3.6 g, 26.05 mmol), and bromobutyronitrile (8.98 g, 60.67 mmol) was refluxed in MeCN (60 mL) for 3 days. The solvent was evaporated, and the residue was taken up in CH_2Cl_2 (300 mL); washed with 100 mL of HCl (1 N), H_2O (50 mL), and brine (50 mL); and then dried over Na_2SO_4. CH_2Cl_2 was evaporated, and the residue was recrystallized from $CHCl_3$/MeOH, yielding a white solid (5 g, 76%).

25,27-Di(cyanomethoxy)-26,28-dihydroxycalix[4]-arene (6). A mixture of calix[4]arene (2 g, 4.7 mmol), K_2CO_3 (1.85 g, 13.4 mmol), and bromoacetonitrile (2.42 g, 20.2 mmol) in MeCN (30 mL) was stirred and heated under reflux for 7 h. Then the suspension was cooled to room temperature, filtered,

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and evaporated under reduced pressure. The product was purified by recrystallization ($CHCl_3$/MeOH) to give a white powder (59%).

General Procedure for Preparation of Tri- and Tetra-(cyanoalkoxy)calix[4]arene. NaH (1 g, 33.20 mmol) and di-(cyanoalkoxy)calix[4]arene (3.30 mmol) were stirred at room temperature in DMF (125 mL). Bromoacetonitrile (3.94 g, 33 mmol) was added, and the mixture was stirred at 75 °C for 24 h. H_2O (250 mL) was added, and the suspension was cooled to room temperature and filtrated. The residue solid was taken up in CH_2Cl_2 (200 mL); washed with 1 N HCl (2 × 100 mL), saturated NH_4Cl (3 × 100 mL), and brine (100 mL); and dried with $MgSO_4$. After filtration, CH_2Cl_2 was evaporated, and the residue was treated with methanol yielding a pure white solid.

5,11,17,23-Tetra-*p*-*tert*-butyl-25,26,27,28-tetrakis(cyanomethoxy)calix[4]arene (7): 1.53 g, 58%.

25,26,27,28-Tetrakis(cyanomethoxy)calix[4]arene (8) was purified by column chromatography (SiO_2, EtOAc/hexane 3:7, $R_f = 0.37$) to obtain **8** as a white powder (0.3 g, 16%).

5,11,17,23-Tetra-*p*-*tert*-butyl-25,27-bis(cyanopropoxy)-26-mono(cyanomethoxy)-28-hydroxycalix[4]arene (3a): 1.93 g, 71%.

General Procedure for Reduction of Cyanoalkylcalix-[4]arene. A solution of compound **4**, **6**, **7**, or **3a** (2.8 mmol) in 100 mL of dry THF was cooled using on ice bath, and then 60 mL (60 mmol) of BH_3 (1 M in THF) was added dropwise under nitrogen. The reaction mixture was then heated at 80 °C for 8 h. After cooling, it was quenched with 50 mL of 1 N HCl and stirred for 1 h. The solvent was removed under reduced pressure, and the residue was stirred with 50 mL of 6 N HCl and heated under reflux for 3 h. After being cooled, the acidic solution was washed with ether and then evaporated to dryness. The residue was suspended in dichloromethane, and 2 N NaOH was added until basic pH. The organic layer was separated, dried, and evaporated.

25,27-Bis(aminobutoxy)-26,28-dihydroxycalix[4]-arene (10): 1.1 g, 76%.

25,27-Bis(aminoethoxy)-26,28-dihydroxycalix[4]-arene (12): 1.4 g, 98%.

5,11,17,23-Tetra-*tert*-butyl-25,26,27,28-tetrakis(aminoethoxy)calix[4]arene (13). Using a similar protocol as that described above with 1.2 g (1.49 mmol) of **7**, 55 mL (55 mmol) of BH_3/THF, and 110 mL of anhydrous THF, a white solid was obtained (0.95 g, 78%): mp 147−149 °C; ^{1}H NMR ($CDCl_3$) δ 1.08 (s, 36 H), 3.20−3.27 (m, 12 H), 3.99 (br t, 8 H), 4.33 (d, 4 H, $J_{AB} = 12.7$ Hz), 6.86 (s, 8 H, H−Ar); ^{13}C NMR ($CDCl_3$) δ 30.3, 31.0, 34.3, 41.4, 62.9, 125.8, 133.9, 146.1, 151.0; IR ν 3391, 3248 (NH), 2954, 2866 (C−H), 1601 (CN), 1479, 1459 (C═C); ES-MS m/z 821.5 $[M + H]^+$ (calcd 821.59), 843.5 $[M + Na]^+$ (calcd 843.59).

5,11,17,23-Tetra-*p*-*tert*-butyl-25,27-bis(aminobutoxy)-26-mono(aminoethoxy)-28-hydroxycalix[4]arene (3b): 2.1 g, 90%.

General Procedure for Synthesis of β-Ketoimine Calix-[4]arenes. Aminoalkyl-calix[4]arene (1.2 mmol), an excess of acetylacetone, and molecular sieves were dispersed in an ethanol/dichloromethane mixture (3/1 v/v). The mixture was heated under reflux for 7 h under nitrogen. The mixture was filtered on dry silica and concentrated. The residue was purified by column chromatography on silica gel.

5,11,17,23-Tetra-*tert*-butyl-25,27-bis[(β-ketoimine)-butoxy]-26,28-dihydroxycalix-[4]arene (14). This compound was purified by column chromatography on silica gel eluting with EtOAc/hexane 8/2 ($R_f = 0.73$) to obtain **14** (0.28 g, 25%): mp 130−132 °C; ^{1}H NMR ($CDCl_3$) δ 0.87 (s, 18 H,), 1.21 (s, 18 H), 1.88 (s, 12 H), 1.98 (m, 8 H), 3.25 (d, 4 H, $J = 13.0$ Hz), 3.35 (q, 4 H, $J = 6.4$ Hz,), 3.92 (t, 4 H, $J = 5.3$ Hz), 4.18 (d, 4 H, $J = 13.0$ Hz), 4.90 (s, 2 H), 6.71 (s, 4 H), 6.97 (s, 4 H), 10.87 (br t, 2 H); ^{13}C NMR ($CDCl_3$) δ 19.3, 27.4, 27.8, 29.2, 31.4, 31.9, 32.2, 34.3, 43.1, 76.1, 95.9, 125.5, 125.9, 128.2, 132.8, 141.9, 147.3, 150.2, 151.0, 163.6, 195.2; IR ν 3378 (NH, OH), 2953, 2867 (C−H), 1610 (CN), 1575, 1485, 1438 (C═C); ES-MS m/z 955 $[M + H]^+$ (calcd 955.65), 977.6 $[M + Na]^+$ (calcd 977.64). $C_{62}H_{86}N_2O_6$ (954.65): calcd C 77.95, H 9.07, N 2.93; found C 78.07, H 9.12, N 2.95.

25,27-Bis[(β-ketoimine)-butoxy]-26,28-dihydroxycalix-[4]arene (15). This product was purified by column chromatography (SiO_2, EtOAc/hexane 6/4, $R_f = 0.18$) to give **15** (0.27 g, 33%): mp 148−150 °C; ^{1}H NMR ($CDCl_3$) δ 1.91 (s, 4 H), 2.04 (s, 6 H), 2.12 (m, 8 H), 3.42 (d, 4 H, $J = 12.8$ Hz), 3.44 (m, 4 H), 4.03 (t, 4 H, $J = 6.2$ Hz), 4.30 (d, 4 H, $J = 13.0$ Hz), 4.97 (s, 2 H), 6.67 (t, 2 H, $J = 7.0$ Hz), 6.69 (t, 2 H, $J = 7.3$ Hz), 6.87 (d, 4 H, $J = 7.5$ Hz), 7.09 (d, 4 H, $J = 7.5$ Hz), 7.90 (s, 2 H), 11.01 (br t, 2 H); ^{13}C NMR ($CDCl_3$) δ 19.1, 27.3, 27.8, 29.2, 32.3, 43.1, 76.4, 95.8, 119.6, 125.8, 129.0, 129.4, 128.4, 133.5, 152.2, 153.6, 163.6, 195.2; IR 3316 (NH, OH), 2924, 2869 (C−H), 1606 (CN), 1569, 1464, 1434 (C═C); ES-MS m/z 731.5 $[M + H]^+$ (calcd 731.40), 753.5 $[M + Na]^+$ (calcd 753.39); $C_{46}H_{54}N_2O_6$ (730.4): calcd C 75.59, H 7.45, N 3.83; found C 75.45, H 7.33, N 3.75.

5,11,17,23-Tetra-*tert*-butyl-25,27-bis[(β-ketoimine)ethoxy]-26,28-dihydroxycalix[4]arene (16). This compound was purified by column chromatography (EtOAc/hexane 8/2, $R_f = 0.25$) to give **16** (0.108 g 10%): mp 182−184 °C; ^{1}H NMR ($CDCl_3$) δ 0.88 (s, 18 H), 1.30 (s, 18 H), 1.94 (s, 6 H), 2.10 (s, 6 H), 3.32 (d, 4 H, $J = 13.2$ Hz), 3.81 (q, 4 H, $J = 6.4$ Hz), 4.04 (t, 4 H, $J = 6.0$ Hz), 4.20 (d, 4 H, $J = 13.2$ Hz), 5.01 (s, 2 H), 6.40 (s, 2 H), 6.69 (s, 4 H), 7.06 (s, 4 H), 10.99 (t, 2 H, $J = 6.4$ Hz); ^{13}C NMR ($CDCl_3$) δ 19.4, 29.2, 31.3, 31.7, 32.1, 34.2, 43.0, 75.6, 96.8, 125.4, 126.0, 128.2, 132.3, 142.0, 147.5, 149.9, 150.8, 163.6, 195.8; IR 3364 (NH, OH), 2958, 2868 (C−H), 1610 (CN), 1575, 1483, 1461 (C═C); ES-MS m/z 899.5 $[M + H]^+$ (calcd 899.59), 921.6 $[M + Na]^+$ (calcd 921.58). $C_{58}H_{78}N_2O_6$ (898.5): C 77.47, H 8.74, N 3.12; found C 77.42, H 8.68, N 3.09.

25,27-Bis[(β-ketoimine)-ethoxy]-26,28-dihydroxycalix-[4]arene (17). This compound was purified by column chromatography (EtOAc/hexane 8/2, $R_f = 0.56$) and recrystallized in CH_2Cl_2/MeOH to give **17** (0.69 g, 85%): mp 232−234 °C; ^{1}H NMR δ 1.92 (s, 6 H), 2.09 (s, 6 H), 3.40 (d, 4 H, $J = 13.3$ Hz), 3.83 (q, 4 H, $J = 6.2$ Hz), 4.07 (t, 4 H, $J = 6.2$ Hz), 4.24 (d, 4 H, $J = 13.2$ Hz), 5.01 (s, 2 H), 6.64 (t, 2 H, $J = 7.5$ Hz), 6.70 (t, 2 H, $J = 7.5$ Hz), 6.78 (d, 4 H, $J = 7.5$ Hz), 6.87 (s, 2 H), 7.09 (d, 4 H, $J = 7.5$ Hz), 11.01 (t, 2 H, $J = 6.2$ Hz); ^{13}C NMR δ 19.4, 29.2, 31.4, 43.0, 75.8, 96.9, 119.5, 125.8, 129.0, 129.4, 128.4, 133.0, 152.1, 153.5, 163.4, 195.9; IR ν 3384 (NH, OH), 2921, 2879 (C−H), 1610 (CN), 1583, 1514, 1455 (C═C). ES-MS m/z 674.9 $[M + H]^+$ (calcd 675.34), 697.2 $[M + Na]^+$ (calcd 697.33). $C_{42}H_{46}N_2O_6$ (674.3): calcd C 74.75, H 6.87, N 4.15; found C 74.71, H 6.82, N 4.12.

5,11,17,23-Tetra-*tert*-butyl-25,26,27,28-tetrakis[(β-ketoimine)ethoxy]calix[4]arene (18). This compound was purified by column chromatography (SiO_2, EtOAc/hexane 6/4, $R_f = 0.24$) to give **18** (0.097, g 7%): mp 194−196 °C; ^{1}H NMR ($CDCl_3$) δ 1.07 (s, 36 H), 1.88 (s, 12 H), 1.96 (s, 12 H), 3.23 (d, 4 H, $J = 12.8$ Hz), 3.71 (q, 8 H, $J = 6.2$ Hz), 4.08 (t, 8 H, $J = 6.8$ Hz), 4.33 (d, 4 H, $J = 12.6$ Hz), 4.96 (s, 4 H), 6.78 (s, 8 H), 10.91 (br t, 2 H); ^{13}C NMR ($CDCl_3$) δ 19.1, 29.1, 31.5, 31.8, 34.3, 43.0, 73.3, 96.1, 125.7, 133.8, 145.6, 152.5, 163.5, 195.2. IR 3400 (NH), 2958, 2922, 2853 (C−H), 1608 (CN), 1571, 1480, 1461 (C═C); ES-MS m/z 1149.8 $[M + H]^+$ (calcd 1149.75). $C_{72}H_{100}N_4O_8$ (1148.7): calcd C 75.22, H 8.77, N 4.87; found C 75.08, H 8.72, N 4.77.

5,11,17,23-Tetra-*tert*-butyl-25,27-bis[(β-ketoimine)-butoxy]-26-mono[(β-ketoimine)-ethoxy]-28-di hydroxycalix-[4]arene (3c). This product was purified by column chromatography (SiO_2, EtOAc/hexane 6/4, $R_f = 0.30$) to give **3c** (0.23 g, 18%): mp 108−110 °C; ^{1}H NMR ($CDCl_3$) δ 0.80 (s, 18 H), 1.25 (t, 4 H, $J = 6.3$ Hz), 1.34 (s, 18 H), 1.80 (m, 4 H), 1.90 (s, 6 H), 1.98 (s, 6 H), 2.03 (s, 3 H), 2.07 (s, 3 H), 3.32−3.18 (m, 8 H), 3.84−3.78 (m, 4 H), 4.14−4.07 (m, 4 H), 4.26 (d, 4 H, $J = 13.6$ Hz), 4.94 (s, 2 H), 5.02 (s, 1 H), 5.24 (s, 1 H), 6.47 (s, 4 H), 7.07 (s, 2 H), 7.15 (s, 2 H),10.88 (m, 3 H); ^{13}C NMR ($CDCl_3$) δ

19.3, 29.1, 27.9, 27.4, 32.0, 31.1, 32.1, 31.4, 30.0, 34.6, 34.3, 34.0, 60.8, 43.2, 43.0, 76.1, 71.6, 95.7, 95.6, 125.2, 125.4, 125.6, 126.3, 129.8, 131.9, 132.2, 136.1, 142.3, 145.9, 146.9, 150.9, 151.1, 151.7, 163.5, 163.9, 194.9, 195.1; IR ν 3537 (NH, OH), 2955, 2867 (C−H), 1609 (C−N), 1573, 1516, 1481, 1437 (C═C); ES-MS *m/z* 1080.8 $[M + H]^+$ (calcd 1080.73), 1102.6 $[M + Na]^+$ (calcd 1102.72). $C_{69}H_{97}N_3O_7$ (1079.7): calcd C 76.70, H 9.05, N 3.89; found C 76.58, H 8.91, N 3.78.

Supporting Information Available: General experimental and extraction methods; X-ray crystallographic data in CIF format of **4**, **7**, and **17** and additional figures of **4** and **7**; UV−vis spectra of **17**, **17**-Cu, **17**-Hg, and **17**-Ag; ^{1}H NMR spectra of **3c**, **17**, and **18**; and characterization of intermediate compounds (**4**, **6**−**8**, **10**, **12**, **13**, **3a**, **3b**). This material is available free of charge via the Internet at http://pubs.acs.org.

JO0495485