

Dicarboxylate Anion Recognition by a Redox-responsive Ditopic Bis(cobalticinium) Calix[4]arene Receptor Molecule

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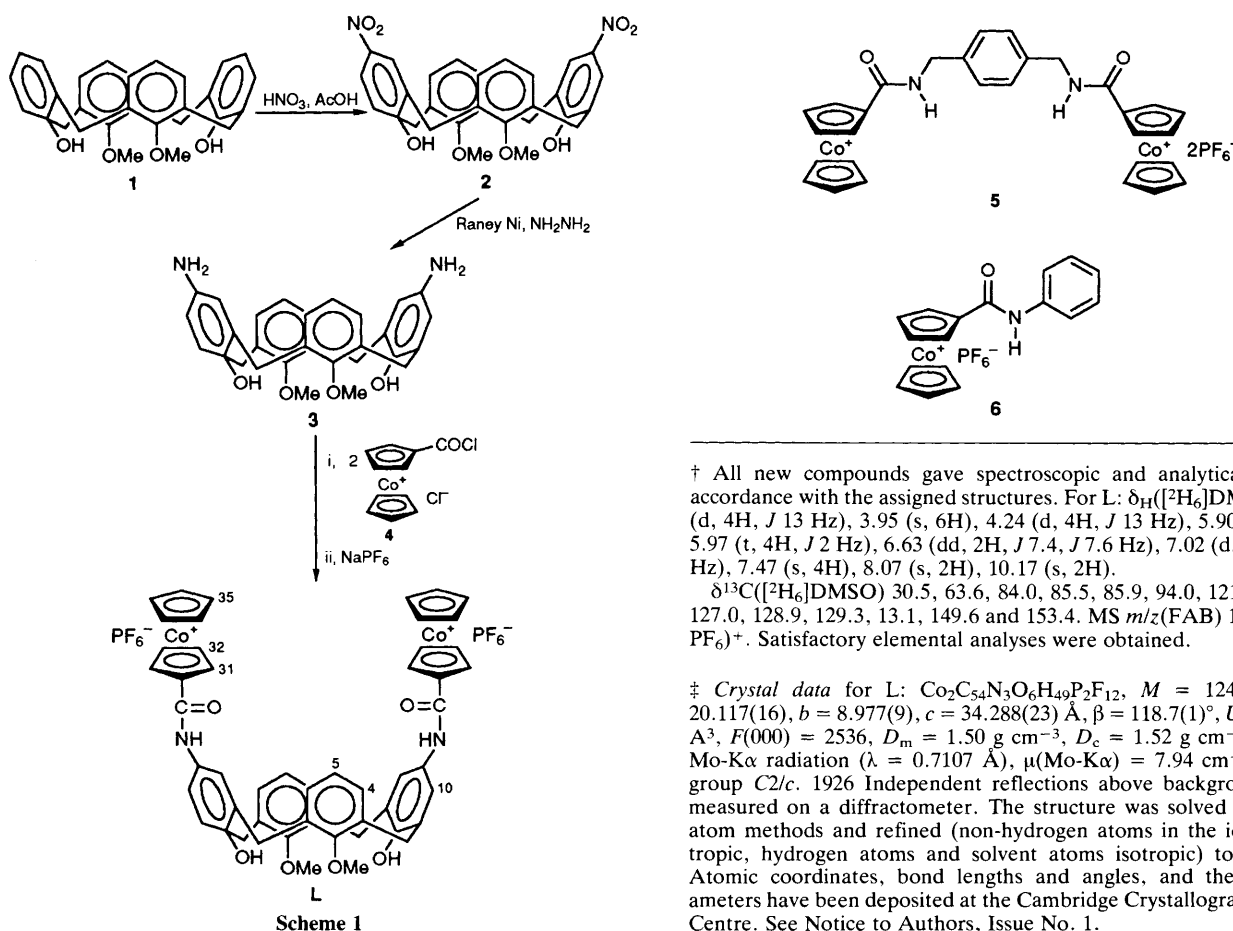
A novel calix[4]arene ditopic anion receptor molecule containing two cobalticinium moieties has been prepared and shown by ¹H NMR and cyclic voltammetry to coordinate and electrochemically recognise anions including the dicarboxylate dianion adipate.

The molecular recognition of anionic guest species by abiotic receptors is an area of intense current interest.¹ Recently we reported the synthesis of a new class of anion receptor based on the redox-active, pH-independent positively charged cobalticinium moiety^{2,3} and demonstrated that simple acyclic amide linked cobalticinium ligand systems can bind and electrochemically recognise halide guest anions.³ The calixarenes⁴ are attractive host molecules on which to construct additional recognition sites for target analytes. Although the calix[4]arene host structural unit has been modified at the lower rim for the recognition of group 1 and 2 metal cations,⁵ to our knowledge the design of calix[4]arene anion receptors has not been described. Using a new upper rim functionalised calix[4]arene building block we report here the synthesis, crystal structure, anion coordination chemistry and electrochemical investigations of a novel bis(cobalticinium) calix[4]arene receptor molecule L that recognises halide, nitrate, hydrogen sulfate and dicarboxylate anionic guest species.

The reaction of 1,3-dimethoxy-calix[4]arene **1** with nitric acid and acetic acid in dichloromethane produced the dinitro calix[4]arene derivative **2** in 50% yield. Reduction of **2** using Raney nickel and hydrazine hydrate gave the new diamino compound **3** in 70% yield. Condensation of **3** and two

equivalents of chlorocarbonyl cobalticinium chloride **4**[†] in dimethylformamide-acetonitrile solvent mixture initially gave a crude dark-red oil which on treatment with an excess amount of sodium hexafluorophosphate followed by silica gel column chromatography (acetonitrile-dichloromethane 4:1) produced the receptor L as a red crystalline solid in 61% yield[‡] (Scheme 1).

Crystals of L suitable for an X-ray structural determination[‡] were grown from an acetonitrile-methanol solvent mixture. The structure consists of discrete cations (Fig. 1) with crystallographically imposed C₂ symmetry, PF₆⁻ anions and solvent acetonitrile molecules with 50% occupancy. The calix[4]arene has the cone conformation stabilised by two O-H...O hydrogen bonds (2.80 Å) around the bottom of the cone. The calix[4]arene is asymmetric in that the unique C_{ar}C_{ar}-CH₂-CH₂ torsion angles are -81.4, -110.2, 98.5 and -71.5°. At the top of the cone the Ph-NH-CO-C₅H₅ moieties are closely planar with torsion angles around the C_{ar}-N, N-C(O) and C(O)-C_{ar} bonds of -18.3, 178.9 and 3.6°, respectively. The acetonitrile solvent molecules are positioned inside the cavity as shown in Fig. 1 between the unattached cyclopentadienyl ring and the calixarene. The closest contacts are from N(81) to the cyclopentadienyl ring {C(61) at 3.44,



[†] All new compounds gave spectroscopic and analytical data in accordance with the assigned structures. For L: $\delta_{\text{H}}([\text{}^2\text{H}_6]\text{DMSO})$ 3.47 (d, 4H, J 13 Hz), 3.95 (s, 6H), 4.24 (d, 4H, J 13 Hz), 5.90 (s, 10H), 5.97 (t, 4H, J 2 Hz), 6.63 (dd, 2H, J 7.4, J 7.6 Hz), 7.02 (d, 4H, J 7.4 Hz), 7.47 (s, 4H), 8.07 (s, 2H), 10.17 (s, 2H).

$\delta^{13}\text{C}([\text{}^2\text{H}_6]\text{DMSO})$ 30.5, 63.6, 84.0, 85.5, 85.9, 94.0, 121.3, 125.1, 127.0, 128.9, 129.3, 131.1, 149.6 and 153.4. MS m/z (FAB) 1192 ($M - \text{PF}_6$)⁺. Satisfactory elemental analyses were obtained.

[‡] Crystal data for L: $\text{Co}_2\text{C}_{54}\text{N}_3\text{O}_6\text{H}_{49}\text{P}_2\text{F}_{12}$, $M = 1243.2$, $a = 20.117(16)$, $b = 8.977(9)$, $c = 34.288(23)$ Å, $\beta = 118.7(1)^\circ$, $U = 5431.4$ Å³, $F(000) = 2536$, $D_m = 1.50$ g cm⁻³, $D_c = 1.52$ g cm⁻³, $Z = 4$, Mo-K α radiation ($\lambda = 0.7107$ Å), $\mu(\text{Mo-K}\alpha) = 7.94$ cm⁻¹, Space-group C2/c. 1926 Independent reflections above background were measured on a diffractometer. The structure was solved by heavy-atom methods and refined (non-hydrogen atoms in the ions anisotropic, hydrogen atoms and solvent atoms isotropic) to R 0.079. Atomic coordinates, bond lengths and angles, and thermal parameters have been deposited at the Cambridge Crystallographic Data Centre. See Notice to Authors, Issue No. 1.

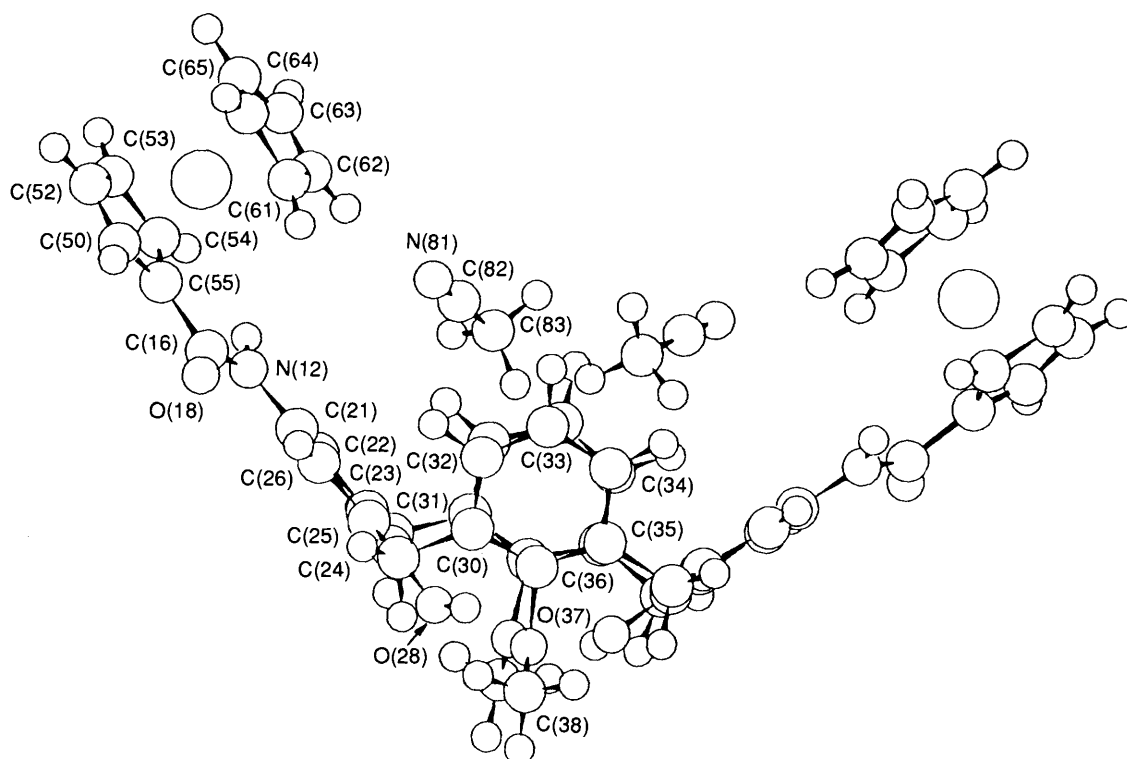
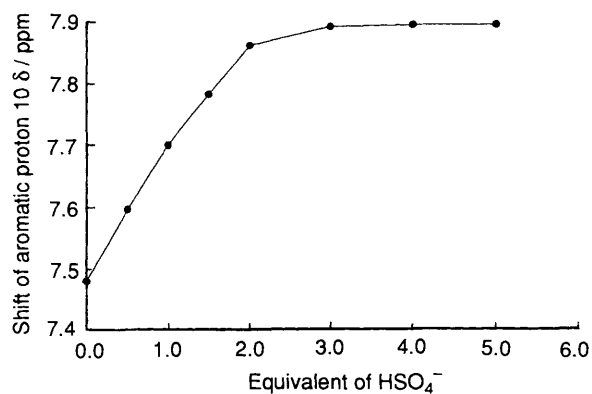
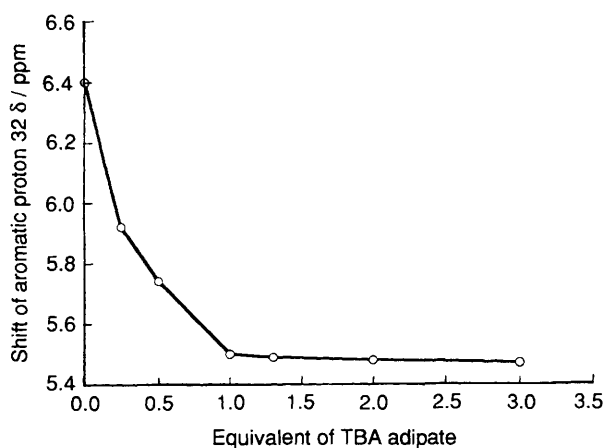


Fig. 1 The structure of L

Fig. 2 ¹H NMR titration curve of L and HSO₄⁻ in [²H₆]DMSOFig. 3 ¹H NMR titration curve of L and adipate [⁻O₂C(CH₂)₄CO₂⁻] in [²H₆]acetone; TBA = tetrabutylammonium

C(62) at 3.30 Å} and to a phenyl ring of the calixarene {C(32) 3.42, C(33) at 3.54 Å}. In the Co(cyclopentadienyl)₂ moiety, the Co–C distances are as expected ranging from 1.94 to 2.06 Å. The two rings are staggered across the metal atom.

The addition of tetrabutylammonium halides, nitrate and hydrogen sulfate to [²H₆]acetone and [²H₆]dimethyl sulfoxide ([²H₆]DMSO) ¹H NMR solutions of L resulted in remarkable shifts of the receptor's protons. For example with HSO₄⁻ in DMSO, the largest downfield shifts are seen for protons H(10) (Δδ 0.4 ppm), H(31) (Δδ 0.3 ppm) and upfield shifts for protons H(32) (Δδ 0.2 ppm) and H(35) (Δδ 0.1 ppm). It is noteworthy that in all cases aryl protons H(4) and H(5) of the calix[4]arene structural framework are also perturbed by these anionic guest species (Δδ 0.22 ppm) suggesting anion complexation takes place within the upper rim of the calix cavity of L. The resulting titration curves (Fig. 2 for example) suggest L:2X⁻ (X = Cl⁻, Br⁻, NO₃⁻, HSO₄⁻) stoichiometric complexes implying L is acting as a ditopic receptor in which each anionic guest is binding in close proximity to the respective cobalticinium moiety. §

Proton NMR complexation experiments of L with dicarboxylate dianions adipate, malonate and oxalate were investigated in [²H]acetone. The titration curve with adipate (Fig. 3) illustrates the formation of a 1:1 stoichiometric solution complex, and, together with the observed significant perturbations of H(4) and H(5) protons of L, these titration results suggest the adipate guest dianion coordinates within the confines of the upper rim cavity of L (Fig. 4).

As evidenced from the smaller magnitudes of the host's proton shifts, comparatively weaker solution complexes are formed with oxalate and malonate dianions. Interestingly the bis(cobalticinium) **5** and simple monocobalticinium **6** derivatives also exhibit significant interactions with dicarboxylate dianions, although precipitation problems thwarted their respective stoichiometries being elucidated.

§ No anion induced proton shifts were observed with the corresponding bis(phenyl)amide calix[4]arene derivative.

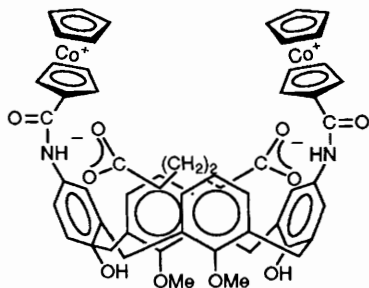


Fig. 4 Proposed solution complex structure of L and adipate

Cyclic voltammetry and coulometric studies revealed L in acetone to undergo a reversible two electron reduction at -0.69 V [vs. SCE (SCE = saturated calomel electrode)]. Adding stoichiometric equivalents of chloride, nitrate and adipate to electrochemical solutions of L resulted in significant cathodic perturbations of the reversible redox wave of 55, 25 and 50 mV, respectively.

In conclusion, a novel redox responsive ditopic anion receptor containing cobalticinium moieties attached to a calix[4]arene has been prepared and shown to complex two halide, nitrate and hydrogen sulfate anions and to form a 1:1 included complex with the adipate dicarboxylate dianion guest. The coordination chemistry of L towards anions of

particular biological importance is currently being investigated.

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