Novel Benzo Crown Ether Cavitand and Benzo Crown Ether–Ferrocenyl Host Molecules that bind Bipyridinium and Sodium Guest Cations

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The syntheses, co-ordination, and electrochemistry of novel macrocyclic benzo crown ether (**6**), (**8**), and benzo crown ether–ferrocenyl (**7**) host molecules, each containing four benzo-15-crown-5 moieties and, in the case of (**7**), eight ferrocenyl redox-active centres, are reported; the new hosts bind bipyridinium and sodium guest cations.

The incorporation of Lewis acid binding sites and multiple redox-active centres into a preorganised[1] macrocyclic structural framework will lead to prototypes of a new class of redox catalytic system capable of promoting redox reactions on a guest substrate such as CO_2 or CO, through a combination of guest inclusion and subsequent Lewis acid catalytic activation (Figure 1). Towards this goal, we report here the preparation, preliminary co-ordination, and electrochemical studies of new macrocyclic benzo crown ether host molecules (**6**), (**7**), and (**8**), each containing four potential Lewis acidic benzo-15-crown-5 binding subunits, and in the case of (**7**), eight ferrocenyl redox-active centres.

The reaction of 4-formylbenzo-15-crown-5 (**1**)[2] and resorcinol (**2**) in the presence of hydrochloric acid and ethanol gave the new tetrameric phenolic benzo crown ether macrocycle (**3**) as a white powdery solid. Condensing (**3**) with an excess of benzoyl chloride (**4**) or chlorocarbonyl ferrocene (**5**)[3] in the presence of triethylamine gave, after column chromatography (alumina, CH_2Cl_2), (**6**) as a creamy white powder (21% overall yield for two steps; not optimised) and (**7**) as an orange crystalline solid (22% overall yield), respectively. Reacting (**3**) with $BrCH_2Cl$ in dry DMF (dimethyformamide) and K_2CO_3 produced the first crown ether cavitand host molecule (**8**) (4% overall yield). Elemental analyses, FAB mass spectrometry, and ^1H and ^{13}C NMR spectroscopy confirmed the proposed structures.

The new host molecules contain two cavities for possible guest inclusion, the upper bowl like cavity and a lower tetrameric benzo crown ether box-like hollow. Stoddart *et al.*[5] and more recently our group[4] have reported that simple bis-benzo crown ethers[4] and dibenzo crown ethers[5] can complex bipyridinium dications diquat (**9**) and paraquat (**10**). In addition Schneider and co-workers[6] have shown that a simple cyclophane (**11**) can bind quaternary ammonium cations in aqueous alkaline solutions. It was of interest therefore to investigate the solution complexation properties of (**6**), (**7**), and (**8**) with (**9**) and (**10**) to elucidate whether inclusion complexation takes place, and if so, in which cavity the guest is bound.

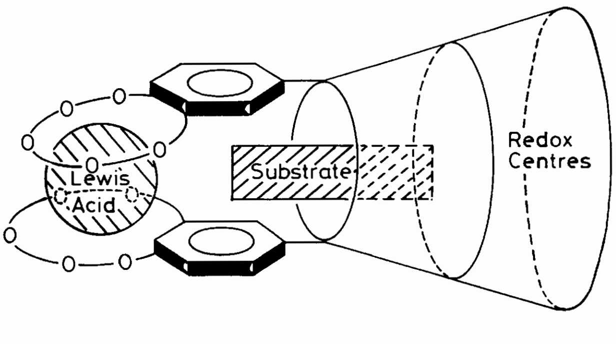

Figure 1. General representation of a new class of redox catalytic system, capable of promoting redox reactions on a guest substrate *via* guest inclusion and Lewis acid catalytic activation.

High field ^1H NMR spectroscopy was used to study the binding of (**9**) and (**10**) by hosts (**6**), (**7**), and (**8**) in solutions of 50% CD_3CN : 50% $CDCl_3$. Table 1 reports the significant large upfield shifts for all the bipyridyl protons of the diquat dicationic guest (**9**) upon complexation with (**6**), (**7**), and (**8**). Smaller upfield shifts of the OCH_2 crown ether protons ($\leqslant$0.07 p.p.m.) of each host were also observed. Using NOE difference spectroscopy,[7] irradiation of the $(N^+CH_2)_2$, 4,4′- or 5,5′-protons of (**9**) resulted in small but significant changes in the intensities of the crown OCH_2 proton absorptions of hosts (**6**)—(**8**), suggesting the $(N^+CH_2)_2$ protons of (**9**) are involved in weak C–H · · · O hydrogen bonding with the oxygen donor atoms of the respective benzo crown ether moieties. Under identical experimental conditions *no* shifts were observed with the model host (**12**) containing no benzo crown subunits. These experimental findings suggest that the planar dicationic guest (**9**) binds in the lower benzo crown ether box-like cavity, intercalating between the electron rich benzo crown ether subunits of the respective host (**6**)—(**8**). Further stoicheio-

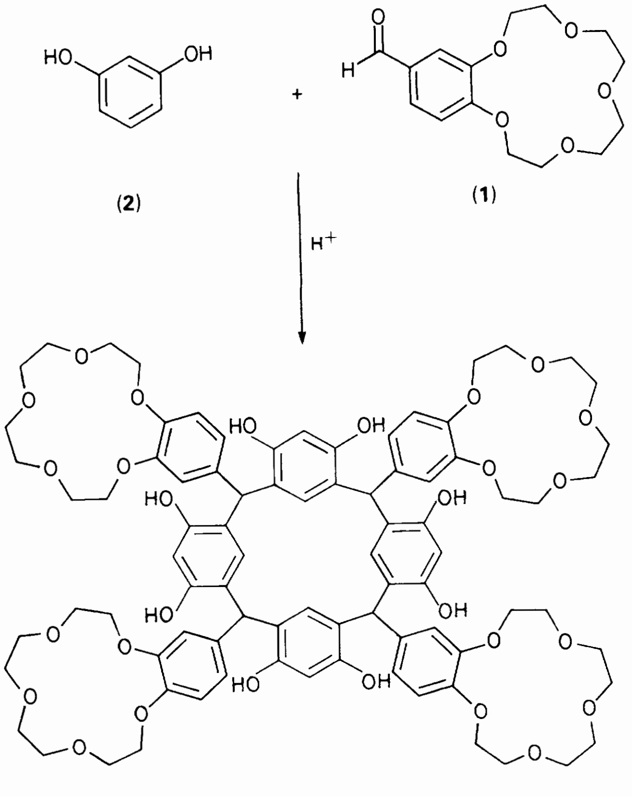

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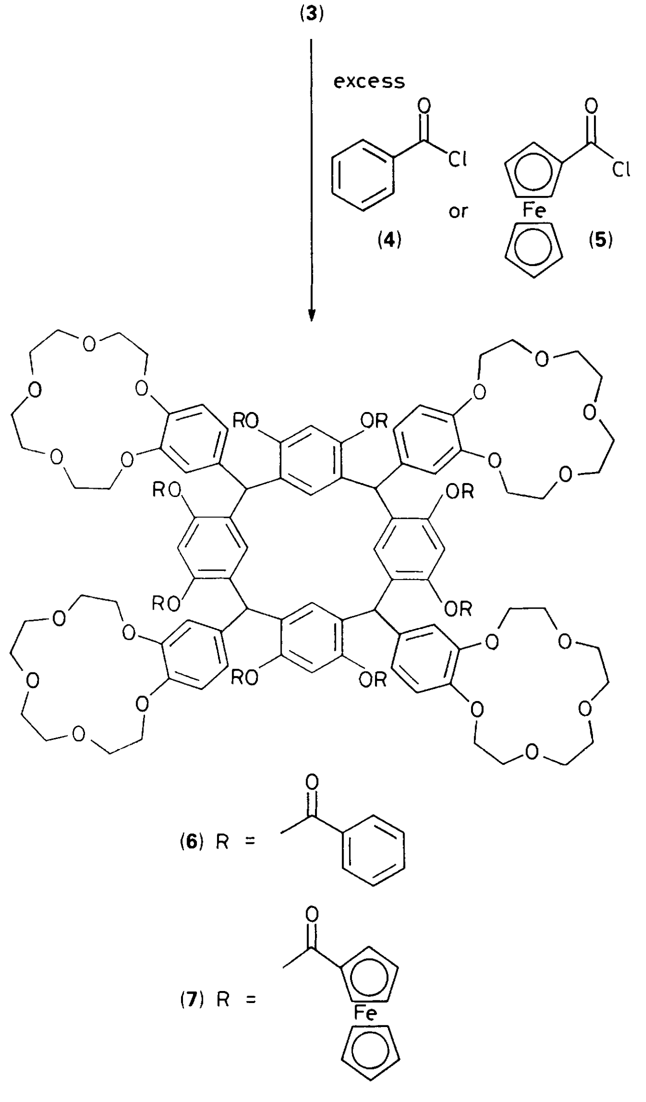
Table 1. ^1H NMR chemical shift differences (Δδ) of diquat guest (**9**) upon complexation with hosts (**6**)—(**8**) in 50% CD_3CN : 50% $CHCl_3$.

	Chemical shifts/δ				
	H-6, -6′	H-4, -4′	H-3, -3′	H-5, -5′	$(N^+CH_2)_2$
(**9**)	8.96	8.84	8.78	8.32	5.15
(**6**) · (**9**)	8.69	8.66	8.54	8.05	5.16
Δδ/p.p.m.	−0.27	−0.18	−0.24	−0.27	+0.01
(**7**) · (**9**)	8.71	8.71	8.71	8.15	5.19
Δδ/p.p.m.	−0.25	−0.13	−0.06	−0.17	+0.04
(**8**) · (**9**)	8.81	8.81	8.75	8.26	5.23
Δδ/p.p.m.	−0.15	−0.03	−0.03	−0.06	−0.08

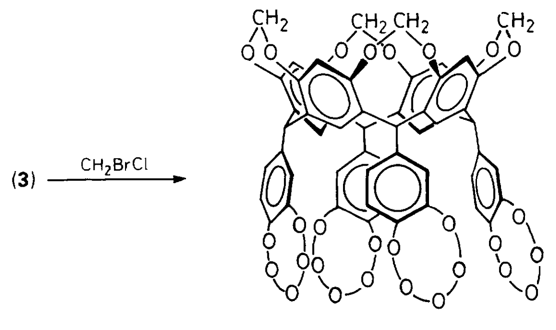


metric additions of (**9**) to NMR solutions of (**6**)—(**8**) gave no evidence of inclusion of (**9**) in the upper bowl-like cavity of each host.

With the paraquat guest (**10**) significant upfield shifts of the bipyridyl protons were again observed with (**6**) and (**7**) (Table 2). However, very modest Δδ values (≤0.02 p.p.m.) were obtained with the rigid cavitand host (**8**). The results of NOE difference spectroscopic experiments with (**10**) implied weak interactions of this guest with the respective benzo crown ether moieties of (**6**) and (**7**). Again no evidence for complexation between (**10**) and the model receptor (**12**) was observed, implying (**10**) is also being included in the lower box-like crown ether cavity.

Table 2. ^1H NMR chemical shift differences (Δδ) of paraquat guest (**10**) upon complexation with hosts (**6**)—(**8**) in 50% CD_3CN : 50% $CHCl_3$.

	Chemical shift/δ		
	H-2, -21′	H-3, -3′	N^+Me
(**10**)	8.86	8.40	4.43
(**6**) · (**10**)	8.78	8.24	4.39
Δδ/p.p.m.	−0.08	−0.16	−0.04
(**7**) · (**10**)	8.83	8.32	4.41
Δδ/p.p.m.	−0.03	−0.08	−0.02
(**8**)·(**10**)	8.87	8.38	4.43
Δδ/p.p.m.	−0.01	−0.02	0.00



(**8**)

Comparing the results shown in Tables 1 and 2, it is noteworthy that the more rigid preorganised cavitand crown ether host molecule (**8**) shows a greater degree of selectivity for the diquat dication (**9**) over the paraquat guest (**10**) than the more flexible hosts (**6**) and (**7**).†

Preliminary co-ordination studies of (**6**)—(**8**) with the spherical metal sodium guest cation reveal one Na^+ is bound in each of the respective benzo-15-crown-5 moieties leading to a host·$4Na^+$ stoicheiometry such as (**13**).

The reversible cyclic voltammogram of (**7**) in 95% acetonitrile–5% dichloromethane gave an oxidation wave at +0·77 V and a reduction wave at +0.67 V (ipa/ipc 1.0; *vs.* standard calomel electrode). Coulometric studies have been thwarted by detrimental electrode deposition, however the cyclic voltammetric results suggest the ferrocene moieties present in (**7**) become oxidised in one step. Addition of (**9**) or Na^+ to electrochemical solutions of (**7**) had little effect ($\Delta E \leq 15$ mV) on the position of the reversible multiple ferrocene oxidation wave or on the respective reduction waves of the diquat guest. This result implies that (**9**) or Na^+ complexed at the benzo crown ether co-ordinating sites are too far away to influence

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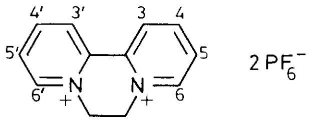
† C.P.K. (Corey–Pauling–Koltun) model studies support this view.



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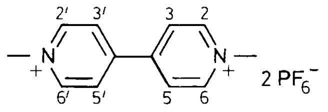

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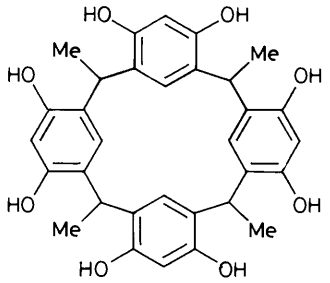

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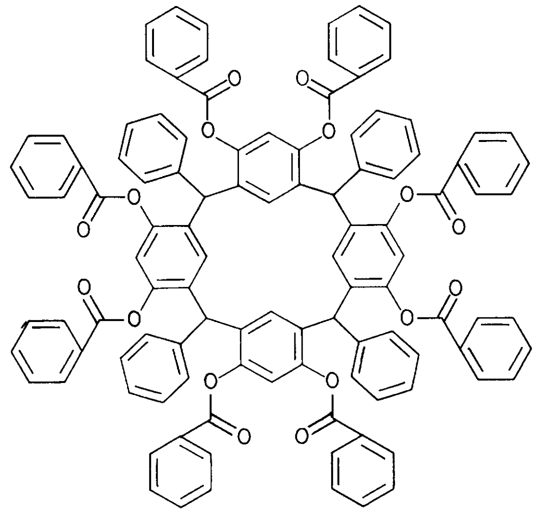

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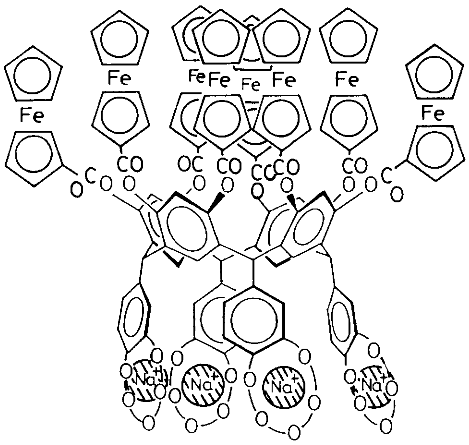

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the electron density at the metallocene metal atom either inductively or through space.

Solution and solid state inclusion complexation studies of related charged and neutral organic and inorganic guests are currently in progress.

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