Synthesis of calix[4]arene receptors incorporating (2,2′-bipyridin-6-yl)methyl and (9-methyl-1,10-phenanthrolin-2-yl)methyl chromophores and luminescence of their Eu^{3+} and Tb^{3+} complexes

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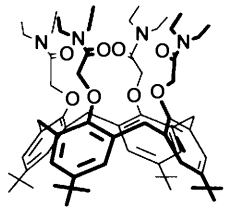
Several new calix[4]arene derivatives in the cone conformation 3–5 and 8–11, incorporating 2,2′-bipyridine or 1,10-phenanthroline chromophores have been synthesized in order to obtain luminescent complexes with Eu^{3+} and Tb^{3+}. Whereas phenanthroline containing ligands 10 and 11 gave no indication of complex formation with lanthanide ions, the ligand 3 incorporating four 2,2′-bipyridine chromophores and the ligands 8 and 9, bearing two amide and two 2,2′-bipyridine groups, were able to sensitize Eu^{3+} and Tb^{3+} luminescence. The Tb^{3+} complex of compound 9 showed intense metal luminescence thanks to the high values of the molar absorption coefficient (ε = 29 000 $dm^3\ mol^{-1}\ cm^{-1}$) and quantum yield (Φ = 0.12).

Cage-type ligands incorporating chromophoric groups have been widely studied in the last few years as suitable ligands for the complexation of lanthanide ions. In fact these complexes are particularly interesting in the case of the Eu^{3+} and Tb^{3+} ions, because luminescent species useful for labelling in time-resolved fluoroimmunoassays (TR-FIAs)[1] may be obtained. In these complexes, luminescence of the metal ion occurs upon light absorption in the ligand followed by ligand-to-metal energy transfer.[1,2] The metal luminescence intensity, the property determining the sensitivity of TR-FIAs, is proportional to the molar absorption coefficient at the excitation wavelength and to the metal luminescence quantum yield upon excitation at the same wavelength.[1]

One approach to the design of lanthanide complexes with cage-type ligands consisted of the encapsulation of the Eu^{3+} and Tb^{3+} ions by the *p-tert*-butylcalix[4]arene tetraacetamide ligand **1**.†[3] These complexes were kinetically inert in water, which is the solvent of interest for TR-FIAs, and the metal ion was efficiently shielded from interaction with water molecules which, as is known, causes non-radiative deactivation of the lanthanide-emitting state *via* vibronic coupling with the O–H groups. Anyway, the luminescence intensity was rather low because of the low molar absorption coefficients even for $[Tb\subset\mathbf{1}]^{3+}$ showing high metal luminescence quantum yield.‡

In order to obtain complexes characterized by more intense absorption, new calix[4]arene ligands incorporating (2,2′-bipyridin-6-yl)methyl and (9-methyl-1,10-phenanthrolin-2-yl)methyl chromophoric units have been designed and synthesized.[4]



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This article is a full account[5] of the synthesis of these new ligands and of the luminescence properties of their Eu^{3+} and Tb^{3+} complexes.

Results and discussion

Synthesis and structure of the ligands

The reaction of calix[4]arene **2a** with 6 equiv. 6-bromomethyl-2,2′-bipyridine[6] **12** in dry *N*,*N*-dimethylformamide (DMF) and in the presence of NaH as a base[7] gives compound **3** in good yield (Scheme 1). The ^1H and ^{13}C NMR spectra, respectively, showing the characteristic two doublets at 4.47 and 3.13 ppm (J = 13.6 Hz) for the bridging $ArCH_2Ar$ protons and a triplet at 31.5 ppm for the corresponding carbon, both indicate a cone structure for compound **3**.[8]

On the other hand the same reaction performed in CH_3CN in the presence of K_2CO_3 as a base produces mainly the isomer **4**, in a 1,3 alternate structure as revealed by the ^1H NMR spectrum (singlet at 3.78 ppm for $ArCH_2Ar$) and by the ^{13}C NMR spectrum (triplet at 37.3 ppm for the bridging methylene carbon of the calix). The two stereoisomers **3** and **4** do not interconvert one into the other even at $T \leqslant 110$ °C.

The reaction of calix[4]arene **2a** with 2.2 equiv. 6-bromomethyl-2,2′-bipyridine **12** in K_2CO_3–CH_3CN gives mainly the diametrically 1,3-disubstituted[9] compound **5**.

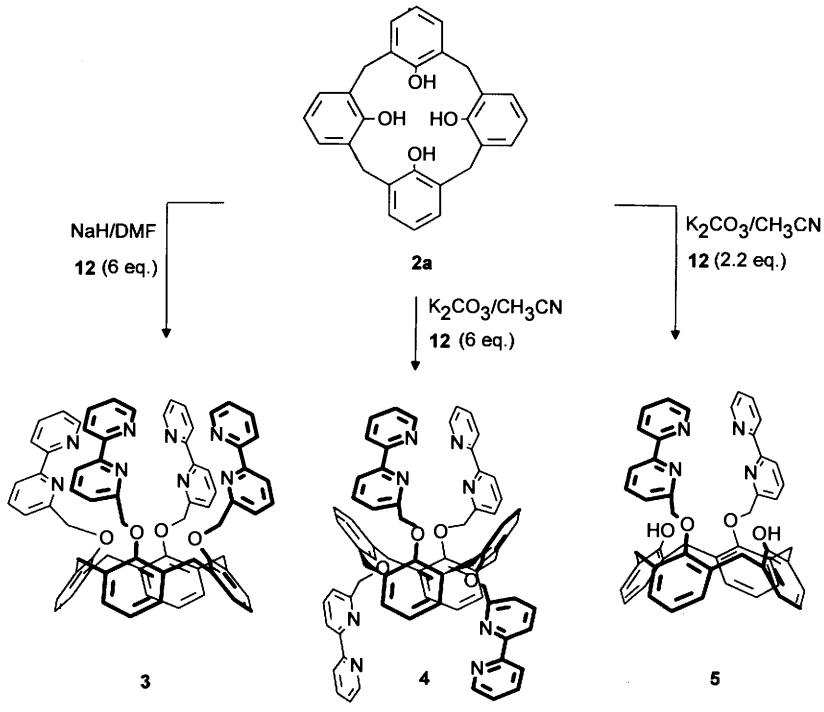
We have also synthesized ligands **8–11** having two amides and two 2,2′-bpy or 1,10-phen binding groups at the lower rim of the calix[4]arene fixed in the cone conformation (Scheme 2). The best synthetic route to **8–11** takes advantage of the high yield synthesis of 1,3-diacetamide derivatives **6** and **7** which are further alkylated with **12** or **13** in conditions producing exclusively the cone conformation. Compound **8** was also obtained by treating the bis(bipyridyl) derivative **5** with NaH and α-chloro-*N*,*N*-diethylacetamide in DMF, but in lower overall yields.

Complexation studies

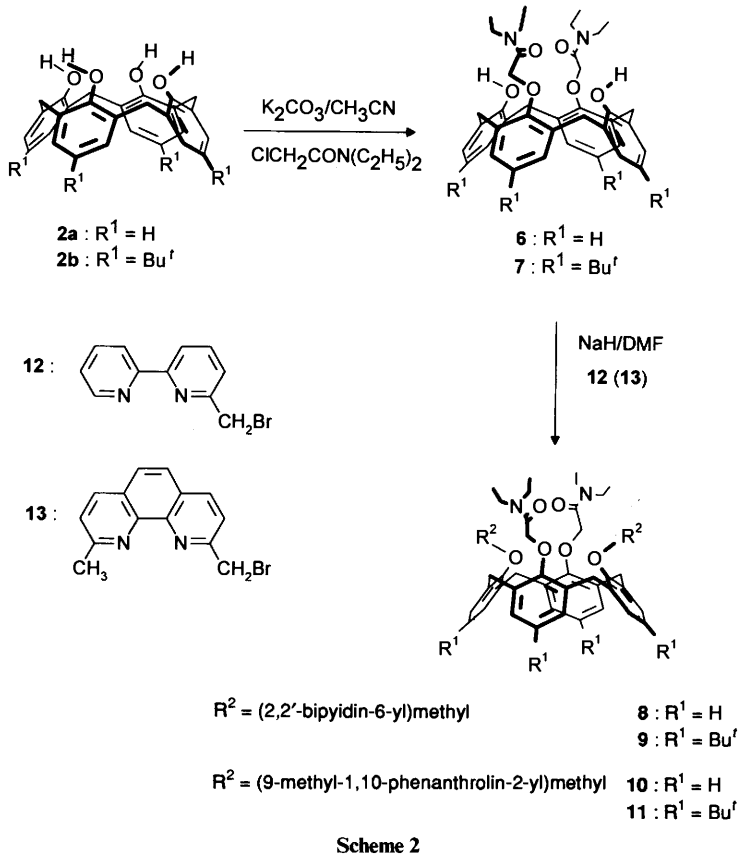
Since Eu^{3+} and Tb^{3+} have ionic radii (0.95 and 0.92 Å, respectively) similar to Na^+ (0.95 Å), the binding properties of

† IUPAC names are given in the Experimental for all the calixarenes that have been synthesised in this work.

‡ ⊂ is the symbol used to indicate the inclusion of the ion into the cage-type ligand (J. M. Lehn, *Struct. Bonding*, 1973, **16**, 1).



Scheme 1



Scheme 2

all the ligands synthesized were first evaluated towards alkali metal cations.

Extraction of sodium picrate (NaPic) from solid to a $CDCl_3$ solution of calixarenes was only observed with the ligands **8** and **9** having two amides and two bipyridines. Integration of the ^1H NMR spectrum, after reaching equilibrium, indicates the formation of a 1 : 1 complex for both ligands and NaPic. The two phase ($H_2O/CHCl_3$) extraction method by Lein and Cram [10] gave positive results with the ligands **8** and **9**, whereas **3** showed for all alkali metal cations association constants K_A in chloroform too low to be measured by this method ($K_A < 10^4$ dm^3 mol^{-1}). The results obtained for ligand **9** are summarized in Table 1 and compared with those previously obtained for the ligand **1**.[11] The results, all together, indicate that the substitution of two or more amides with softer binding groups like bipyridine (bpy) or phenanthroline strongly reduces the affinity of the ligands towards alkali metal ions, although the selectivity towards sodium observed for the ligand **1** and other calix[4]arene podands in the cone conformation [11] is retained also by the ligand **9**.

Solid samples of the Eu^{3+} and Tb^{3+} complexes of all the ligands could not be obtained. However, formation of such complexes in CH_3CN solution occurred for the ligands **3**, **8** and **9**. Titration experiments to register the changes in the absorption spectra and in the metal luminescence intensity upon ligand excitation were carried out.

On the basis of the titration curves a 1:1 stoichiometry and an association constant of the order of 10^5 dm^3 mol^{-1} were obtained for Tb^{3+} and Eu^{3+} complexes of the ligands **3**, **8** and **9**. Concerning the ligands **10** and **11**, little change in the absorption spectra and no metal luminescence upon ligand excitation were observed, so that no clear indication of complex formation was obtained and further studies were not performed. The photophysical behaviour of the complexes of the ligands **3**, **8** and **9** has been studied in solutions where *ca.* 90% of the ligand was complexed. The absorption spectra of the ligands **3**, **8** and **9** differ only in intensity (Table 2) indicating that the absorption in the range 220–400 nm is mostly due to the bpy units. Upon addition of the Eu^{3+} and Tb^{3+} perchlorate salts, significant red shifts were observed in the ligand absorption spectra, which, as previously reported,[1] is characteristic for complexation. The absorption maximum at λ = 310 nm is close to that registered for previously studied lanthanide complexes containing bpy units.[1]

Comparison between the absorption and the metal luminescence excitation spectra further suggests the complex formation. In particular, the absorption with a maximum at 310 nm, due to the bpy moiety, is present in the excitation spectrum. The peak at 250 nm observed in this spectrum, which is not seen in the absorption spectrum of the complex, is also due, most likely, to absorption in the bpy chromophore. Finally, the lack of ligand fluorescence in the presence of the lanthanide salts again suggests complex formation. Decrease in the ligand fluorescence quantum yield has previously been observed for Eu^{3+} and Tb^{3+} complexes containing bpy units.[2,12]

In Table 2, the metal luminescence lifetimes and quantum yields upon ligand excitation are reported. The lifetimes of the metal emitting states are rather high for both Eu^{3+} and Tb^{3+} complexes. Note that while the lifetimes are rather similar for the complexes of the ligands **3**, **8** and **9** with the same ion, the quantum yields are very different. Considering that the ligands are very similar to each other and that the same trend was observed for Eu^{3+} and Tb^{3+} complexes, the different Φ values may be due to different metal–ligand interactions. More specifically, the lower values for the complexes with four bpys are attributed to a worse metal–ligand interaction, since the four chromophores may undergo steric hindrance when approaching the metal ion. This hypothesis is also suggested by the CPK model of the complex.

In conclusion, the Eu^{3+} and Tb^{3+} complexes of the ligands **3**, **8** and **9** present a more intense luminescence than the analogous complexes of the ligand **1**, thanks to much higher molar absorption coefficients and fairly good luminescence quantum yields, comparable to other bpy containing cage-type ligands.[1,5] Anyway, the lack of thermodynamic stability is, of course, a significant disadvantage for the application in TR-FIAs. This work points out that further elaboration of mixed functionalized calix[4]arenes may lead to improvement in both stability and luminescence intensity of the complexes.

Table 1 Association constants (K_A) and binding free energies ($-\Delta G°$) of complexes of the ligands **1** and **9** with alkali picrates in $CHCl_3$ saturated with H_2O at 295 K

	Ligand **1**		Ligand **9**	
	$K_A/10^8$ dm^3 mol^{-1}	$-\Delta G°$/kJ mol^{-1}	$K_A/10^8$ dm^3 mol^{-1}	$-\Delta G°$/kJ mol^{-1}
Li^+	15.0	51.5	6.0	48.6
Na^+	8300	67.4	16.7	51.9
K^+	23.0	52.6	0.90	44.8
Rb^+	0.85	44.8	0.64	43.1
Cs^+	0.001	28.5	0.51	42.7

Experimental

NMR spectra were recorded on Bruker spectrometers AC 100 (^1H NMR 100 MHz, ^{13}C NMR 25 MHz) and AMX 400 (^1H NMR 400 MHz). Chemical shifts are reported as values in ppm using TMS (0.0) as an internal standard. *J* Values are given in Hz. Mass spectra (CI, CH_4) were recorded with the FINNIGAN spectrometer MAT SSQ 710, while IR spectra were recorded by the Perkin-Elmer spectrophotometer mod. 298.

The UV–VIS absorption spectra were measured with a Perkin-Elmer Lambda 6 spectrophotometer. The luminescence spectra were obtained with a Perkin-Elmer LS 50 and a 650-40 spectrofluorimeter. The luminescence decays were acquired by a Perkin-Elmer LS 50 spectrofluorimeter and analysed with a least-squares fitting program. The luminescence quantum yields were obtained by the method described by Haas and Stein[13] using as standards $Ru(bpy)_3^{2+}$ (Φ = 0.028 in aerated water)[14] for the Eu^{3+} complexes and quinine sulfate (Φ = 0.546 in 0.5 mol dm^{-3} H_2SO_4)[15] for the Tb^{3+} complexes. The solvent used for the photophysical measurement was CH_3CN (Uvasol, Merck).

p-tert-Butylcalix[4]arene **2b**,[16] calix[4]arene **2a**[17] and 6-bromomethyl-2,2′-bipyridine **12**[6] were prepared following published procedures. All reactions with calixarenes were performed under nitrogen atmosphere. Sodium hydride was used in the form of a 60% suspension in oil.

Separations by column chromatography were performed on silica gel (particle size, ø 32–63 μm).

2-Bromomethyl-9-methyl-1,10-phenanthroline 13[18]

A solution of 2,9-dimethylphenanthroline (2.26 g, 10 mmol), *N*-bromosuccinimide (2.23 g, 12.5 mmol) and azoisobutyronitrile (8.5 mg) in benzene (170 cm^3) was irradiated by a UV lamp (125 W) at room temperature for 6 h. After filtration the solvent was removed under reduced pressure and the monobromoderivative **13** was obtained by chromatography on silica gel (CH_2Cl_2:

Table 2 Absorption and metal luminescence data[a]

Compound	Absorption λ_{max}/nm	Absorption $\varepsilon_{max}/10^3$ dm^3 mol^{-1} cm^{-1}	Lifetime[b] τ/ms	Luminescence quantum yield[c] $\Phi \times 10^2$
$[Eu\subset\mathbf{3}]^{3+}$	307	50.0	0.65	< 1
$[Tb\subset\mathbf{3}]^{3+}$	305	46.7	1.4	2
$[Eu\subset\mathbf{8}]^{3+}$	306	34.0	0.50	1
$[Tb\subset\mathbf{8}]^{3+}$	305	30.5	1.65	5
$[Eu\subset\mathbf{9}]^{3+}$	305	28.0	0.65	4
$[Tb\subset\mathbf{9}]^{3+}$	306	29.0	1.9	12

[a] In aerated acetonitrile solution at 300 K. [b] Measured in correspondence with the maximum emission bands: λ = 610–615 nm corresponding to the $^5D_0 \rightarrow {}^7F_2$ transition for the Eu^{3+} complexes and λ = 540–545 nm corresponding to the $^5D_4 \rightarrow {}^7F_5$ transition for the Tb^{3+} complexes. [c] Excitation in ligand-centred bands.

MeOH 100:1) as pale yellow crystals (0.59 g, 20%) (Found: C, 58.6; H, 3.6; N, 9.9. $C_{14}H_{11}BrN_2$ requires: C, 58.40; H, 3.85; N, 9.73%); δ_H(100 MHz, $CDCl_3$) 8.28 (1 H, d, *J* 8.2, 4-H), 8.19 (1 H, d, *J* 8.2, 7-H), 7.90 (1 H, d, *J* 8.2, 3-H), 7.79 (1 H, s, 5-H), 7.78 (1 H, s, 6-H), 7.55 (1 H, d, *J* 8.2, 8-H), 4.97 (2 H, s, CH_2Br) and 2.98 (3 H, s, CH_3); *m/z* 207 (M^+ − HBr, 100%).

$1^2,3^2,5^2,7^2$-Tetrakis[(2,2′-bipyrid-6-yl)methoxy]-1,3,5,7(1,3)-tetrabenzenacyclooctaphane (cone) 3

A solution of calix[4]arene **2a** (0.2 g, 0.48 mmol) and NaH (0.08 g, 3.8 mmol) in dry DMF (15 cm^3) was stirred for *ca.* 1 h at 50 °C. After cooling to room temperature **12** (0.72 g, 2.89 mmol) was added and the reaction was continued for 24 h. After addition of water (50 cm^3) the product was filtered and purified by column chromatography on silica gel with ethyl acetate:triethylamine 4:1 as eluent. Recrystallization from methanol yielded **3** as a white solid (0.21 g, 40%), mp 186 °C (Found: C, 78.6; H, 5.3; N, 10.4. $C_{72}H_{56}N_8O_4$ requires: C, 78.81; H, 5.14; N, 10.21%); ν_{max}(KBr)/cm^{-1} 1570, 1560, 1460 and 1420 (C=C, C=N); δ_H(400 MHz, $CDCl_3$) 8.59 (4 H, ddd, *J* 4.8, 1.7 and 0.7, 6′-H), 8.17 (4 H, dd, *J* 7.4 and 1.2, 3′-H), 8.13 (4 H, d, *J* 7.8, 3-H), 7.54 (4 H, ddd, *J* 7.4, 7.4 and 1.7, 4′-H), 7.50 (4 H, dd, *J* 7.8 and 0.8, 5-H), 7.46 (4 H, t, *J* 7.8, 4-H), 7.19 (4 H, ddd, *J* 7.4, 4.8 and 1.2, 5′-H), 6.62 (12 H, s, Ar-H), 5.25 (8 H, s, CH_2-bpy), 4.47 (4 H, d, *J* 13.6, H_{ax}) and 3.13 (4 H, d, *J* 13.6, H_{eq}); δ_C($CDCl_3$) 157.4 (s, bpy-2), 156.1 (s, bpy-6), 155.2 (s, bpy-2′, Ar-*ipso*), 148.9 (d, bpy-6′), 137.2 (d, bpy-4), 136.7 (d, bpy-4′), 134.9 (s, *o*-Ar), 129.5 (d, *m*-Ar), 123.6 (d, bpy-5′), 123.1 (d, bpy-5), 122.4 (d, bpy-3′), 121.3 (d, bpy-3), 119.6 (d, *p*-Ar), 77.4 (t, bpy-CH_2) and 31.5 (t, Ar-CH_2-Ar); *m/z* 1097 (M^+, 100%).

$1^2,3^2,5^2,7^2$-Tetrakis[(2,2′-bipyridin-6-yl)methoxy]-1,3,5,7(1,3)-tetrabenzenacyclooctaphane (1,3-alt) 4

A solution of calix[4]arene **2a** (0.2 g, 0.47 mmol), K_2CO_3 (0.2 g, 1.4 mmol) and the bromoderivative **12** (0.7 g, 2.8 mmol) in acetonitrile (15 cm^3) was stirred under reflux for 48 h. The solvent was evaporated and the residue was dissolved in CH_2Cl_2 (30 cm^3). The organic layer was washed twice with water (2 × 50 cm^3) and dried ($MgSO_4$). After removal of the solvent, **4** was purified by chromatography on silica gel (hexane:ethyl acetate 1:1). The yield was 0.21 g (40%), mp > 300 °C (Found: C, 78.6; H, 5.0; N, 10.5. $C_{72}H_{56}N_8O_4$ requires: C, 78.81, H, 5.14; N, 10.21%); ν_{max}(KBr)/cm^{-1} 1585, 1570, 1470, 1455 and 1430 (C=C, C=N); δ_H(400 MHz, $CDCl_3$) 8.75 (4 H, d, *J* 4.4, 6′-H), 8.43 and 8.42 (4 H, d, *J* 7.7, 3-H and 3′-H), 7.87 and 7.84 (4 H, t, *J* 7.7, 4-H and 4′-H), 7.36 (4 H, dd, *J* 7.7, 4.4, 5′-H), 6.98 (4 H, d, *J* 7.7, 5-H), 6.78 (8 H, d, *J* 7.5, *m*-Ar-H), 6.44 (4 H, t, *J* 7.5, *p*-Ar-H), 5.05 (8 H, s, CH_2-bpy) and 3.78 (8 H, s, Ar-CH_2-Ar); δ_C($CDCl_3$) 157.4 (s, bpy-2), 156.2 (s, bpy-6), 155.5 (s, bpy-2′), 154.9 (s, Ar-*ipso*), 149.3 (d, bpy-6′), 137.0 (d, bpy-4), 136.7 (d, bpy-4′), 134.1 (s, *o*-Ar), 130.9 (d, *m*-Ar), 123.7 (d, bpy-5′), 122.7 (d, bpy-5), 122.3 (d, bpy-3′), 121.1 (d, bpy-3), 119.5 (d, *p*-Ar), 72.6 (t, bpy-CH_2) and 37.3 (t, Ar-CH_2-Ar); *m/z* 1097 (M^+, 80%), 929 (M^+ − CH_2bpy, 100%).

$3^2,7^2$-Bis[(2,2′-bipyridin-6-yl)methoxy]-$1^2,5^2$-dihydroxy-1,3,5,7-(1,3)tetrabenzenacyclooctaphane 5

Compound **5** was prepared as described above using calix[4]arene **2a** (0.2 g, 0.47 mmol) in acetonitrile (15 cm^3), K_2CO_3 (0.08 g, 0.56 mmol) and the bromoderivative **12** (0.24 g, 0.95 mmol). The yield was 0.14 g (40%), mp 238 °C (Found: C, 78.7; H, 5.5; N, 7.5. $C_{50}H_{40}N_4O_4$ requires: C, 78.93; H, 5.30; N, 7.36%); ν_{max}(KBr)/cm^{-1} 3360 (OH), 1585, 1570, 1465 and 1450 (C=C, C=N); δ_H(100 MHz, $CDCl_3$) 8.64 (2 H, ddd, *J* 4.8, 1.7 and 0.8, 6′-H), 8.41 (2 H, dd, *J* 6.9, 1.2, 3′-H), 8.33 (1 H, d, *J* 7.6, 3-H), 8.10 (2 H, d, *J* 7.6, 5-H), 8.01 (2 H, s, OH), 7.64 (2 H, ddd, *J* 7.8, 6.9 and 1.7, 4′-H), 7.61 (2 H, t, *J* 7.6, 4-H), 7.25 (2 H, ddd, *J* 7.8, 4.8 and 1.2, 5′-H), 7.12 (4 H, d, *J* 7.2, *m*-Ar-H), 6.88 (4 H, d, *J* 7.2, *m*-Ar-H), 6.73 (2 H, t, *J* 7.2, *p*-Ar-H), 6.65 (2 H, t, *J* 7.2, *p*-Ar-H), 5.26 (4 H, s, CH_2-bpy), 4.47 (4 H, d, *J* 13, H_{ax}) and 3.45 (4 H, d, *J* 13, H_{eq}); δ_C($CDCl_3$) 156.4 (s, bpy-2), 155.9 (s, bpy-2′), 155.7 (s, bpy-6), 153.4 and 151.9 (s, Ar-*ipso*), 149.2 (d, bpy-6′), 138.2 (d, bpy-4), 136.9 (d, bpy-4′), 133.0 and 127.9 (s, *o*-Ar), 129.2 and 128.7 (d, *m*-Ar), 125.7 and 119.2 (d, *p*-Ar), 123.8 (d, bpy-5 and -5′), 121.3 (d, bpy-3′), 120.1 (d, bpy-3), 78.8 (t, bpy-CH_2) and 31.4 (t, Ar-CH_2-Ar); *m/z* 761 (M^+, 100%).

$3^2,7^2$-Bis(*N*,*N*-diethylaminocarbonylmethoxy)-$1^2,5^2$-dihydroxy-1,3,5,7(1,3)tetrabenzenacyclooctaphane (cone) 6

A solution of calix[4]arene **2a** (1 g, 2.3 mmol), K_2CO_3 (0.39 g, 2.8 mmol) and α-chloro-*N*,*N*-diethylacetamide (0.68 cm^3, 4.9 mmol) in acetonitrile (100 cm^3) was refluxed for 3 days. The solvent was removed, the residue was dissolved in CH_2Cl_2 (50 cm^3) and washed once with 10% HCl (50 cm^3) and twice with water (2 × 50 cm^3). After drying ($MgSO_4$) and removal of the solvent, bisamide **6** was separated by column chromatography on silica gel using hexane:ethyl acetate 1:2 as eluent (0.30 g, 20%), mp 210 °C (Found: C, 73.5; H, 7.0; N, 4.5. $C_{40}H_{46}N_2O_6$ requires C, 73.82; H, 7.12; N, 4.30%); δ_H(100 MHz, $CDCl_3$) 8.15 (2 H, s, OH), 6.96 (4 H, d, *J* 7.1, *m*-Ar-H), 6.91 (4 H, d, *J* 6.0, *m*-ArH), 6.79 (2 H, t, *J* 6.0, *p*-Ar-H), 6.64 (2 H, t, *J* 7.1, *p*-Ar-H), 4.77 (4 H, s, CH_2CO), 4.5 (4 H, d, *J* 14.1, H_{ax}), 3.47 (8 H, q, *J* 7.4, CH_2CH_3), 3.34 (4 H, d, *J* 14.1, H_{eq}) and 1.24 (12 H, t, *J* 7.4, CH_2CH_3); δ_C($CDCl_3$) 167.0 (s, C=O), 153.5 and 152.9 (s, *ipso*-Ar), 133.6 and 128.0 (s, *o*-Ar), 128.9 and 128.2 (d, *p*-Ar), 125.2 and 118.7 (d, *m*-Ar), 73.7 (t, CH_2CO), 41.0 and 40.0 (t, CH_2CH_3), 31.6 (t, $ArCH_2Ar$), 14.0 and 12.8 (q, CH_2CH_3); *m/z* 651 (M^+, 100%).

$1^5,3^5,5^5,7^5$-Tetra-*tert*-butyl-$3^2,7^2$-bis(*N*,*N*-diethylaminocarbonylmethoxy)-$1^2,5^2$-dihydroxy-1,3,5,7(1,3)tetrabenzenacyclooctaphane (cone) 7

Bisamide **7** was prepared as described above for compound **6** using *tert*-butylcalix[4]arene **2b** (2.25 g, 3.47 mmol), K_2CO_3 (0.5 g, 3.79 mmol) and α-chloro-*N*,*N*-diethylacetamide (1 cm^3, 7.27 mmol) in acetonitrile (100 cm^3). Recrystallization from hexane yielded **7** as a white solid (2.55 g, 84%), mp 239 °C (Found: C, 76.6; H, 8.7; N, 3.5. $C_{56}H_{78}N_2O_6$ requires C, 76.85; H, 8.98; N, 3.20%); ν_{max}(KBr)/cm^{-1} 3340 (OH), 1640 (C=O); δ_H(100 MHz, $CDCl_3$) 7.85 (2 H, s, OH), 6.81 (8 H, s, *m*-Ar-H), 4.81 (4 H, s, CH_2CO), 4.45 (4 H, d, *J* 12.8, H_{ax}), 3.41 (8 H, q, *J* 7.3, CH_2CH_3), 3.27 (4 H, d, *J* 12.8, H_{eq}), 1.24 (12 H, t, *J* 7.3, CH_2CH_3), 1.15 and 1.04 (18 H, s, Bu^t-H); δ_C($CDCl_3$) 167.7 (s, C=O), 152.0 and 150.2 (s, *ipso*-Ar), 147.2 and 141.5 (s, *p*-Ar), 133.4 and 127.9 (s, *o*-Ar), 125.6 and 124.9 (d, *m*-Ar), 73.5 (t, CH_2CO), 41.1 and 40.1 (t, CH_2CH_3), 33.9–33.7 [s, $C(CH_3)_3$], 31.9 (t, $ArCH_2Ar$), 31.6–31.2 [q, $C(CH_3)_3$] and 14.3–12.9 (q, CH_2CH_3); *m/z* 876 (M^+ + 1, 100%).

$3^2,7^2$-Bis[(2,2′-bipyridin-6-yl)methoxy]-$1^2,5^2$-bis(*N*,*N*-diethylaminocarbonylmethoxy)-1,3,5,7(1,3)-tetrabenzenacyclooctaphane (cone) 8

Route A. A sample of **5** (0.3 g, 0.34 mmol) and NaH (0.12 g, 2.9 mmol) were dissolved in dry DMF (15 cm^3) and stirred for 1 h at room temperature. Then α-chloro-*N*,*N*-diethylacetamide (0.18 cm^3, 1.3 mmol) was added. After 24 h stirring the reaction mixture was quenched with water (2 cm^3) and the solvent was removed. The residue was purified by chromatography on silica gel with ethyl acetate:triethylamine 1:1 to yield **8** as a white solid (0.17 g, 44%).

Route B. To a solution of **6** (0.1 g, 0.15 mmol) and NaH (0.045 g, 1.12 mmol) in dry DMF (15 cm^3) was added **12** (0.15 g, 0.6 mmol). The reaction was stirred at room temperature for one night and then stopped by adding water. The precipitate was filtered and purified on silica gel using ethyl acetate:triethylamine 20:1 as eluent (0.17 g, 50%), mp 120 °C (Found: C, 88.0; H, 6.1; N, 8.75. $C_{62}H_{62}N_6O_6$ requires C, 75.43; H, 6.33; N, 8.51%); ν_{max}(KBr)/cm^{-1} 1660 (C=O), 1580, 1560, 1460 and 1430 (C=C, C=N); δ_H(400 MHz, $CDCl_3$) 8.63 (2 H, ddd, *J* 4.8, 1.6 and 0.8, 6′-H), 8.29 (2 H, d, *J* 7.8, 3′-H), 8.22 (2 H, d, *J* 7.8, 3-H), 8.04 (2 H, d, *J* 7.8, 5-H), 7.79 (2 H, t, *J* 7.8, 4-H), 7.70 (2 H, ddd,

J 7.8, 7.8 and 1.6, 4′-H), 7.22 (2 H, ddd, J 7.8, 4.8 and 1.1, 5′-H), 6.68 (6 H, bs, Ar-H), 6.53 (6 H, s, Ar-H), 5.43 (4 H, s, CH_2-bpy), 4.65 (4 H, d, J 14, H_{ax}), 4.49 (4 H, s, CH_2CO), 3.30 (4 H, q, J 6.8, CH_2CH_3), 3.18 (4 H, d, J 14, H_{eq}), 2.95 (4 H, q, CH_2, J 6.8, CH_2CH_3), 1.04 (6 H, t, J 6.8, CH_2CH_3) and 0.84 (6 H, t, J 6.8, CH_2CH_3); δ_C($CDCl_3$) 167.7 (s, C=O), 157.9 (s, bpy-2), 156.3 (s, bpy-2′ and -6), 156.0 and 155.3 (s, *ipso*-Ar), 148.9 (d, bpy-6′), 137.2 (d, bpy-4), 136.6 (d, bpy-4′), 135.6 (s, *o*-Ar), 134.4 (s, *o*-Ar), 128.4 (d, *m*-Ar), 124.3 (d, *p*-Ar), 123.6 (d, bpy-5 and -5′), 122.4 (d, bpy-3′), 121.4 (d, bpy-3), 119.5 (d, *p*-Ar), 77.5 (t, bpy-CH_2), 71.4 (t, CH_2CO), 40.6 and 39.8 (t, CH_2CH_3), 31.6 (t, Ar-CH_2-Ar), 14.1 and 13.1 (q, CH_2CH_3); m/z 987 (M^+, 100%).

$1^5,3^5,5^5,7^5$-Tetra-*tert*-butyl-$3^2,7^2$-bis[(2,2′-pyridin-6-yl)methoxy]-$1^2,5^2$-bis(*N*,*N*-diethylaminocarbonylmethoxy)-1,3,5,7(1,3)-tetrabenzenacyclooctaphane (cone) 9

Calixarene **9** was prepared as described above for **8** (route B) using **7** (0.3 g, 0.34 mmol), the bromoderivative **12** (0.25 g, 1 mmol) and NaH (0.12 g, 2.9 mmol) in dry DMF (15 cm^3). After 24 h stirring the reaction was quenched with water (2 cm^3) and the solvent was removed under reduced pressure. The residue was purified by column chromatography on silica gel with ethyl acetate : triethylamine 1 : 1 as eluent and crystallized from hexane to yield 0.20 g (50%) of **9**, mp 185 °C (Found: C, 77.6; H, 7.6; N, 6.8. $C_{78}H_{94}N_6O_6$ requires C, 77.32; H, 7.82; N, 6.95%); ν_{max}(KBr)/cm^{-1} 1660 (C=O), 1580, 1560, 1470 and 1430 (C=C, C=N); δ_H(400 MHz, $CDCl_3$) 8.62 (2 H, ddd, J 4.8, 1.8 and 0.8, 6′-H), 8.27 (2 H, ddd, J 7.8, 1.2 and 0.8, 3′-H), 8.15 (2 H, dt, J 7.9 and 0.7, 3-H), 8.04 (2 H, dd, J 7.9 and 0.7, 5-H), 7.81 (2 H, t, J 7.9, 4-H), 7.68 (2 H, ddd, J 7.7, 7.8 and 1.8, 4′-H), 7.23 (2 H, ddd, J 7.7, 4.8 and 1.2, 5′-H), 6.94 (4 H, s, *m*-Ar-H), 6.60 (4 H, s, *m*-Ar-H), 5.54 (4 H, s, CH_2-bpy), 4.50 (4 H, d, J 12.7, H_{ax}), 4.33 (4 H, s, CH_2CO), 3.28 and 2.95 (4 H, q, CH_2CH_3), 3.09 (4 H, d, J 12.7, H_{eq}), 1.21 and 0.93 (36 H, s, CH_3-Bu^t), 1.02 and 0.85 (12 H, t, CH_2CH_3); δ_C($CDCl_3$) 167.6 (s, C=O), 158.8 (s, bpy-2), 156.5 (s, bpy-6), 154.8 (s, bpy-2′), 153.6 and 152.9 (s, *ipso*-Ar), 148.8 (d, bpy-6′), 144.6 (s, p-Ar), 137.1 (d, bpy-4), 136.7 (d, bpy-4′), 134.7 and 132.6 (s, *o*-Ar), 125.3 and 125.0 (d, *m*-Ar), 124.5 (d, bpy-5′), 123.4 (d, bpy-5), 121.4 (d, bpy-3′), 119.3 (d, bpy-3), 77.4 (t, CH_2-bpy), 71.9 (t, CH_2CO), 40.6 and 39.7 (t, CH_2CH_3), 33.9 and 33.7 [s, $C(CH_3)_3$], 31.9 (t, Ar-CH_2-Ar), 31.6 and 31.2 [q, $C(CH_3)_3$], 14.2 and 13.0 (q, CH_2CH_3); m/z 1212 (M^+, 100%).

$1^2,5^2$-Bis(*N*,*N*-diethylaminocarbonylmethoxy)-$3^2,7^2$-bis[(9-methyl-1,10-phenanthrolin-2yl)methoxy]-1,3,5,7(1,3)tetrabenzenacyclooctaphane (cone) 10

Compound **10** was synthesized as described above for **8** (route B) using the bisamide **6** (136 mg, 0.2 mmol), the bromoderivative **13** (180 mg, 0.6 mmol) and NaH (70 mg, 1.75 mmol) in dry DMF (20 cm^3). The product was separated by chromatography on silica gel with ethyl acetate : triethylamine 10 : 1 to yield 70 mg (33%), mp 177 °C (decomp.) (Found: C, 76.6; H, 6.3; N, 8.1. $C_{68}H_{66}N_6O_6$ requires C, 76.81; H, 6.26; N, 7.90%); δ_H(400 MHz, $CDCl_3$) 8.87 (2 H, d, J 8.2, 4-H), 8.24 (2 H, d, J 8.2, 3-H), 8.13 (2 H, d, J 8.1, 7-H), 7.71 (2 H, d, J 8.7, 5-H), 7.67 (2 H, d, J 8.7, 6-H), 7.50 (2 H, d, J 8.1, 8-H), 6.98 (4 H, d, J 7.5, *m*-Ar-H), 6.84 (2 H, t, J 7.5, *p*-Ar-H), 6.45 (2 H, t, J 7.6, *p*-Ar-H), 6.27 (4 H, d, J 7.6, *m*-Ar-H), 5.45 (4 H, s, CH_2-phen), 5.03 (4 H, d, J 12, H_{ax}), 4.93 (4 H, s, CH_2CO), 3.35 (4 H, q, J 7, CH_2CH_3), 3.34 (4 H, d, J 12, H_{eq}), 2.93 (6 H, s, CH_3-phen), 2.91 (4 H, q, J 7, CH_2CH_3), 1.07 (6 H, t, J 7, CH_2CH_3) and 0.63 (6 H, t, J 7, CH_2CH_3); m/z 1063 (M^+, 100%).

$1^5,3^5,5^5,7^5$-Tetra-*tert*-butyl-$1^2,5^2$-bis(*N*,*N*-diethylaminocarbonylmethoxy)-$3^2,7^2$-bis[(9-methyl-1,10-phenanthrolin-2-yl)methoxy]-1,3,5,7(1,3)tetrabenzenacyclooctaphane (cone) 11

Calixarene **11** was prepared as described above for compound **8** (route B) using the bisamide **7** (200 mg, 0.23 mmol), the bromoderivative **13** (196 mg, 0.68 mmol) and NaH (60 mg, 1.5 mmol) in dry DMF (15 cm^3). The product was isolated by chromatography on silica gel using ethyl acetate : triethylamine 10 : 1 as eluent (90 mg, 30%), mp 239 °C (decomp.) (Found: C, 78.5; H, 7.4; N, 6.7. $C_{84}H_{98}N_6O_6$ requires C, 78.35; H, 7.67; N, 6.53%); δ_H(100 MHz, $CDCl_3$) 8.82 (2 H, d, J 8.3, 4-H), 8.03 (2 H, d, J 8.3, 3-H), 7.96 (2 H, d, J 8.4, 7-H), 7.49 (2 H, d, J 8.7, 5-H), 7.43 (2 H, d, J 8.7, 6-H), 7.28 (2 H, d, J 8.4, 8-H), 6.94 (2 H, s, Ar-H), 6.65 (2 H, s, Ar-H), 5.79 (4 H, s, CH_2-phen), 4.75 (4 H, d, J 13.3, H_{ax}), 4.53 (4 H, s, CH_2CO), 3.4–3.1 (8 H, m, CH_2CH_3 and H_{eq}), 2.87 (6 H, s, CH_3-phen), 2.77 (4 H, q, J 7.3, CH_2CH_3), 1.19 (18 H, s, CH_3-Bu^t), 1.13 and 0.99 (6 H, t, J 7.3, CH_2CH_3), 1.19 and 0.92 (18 H, s, CH_3-Bu^t); δ_C($CDCl_3$) 167.9 (s, C=O), 160.5 (s, phen-2), 159.1 (s, phen-9), 154.5 and 152.6 (s, *ipso*-Ar), 144.9 and 144.8 (s, *p*-Ar and phen-10a, b), 136.6 and 136.2 (d, phen-4 and -7), 134.1 and 132.9 (s, *o*-Ar), 127.9 (s, phen-4a, b), 126.7 (d, phen-5 and -6), 125.7 and 125.3 (d, *m*-Ar), 123.3 (d, phen-3 and -8), 79.3 (t, CH_2-phen), 71.9 (t, CH_2CO) 40.9 and 39.9 (t, CH_2CH_3), 34.0 and 33.8 [s, $C(CH_3)_3$], 31.9 (t, Ar-CH_2-Ar), 31.6 and 31.3 [q, $C(CH_3)_3$], 25.7 (q, CH_3-phen), 14.1 and 13.0 (q, CH_2CH_3); m/z 1288 (M^+, 100%).

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References

1 N. Sabbatini, M. Guardigli and J.-M. Lehn, *Coord. Chem. Rev.*, 1993, **123**, 201 and references therein.
2 B. Alpha, R. Ballardini, V. Balzani, J.-M. Lehn, S. Perathoner and N. Sabbatini, *Photochem. Photobiol.*, 1990, **52**, 299.
3 N. Sabbatini, M. Guardigli, A. Mecati, V. Balzani, R. Ungaro, E. Ghidini, A. Casnati and A. Pochini, *J. Chem. Soc., Chem. Commun.*, 1990, 878.
4 For other calix[4]arenes bearing 2,2′-bpy groups see: P. D. Beer, J. P. Martin and M. G. B. Drew, *Tetrahedron*, 1992, **45**, 9917; U. Gilles and R. Ziessel, *Tetrahedron Lett.*, 1994, **35**, 6299; J.-B. Regnouf de Vains and R. Lamartine, *Helv. Chim. Acta*, 1994, **77**, 1817; R. Grigg, J. M. Holmes, S. K. Jones and N. Amilaprasadh, *J. Chem. Soc., Chem. Commun.*, 1994, 185; P. D. Beer, Z. Chen, A. J. Goulden, A. Grieve, D. Hesek, F. Szemes and T. Wear, *J. Chem. Soc., Chem. Commun.*, 1994, 1269.
5 For communication of preliminary results see: N. Sabbatini, M. Guardigli, I. Manet, R. Ziessel, G. Ulrich, R. Ungaro, A. Casnati and C. Fischer, *New J. Chem*, 1995, **19**, 137.
6 G. R. Newcome, V. K. Gupta and F. R. Fronczek, *Inorg. Chem.*, 1983, **22**, 171.
7 L. C. Groenen, A. Casnati, B. M. M. Ruël, P. Timmerman, W. Verboom, S. Harkema, A. Pochini, R. Ungaro and D. N. Reinhoudt, *Tetrahedron Lett.*, 1991, **32**, 2675.
8 C. Jaime, J. de Mendoza, P. Prados, P. M. Nieto and C. Sánchez, *J. Org. Chem.*, 1991, **56**, 3372; C. D. Gutsche and L. J. Bauer, *J. Am. Chem. Soc.*, 1985, **107**, 6052.
9 J.-D. van Loon, A. Arduini, L. Coppi, W. Verboom, A. Pochini, R. Ungaro, S. Harkema and D. N. Reinhoudt, *J. Org. Chem.*, 1990, **55**, 5639; J.-D. van Loon, W. Verboom and D. N. Reinhoudt, *Org. Prep. Proced. Int.*, 1992, **24**, 437.
10 G. M. Lein and D. J. Cram, *J. Am. Chem. Soc.*, 1985, **107**, 448.
11 R. Ungaro and A. Pochini, in *Calixarenes: a Versatile Class of Macrocyclic Compounds*, eds. J. Vicens and V. Böhmer, Kluwer, Dordrecht, 1990, p. 127.
12 N. Sabbatini, M. Guardigli, F. Bolletta, I. Manet and R. Ziessel, *Angew. Chem., Int. Ed. Engl.* 1994, **33**, 1501.
13 Y. Haas and G. Stein, *J. Phys. Chem.*, 1971, **75**, 3668.
14 K. Nakamaru, *Bull. Chem. Soc. Jpn.*, 1982, **55**, 2697.
15 S. R. Meech and D. Phillips, *J. Photochem.*, 1983, **23**, 193.
16 C. D. Gutsche, *Org. Synth.*, 1989, **68**, 233.
17 C. D. Gutsche and L.-G. Lin, *Tetrahedron*, 1986, **42**, 1633.
18 J. L. Toner, EP 0 288 256 A2.

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