



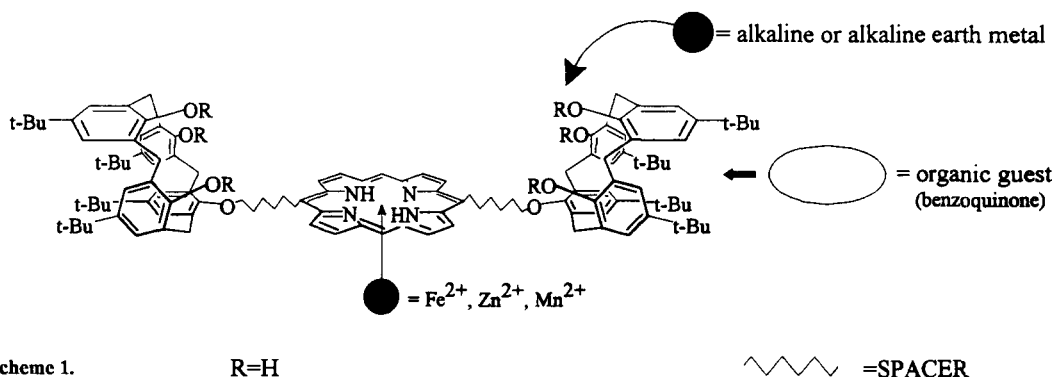
Efficient Combination of Calix[4]arenes and *meso*-Diphenylporphyrins

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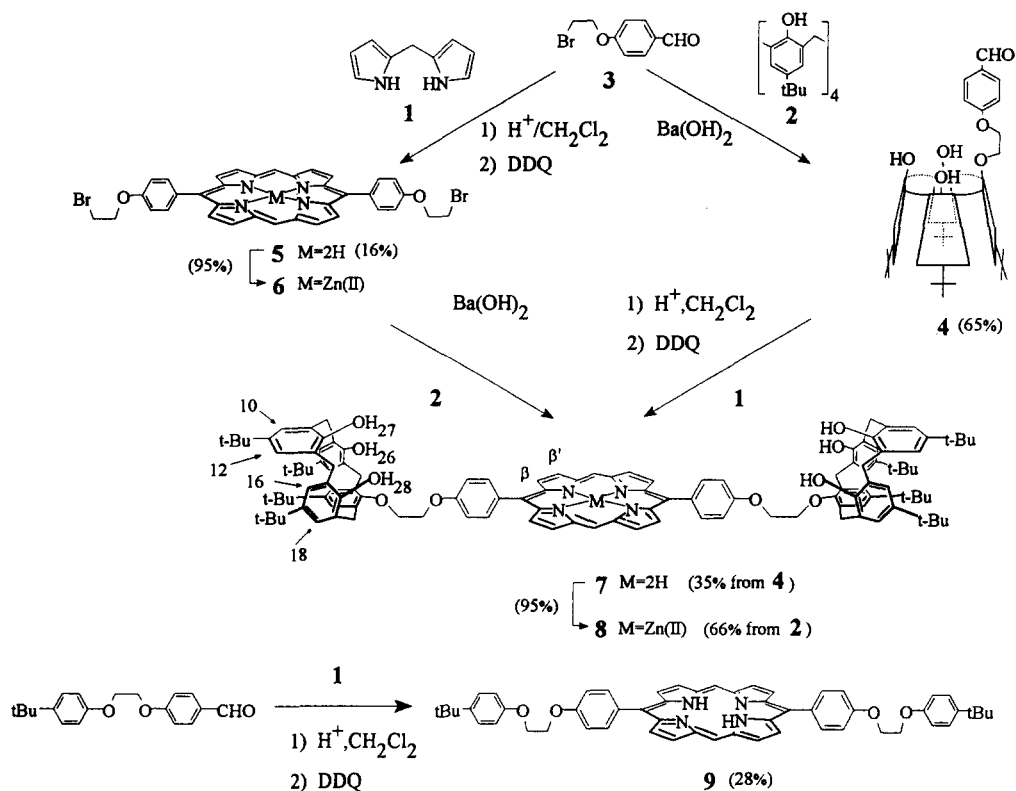
Abstract: The selective mono-alkylation of a calix[4]arene with a functionalized benzaldehyde followed by the condensation with dipyrromethane afforded in good yield a porphyrin substituted by two calix[4]arenes. The same multisite ligand was alternatively obtained by double monoalkylation of two calix[4]arenes with a functionalized porphyrin. The two calixarene units are in cone shape and thus can accommodate neutral organic guests. The efficiency of the fluorescence quenching of two porphyrins by benzoquinone has been evaluated and compared. In a first approximation, Stern-Volmer plots provide evidence for an enhanced quenching when calixarene hosts are bound to the porphyrin.

Assemblies of two calix[4]arenes and porphyrins¹ have been reported in the literature but, so far, only random combinations of dialdehydes and pyrroles² or dialdehydes and dipyrromethanes³ have afforded low yields of calixarenes combined with porphyrins. We describe hereafter, the geometrically controlled combination of calix[4]arene and 5,15-diphenyl porphyrins in efficient yields, thus providing multisite ligands bearing potential binding sites for transition metals, alkali or alkaline-earth metals, and organic fragments depicted in Scheme 1.



The synthetic approaches shown in Scheme 2 were designed taking advantage of numerous reported methods for partial alkylation of calix[4]arenes with alkyl halides⁴, and also using the very convenient synthesis of *meso*-diphenyl porphyrins from unsubstituted dipyrromethane and benzaldehydes.⁵ The dipyrromethane 1⁶

and *p*-tertio butyl calix[4]arene **2**⁷ were synthesized as described in the literature. The functionalized aldehyde **3**⁸ was obtained in 80% yield from the alkaline condensation of an excess of 1,2-dibromo ethane and *p*-hydroxy benzaldehyde. Monoalkylation of **2** with a slight excess (1.35 eq.) of functionalized aldehyde **3** ($\text{Ba}(\text{OH})_2/\text{BaO}/\text{DMF}$)⁴ afforded the derivative **4**⁹ in 65% yield. The free base porphyrin **7**¹⁰ was synthesized by further condensation of **4** with a stoichiometric amount of **1**.



Scheme 2.

Following a second route, the same porphyrin **7** was obtained in a stepwise fashion. The condensation of equimolar amounts of dipyrromethane **1** and functionalized aldehyde **3** (CH_2Cl_2 /traces of CF_3COOH /room temperature 1 day) followed by mild oxidative conditions (dichloro-dicyano-quinone/ CH_2Cl_2 /room temperature 2 hours) yielded the *meso*-di(*p*-bromoethoxy)phenyl porphyrin **5**.¹⁰ When reacted with two equivalents of *p*-tertio butyl calix[4]arene **2** in presence of $\text{Ba}(\text{OH})_2$ (DMF, 20 hours), the porphyrin **5** afforded the double calix[4]arene **7** as a result of the mono alkylation of each calixarene. A similar procedure employing the zinc(II) complex **6** of porphyrin **5** enable us to obtain directly the zinc(II) complex **8**.¹⁰

The porphyrin derivatives as well as the zinc(II) complexes obtained were characterized by usual techniques (see note 10), and also by fluorescence measurements.¹¹ The absorption, fluorescence, and emission spectra of compound **7** in THF are depicted in Figure 1. As the cavity of calix[4]arenes is approximatively adapted to accomodate a benzoquinone, fluorescence quenching experiments comparing the test compound **9** and the free base **7**. The decay of fluorescence was followed during the addition of increasing amounts of benzoquinone to solutions of **7** or **9** in $\text{H}_2\text{O}/\text{THF}$ mixtures (19/1 in volume). The variation of I_0/I (I_0 =emission

intensity without quencher and I =emission intensity in presence of quencher) as a function of the concentration of benzoquinone $[Q]$ is plotted in Figure 2 for 7 and 9.

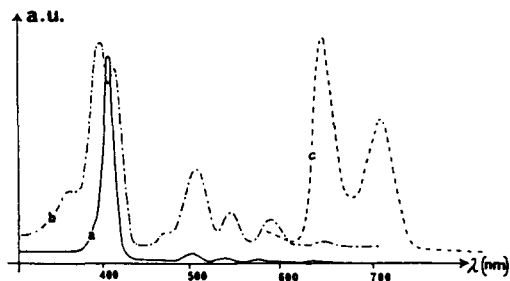


Figure 1: (a) absorption in THF, arbitrary units (a.u.); (b) excitation at $\lambda_{em}=710\text{nm}$ in THF a.u. (c) emission at $\lambda_{exc}=502\text{nm}$

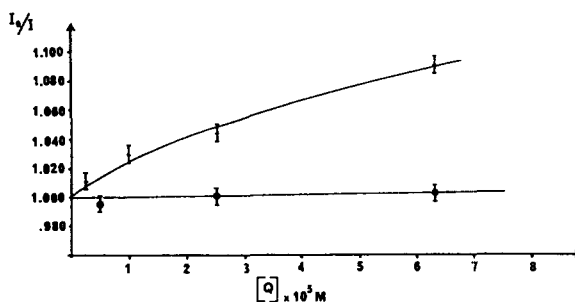


Figure 2: $[7]=0.5 \cdot 10^{-5}\text{M}$, (-).
 $[9]=0.5 \cdot 10^{-5}\text{M}$, (●).

The Stern-Volmer constant k_{SV} was obtained from the relation $I_0/I_n=1+k_{SV}[Q]_n$. Even though the analysis of the system is complicated by the possible competition between a quenching by free benzoquinone (process involved in the emission quenching for porphyrin 9) and quenching by benzoquinone complexed in a calixarene cavity (both processes being involved in the quenching for 7), the presence of the calix[4]arene covalently bound to the photoactive moiety enhances the efficiency of the emission extinction. This occurs only in water/THF mixtures where hydrophobic interactions between the calix[4]arene cavity and the quinone can be developed. Indeed, no enhancement of the fluorescence quenching has been observed when distilled THF was used. In the 19/1 water/THF mixture, while for 9 the expected linear plot (●) affords a k_{SV0} value of $250 \pm 50\text{M}^{-1}$, the shape of the Stern Volmer plot obtained for compound 7 is similar to those obtained in a system containing a cyclodextrin covalently bound to a porphyrin.¹² The curved plot (-) is easily deconvoluted in two linear plots, thus giving two values for k_{SV} . The first value $k_{SV1}=3600 \pm 800\text{M}^{-1}$ corresponds to the enhanced quenching due to the complexation of benzoquinone in the calixarene host. The second value $k_{SV2}=1100 \pm 400\text{M}^{-1}$ is closer to the value of k_{SV0} and is representative of the contribution of the usual quenching by free benzoquinone. In conclusion, at low concentration of quinone, the fluorescence quenching of the porphyrin seems to be considerably enhanced by the attachment of two calixarenes to the photoactive subunit. At higher concentration the quenching is still favoured by the presence of the hydrophobic receptors.

As the approximation of the quenching efficiency using this method requires similar values for the excited state lifetime τ_0 of both porphyrins 7 and 9, further investigations of the photophysical properties of these compounds are currently under progress.

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References and Notes:

- 1) An exemple of coupling via amide bond formation of one calix[4]arene and a porphyrin has been described: Nagasaki, T.; Fujishima, H.; Shinkai, S. *Chem. Lett.* **1994**, 989-992.
- 2) Rudkevich, D. M.; Verboom, W.; Reinhoudt, D. N. *Tetrahedron Lett.* **1994**, 35, 7131-7134.
- 3) Asfari, Z.; Vicens, J.; Weiss, J. *Tetrahedron Lett.* **1993**, 34, 627-628.
- 4) For a review see: Shinkai, S. *Tetrahedron* **1993**, 49, 8933-8968.
- 5) Manka, S.J.; Lawrence, D. S. *Tetrahedron Lett.* **1989**, 30, 6889-6892.

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- 8) Trutschel, R.; Meister, G.; Altmann, H.; Fechtel, U.; Matschiner, H. *J. Appl. Electrochem.* **1991**, *21*, 910-914.
- 9) ^1H NMR of **4**, δ ppm, CDCl_3 , 300 MHz: 10.1 (s, 1H, $\text{OH}_{27\text{-calix}}$), 9.93 (s, 1H, CHO), 9.31 (s, 2H, $\text{OH}_{26,28\text{-calix}}$), 7.90 (d, 2H, $J_{\text{AB}}=8.9\text{Hz}$, $\text{H}_{\text{Arbenzald}}$), 7.20 (d, 2H, $J_{\text{AB}}=8.9\text{Hz}$, $\text{H}_{\text{Arbenzald}}$), 7.11 and 7.01 (2s, 2H ea., $\text{H}_{\text{Ar}10,12,22,24\text{-calix}}$), 7.06 and 6.98 (2d, 2H ea., $J=2.3\text{Hz}$, $\text{H}_{\text{Ar}4,6,16,18\text{-calix}}$), 4.69 and 4.56 (2m, 2H ea., $\text{OCH}_2\text{CH}_2\text{O}$), 4.45 and 4.18 (2d, 2H ea., $J_{\text{AB}}=13.3\text{Hz}$, ArCH_2Ar), 3.44 and 3.40 (2d, 2H ea., $J_{\text{AB}}=13.3\text{Hz}$, ArCH_2Ar), 1.21 (2s overlay., 27H, t- C_4H_9), 1.20 (s, 9H, t-Bu).
- 10) All new compounds have been fully characterized. Selected data are presented hereafter for the porphyrin derivatives **5-9**. Spectra were assigned accordingly to the proton labelling scheme given in Figure 1.
- 5**: ^1H NMR, δ ppm, CDCl_3 , 300 MHz: 10.30 (s, 2H, $\text{H}_{\text{methene}}$), 9.39 (d, 4H, $J_{\text{AB}}=4.8\text{Hz}$, H_β), 9.09 (d, 4H, $J_{\text{AB}}=4.8\text{Hz}$, H_β), 8.19 (d, 4H, $J_{\text{AB}}=8.5\text{Hz}$, H_{Ar}), 7.36 (d, 4H, $J_{\text{AB}}=8.5\text{Hz}$, H_{Ar}), 4.63 (t, 4H, $J_{\text{AB}}=6.3\text{Hz}$, CH_2OAr), 3.88 (t, 4H, $J_{\text{AB}}=6.3\text{Hz}$, CH_2Br), -3.08 (s, 2H, NH). UV-Vis, THF $\lambda_{\text{maxnm}}(\epsilon \text{ mol}^{-1}\cdot\text{l}\cdot\text{cm}^{-1})$: 408(270000), 502(14000), 537(6200), 578(3500), 634(1500). Emission ($\lambda_{\text{exc}}=502\text{nm}$), THF $\lambda_{\text{maxnm}}(\text{rel. int. } \%)$: 634(56), 700(37). FAB $^+$: Calculated: 708.5, Measured: 709.1(11%).
- 6**: ^1H NMR, δ ppm, Pyridine d- $_5$, 300 MHz: 10.14 (s, 2H, $\text{H}_{\text{methene}}$), 9.31 (d, 4H, $J_{\text{AB}}=4.4\text{Hz}$, H_β), 9.02 (d, 2H, $J_{\text{AB}}=4.4\text{Hz}$, H_β), 8.11 (d, 4H, $J_{\text{AB}}=8.3\text{Hz}$, H_{Ar}), 7.26 (d, 4H, $J_{\text{AB}}=8.3\text{Hz}$, H_{Ar}), 4.57 (t, 4H, $J_{\text{AB}}=6.2\text{Hz}$, OCH_2), 3.82 (t, $J_{\text{AB}}=6.2\text{Hz}$, CH_2Br). UV-Vis, THF $\lambda_{\text{maxnm}}(\epsilon \text{ mol}^{-1}\cdot\text{l}\cdot\text{cm}^{-1})$: 304(20000), 392sh(40000), 414(458000), 544(17300). Emission ($\lambda_{\text{exc}}=544\text{nm}$), THF $\lambda_{\text{maxnm}}(\text{rel. int. } \%)$: 590(39), 638(58), 700(3). FAB $^+$: Calculated: 771.82, Measured: 771.8(28%).
- 7**: ^1H NMR, δ ppm, CDCl_3 , 300 MHz: 10.33 (s, 2H, D_2O exch. OH_{27}), 10.28 (s, 2H, $\text{H}_{\text{methene}}$), 9.58 (s, 4H, $\text{OH}_{26,28}$), 9.34 (d, 4H, $J_{\text{AB}}=4.5\text{Hz}$, H_β), 9.15 (d, 4H, $J_{\text{AB}}=4.5\text{Hz}$, H_β), 8.24 (d, 4H, $J_{\text{AB}}=8.6\text{Hz}$, H_{Ar}), 7.53 (d, 4H, $J_{\text{AB}}=8.6\text{Hz}$, H_{Ar}), 7.20 and 7.10 (2s, 4H ea., $\text{H}_{10,12,22,24}$), 7.14 and 7.04 (2d, 4H ea., $J_{\text{AB}}=2.3\text{Hz}$, $\text{H}_{4,6,16,18}$), 4.94 and 4.76 (2m, 4H ea., $\text{OCH}_2\text{CH}_2\text{O}$), 4.67 (d, 4H, $J_{\text{AB}}=13.1\text{Hz}$, ArCH_2Ar), 4.38 (d, 4H, $J_{\text{AB}}=13.8\text{Hz}$, ArCH_2Ar), 3.57 (d, 4H, $J_{\text{AB}}=13.1\text{Hz}$, ArCH_2Ar), 3.50 (d, 4H, $J_{\text{AB}}=13.8\text{Hz}$, ArCH_2Ar), 1.26 (2s ovl., 18H ea., t-Bu $_{11}$ and $_{23}$), 1.25 (s, 36H, t-Bu $_5$ and $_{17}$), -3.08 (s, 2H, NH). UV-Vis, THF $\lambda_{\text{maxnm}}(\epsilon \text{ mol}^{-1}\cdot\text{l}\cdot\text{cm}^{-1})$: 288(23700), 408(346000), 502(16400), 538(7900), 578(5400), 633(2100). Emission ($\lambda_{\text{exc}}=502\text{nm}$), THF $\lambda_{\text{maxnm}}(\text{rel. int. } \%)$: 637(71), 700(44). FAB $^+$: Calculated 1843.04, Measured 1843.8(18%).
- 8**: ^1H NMR, δ ppm, Pyridine d- $_5$, 300 MHz: 10.51 (s, 2H, $\text{H}_{\text{methene}}$), 10.14 (broad s, 6H, $\text{OH}_{26,27,28}$), 9.62 (d, 4H, $J_{\text{AB}}=3.4\text{Hz}$, H_β), 9.40 (d, 4H, $J_{\text{AB}}=3.4\text{Hz}$, H_β), 8.38 (d, 4H, $J_{\text{AB}}=6.9\text{Hz}$, H_{Ar}), 7.75 (d, 4H, $J_{\text{AB}}=6.9\text{Hz}$, H_{Ar}), 7.52, 7.38, 7.41 and 7.17 (4s, 4H ea., $\text{ArH}_{4,6,10,12,16,18,22,24}$), 5.03 and 4.82 (2m and 1s overlay, 12 H, $\text{OCH}_2\text{CH}_2\text{O}$ and ArCH_2Ar), 4.70 (d, 4H, $J_{\text{AB}}=12.6\text{Hz}$, ArCH_2Ar), 3.87 (d, 4H, $J_{\text{AB}}=12.6\text{Hz}$, ArCH_2Ar), 3.68 (d, 4H, $J_{\text{AB}}=13.8\text{Hz}$, ArCH_2Ar), 1.36 (s, 36H, t-Bu), 1.07 (s, 36H, t-Bu). UV-Vis, THF $\lambda_{\text{maxnm}}(\epsilon \text{ mol}^{-1}\cdot\text{l}\cdot\text{cm}^{-1})$: 284(25000), 418(333000), 544(13000). Emission ($\lambda_{\text{exc}}=544\text{nm}$), THF $\lambda_{\text{maxnm}}(\text{rel. int. } \%)$: 590(41), 638(60), 700(6). FAB $^+$: Calculated 1907.8, Measured 1907.6 (15%).
- 9**: ^1H NMR, δ ppm, CDCl_3 , 300 MHz: 10.30 (s, 2H, $\text{H}_{\text{methene}}$), 9.38 (d, 4H, $J_{\text{AB}}=4.4\text{Hz}$, H_β), 9.09 (d, 4H, $J_{\text{AB}}=4.4\text{Hz}$, H_β), 8.19 (d, 4H, $J_{\text{AB}}=8.6\text{Hz}$, H_{Ar}), 7.40 and 7.04 (2d, 4H ea., $J_{\text{AB}}=8.8\text{Hz}$, $\text{H}_{\text{Ar-tBu}}$), 7.39 (d, 4H, $J_{\text{AB}}=8.6\text{Hz}$, H_{Ar}), 4.65 and 4.54 (2m, 4H ea., $\text{OCH}_2\text{CH}_2\text{O}$), 1.36 (s, 18H, t-Bu), -3.06 (s, 2H, NH). UV-Vis, THF $\lambda_{\text{maxnm}}(\epsilon \text{ mol}^{-1}\cdot\text{l}\cdot\text{cm}^{-1})$: 408(300000), 502(14000), 538(7200), 578(5100). Emission ($\lambda_{\text{exc}}=502\text{nm}$), THF $\lambda_{\text{maxnm}}(\text{rel. int. } \%)$: 634(82), 700(51). FAB $^+$: Calculated 847.1, Measured 847.3 (62%).
- 11) Excitation spectra have also been recorded for each porphyrin derivative and no difference when compared to the absorption spectra has been noticed..
- 12) a) Nango, M.; Higuchi, M.; Gondo, H.; Hara, M. *J. Chem. Soc. Chem. Commun.* **1989**, 1550-1553.
b) Similar systems have been studied following the photogenerated ESR signal of quinones in cyclodextrins bounded to porphyrins, see: Gonzalez, M C.; McIntosh, A. M.; Bolton, J. R.; Weedon, A. C. *J. Chem. Soc. Chem. Commun.* **1984**, 1138-1140.

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