Straightforward Syntheses That Avoid Scrambling of meso -Substituted [28]Hexaphyrins
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To cite this version:

HAL Id: hal-01683280
https://hal.science/hal-01683280
Submitted on 16 Apr 2018

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Abstract: A two-step synthesis of meso-substituted [28]hexaphyrins in an aqueous medium was developed and optimized, and scrambling processes are avoided despite the use of a high acid concentration. The efficiency of this procedure relies on the nature of the starting material, and it can be extended to the straightforward preparation of unprecedented AB₂C₂D₂-[28]hexaphyrins bearing up to four different kinds of meso-appended aryl group.

Introduction

Expanded porphyrins and their core-modified analogues have been the subject of growing interest because of their versatile chemical, optical, and electrochemical properties as well as their unique coordination chemistry. Among the numerous described expanded porphyrinoid structures, hexaphyrin-(1.1.1.1.1.1) derivatives (Scheme 1), which can be viewed as the first expanded porphyrin homologues (alternating pyrrole units and bridging carbon atoms), were the subject of particularly intense research activity because of their fascinating physicochemical properties. For example, their cavities are suitable for the concomitant coordination of two identical or different metal centers. Moreover, although most of the [26]hexaphyrins are planar macrocycles that exhibit Hückel aromaticity, their reduced forms, [28]hexaphyrins (Scheme 1), and their metal complexes may have twisted Möbius structures in solution. Consequently, the oxidation state of a hexaphyrin has a crucial impact on its light-absorption and emission properties.

The main synthetic procedures that provide access to meso-substituted hexaphyrins are summarized in Scheme 1. The first stable derivative bearing six meso-pentafluorophenyl groups was prepared through a simple and straightforward synthesis from commercially available pyrrole (1, R = H) and pentafluorobenzaldehyde (Scheme 1, route a). This strategy can be used to introduce various kinds of meso substituents together with various β groups if these are born by the starting pyrrole unit 1 (R ≠ H). Nevertheless, this one-pot procedure produces complex mixtures of expanded porphyrins, which are difficult to separate and purify. This problem can be overcome through ring-size-selective syntheses of hexaphyrins from oligopyrroles.

For example, the acidic condensation of meso-substituted dipyrromethanes 3 with aldehydes 2 followed by oxidation can produce A₁B₁-hexaphyrin derivatives bearing up to two different kinds of meso groups (Scheme 1, route b). The first example of a meso-substituted hexaphyrin bearing six phenyl groups was prepared through the condensation of a tripyrrane 4 with benzaldehyde in an acidic medium (Scheme 1, route c). This approach was later used to synthesize simple to very sophisticated hexaphyrin derivatives such as A₂B₂-type compounds bearing an internal strap or dyes incorporating boron-dipyromethene (Bodipy) units. Less-symmetric compounds were prepared through the acidic condensation of tetrapyrranes 5.
with dipyrromethane dicarbinols 6 (Scheme 1, route d). This elegant strategy allows access to derivatives bearing up to six different meso groups and was used to prepare unsymmetrical compounds bearing a free meso position or hexaphyrin dimers.[11] Reactive compounds 6 were also condensed with β-substituted pyrrole units 1 to prepare partially β-substituted hexaphyrins (Scheme 1, route e).[12]

The use of cyclic or linear oligopyrranes often suffers from a major drawback called “scrambling”. These compounds are usually condensed or prepared in an acidic medium, which can also cause their acidolysis into fragments that then recombine into other different oligopyrranes.[13] For example, this scrambling process was evident during the condensation of a tripyrane 4 with an aldehyde or an N-sulfonyl-substituted aldimine forming the unexpected N-fused pentaphyrins, heptaphyrins, or octaphyrins.[8c,10f] The acidolysis of oligopyrranes can be avoided through the use of sterically hindered or strongly electron-withdrawing meso-aryl substituents,[14] and, in a spectacular breakthrough, Koszarna and Gryko showed in 2006 that it can also be suppressed if the solvent is an alcohol/water mixture, despite the use of very high concentrations of aqueous HCl.[15] This efficient preparation of trans-A2B corroles was later extended to the synthesis of porphyrins bearing up to three different kinds of meso substituents.[16] We report herein how this strategy can be extended to the straightforward preparation of simple or complex meso-substituted [28]hexaphyrins bearing up to four different kinds of meso groups.

Results and Discussion

The optimized preparation of a trans-A2B2 porphyrin starting from a dipyrromethane (DPM) 3 and an aldehyde 2 in an aqueous medium was chosen as the starting point for the development of a new synthetic route to meso-substituted expanded porphyrin derivatives (Scheme 2). Equal amounts of DPM and aldehyde were dissolved in 4 mm concentrations in an ethanol/water (4:1) mixture in the presence of an HCl concentration of 38 mM. The porphyrinogen was then oxidized by p-chloranil in boiling chloroform for 1 h. Under these conditions with DPM 3a, aldehyde 2a, and p-chloranil (2 equiv.; Table 1, Entry 1), no expanded porphyrin was observed in the final mixture. The concentration of the starting materials was then increased to 100 mM, because this value was optimal for the production of A4B4-octaphyrins from DPM (Table 1, Entry 2).[8e] The chromatographic purification of the oxidized reaction mixture revealed that only one supplementary colored compound was eluted after the trans-A2B2 porphyrin. A combination of 1H NMR spectroscopy, UV/Vis spectroscopy, and mass spectrometry analyses proved that this compound was the [28]hexaphyrin 7a.

![Scheme 2. Syntheses of meso-substituted [28]hexaphyrins 7a and 7b as well as [26]hexaphyrin 8a.](image-url)

### Table 1. Optimization of the synthesis of [28]hexaphyrin 7a.

<table>
<thead>
<tr>
<th>Entry</th>
<th>[3a] [mmol/L]</th>
<th>Solvent</th>
<th>t [h]</th>
<th>Oxidation step[a]</th>
<th>UV yield [%]</th>
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<td>(a)</td>
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<tr>
<td>2</td>
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<td>EIOH</td>
<td>16</td>
<td>(c)</td>
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[a] Oxidation step: (a) p-chloranil (2 equiv.) in CHCl3 under reflux (1 h), (b) p-chloranil (3 equiv.) in CHCl3 under reflux (1 h), (c) air in CHCl3 under reflux (1 h).
[b] Isolated yield. [c] Optimal conditions.
(Scheme 2) and not the expected A₈B₄-octaphyrin. This result was quite surprising, because previous syntheses of [26]hexaphyrins starting from DPM 3a and aldehydes required ortho-substituted benzaldehyde derivatives,[8b] Moreover, despite the highly acidic conditions, no scrambling occurred, as demonstrated by the single isotope cluster in the corresponding HR mass spectrum (see the Supporting Information). Consequently, we attempted to improve the first isolated synthetic yield (2%) of 7a by varying the different reactions parameters such as the concentration of the reactants and the time of the acidic condensation (Table 1).

The first small sample of 7a was used to record its UV/Vis spectrum and to measure the molar absorptivity at the Soret-like band maximum (λmax = 610 nm). For each subsequent experiment, the solvent volume was kept constant (25 mL) during the acidic condensation and the oxidation steps. On the contrary, the concentrations of the reactants, the nature of the organic solvent, and the amount and the nature of the oxidant were varied. After the oxidation step, multiple colored species in the reaction mixture were detected by TLC or UV/Vis spectroscopy. Consequently, a 1 mL aliquot was collected from this mixture and passed through a short silica gel chromatography column with dichloromethane as the solvent (see Scheme 3). The first red fractions containing the trans-A₂B₂ porphyrin and traces of p-chloranil were removed before the elution of 7a (Scheme 3). All the following blue fractions containing 7a were gathered in a volumetric flask filled with dichloromethane. The UV/Vis spectrum of the resulting solution was then recorded and used to determine the corresponding UV yield. Considering the different preceding steps (extraction, washing, purification, etc.), a probable overestimation of the UV yields cannot be excluded and could be partly responsible for the discrepancies between the UV and isolated yields. As these uncertainties cannot be the principal source of the trends affecting the UV yield, we kept this short and quick procedure for the optimization of the synthetic preparation of 7a.

The highest UV yield was reached when a DPM concentration of 33.3 mM was used, as observed previously for the synthesis of [26]hexaphyrins (20%; Table 1, Entry 4).[8b] The replacement of ethanol by other organic solvents as well as the modification of the acidic condensation time did not increase the yield of 7a (Table 1, Entries 7–12). Interestingly, no expanded porphyrin was detected when a higher quantity of p-chloranil (3 equiv.) was introduced during the oxidation step or when air was the oxidizing agent (Table 1, Entries 13 and 14). Consequently, meso-substituted [28]hexaphyrins or [26]hexaphyrins are probably unstable under strong oxidative conditions, which have to be avoided when considering their interconversion. This transformation was effective when 7a was dissolved in a suspension of MnO₂ in dichloromethane to afford quantitatively its oxidized form [26]hexaphyrin 8a (Scheme 2).

The optimized conditions were used on a preparative scale to produce [28]hexaphyrins 7a and 7b with yields of 8 and 11%, respectively. The nature of the starting compounds is crucial. For example, only 2% of 7a was formed when DPM 3a and aldehyde 2a were replaced by 3b and 2b, respectively (Scheme 2). Although the meso-pentafluorophenyl group stabilizes dipyrromethane 3a slightly towards acidolysis,[14] no scrambling occurred during the utilization of 3b, as illustrated by the concomitant formation of only the corresponding trans-A₂B₂ porphyrin. Moreover, a single and pure hexaphyrin (7a) was formed, as proved by its HR mass spectrum. The difference between the two yields could be due to a different preorganization of the intermediate oligopyrranes towards the cyclization. In the same way, we were not successful in preparing meso-free or meso-alkyl derivatives by condensation of DPMs 3c–3e with aldehyde 2b or of DPM 3a with aldehyde 2d (Scheme 2).

The lack of scrambling observed under the optimized conditions prompted us to introduce bilanes 5 into the reaction mixture (Scheme 4). Triarylbilanes (5a–5f) were then prepared under the conditions reported by the Gryko group and purified by silica chromatography (see the Experimental Section).[15] As-

Scheme 3. Schematic representation of the procedure used to measure the UV yields of 7a during the optimization of the synthetic parameters.
assuming that bilanes are formed in situ through the condensation of two DPM molecules with an aldehyde during the first step of the [28]hexaphyrins synthesis, we studied the condensation of bilanes with aldehyde and DPM in a 1:2:1 ratio and with a three times lower DPM concentration of 11.1 mM (Scheme 4). Compound 7c was then produced with a mixture of different porphyrins and isolated in an encouraging yield of 6% through the condensation of 3a, 2a, and 5a (Scheme 4). The yield of this synthesis is again dependent on the nature of the starting materials and decreases with the electron-withdrawing strength of the substituents. Several combinations were tested (3a/2a/5b, 3a/2a/5d, 3c/2b/5c, and 3b/2e/5e) and failed to give any expanded porphyrins. However, when the procedure was applied to the two sets 3b/2a/5a and 3a/2e/5f, the purification of the final reaction mixture afforded the new compounds 7d and 7e in yields of 1%. Compound 7d is the cis isomer of 7a in which three successive meso carbon atoms bear identical substituents. Although the synthetic yield of 7e is low (1%), this result demonstrates how this simple procedure can lead to sophisticated compounds bearing up to four different kinds of meso-aryl groups. However, we noticed that [28]hexaphyrins display moderate stabilities emphasized by electron-donating substituents. After 1 year, the solid compounds 7a–7e had converted slowly into mixtures of colored compounds containing their [26] isomers, even though they were stored at −20 °C under argon.

The complete 1H NMR spectroscopic characterization of [28]hexaphyrins is difficult because of the equilibria between the different interconverting twisted Möbius isomers.[4b] The complexity of this task is increased here by the presence of different tautomeric forms resulting from the substitution pattern. Consequently, the complete assignment of the 1H NMR signals of 7a–7e and 8a is far beyond the scope of the present work, which focuses on their synthetic preparation. We chose to report the 1H NMR data recorded in deuterated tetrahydrofuran (THF) in the Experimental Section, because this solvent gave the best-resolved spectra at room temperature (see the Supporting Information). On the other hand, the UV/Vis spectra of [28]hexaphyrins 7a–7e give the first insights into the relationship between the nature of the meso-aryl groups and the physicochemical properties of these derivatives (see the Supporting Information). The Soret-like band maxima of 7a–7e are reported in Table 2 and are compared with that of 7f, which bears six meso-pentafluorophenyl groups.[6] Peripheral electron-donating groups produce a redshift of the absorption maximum. For example, when the three 5,15,25 meso groups of 7f are replaced by p-fluorophenyl groups in 7b and by p-tolyl groups in 7a, the Soret-like band is redshifted by 44 and 49 nm, respectively. A larger redshift is observed for 7e bearing several electron-donating groups. Although the bulkiness of the meso substituents cannot be excluded as the source of these shifts, the light-absorption properties of [28]hexaphyrins are also controlled by their symmetry, as illustrated by the different absorption maxima of the two isomeric compounds 7a and 7d (λ = 610 and 602 nm respectively).

**Conclusions**

We have described herein a new strategy to produce meso-substituted [28]hexaphyrins in a mixture of ethanol and water as the solvent with high concentrations of HCl. The yields are...
modest, but these syntheses afford single expanded porphyrins without any scrambling that can be separated readily from the other porphyrin products. Starting from bilanes, this new procedure can afford unprecedented 28]hexaphyrins bearing up to four different kinds of meso substituents and, thereby, extends the variety of these compounds and enables the study of their physicochemical properties.

Experimental Section

General: Pure pyrrole was freshly purified by passage through a short chromatography column filled with neutral alumina. All other reagents were purchased from commercial suppliers and used without further purification. Column chromatography was performed with Geduran silica gel 40–63 μm from VWR. The reactions were monitored by thin-layer chromatography (Merck 60 F254). 1H NMR spectra were recorded at 500 MHz with a Bruker Avance DPX-500 spectrometer, at 400 MHz with a Bruker Avance DPX-400 spectrometer, at 300 MHz with a Bruker Avance DPX-300 instrument, or at 200 MHz with a Bruker Avance DPX-200 instrument. 1H NMR chemical shifts are given in ppm relative to the residual solvent peaks of CDCl3 (δ = 7.26 ppm) or [D8]THF (δ = 1.72 and 3.58 ppm). UV/Vis spectra were recorded with a Shimadzu UV-2401 (PC) instrument or with a Varian Cary 1E spectrophotometer. HRMS-ESI data were recorded and used to determine the corresponding amount of [28]hexaphyrin derivatives (0.46 g, 0.57 mmol, 34 %). 1H NMR (300 MHz, CDCl3): δ = 8.10 (s, 2 H, NH), 7.99 (s, 2 H, NH), 6.73 (m, 2 H, H-α), 6.15 (m, 2 H, H-β), 5.99 (m, 2 H, H-β), 5.73–7.99 (m, 7 H, H-β/[Hiterals]; ppm). HRMS-ESI: calcd. for C66H29F18N6 [M + H]+: 1247.2161; found 1247.2161.

5,15,25,35-Tetrafluorophenyl)porphyrins: A solution of 5-(pentfluorophenyl)dipyromethane (3a; 0.26 g, 0.83 mmol, 1 equiv.) and p-toluene sulfonic acid (3c; 0.26 g, 0.83 mmol, 1 equiv.) in ethanol (20 mL) was stirred, and a solution of HCl (37 % 0.1 mL) in water (5 mL) was added. The reaction mixture was stirred for 16 h and then extracted with CHCl3 (150 mL). The organic phase was washed three times with water (100 mL) and once with a saturated aqueous solution of NaNHCO3 (100 mL), dried with MgSO4, and filtered, and p-chloranil (410 mg, 1.67 mmol, 2 equiv.) was added. The resulting mixture was heated to reflux for 1 h, cooled to room temperature, and concentrated under reduced pressure. The crude residue was purified by silica gel chromatography (CHCl3) to afford pure 7a as a dark blue powder (27 mg, 22 μmol, 8 %). 1H NMR (400 MHz, [D8]THF, 25 °C): δ = 9.22 (br. s, NHouter), 8.03 (d, JHouter = 7.8 Hz, 2 H, Ar-H), 7.92 (m, 6 H, β-Houter), 7.68 (d, JHouter = 7.8 Hz, 2 H, β-Houter), 7.54 (d, JHouter = 7.8 Hz, 2 H, Ar-H), 7.49 (d, JHouter = 7.7 Hz, 4 H, Ar-H), 7.26 (d, JHouter = 7.9 Hz, 4 H, Ar-H), 4.72 (s, 2 H, NNHouter), 2.58 (s, 3 H, CH3), 2.44 (s, 6 H, CH3), 2.38 (br. s, 4 H, β-Houter) ppm. UV/Vis (CHCl3): λmax (nm) = 397 (4.59), 441 (4.47), 610 (5.19), 640 (4.93), 778 (4.16), 869 (3.99), 925 (3.92), 1051 (3.83) nm. HRMS-ESI: calcd. for C66H29F18N6 [M + H]+: 1235.2912; found 1235.2919.

5,15,25,35-Tris(pentafluorophenyl)-10,20,30-tris(4-fluorophenyl)hexaphyrin[28] (7b): A solution of 5-(pentfluorophenyl)dipyromethane (3a; 0.26 g, 0.83 mmol, 1 equiv.) and p-fluorobenzonitrile (2c; 89 μL, 0.83 mmol, 1 equiv.) in ethanol (20 mL) was stirred, and a solution of HCl (37 % 0.1 mL) in water (5 mL) was added. The reaction mixture was stirred for 16 h and then extracted with CHCl3 (150 mL). The organic phase was washed three times with water (100 mL) and once with a saturated aqueous solution of NaNHCO3 (100 mL), dried with MgSO4, and filtered, and p-chloranil (410 mg, 1.67 mmol, 2 equiv.) was added. The resulting mixture was heated to reflux for 1 h, cooled to room temperature, and concentrated under reduced pressure. The crude residue was purified by silica gel chromatography (CHCl3) to afford pure 7b as a dark blue powder (38 mg, 30 μmol, 11 %). 1H NMR (400 MHz, [D8]THF, 25 °C): δ = 8.16 (m, 2 H, Ar-H), 7.97 (m, 2 H, β-Houter), 7.92 (m, 4 H, β-Houter), 7.74 (m, 2 H, β-Houter), 7.64 (m, 4 H, Ar-H), 7.49 (m, 2 H, Ar-H), 7.22 (m, 4 H, Ar-H), 4.75 (br. s, 1 H, NNHouter), 4.10 (br. s, 1 H, NNHouter), 2.18 (s, 2 H, β-Houter), 1.93 (s, 2 H, β-Houter) ppm. UV/Vis (CHCl3): λmax (nm) = 398 (4.69), 605 (5.17), 776 (4.16), 864 (4.03), 918 (3.97), 1041 (3.81) nm. HRMS-ESI: calcd. for C66H29F18N6 [M + H]+: 1247.2161; found 1247.2161.

5,10,15-Tris(pentafluorophenyl)tetrapyrarane (5a): Pentfluorobenzaldehyde (0.62 mL, 5 mmol) and pyrrole (694 μL, 10 mmol) were dissolved in a mixture of MeOH (200 mL) and water (200 mL). Subsequently, HCl (36 %, 4.25 mL) was added, and the reaction mixture was stirred at room temperature for 3 h. The resulting precipitate was collected by filtration and washed with an MeOH/H2O mixture (1:1; 100 mL) and with water (100 mL). The resulting paste was purified by silica gel chromatography (n-hexane/ethyl acetate/CHCl3, 7:1:2) to yield the pure bilane 5a as a mixture of stereoisomers (0.46 g, 0.57 mmol, 34 %). 1H NMR (300 MHz, CDCl3, 25 °C): δ = 8.10 (s, 2 H, NH), 7.99 (s, 2 H, NH), 6.73 (m, 2 H, H-α), 6.15 (m, 2 H, H-β), 5.99 (m, 2 H, H-β), 5.73–7.99 (m, 7 H, H-β/[Hiterals]; ppm). HRMS-ESI: calcd. for C37H34F18N6 [M + H]+: 803.1286; found 803.1285. These analytical data are in accordance with the literature values.[15,16]

5,10,15-Tris(p-methylphenyl)tetrapyrarane (5b): p-Toluylaldehyde (0.59 mL, 5 mmol) and pyrrole (694 μL, 10 mmol) were dissolved in a mixture of MeOH (200 mL) and water (200 mL). Subsequently, HCl (36 %; 4.25 mL) was added, and the reaction mixture was stirred at room temperature for 3 h. The resulting precipitate was collected by filtration, washed with an MeOH/H2O mixture (1:1; 100 mL) and with water (100 mL). The resulting paste was purified by silica gel chromatography (n-hexane/ethyl acetate/CHCl3, 7:1:2) to yield the pure bilane 5b as a mixture of stereoisomers (0.55 g, 0.96 mmol, 57 %). 1H NMR (300 MHz, CDCl3): δ = 8.16 (s, 2 H, NH), 7.66 (s, 2 H, NH), 7.00–7.10 (m, 12 H, Ar-H), 6.66 (m, 2 H, H-α), 6.12 (m, 2 H, H-β), 5.86 (m, 2 H, β-H), 5.65–5.76 (m, 4 H, H-β), 5.32 (m, 2 H, H-outer), 5.21 (m, 1 H, H-outer), 2.33 (s, 9 H, CH3) ppm. HRMS-ESI: calcd. for C66H29F18N6 [M + H]+: 1247.3169; found 1257.3168.

10-(Pentafluorophenyl)tetrapyrarane (5c): Dipyromethane (3c; 585 mg, 4 mmol) and pentfluorobenzaldehyde (2b; 247 μL, 2 mmol) were dissolved in MeOH (200 mL). Subsequently, a solution
of HCl (36 %, 10 mL) in water (200 mL) was added, and the reaction mixture was stirred at room temperature for 2 h. The resulting precipitate was collected by filtration and washed with a mixture of MeOH/H2O (1:1; 200 mL) and then with water (100 mL). Subsequent silica gel chromatography (n-hexane/ethyl acetate/CH2Cl2, 7:1:2) afforded the pure bilane 5c as a mixture of stereoisomers (181 mg, 0.21 mmol, 48 %).1H NMR (300 MHz, CDCl3): δ = 7.90 (1H, H-Hinner), 7.57 (s, 1H, H-Hinner), 7.48 (m, 2H, H-Houter), 7.36–7.41 (m, 2H, H-Houter), 7.30 (m, 2H, H-Houter), 6.85 (d, JH,H = 8.0 Hz, 2H, Ar-H), 6.67 (m, 2H, H-Houter), 6.28 (m, 2H, H-Houter), 6.14 (m, 2H, H-Houter), 5.80 (m, 4H, H-Houter), 5.68 (m, 2H, H-Houter), 5.34 (s, 1H, H-Hinner) ppm. HRMS-ESI: calcd. for C37H28F4N4O [M + H]+ 753.1643; found 753.1646.

5-(4-Fluorophenyl)dipyrromethane (5f): A solution of 5-(4-fluorophenyl)dipyrromethane (3f: 83 mg, 0.2 mmol) and p-tolualdehyde (2e: 66 μL, 0.56 mmol, 2 equiv.) in EtOH (20 mL) was added a solution of HCl (36 %; 0.1 mL) in water (5 mL). This mixture was stirred at room temperature for 16 h and then extracted with CHCl3 (150 mL). The organic phase was washed three times with water (100 mL) and once with a saturated aqueous solution of NaHCO3 (100 mL). The organic layer was dried with MgSO4, and p-chloranil (410 mg, 1.67 mmol, 2 equiv.) was added. The resulting mixture was heated to reflux for 1 h, cooled to room temperature, and concentrated under reduced pressure. The reaction mixture was purified by silica gel chromatography (CH2Cl2/CH3OH = 9:1) to afford 7f as a dark blue powder (22 mg, 17 μmol, 6 %).1H NMR (300 MHz, [D8]THF, 25 °C): δ = 6.91 (br. s, 1H, NHouter), 7.82 (d, JH,H = 8.4 Hz, 2H, Ar-H), 7.77 (d, JH,H = 8.2 Hz, 2H, Ar-H), 7.24 (d, JH,H = 8.4 Hz, 4H, Ar-H), 7.14 (d, JH,H = 8.0 Hz, 4H, Ar-H), 6.98 (d, JH,H = 8.4 Hz, 4H, Ar-H), 6.91 (d, JH,H = 8.2 Hz, 2H, Ar-H), 6.76 (d, JH,H = 8.2 Hz, 2H, Ar-H), 6.80 (d, JH,H = 8.4 Hz, 4H, Ar-H), 6.57 (d, JH,H = 8.0 Hz, 4H, Ar-H), 6.47 (s, NHinner), 4.08 (s, 1H, NHinner), 3.85 (s, 3H, OCH3) ppm. UV/Vis (CH2Cl2): λmax (εmax) = 392 (0.41), 437 (0.35), 602 (1.00), 772 (0.21) nm. HRMS-ESI: calcd. for C37H31F4N4O [M + H]+ 623.2229; found 623.2227.

5-(4-Fluorophenyl)-5,15-bis(4-fluorophenyl)tetrpyrrane (5g): A solution of 5-(4-fluorophenyl)dipyrromethane (3f: 83 mg, 0.2 mmol) and p-tolualdehyde (2e: 66 μL, 0.56 mmol, 2 equiv.) in EtOH (20 mL) was added a solution of HCl (36 %; 0.1 mL) in water (5 mL). This mixture was stirred at room temperature for 16 h and then extracted with CHCl3 (150 mL). The organic phase was washed three times with water (100 mL) and once with a saturated aqueous solution of NaHCO3 (100 mL). The organic layer was dried with MgSO4, and p-chloranil (410 mg, 1.67 mmol, 2 equiv.) was added. The resulting mixture was heated to reflux for 1 h, cooled to room temperature, and concentrated under reduced pressure. The crude mixture was purified by silica gel chromatography (CH2Cl2/CH3OH = 9:1) to afford 7g as a dark blue powder (3.2 mg, 2.8 μmol, 1 %).1H NMR (300 MHz, [D8]THF): δ = 7.86 (1H, H-Hinner), 7.58 (s, 1H, H-Hinner), 7.45 (d, JH,H = 8.0 Hz, 4H, Ar-H), 7.26 (d, JH,H = 8.4 Hz, 4H, Ar-H), 7.14 (d, JH,H = 8.4 Hz, 4H, Ar-H), 7.06 (d, JH,H = 8.0 Hz, 4H, Ar-H), 6.97 (d, JH,H = 8.2 Hz, 2H, Ar-H), 6.75 (d, JH,H = 8.2 Hz, 2H, Ar-H), 6.71 (d, JH,H = 8.0 Hz, 4H, Ar-H), 6.56 (d, JH,H = 8.0 Hz, 4H, Ar-H), 6.48 (s, NHinner), 4.08 (s, 1H, NHinner), 3.85 (s, 3H, OCH3) ppm. UV/Vis (CH2Cl2): λmax (relative intensity) = 392 (0.30), 437 (0.26), 602 (1.00), 772 (0.12) nm. HRMS-ESI: calcd. for C37H31F4N4O [M + H]+ 623.2229; found 623.2227.

5-(4-Fluorophenyl)-5,15-bis(4-fluorophenyl)tetrpyrrane (5h): A solution of 5-(4-fluorophenyl)dipyrromethane (3f: 83 mg, 0.2 mmol, 1 equiv.), bilane 5f (18 mg, 0.02 mmol, 1 equiv.), and p-tolualdehyde (2e: 66 μL, 0.56 mmol, 2 equiv.) in EtOH (20 mL) was added a solution of HCl (36 %; 0.1 mL) in water (5 mL). This mixture was stirred at room temperature for 16 h and then extracted with CHCl3 (150 mL). The organic phase was washed three times with water (100 mL) and once with a saturated aqueous solution of NaHCO3 (100 mL). The organic layer was dried with MgSO4, and p-chloranil (410 mg, 1.67 mmol, 2 equiv.) was added. The resulting mixture was heated to reflux for 1 h, cooled to room temperature, and concentrated under reduced pressure. The crude mixture was purified by silica gel chromatography (CH2Cl2/CH3OH = 9:1) to afford 7h as a dark blue powder (3.2 mg, 2.8 μmol, 1 %).1H NMR (300 MHz, [D8]THF): δ = 7.86 (1H, H-Hinner), 7.58 (s, 1H, H-Hinner), 7.45 (d, JH,H = 8.0 Hz, 4H, Ar-H), 7.26 (d, JH,H = 8.4 Hz, 4H, Ar-H), 7.14 (d, JH,H = 8.4 Hz, 4H, Ar-H), 7.06 (d, JH,H = 8.0 Hz, 4H, Ar-H), 6.97 (d, JH,H = 8.2 Hz, 2H, Ar-H), 6.75 (d, JH,H = 8.2 Hz, 2H, Ar-H), 6.71 (d, JH,H = 8.0 Hz, 4H, Ar-H), 6.56 (d, JH,H = 8.0 Hz, 4H, Ar-H), 6.48 (s, NHinner), 4.08 (s, 1H, NHinner), 3.85 (s, 3H, OCH3) ppm. UV/Vis (CH2Cl2): λmax (relative intensity) = 392 (0.30), 437 (0.26), 602 (1.00), 772 (0.12) nm. HRMS-ESI: calcd. for C37H31F4N4O [M + H]+ 623.2229; found 623.2227.
5,15,25-Tris(pentfluorophenyl)-10,20,30-tris(4-methylphenyl)-
hexaphyrin[26] (8a): MnO2 (1 mg, 12 μmol, 1 equiv.) was added to a solution of hexaphyrin[26] 7a (15 mg, 12 μmol, 1 equiv.) in 
CH2Cl2 (20 mL). The progress of the reaction was monitored by 
UV/Vis absorption spectroscopy. After 90 min, the reaction mixture 
was purified by silica gel chromatography (CH2Cl2) to afford the 
product 8a (48 mg, 92%; δ 1H = 6.90, 7.44, 7.70 ppm, 13C = 125.9, 
130.6, 135.2, 138.5, 140.5 ppm). 1H NMR (400 MHz, D2O/THF, 25 °C): δ = 9.43 (d, J = 4.7 Hz, 2 H, H-1a-H-1b), 9.21 (d, 
J = 4.7 Hz, 2 H, H-2a-H-2b), 9.07 (d, J = 4.7 Hz, 2 H, H-3a-H-3b), 
9.05 (d, J = 4.7 Hz, 2 H, H-3a-H-3b), 8.52 (d, J = 7.6 Hz, 4 H, 
Ar-H), 8.27 (d, J = 7.7 Hz, 2 H, Ar-H), 7.73 (d, J = 7.7 Hz, 2 H, 
Ar-H), 7.69 (d, J = 4.7 Hz, 4 H, Ar-H), 2.74 (s, 3 H, CH3), 2.70 (s, 6 
H, CH3), 1.53 (s, 2 H, H-1a-H-1b), 1.60 (s, 2 H, H-1a-H-1b) ppm. UV/Vis 
(CH2Cl2): λmax = 434 (4.47), 577 (4.94), 734 (3.98), 804 
(3.95), 912 (3.70), 1049 (3.82) nm. HRMS-ESI calcd. for C68H36F12N6 
[M + H]+: 1233.2756; found 1233.2764.

Acknowledgments

R. P. gratefully acknowledges the FP7 Future and Emerging 
Technologies for Energy Efficiency Programme through the 
project PEPDIODE.

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