Confused Porphyrins

Doubly N-Fused Pentaphyrin

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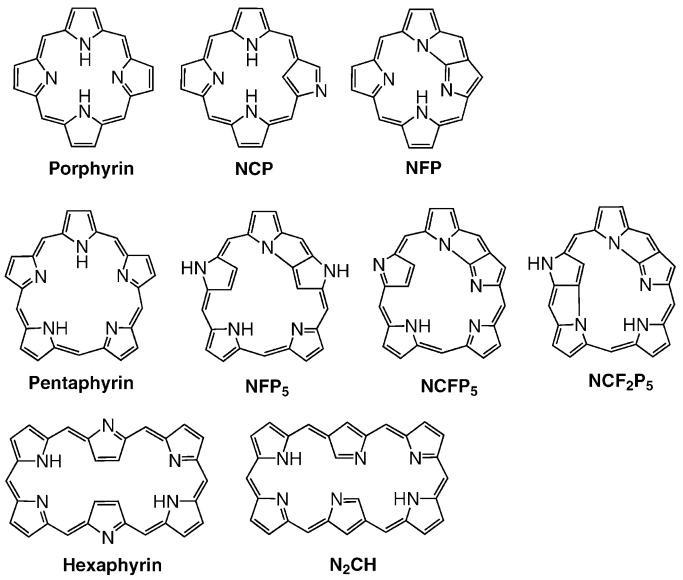
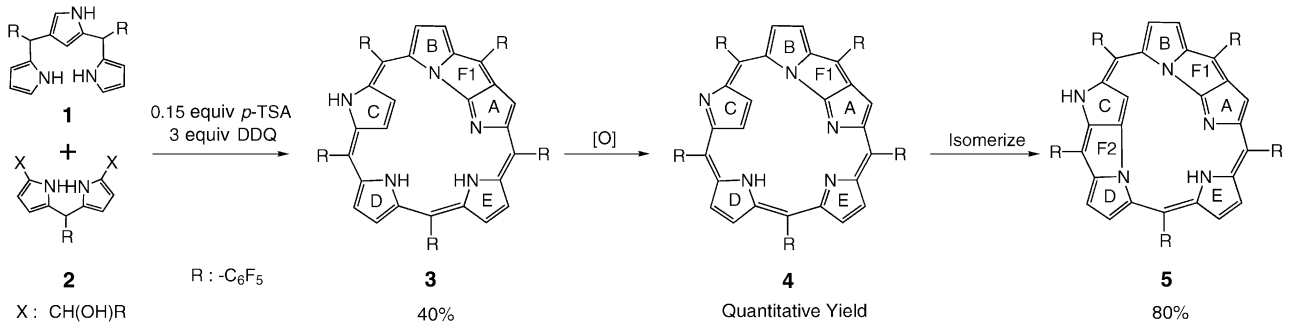


Increasing attention has recently been devoted to porphyrin analogues because of interest in their versatile electronic structures, rich coordination chemistry, and their possibilities for use in a variety of applications.[1] Among the various modifications of the porphyrin framework, changing the positions of the pyrrole linkage from α-α′ to α-β′ is of particular interest because so-called confused porphyrinoids could be synthesized easily by using one-pot pyrrole–aldehyde condensation or by replacing the oligopyrrole units with a confused ring in the standard porphyrin synthesis. Such analogues exhibit the peculiar chemistry already shown by N-confused porphyrin (NCP).[2] Previously, we reported the first example of hexapyrrolic confused porphyrinoids, the doubly N-confused hexaphyrins (N_2CH), that possess two N_3C compartments for the complexation of two metal ions in the cavity.[3] The successful results obtained with these hexaphyrins encouraged us to extend this approach to other expanded porphyrinoids. As a target, we chose a pentapyrrolic porphyrin, pentaphyrin,[4] because the *meso*-aryl pentaphyrin is shown to exist in the form of the N-fused pentaphyrin (NFP_5) and thus, the introduction of the confused pyrrole into its tripentacyclic ring may afford the isomer of NFP_5 which displays different chemical and physical properties.[5] Herein we report the first synthesis and structural characterization of the novel pentapyrrolic porphyrinoids: N-confused, N-fused pentaphyrin ($NCFP_5$) and N-confused, doubly N-fused pentaphyrin (NCF_2P_5). Amazingly, NCF_2P_5 has two different types of fused tripentacyclic rings (confused and normal) in the core. Such tripentacyclic rings were originally found in the N-fused porphyrin (NFP) derived from NCP and NFP_5.[5,6] Introduction of the confused pyrrole rings, at least in the tetra- and pentapyrrolic macrocycles, generally promotes the formation of a fused tripentacyclic ring.

The synthesis of the N-confused pentaphyrins is outlined in Scheme 1. Briefly, a [3+2] acid-catalyzed condensation of N-confused tripyrrane **1** and dipyrromethane dicarbinol **2** in the presence of *p*-toluenesulfonic acid (*p*-TSA), followed by oxidation with 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ), resulted in the reduced form of N-confused, N-fused pentaphyrin ($NCFP_5$, **3**) as a brown solid in 40% yield. The FAB mass spectrum of **3** showed a signal for the molecular ion at *m*/*z* 1217, which suggests the presence of the pentapyrrolic macrocycle. Signals attributed to **3** appeared in the region from $\delta = 5$ to 13 ppm in the ^{1}H NMR spectrum recorded in $CDCl_3$ (Table 1). The pyrrolic β-CH and NH protons of inverted ring C resonated at $\delta = 7.38$, 7.02, and 8.82 ppm, while the singlet signal corresponding to the β-CH group of fused ring A was observed at $\delta = 5.67$ ppm, which



Scheme 1. Synthesis of N-confused, doubly N-fused pentaphyrin (**5**).

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Table 1: Selected physical data for **3**–**5**.

3: m.p. >300 °C (decomp); ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 12.21$ (s, 1H, NH), 8.82 (s, 1H, NH), 7.38 (dd, $J = 3.6$, 2.4 Hz, 1H), 7.15 (br s, 1H, NH), 7.02 (dd, $J = 3.6$, 4.2 Hz, 1H), 6.39 (m, 1H), 6.21 (m, 3H), 5.91 (d, $J = 6.0$ Hz, 1H), 5.75 (d, $J = 6.0$ Hz, 1H), 5.67 (s, 1H, β-CH of ring A); UV/Vis (CH_2Cl_2): λ_{max} [nm] (ε [$mol^{-1}\,dm^3\,cm^{-1}$]): 448 (60000), 509 (41000), 718 (6600); HRMS (FAB): calcd for $C_{55}H_{13}F_{25}N_5$ $[M+H]^+$: 1218.0772; found: 1218.0789; elemental analysis calcd for $C_{55}H_{12}F_{25}N_5$: C 54.25, H 0.99, N 5.75; found: C 54.20, H 1.21, N 5.74.

4: m.p. >300 °C (decomp); ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 8.68$ (m, 1H), 8.57 (d, $J = 6.0$ Hz, 1H), 8.26 (s, 1H, β-CH of ring A), 7.76 (m, 1H), 7.64 (d, $J = 6.0$ Hz, 1H), 7.57 (d, $J = 3.0$ Hz, 1H), 7.45 (d, $J = 6.0$ Hz, 1H), 4.04 (d, $J = 6.0$ Hz, 1H) 3.75 (d, $J = 6.0$ Hz, 1H), 3.65 (s, 1H, NH); UV/Vis (CH_2Cl_2): λ_{max} [nm] (ε [$mol^{-1}\,dm^3\,cm^{-1}$]): 351 (40000), 380 (43000), 517 (69000); HRMS (FAB): calcd for $C_{55}H_{11}F_{25}N_5$ $[M+H]^+$: 1216.0615; found: 1216.0601.

5: m.p. >300 °C (decomp); ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 12.07$ (s, 1H, NH), 7.95 (s, 1H, β-CH of ring C), 7.38 (s, 1H, NH), 6.38 (m, 1H), 6.21 (m, 1H), 5.89 (m, 1H), 5.71 (d, $J = 6.0$ Hz, 1H), 5.66 (m, 1H), 5.61 (d, $J = 6.0$ Hz, 1H), 5.52 (s, 1H, β-CH of ring A); UV/Vis (CH_2Cl_2): λ_{max} [nm] (ε [$mol^{-1}\,dm^3\,cm^{-1}$]): 401 (57000), 503 (42000), 584 (13000), 630 (10000); HRMS (FAB): calcd for $C_{55}H_{11}F_{25}N_5$ $[M+H]^+$: 1216.0615; found: 1216.0672; elemental analysis calcd for $C_{55}H_{10}F_{25}N_5$: C 54.34, H 0.83, N 5.76; found: C 54.36, H 0.98, N 5.99.

proved that **3** was a 24π nonaromatic compound. Furthermore, the inner NH group of normal ring E appeared at $\delta =$ 12.21 ppm as a result of the strong hydrogen-bonding interaction with the neighboring nitrogen atom of ring A. Like NFP,[6] the absence of an α-CH (ring A) resonance suggested that it was directly fused with the adjacent pyrrole N atom, thus resulting in the formation of a tripentacyclic ring (A-F1-B). The electronic spectrum of **3** showed three broad bands between 445 and 720 nm, with the tail of the longest wavelength band reaching to around 1000 nm (Figure 1).

Further oxidation of **3** resulted in the quantitative formation of **4**. The FAB mass spctrum of **4** showed a molecular ion signal at m/z 1215, which is two mass units less than that of **3**. In contrast to **3**, the ^{1}H NMR spectrum of **4** (Table 1) was consistent with a 22π aromatic ring current effect, where the β-CH atoms on rings C and A resonated at $\delta = 4.04$, 3.75, and 8.26 ppm, and the inner NH proton was

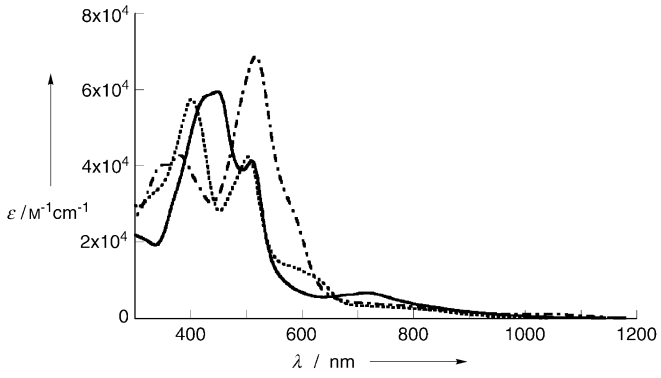

Figure 1. Absorption spectra of **3** (——), **4** (–•–•), and **5** (••••).

observed at $\delta = 3.65$ ppm. The aromatic nature of **4** was also suggested from a Soret-like band at 517 nm in the electronic spectrum. However, compound **4** was quite unstable and gradually isomerized in CH_2Cl_2 at room temperature over two days to form the doubly N-fused porphyrinoid **5** as a brown solid in 80% yield.[7]

The FAB mass spectrum of **5** showed a molecular ion signal at m/z 1215, which suggested that the compound was an isomer of **4**. Surprisingly, the ^{1}H NMR spectrum of **5** (Table 1) showed that one of the β-CH protons in ring C had disappeared. The newly formed NH group and the β-CH protons of ring C resonated at $\delta = 7.38$ and 7.95 ppm, respectively, while the β-CH group of ring A resonated at 5.52 ppm. In addition, the inner NH proton (ring D) of **4** shifted to the neighboring pyrrole (ring E) and resonated at $\delta = 12.07$ ppm. The NMR spectrum is thus consistent with the formation of a second tripentacyclic ring (C-F2-D) as well as the 24π anti-aromatic nature of the molecule. Thus, isomerization took place with loss of aromatic stabilization of the pentaphyrin core. The detailed mechanism for the isomerization of **4** is not clear yet, but it is likely that the release of steric repulsion between the inverted pyrrole rings C and D might be triggered by the formation of a shorter atomic distance between the pyrrolic N atom of ring D and the to-be-bonded carbon atom of ring C in **4**. This distance has been estimated to be 2.969 Å from the optimized structures calculated at the PM3 level (see the Supporting Information). The electronic absorption spectrum of **5** showed three broad bands between 300 and 800 nm, which further supports the anti-aromatic character of **5** (Figure 1).

The explicit structure of the N-confused, doubly N-fused pentaphyrin (NCF_2P_5, **5**) was revealed by X-ray single-crystal analysis (Figure 2).[8] As predicted from the above observations, there are two tripentacyclic rings (A-F1-B and C-F2-D) and a pyrrole ring in the macrocycle (**5**). Both the nitrogen atoms in one of the fused rings (A-F1-B) are inside the ring, while in the other tripentacyclic ring (C-F2-D), the outward and inward pointing nitrogen atoms were found in the macrocyclic core. The core plane consisting of 30 atoms is highly distorted from the least-squares plane, with a mean deviation of 0.413 Å. The dihedral angles between the core plane and the fused rings A-F1-B and C-F2-D, and the N5 pyrrole ring are 18.3(1), 162.2(2), and 130.1(3)°, respectively. Each asymmetric unit of the crystal data contains one pentaphyrin with a cocrystallized acetonitrile solvent molecule. The distance between N3 and the nitrogen atom of the acetonitrile molecule is 2.95(1) Å, which is within the range of a hydrogen-bonding interaction.

To confirm the positions of the nitrogen atoms unambiguously, the bond lengths and angles of the two fused rings were compared with those of NFP and NFP_5. The bond length (N1–C3) and angles (C1-N1-C3) of ring A-F1-B are 1.30(1) Å and 101.6(8)°, which are comparable to the values found in confused NFP (1.28 Å and 104°).[6] On the other hand, the corresponding bond length (C12–C13) and angle (C11-C12-C13) for ring C-F2-D are 1.37(1) Å and 107.1(9)°, which are similar to those of 1.39(1) Å and 107.3(9)° in normal NFP_5.[5] Thus, ring A-F1-B is considered to be a confused tripentacyclic ring, while ring C-F2-D is assigned as a normal

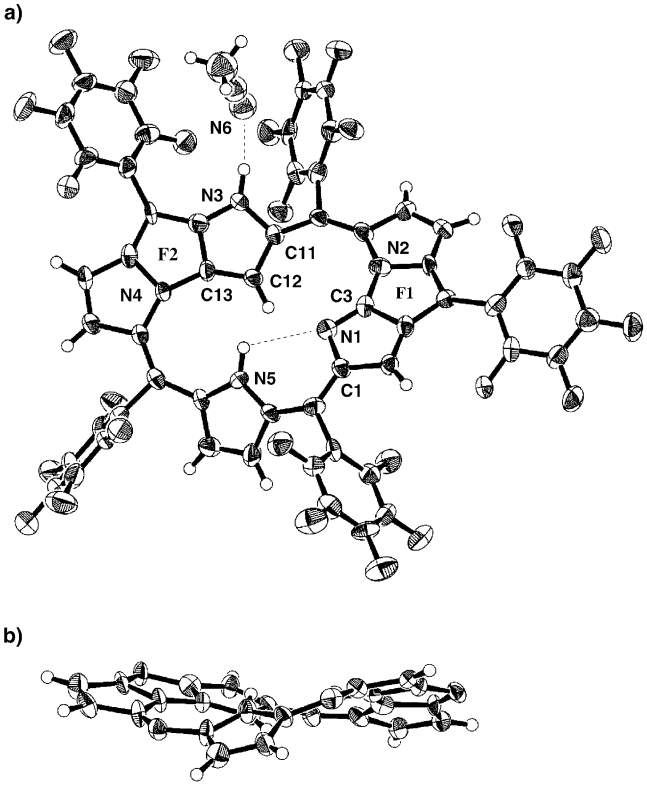

Figure 2. X-ray structure of N-confused, doubly N-fused pentaphyrin **5**: a) top view and b) side view. Hydrogen-bonding interactions are indicated by broken lines. The solvent molecule and the *meso*-pentafluorophenyl groups are omitted for clarity in (b).

tripentacyclic ring. Bond alternation (single, double) is very clearly observed in the structure, which reflects the non- or weak antiaromatic character of **5** (Figure 3). Similar to NFP and NFP_5, the proton on N5 shows an intramolecular hydrogen-bonding interaction with the adjacent pyrrolic nitrogen atom N1 that is at a distance of 2.95(1) Å.

In summary, we have successfully demonstrated the synthesis of N-confused, N-fused pentaphyrin and N-confused, doubly N-fused pentaphyrin. It has been clearly shown that the *meso*-aryl β-free derivatives display an interesting structural diversity,[9] which is unknown for the β-substituted pentaphyrins. The two different types of fused rings indicate that both the inverted conformation of normal and confused pyrrole rings can induce the formation of a tripentacyclic ring. The introduction of further confusion into the macrocyclic system would open the way to hitherto unexplored N-fused porphyrinoid chemistry. Efforts to prepare a series of confused expanded porphyrins are currently underway.

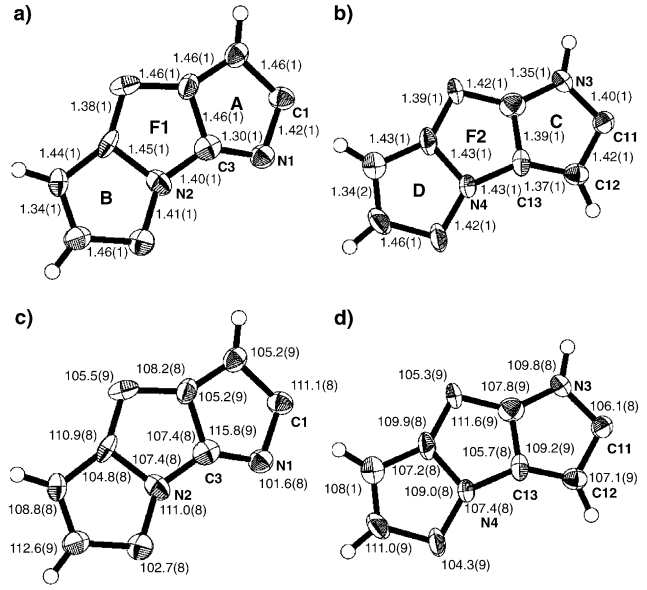

Figure 3. Bond lengths [Å] and angles [°] of the tripentacyclic rings: A-F1-B (a, c) and C-F2-D (b, d).

Experimental Section

3: A mixture of **1** (100 mg, 0.18 mmol) and **2** (126 mg, 0.18 mmol) in CH_2Cl_2 were stirred in a nitrogen atmosphere for 15 min at room temperature. *p*-Toluenesulfonic acid (*p*-TSA; 5.1 mg, 0.027 mmol) was then added to the above mixture and the solution stirred for a further 1 h in the dark. The reaction mixture was then passed through a column of silica gel using CH_2Cl_2 (200 mL) as the eluent. DDQ (122 mg, 0.54 mmol) was added to the combined solution and the mixture stirred for a further 1 h at room temperature. After removal of the solvent, the crude product was purified by column chromatography, first on basic alumina and then on silica gel. A brown fraction was eluted with CH_2Cl_2/hexane (40:60) which, on removal of the solvent, gave **3** (87 mg, 40%) as a brown solid.

4: DDQ (19 mg, 0.018 mmol) was added to a solution of **3** (20 mg, 0.016 mmol) in CH_2Cl_2 (10 mL), and the mixture was stirred at room temperature for 10 min. After removal of the solvent, the crude product was purified by column chromatography firstly on alumina and then on silica gel. A pink fraction eluted with CH_2Cl_2/hexane (90:10) which gave **4** (20 mg, 100%) as a green solid.

5: Compound **4** (15 mg, 0.012 mmol) was dissolved in CH_2Cl_2 (15 mL). The color of the solution gradually changed from pink to brown over 2 days at room temperature. The solvent was evaporated and the residue purified by column chromatography on silica gel. A brown fraction was eluted with CH_2Cl_2/hexane (20:80) which gave **5** (12 mg, 80%) as a brown solid. The remaining product was identified as starting material **4**.

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[1] *The Porphyrin Handbook*, *Vol. 2* (Eds.: K. M. Kadish, K. M. Smith, R. Guilard), Academic, San Diego, **2000**.
[2] a) H. Furuta, T. Asano, T. Ogawa, *J. Am. Chem. Soc.* **1994**, *116*, 767–768; b) P. J. Chmielewski, L. Latos-Grażyński, K. Rachlewicz, T. Głowiak, *Angew. Chem.* **1994**, *106*, 805–808; *Angew. Chem. Int. Ed. Engl.* **1994**, *33*, 779–781; c) H. Furuta, H. Maeda, A. Osuka, *Chem. Commun.* **2002**, 1795–1804; d) L. Latos-Grażyński in ref. [1], chapt. 14.
[3] A. Srinivasan, T. Ishizuka, A. Osuka, H. Furuta, *J. Am. Chem. Soc.* **2003**, *125*, 878–879.
[4] β-Alkyl *meso*-free pentaphyrins and their analogues are synthesized, see a) H. Rexhausen, A. Gossauer, *J. Chem. Soc. Chem. Commun.* **1983**, 275; b) A. Jasat, D. Dolphin, *Chem. Rev.* **1997**, *97*,

2267 – 2340; c) J. L. Sessler, S. J. Weghorn, *Expanded, Contracted and Isomeric Porphyrins*, Pergamon, New York, **1997**.
[5] J.-Y. Shin, H. Furuta, A. Osuka, *Angew. Chem.* **2001**, *113*, 639 – 641; *Angew. Chem. Int. Ed.* **2001**, *40*, 619 – 621.
[6] a) H. Furuta, T. Ishizuka, A. Osuka, T. Ogawa, *J. Am. Chem. Soc.* **1999**, *121*, 2945 – 2946; b) H. Furuta, T. Ishizuka, A. Osuka, T. Ogawa, *J. Am. Chem. Soc.* **2000**, *122*, 5748 – 5757; c) B. Kiran, M. H. Nguyen, *J. Organomet. Chem.* **2002**, *643–644*, 265 – 271.
[7] It is noteworthy that the reported partially *meso*-aryl-substituted pentaphyrins were also quite unstable, even in the solid state, and decomposed when exposed to air with a half-live of several days: C. Brückner, E. D. Sternberg, R. W. Boyle, D. Dolphin, *Chem. Commun.* **1997**, 1689 – 1690.
[8] Crystal data for **6**: $C_{55}H_{10}N_5F_{25}\cdot CH_3CN$, $M_r = 1256.73$, triclinic, space group $P\bar{1}$ (no. 2), $a = 10.287(8)$, $b = 11.981(9)$, $c = 19.08(1)$ Å, $\alpha = 89.86(6)$, $\beta = 83.19(6)$, $\gamma = 87.38(6)°$, $V = 2332.8(3)$ Å^3, $T = -150.0\,°C$, $Z = 2$, 19939 measured reflections, 10250 unique reflections, 3169 with $I \geq 3\sigma(I)$ used in refinement, $R = 0.072$, $R_w = 0.057$, GOF = 0.756. CCDC-219943 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/conts/retrieving.html (or from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB21EZ, UK; fax: (+44) 1223-336-033; or deposit@ccdc.cam.ac.uk).
[9] By applying the same synthetic procedure as used for **3**, the reduced form of normal N-fused pentaphyrin (NFP_5) was obtained from normal tripyrrane and dipyrromethane dicarbinol **6** in 36% yield, and further oxidation led to the quantitative formation of aromatic NFP_5, which was twofold higher than that of the reported Rothemund-type synthesis; see ref. [5].