# *meso*-Substituted expanded porphyrins: new and stable hexaphyrins

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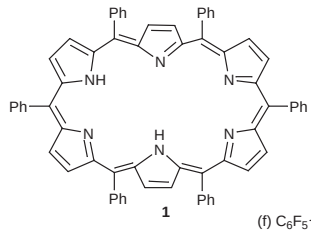
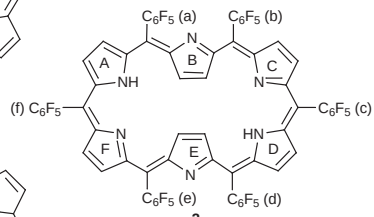
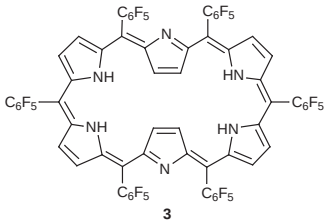
**New hexapyrrolic macrocycles have been synthesized and characterized by UV–VIS, mass and NMR spectroscopy and X-ray crystallography.**

In recent years there has been considerable research directed towards the synthesis and study of systems involving expanded porphyrin macrocycles. Such systems are finding applications in the fields of medicine, neutral substrate binding and anion recognition.[1]

Recent studies have shown that inverted[2] and expanded[3] porphyrins can be formed during the Rothemund synthesis of porphyrins. Very recently the synthesis of an interesting expanded porphyrin, the hexaphenylhexaphyrin **1**, has been reported.[4] The poor stability of that compound hampered its spectroscopic characterisation.




Here we report the synthesis and characterisation by spectroscopic techniques of stable *meso*-hexa(pentafluorophenyl)hexaphyrins **2** and **3**; the structure considered for **2** was also confirmed by X-ray crystallography. These new compounds were obtained during the Rothemund synthesis of *meso*-tetra(pentafluorophenyl)porphyrin under modified experimental conditions:[5] addition of pentafluorobenzaldehyde to a refluxing mixture of glacial AcOH and $PhNO_2$, followed by the dropwise addition of pyrrole. The final mixture was refluxed for 45 min, the solvents were removed by distillation, and the residue was then purified by silica gel column chromatography. The first fraction to be collected contained the expected porphyrin (15%), and a more polar bluish fraction was then eluted (*ca.* 1%). Thin layer chromatographic (TLC) analysis of this fraction revealed the presence of two main compounds with blue and violet colours: $\lambda_{max}(CH_2Cl_2)$/nm (log $\varepsilon$) 591 (4.95), 762 (3.82) and 568 (5.64), 712 (4.67), respectively (Fig. 1).

Both compounds show, in their mass spectra (LSIMS), the same molecular ions at *m/z* 1462, which correspond to molecules formed from six pyrroles and six pentafluorobenzaldehyde units. The fact that both compounds show the same molecular ions was an unexpected observation, since they can be interconverted by hydrogenation–dehydrogenation processes: by reacting the blue compound with DDQ in $CHCl_3$ the violet one is obtained and reduction of the violet compound with $TsNHNH_2$ gives the blue one.

Surprisingly, the $^1$H NMR spectra of these compounds show that they have aromatic features: for the major (violet) compound, signals at $\delta$ −2.43, −1.98, 9.11 and 9.49 are observed. The analysis of this spectrum, together with the HETCOR ($^1$H/$^{13}$C) spectrum, revealed that the singlet (4H) at $\delta$ −2.43 correlates with the carbon resonance at $\delta$ 122.9. The very broad singlet at $\delta$ −1.98 shows no correlation with carbons and was, thus, attributed to N*H* protons. This signal became more narrow when the proton spectrum was registered at 273.1 K. Based on these spectra, and on the $^{19}$F NMR spectrum (*vide infra*), the structure **2** is proposed for this macrocycle. For the blue compound the hydrogenated structure **3** is considered, based mainly on its mass and NMR spectra and its dehydrogenation to **2**. The $^1$H NMR spectrum of the blue compound is significatively different from that of compound **2**: signals at $\delta$ 2.55 (4H, s), 4.40 (br s), 7.63 (4H, d, *J* 4.7) and 7.73 (4H, d, *J* 4.7) are observed; there are no signals at negative $\delta$ values. The signal at $\delta$ 4.40 is due to the N*H* protons since it disappears after shaking with $D_2O$. From the HETCOR ($^1$H/$^{13}$C) experiment we can observe a correlation between the singlet at $\delta$ 2.55 and the resonance at $\delta$ 119.4 while the doublets at $\delta$ 7.63 and 7.73 correlate, respectively, with the carbon resonances at $\delta$ 130.2 and 129.2. From the NMR spectra of the blue product it is obvious that there are no sp$^3$ carbons in this reduced compound.

The fact that both compounds show the same ion at *m/z* 1462 can be explained by a fast hydrogenation of **2** to **3** during the acquisition of the mass spectra.† This was confirmed by the use of deuterated nitrobenzyl alcohol as matrix: **2** gives a signal at *m/z* 1466, corresponding to the addition of '2D' plus the exchange of the two N*H* by N*D*; **3** gives a set of signals at *m/z* 1463–1466 corresponding to the successive exchange of the four N*H* by N*D*.

For compound **2**, the resonance at $\delta$ −2.43 corresponds to the 'inner', strongly shielded, four β-protons of the two inverted pyrrole rings (B and E). Since the N*H* protons resonate at $\delta$ −1.98 we can say that they are 'inside' the macrocycle and not in the inverted pyrrole rings. The 'outer' β-pyrrolic protons appear as two doublets (4H each) at $\delta$ 9.11 and 9.44; they correlate, in the HETCOR ($^1$H/$^{13}$C) spectrum, with the carbon resonances at $\delta$ 132.5 and 135.0, respectively. This last observation confirms that each pyrrole ring (A, C, D and F) has

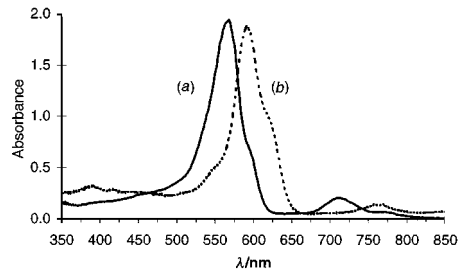



**Fig. 1** Electronic spectra of compounds (*a*) **2** and (*b*) **3**.

non-equivalent β-pyrrolic carbons and protons. The resonances of all α-pyrrolic carbons ($\delta$ 156.3 for rings B, E and 149.5, 149.7 for the other rings) were determined by the connectivities found in the HMBC spectrum. The resonances of the *meso* carbons appear at $\delta$ 106.2 and 117.4, whereas those of the pentafluorophenyl rings appear as multiplets with low intensity (due to both relaxation processes and coupling with the fluorine atoms).

From the $^{19}$F NMR spectrum of **2** (Table 1), by comparing the relative signal integrals, we can conclude that there are two types of pentafluorophenyl rings in a 2 : 1 ratio. This result is also compatible with the proposed structure: the two *meso*-pentafluorophenyl rings (c) and (f) are in a different environment than the other four phenyl rings.

The acidic character of the N*H* protons and the stability of *meso*-hexa(pentafluorophenyl)hexaphyrin **2** was demonstrated by the following experiments: (i) addition of several drops of a solution of NaOD (in $D_2O$) to a $CDCl_3$ solution of this compound, followed by a gentle shaking, led to the appearance of two signals ($\delta$ −2.43 and −5.91) in the negative region of the $^1$H NMR spectrum; (ii) after a more vigorous shaking, only the resonance at $\delta$ −5.91 was observed for the β-H of rings B and E. This strong shielding of the 'inner' protons suggests the conversion of the macrocycle into the corresponding dianion; (iii) the neutralization of this solution allowed us to recover the *meso*-hexa(pentafluorophenyl)hexaphyrin **2**.

All the NMR results discussed here support the proposed structure **2** for this new 26π electron macrocycle. The final proof for the structure of this compound was obtained by X-ray single crystal diffraction.

The X-ray structure of **2**‡ is presented in Fig. 2. The macrocycle displays a nonplanar conformation [see Fig. 2(*b*)] with four *exo* pyrrolic rings (A, C, D and F) and two *endo* rings (B and E). π-Electron delocalization in the macrocyclic core is apparent from the observed range of bond lengths: 1.33(1)–1.39(1) Å for the N–Cα bonds and 1.39(1)–1.42(1) Å for the Cα-C*meso* bonds. On the other hand, the range found for the C–C bond lengths in the pyrrole rings suggest that these bonds have some double or single bond character: 1.36(1)–1.32(1) Å for the Cβ–Cβ bonds and 1.42(1)–1.46(1) Å for the Cα–Cβ bonds. The six pentafluorophenyl rings are tilted by 47.3(1), 43.3(1), 51.0(1), 68.4(1), 78.8(1) and 81.4(1)° relative to the least-square plane defined by the atoms of the macrocyclic core. Consequently, the average bond length between the *meso* carbons and pentafluorophenyl rings of 1.50(1) Å indicates an absence of a π interaction between those rings and the macrocyclic core.

This set of structural features is consistent with a 26π electron aromatic current ring extended over the nitrogens, the α-pyrrolic carbons and the *meso* carbons of the macrocyclic ring.

The nonplanarity of the macrocycle is due to its large dimensions [N(39)···N(45) 2.93(1), N(18)···N(24) 2.82(1), N(24)···N(39) 7.58(1) and N(18)···N(45) 7.60(1) Å] and the bulk of the *meso*-pentafluorophenyl rings. In order to minimise the steric interactions, the macrocycle looses the planarity of its core, leading an average deviation of 0.536(8) Å of the atoms belonging to the macrocyclic core from the least-squares plane defined by their atomic positions.

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**Table 1** $^{19}$F NMR chemical shifts (ppm, from TFA) observed in the spectrum of the *meso*-hexa(pentafluorophenyl)hexaphyrin **2**

| | (a), (b), (d) and (e) phenyl rings | (c) and (f) phenyl rings |
|---|---|---|
| *o*-F | −136.19 (4F) | −135.63 (2F) |
| *m*-F | −162.22 (4F) | −159.61 (2F) |
| *p*-F | −151.94 (2F) | −149.08 (1F) |

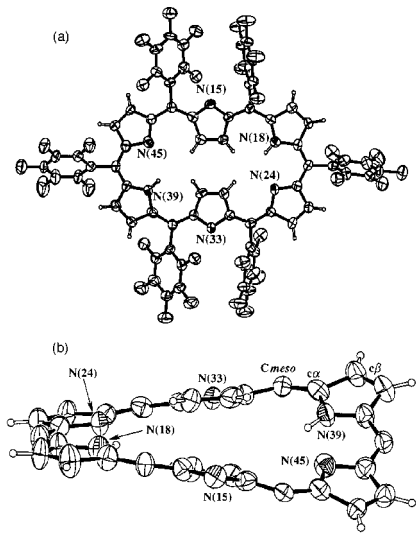


**Fig. 2** (*a*) Top and (*b*) side views of **2** (thermal ellipsoids at the 40% probability level). The side view shows the nonplanarity of the macrocyclic core. In both views only the labelling scheme for nitrogen atoms is presented, and in (*b*) the phenyl rings are omitted for clarity.

## Notes and references

† A similar hydrogenation process was observed during the acquisition of the mass spectrum of the *meso*-tetra(pentafluorophenyl)porphyrin.

‡ *Crystal data* for **2**: $C_{66}H_{14}F_{30}N_6$, $M$ = 1460.83; monoclinic, space group $P2_1/c$, $a$ = 10.911(10), $b$ = 27.242(23), $c$ = 19.466(21) Å, $\beta$ = 90.31(1)°, $V$ = 5786(10) Å$^3$, $Z$ = 4, $D_c$ = 1.677 g cm$^{-3}$, $\mu$ = 0.168 mm$^{-1}$. A violet needle-like crystal was mounted in a Lindmann capillary under saturated atmosphere of the mother-liquor. The X-ray data were collected with graphite monochromated Mo-Kα radiation ($\lambda$ = 0.71073 Å) on a Mar-research image plate system at Reading University. The crystal was positioned at 75 mm from the plate. An exposure time of 5 min was used per 2º frame collected. Data analysis was performed with the XDS program (ref. 6). Intensities were not corrected for absorption effects. 12030 reflections collected in the range 2.0 < $\theta$ < 26.1 (*hkl* range indices: 0 ⩽ $h$ ⩽ 11, −33 ⩽ $k$ ⩽ 33, −19 ⩽ $l$ ⩽ 19) were merged in the Laue symmetry group 2/*m* to 7246 unique reflections with a $R_{int}$ = 0.0454. The structure was solved by direct methods and refined by full-matrix least-squares methods on $F^2$ using the SHELX-97 package (ref. 7) Anisotropic parameters were used for all non-hydrogen atoms. The hydrogen atoms were included in the refinement in geometric positions with a $U_{iso}$ = 1.2$U_{eq}$ of the parent nitrogen atom. In agreement with $^1$H NMR results, two geometric arrangements for two N–H protons were considered: one proton at N(39) and one at N(18) or alternatively one proton at N(24) and the other at N(45). The first arrangement was considered as correct since it gave a slightly lower $R$ value (0.0789) than the second (0.0795). The final refinement of 920 parameters converged to $R$ and $wR$ values of 0.0785 and 0.2094 and GOF = 0.862 for the data with $I$ > 2$\sigma$($I$). The final $R$ and $wR$ values for all *hkl* data were 0.2304 and 0.2750, respectively. In the last difference Fourier map the residual electronic density was in the range of −0.341 to 0.281 e Å$^{-3}$. Molecular diagrams were made with ZORTEP (ref. 8). CCDC 182/1139. Crystal data are available in CIF format from the RSC web site, see: http://www.rsc.org/suppdata/cc/1999/385/

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