5,15,25-tris-nor-Hexapyrrin: the First Structurally Characterized Linear Hexapyrrin

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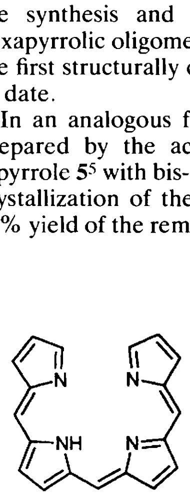
The first structurally characterized linear hexapyrrin is prepared with the solid state structure of the dihydrochloric acid salt showing it to lie in a nearly planar S-shaped conformation.

Linear oligopyrroles, such as bilin **1**, have been extensively studied,[1,2] and not surprisingly, have been prepared and scrutinised extensively in their role as building blocks for naturally occurring tetrapyrrolic macrocycles such as porphyrins, chlorins and corrins.[2] The same is true, but to a much lesser extent, for linear penta- and hexa-pyrroles. Indeed, few examples (*e.g.* **2** and **3**) of these latter kinds of compounds are known, with even less being known about their generalized structure and reactivity.[3,4] In this communication we report the synthesis and single crystal X-ray structure of the hexapyrrolic oligomer **4** that, to the best of our knowledge, is the first structurally characterized linear hexapyrrin prepared to date.

In an analogous fashion to hexapyrrin **3**,[4a] molecule **4** is prepared by the acid catalysed condensation of diformyl bipyrrole **5**[5] with bis-α-free bipyrrole **6**[5] (see Scheme 1). After crystallization of the crude reaction mixture, one obtains a 79% yield of the remarkably stable, highly crystalline 5,15,25-tris-nor-hexapyrrin **4**.† Unlike hexapyrrin **3**, this molecule is fully conjugated (24 π-electrons) along its entire length. As a result of this extended π-conjugation, molecule **4** displays rather intense absorbance bands in the visible and near IR region: λ_{max}/nm (ε/dm^3 mol^{-1} cm^{-1}): 502 (173000), 730 (46000), 806 (119000). The location (and blue shift) of these absorbance bands fits nicely into a progression of increasingly long, fully conjugated oligopyrrolic chromophores.[1]



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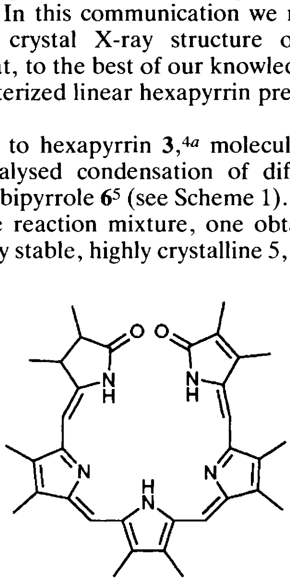

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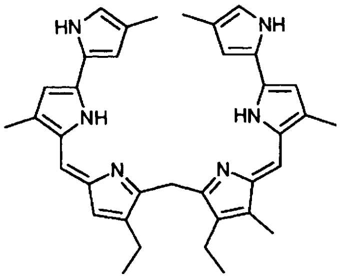

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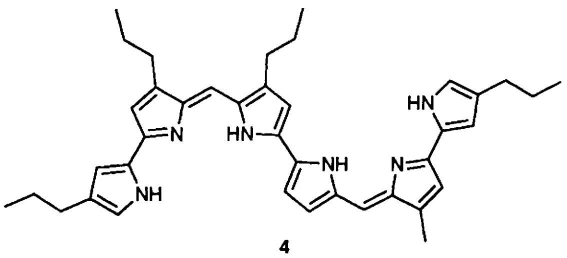

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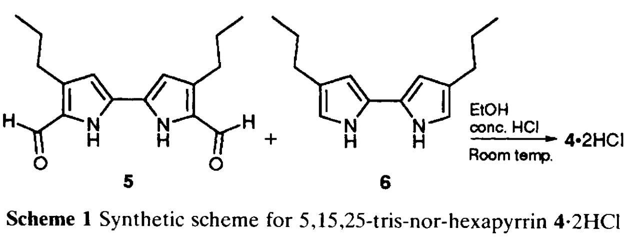


Scheme 1 Synthetic scheme for 5,15,25-tris-nor-hexapyrrin **4**·2HCl

In marked contrast to the solid state helical structure of pentapyrrin **2**,[3e] single crystal X-ray analysis of the dihydrochloric acid salt of **4** shows the molecule to lie in a nearly perfectly planar, extended S-shaped conformation (Fig. 1).‡ This conformation results in the formation of two clefts, each occupied by a chloride anion. Each chloride anion is held within hydrogen bonding distance of three proton-bearing nitrogen atoms [3.102(3) Å < Cl···H–N < 3.250(4) Å]. These three hydrogen-bonding interactions, it is presumed, provide the conformational rigidity required to allow for the observed intensity of the unusually sharp absorbance band at 502 nm in the VIS spectrum.

Information concerning the solution state structure of **4**·2HCl was gleaned from NOE spectroscopy. NOE between CH(12), (12′) and NH(3′), (3) (see Fig. 1 for atom numbering) confirmed that the S-shaped conformation observed in the solid is also prevalent in solution.§ However, the existence of a helical structure as a minor contributing species could not be ruled out by this method since no new crosspeaks would be observed for such a conformation. Certainly, the ability of this hexapyrrin to deform from planarity in solution was confirmed by the acid-catalysed reaction of hexapyrrin **4** with benzal-

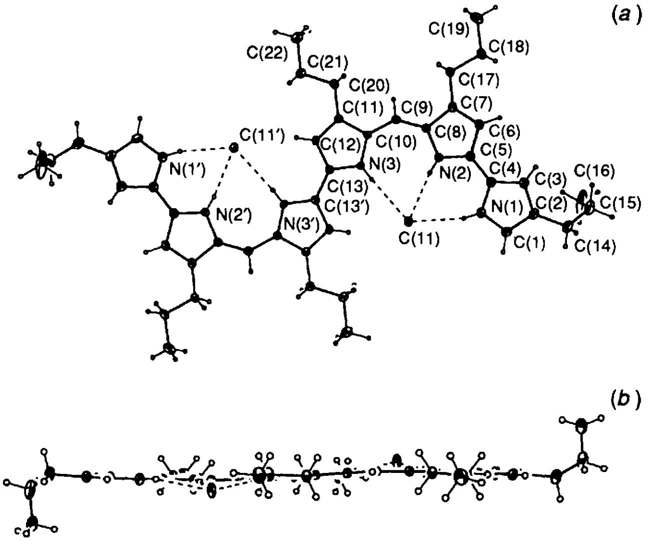
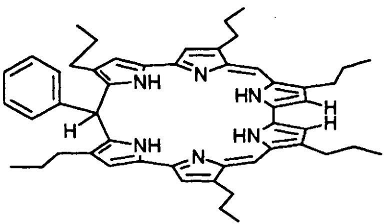


Fig. 1 Thermal ellipsoid plots of **4**·2HCl. Thermal ellipsoids are scaled to the 30% probability level. H atoms are scaled to an arbitrary size. (*a*) The hexapyrrin lies on an inversion centre at 1/2, 0, 1/2. Atoms labelled by ′ are related by $1 - x, -y, 1 - z$. Hydrogen-bonding interactions are indicated with dashed lines. The Cl$^-$ ion is within H-bonding distance of the pyrrole NH groups. The relevant distances (Å) and angles (°) are: N(1)–H(1)N···C(11), N···Cl 3.169(4), H···Cl 2.42(4), N–H···Cl 162(4); N(2)–H(2)N···C(11), N···Cl 3.102(3), H···Cl 2.33(4), N–H···Cl 172(4); N(3)–H(3)N···C(11), N···Cl 3.250(4), H···Cl 2.47(4), N–H···Cl 176(3). Side: The hexapyrrin is nearly planar in the solid state. The Cl$^-$ ion lies 0.537(1) Å above the plane through the nitrogen atoms to which it is hydrogen bonded.



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dehyde to produce macrocycle **7** in 83% yield.¶ Thus, even though the planar S-like conformation is a prevalent one in solution, it is not the only one that can be sampled under acid-catalysed or other equilibrating conditions.

The hydrogen-bonding interactions observed in the solid state and presumably also in solution make hexapyrrin **4** potentially well-suited for anion binding and/or transport experiments. Also, like other linear oligopyrroles, this molecule may form complexes with metal cations and potentially serve as an efficient through-membrane carrier for metal cations.[3d,4c,6] Finally, because hexapyrrin **4** contains reactive α- and β-free pyrrolic positions, it is possible to conceive that this compound could react with electrophilic materials other than benzaldehyde to produce a range of macrocyclic or nonmacrocyclic oligopyrrolic materials. Such possibilities are currently being explored in this laboratory.

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Footnotes

† The systematic name for **4** is 5,5′-bis((4,4′-dipropyl-2,2′-bipyrrol-5-yl)vinyl)-4,4′-dipropyl-2,2′-bipyrrole. **4**·2HCl crystallizes as brown, lustrous prisms mp decomp. above 230 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.00 (t, *J* 7.3 Hz, 6 H, $CH_2CH_2CH_3$), 1.08 (t, *J* 7.3 Hz, 12 H, $CH_2CH_2CH_3$), 1.68 (sextet, *J* 7.4 Hz, 4 H, $CH_2CH_2CH_3$) 1.82 (m, 8 H, $CH_2CH_2CH_3$), 2.61 (t, *J* 7.5 Hz, 4 H, $CH_2CH_2CH_3$), 2.82 (m, 8 H, $CH_2CH_2CH_3$), 6.19 (s, 2 H, α-pyrrolic H), 6.93 (s, 2 H, β-pyrrolic H), 7.08 (s, 2 H, β-pyrrolic H), 7.22 (s, 2 H, *meso*-H), 7.70 (s, 2 H, β-pyrrolic H), 11.16 (br, 2 H, NH), 11.62 (br, 2 H, NH), 11.82 (br, 2 H, NH); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 13.9, 14.0, 14.1, 23.4, 24.2, 28.7, 28.8, 29.0, 112.1, 116.4, 116.6, 118.0, 121.9, 126.9, 128.9, 129.1, 131.7, 135.9, 144.2, 147.3, 150.9; UV–VIS (CH_2Cl_2): λ_{max}/nm (ε) = 502 (173000), 730 (46000), 806 (119000); LRMS (FAB): *m/z* 705 (15%), 669 (100%); HRMS (FAB): calc. for $C_{44}H_{56}N_6$ *m/z* = 668.4566, found: 668.4550.

‡ *Crystal data*: **4**·2HCl $(C_{44}H_{58}N_6)^{+2}$-$2Cl^-$·$2CHCl_3$, M_r = 861.28. Dark brownish crystals were grown by vapour diffusion of hexanes into a solution of $(C_{44}H_{58}N_6)^{+2}$-$2Cl^-$ in $CHCl_3$ in the triclinic, space group $P\bar{1}$ with *a* 8.376(2), *b* 8.888(2), *c* 16.847(3) Å, α 98.63(2), β 92.95(2), γ 97.84(2)°, *V* 1225.1(5) Å^3, Dc 1.33 cm^{-3}, μ (Mo-Kα) 4.996 cm^{-1}, λ 0.71073 Å. Data were collected at 173 K on a Nicolet P3 diffractometer at −100 °C, equipped with a Nicolet LT-2 low-temperature device and using a graphite monochromator with Mo-Kα radiation (λ 0.71073 Å). A total of 6038 reflections were collected, of which 5650 were unique. The *R* for averaging symmetry equivalent reflections was equal to 0.019. Data were corrected for Lp effects but not absorption (μ 4.996 cm^{-1}). Data reduction and decay correction were performed using the SHELXTL-Plus software package.[7] The structure was solved by direct methods and refined by full-matrix least-squares analysis[7] with anisotropic thermal parameters for the non-H atoms. The molecule lies on an inversion center at 1/2, 0, 1/2 and, therefore, $Z = 1$. A total of 379 parameters were refined in blocks to a final $R = 0.0654$, w$R = 0.0622$ and a goodness-of-fit = 1.943 using 3289 reflections having $F > 4\sigma(F)$. Atomic coordinates, bond lengths and angles, and thermal parameters have been deposited at the Cambridge Crystallographic Data Centre. See Information for Authors, Issue No. 1.

§ The assignment of CH(12) and CH(12′) was made by the following observed NOE crosspeaks: CH_2(20), (17) and CH_2(20′), (17′) and CH(9), (9′); CH_2(17), (17′) and CH(6), (6′); CH_2(14), (14′) and CH(3), (3′); CH_2(14), (14′) and CH(1), (1′).

¶ Macrocycle **7** may be thought of as a dihydro-reduced intermediate along the pathway to a mono meso-substituted rosarin.[8] Appropriate characterization data has been obtained for this macrocycle (^{1}H and ^{13}C NMR, HRMS (FAB), UV–VIS).

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