5,10,15,20-Tetraphenylsapphyrin—Identification of a Pentapyrrolic Expanded Porphyrin in the Rothemund Synthesis

Piotr J. Chmielewski, Lechosław Latos-Grażyński,* and Krystyna Rachlewicz

Abstract: The Rothemund-type condensation of pyrrole and benzaldehyde yields, apart from 5,10,15,20-tetraphenylporphyrin ($TPPH_2$) and inverted tetraphenylporphyrin 2-aza-21-carba-5,10,15,20-tetraphenylporphyrin ($CTPPH_2$), a unique pentapyrrolic macrocyclic molecule with the aromatic nucleus of sapphyrin, namely, 5,10,15,20-tetraphenylsapphyrin ($TPSH_3$). Its unorthodox structural skeleton with an inverted pyrrole ring lying opposite to the bipyrrole unit accounts for the spectroscopic properties of the novel sapphyrin. The diprotonation of $TPSH_3$ acts as a trigger for a structural transformation involving a flip of the pyrrole units, which relocates the 27-NH pyrrolic nitrogen from the periphery into the center of the macrocycle. The formation of 5,10,15,20-tetraphenylsapphyrin proves that the pentapyrrolic product is accessible by the mechanism of the Rothemund synthesis.

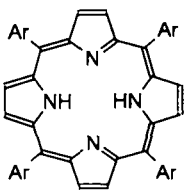
Keywords
porphyrinoids · Rothemund synthesis · sapphyrin

Introduction

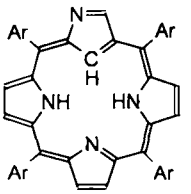
meso-Substituted porphyrins are favorable building blocks for the design of molecules with finely tuned chemical properties including a refined molecular architecture. Particular attention has been focused on biomimetic studies of dioxygen binding, catalysis, electron transfer, and novel artificial molecular devices involved in energy transfer.[1]

Since the first synthesis reported by Rothemund, 5,10,15,20-tetraphenylporphyrin and its aryl or alkyl analogues have been conventionally synthesized by a variety of procedures involving one- or two-step condensation of the pyrrole and aldehyde of choice.[2–6] A similar approach has been used for the efficient synthesis of core-modified porphyrins.[7] New routes to *meso*-tetraarylporphyrins, which make use of a MacDonald-type [2 + 2] condensation, were recently described, and unsymmetrically functionalized tetraarylporphyrins were prepared.[8] In spite of the impressive efforts to optimize tetraarylporphyrin synthesis, there has been little attention given to developing a feasible route to other oligopyrrolic macrocycles by direct reaction of two basic structural elements, a pyrrole and an alkyl or arylaldehyde.

Recently we discovered 2-aza-21-carba-5,10,15,20-tetra-*p*-tolylporphyrin ($CTTPH_2$), a novel isomer of the porphyrin 5,10,15,20-tetra-*p*-tolylporphyrin ($TTPH_2$) with an inverted pyrrole ring.[9] Around the same time, the synthesis and the X-ray structure of 2-aza-21-carba-5,10,15,20-tetraphenylporphyrin ($CTPPH_2$) was reported.[10] An isomer of 21-*N*-methyl-5,10,15,20-tetraphenylporphyrin with an inverted N-methylated pyrrole ring, 2-methyl-2-aza-5,10,15,20-tetraphenylporphyrin, has also been synthesized.[11] Formally a 21-carbaporphyrin, this compound still remains in the tetrapyrrolic class of macrocycles, since the porphyrin framework is preserved. To the best of our knowledge, only two other cases of porphyrin isomers are known: [18]porphyrin-(2.0.2.0) (porphycene) and [18]porphyrin-(2.1.0.1) (corrphycene).[12, 13] Compared to the regular and inverted porphyrin macrocycles, profound rearrangements of the linkage patterns between the four pyrrole moieties are required to generate frameworks of (2.0.2.0) or (2.1.0.1) isomers.



$TPPH_2$
$TTPH_2$

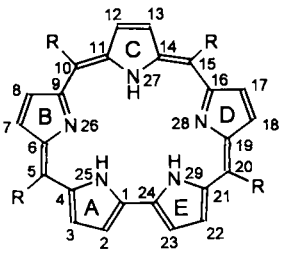


$CTPPH_2$ Ar = Ph
$CTTPH_2$ Ar = *p*-Tolyl

The fact that a 21-carbaporphyrin is accessible through a one-step mutation in the cyclopolymerization means that we have to revise the thesis that tetraphenylporphyrin is the sole macrocyclic product of the Rothemund-type condensation.[2–6] In fact, it raises a general question as to the involvement of other spontaneous cyclopolymerization routes, which might afford macrocycles belonging to the family of expanded porphyrins. This logical, formal extension of the self-assembly of pyrroles and aldehydes into a cyclic structure merely requires the incorporation of one pyrrole ring between *meso* and α carbons of the porphyrin macrocycle. Such an addition would lead to a larger aromatic, pyrrole-containing system, namely, sapphyrin.

[*] Prof. Dr. L. Latos-Grażyński, Dr. P. J. Chmielewski, Dr. K. Rachlewicz
Institute of Chemistry, University of Wrocław
14 F. Joliot-Curie Street, Wrocław 50383 (Poland)
Telefax: Int. code + (71)222-348
e-mail: llg@chem.uni.wroc.pl

0570-0833/95/0101-0068 $ 10.00+.25/0



Sapphyrin is the simplest member in the class of expanded porphyrins. The molecule possesses an overall aromatic 22 π-electron annulene framework.[14–19] In the representation of the structural formula of sapphyrin, the NH protons are generally located at the corners of an isosceles triangle marked out by the 25-N, 27-N, and 29-N pyrrolic nitrogens,[15–18] although this presumably reflects only an aesthetic preference for a mirror symmetry. Decaalkyl-substituted sapphyrin was discovered by Woodward and co-workers in their effort to synthesize vitamin B_{12}.[14, 16] The synthetic procedures, subsequently developed by Brodhurst et al.,[15] Bauer et al.,[16] and Sessler et al.,[17] require preorganized substrates and involve the MacDonald-type [3+2] condensation between a functionalized bipyrrole and a dicarboxyl-substituted dipyrrane.

In this paper, we report that the condensation of the pyrrole and benzaldehyde yields, apart from tetraphenylporphyrin and inverted tetraphenylporphyrin, a unique pentapyrrolic macrocyclic molecule possessing an aromatic sapphyrin nucleus, namely, 5,10,15,20-tetraphenylsapphyrin ($TPSH_3$). Structural and spectral properties of $TPSH_3$ are of particular interest because of its potential application as a ligand, a selective anion receptor, and a photosensitizer in photodynamic therapy.

Results and Discussion

The reaction of benzaldehyde ([D_5]benzaldehyde) with excess pyrrole (1:3 molar ratio) in dichloromethane and catalyzed by $BF_3 \cdot Et_2O$ (i.e., under modified conditions compared to those used in the optimized synthesis of a tetrapyrrole macrocycle[2–6]) yielded the expected tetraphenylporphyrin and isomeric 21-carbaporphyrin as the main macrocyclic substances, although with reduced yields. By carefully examining the minor fractions, we succeeded in pinpointing and isolating $TPSH_3$. This product was also identified by ^{1}H NMR spectroscopy as one of the products of the condensation of pyrrole and benzaldehyde (3:1 molar ratio) in refluxing propionic acid. Mass spectrometry (m/z = 679, HR-MS m/z = 679.2728) gave the empirical formula $C_{48}H_{33}N_5$ for the condensation product of interest. An electronic spectrum of $TPSH_3$ shows a split Soret-like band at 493 and 518 nm, indicative of polypyrrolic aromatic macrocycles, accompanied by Q bands at 640, 697, 710, and 790 nm (Fig. 1). The $TPSH_3$ also exhibits fluorescence properties as a result of an excitation in the Soret band region.

To account for the NMR spectral characteristic of $TPSH_3$ (Fig. 2 and 3, Table 1), we were forced to propose an unorthodox structural skeleton of sapphyrin in which the **C** pyrrole ring, opposite to the bipyrrole unit, is inverted. No structural data for neutral polyalkylated sapphyrins is available. Crystal structure analyses of the protonated forms typically demonstrate that a roughly planar arrangement is adopted with pyrrole nitrogens pointing toward the center of the macrocycle.[18, 19] In addition, the crystal structure of ozaphyrin, a furan-containing analogue of sapphyrin, shows that it is planar and that all pyrrolic nitrogens and furan oxygens are located inside the macrocycle.[20] The ^{1}H NMR study reveals that such a structure also prevails in solution for ozaphyrin and thioazaphyrin (thiophene-containing analogue of sapphyrin).[21]

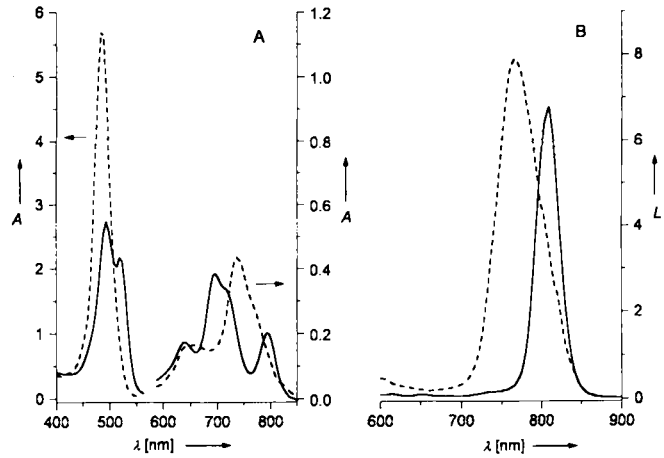


Fig. 1. The electronic (A) and fluorescence (B) spectra of $TPSH_3$ (solid line) and $TPSH_5^{2+}$ (dashed line) in dichloromethane. $TPSH_5^{2+}$ was obtained by addition of HCl. Excitation wavelengths were chosen at 520 nm ($TPSH_3$) and 490 nm ($TPSH_5^{2+}$) to produce the most intense fluorescence.

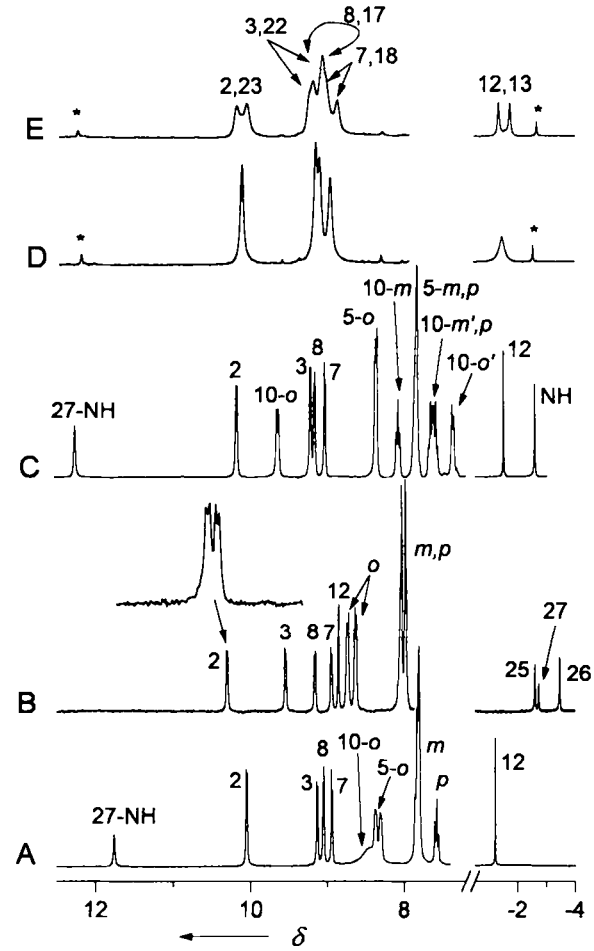


Fig. 2. The ^{1}H NMR spectra (300 MHz) of: A: $TPSH_3$ in [D]chloroform at 20 °C. B: $TPSH_5^{2+}$ in [D]chloroform containing HCl at 20 °C. The inset in spectrum B shows a representative example of the four-bond $^4J_{HH}$ coupling between β-CH and NH protons observed for all pyrrolic protons. C: $TPSH_3$ in [D_2]dichloromethane at −70 °C (the NH resonance reflects averaging among 25,26,28,29-NH positions). D: [D_{20}]$TPSD_3$ in [D_2]dichloromethane at −70 °C. E: [D_{20}]$TPSD_3$ in [D_2]dichloromethane at −94 °C. The *meso*-phenyl resonances, seen in A–C, are absent in D and E owing to the deuterium substitution. Resonance assignments follow the systematic numbering of the sapphyrin skeleton; *o*, *ortho*; *m*, *meta*; *p*, *para* phenyl resonances. In the case of an apparent equivalency of two positions, only a single label is shown. The residual NH resonances in D and C are marked by *.

  0570-0833/95/0101-0069 $ 10.00+.25/0

The unambiguous assignment of the $TPSH_3$ resonances was obtained by a selective deuteration of the 5,10,15,20-phenyl groups ($[D_{20}]TPSH_3$), an exchange of labile NH protons by deuterons in the presence of D_2O ($TPSD_3$), and 2D ^1H NMR COSY and NOESY experiments carried out at $-70\,^\circ C$ in $[D_2]$dichloromethane (Fig. 3). The ^1H NMR spectrum of $TPSH_3$ exhibits two AB patterns in the $\delta = 10.2-9.0$ region,

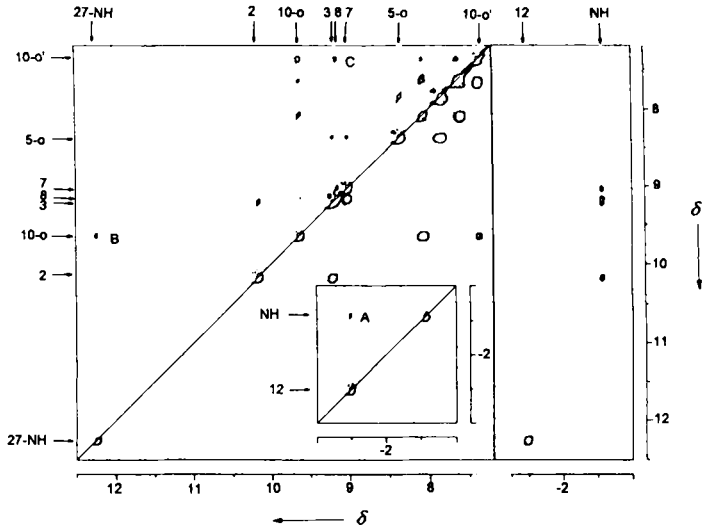


Fig. 3. The 2D ^1H NMR spectra (300 MHz) of $TPSH_3$ in $[D_2]$dichloromethane at $-70\,^\circ C$. The upper left triangle shows the NOESY map. The sections on the right show the COSY contours. The inset shows the upfield part of the COSY and NOESY maps. Assignments for the various resonances, marked by arrows, correspond to those in Figure 2. The crucial cross-peaks are labeled in the NOESY map: A: 25,26,28,29-NH–12,13-CH; B: 27-NH–*ortho* proton (*o'*) of the 10,15-phenyl rings; C: 7-H–*ortho* proton (*o*) of the 10-phenyl ring. The cross-peaks A, B, C correspond to through-space contacts indicated in Figure 4 by arrows.

which are readily assigned to regular pyrrole protons (rings: **A**, **B**, **D**, **E**). Two inner NH protons gave a broad singlet at 25 °C that sharpened to a narrow singlet at $-90\,^\circ C$ ($\Delta\nu_{1/2} = 9.9$ Hz). The definitive confirmation of the proposed $TPSH_3$ configuration was provided by the diagnostic chemical shifts of the scalar-coupled 12,13-CH ($\delta = -1.498$) and 27-NH ($\delta = 12.236$) resonances, which can both be assigned to the inverted pyrrole ring (Fig. 3, COSY section). In addition, the two strong nuclear Overhauser effects (NOE) of the inverted pyrrole ring **C** require the following spatial contacts: 25,26,28,29-NH–12,13-CH (Fig. 3, NOESY section, cross-peak A) and 27-NH–*ortho*-proton (*o'*) of the 10,15-phenyl rings (Fig. 3, NOESY section, cross-peak B). These are only attainable for the sapphyrin skeleton with an inverted structure.

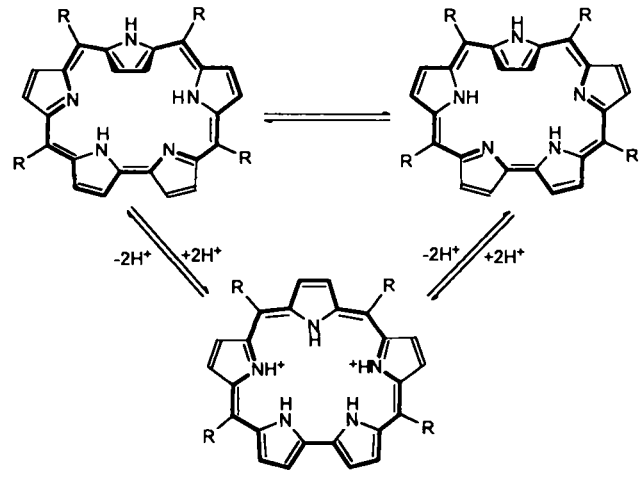
The 5,10,15,20-tetraphenylsapphyrin $TPSH_3$ is aromatic, because all outer pyrrole and *meso* phenyl resonances are strongly shifted downfield by the ring current effect (Table 1). The remarkable shift differences between outer and inner CH ($\Delta\delta = 11.6$) and NH ($\Delta\delta = 14.8$) pyrrolic protons support this conclusion, although other 22 π-electron planar conjugated systems demonstrate even larger shift differences between outer and inner CH protons ($\Delta\delta = 20$).[22] The nonplanarity of the sapphyrin core accounts for the relatively small ring current effect. The rotation of 10,15-phenyl rings is slow below $-60\,^\circ C$, and two well-separated *ortho* resonances are observed as a result of the nonplanarity of the sapphyrin macrocycle (Fig. 2, spectrum C). The considerable difference in the 2-H and 3-H chemical shifts reflects the fact that the 3-H, but not the 2-H proton, is shifted upfield by the ring current of the 5-phenyl ring.

Table 1. ^1H NMR data of $TPSH_3$ and its dications [a].

Proton assignment	$TPSH_3$ [b]	$TPSH_3$	$TPSH_5^{2+}$ (HCl)	$TPSH_5^{2+}$ (HF)	$TPSH_5^{2+}$ (TFA)	$TPSH_5^{2+}$ (DCA)
2, 23	10.155 [c]	10.055 [c]	10.300 [e]	10.017 [e]	9.962 [e]	10.049 [e]
3, 22	9.205 [c]	9.137 [c]	9.205 [e]	9.421 [e]	9.390 [e]	9.449 [e]
7, 18	9.016 [d]	8.945 [f]	8.945 [f]	8.739 [f]	8.381 [f]	8.339 [f]
8,17	9.151 [d]	9.057 [d]	9.160 [f]	8.544 [f]	9.760 [f]	8.578 [f]
12, 13	−1.498	−1.281	8.851 [g]	8.504 [g]	8.580 [g]	8.652 [g]
25NH, 29NH	−2.579	−1.9(b)	−2.60	−3.814	−1.215	−1.312
26NH, 28NH	−2.579	−1.9(b)	−3.47	−3.895	−1.975	−2.080
27NH	12.236	11.767	−2.74	−3.91	−1.975	−1.907
ortho	9.627	8.46(b)	8.73(m)	[h]	8.60	[h]
	7.362	8.38(m)	8.63(m)			
	8.353	8.31(m)				
meta	8.069	7.84(m)	8.03(m)	[h]	7.97(m)	[h]
	7.57		7.98(m)			
	7.83					
para	7.63	7.58(m)	7.98(m)	[h]	8.04(m)	[h]
	7.83					

[a] Unless specified otherwise, the spectra were recorded at 293 K for [D]chloroform solutions; chemical shifts relative to TMS; TFA = trifluoroacetic acid; DCA: dichloroacetic acid. [b] Spectrum recorded at 203 K in $[D_2]$dichloromethane. [c] $J_{AB} = 4.6$ Hz. [d] $J_{AB} = 4.3$ Hz. [e] $J_{AB} = 4.3$, $^4J_{HH} = 1.6$ Hz. [f] $J_{AB} = 4.3$, $^4J_{HH} = 1.5$ Hz. [g] $^4J_{HH} = 1.4$ Hz. [h] Sample deuterated at all *meso*-phenyl positions ($[D_{20}]TPSH_5^{2+}$).

The titration of $TPSH_3$ with HCl dissolved in [D]chloroform was monitored by ^1H NMR spectroscopy. The gradual formation of a cationic species $TPSH_5^{2+}$ was observed (Fig. 2, spectrum B). We found that the diprotonation of $TPSH_3$ acts as a trigger for a profound structural transformation, which involves a dramatic flip of the **C** ring and relocates the 27-NH pyrrolic nitrogen from the periphery to the center of the macrocycle (Scheme 1, Fig. 4). Apparently the structural rearrangement involves a rotation around the C10–C11 and C14–C15 bonds. The dication contains a central core in which a hydrogen atom is attached to each of the five inner nitrogen atoms. This was confirmed by the scalar coupling of NH resonances ($\delta = -2.60$ (25,29-NH); -2.74 (27-NH); -3.47 (26,28-NH)) and pyrrole protons (Fig. 2, spectrum B). The most notable spectroscopic features, revealing an unusual flexibility of the sapphyrin macrocycle, include a spectacular upfield ↔ downfield jump of the 27-NH ($\delta = 11.75 \rightarrow -2.74$) and 12,13-H ($\delta = -1.21 \rightarrow 8.87$) resonances. In particular, the upfield NH resonance split into a 2:1:2 pattern is consistent with the formation of the dication.



Scheme 1. Structural changes in $TPSH_3$ on protonation.

© VCH Verlagsgesellschaft mbH, D-69451 Weinheim, 1995 0570-0833/95/0101-0070 $ 10.00+.25/0 Chem. Eur. J. 1995, 1, No. 1

Addition of HF or carboxylic acids (trifluoracetic acid, dichloroacetic acid) instead of HCl resulted in a similar behavior of $TPSH_3$. A well-defined dependence of the spectral parameters on the nature of a counteranion was established (Table 1). A formation of a tight ion pair $[TPSH_5^{2+}][anion]_n$ ($n = 1$ or 2) or an encapsulation of an anion within the charged sapphyrin nucleus might account for this observation.[17] Under the conditions of our experiment, in the ^1H NMR spectrum of the fluoride salt of $TPSH_5^{2+}$, the expected $^1H-^1F$ coupling, determined previously for an analogous dication of dekaalkyl sapphyrin, was not observed.[19a]

The flexibility of tetraphenylsapphyrin does not yet have any parallel in the widely investigated pyrrole-alkylated, *meso*-unsubstituted sapphyrins. On the other hand, the flexibility of the larger expanded porphyrins has been observed. The impressive rotations of the two pyrrole units of the hexaphyrin macrocycle were encountered in the course of a palladium–amine dichloride coordination.[23] Protonated forms of the nonaromatic expanded porphyrins hexapyrrolic rosarin and decapyrrolic turcasarin adopt demonstrated remarkably twisted conformations.[24]

Unlike tetraphenylporphyrin[25] and its β-substituted derivatives,[26] but similar to porphycene,[27] the tetraphenylsapphyrin $TPSH_3$ tautomerizes extremely fast even at $-90\,^\circ C$ with the rapid exchange of two imino protons between the four structurally inequivalent internal nitrogens of sapphyrin. The outer 27-NH proton is not involved in the process. A single NH resonance, assigned to two internal NH protons, shows *simultaneous scalar coupling to all eight protons* of the pyrrolic **A**, **B**, **D**, **E** rings, observed as a peculiar set of four cross-peaks in the COSY experiment (Fig. 3, COSY map). This coupling can only be accounted for by the time-averaged interaction of inner NH protons with all eight pyrrole protons. Analogously, a single quintet for two NH protons is observed due to the averaged scalar coupling to all four ^{15}N nuclei of ^{15}N-$TPPH_2$.[28] To get an insight in the structure of $TPSH_3$ tautomers, we explored an isotopic effect, known to be very large in porphyrins,[29] that slows down the migration process in the inner regions of sapphyrin. The tautomerism of $TPSD_3$ was found to be slow on the ^1H NMR time scale below $-85\,^\circ C$, and two sets of signals of equal intensity were clearly identified at $-94\,^\circ C$ (Fig. 2, spectra D, E). We presume that the equilibrium corresponds to the exchange between two degenerate asymmetric tautomers (25-NH, 26-N, 28-NH, 29-N) and (25-N, 26-NH, 28-N, 29-NH) (Scheme 1). Although the NH exchange process might involve the metastable *cis*-tautomers (25-NH, 26-NH, 28-N, 29-N), (25-N, 26-N, 28-NH, 29-NH), (25-NH, 26-N, 28-N, 29-NH), and (25-N, 26-NH, 28-NH, 29-N), there is no direct spectral evidence for their abundant formation. In our opinion the *cis* NH–NH interaction of the inner NH protons results in the formation of the relatively high-energy tautomers (25-NH, 26-NH, 28-N, 29-N), (25-N, 26-N, 28-NH, 29-NH), and (25-NH, 26-N, 28-N, 29-NH).[25, 29] The simultaneous 28-NH–13-H and 26-NH–12-H interactions provide an alternative route for the comparative destabilization of the tautomer (25-N, 26-NH, 28-NH, 29-N).

Molecular mechanic calculations were used to visualize the structure of $TPSH_3$ and $TPSH_5^{2+}$ (Fig. 4). The inversion of the pyrrolic ring is apparent from the side view of the macrocycle, when it is compared to the basically planar structure of the dication. All bond lengths and angles are within the limits expected for porphyrins or sapphyrin.[18–20] In the model the inverted pyrrolic ring is bent out of the plane defined by the inner nitrogens of the sapphyrin core. The remaining pyrrole rings essentially lie in a plane. The extent of distortion, reflected

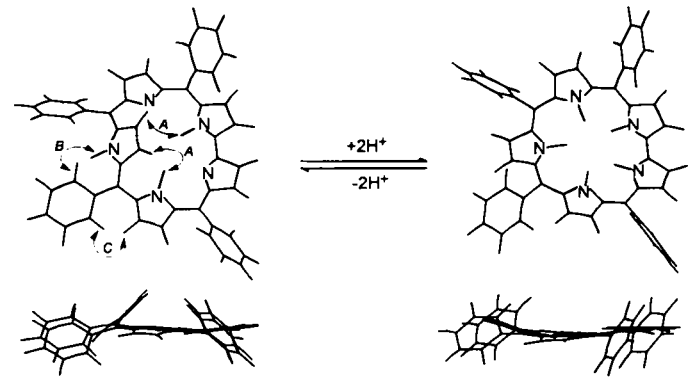


Fig. 4. Drawing of $TPSH_3$ and $TPSH_5^{2+}$ obtained from molecular mechanics calculations. Projections emphasize the difference of the pyrrole arrangements in $TPSH_3$ and $TPSH_5^{2+}$. Arrows indicate the selected through-space contacts observed as NOEs (see Fig. 3).

by a dihedral angle C9-C10-C11-C12 of approximately 44° (165° for $TPSH_5^{2+}$), should still allow delocalization of the 22 π-electrons of sapphyrin. In the five-coordinate complexes of 21-thiatetraphenylporphyrin[30] and *N*-methyltetraphenylporphyrin,[31] in which comparable twisting of one of the five-membered rings (N-methylated pyrrole or thiophene) out of the plane of the core is observed, π delocalization in and the aromacity of the $4n + 2$ systems are preserved (established by an analysis of the structural parameters).

The simple pyrrole–aldehyde condensation provides the very first example of a self-directed route to expanded porphyrins from basic monomeric elements. Controlled condensation of oligomeric polypyrroles or porphobilinogen, aimed at probing the extreme selectivity of biomimetic cyclotetrapyrrolic synthesis, resulted exclusively in the formation of porphyrins as sole aromatic macrocyclic products.[32] To the best of our knowledge, the cyclocondensation investigated by Schumacher and Franck, leading to an inverted porphyrinoid with peripheral N-atoms, provided a unique example of a pentapyrrolic instead of tetrapyrrolic macrocycle closure, although achieved only on the pentaporphyrinogen oxidation level.[32c]

For the mechanism of $TPSH_3$ formation, we suggest that excess pyrrole molecules attacks tetrapyrromethane in its preferred helical conformation[32, 33] to create a helical pentapyrrolic structure. It was recently demonstrated by X-ray crystallography that an open-chain tetrapyrrolic compound related to porphyrin, octaethylbilindione, adopts a tightly coiled arrangement when it is coordinated to iron(III) or manganese(III). The significant distortion from planarity avoids the overlap of the terminal ligand substituents and allows the further extention of the structure to form a peculiar dimeric compound.[34] The helical geometry of a pentapyrrolic chain (Fig. 5), modeled and optimized by molecular mechanics calculations, provides the orientation required for the pentapyrrolic macrocyclic ring closure through a classic acidic $\alpha-\alpha$ pyrrole coupling[35] to afford a sapphyrinogen-related molecule, subsequently oxidized to sapphyrin.

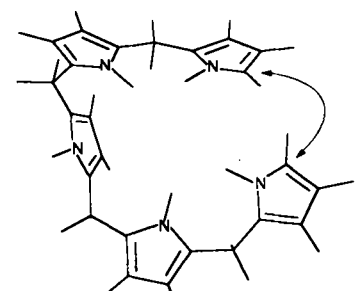
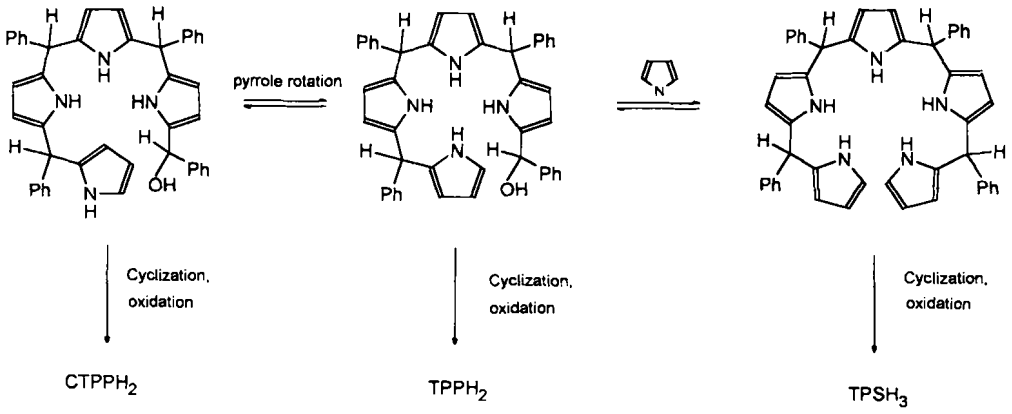


Fig. 5. Acyclic pentapyrrole.

Conclusion

The equilibria shown in Scheme 2 seem to play a crucial role in the benzaldehyde–pyrrole condensation before the final oxidation step to produce aromatic macrocycles. The isolation of 5,10,15,20-tetraphenylsapphyrin as one of the products provides simple and convincing proof that the pentapyrrolic products can be formed by the mechanism of the Rothemund synthesis.



Scheme 2. Some of the equilibria involved in the benzaldehyde–pyrrole condensation (R = Ph).

Finally, we would like to point out that tetraphenylsapphyrin has a similar relationship to decaethylsapphyrins as tetraphenylporphyrin to octaethylporphyrin, since identical substituents at *meso*- and *β*-pyrrole positons are present in both pairs. We can thus expect that tetraphenylsapphyrin will play a similar stimulating role in the world of expanded porphyrins as tetraphenylporphyrin in the area of porphyrin chemistry, and become a favored modular building block for the design of molecules with precisely adjusted chemical properties.

Experimental Procedure

All solvents were purified by standard procedures. [D_5]Benzaldehyde used in synthesis of [D_{20}]$TPSH_3$ was obtained by oxidation in [D_8]toluene with $Ce(NH_4)_2(NO_3)_6$ [36]. [D]Chloroform (AG Glaser) and [D_2]dichloromethane (CIL) were dried before use by passing the solvents through basic alumina.

$TPSH_3$: The condensation of benzaldehyde (8 mmol) and pyrrole (24 mmol) in dichloromethane (1 L) catalyzed by BF_3 etherate (3 mmol), conducted over 1 h under nitrogen at room temperature, followed by oxidation with *p*-chloranil (2 g) under reflux for 1 h, gave a mixture of $TPPH_2$, $CTPPH_2$, and $TPSH_3$. The solution was evaporated to dryness. The solid material was chromatographed on basic alumina to remove tarry products. The crude porphyrin products were eluted with dichloromethane. Small amount of basic alumina was added to the solution, and the solvent was removed on a rotary evaporator. The solid material obtained was transferred to the top of a column packed with basic alumina and eluted with tetrachloromethane. The first eluted band contained $TPPH_2$. The second brown band, containing $TPSH_3$, was eluted with tetrachloromethane/dichloromethane (10/1 v/v). This fraction was evaporated, and the product recrystallized from benzene/methanol to give 15 mg (0.022 mmol, 1.1 %) of $TPSH_3$. UV/Vis (CH_2Cl_2): λ_{max} [nm] (ε) = 395 (Soret) (10200), 493 (74900), 518 (59300), 640 (4600), 697 (10500), 715 (sh), 795 (5400); MS (EI): m/z (%) = 679 (40), HR-MS: m/z = 679.2728 (found for M^+), 679.2736 (calcd for $C_{48}H_{33}N_5$); elemental analysis: calcd for $C_{48}H_{33}N_5$: C, 84.81; H, 4.89; N, 10.30; found: C, 85.01; H, 5.07; N, 10.22; ^{13}C NMR (75.47 MHz, [D]chloroform, 20 °C): δ = 126.4 (2,23-C), 129.1 (3,22-C), 130.3 (7,18-C), 126.3 (8,17-C, 12,13-C), 134.8 (5,20-*o*), 134.3 (10,15-*o*), 129.4, 127.0 (*m*), 127.3 (*p*). [$TPSH_3$]Cl_2: UV/Vis (CH_2Cl_2): λ_{max}/[nm] (ε) = 484 (Soret) (162400), 648 (3400), 736 (10800), 771 (sh).

[D_{20}]$TPSH_3$ was obtained in an analogous way as $TPSH_3$, except that benzaldehyde was replaced by [D_5]benzaldehyde.

Generation of dicationic forms: The solution of the acid (trifluoroacetic acid, HCl, or dichloroacetic acid) in [D]chloroform was added to the ^1H NMR tube containing the solution of $TPSH_3$ by a syringe, and the progress of the reaction was followed by ^1H NMR spectroscopy. A different approach was applied when HF was used. Typically, 2 mg of sapphyrin in 2 mL of dichloromethane and 0.4 mL of HF in water were mixed together. The solutions were shaken to mix the two layers, and the layers were allowed to separate. The aqueous layer was removed by a pipet. The dichloromethane was evaporated from the sample under vacuum and the sample was dried for 12 h under vacuum. The dicationic form was then dissolved in [D]chloroform and transferred into an NMR tube.

Instrumentation: NMR spectra were recorded on a Bruker AMX300 spectrometer. The standard Bruker software for ^1H COSY, ^1H NOESY, and ^1H–^{13}C correlated shift experiments was applied. Absorption spectra were measured on a Spekord M-42 spectrometer. Fluorescence spectra were obtained using a SPF-500 (SLM AMINCO) instrument. Mass spectra (EI) were recorded on an AD-604 spectrometer.

Molecular Mechanics Calculations: Molecular mechanics calculations were carried out with the HyperChem software (Autodesk) and displayed on the IBM 486 personal computer. The standard MM + force field was applied.

Acknowledgment: This work was supported by the State Committee for Scientific Research (Grant 207329101).

Received: October 19, 1994 [F4]

[1] (a) B. Morgan, D. Dolphin, *Struct. Bonding* **1987**, *64*, 115; (b) J. S. Lindsey, S. Prathapan, T. E. Johnson, R. W. Wagner *Tetrahedron* **1994**, *30*, 8941
[2] (a) P. Rothemund, *J. Am. Chem. Soc.* **1936**, *58*, 625; (b) P. Rothemund *ibid.* **1939**, *61*, 2912.
[3] (a) A. D. Adler, F. R. Longo , W. Shergalis, *J. Am. Chem. Soc.* **1964**, *86*, 3145; (b) A. D. Adler, F. R. Longo, J. D. Finarelli, J. Goldmacher, J. Assour, L. Korsakoff, *J. Org. Chem.* **1967**, *32*, 476; (c) A. D. Adler, L. Sklar, F. R. Longo, J. D. Finarelli, M. G. Finarelli, *J. Heterocyclic Chem.* **1968**, *5*, 669.
[4] D. Dolphin, *J. Heterocyclic Chem.* **1970**, *7*, 275.
[5] (a) A. M. d'A. Rocha Gonsalves, M. M. Pereira, *J. Heterocyclic Chem.* **1985**, *22*, 931; (b) A. M. d'A. Rocha Gonsalves, J. M. T. B. Varejo, M. M. Pereira, *ibid.* **1991**, *28*, 635.
[6] (a) J. S. Lindsey, H. C. Hsu, I. C. Schreiman *Tetrahedron Lett.* **1986**, *27*, 4969; (b) J. S. Lindsey, I. C. Schreiman, H. C. Hsu, P. C. Kearney, A. M. Marguerettaz, *J. Org. Chem.* **1987**, *52*, 827; (c) J. S. Lindsey, R. W. Wagner *ibid.*, **1989**, *54*, 828; (d) J. S. Lindsey, K. A. MacCrum, J. S. Tyhonas, Y.-Y. Chuang *ibid.* **1994**, *59*, 579; (e) J. Lindsey, in *Metalloporphyrin-Catalyzed Oxidations* (Eds.: F. Montanari, I. Casella), Kluwer, Academic Publisher, Dordrecht, The Netherlands, **1994**, p. 49.
[7] (a) L. Latos-Grażyński, J. Lisowski, M. M. Olmstead, A. L. Balch, *J. Am. Chem. Soc.* **1987**, *109*, 4428; (b) P. Chmielewski, M. Grzeszczuk, L. Latos-Grażyński, J. Lisowski *Inorg. Chem.* **1989**, *28*, 3546.
[8] D. M. Wallace, S. H. Leung, M. O. Senge, K. M. Smith, *J. Org. Chem.* **1993**, *58*, 7245.
[9] (a) First reported by P. J. Chmielewski and L. Latos-Grażyński at the 12th Summer School on Coordination Chemistry, Karpacz, Poland, **1993**; (b) P. J. Chmielewski, L. Latos-Grażyński, K. Rachlewicz, T. Głowiak *Angew. Chem.* **1994**, *106*, 805; *Angew. Chem. Int. Ed. Engl.* **1994**, *33*, 779.
[10] H. Furuta, H. Asano, T. Ogawa, *J. Am. Chem. Soc.* **1994**, *116*, 767.
[11] P. J. Chmielewski, L. Latos-Grażyński, *J. Chem. Soc. Perkin 2*, in press.
[12] E. Vogel, M. Kocher, H. Schmickler, J. Lex, *Angew. Chem.* **1986**, *98*, 262; *Angew. Chem. Int. Ed. Engl.* **1986**, *25*, 257.
[13] (a) J. L. Sessler, E. A. Brucker, S. J. Weghorn, M. Kisters, M. Schäfer, J. Lex, E. Vogel, *Angew. Chem.* **1994**, *106*, 2402; *Angew. Chem. Int. Ed. Engl.* **1994**, *33*, 2308; (b) A. Aukauloo, R. Guilard, *New. J. Chem.* **1994**, *18*, 1205.
[14] (a) First reported by R. B. Woodward at the aromacity conference, Sheffield UK, **1966**; (b) M. M. King, Ph.D. thesis, Harvard University, Cambridge MA, USA , **1970**.
[15] M. J. Brodhurst, R. Grigg, A. W. Johnson, *J. Chem. Soc. Perkin 1* **1972**, 2111.
[16] V. J. Bauer, D. L. J. Clive, D. Dolphin, J. B. Paine III, F. L Harris, M. M. King, J. Loder, S.-W. Chien Wang, R. B. Woodward, *J. Am. Chem. Soc.* **1983**, *105*, 6429.
[17] J. L. Sessler, M. J. Cyr, V. Lynch, E. McGhee, J. A. Ibers, *J. Am. Chem. Soc.* **1990**, *112*, 2810.

[18] (a) J. L. Sessler, M. Cyr, H. Furuta, V. Král, T. Mody, T. Morishima, M. Shionoya, S. Weghorn, *Pure Appl. Chem.* **1993**, *65*, 393; (b) J. L. Sessler, A. K. Burrell, *Top. Curr. Chem.*, **1992**, *161*, 179; (c) J. L. Sessler, M. J. Cyr, A. K. Burrell *Synlett* **1991**, 127; (d) B. L. Iverson , K. Shreder, V. Král, D. A. Smith, J. Smith, J. L. Sessler *Pure Appl. Chem.* **1994**, *66*, 845.

[19] (a) M. Shionoya, H. Furuta, V. Lynch, A. Harriman, J. L. Sessler, *J. Am. Chem. Soc.* **1992**, *114*, 5714; (b) B. L. Iverson, K. Shreder, V. Král, J. L. Sessler, *ibid.* **1993**, *115*, 11022.

[20] D. C. Miller, M. R. Johnson, J. J. Becker, J. A. Ibers, *J. Heterocycl. Chem.* **1993**, *30*, 1485.

[21] (a) M. R. Johnson, D. C. Miller, K. Bush, J. J. Becker, J. A. Ibers, *J. Org. Chem.* **1992**, *57*, 4414; (b) D. C. Miller, M. R. Johnson, J. A. Ibers, *ibid.* **1994**, *59*, 2877

[22] H. König, C. Eickmeier, M. Möller, U. Rodewald, B. Frank, *Angew. Chem.* **1990**, *102*, 1437; *Angew. Chem. Int. Ed.* **1990**, *29*, 1393.

[23] R. Charriere, Thesis University of Fribourg (Switzerland), see ref. [18b], p. 246

[24] (a) J. L. Sessler, S. J. Weghorn, T. Morishima, M. Rosingana, V. Lynch, V. Lee, *J. Am. Chem. Soc.* **1992**, *114*, 8306; (b) J. L. Sessler, S. J. Weghorn, V. Lynch, M. R. Johnson, *Angew. Chem.* **1994**, *106*, 1572; *Angew. Chem. Int. Ed.* **1994**, *33*, 1509.

[25] C. B. Storm, Y. Teklu, *J. Am. Chem. Soc.* **1972**, *94*, 53.

[26] M. J. Crossley, L. D. Field, M. M. Harding, S. Sternhell, *J. Am. Chem. Soc.* **1987**, *109*, 2335.

[27] (a) E. Vogel, M. Köcher, H. Schmicker, J. Lex, *Angew. Chem.* **1986**, *98*, 262; *Angew. Chem. Int. Ed. Engl.* **1986**, *25*, 257; (b) B. Wehrle, H.-H. Limbach, M. Köcher, O. Ermer, E. Vogel, *ibid.* **1987**, *99*, 914 and **1987**, *26*, 934.

[28] (a) H. J. C. Yeh, M. Sato, I. Morishima, *J. Magn. Res.* **1977**, *26*, 365; (b) C. S. Irving, A. Lapidot, *J. Chem. Soc. Chem. Commun.* **1977**, 184; (c) J. Hennig, H. H. Limbach, *J. Chem. Soc. Faraday Trans. 2* **1979**, *79*, 752.

[29] M. Schlabach, H.-H. Limbach, E. Bunnenberg, A. Y. L. Shu, B.-R. Tolf, C. Djerassi, *J. Am. Chem. Soc.* **1993**, *115*, 4554.

[30] L. Latos-Grażyński, J. Lisowski, M. M. Olmstead, A. L. Balch *Inorg. Chem.* **1989**, *28*, 1183

[31] (a) D. K. Lavallee, *The Chemistry of N-Substituted Porphyrins*, VCH, Weinheim, **1987**. (b) A. L. Balch, C. C. Cornman, L. Latos-Grażyński, M. M. Olmstead, *J. Am. Chem. Soc.* **1990**, *112*, 7552.

[32] (a) B. Franck, *Angew. Chem.* **1982**, *92*, 327; *Angew. Chem. Int. Ed. Engl.* **1982**, *21*, 343; (b) G. Bringmann, B. Franck, *Liebigs. Ann. Chem.* **1982**, 1272; *ibid.* **1982**, 1261; (c) K.-H. Schumacher, B. Franck, *Angew. Chem.* **1989**, *101*, 1292; *Angew. Chem. Int. Ed. Engl.* **1989**, *28*, 1243.

[33] L. F. Tietze, H. Geissler, *Angew. Chem.* **1993**, *105*, 1087; *Angew. Chem. Int. Ed. Engl.* **1993**, *32*, 1038.

[34] (a) A. L. Balch, L. Latos-Grażyński, B. C. Noll, M. M. Olmstead, N. Saffari, *J. Am. Chem. Soc.* **1993**, *115*, 9056. (b) A. L. Balch, M. Mazzanti, B. C. Noll, M. M. Olmstead, *J. Am. Chem. Soc.* **1994**, *116*, 9114.

[35] H. A. Potts, G. F. Smith, *J. Chem. Soc.* **1957**, 4018.

[36] L. Syper, *Tetrahedron Lett.* **1966**, *37*, 4493.