Figure-eight aromatic core-modified octaphyrins with six *meso* links: syntheses and structural characterization†

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The synthesis and structural characterization of the first examples of aromatic core-modified figure-eight octaphyrins with six *meso* links and their formation with and without acid catalysts are highlighted.

Research in the field of the macrocycles containing polypyrrolic units is of progressive interest due to their versatility in applications such as PDT,[1] neutral substance binding, anion recognition,[2] complexation with metallic ions[3] and many others. Among these polypyrrolic macrocycles, cyclooctapyrroles otherwise termed as octaphyrins are of marked interest because of their conformational flexibility. This provides ample scope for the studies on their aromaticity, coordination chemistry and the structure property relationship of these macrocycles. The two main factors which are responsible for deciding the conformations are; the number of *meso* links and the nature of *meso* substituents present in the frame work. The majority of octaphyrins known in literature adopt twisted figure-eight conformation as in **1** and **2** (Chart 1) leading to loss of aromaticity.[4] Recently we were successful in synthesizing octaphyrins with a planar conformation as in **3** by adopting two strategies; (i) by replacing a few pyrrole rings by other heterocyclic rings like thiophene and selenophene, (ii) by increasing the steric bulk at the *meso* carbons.[5] This planarity in octaphyrins was of course achieved *via* ring inversions where each of the thiophene rings of the bithiophene units were inverted. But the site of ring inversion mainly depends on the nature of *meso* substituents. A change from mesityl substituent to *m*-xylyl substituent results in the inversion of pyrrole rings rather than thiophene rings.[5]

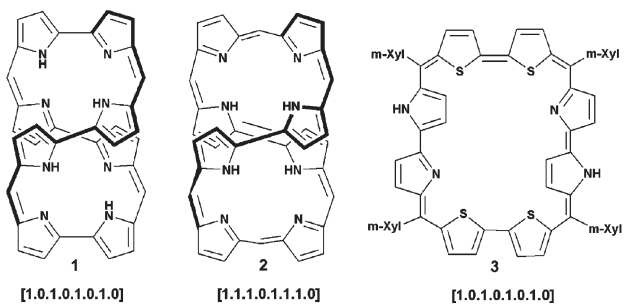

Chart 1 Figure-eight and planar octaphyrins.

† Electronic supplementary information (ESI) available: FAB mass for **5**, **6** & **7**, UV-vis for **6** & **7**, NMR for **5** and selective synthetic procedure for **5**. See http://www.rsc.org/suppdata/cc/b5/b502327k/

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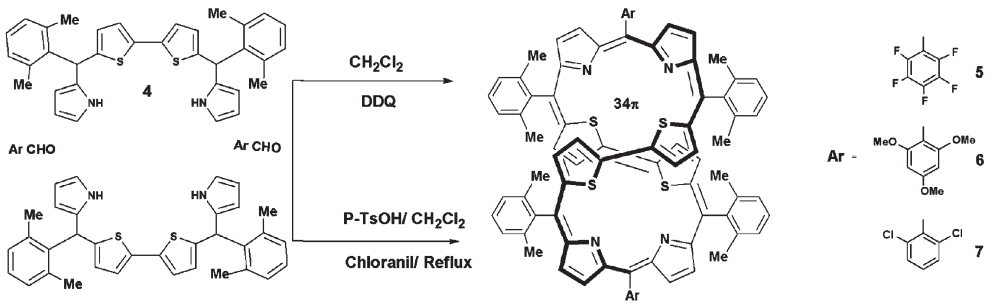
Keeping the above strategy in mind, we wanted to see the effect of increasing the number of *meso* linkages from four to six on the conformation of octaphyrins.

In this communication, we wish to report the first structurally characterized aromatic core modified [34] octaphyrin in which eight heterocyclic rings are linked through six *meso* carbon bridges in a (1.1.1.0.1.1.1.0) fashion. Our aim here was to construct octaphyrins in which twisting of the bithiophene rings could well be restricted by fixing xylyl substituents in the precursor itself *i.e.*, to the modified tetrapyrrane **4**, thereby leading to planar octaphyrins. But to our surprise, we ended up with a figure-eight conformer in the reaction of this modified tetrapyrrane with bulkier aryl aldehydes. This reaction proceeded even in the absence of acid catalyst as well as in the presence of acid catalysts like *p*-tolyl sulfonic acid and methane sulfonic acid. The yields of these macrocycles have been optimized for each of the *meso* substituents.

From a synthetic perspective, the formation of *meso*-aryl substituted expanded porphyrins is mainly due to a consequence of the steric congestion around the formyl group and the electron deficient property of the aryl aldehyde.[6] Thus as an extension, we have synthesized the title compounds **5**, **6** & **7** by including two *meso* links in between the tetrapyrrane units by appropriately choosing the aryl aldehydes. As shown in the Scheme 1, we have chosen the precursor *i.e.*, modified tetrapyrrane with xylyl substituents **4** and the electron deficient pentafluoro benzaldehyde for condensing two such tetrapyrrane moieties. Since this aldehyde is known to be highly reactive, the reaction was carried out without adding any acid catalyst. Unexpectedly, we ended up obtaining **5** after purification in almost 5% yield. A survey of literature predicts that non-catalyzed reactions of pyrrole and aldehydes yield corroles.[7] In a recent report, a synthetic strategy has been designed for a non-catalysed reaction in which dipyrromethane and aryl aldehydes are condensed to obtain corrole.[8] The presence of electron donating groups on the *meso* aryl unit of the dipyrromethane and the electron withdrawing nature of aryl aldehyde favors the cyclisation of two dipyrromethanes and an aldehyde in a single oxidation step. On the other hand, catalyzing the same reaction with acid yielded porphyrins of the type A2B2 instead of AB2 corroles. If this was true, in the present reaction one would have expected the formation of octaphyrins with five *meso* links (1.1.1.0.1.1.0.0). Even though, compound **5** was obtained in acid free condition, we were interested in carrying out the reaction with the protic acids as catalysts and to check the possibility of formation of the octaphyrin. Our result shows that compound **5** can be obtained in ~11% yield in the presence of 0.2 equivalents of *p*-tolyl sulfonic



Scheme 1 The formation of octaphyrins by [4+4] acid catalysed condensation.

acid and 0.1 equivalent of methane sulfonic acid with respect to tetrapyrrane in nearly 8% yield. A perusal of the literature[9] shows that Lewis acids are also best suited for synthesizing expanded porphyrins. However, in the presence of Lewis acid we were not successful in getting the desired product, rather we ended up with some polymeric products. On the other hand, when electron rich aldehyde like 2,4,6-trimethoxybenzaldehyde was used in acid free condition, the corresponding macrocycle **6** was not obtained. Even Lewis acid catalysts like $SnCl_4$, $BF_3.Et_2O$ did not yield the corresponding octaphyrins. Thus, we preferred to carry out the reaction in presence of protic acids like *p*-tolyl sulfonic acid and methane sulfonic acid and we observed that *p*-tolyl sulfonic acid is well suited for our reaction when we used 0.5 equivalents with respect to the starting precursor *i.e.*, modified tetrapyrrane where the desired product **6** was obtained in almost 10% yield. Increasing the acid concentration to one and two equivalents reduces the yield to almost 1% but increasing the aldehyde concentration to two fold with respect to the tetrapyrrane does not have any marked effect on the yield of the macrocycles. In the same way 0.3 equivalents of methane sulfonic acid gave **6** in a total yield of 8%, whereas use of 0.5 and 1 equivalents of the aforesaid acid reduces the percentage yield of the final product **6** to around 1–2%. Thus there was no use in going for higher and higher equivalents of acid. Our attempt to obtain macrocycle **7** by condensing 2,6-dichlorobenzaldehyde, which is neither so reactive nor so electron rich aldehyde in acid free conditions, was again a failure. But the macrocycle was obtained in 7% yield by using 0.5 equivalents of *p*-tolyl sulfonic acid with respect to modified tetrapyrrane **4**, whereas 0.2 equivalents of methane sulfonic acid catalysed the condensation reaction resulting in the formation of **7** in 5% yield. Here we would like to emphasize that this is the first example where core modified expanded porphyrins have been obtained in an acid free condensation reaction. The most interesting feature of our method is the isolation of only the single desired product, allowing easy purification. The mechanism of formation of these macrocyles is based on the well known MacDonald synthesis of porphyrins.[10]

The proposed structure of the macrocycle comes from the various spectroscopic analyses and the single crystal X-ray structure obtained for **5**. The FAB mass spectra show a M+ peak at *m*/*z* 1410 for **5**, 1410 for **6** and 1368 for **7** confirming the free base composition of these macrocycles. As expected for larger macrocycles, these octaphyrins were found to be conformationally fluxional and the ^{1}H NMR could not be well resolved at room temperature. By lowering the temperature up to 208 K for **5**, we were able to isolate a comparatively well resolved ^{1}H NMR spectra. For example, for macrocycle **5**, five distinct singlets were observed in the deshielded region without having any correlation in the two dimensional COSY spectrum. Based on this and the integration of each peak, the peak at 14.01 ppm has been assigned to the eight β-CH protons of the bithiophene units whereas the peaks at 16.42 ppm, 15.61 ppm, 9.80 ppm and at 9.20 ppm have been assigned to the β-pyrrolic protons of the four pyrrole rings which are magnetically distinct. On the other hand, the peaks in the aromatic region from 7.53 ppm to 5.78 ppm have been assigned to the phenyl protons of xylyl rings and the peak at 2.75 ppm has been assigned for the methyl protons of the xylyl rings (see supporting information†). Thus in accordance with our prior ^{1}H NMR observation for compound **3**, in the present case the observation of downfield shifts for the β-CH protons of the heterocyclic rings confirms that the macrocycle **5** has an aromatic ring current in the solution state. No well resolved ^{1}H NMR spectral observations were obtained in the case of macrocycles **6** and **7**. Rather, the formation of these two macrocycles was confirmed from FAB mass spectra and the UV-Vis spectra which show more or less the same patterns of spectra (see supporting information†) like macrocycle **5** as shown in Fig. 1. The UV-Vis spectra of these macrocyles are dominated by a broad Soret type band at 517 nm ($\varepsilon = 6.87 \times 10^4$) followed by a Q-band like absorption at 671 nm ($\varepsilon = 1.64 \times 10^4$) (Fig. 1). The broad Soret-like absorption confirms the non-planar structure for the macrocycle. Upon protonation, the Soret band experiences a large red shift of 176 nm ($\varepsilon = 1.01 \times 10^5$) with an increase of one order in ε values and the Q band also experiences red shift of 123 nm. This red shift observed upon protonation is typical of aromatic

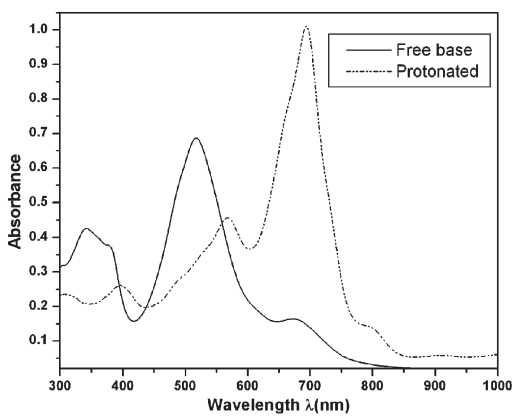


Fig. 1 Electronic absorption spectra of **5** [$\sim 10^{-6}$ M] and the protonated derivative in CH_2Cl_2. Protonation is achieved by adding 10% TFA in CH_2Cl_2.

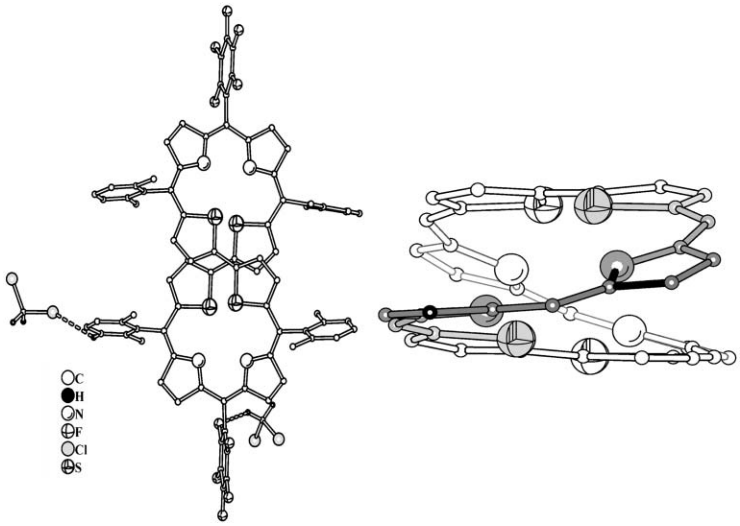


Fig. 2 Single crystal X-ray structure of **5** and its side view. Hydrogen atoms and *meso* substituents in side view are removed for clarity.

meso-aryl expanded porphyrins.[6] Taken together, these changes in electronic spectra suggest the typical porphyrinic nature of the macrocycles.

Final confirmation for the structure of these macrocycles came from the single crystal X-ray analysis of **5**§ which shows a figure-eight conformation (Fig 2). The conformation of the molecule arises mainly because the thiophene rings of the bithiophene units are rotated about their linking bond. The torsional angles of each bithiophene units are different and are in the range of 170.0° (S1–C4–C5–S2) and 158.6° (S3–C23–C24–S4). As seen in the crystal structure there are two solvent molecules bound to the macrocycle through hydrogen bonding interactions and the metric parameters are: **C–H—F:** C–H 0.970(14); H—F 2.549(31); C—F 3.330(49) Å and C–H—F 137.57(35)°; **C–H—Cl:** C–H 0.930(4); H—Cl 2.928(2); C—Cl 3.619(5) Å and C–H—Cl 132.20(26)°.

In conclusion, we have described a simple but efficient method for synthesizing core-modified aromatic figure-eight octaphyrins in moderate yields. In spite of the presence of bulky substituents at the *meso* positions, the octaphyrins adopt figure-eight conformation but the aromaticity of the macrocycle is still sustained as confirmed from the ^{1}H NMR. These observations clearly suggest that the conformation of octaphyrins are highly sensitive to the nature of substituents as well as the number of *meso* links and a fine balance of these two factors eventually decides the nature of the conformer.

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Notes and references

§ *Crystallographic summary* for $C_{84}H_{56}Cl_4F_{10}N_4S_4$, **5**: Crystals were grown by slowly diffusing dry methanol over a dichloromethane solution of **5**. Blue needles, monoclinic, *P*21/*n*, $\mu = 0.345$ mm^{-1}, $Z = 4$ in a cell of dimension: $a = 18.713(4)$, $b = 13.740(3)$, $c = 29.251(6)$ Å. $\alpha = 90.00°$, $\beta = 97.38(3)°$, $\gamma = 90.00°$, 7459(3)Å^3, $\rho_{cal} = 1.408$ Mg m^{-3}, $F(000) = 3240$. A total of 18441 unique reflections were measured on a CCD area detector using graphite monochromatized Mo–Kα radiation ($\lambda = 0.71073$ Å) at −173 °C. The structure was refined on F^2 to an $Rw = 0.2417$, with a conventional $R = 0.0815$, and a goodness of fit = 1.045 for 963 parameters using the SHELX-97 package (ref. 11). CCDC 262999. See http://www.rsc.org/suppdata/cc/b5/b502327k/ for crystallographic data in CIF or other electronic format.

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