A strategy for the stepwise ring annulation of all four pyrrolic rings of a porphyrin†

Tony Khoury and Maxwell J. Crossley*

Received (in Cambridge, UK) 21st September 2007, Accepted 29th October 2007
First published as an Advance Article on the web 5th November 2007
DOI: 10.1039/b714612d

The repeated introduction of an α-dione unit and its reaction with an arene-1,2-diamine allows the stepwise annulation of all four pyrrolic rings of a porphyrin, as is demonstrated by the synthesis of a trisquinoxalinoporphyrin, a tetrakisquinoxalinoporphyrin and the more elaborated bisporphyrin.

Porphyrins with β,β′-pyrrolic bonds that are fused with aromatic rings have applications in a variety of fields from molecular electronics to biomedicine.[1–3] The syntheses of the simplest tetra-annulated representatives, the tetrabenzoporphyrins[4,5] and tetranaphthaloporphyrins,[6] have been reported. The methodology for their construction, however, is not amenable for making more elaborate arrays or for stepwise building-up of square grid networks of porphyrins (Fig. 1), which might find use in molecular circuitry and other molecular electronics applications. We now outline a strategy that allows the stepwise ring annulation of each of the four pyrrolic rings of a porphyrin. The key to this approach is the successive introduction into each ring of a functionality that can be elaborated readily. We have chosen to expand an approach to ring annulation outlined in the synthesis of much simpler extended porphyrin systems, in which the ring fusion was created by the reaction of a porphyrin-α-dione with an arene-1,2-diamine.[7]

Our approach is illustrated by the synthesis of end-capped trisquinoxalinoporphyrin **1** and tetrakisquinoxalinoporphyrin **2**, which are extended in three and four directions, respectively, and the bis-porphyrin **3**, in which the possibilities for constructing extended porphyrin arrays are demonstrated. Systems **1** and **2**, which are laterally-extended porphyrins with an enlarged π-electronic framework, are interesting compounds in their own right.

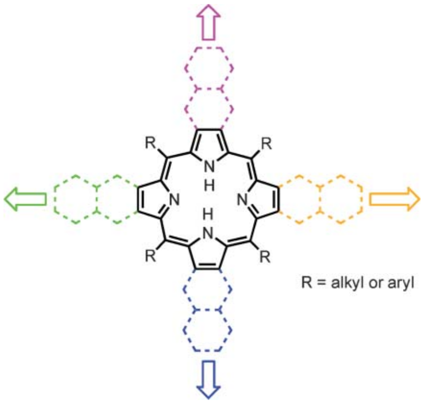
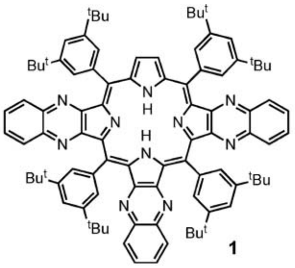
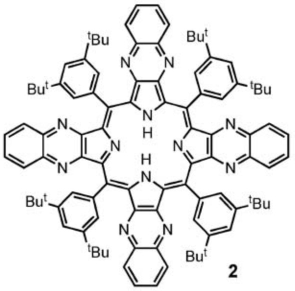


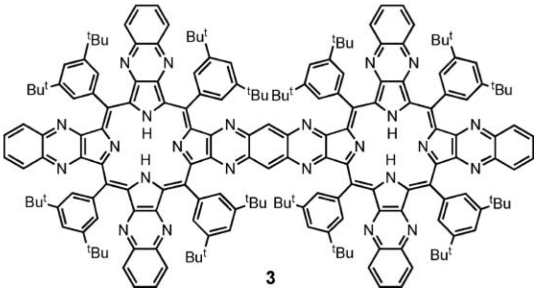
Fig. 1 Stepwise functionalisation of porphyrin pyrrolic rings allows controlled mono-, *syn*-bis-, *anti*-bis-, tris- and tetrakis-annulation.



1



2



3

In previous work, we have developed the syntheses of porphyrin-2,3-diones from 2-aminoporphyrins and 2-hydroxyporphyrins, and porphyrin-2,3,7,8-tetraones and porphyrin-2,3,12,13-tetraones from diaminoporphyrins.[7,8] These have been used to create extended porphyrin systems for a variety of uses.[7–11] Our synthesis of the tetraones[7] involved initial dinitration of the porphyrin periphery, which led to a mixture of isomers that were carried forward to common products. Porphyrins with two functionalised pyrrolic rings are also accessible in a stepwise manner by the nitration of porphyrin-2,3-diones and further elaboration, and by similar sequences on quinoxalino[2,3-*b*]porphyrins.[12] The latter compounds serve as models of more elaborate

---

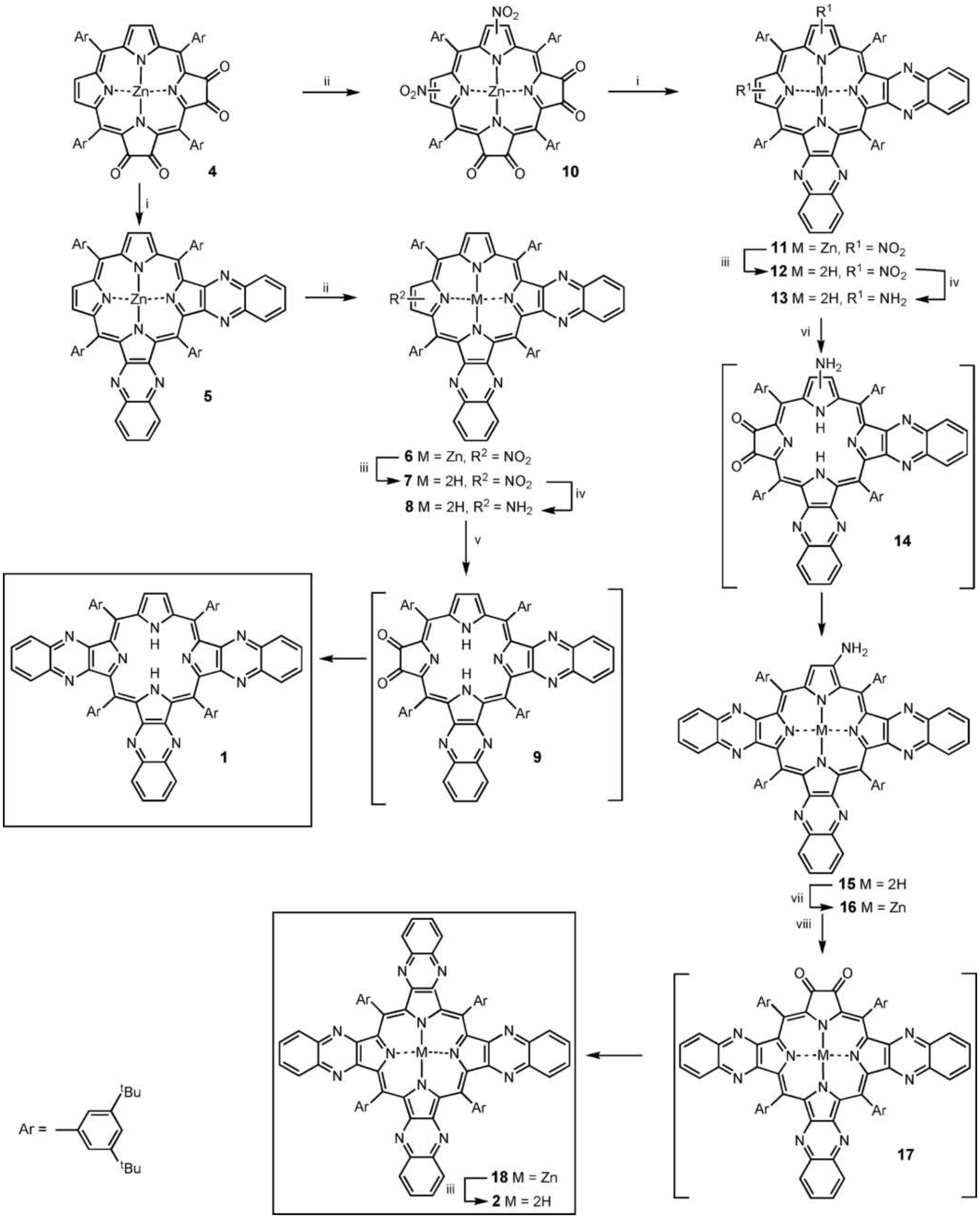
School of Chemistry, The University of Sydney, Building F11, NSW 2006, Australia. E-mail: m.crossley@chem.usyd.edu.au; Fax: +61 2 9351 3329; Tel: +61 2 9351 2751

† Electronic supplementary information (ESI) available: Selected spectra and characterisation data. See DOI: 10.1039/b714612d

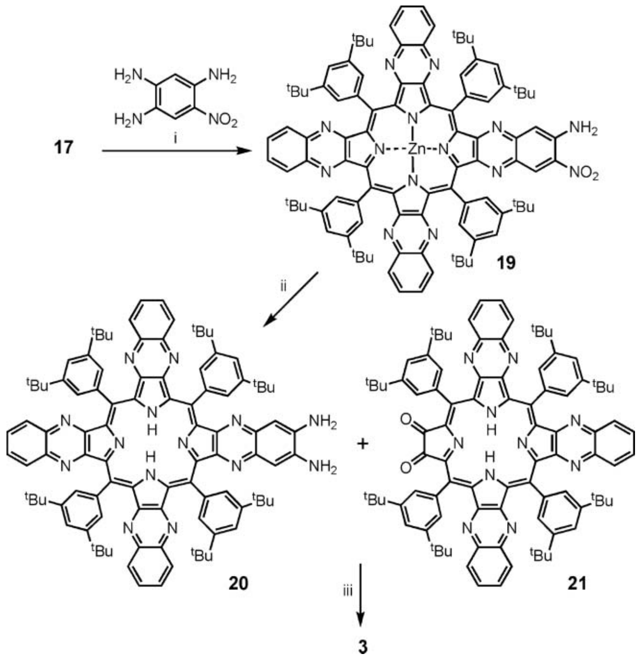
systems and allow the introduction of two different annulated ring systems, for example one appending a C_{60} and the other a ferrocene.[11] The route to compounds **1** and **2** is outlined in Scheme 1. Corner zinc(II) porphyrin-tetraone[7] **4** was functionalised further at one or both β,β′-pyrrolic faces for the synthesis of trisquinoxalinoporphyrin **1** and tetrakisquinoxalinoporphyrin **2**.‡

Trisquinoxalinoporphyrin **1** was prepared by first reacting **4** with *ortho*-phenylenediamine in CH_2Cl_2 solution to afford the corner zinc(II) bisquinoxalinoporphyrin **5** in 90% yield. Nitration of **5** afforded an inseparable mixture of corner zinc(II) 12- and 13-nitro-bisquinoxalinoporphyrins **6** in 83% yield, but both gave the same dione subsequently. Demetallation of **6** was achieved using HCl, affording corner 12- and 13-nitro-bisquinoxalinoporphyrins **7** in 89% yield. The tin(II)-mediated reduction of **7** gave the corresponding corner 12- and 13-amino-bisquinoxalinoporphyrins **8**, which were photo-oxidised in the presence of *ortho*-phenylenediamine for 5 h to give trisquinoxalinoporphyrin **1** in 64% yield. The intermediate corner bisquinoxalinoporphyrin-12,13-dione **9** was formed as an intermediate. The overall yield from **4** of **1** was 47%.

Corner zinc(II) porphyrin-tetraone **4** also served as a precursor to tetrakisquinoxalinoporphyrin **2**. Nitration of **4** in gave an isomeric mixture of corner zinc(II) 12,17-, 12,18- and 13,17-dinitro-porphyrin-tetraones **10** in 59% yield. Reaction of **10** with *ortho*-phenylenediamine gave the corner zinc(II) 12,17-, 12,18- and 13,17-dinitro-bisquinoxalinoporphyrins **11** in 66% yield.



Scheme 1 *Reagents and conditions:* (i) *ortho*-phenylenediamine in CH_2Cl_2, 5 min; (ii) NO_2 in light petroleum, CH_2Cl_2; (iii) HCl–CH_2Cl_2; (iv) $SnCl_2{\cdot}2H_2O$ in HCl–Et_2O; (v) O_2 and *ortho*-phenylenediamine in CH_2Cl_2, *hv*, 5 h; (vi) O_2 and *ortho*-phenylenediamine in CH_2Cl_2, *hv*, 45 min; (vii) $Zn(OAc)_2{\cdot}2H_2O$ in $CHCl_3$–CH_3OH, heat, 5 min; (viii) O_2 and *ortho*-phenylenediamine in CH_2Cl_2 *hv*, 20 min.



Scheme 2 *Reagents and conditions:* (i) O_2 in CH_2Cl_2, *hv*, 80 min; (ii) $HCl–CH_2Cl_2$, 2 h, followed by $SnCl_2\cdot 2H_2O$ in $HCl–Et_2O$, 10 min; (iii) toluene, reflux, 36 h.

Treatment of **11** with a $HCl–CH_2Cl_2$ solution afforded free base corner 12,17-, 12,18- and 13,17-dinitro-bisquinoxalinoporphyrins **12** in 83% yield. The isomeric mixture **12** was reduced using $SnCl_2\cdot 2H_2O$ in $HCl–Et_2O$ to afford the diamino analogues **13**, which were then photo-oxidised in the presence of *ortho*-phenylenediamine to afford amino-trisquinoxalinoporphyrin **15** in 83% yield by way of dione **14**. The amino-trisquinoxalinoporphyrin **15** was converted into its zinc(II) derivative **16**. Photo-oxidation of **16** gave zinc(II) trisquinoxalinoporphyrin-dione **17**, which was reacted *in situ* with *ortho*-phenylenediamine to afford zinc(II) tetrakisquinoxalinoporphyrin **18** in 84% yield. Demetallation of **18** by treatment with HCl in CH_2Cl_2 gave tetrakisquinoxalinoporphyrin **2** in 93% yield. The overall yield of **2** from **4** was 22%.

The complete demetallation of zinc(II) tetrakisquinoxalinoporphyrin **18** by HCl treatment required 5 h, in contrast to simple zinc(II) porphyrins, which are demetalled in a matter of seconds with this reagent. This difference is an indication that the quinoxalino substituents are able to exert a strong electron-withdrawing effect on the porphyrin ring, especially under acidic conditions.

In order to illustrate how the synthetic strategy outlined here can be utilised for the preparation of more elaborated systems, bis-porphyrin **3**, in which all pyrrolic rings are annulated, was synthesised. The photo-oxidation of **17** in the presence of 1,2,4-triamino-5-nitro-benzene afforded zinc(II) amino-nitro-tetrakisquinoxalinoporphyrin **19** in 65% yield (Scheme 2). The conversion of **19** into the diamino-tetrakisquinoxalinoporphyrin **20** in 78% yield was achieved by acidic demetallation followed by reduction using $SnCl_2\cdot 2H_2O$. The condensation of diamine **20** and trisquinoxalinoporphyrin-dione **21**, obtained by the photo-oxidation of **15**, afforded the elaborated bis-porphyrin **3** in 62% yield.

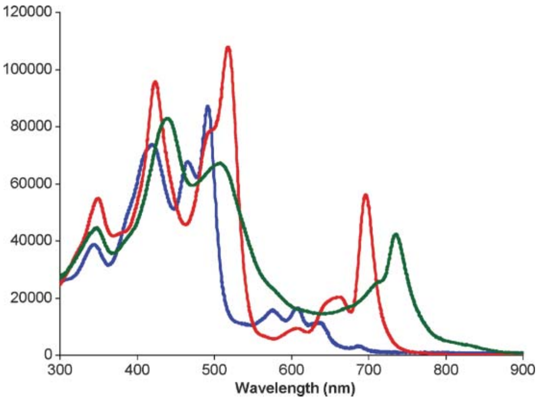


Fig. 2 Electronic absorption spectra in $CHCl_3$ of trisquinoxalinoporphyrin **1** (blue), tetrakisquinoxalinoporphyrin **2** (red) and bis-porphyrin **3** (green).

Increasing the number of quinoxaline units fused to the porphyrin macrocycle results in a widening of the light absorption window and a red-shift in electronic spectra compared to simple porphyrins due to the increase in the π-electronic network. For example, **2** and **3** exhibit a wide absorption window, with Q band maxima up to 697 and 735 nm, respectively (Fig. 2). Such broad absorption properties might find use in artificial light harvesting systems and light detectors.

In this work, a strategy for the step-wise annulation of all four pyrrolic rings of a porphyrin has been demonstrated, and a synthetic protocol has been established that will enable the generation of more complex systems that may be of value in applications from molecular electronics to artificial light harvesting systems.

Notes and references

‡ All new compounds have been fully characterised, including elemental analysis and/or high resolution ESI-FT/ICR.

1 T. D. Lash, in *The Porphyrin Handbook*, ed. K. M. Kadish, K. M. Smith and R. Guilard, Academic Press, New York, 2000, vol. **2**, pp. 125.
2 O. S. Finikova, A. V. Cheprakov and S. A. Vinogradov, *J. Org. Chem.*, 2005, **70**, 9563.
3 V. Gottumukkala, O. Ongayi, D. G. Baker, L. G. Lomax and M. G. H. Vincente, *Bioorg. Med. Chem.*, 2006, **14**, 1871.
4 N. Kobayashi, W. A. Nevin, S. Mizunuma, H. Awaji and M. Yamaguchi, *Chem. Phys. Lett.*, 1993, **205**, 51.
5 S. Ito, T. Murahima, H. Uno and N. Ono, *Chem. Commun.*, 1998, 1661.
6 O. S. Finikova, A. V. Cheprakov, P. J. Carroll and S. A. Vinogradov, *J. Org. Chem.*, 2003, 7517.
7 M. J. Crossley, L. J. Govenlock and J. K. Prashar, *J. Chem. Soc., Chem. Commun.*, 1995, 2379.
8 M. J. Crossley and L. G. King, *J. Chem. Soc., Chem. Commun.*, 1984, 3523.
9 M. J. Crossley and P. L. Burn, *J. Chem. Soc., Chem. Commun.*, 1991, 1569.
10 M. J. Crossley, P. J. Sintic, J. A. Hutchison and K. P. Ghiggino, *Org. Biomol. Chem.*, 2005, **3**, 852.
11 D. Curiel, K. Ohkubo, J. R. Reimers, S. Fukuzumi and M. J. Crossley, *Phys. Chem. Chem. Phys.*, 2007, **9**, 5260.
12 M. J. Crossley, C. S. Sheehan, T. Khoury, J. R. Reimers and P. J. Sintic, *New J. Chem.*, 2007, DOI: 10.1039/b712643c.