J|A|C|S
COMMUNICATIONS

Synthesis and Characterization of Tetraphenyl-21,23-dideazaporphyrin: The Best Evidence Yet That Porphyrins Really Are the [18]Annulenes of Nature

Timothy D. Lash,* Sarah A. Jones, and Gregory M. Ferrence
Department of Chemistry, Illinois State University, Normal, Illinois 61790-4160

Received June 20, 2010; E-mail: tdlash@ilstu.edu

Abstract: McMurry coupling of a pyrrole bisacrylaldehyde afforded a dipyrrolic macrocycle that is structurally midway between 1,10-diaza[18]annulene and the porphyrins. The diprotonated dication of this system retains porphyrin-like properties and provides insights into the nature of porphyrinoid aromaticity.

Porphyrins (**1**) and their derivatives are involved in many diverse biological processes and have been extensively investigated over the last 100 years.[1] They are widely recognized as nonbenzenoid aromatic compounds that show highly diatropic characteristics, but surprisingly, the origin of these properties remains controversial.[2−5] One particularly successful model attributes the aromatic properties of porphyrins to the presence of an [18]annulene substructure (shown in bold for structure **1**) within the macrocycle (Figure 1).[6−8] Alternatively, the 16 core atoms may act as a [16]annulene dianion **1a**, where the aromatic pathway bypasses the external pyrrolic carbons. Although NH tautomerization occurs rapidly at room temperature, the pyrrolenine rings in porphyrins and related macrocycles have been shown to possess more double-bond character at positions 7,8 and 17,18 than the corresponding bonds at the 2,3 and 12,13 positions in the pyrrole units,[9] and these observations indicate that structure **1** is favored over the "internal cross" model **1a**. Nevertheless, **1a** provides a viable model for metalloporphyrins. Over the last dozen years, the [18]annulene model for porphyrinoid aromaticity has been increasingly questioned, and alternative proposals and computational models have been developed.[2−5] On the basis of a detailed analysis of bond lengths from X-ray crystallography and computed NICS values, Schleyer and coworkers[2] proposed that global aromaticity for the porphyrin system can be better explained using the 22-π-electron delocalized model **1b** that incorporates the nitrogen electron pairs of the pyrrole subunits. Other theoretical studies have attributed the majority of the aromatic characteristics to the individual pyrrolic subunits.[5] Although all of the theoretical studies have been insightful, the [18]annulene model has been particularly successful in predicting the characteristics of synthetic porphyrinoids such as porphycene (**2**)[3] and carbaporphyrins **3**.[4] Furthermore, vacataporphyrin (21-deazaporphyrin; **4**), which is obtained by heating a telluraporphyrin with HCl, has been shown to retain highly diatropic characteristics, and its UV−vis absorption spectra are strikingly porphyrin-like in nature.[10] The macrocycle is also near planar, and the geometry of the tripyrrolic fragment is very similar to the arrangement in true porphyrins. This system retains the [18]annulene core but no longer has the 22-π-electron pathway found in **1b**.[10] In this communication, we report the synthesis of a further simplified porphyrinoid system that has lost both of the pyrrole-type nitrogens and further examine whether this hybrid bridged [18]annulene porphyrinoid still retains identifiable porphyrin-like characteristics.

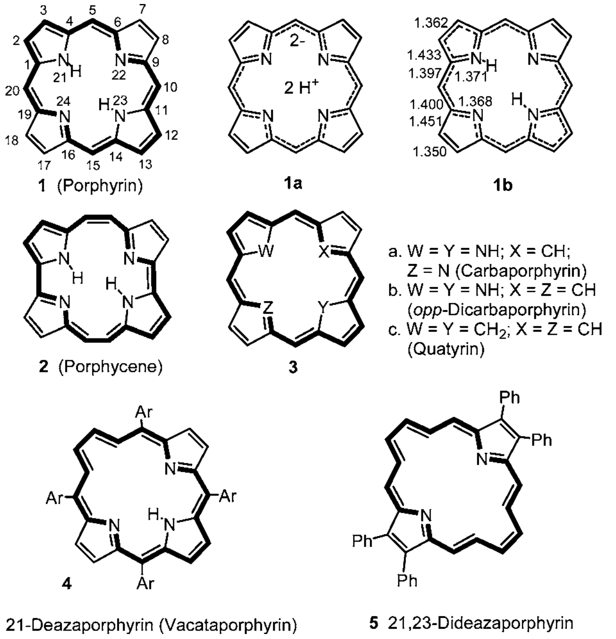
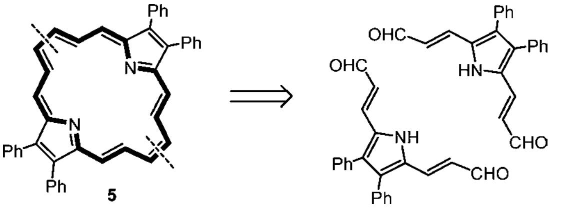


Figure 1. Representative porphyrin structures illustrating three different models for porphyrinoid aromaticity and several related aromatic compounds. Structure **1b** shows selected experimental bond lengths taken from ref 2. The IUPAC numbering system for porphyrins is shown for structure **1**.

Scheme 1. Retrosynthetic Analysis of a Dideazaporphyrin

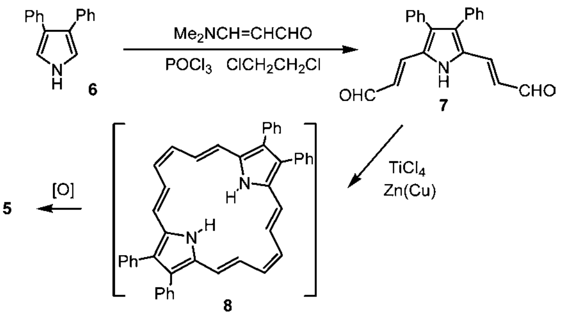


Dideazaporphyrin can in principle be prepared by McMurry coupling of a pyrrole bisacrylaldehyde (Scheme 1). This type of pyrrolic intermediate can be prepared by reacting an α-unsubstituted pyrrole (in this case, diphenylpyrrole **6**) with 3-(dimethylamino)acrolein and $POCl_3$ in refluxing 1,2-dichloroethane (vinylogous Vilsmeier−Haack reaction), and the required dialdehyde **7** can be isolated in 85% yield (Scheme 2). Aldehydes of this type have recently been used to prepare expanded porphyrins[11] but have not previously been investigated for applications in McMurry coupling reactions. Reaction of $TiCl_4$ with Zn(Cu) in THF gave a slurry of the McMurry reagent, and this was reacted with dialdehyde **7** for 1 h (Scheme 2). After workup, purification by column chromatography, and recrystallization, dideazaporphyrin **5** was isolated in 23% yield. Although the potentially antiaromatic species **8** may be formed initially, spontaneous oxidation appears to occur, giving **5**.

The UV−vis spectrum of the free-base form of **5** in $CHCl_3$ was porphyrin-like, showing a medium-sized Soret band at 401 nm ($\varepsilon = 8.6 \times 10^4\ M^{-1}\ cm^{-1}$) and a smaller band at 565 nm (Figure 2).

10.1021/ja105146a © 2010 American Chemical Society

Scheme 2. McMurry Synthesis of Dideazaporphyrin **5**



Furthermore, addition of trifluoroacetic acid (TFA) afforded the related dication **5**H_2^{2+}, which gave an intense Soret band at 422 nm ($\varepsilon = 1.5 \times 10^5$ M^{-1} cm^{-1}) and Q bands at 602, 669, and 747 nm. These data indicate that the dication closely resembles an aromatic porphyrinoid species. Titration with TFA led to the direct formation of the dication without any indication of a monocationic species, but it is worth noting that porphyrins also rarely show the formation of monoprotonated monocations.[1]

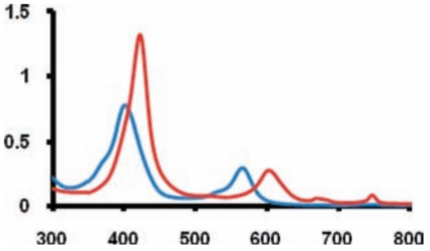


Figure 2. UV–vis spectra of dideazaporphyrin **5**. Blue line: free base in 1% $Et_3N/CHCl_3$. Red line: dication **5**H_2^{2+} in 1% TFA/$CHCl_3$.

The proton NMR spectra of **5** in $CDCl_3$ were generally poorly resolved because of the low solubility of this macrocycle, although well-resolved spectra could be obtained in very dilute solutions where aggregation was minimized. The internal CH protons afforded a multiplet at −2.52 ppm, while the external vinylene protons gave rise to two partially overlapped resonances at 9.88 and 9.96 ppm. These values demonstrate the presence of a significant ring current, although the coupling and chemical shifts for these protons are not too different from those observed for [18]annulene.[12] However, upon addition of a drop of TFA, dication **5**H_2^{2+} was formed, and this species showed greatly enhanced diatropicity, with the interior protons giving a multiplet at −5.45 ppm and the external protons exhibiting two partially overlapped resonances at 11.07 and 11.11 ppm (Figure 3). The difference in the chemical shifts ($\Delta\delta$) increased from 12.48 to over 16.5 ppm, making these values comparable to those seen in porphyrins and carbaporphyrins.[8] The NMR results complement the UV–vis data in showing that the dication more closely resembles porphyrinoid systems than does the free base **5**. We attribute the increased porphyrin-type character in **5**H_2^{2+} to beneficial charge delocalization that is associated with the more planar aromatic system.[8] As expected, the ^{13}C NMR spectrum of **5**H_2^{2+} in TFA/$CDCl_3$ showed nine resonances, and on the basis of the HMQC spectrum, the internal CH was assigned to the peak at 134.5 ppm.

X-ray-quality crystals of **5** were obtained by vapor diffusion of hexanes into a chloroform solution containing a small amount of benzene. The structure confirms the identity of the macrocycle and shows an essentially planar core (0.031 Å rms deviation for the diaza[18]annulene unit), with the deviations being most likely attributable to steric crowding of the four internal hydrogen atoms (Figure 4). The crystallographically measured bond distances are consistent with an aromatic [18]annulene containing the two nitrogen atoms, while the pyrrole β-carbon atoms are mostly “cut off” from the aromatic pathway by 1.470(2) Å single bonds. As is the case for porphyrins, the C−N bonds fall midway between the values expected for single and double bonds, although these values are ∼0.01 Å shorter for **5**.

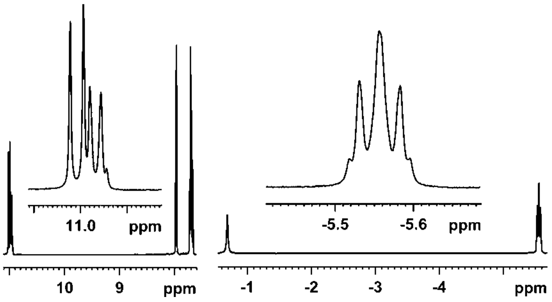


Figure 3. Proton NMR spectrum (500 MHz) of **5**H_2^{2+} in TFA/$CDCl_3$.

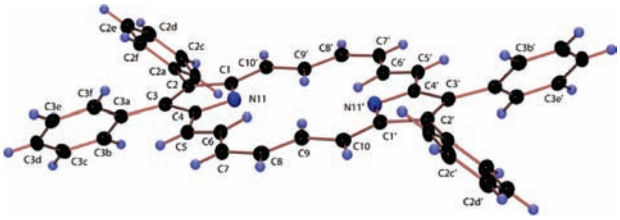


Figure 4. X-ray crystal structure of dideazaporphyrin **5**.

In conclusion, the aromatic characteristics of porphyrins clearly result from a number of features, but the essence of these properties appears to be encapsulated in the diaza[18]annulene substructure. The dideazaporphyrin system shows great promise for further investigations in this area.

Acknowledgment. This work was supported by the National Science Foundation under Grants CHE-0911699 (to T.D.L.) and (CHE-0348158) (to G.M.F.) and the Petroleum Research Fund, administered by the American Chemical Society. Funding for a 500 MHz NMR spectrometer was provided by the National Science Foundation under Grant CHE-0722385. The authors also thank Youngstown State University’s Matthias Zeller for X-ray data collection.

Supporting Information Available: Full experimental details; ^1H NMR, $^1H-^1H$ COSY, HMQC, ^{13}C NMR, UV−vis, and mass spectra; and crystallographic data (CIF). This material is available free of charge via the Internet at http://pubs.acs.org.

References

(1) Smith, K. M. In *Porphyrins and Metalloporphyrins*; Smith, K. M., Ed.; Elsevier: Amsterdam, 1975; pp 3−28.
(2) Cyranski, M. K.; Krygowski, T. M.; Wisiorowski, M.; Hommes, N. J. R. v. E.; Schleyer, P. v. R. *Angew. Chem., Int. Ed.* **1998**, *37*, 177–180.
(3) Steiner, E.; Soncini, A.; Fowler, P. W. *Org. Biomol. Chem.* **2005**, *3*, 4053–4059.
(4) Juselius, J.; Sundholm, D. *J. Org. Chem.* **2000**, *65*, 5233–5237.
(5) (a) Aihara, J.-i.; Kimura, E.; Krygowski, T. M. *Bull. Chem. Soc. Jpn.* **2008**, *81*, 826–835. (b) Aihara, J.-i. *J. Phys. Chem. A* **2008**, *112*, 5305–5311.
(6) Sondheimer, F.; Wolovsky, R.; Amiel, Y. *J. Am. Chem. Soc.* **1962**, *84*, 274–284.
(7) Vogel, E. *J. Heterocycl. Chem.* **1996**, *33*, 1461–1487.
(8) (a) Lash, T. D. *Synlett* **2000**, 279–295. (b) Lash, T. D. *Chem.—Eur. J.* **2007**, *13*, 5461–5481.
(9) (a) Crossley, M. J.; Harding, M. M.; Sternhell, S. *J. Am. Chem. Soc.* **1992**, *114*, 3266–3272. (b) Liu, D.; Lash, T. D. *J. Org. Chem.* **2003**, *68*, 1755–1761.
(10) Pacholska, E.; Latos-Grazynski, L.; Ciunik, Z. *Chem.—Eur. J.* **2002**, *8*, 5403–5406.
(11) (a) Xu, L.; Ferrence, G. M.; Lash, T. D. *Org. Lett.* **2006**, *8*, 5113–5116. (b) Zhang, Z.; Ferrence, G. M.; Lash, T. D. *Org. Lett.* **2009**, *11*, 1249–1252.
(12) Stevenson, C. D.; Kurth, T. L. *J. Am. Chem. Soc.* **2000**, *122*, 722–723.

JA105146A