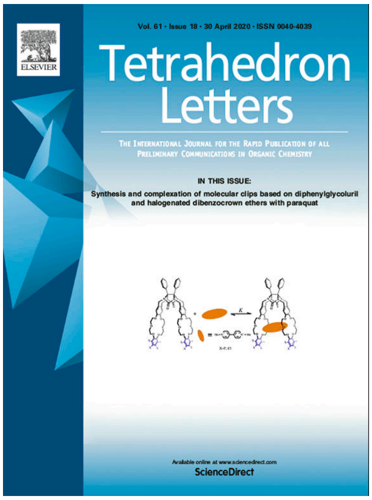

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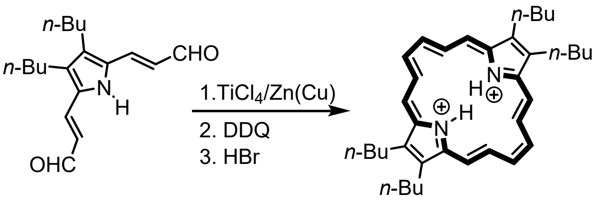

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Tetrabutyldideazaporphyrin

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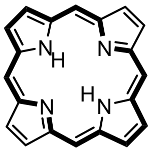
ABSTRACT

McMurry coupling of a dibutylpyrrole diacrylaldehyde afforded an unstable tetrabutyldideazaporphyrin. Although this porphyrin analogue was highly unstable, proton NMR spectroscopy demonstrated that it retained a high degree of diatropic character.

Introduction



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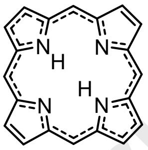

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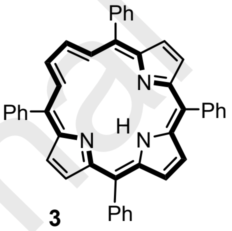
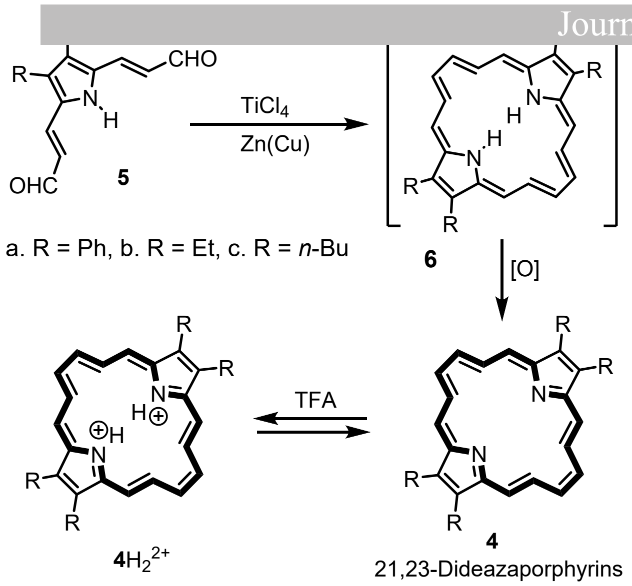
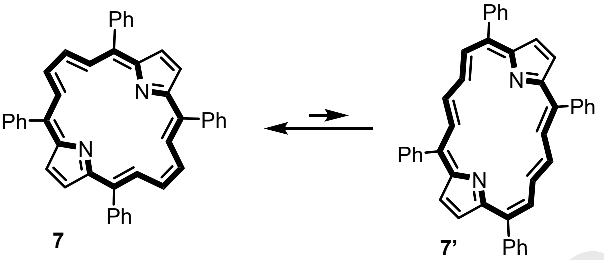


3
vacataporphyrin

Porphyrins **1** are macrocyclic systems that have been widely studied due to their importance as natural products (hemes, chlorophylls, etc.),[1] photosensitizers,[2] catalysts,[3] sensors[4] and so on. These structures are built up from four pyrrolic subunits and all twenty-four atoms within the porphyrin framework are sp^2 hybridized. Porphyrins are examples of nonbenzenoid aromatic compounds and have a high degree of thermodynamic stabilization. Proton NMR spectroscopy provides a convenient method for assessing the diatropic characteristic of this system and commonly shows the external *meso*-protons downfield near +10 ppm while the internal NH protons often appear upfield at -4 ppm.[5] The origin of aromaticity in porphyrin-type structures has been widely debated.[6] Many synthetic porphyrin chemists consider porphyrins to be examples of bridged [18]annulenes due to the presence of an 18π electron delocalization pathway (shown in bold for structure **1**).[6] Other models have been proposed, including a 22π electron version that incorporates two of the pyrrole lone pair electrons (structure **2**).[7] However, a deazaporphyrin **3** named vacataporphyrin was reported that retained porphyrin-like aromaticity even though the structure lacks one of the nitrogens found in porphyrin structures.[8] Furthermore, carbaporphyrinoid systems have been described where one or two of the nitrogen atoms have been replaced with carbon atoms.[9] In order to further probe the aromatic characteristics of porphyrinoids, a dideazaporphyrin **4a** was synthesized by McMurry coupling of pyrrole diacrylaldehyde **5a** (Scheme 1).[10] Although a potentially antiaromatic intermediate **6** may be formed, this spontaneously oxidizes to give the aromatic product. Tetraphenyldideazaporphyrin **4a** exhibited porphyrin-like properties, and the UV-vis spectrum afforded a Soret band at 401 nm and a weaker absorption at 565 nm.[10] The proton NMR spectrum for **4a** showed the presence of a strong diamagnetic ring current and the internal CH protons were shifted upfield to -2.52 ppm, while the external macrocyclic protons appeared downfield between 9.8 and 10.0 ppm. Addition of trifluoroacetic acid (TFA) generated a dicationic species **4a**H_2^{2+} that exhibited enhanced diatropicity. In this species, the interior protons appeared further upfield at -5.45 ppm while the exterior protons shifted further downfield to give resonances at 11.07 and 11.11 ppm. The UV-vis spectrum for the dication also showed a stronger Soret band at 422 nm and a series of Q bands between 600 and 750 nm. Subsequently, a second example of a dideazaporphyrin **7** was reported by Latos-Grazynski and this “divacataporphyrin” also exhibited aromatic characteristics.[11] Interestingly, the proton NMR spectrum of **7** showed the presence of a minor conformation **7’** that was in equilibrium with the principal species (Scheme 2).[11]



Scheme 1. Synthesis of dideazaporphyrins.



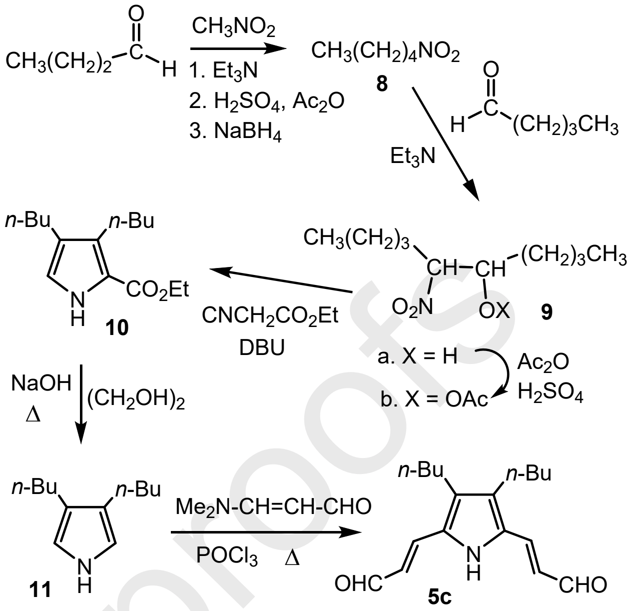
Scheme 2. Isomerization of a dideazaporphyrin.

Results and Discussion

In the initial publication, we concluded that the spectroscopic results confirmed that porphyrins have [18]annulene-like characteristics.[10] This inspired further computational studies by others that considered the merits of this assertion.[12,13] It had been our intention to stimulate discussion in this area and the [18]annulene model for porphyrinoid aromaticity must be considered to be an oversimplification. Schleyer and coworkers concluded that the aromatic characteristics for macrocyclic systems of this type are multifaceted and "energetic and magnetic aromaticity measures" may not always be in agreement.[12] The results indicated that the spectroscopic properties of porphyrins derive from the macrocyclic π conjugation pathways but may not necessarily play an important role in determining the thermodynamic stability of these structures.[12] In order to further investigate these issues, the synthesis of dideazaporphyrins that do not bear aryl substituents was investigated. The phenyl substituents in **4a** may be involved in a degree of π-conjugation and the properties of alkyl substituted structures could provide a useful contrast.

Initially, the synthesis of tetraethyldideazaporphyrin **4b** was investigated. McMurry coupling of the known dialdehyde **5b**[14] was conducted under the same conditions used to prepare **4a**. However, while the targeted species could be detected by UV-vis spectroscopy, the macrocycle could not be isolated. The problems encountered were two-fold: 1) the dideazaporphyrin appeared to be somewhat unstable; and 2) the product was virtually insoluble in organic solvents such as chloroform. In order to overcome the latter issue, longer chain substituents were introduced onto the pyrrolic precursor. It was necessary to

he formation of isomers and, given this restriction, dibutylpyrrole **5c** was selected for this investigation.



Scheme 3. Synthesis of a dibutylpyrrole diacrylaldehyde.

The alkyl substituents were introduced using the Barton-Zard methodology.[15,16] Initially, 1-nitropentane (**8**) was required and this was prepared by reacting butyraldehyde with nitromethane (Henry reaction) in the presence of triethylamine, followed by acetylation with acetic anhydride-H_2SO_4 and reduction with sodium borohydride (Scheme 3).[17] Triethylamine-catalyzed Henry reaction of **8** with valeraldehyde generated hydroxynitrodecane **9a** and subsequent acetylation afforded the related acetate **9b** as a mixture of diastereomers. Condensation of **9b** with ethyl isocyanoacetate in the presence of two equivalents of DBU gave dibutylpyrrole ethyl ester **10** in 40% yield. This was subjected to base catalyzed hydrolysis and decarboxylation with sodium hydroxide in ethylene glycol at 200 °C to produce 3,4-dibutylpyrrole (**11**) in virtually quantitative yield. This doubly α-unsubstituted pyrrole underwent a vinylogous Vilsmeier-Haack reaction with phosphorus oxychloride and 3-dimethylaminoacrolein in refluxing 1,2-dichloroethane and, following hydrolysis with aqueous sodium acetate, gave the required stretched dialdehyde **5c**. The proton NMR spectrum for **5c** gave a doublet of doublets at 6.90 ppm (J = 7.8, 15.6 Hz), a doublet at 7.34 ppm (J = 15.7 Hz) and a doublet at 9.64 ppm (CHO, J = 7.8 Hz) for the two acrylaldehyde side chains, confirming that the alkene units have a *trans*-configuration.

McMurry coupling of **5c** with titanium(IV) chloride and a zinc-copper couple in THF was investigated. In reactions of diphenylpyrrole diacrylaldehyde **5a** with $TiCl_4$-Zn/Cu, no oxidation of the intermediates was required. However, the formation of **4c** from **5c** was only evident after an oxidation step. This was accomplished by brief exposure to 2,3-dichloro-5,6-dicyanobenzoquinone (DDQ). The resulting product proved to be rather unstable, particularly in the free base form. Protonation gave a dicationic species **4c**H_2^{2+} that could be isolated, but even so decomposition readily occurred. The product was isolated as either the dihydrobromide or the trifluoroacetate salt. The UV-vis spectrum for the dicationic species **4c**H_2^{2+} gave a strong Soret band at 413 nm and Q bands at 585, 660 and 735 nm (Figure 1).

Alth absorptions are hypsochromically shifted by 9-16 nm. Nevertheless, the spectrum retains a remarkably porphyrin-like appearance, indicating that this species has similar electronic features. Addition of triethylamine afforded the free base form **4c** and this gave a diminished Soret band at 384 nm and a weaker absorption at 536 nm (Figure 1). This spectrum is still similar to a porphyrin-type system, but also closely resembles the electronic spectrum for [18]annulene.[18] The UV-vis spectrum for **4c** is blue shifted compared to its tetraphenyl counterpart **4a** by 17-29 nm. These results indicate that the porphyrinoid core in **4a** has a significant conjugation interaction with the phenyl substituents.

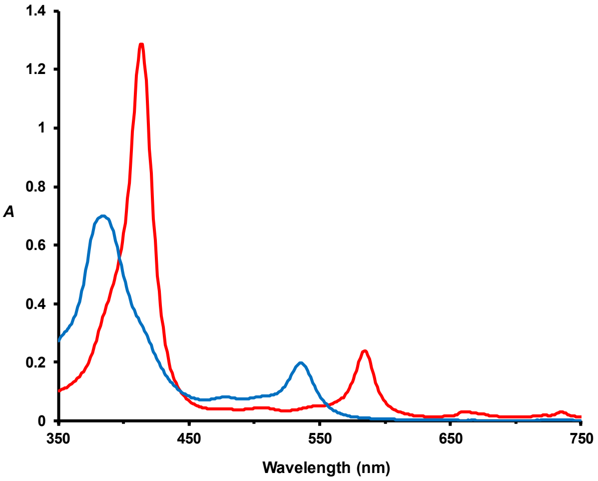


Figure 1. UV-vis spectra of **4c**.2HBr in chloroform (red line) and 1% Et_3N-chloroform (blue line).

The proton NMR spectrum of **4c**H_2^{2+} demonstrated that this species is highly diatropic. The internal CH protons were strongly shielded, giving a multiplet at -5 ppm, and the NHs afforded a resonance at -1.1 ppm (Figure 2). In addition, the external protons were strongly deshielded and produced a multiplet at 10.9 ppm, confirming the presence of a strong aromatic ring current. The NMR spectrum for the free base form could only be obtained by adding a small amount of NaOD in D_2O to the NMR tube. The resulting NMR spectrum, while of poor quality, showed the internal CH protons upfield at -2.4 ppm and the external protons downfield near 9.7 ppm. The results show that the free base has decreased diatropicity but still has a substantial ring current that is comparable to [18]annulene and many porphyrinoid systems. Hence, the high degree of aromatic character evident in these proton NMR spectra does not appear to have any bearing on the stability of the structures.

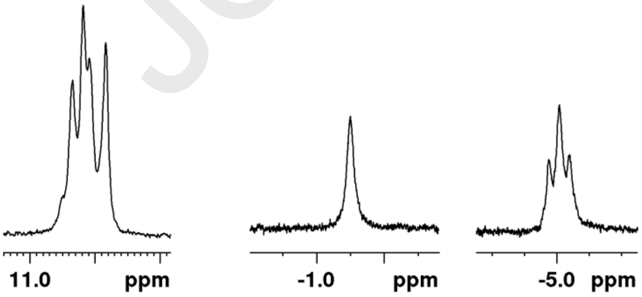


Figure 2. Partial proton NMR spectrum of **4c**.2HBr in $CDCl_3$ showing the downfield and upfield regions.

In conclusion, the formation of a tetraalkyl dideazaporphyrin by McMurry coupling of a pyrrole diacrylaldehyde has been investigated. The product exhibits porphyrin-like spectroscopic properties, including strongly diatropic NMR spectra, but is nevertheless highly unstable. The results concur with recent computational analyses.

Acknowledgments

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Declaration of Competing Interest

The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Electronic Supplementary Information

Experimental procedures and selected ^{1}H NMR, ^{1}H-^{1}H COSY, HSQC, DEPT-135, ^{13}C NMR, and UV-Vis spectra are provided.

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Highlights

- Analysis of aromatic character in porphyrinoid systems
- Relationship between porphyrins and [18]annulene
- McMurry synthesis of conjugated macrocycles
- Magnetic aromaticity (diatropicity) is not a measure of stability

1.

3.

Declaration of Competing Interest

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