

Microscale Synthesis and ^1H NMR Analysis of Tetraphenylporphyrins

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We describe an experiment combining the synthesis of several porphyrins with ^1H NMR analysis. The synthesis of these bright-purple crystalline compounds can be accomplished in a two-and-a-half-hour laboratory period. This set of experiments can be combined with experiments we reported in this *Journal* (1) in which the microscale synthesis and visible electronic absorption of the metalloporphyrins Zn^{II} (TPP) and Ni^{II} (TPP) are described.

Tetraphenylporphyrin, H_2 [TPP], and the H_2 [(*p*-X) $_4$ TPP] analogues are easily synthesized from inexpensive materials using microscale glassware. H_2 [TPP] is prepared through the condensation of 4 units of pyrrole with 4 units of benzaldehyde (Fig. 1), and the substituted analogues, H_2 [(*p*-X) $_4$ TPP], are produced using the appropriate substituted benzaldehyde. The mechanism of this condensation reaction has been studied in detail (2).

Tetraphenylporphyrin, H_2 [TPP], and para-substituted tetraphenylporphyrins, H_2 [(*p*-X) $_4$ TPP], where X = CN, CH_3 , and OCH_3 , generate simple ^1H NMR spectra, owing to their highly symmetrical nature (Fig. 1). At room temperature, porphyrin systems possess a fourfold symmetry, due to the rapid exchange of the inner two N-H protons about the four pyrrole nitrogens (3). These compounds provide an excellent introduction into the effects that aromaticity and electron donating/withdrawing groups have on ^1H NMR chemical shifts. ^1H NMR chemical shift data provide important physical evidence for delocalized π electrons in aromatic systems (4). Porphyrin systems contain 18 π electrons (5), thus meeting the Hückel ($4n + 2$) rule.¹ Furthermore, the ^1H NMR spectra of the para-substituted compounds, H_2 [(*p*-X) $_4$ TPP], provide an excellent example of spin-coupling systems (between the ortho and meta protons on the phenyl rings) with a range of $\Delta\nu/J$ ratios. The AA'BB' to AA'XX' coupling systems can be used to discuss the difference between chemical and magnetic equivalence.

Experimental Procedure

Synthesis of H_2 [TPP] and H_2 [(*p*-X) $_4$ TPP] (X = CN, CH_3 , and OCH_3)

The microscale synthesis of the porphyrins has been adapted from the synthesis reported by Adler et al. (6). The appropriate benzaldehyde is refluxed for 30 min with 0.08 mL of pyrrole in 12 mL of propionic acid in a 25-mL round-bottom flask fitted with a water condenser. The pyrrole must be from a freshly opened bottle or have recently been purified by vacuum distillation. After refluxing, the reaction mixture is cooled to room temperature and 10 mL of cold methanol is added. The flask is then chilled in an ice bath while stirring, and crystallization is induced by scratching the sides of the flask with a glass stirring rod. The deep-purple crystals are filtered by vacuum filtration with a Buchner funnel. The flask and crystals are washed with three 0.5-mL portions of cold methanol followed by three 0.5-mL portions of boiling distilled water. The crystals are air-dried on the Buchner funnel for 15 min and may be dried in a vacuum desiccator until the next lab period if desired.

The syntheses of the substituted porphyrins are performed in a similar manner using the following portions of the corresponding substituted benzaldehyde reagents:

for H_2 [(*p*-CN) $_4$ TPP], 0.1552 g of 4-cyanobenzaldehyde;

for H_2 [(*p*- CH_3) $_4$ TPP], 0.14 mL of *p*-tolualdehyde; and

for H_2 [(*p*- OCH_3) $_4$ TPP], 0.14 mL of 4-methoxybenzaldehyde (*p*-anisaldehyde)

Average yields are about 40 mg (23%). All the benzaldehydes

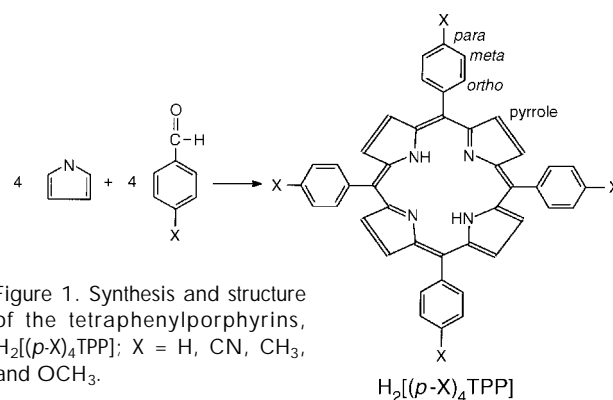


Figure 1. Synthesis and structure of the tetraphenylporphyrins, H_2 [(*p*-X) $_4$ TPP]; X = H, CN, CH_3 , and OCH_3 .

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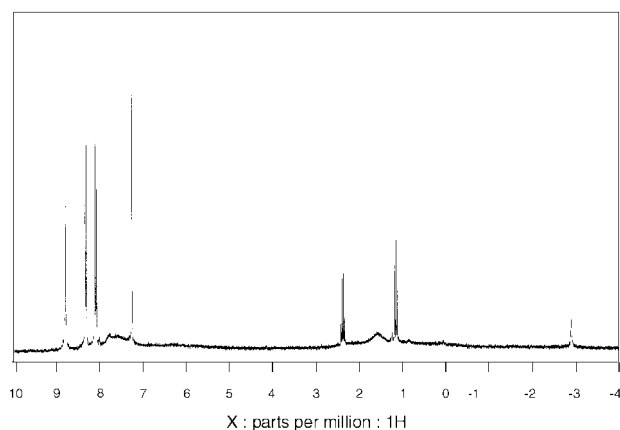


Figure 2. ^1H NMR of $\text{H}_2[(p\text{-CN})_4\text{TPP}]$ in CDCl_3 . Solvent peak of CDCl_3 at 7.25 ppm. Residual propionic acid appears as a quartet centered at 2.39 ppm and a triplet at 1.15 ppm. Water appears as a broad peak centered at 1.5 ppm.

are commercially available.²

The resulting porphyrins can be characterized by visible absorption or ^1H NMR spectroscopy without further purification. The only impurities observed in the NMR are propionic acid and water. The NMR samples are prepared by dissolving 4 mg of porphyrin in 0.4 mL of CDCl_3 solvent (~ 0.016 M). Higher concentrations are not recommended owing to the potential for aggregation of porphyrins in solution. Suitable ^1H NMR spectra are obtained after 8 scans on a 270-MHz NMR spectrometer. If time allows, more scans can be used to yield better resolution of the AA'XX' patterns.

Results and Discussion

The full ^1H NMR spectrum of $\text{H}_2[(p\text{-CN})_4\text{TPP}]$ is shown in Figure 2, and an overlay of all the porphyrin spectra in the aromatic region is presented in Figure 3. The ^1H NMR chemical shifts of all the porphyrins are listed in Table 1. The protons (ortho, meta, para) on the phenyl rings are identified with respect to their positions relative to the porphyrin ring system.

The effect of the porphyrin ring diamagnetic anisotropy is evident in the deshielding of the phenyl and pyrrole protons and in the shielding of the inner N-H protons. This can be demonstrated by comparing the porphyrins' ^1H NMR chemical shift values with those of their respective benzaldehyde precursors (the porphyrins' proton resonances are shifted ca. 0.30 ppm downfield). The porphyrins' diamagnetic anisotropy effects can be compared to those in benzene and annulenes (4). The singlet N-H peaks (due to rapid exchange of the N-H protons) are found at very high field (-2.9 ppm), since they are located within the shielding cone of the porphyrin ring.

The effects due to electron-donating and electron-withdrawing groups are readily apparent within this set of para-substituted porphyrins (Fig. 3). The electron-donating groups in $\text{H}_2[(p\text{-X})_4\text{TPP}]$ ($\text{X} = \text{OCH}_3$ and CH_3) cause the protons in the phenyl ring to be more shielded (upfield chemical shifts), whereas elec-

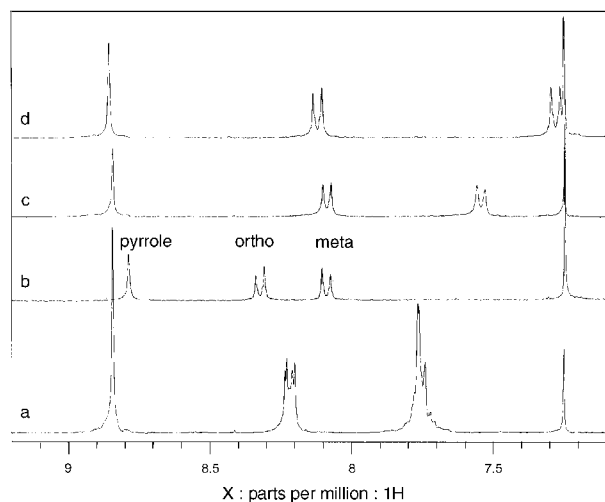


Figure 3. ^1H NMR overlay of the aromatic regions. Solvent peak of CDCl_3 at 7.25 ppm. Spectrum: (a) $\text{H}_2[\text{TPP}]$; (b) $\text{H}_2[(p\text{-CN})_4\text{TPP}]$; (c) $\text{H}_2[(p\text{-CH}_3)_4\text{TPP}]$; (d) $\text{H}_2[(p\text{-OCH}_3)_4\text{TPP}]$.

tron-withdrawing groups at the para site ($\text{X} = \text{CN}$) result in decreased shielding (downfield chemical shifts). The extent of shielding shows that the methoxy group has a greater inductive effect than the methyl group, causing a greater increase in the σ electron density of the carbon atom to which it is bonded. Shielding–deshielding effects are more pronounced in the protons ortho to the para-substituents (identified as the meta protons) than in the protons meta relative to the para-substituents (identified as the ortho protons) owing to the greater electron-attracting inductive effects at a position in which resonance effects are minimal (4).

The ^1H NMR resonances of the ortho and meta protons on the phenyl rings of the $\text{H}_2[(p\text{-X})_4\text{TPP}]$ compounds provide a very clear demonstration of the progression of an AA'XX' coupling pattern to an AA'BB' coupling pattern. When the chemical shift difference (in Hz) is about 10 times larger than the coupling constant J (in Hz), a system that looks similar to a simple AX doublet pattern appears (4)—as in the case of $\text{H}_2[(p\text{-OCH}_3)_4\text{TPP}]$, in which $\Delta\nu/J \approx 26$. For $\text{H}_2[(p\text{-CH}_3)_4\text{TPP}]$ where $\Delta\nu/J \approx 18$, a slight distortion of the coupling pattern is apparent; and for $\text{H}_2[(p\text{-CN})_4\text{TPP}]$ in which $\Delta\nu/J \approx 8$, the pattern approaches AB. Close scrutiny of the ortho/meta doublet patterns reveals additional small couplings rather than distinct symmetrical peaks. This is because the ortho protons as well as the meta protons are not magnetically equivalent nuclei (4a). For $\text{H}_2[\text{TPP}]$ a complex ^1H NMR pattern is observed for the ortho/meta protons, due to the existence of para protons.

Table 1. ^1H NMR Data for $\text{H}_2[\text{TPP}]$ and $\text{H}_2[(p\text{-X})_4\text{TPP}]$

Porphyrin	Chemical Shift/ppm							J_{om}/Hz
	Proton					-OCH ₃	-CH ₃	
	Pyrrole	ortho	meta	para	N-H			
$\text{H}_2[\text{TPP}]$	8.85	8.28	7.75	7.77	-2.79	-	-	7
$\text{H}_2[(p\text{-OCH}_3)_4\text{TPP}]$	8.85	8.11	7.28	-	-2.76	4.09	-	9
$\text{H}_2[(p\text{-CH}_3)_4\text{TPP}]$	8.85	8.09	7.54	-	-2.79	-	2.70	8
$\text{H}_2[(p\text{-CN})_4\text{TPP}]$	8.79	8.32	8.09	-	-2.89	-	-	8

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Notes

1. The phenyl rings are considered to be noncoplanar with the plane of the porphyrin ring system and are not considered to participate in the porphyrin rings' π electron aromaticity (β).

2. Owing to the relatively high solubility of $H_2[(p-OCH_3)_4TPP]$ an additional step must be performed. After refluxing, the reaction mixture is allowed to cool for 5 min. A Hickman still head is attached to the round-bottom flask and a water condenser is connected to the top of the still. The reaction mixture is reduced in volume to approximately 6 mL, whereby propionic acid is collected in the Hickman still. The porphyrin is vacuum filtered on a Buchner funnel and washed as outlined.

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