

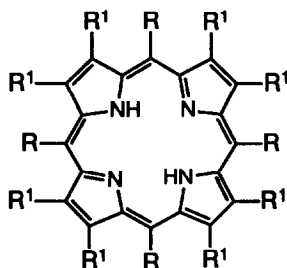
THE SYNTHESIS AND SOLUTION CONFORMATION OF DODECAPHENYLPORPHYRIN

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Abstract: The synthesis of 2,3,5,7,8,10,12,13,15,17,18,20-dodecaphenylporphyrin (DPP; 3) is reported; compared with similar porphyrins it shows a red-shifted electronic absorption spectrum, indicating a non-planar conformation in solution. Variable temperature 500 MHz NMR experiments give a ΔG^\ddagger of 10.9 kcal mol⁻¹ at 253 K for inversion of the macrocycle.

Aryl-substituted porphyrins have been employed in many investigations of the chemical, structural and spectroscopic properties of porphyrins.^{1,2} One of the most widely used model systems is 5,10,15,20-tetraphenylporphyrin (TPP; 1), which was originally prepared by Rothmund in 1936 from the reaction of benzaldehyde and pyrrole in a sealed bomb at 150°C for 24 hours.³ An improved synthesis was reported by Adler et al. in 1967,⁴ whilst Lindsey and co-workers have recently described the acid catalyzed condensation of pyrrole and benzaldehyde to form tetraphenylporphyrinogen and subsequent oxidation to give the porphyrin.⁵ Two syntheses of a porphyrin bearing eight phenyl rings have also been reported.^{6,7} In 1965, Friedman⁶ reported that refluxing the Mannich base of 3,4-diphenylpyrrole with ethyl magnesium bromide and subsequent demetalation with acetic acid gave 2,3,7,8,12,13,17,18-octaphenylporphyrin (OPP; 2). Maruyama and co-workers⁷ have also prepared OPP by the reduction of ethyl 3,4-diphenylpyrrole-2-carboxylate with LiAlH₄, followed by treatment with acetic acid and then an oxidizing agent.



- (1) R = phenyl, R¹ = H
- (2) R = H, R¹ = phenyl
- (3) R = R¹ = phenyl

Despite these efforts, the synthesis of a porphyrin bearing twelve phenyl rings [2,3,5,7,8,10,12,13,15,17,18,20-dodecaphenylporphyrin (DPP; 3)] has yet to be reported. This synthesis is particularly topical because steric crowding of the phenyl rings may cause the macrocycle to adopt a non-planar conformation. The X-ray structures of several sterically crowded 2,3,7,8,12,13,17,18-octaalkyl-5,10,15,20-tetraphenylporphyrins show a non-planar saddle conformation with alternating pyrrole rings pointing up or down, whilst variable temperature proton NMR experiments indicate that the macrocycle is also non-planar in solution and capable of undergoing an unusual macrocyclic inversion process.^{8,9} Non-planar conformational distortions of the porphyrin macrocycle have been proposed as a mechanism for modifying the optical properties of photosynthetic chromophores.^{10,11} Recent theoretical calculations on the effects of non-planarity in zinc porphyrins indicate that the highest occupied molecular orbital should be destabilized with respect to the lowest

unoccupied molecular orbital thereby correctly predicting a red-shift of the first visible absorption band of a non-planar zinc porphyrin.¹¹ We therefore decided to synthesize DPP and investigate the light absorption properties and solution conformation of this unusual molecule.

DPP was prepared from 3,4-diphenylpyrrole⁶ and benzaldehyde using a procedure similar to that which Lindsey and co-workers⁵ applied to the synthesis of TPP. Benzaldehyde (2.76 mM) and 3,4-diphenylpyrrole (2.76 mM) were added to 275 ml of distilled dichloromethane in a 500 ml round-bottomed flask. The mixture was stirred under nitrogen for 15 minutes, BF_3OEt_2 (0.276 mM) was added by syringe and the mixture was shielded from ambient light and stirred for 1 hour. After this time, DDQ (2.76 mM) was added to oxidize the porphyrinogen and the reaction mixture was refluxed for 30 minutes. A visible spectrum of the crude reaction mixture showed a Soret band indicative of porphyrin formation. The solvent was then removed under vacuum and the porphyrin purified using a Brockmann Grade III alumina column eluted with 40% dichloromethane in cyclohexane. The green porphyrin dication fraction was found to contain small amounts of contaminants and was purified again using a Brockmann Grade III alumina column with toluene as eluent. The toluene was removed under high-vacuum to yield green crystals of the DPP dication. These were dissolved in a minimum volume of dichloromethane and 1% KOH in ethanol was added dropwise until the solution turned a brown color, indicating formation of the free base porphyrin. Addition of more ethanol caused the free base porphyrin to deposit from solution as green crystals which changed to a black powder upon drying. The yield of DPP was 48 mg (0.039 mM, 5.7%). DPP is soluble in a range of organic solvents but is easily protonated by small amounts of acid or water.

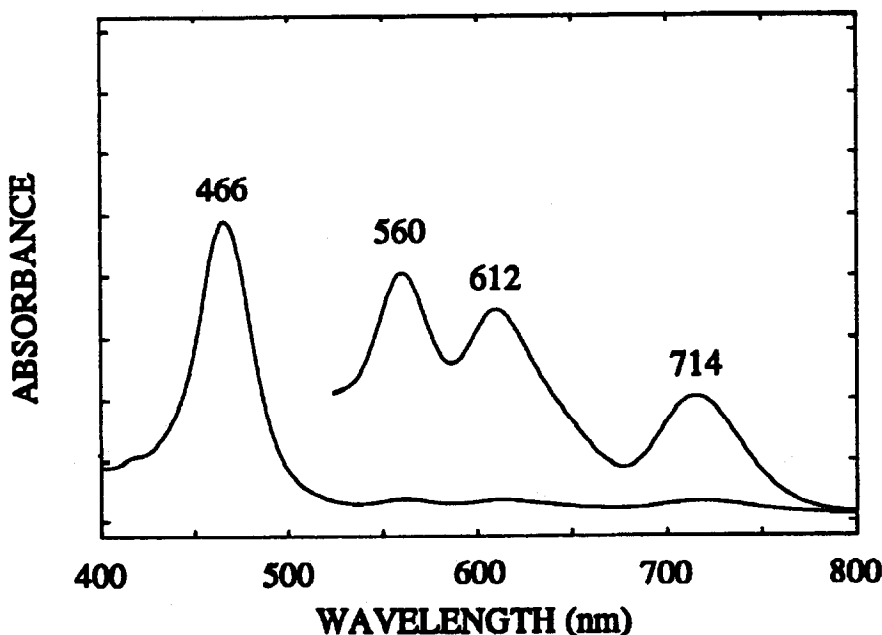


Figure 1. Visible absorption spectrum of DPP (3) in chloroform.

The visible absorption spectrum of DPP is shown in Figure 1. The absorption maxima [466, 560, 612, 714 nm]

are indeed red-shifted compared with TPP [414, 514, 548, 588, 646 nm] and OPP [414, 514, 550, 583, 635 nm]⁶ with the magnitude of the red-shifts being similar to those of other non-planar porphyrins.^{8,9} Variable temperature NMR studies confirm that DPP adopts a non-planar conformation in solution. The 500 MHz proton NMR spectrum of DPP in CD₂Cl₂ at 25°C shows a doublet at 7.61 ppm which can be assigned as the meso phenyl ortho protons, two multiplets at 6.79 ppm and 6.68 ppm which overlap slightly, and a broad signal for the NH proton at approximately -1 ppm. Upon cooling the resonances broaden and coalesce, until at -80°C there are six doublets and nine triplets in the aromatic region, each integrating to one proton (Figure 2). At this temperature NH tautomerism is expected to be slow on the NMR timescale.¹² If the molecule were planar, or adopted a non-planar conformation with rapid inversion of the macrocycle, there should be one signal for each ortho, meta and para position of the meso phenyl protons and two sets of signals for the phenyl protons on -NH- and =N- containing rings, giving a total of nine signals. This pattern of signals is clearly inconsistent with the observed spectrum. However, a non-planar saddle conformation with porphyrin inversion also slow on the NMR timescale should further split the ortho and meta signals of the pyrrole phenyl protons because the molecule no longer possesses a plane of symmetry. The ortho and meta meso phenyl signals should also split again when localization of the NH protons on trans pyrrole rings makes each face of the porphyrin different, giving a total of fifteen signals each integrating to one proton. The observed pattern is therefore consistent with a non-planar saddle conformation of the porphyrin macrocycle, with NH tautomerism and ring inversion being slow on the NMR timescale at -80°C. The four downfield doublets can be assigned as the two pyrrole ortho phenyl protons pointing outwards (Ha and Hb) which should be in the deshielding region of the porphyrin ring current and also the two ortho meso phenyl protons (Hm). The two upfield signals can be assigned as the two pyrrole ortho phenyl protons pointing inwards (Hc and Hd) which should be located above the porphyrin ring and in the shielding region of the porphyrin ring current.

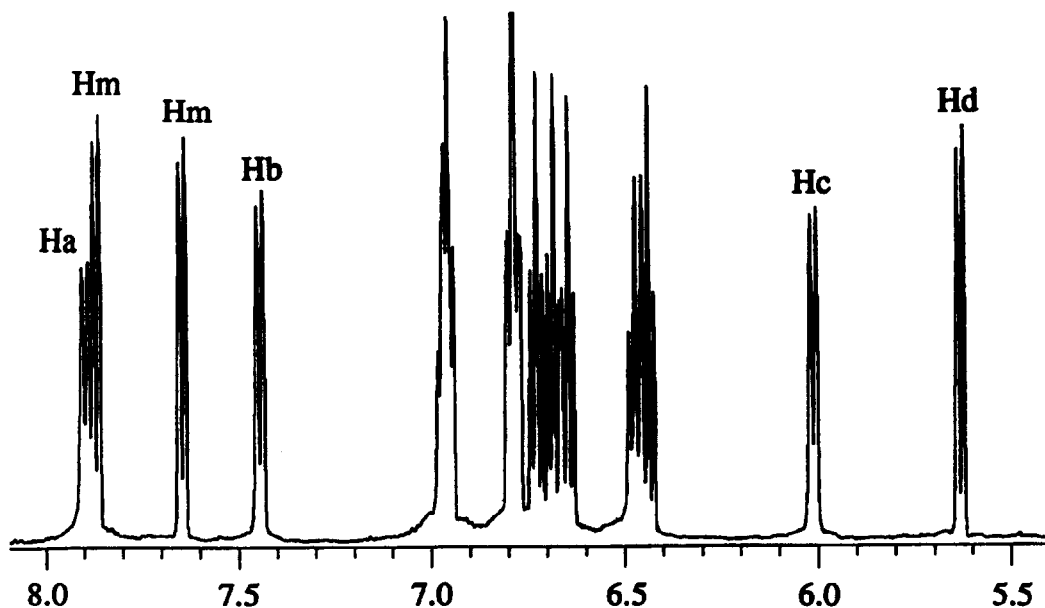


Figure 2. 500 MHz proton NMR spectrum of DPP (3) in CD₂Cl₂ at -80°C; chemical shifts are with respect to the solvent peak at 5.30 ppm.

To investigate the free energies of activation (ΔG^\ddagger) for porphyrin inversion and NH tautomerism, saturation transfer experiments were carried out at -60 and -40°C . At -60°C saturation transfer can be observed between the pairs of ortho protons exchanged by porphyrin inversion (eg. Ha and Hc, Hb and Hd) but there is little saturation transfer between the protons which are exchanged by NH tautomerism (eg. Ha and Hb, Hc and Hd). At -40°C saturation transfer is observed for both exchange mechanisms, with irradiation of Hd giving saturation transfer to Ha, Hb and Hc. The exchange rate for NH tautomerism is therefore slower than for macrocyclic inversion, in agreement with the observation that the pyrrole para phenyl protons (which are unaffected by porphyrin inversion) coalesce at a higher temperature than the protons which are affected by both processes. Using the standard equation,¹³ ΔG^\ddagger for NH tautomerism at coalescence (263 K) is calculated to be $13.0 \text{ kcal mol}^{-1}$. An approximate ΔG^\ddagger value for porphyrin inversion is calculated to be $10.9 \text{ kcal mol}^{-1}$ at the coalescence temperature (253 K) of the pyrrole ortho phenyl protons. For 2,3,7,8,12,13,17,18-octaethyl-5,10,15,20-tetraphenylporphyrin the ΔG^\ddagger s for macrocyclic inversion and NH tautomerism are 18.1 and $13.7 \text{ kcal mol}^{-1}$ respectively.⁸ Exchanging the pyrrole ethyl substituents for phenyl rings therefore involves a considerable reduction in the barrier for macrocyclic inversion but little change in the barrier for NH tautomerism.

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