

Synthesis of Some Mono, Di, and Trisubstituted Tetraarylporphyrins (1)

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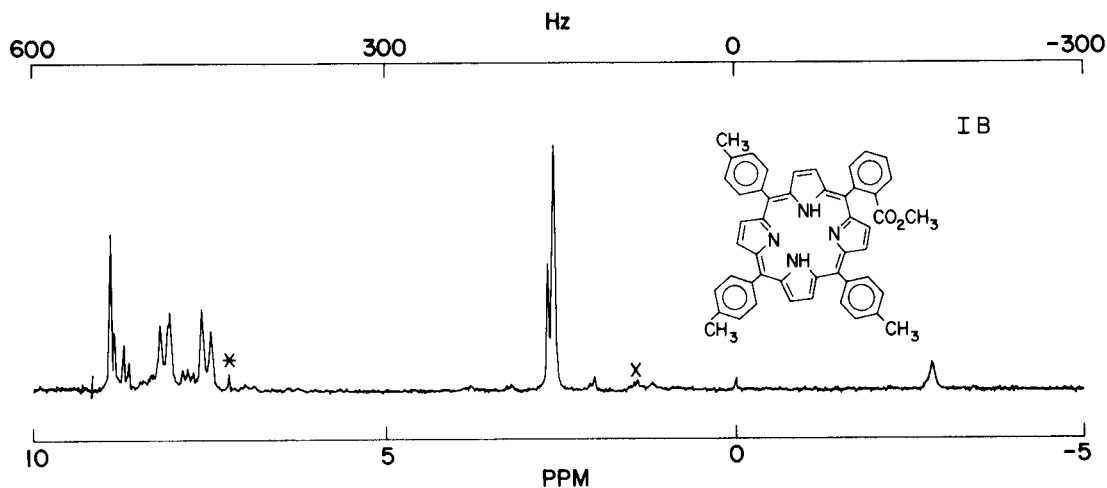
Received January 9, 1975

It is known that the primary electron donor unit of photosynthesis consists of a special aggregate of two to four chlorophyll (or bacteriochlorophyll) molecules (3,4,5,6,7). This aggregate is oxidized by removing one electron in the photoevent. Progress in understanding the primary photochemistry depends on the construction of appropriate model complexes whose exact chemistry and 3-dimensional structure can be ascertained. Aside from an anhydrous chlorophyll *a* dimer (8), it has not been possible to prepare well defined aggregates of chlorophyll in solution.

Recent work (9,10) has demonstrated that synthetic porphyrins, chlorins and bacteriochlorins, are appropriate models for understanding chlorophyll and bacteriochlorophyll redox chemistry. Furthermore, Dolphin *et al.* (11) have used covalently linked porphyrins to study energy transfer.

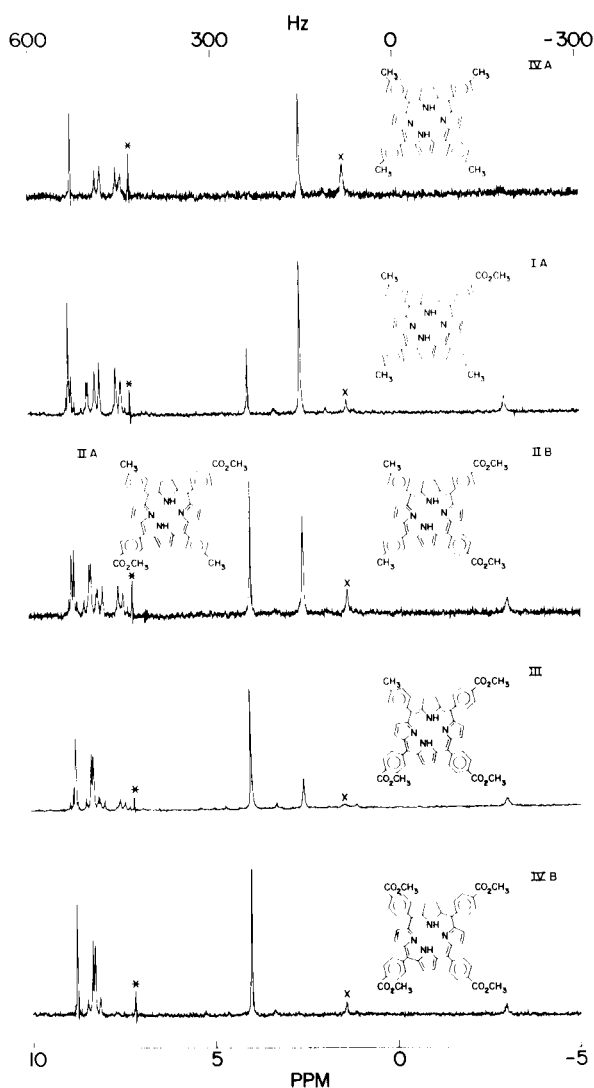
In our current work involving the construction of model systems for the primary electron donor unit of photosynthesis we have synthesized a series of mono, di, and tri *para* substituted tetraarylporphyrins, and also a mono *ortho* substituted tetraarylporphyrin. The compounds are: IA. 5-(4-carbomethoxyphenyl)-10,15,20-tritolylporphyrin, IB. 5-(2-carbomethoxyphenyl)-10,15,20-tritolylporphyrin, IIA. 5,15-di(4-carbomethoxyphenyl)-10,20-ditolylporphyrin, IIB. 5,10-di(4-carbomethoxyphenyl)-15,20-ditolylporphyrin, and III. 5,10,15-tri(4-carbomethoxyphenyl)-20-tolylporphyrin.

We intend to eventually synthesize porphyrin oligomers, utilizing the new compounds described. By a systematic study of the chemical and photochemical properties of these well defined porphyrin oligomers we hope to better understand the process of trapping light energy in photosynthesis.



Legend for Fig. 1

Nmr data for compound IB. $\Delta = 8.90-8.58$ (m, 8H, B-pyrrole); 8.50-7.68 (m, 4H, carbomethoxyphenyl-3,4,5,6-protons); 8.10 (d, 6H, $J = 8.0$ Hz, tolyl-2,6-protons); 7.52 (d, 6H, $J = 80$ Hz, tolyl-3,5-protons); 2.75 (s, 3H, methyl ester); 2.68 (s, 9H, methyls); -2.62 (s, 2H, pyrrole N-H).



Legend for Fig. 2

Nmr Data for Compounds:

IV A. $\Delta = 8.80$ (s, 8H, β -pyrrole); 8.05 (d, 8H, $J = 8.0$ Hz, tolyl-2,6-protons); 7.50 (d, 8H, $J = 8.0$ Hz, tolyl-3,5-protons); 2.67 (s, 12H, methyl).

IA. $\Delta = 8.91$ -8.68 (m, 8H, β -pyrrole); 8.37 (AB quartet, 4H, carbomethoxyphenyl-2,3,5,6-protons); 8.08 (d, 6H, $J = 8.0$ Hz, tolyl-2,6-protons); 7.52 (d, 6H, $J = 8.0$ Hz, tolyl-3,5-protons); 4.05 (s, 3H, methyl ester); 2.63 (s, 9H, methyl); -2.80 (s, 2H, pyrrole N-H).

II A. $\Delta = 8.88$ -8.66 (m, 8H, β -pyrrole); 8.32 (AB quartet, 8H, carbomethoxyphenyl-2,3,5,6-protons); 8.05 (d, 4H, $J = 8.0$ Hz, tolyl-2,6-protons); 7.50 (d, 4H, $J = 8.0$ Hz, tolyl-3,5-protons); 4.07 (s, 6H, methyl esters); 2.67 (s, 6H, methyls); -3.13 (s, 2H, pyrrole N-H).

II B. $\Delta = 8.90$ -8.67 (m, 8H, β -pyrrole); 8.33 (AB quartet, 8H, carbomethoxyphenyl-2,3,5,6-protons); 8.07 (d,

4H, $J = 8.0$ Hz, tolyl-2,6-protons); 7.50 (d, 4H, $J = 8.0$ Hz, tolyl-3,5-protons); 4.05 (s, 6H, methyl esters); 2.63 (s, 6H, methyls); -2.85 (s, 2H, pyrrole N-H).

III. $\Delta = 8.90$ -8.68 (m, 8H, β -pyrrole); 8.32 (AB quartet, 12H, carbomethoxyphenyl-2,3,5,6-protons); 8.03 (d, 2H, $J = 8.0$ Hz, tolyl-2,6-protons); 7.50 (d, 2H, $J = 8.0$ Hz, tolyl-3,5-protons); 4.07 (s, 9H, methyl esters); 2.65 (s, 3H, methyls); -2.80 (s, 2H, pyrrole N-H).

IV B. $\Delta = 8.77$ (s, 8H, β -pyrrole); 8.32 (AB quartet, 16H, carbomethoxyphenyl-2,3,5,6-protons); 4.08 (s, 12H, methyl esters); -2.75 (s, 2H, pyrrole N-H).

Table I

Para Series		
Compound	Rf	Rel. Amount
IV A	.92	10%
IA	.71	35
II A	.52	15
II B	.44	20
III	.28	15
IV B	.17	5
Ortho Series		
IV A	.92	75
IB	.74	20
di, tri, and tetra ortho substituted		5

EXPERIMENTAL

Para Substituted Porphyrins.

A solution of 12.0 g. (0.073 mole) of 4-carbomethoxybenzaldehyde and 8.77 g. (0.073 mole) of *p*-tolualdehyde in 600 ml. of propionic acid was brought to reflux and 9.80 g. (0.146 mole) of pyrrole was then added. Refluxing was continued for ½ hour and then 300 ml. of ethylene glycol was added. The reaction mixture was allowed to cool and kept at 4° overnight. It was filtered the following morning and the purple crystals obtained were washed well with 1:1 methanol-water. The yield of mixed porphyrins was 3.15 g. (11.6% based on an average molecular weight of 744.36 and the concentration of pyrrole). The mixed porphyrins were separated as described below using preparative thin layer chromatography.

Ortho Substituted Porphyrins.

A solution of 7.50 g. (0.046 mole) of 2-carbomethoxybenzaldehyde and 5.53 g. (0.046 mole) of *p*-tolualdehyde in 250 ml. of propionic acid was brought to reflux and 6.17 g. (0.092 mole) of pyrrole was then added. Reflux was continued for 20 minutes and then 200 ml. of ethylene glycol was added. The reaction mixture was allowed to cool and kept at 4° overnight. It was filtered the following morning yielding 1.15 g. of a purple-black solid. This material was washed well with 1:1 methanol-water and then was chromatographed on a 110 g. silica gel column using reagent grade chloroform as eluant. The porphyrin bands were eluted quickly leaving the black impurity behind. The chloroform was removed

Table II

Compound	Calculated			Found		
	C	H	N	C	H	N
IA C ₄₉ H ₃₈ N ₄ O ₂ m.w. 714.87	82.33	5.36	7.84	81.63	5.43	7.93
IB C ₄₉ H ₃₈ N ₄ O ₂ m.w. 714.87	82.33	5.36	7.84	81.87	5.17	7.61
IIA C ₅₀ H ₃₈ N ₄ O ₄ m.w. 758.88	79.14	5.05	7.38	78.69	4.91	7.15
IIB C ₅₀ H ₃₈ N ₄ O ₄ m.w. 758.88	79.14	5.05	7.38	79.14	5.01	7.34
III C ₅₁ H ₃₈ N ₄ O ₆ m.w. 802.89	76.30	4.77	6.98	76.27	5.03	6.97

Table III

IA (Benzene) λ , nm ($\epsilon \times 10^{-3}$)	IB (Benzene) λ , nm ($\epsilon \times 10^{-3}$)	IVA (3) (Benzene) λ , nm ($\epsilon \times 10^{-3}$)	IVA (4) (Benzene) λ , nm ($\epsilon \times 10^{-3}$)	IVA (4) (Pyridine) λ , nm ($\epsilon \times 10^{-3}$)	IVB (4) (Pyridine) λ , nm ($\epsilon \times 10^{-3}$)
649 (4.3)	650 (4.4)	650 (4.1)	650 (4.4)	651 (4.7)	650 (3.2)
592 (5.2)	593 (5.4)	592 (5.4)	592 (5.4)	594 (5.1)	592 (5.3)
550 (9.4)	551 (9.2)	550 (8.2)	550 (9.7)	552 (10.0)	551 (8.3)
515 (18.3)	516 (18.6)	516 (18.9)	516 (19.0)	517 (17.8)	516 (17.8)
485 (3.6)	484 (3.8)	485 (3.7)	485 (4.2)	485 (4.1)	485 (3.7)
421 (460)	421 (473)	420 (490)	420 (483)	422 (454)	423 (403)

under reduced pressure leaving 0.46 g. of mixed porphyrins (2.9% based on an average molecular weight of 681.87 and the concentration of pyrrole). The mixed porphyrins were separated as described using preparative thin layer chromatography.

Results and Discussion.

The new compounds were obtained by a mixed aldehyde synthetic approach in which two equivalents of *p*-tolualdehyde and two equivalents of either 4-carbomethoxybenzaldehyde or 2-carbomethoxybenzaldehyde were condensed with four equivalents of pyrrole to yield a mixture of porphyrins. The synthetic procedure used is a modification of that initially developed by Rothmund (12) and refined by Adler, *et al.* (13) to synthesize tetra substituted porphyrins. The tetra substituted compounds of the *para* series, IVA. 5,10,15,20-tetratolylporphyrin, and IVB. 5,10,15,20-tetra(4-carbomethoxyphenyl)porphyrin, were previously reported (14,15).

The mixtures of substituted porphyrins were separated by preparative thin layer chromatography, in the dark, using Quantum PLQF silica gel plates and 2:1 benzene-chloroform.

The R_f values and approximate relative amounts of each porphyrin are given in Table I for both the *para* and *ortho* series. As expected, the more polar compounds had lower R_f values. The *ortho* substituted porphyrins were produced in very small percentages, presumably due to the close

proximity of the aldehyde and ester function. Attempts to increase their percentages by increasing the percentage of 2-carbomethoxybenzaldehyde led to lower yields and greater difficulty in the isolation of products. Only the mono substituted *ortho* compound was isolated and characterized.

The proposed structures and the nmr data supporting these structures for the *ortho* and *para* series are shown in figures 1 and 2 respectively. All spectra were recorded on a Varian T-60 spectrometer. The solvent used was 99.8% chloroform-D. The chloroform-H peak was used as an internal standard and assigned a Δ value of 7.20. This peak is marked with an asterisk in all the spectra. The variable peak which is seen at about 1.4 Δ is due to non-bonded water and is marked with an X. The nmr data unambiguously distinguishes the mono, di, tri, and tetra substituted compounds. The ratio of integrated areas for the peaks corresponding to the methyl esters, and the tolyl methyls is as expected in all cases. The peak corresponding to the methyl ester of the *ortho* substituted compounds is shifted upfield due to ring current effects, also as expected.

The nmr data was not helpful in distinguishing between the disubstituted isomers. However, in the absence of other data, the tentative structural assignments given to the two isomers were made on the basis of their R_f values. Compound IIA would be expected to have a small dipole mo-

ment relative to IIB. The less polar compound would be expected to have a greater R_f, hence the assignments. Work is presently underway to verify these assignments.

Mass spectral data also supports the assigned structures. All the compounds showed the expected parent peak, but also a parent mass plus 61 peak. The plus 61 peak was approximately 20-30% of the parent peak for all compounds. This peak is thought to arise from traces of metalloporphyrins formed by the porphyrins abstracting traces of metal ions from solvents, *etc.* There is evidence (16) that metalloporphyrins are more volatile than the free bases. Therefore, traces of metalloporphyrins could lead to sizeable peaks in as much as the peak intensities that are recorded are proportional to the quantities of material that are in the gas phase.

The copper complex of compound IIB was prepared and its mass spectrum taken. It showed the expected parent peak, with no higher peaks. In control experiments we found that a 3% content of a copper derivative in the free porphyrin sample was sufficient to give the extra peak observed. We speculate therefore that the plus 61 peak is due to small amounts of relatively highly volatile copper porphyrins.

Analytical data for the new compounds are given in Table II. All analyses were performed at Micro-Tech Laboratories, Inc., Skokie, Illinois. Good agreement with the expected composition was found.

A qualitative examination of the visible spectra of the new compounds showed them to be indistinguishable from each other and from tetratolylporphyrin. Extinction coefficients were determined for compounds IA and IB. The data is shown in Table III along with the previously reported spectral data for compounds IVA and IVB (14,15). Substitution of one of the tolyl methyl groups of tetratolyl porphyrin with a carbomethoxy group (either at the 2 or 4 position) does not significantly affect the absorbance spectra.

Acknowledgments.

We wish to thank Walter Sveck, Jim Norris, and Robert G. Scott of Argonne Nat'l. Laboratories for their help in obtaining the mass spectral data. We also wish to thank Dr. Robert Little for stimulating discussions.

REFERENCES

- (1) This investigation was supported by research grants from the National Science Foundation (GB-42860) and the National Institutes of Health (GM 11741).
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