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Nuclear Magnetic Resonance Spectra of Porphyrins*

WINSLOW S. CAUGHEY AND W. S. KOSKI

From the Department of Physiological Chemistry, The Johns Hopkins School of Medicine, and the Department of Chemistry, The Johns Hopkins University, Baltimore, Maryland

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The nuclear magnetic resonance spectra of twenty-two porphyrins in $CDCl_3$ solutions are reported. Included are metal complexes of Ni(II), Pd(II), and Zn(II) and a chlorin. Interpretations of effects of the spectra due to differences in the electron-withdrawing, magnetically anisotropic, and shielding characteristics of substituents, and in their relative positions, have led to detailed proton assignments of value in the characterization of natural porphyrins and their derivatives. Particularly important in these interpretations are long-range deshielding effects of magnetically anisotropic substituents and the effect of the ring-current field. The latter effect decreases with increasingly electron-withdrawing substituents (as reflected in decreasing nitrogen basicity) and upon metal complex formation, but is not greatly affected by chlorin formation.

Several reports on the n.m.r. spectra of porphyrins have recently appeared (Becker and Bradley, 1959; Ellis *et al.*, 1960; Becker *et al.*, 1961; Abraham *et al.*, 1961; Abraham, 1961). As in these spectra the different protons extend over a wide range of resonance frequencies and spin-spin interaction between groups at different positions on the ring is not observed, the spectra can be more readily interpreted than might be expected and thus constitute an extremely useful and much needed means for elucidating the structure of porphyrins and related compounds.

In this paper we wish to report our studies on the n.m.r. spectra of porphyrins. The porphyrins previously studied with one exception contained only substituents which have nearly equivalent "electron-withdrawing capacity" (simple alkyl groups, or hydrogen in the case of porphin). In this study compounds with strongly electron-withdrawing substituents are also included as are compounds of varying symmetry of substitution. Effects due to metal complex formation were noted and a chlorin (*i.e.*, dihydroporphyrin) has been compared with its corresponding porphyrin. These spectra were of interest both for characterizing new compounds, such as the green *a*-type heme associated with cytochrome oxidase (Caughey and York, 1962) and also as an extension of other studies of structural effects in porphyrins and metalloporphyrins (Caughey *et al.*, 1962; Alben and Caughey, 1962). Marked effects of changes in structure upon the strength of the ring current field and of long-range deshielding by magnetically anisotropic substituents have been observed, and a number of new assignments for protons commonly encountered among natural and synthetic porphyrins have been made.

EXPERIMENTAL

N.m.r. spectra were obtained with a Varian Associates spectrometer operating at 40 mc./second. Spectra were scanned from low to high field at rates of 70 to 300 cps/minute. The porphyrins were dissolved in $CDCl_3$ at a concentration ~ 0.1 M. Tetramethylsilane (TMS) was used as an internal reference. The data are expressed in p.p.m. referred to tetramethylsilane as 10.00 (τ-values) according to Tiers (1958).

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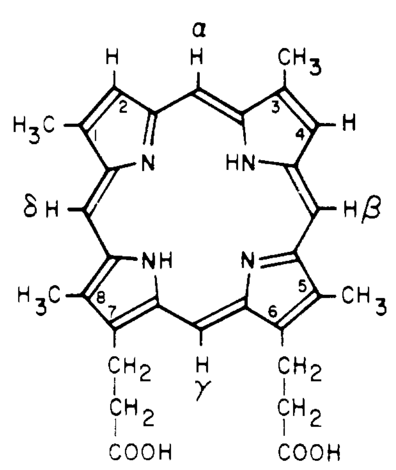

FIG. 1. Deuteroporphyrin IX.

Materials.[1]—Chlorin e_6Me_3 (#17) and its corresponding porphyrin, 2-vinylchloroporphyrin e_6Me_3 (#18), were kindly supplied by Professor A. H. Corwin. ETIO II (#1) was prepared from 4,4'-dimethyl - 3,3' - diethyldipyrrylmethene - 5,5'-dicarboxylic acid in formic acid solution (Fischer and Halbig, 1926). Me_4Cbe_4P-IV (#16) was prepared from 3,3' - dicarbethoxy - 5,5' - dichloro-4,4' - dimethylpyrromethene, 4,4' - dicarbethoxy-3,3',5,5'-tetramethylpyrromethene, and cupric acetate as the copper complex with subsequent removal of the copper with sulfuric acid (Kleinspehn *et al.*, 1959). The remaining porphyrins were obtained from protohemin chloride as original starting material, purified chromatographically, and crystallized. In each case the elemental analyses (C, H, and N) found were in close agreement with theoretical values, and visible, ultraviolet, and infrared spectra were consistent with their structures. Chromatographic evidence suggested the monopropionyl (#13) and mononitro (#15) compounds were homogeneous 2 *or* 4 substituted compounds and not a mixture of 2 *and* 4 substituted isomers. Details of the preparations are being published separately.[2]

RESULTS

All of the compounds used in this study with the exception of four (compounds 1, 16, 17, and 18 of Table I) are structurally related to protoporphyrin IX iron (II) complex (heme), the prosthetic group of hemoglobin and several other hemoproteins, and may be considered to be derivatives of deuteroporphyrin IX (Fig. 1). The structural variation among these derivatives therefore involves differences in substituent in the 2 and/or 4 positions, in the alkoxy group (methoxy or ethoxy) of the propionic esters in positions 6 and 7, and in the atom (metal or hydrogen) bound to the nitrogens at the center of the ring. Chlorin e_6Me_3 (#17) and the corresponding porphyrin [2-vinylchloroporphyrin e_6 trimethyl ester (#18)] bear a structural relationship to chlorophyll, from which they are obtained. The synthetic materials, ETIO II (#1) and Me_4-Cbe_4P-IV (#16), each contain only two different substituent groups, methyl and ethyl in the former case and methyl and ethoxycarbonyl in the latter case.

Low solubility in $CDCl_3$ prevented the study of several available compounds, such as the dimethyl esters of the 2,4-diformyl, 2,4-diacetyl, and 2,4 - dibromo - deuteroporphyrins IX. In other cases, although sufficient concentrations to observe a spectrum were achieved, the signal-to-noise ratio was rather low.

The τ-values for these spectra along with partial assignments are in Table I. The spectra and structures of four representative compounds appear in Figures 2 and 3. The peaks at extremely low fields (-0.55 to 1.58) must surely result from the protons on the methine bridge carbons, *i.e.* the α, β, γ, and δ protons (Fig. 1), as previously suggested (Becker and Bradley, 1959; Ellis *et al.*, 1960). In some compounds a single peak is observed; in others, multiple peaks for each of these protons are readily resolved. With the deuteroporphyrins and in Pr DEUT Me_2 (#13) (in NO_2 DEUT Me_2 (#15) the assignment is less clear at ~ 1.92), the 2,4-protons at the β-positions of the pyrrole rings are from 0.55 to 0.96 higher field than the methine protons and range from 1.03 to 1.49.

With PROTO Me_2 (#11) and PROTO Et_2 (#12) the three peaks in the region 3.50 to 4.10 are attributed to the vinyl groups (Becker *et al.*, 1961; Abraham *et al.*, 1961). In ETIO II (#1) the quartet centered at 5.89 with splitting of 8.1 cps and relative heights of 1:3:3:1 is clearly due to methylene protons of the ethyl groups. Analogous quartets are indicated in the spectra of MESO Me_2 (#2) and MESO Et_2 (#3); however, here the frequency assignments are complicated by peaks in this region from the α-methylene

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[1] For convenience the following abbreviations are used in this paper: ETIO II for etioporphyrin II (i.e., 1,4,5,8-tetramethyl-2,3,6,7-tetraethylporphin), MESO for mesoporphyrin IX (i.e., 2,4-diethyldeuteroporphyrin IX), DEUT for deuteroporphyrin IX (Fig. 1), Cp_2 DEUT Me_2Et_2 for 2,4-bis(2-carboxycyclopropyl)deuteroporphyrin IX 2,4-diethyl ester 6,7-dimethyl ester, Ac-Ox_2 DEUT for 2,4-diacetyldeuteroporphyrin IX dioxime, PROTO for protoporphyrin IX (i.e., 2,4-divinyldeuteroporphyrin IX), Pr DEUT for 2(or 4)-propionyldeuteroporphyrin IX, Cbm_2 DEUT for 2,4-dicarbomethoxydeuteroporphyrin IX, NO_2 DEUT for 2(or 4)-nitrodeuteroporphyrin IX, Me_4Cbe_4P-IV for 1,4,6,7-tetramethyl-2,3,5,8-tetrakisethoxycarbonylporphin, the prefixes Ni, Pd, and Zn for nickel(II), palladium(II), and zinc(II) complexes, respectively, and the suffixes Me and Et for methyl and ethyl esters respectively. The numbers in parentheses, e.g. (#11), following the abbreviations refer to the compound numbers used in Table I

[2] W. S. Caughey and co-workers, in preparation.

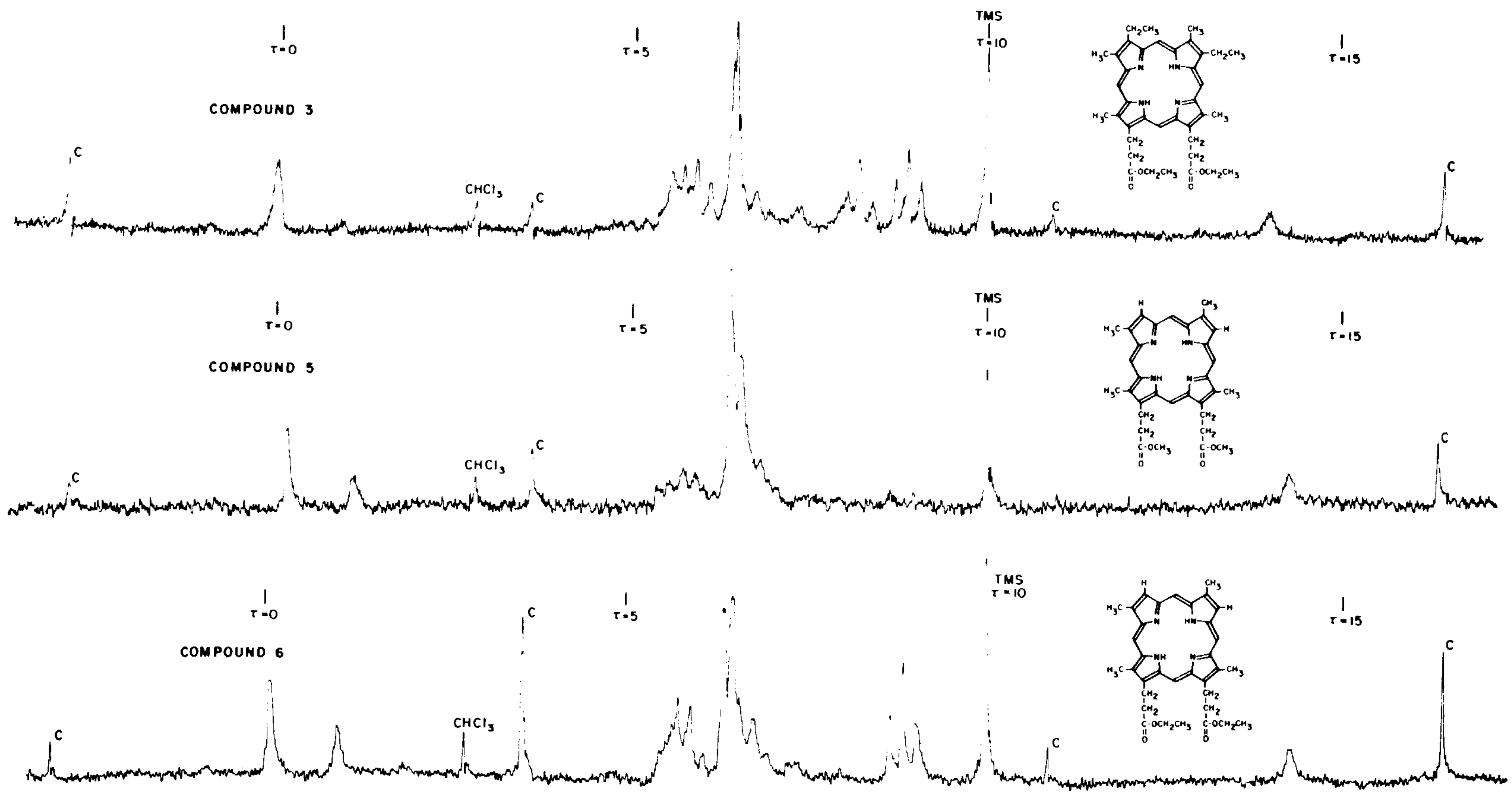

FIG. 2.—N.m.r. spectra of porphyrins. Compound 3, mesoporphyrin IX dimethyl ester; compound 5, deuteroporphyrin IX dimethyl ester; compound 6, deuteroporphyrin IX diethyl ester; Peaks marked "c" designate cycle peaks.

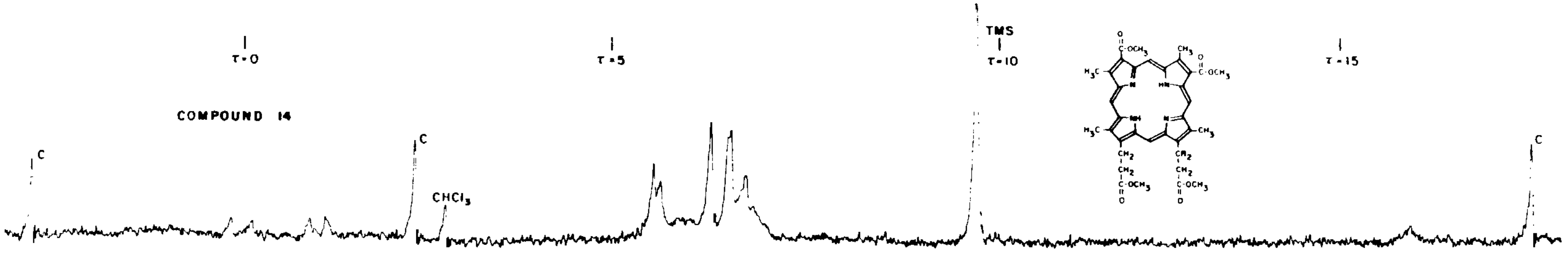

FIG. 3.—N.m.r. spectrum of compound 14, deuteroporphyrin IX 2,4-dicarboxylic acid, tetramethyl ester.

TABLE I

N.M.R. DATA FOR PORPHYRINS (τ-VALUES IN DEUTEROCHLOROFORM)

Compound No.	Porphyrin	Methine-H	2,4-H	Cyclopr-OCH_2-CH$_3$	Ring-COOCH_3	-CH_2-CH$_2$-COOR	Prop-OCH_2-CH$_3$	Prop-OCH_3	Ring-CH$_3$	-CH$_2$-CH_2-COOR	Ring-CH$_2$CH_3	Cyclopr-OCH$_2$-CH_3	Prop-OCH$_2$-CH_3	N-H	Othe H
1	Etioporphyrin II	−0.08							6.38		8.13			13.78 (br)	5.89[a]
2	Mesoporphyrin IX Me$_2$	−0.05						6.36	6.48 (M)	6.79	8.20			13.94	
3	Mesoporphyrin IX Et$_2$	−0.07					5.79		6.44 (M)	6.74	8.18		8.88	14.00	
4	Coproporphyrin III Me$_4$[b]	−0.06				5.62		6.31 6.33 6.35	6.38 6.40 6.43	6.75				13.92	
5	Deuteroporphyrin IX Me$_2$	0.11	1.07 (br)			5.75		6.36	6.40[c] 6.51 (D)	6.81				14.26	
6	Deuteroporphyrin IX Et$_2$	0.08	1.03				5.82		6.38 (D) 6.48 (D)	6.78			8.87	14.28	
7	2,4-Bis(2-carboxycyclopropyl)deuteroporphyrin IX 6,7-Me$_2$ 2,4-Et$_2$	0.04 0.21 (D) 0.38		5.44				6.34	6.56 (M)	6.78		8.43		14.27 (br)	7.50–8.80[d]
8	2,4-Bis(2-carboxycyclopropyl)deuteroporphyrin IX Me$_4$	0.08 0.22 (D) 0.42						6.35	6.61 (M)	6.79				14.15 14.36 (br)	7.50–8.80[d] 5.93[e]
9	2,4-Bis(2-carboxycyclopropyl)deuteroporphyrin IX Et$_4$	−0.04 0.06 (D) 0.24		5.42			5.83		6.47 (M)	6.77		8.42	8.86		7.50–8.80[d]
10	2,4-Diacetyldeuteroporphyrin IX Me$_2$ dioxime	−0.13 0.19 0.35 0.56				5.78		6.34	6.39 (M) 6.59						7.04 (M)[f]
11	Protoporphyrin IX Me$_2$	0.28 0.38 (D) 0.45				5.72		6.36	6.59	6.82				14.57 (br)	3.58, 3.78, 4.10[g]
12	Protoporphyrin IX Et$_2$	0.27 0.30 0.41 0.48					5.83		6.58 (wk) 6.63	6.83			8.86	14.65 (br)	3.62, 3.81, 4.08[g]
13	2 (or 4)-Propionyldeuteroporphyrin IX Me$_2$	−0.55 0.29 0.36 0.43, 0.50[h]	1.05 (wk)			5.80		6.34	6.39 6.50 6.55 6.68	6.84				14.50 (br)	8.26, 8.42, 8.61 8.75, 9.12[i]

Compound No.	Porphyrin	Methine-H	2,4-H	Cyclopr-OCH_2-CH$_3$	Ring-COOCH_3	-CH_2-CH$_2$-COOR	Prop-OCH_2-CH$_3$	Prop-OCH_3	Ring-CH$_3$	-CH$_2$-CH_2-COOR	Ring-CH$_2$$CH_3$	Cyclopr-OCH$_2$-CH_3	Prop-OCH$_2$-CH_3	N-H	Other H
14	Deuteroporphyrin IX-2,4-	−0.15			5.58			6.37	6.61 (M)	6.96				15.94 (br)	
	dicarboxylic acid, Me$_4$	0.13			5.68				6.84						
		0.90													
		1.14													
15	2(or 4)-Nitrodeutero-	0.83	~1.92			6.12		6.38	6.46	7.14				16.26	
	porphyrin IX Me$_4$	1.04							6.67						
		1.24							6.86						
		1.38							6.99						
16	Tetrakis(ethoxycarbonyl)-	0.08 (br)							6.99 (M)						5.18, 5.35[j]
	tetramethylporphyrin	1.58 (br)							7.49 (M)						8.19, 8.34[k]
	IV														
17	Chlorin e$_6$Me$_3$	0.27			5.71			6.35	6.40		8.32			11.42	4.65[l]
		0.43							6.55						6.20[m]
		1.20							6.79						7.72[n]
															8.77
18	2-Vinylchloroporphyrin	0.28			5.66			6.26	6.41	(7.19)	8.34			13.51	4.09[l]
	e$_6$Me$_3$	0.40							6.58						6.20[m]
		0.52							6.69						8.74
									6.78						
19	Deuteroporphyrin IX Me$_2$,	0.68	1.41 (br)			5.98		6.35	6.65 (D)	6.98					
	nickel(II) complex								6.76 (D)						
20	Deuteroporphyrin IX Et$_2$,	0.72	1.49 (br)			5.99	5.86		6.65	6.98			8.86		
	nickel(II) complex								6.70						
									6.77						
									6.80						
21	Deuteroporphyrin IX Me$_2$,	0.55	1.36 (br)			5.98		6.33	6.51	6.97					
	palladium(II) complex	0.61							6.63						
		0.78 (D)							6.71						
									6.85						
22	Compound 7, nickel(II)	0.42		5.49				6.33	6.75			8.46			7.50–8.80[d]
	complex	0.65							6.83 (M)						
		0.73													
		0.89													
23	Compound 7, zinc(II)	0.71		5.41				6.37	6.92 (M)			8.39			7.50–8.80[d]
	complex	0.90													
		1.04													
		1.14													

(Prop- = propionate; Cyclopr- = cyclopropylcarboxylate). (br) = broad; (wk) = weak; (D) = doublet; (M) = multiple.

[a] -CH_2CH$_3$. [b] Data from Becker, *et al.*, 1961. [c] Shoulder on 6.36 peak, D. [d] Several weak and poorly resolved peaks in this region presumably are associated with cyclopropyl groups. [e] Cyclopropyl-COOCH_3. [f] -CH_3 of acetyl oxime groups, tentative. [g] Weak peaks of equal height due to vinyl groups. [h] These are each about half the area of the peaks at −0.55, 0.29, and 0.36. [i] Attributable to 2(or 4)-propionyl. [j] Centers of two quartets J = 7.0 cps) of equal area due to COOCH_2CH$_3$. [k] Triplets of equal area due to COOCH$_2$$CH_3$. [l] γ-$CH_2$COOCH$_3$. [m] γ-CH$_2COOCH_3$. [n] 8-$CH_3$ (?)

protons of the propionic ester groups which in other compounds are clearly observed as triplets at 5.7 to 6.1 with typical J values of 6.5 cps. Triplets due to the β-methylene protons of the propionic ester groups appear in the 6.7 to 7.1 region. Prominent peaks from methyl groups substituted directly on the ring occur from 6.3 to 7.5 with groups in different positions frequently having different τ-values. Methyl protons of ring-substituted ethyl groups give rise to triplets (av. J, 7.5 cps) at 8.1 to 8.2. The peak at 7.04 noted for Ac-Ox$_2$ DEUT Me$_2$ (#10) probably arises from the methyl protons of the acetyloxime groups.

Quartets (av. J of 7.1 cps) due to alkyl methylene protons of ethyl esters of the propionic, 2-cyclopropylcarboxylic, and carboxylic acids are at 5.8, 5.4, and 5.1–5.4 respectively; triplets from the corresponding methyl groups appear at 8.9, 8.4, and 8.2–8.3. In the analogous methyl esters, the methyl protons are at 6.32 to 6.40, 5.93, and 5.58 to 5.68 respectively.

The peaks at extremely high field (11.4 to 16.3), as previously suggested (Becker and Bradley, 1959; Ellis *et al.*, 1960), undoubtedly result from protons bound to nitrogen at the center of the ring since they are not observed in the metal complexes. This N-H peak is often broad and weak, presumably owing to N^{14} quadrupole interaction. In one case, Cp$_2$ DEUT Me$_4$ (#8), there was clearly a doublet. With a few metal-free compounds, particularly those of low solubility, this peak was not detected.

DISCUSSION

Although a rigorous theoretical treatment of these data will not be attempted, several correlations will be considered that are self-consistent among the data and have proved useful in interpreting the marked effects of structure on the n.m.r. spectra of these compounds.

Ring Current Effects.—The wide separation of τ-values ranging from the methine protons at extremely low fields to the nitrogen-bound protons at high fields can be ascribed in large part to the so-called "ring currents" associated with the aromatic ring system. That the ring current field effects here are considerably greater than those noted in substituted benzenes can be seen in MESO Me$_2$ (#2) with methine protons at −0.05, 2.68 p.p.m. low field from benzene protons (2.73), and in the ring-CH$_3$ groups at 1.18 p.p.m. low field from toluene-CH$_3$ (7.66) (Jackman, 1959a,b). The extent of these effects on a given proton depends on its location in respect to the field; thus the $-CH_2CH_3$ of MESO Me$_2$ (#2) is only 0.57 p.p.m. low field from ethylbenzene (8.77) (Jackman, 1959c). Similarly, whereas the τ-values for the alkyl protons of propionic ester groups are in the usual region for aliphatic acid esters and thus appear unaffected by the ring current field, as the chain length of the acid substitutent is shortened such field effects are increasingly noted in that the ester alkyl protons appear at lower fields. With the Cp$_2$ DEUT compounds the low field positions of ethyl and methyl protons of the 2-cyclopropylcarboxylic acid ester groups indicate that these protons experience significant ring current fields and thereby provide strong evidence for the carboxyl group on the cyclopropyl ring being *cis* to the porphyrin ring. Protons in 2,4-positions appear at higher fields than methine protons; in deuterofluoroacetic acid the β-protons of porphin are at 1.3 p.p.m. higher field than the methine protons (Abraham *et al.*, 1961). Thus although both are bound directly to the aromatic ring system, the protons located at β-positions of the pyrrole rings appear influenced to a lesser extent by ring currents than are protons on the methine bridge positions (Abraham, 1961).

Substituent Effects.—In compounds with only saturated alkyl groups in positions 1 through 8 (*e.g.*, compounds 1 to 4) the eight β-pyrrole positions are nearly equivalent, as are the four methine protons (α, β, γ, and δ). If such an alkyl group is replaced with increasingly effective "electron-withdrawing" substituents, a general shift to higher field is observed for all peaks which represent protons that are influenced by ring currents (Table II). Also, the ring positions are no longer necessarily equivalent. These data indicate that the nature of the ring substituents can influence the strength of the ring current field and the degree of chemical nonequivalence in the ring positions, that magnetically anisotropic substituents effect the long-range deshielding of neighboring protons, and that shielding effects are also observed. However it is usually difficult to accurately evaluate the relative contribution of each of these effects.

The nonequivalence of ring positions is particularly apparent in the methine-proton spectra. In Cbm$_2$ DEUT Me$_2$ (#14) the methine-protons appear at −0.15, 0.13, 0.90, and 1.14, to which can be assigned the α, β, γ and δ positions respectively (Fig. 3). The strongly electron-withdrawing methoxycarbonyl groups give rise to a marked general *high field* shift compared with a compound such as MESO Me$_2$ (#2) (Table II) and also, being magnetically anisotropic, these groups exert a deshielding effect which tends to shift neighboring protons to *lower fields.* The assignments are made solely on the basis of the relative effectiveness of this deshielding to be expected at each methine position—an approach which appears justified with many compounds possessing strongly magnetically anisotropic substituents. Thus, the α and β protons, being adjacent to ring-substituted methoxycarbonyl groups, can be expected at lower fields than the γ and δ protons. As the α-H is between, and deshielded by, both methoxycarbonyl groups, it is undoubtedly the peak at lowest field (−0.15). Being most remote from the methoxycarbonyls, the γ-H is considered to be at 1.14. The δ-H,

TABLE II

SELECTED PROTON τ-VALUES AND BASICITIES OF 2,4-DISUBSTITUTED DEUTEROPORPHYRIN IX DIMETHYL ESTERS

Compound No.	2,4-Substituent	Methine-H[a]	Ring-CH_3[a]	CH_2CH_2COOR	N-H	pK_3[b] (± 0.1)
2	ethyl	−0.05	6.48 (M)	6.79	13.94	5.8
5	hydrogen	0.11	6.51	6.81	14.26	5.5
7	2-ethoxycarbonyl-cyclopropyl	0.38	6.56	6.78	14.27	4.8
11	vinyl	0.45	6.59	6.82	14.57	4.8
10	acetyloxime	0.56	6.59			4.5
13	hydrogen, propionyl	0.50	6.68	6.84	14.50	4.2
14	methoxycarbonyl	1.14	6.84	6.96	15.94	3.0
15	hydrogen, nitro	1.38	6.99	7.14	16.26	3.2

[a] In cases where there is more than one value, the value at highest field is taken as being least affected by deshielding effects. [b] These data pertain to the equilibrium between neutral porphyrin and monocation in 2.5% sodium dodecyl sulfate at 25° from J. N. Phillips and W. S. Caughey, in preparation; *cf.* Phillips (1960).

slightly deshielded by the 2-methoxycarbonyl group, is at 0.90, and the β-H, adjacent to the 4-position, appears at 0.13. Similarly, in the spectrum of Pr DEUT Me_2 (#13) the methine-proton at low field (−0.55), considerably removed from the nearest other methine-proton at 0.29, can be assigned to the methine bridge position adjacent to the one propionyl group in the molecule. As the methine protons are at 0.28, 0.40, and 0.52 in 2-vinylchloroporphyrin e_6Me_3 (#18) and at 0.27, 0.43, and 1.20 in chlorin e_6Me_3 (#17), it can be reasonably assumed that the γ-H is at 1.20 in the chlorin and at 0.52 in the porphyrin while the other two protons (α and β) have nearly identical values in the two compounds. The δ-H in both compounds would be less affected by deshielding than the α or β protons. The higher field value in the case of the chlorin could result from the presence of saturated carbons at positions 7 and 8 thereby affecting the ring current field strength at the δ-H, and possibly the groups at position 8 in the chlorin shield the δ-H more effectively than is the case in the porphyrin. The assignment of α and β protons is less clear. However, a consideration of the relative effectiveness of vinyl and methoxycarbonyl groups in deshielding would suggest as assignment of 0.27 and 0.28 to the β-H and 0.43 and 0.40 to the α-H for the chlorin and porphyrin respectively.

The ring methyl proton (R-CH_3) spectra also reflect nonequivalence of ring positions. A consideration of long-range deshielding effects is useful for making R-CH_3 assignments in a number of cases. However, the deshielding effects are less marked for ring methyl protons than for the methine protons (similar findings are noted with substituted benzenes [Elvidge and Jackman, 1961]). In the highly symmetrical ETIO II (#1) the R-CH_3 absorption appears as a single sharp peak at 6.38. However, in the less symmetrical Me_4Cbe_4P-IV (#16) with two pairs of equivalent R-CH_3 positions there are two peaks of similar area at 6.99 and 7.49. As the 1,4 R-CH_3 groups should experience the greatest deshielding, they can be assigned the low field position. The striking effect of the four strongly electron-withdrawing ethoxycarbonyl groups in the compound on the ring current field strength is shown by the high field R-CH_3 value, which is nearly as high as the R-CH_3 value for toluene (7.66). Even higher values might be expected were it not for the deshielding effects. In compounds such as Ac-Ox_2 DEUT Me_2 (#10) and Cbm_2 DEUT Me_2 (#14) with R-CH_3 spectra characterized by a single peak of approximately one third the area of a broader multiple peak at lower field, on the basis of the relative amount of long range deshielding to be expected, the higher peak can be assigned to the 8-CH_3 and the multiple peak to the 1, 3, and 5 R-CH_3 groups. In chlorin e_6Me_3 (#17) and its corresponding porphyrin (#18) the R-CH_3 spectra are well resolved into sharp single peaks of approximately equivalent area. As expected the chlorin has three such peaks and the porphyrin has four (the 8-CH_3 of the chlorin not being directly substituted on the aromatic ring system does not appear in the usual R-CH_3 region). A consideration of long-range deshielding effects would assign the 5, 1, and 3 methyl groups of the chlorin τ-values of 6.40, 6.55, and 6.79, respectively, and the methyl groups of the porphyrin at positions 5, 1, 8, and 3 τ-values of 6.41, 6.58, 6.69, and 6.78 respectively.

Long-range deshielding by magnetically anisotropic groups is clearly not the only factor leading to nonequivalence of ring positions. For example, in NO_2 DEUT Me_2 (#15), where the R-CH_3 range is comparable to the methine-proton range, it is reasonable to attribute a major portion of the nonequivalence of ring-positions to a chemical nonequivalence due to the strongly electron-withdrawing nitro group. Nor does it seem reasonable to ascribe the separation of the 2,4-$COOCH_3$ protons of Cbm_2 DEUT Me_2 (#14) to long-range deshielding effects (*e.g.*, by propionic ester carbonyls). With DEUT Me_2 (#5) and DEUT Et_2 (#6) and their nickel (II) complexes the R-CH_3 values fall into two pairs with a separation of about 0.10 p.p.m. This separation is reasonably ascribed to lesser shielding of the 1,3-methyls by the 2,4-hydrogens compared with the 5,8-methyls adjacent to the 6,7-propionic ester groups. Deshielding by the carbonyls of the propionic ester group is an unlikely cause of the separation since if this were the case much greater separations in the methine-proton values than those observed would be expected and similar effects should also be noted in the MESO compounds.

Deshielding by Magnetically Anisotropic Groups.—The methine-proton spectra indicate that the effectiveness of the 2,4-substituents in DEUT compounds in deshielding neighboring protons increases in the order vinyl, cyclopropylcarboxylic ester, acetyl oxime, and methoxycarbonyl; in the monosubstituted compounds the propionyl group is roughly equivalent to the methoxycarbonyl group, and much more effective than the nitro group. The degree of deshielding experienced by a proton will depend on the distance, and the effectiveness of shielding, between the proton and the magnetically anisotropic group. As noted above fairly long-range effects are apparently observed. Thus, in Cbm_2 DEUT Me_2 (#14) the deshielding effect of the methoxycarbonyls on protons at a methine bridge across the pyrrole ring ($\sim$0.25 p.p.m.) is about one-fourth the effect on protons on an adjacent methine bridge carbon ($\sim$1.0 p.p.m.).

Differences in deshielding effects are noted between chlorin e_6Me_3 (#17) and the corresponding porphyrin (#18). The 7-propionic ester OCH_3 of the porphyrin is at 6.26 whereas in all other compounds propionic ester OCH_3 protons are between 6.33 and 6.38. In chlorin e_6Me_3 (#17) it is at 6.35. Also, a reasonable assignment for the γ-CH_2 is at 4.09 and 4.65 in the porphyrin and chlorin respectively (the acetate-CH_2 in uroporphyrin I Me_8 is at 4.89 [Becker *et al.*, 1961]). In the porphyrin, where the bonds to the ring at positions 6, γ, and 7 tend to be coplanar with the ring, the 7-propionic ester OCH_3 can experience deshielding exerted by the γ-ester carbonyl and the γ-CH_2 can be deshielded by the 7-propionic ester carbonyl. In the chlorin, however, the steric compression about the 7 and γ positions is relieved and the long-range deshielding reduced. The OCH_3 groups in the 6 and γ positions are at essentially the same frequency in both compounds; 6-OCH_3 is 0.05 p.p.m. lower field in the porphyrin. These data thus provide physical evidence compatible with the stereochemical reasoning used so successfully by Woodward (1961) in his approach to the synthesis of chlorophyll.

Effect of Metal Iron.—With each of the metal complexes studied the introduction of the metal ion resulted in a general shift to higher field for those protons affected by the ring current field. This shift increases in the order Pd(II) $\leqslant$ Ni(II) $<$ Zn(II). The presence of Ni(II) or Zn(II) does not appreciably affect the separation in values for methine-H or R-CH_3. However in Pd(II) DEUT Me_2 (#21) separations in both methine-proton and R-CH_3 are greater than those observed for Ni(II) DEUT Me_2 (#19). Possibly the greater size of Pd(II), as noted in phthalocyanines (Robertson and Woodward, 1940), leads to distortion of the porphyrin ring.

Ring Current Concept.—The concept of large ring current field is most helpful in the interpretation of porphyrin n.m.r. spectra. However, neither the model of a single current loop of 18 π-electrons (Becker and Bradley, 1959; Ellis *et al.*, 1960) nor the analysis used by Abraham (1961) appear consistent with the fact that peripheral protons and nitrogen bound protons shift in the *same* direction with substituent changes. As noted in Table II, there is a general shift to high field of all protons affected by ring-currents with increasingly electron-withdrawing substituents. In benzenes a shift in the opposite direction is found. Since nitrogen basicity decreases with increasing electron-withdrawing capacity of substituents, shifts due to changes in local diamagnetic shielding would be in the opposite direction and therefore cannot explain the N-H shifts observed. Introduction of a metal ion also results in high field shift which increases in the order Pd(II), Ni(II), Zn(II), which is also the order of decreasing ligand field stabilization and decreasing tendency for π-bonding. There appears to be little difference in ring-current field between the chlorin (#17) and the corresponding porphyrin (#18) as noted in terms of peripheral proton values (excluding positions 7 and 8), though a marked difference in N-H values is found.

As the ring-current can be considered to result from the high degree of π-electron delocalization in the system, it is attractve to consider the strength of the ring-current field as a measure of the extent of delocalization, or the aromaticity of the molecule. Such a correlation has been attempted for 6-electron systems (Elvidge and Jackman, 1961). The aromatic character of porphyrin systems can thus be considered as being sensitive to the nature of substituents at the periphery of the ring and bound to the central nitrogens (*e.g.*, hydrogen, or metal ion).

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