Infrared Studies of the Porphyrin Molecule

BY C. S. VESTLING AND J. R. DOWNING

The work of Hans Fischer and associates[1] has furnished strong evidence that Kuster's formulation of the porphyrin nucleus is the correct one. There are some details, however, which are lacking.

Corwin and Quattlebaum[2] exclude "resonance isomers" and discuss the possibility of cis or trans N-isomers in the porphyrin series
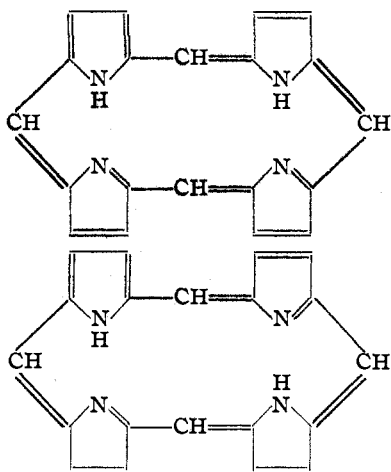
Fischer[3] has suggested the possibility of N-isomerism in dipyrrylmethenes. Conant and Bailey,[4] however, were unable to demonstrate N-isomerism in isomeric porphyrins by preparation of metallic complexes. The electrometric titrations of Conant, Chow and Dietz[5] in glacial acetic acid have been accepted as evidence for the presence of two basic groups in the prophyrins.

Preliminary examination of molecular models of the porphyrin nucleus indicates atomic distances which are distinctly favorable for the presence of N–H–N bonding. Hence it was decided to examine this problem using the method of infrared spectroscopy, originally proposed by Wulf.[6]

Infrared absorption spectra studies in this Laboratory[7] have proved to be of great value in struc-

tural work on organic acids, amides, and other compounds.[8,9] It is possible with this technique to identify various characteristic bonding frequencies. Their presence or absence can be demonstrated rather conclusively. Further, the method is especially applicable to small quantities of materials.

The problem was, therefore, that of noting the presence or absence of characteristic absorption peaks in a study of synthetic etioporphyrin I, iron etioporphyrin I chloride (etiohemin chloride), two dipyrrylmethenes, and the copper complex of one of them.

The data shown in the curves to follow suggest that hydrogen bonding may result in the structures below, which account for the observed lack of isomerism
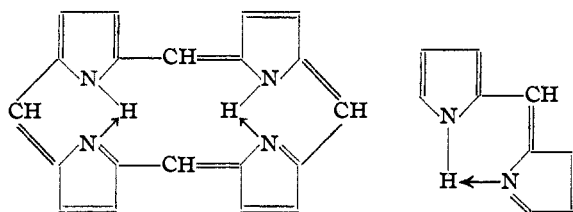
Experimental

The prism spectrograph used in this work has been described.[10] The source of radiation was a 220-volt Nernst glower. The instrument was calibrated to 0.01 μ with reference to the 2.673 μ band of water vapor. Solutions in carbon tetrachloride were measured with carbon tetrachloride as a blank, and the molar absorption coefficient, K, was plotted against wave numbers (cm.$^{-1}$). K was calculated from the expression

$$K = \frac{1}{cd} \log \frac{I_0}{I}$$

where I is the intensity through the solution; I_0 is the intensity through an equal thickness of pure solvent; c is the molar concentration; and d the cell length. In cases where the concentration was indefinite because of low solubility, the absorption ($\log I_0/I$) was plotted instead of the molar absorption coefficient.

The materials used in this investigation were carefully purified. Where possible, analyses of important compounds are reported.

The authors are indebted to Dr. R. E. Ellingson for a

(1) H. Fischer and H. Orth, "Die Chemie des Pyrrols," Vol. II, Akademische Verlagsgesellschaft m. b. H., Leipzig, 1937.

(2) A. H. Corwin and W. M. Quattlebaum, Jr., THIS JOURNAL, 58, 1083 (1936).

(3) H. Fischer, Z. physiol. Chem., 128, 63 (1923).

(4) J. B. Conant and C. F. Bailey, THIS JOURNAL, 55, 796 (1933).

(5) J. B. Conant, B. F. Chow and E. M. Dietz, ibid., 56, 2185 (1934).

(6) G. E. Hilbert, O. R. Wulf, S. B. Hendricks and U. Liddel, ibid., 58, 548 (1936).

(7) W. H. Rodebush and A. M. Buswell, J. Phys. Chem., 43, 219 (1939).

(8) A. M. Buswell, W. H. Rodebush and M. F. Roy, THIS JOURNAL, 60, 2239 (1938).

(9) A. M. Buswell, W. H. Rodebush and M. F. Roy, ibid., 60, 2444 (1938).

(10) A. M. Buswell, V. Deitz and W. H. Rodebush, J. Chem. Phys., 5, 501 (1937).

supply of 3,5,3',5'-tetramethyl-4,4'-dicarbethoxydipyrryl-methene (Piloty's). Beautiful red needles of this compound were recrystallized from benzene–hexane; they decomposed at 190°. Hydrogenation with Adams platinum catalyst yielded white crystals of the dipyrrylmethane which melted at 228–229° (uncorr.) with some decomposition.

Anal. Calcd. for $C_{19}H_{24}O_4N_2$: N, 8.14. Found: N, 8.16.

3,4',5 - Trimethyl - 3',4 - dicarbethoxy - 5' - bromodipyrrylmethane was synthesized as described below.
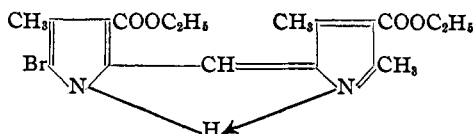
It must be pointed out that the exact structure of this compound is not conclusively proved, although the mode of synthesis and analysis suggest the structure given. 2,4-Dimethyl-3-carbethoxypyrrole was freshly recrystallized from cold methanol, dissolved in cold, dry ether (ice–salt temperature), and treated slowly with two moles of bromine (Baker c. p.) in cold ether. At first a flocculent light-colored precipitate formed; when one mole of bromine had been added, the system suddenly turned red. A vigorous evolution of hydrogen bromide took place throughout. The reaction product was a light red amorphous methene hydrobromide. The free base was obtained by grinding with cold concentrated ammonium hydroxide in a mortar and extracting with boiling hexane to yield after slow crystallization long (2 mm.), red needles.

Anal. Calcd. for $C_{18}H_{21}O_4N_2Br$: N, 6.85. Found: N, 6.89.

The copper complex of this material was prepared by prolonged shaking of a chloroform solution of the dipyrryl-methene hydrobromide with concentrated aqueous $CuSO_4 \cdot NH_4OH$. Macroscopic green crystals of the copper complex were obtained in good yield and used without analysis.

Etioporphyrin I (1,3,5,7-tetramethyl-2,4,6,8-tetraethyl-porphin) was synthesized by Walter Schlesinger according to the methods of Fischer, *et al.*[1] The absorption maxima of the purified crystalline material in chloroform are: I, 484–508 mμ; II, 524–536 mμ; III, 560–570 mμ; IV, 610–618 mμ; order of intensity: I, II, III, IV.

Anal. (recrystallized material). Calcd. for $C_{32}H_{38}N_4$: C, 60.33; H, 7.94; N, 11.71. Found: C, 80.99, 79.83; H, 8.17, 7.93; N, 11.83.

The preparation of iron etioporphyrin I chloride will be described elsewhere. Beautiful macroscopic octagonal platelets of metallic luster were obtained porphyrin-free in better than 90% yields. Their purity was indicated by a series of reductive titrations.[11]

In the curves shown, the peaks at 3.30–3.50 μ are due to aliphatic C–H vibrations, since they are identical in frequency with absorption peaks observed in numerous other compounds containing such groups.

The significant peaks from the standpoint of this research are those at 3.03 μ in Fig. 1 (I), 3.11 μ in Fig. 1 (II) and 3.01 μ in Fig. 2 (I). The complete disappearance of these peaks (Figs. 1 (III) and 2 (II)) when metallic derivatives are formed by replacement of the hydrogens of the N–H groups shows that they are absorption maxima caused by N–H vibrations. In the case of etiohemin I (Fig. 2 (II)) the complete disappearance of the N–H peak indicates conclusively that both hydrogens attached to nitrogens in the porphyrin nucleus are replaced by the iron upon substitution.
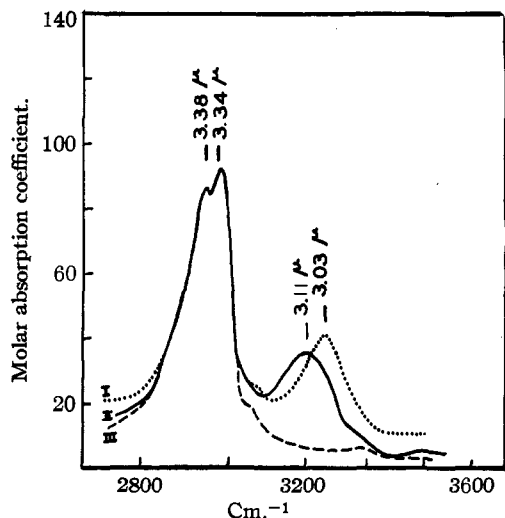

Fig. 1.—I, 3,4',5-Trimethyl-3',4-dicarbethoxy-5'-bromodipyrrylmethene (0.002 *M* in 10.180 cm. cell). II, 3,5,3',5'-Tetramethyl-4,4'-dicarbethoxydipyrryl methene (0.008 *M* in 2.532 cm. cell). III, Copper complex of 3,4',5-trimethyl-3',4-dicarbethoxy-5'-bromodipyrrylmethene (0.002 *M* in 10.180 cm. cell.)
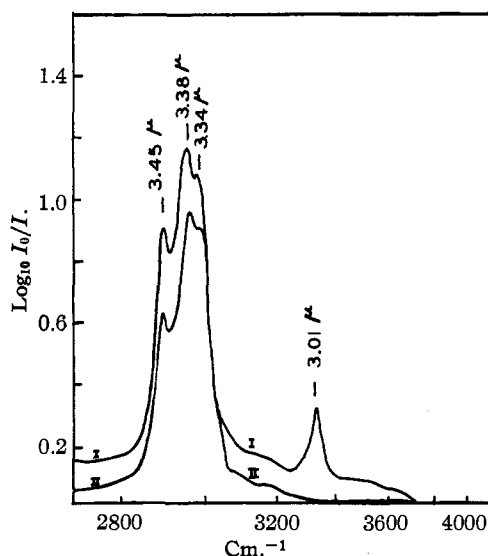

Fig. 2.—I, Etioporphyrin I (<0.001 *M* in 10.180 cm. cell). II, Etiohemin I (<0.0005 *M* in 10.180 cm. cell).

(11) C. S. Vestling, unpublished data.

The question of whether or not these peaks may be assigned to N–H–N bonding between the secondary pyrrole nitrogens and the tertiary nitrogens in these compounds arises from a consideration of the structures involved. It must be stated at once that infrared spectroscopy can only give evidence for *intra*molecular bonding when a set of absorption frequencies can be compared with those exhibited by like acceptors and donors in different molecules. On the other hand, *inter*molecular bonding between molecules of like or unlike species may be demonstrated conclusively by observing the effect of concentration changes in solution upon "bonded" or "unbonded" peaks. This criterion of course becomes inapplicable in testing for intramolecular bonding.

Since the absorption peaks in question differ markedly from the pyrrole N–H peak at 2.85 μ,[12] one is inclined to suggest that N–H–N bonding exists in these molecules. However, this is unproved as yet, since the character of the substituted pyrrole rings may have been changed in the formation of these compounds. This seems pos-

(12) A. M. Buswell, J. R. Downing and W. H. Rodebush, THIS JOURNAL, **61**, 3252 (1939).

sible in light of the recent work on unbonded N–H frequencies.[13] Hence we can only state at present that the absorption peaks occur at frequencies which might be expected[12] if N–H–N bonding were existent in the porphin and dipyrrylmethene nuclei.

The authors wish to express their gratitude to Professors A. M. Buswell and W. H. Rodebush for use of the infrared apparatus and for timely suggestions.

Summary

1. The infrared absorption of two dipyrrylmethenes, the copper complex of one of them, etioporphyrin I, and etiohemin I chloride has been measured. Replacement of acidic hydrogens with metal atoms eliminated nitrogen–hydrogen absorption in the dipyrrylmethenes and in etioporphyrin I.

2. The possibility of N–H–N bonding in these compounds is discussed.

(13) A. M. Buswell, G. W. McMillan, W. H. Rodebush and F. T. Wall, *ibid.*, **61**, 2809 (1939).

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The Hydrolysis of Bromine. The Hydration of the Halogens. The Mechanism of Certain Halogen Reactions

BY HERMAN A. LIEBHAFSKY

Corrections.—Jones and Baeckstrom[1] and Liebhafsky[2] have independently established 5.8 (10^{-9}) as the value of K_1, the equilibrium constant of the bromine hydrolysis, at 25°. The temperature coefficients of this reaction (*cf.* Ref. 2, Table II, last column) are probably more accurately known than is K_1 at any temperature except 25°. For these reasons, it is especially desirable to correct a computational error that Professors R. H. Gillette and H. A. Young of the Division of Chemistry, University of California at Davis, have kindly called to my attention. Through some mischance, 11.9(10^{-9}) at 35°, the result for Series 5, instead of 11.3(10^{-9}), the result for Series 7 (*cf.* Ref. 2, Table II), was used in deriving an incorrect equation for K_1 as a function of temperature. A table and a conclusion in Ref. 2 consequently should be changed to read as follows.

(1) Jones and Baeckstrom, THIS JOURNAL, **56**, 1517 (1934).
(2) Liebhafsky, *ibid.*, **56**, 1500 (1934).

TABLE IV (Ref. 2)

SUMMARY OF BEST VALUES FOR $K_1 \times 10^{-9}$ AT DIFFERENT TEMPERATURES

	0°	10°	25°	30°	35°
Liebhafsky	0.69	1.76	5.8	8.2	11.3
Computed	.88	1.95	(5.8)[a]	8.14	(11.3)[a]
Selected[b]	.70	1.78	5.8	8.3	11.3

[a] Value assumed in deriving the equation log K_1 = 0.6876 − 2660.3/T from which computed values were obtained. [b] Only these finally selected values for K_1 are expressed in activities. (Similar changes are to be made in Ref. 3, p. 95, Table I.)

Summary (Ref. 2)

4. The temperature variation of the K_1 for bromine is anomalous in the neighborhood of 10°; but the departure of d(log K_1)/d(1/T) from constancy is less pronounced than that observed by Jakowkin in the case of chlorine.

Also, the line "a. Measurements at 0° by Jones and Hartmann" has been omitted above the first row of data in Table III.