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PORPHYRINS.

23.* SYNTHESIS AND PROPERTIES OF ETHANEBISPORPHYRINS

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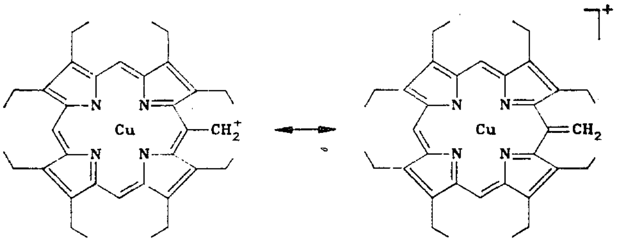
It has been shown that copper complexes of meso-hydroxy(alkoxy)methylporphyrins in trifluoroacetic acid readily dimerize to give copper complexes of ethanebisporphyrins. Selective removal of one copper atom from the dimer molecule has been achieved. The previously unknown conversion of ethanebisporphyrins to ethylenebisporphyrins has been found to take place.

It was shown previously [2] that copper complexes of meso-hydroxymethylporphyrins when protonated with trifluoroacetic acid (TFA) or gaseous HCl in solutions of dichloroethane or chloroform form a stabilized carbocation of type I, which readily reacts with nucleophiles to form the corresponding addition products. At the present time carbocations of a similar type are widely used for forming a large variety of substituents around the periphery of the porphyrin ring [3, 5].



We have found that in TFA medium in the absence of nucleophilic reagents, carbocations of copper porphyrin complexes undergo new conversions, as a result of which the main reaction products are dimeric porphyrins. Thus, when the copper complex of meso-hydroxymethyloctaethylporphyrin II is dissolved in TFA, after 5-10 min dimeric complexes III and IV are formed. The ratio of dimers varies according to the concentration of initial complex II in the reaction mixture. When changing from dilute solvents, where the ratio of dimers is 1:1, to concentrated solvents, the reaction is shifted in favor of the formation of dimer III. When the reaction mixture is treated with concentrated H_2SO_4, dimer IV decomposes and the yield of free bisporphyrin V reaches 50-55%.

The formation of bisporphyrin VII was previously detected by Johnson and coworkers [6] by prolonged heating of the nickel complex of meso-hydroxymethyloctaethylporphyrin in DMF in the presence of catalytic amounts of sulfuric acid. A determining role in dimerization is thought to be played by the central nickel atom. During reaction it changes to a trivalent state and transfers one electron to the macrocycle, thus converting it to a radical capable of dimerizing. One of the arguments in favor of such a reaction mechanism was the low yield (12%) of dimeric product III from copper complex II, since transfer of an electron from the central copper atom is questionable.

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*For Communication 22, see [1].

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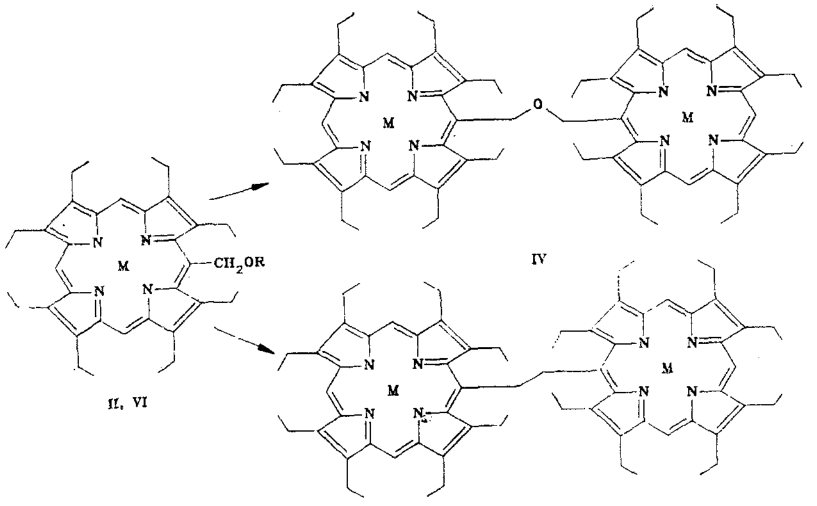


II M=Cu, R=H; III M=M′=Cu; IV M=Cu; V M=M′=2H; VI M=Cu, R=Et;
VII M=M′=Ni; VIII M=Ni, M′=2H; IX M=Cu, M′=2H

In our case dimerization occurs with a relatively high yield also with copper complexes. The formation of bisporphyrin ether IV can readily be explained by the classical pathway for interaction of carbocations with alcohols [7]. The formation of bisporphyrin III can be represented by scheme (1) or (2):

$$\mathrm{MP{-}CH_2^+ + MP^+{=}CH_2 \rightarrow [MP{-}CH_2{-}CH_2{-}PM]^{++} \xrightarrow{2\bar{e}} MP{-}CH_2{-}CH_2{-}PM}; \tag{1}$$

$$\mathrm{2PM{-}CH_2^+ \xrightarrow{2e} 2MP{-}CH_2^{\cdot} \rightarrow MP{-}CH_2{-}CH_2{-}PM}, \tag{2}$$

where MP is metalloporphyrin. Transfer of electrons to the bisporphyrin dication or the carbocation (as in the reactions with ferrocenes [8]) is achieved by oxidation of other porphyrin molecules. The oxidized porphyrins afford a number of secondary compounds, and the yield of the main product does not exceed 56%.

Similar results are obtained when ethoxymethyl derivative VI is used as the starting material, which indicates the general nature of the formation of dimeric products from carbocation I.

The dimeric porphyrins obtained have several specific properties. It is well known that demetallation of copper complexes of porphyrins does not occur when TFA is used. In porphyrin chemistry, for demetallation of metallocomplexes the method of treating them with a mixture of TFA and concentrated H_2SO_4 has been widely used for some time. However, for complex III demetallation under these conditions leads to the removal of copper from only one part of the molecule, giving complex IX. Moreover, even a short exposure of complex III to TFA alone gives complex IX in 67% yield. When considering the dimer to be a meso-substituted porphyrin, we used meso-methyloctaethylporphyrin as a model in order to elucidate this effect. It was found that when the copper complex of meso-methyloctaethylporphyrin was dissolved in TFA, it underwent demetallation, which was most probably due to the formation of a phlorin structure [9]. A similar process for formation of a phlorin structure at the first stage occurs also for dimer III. After elimination of a copper atom from one part of the molecule, the possibility of protonation on the central nitrogen atoms to the corresponding dication occurs, which inhibits demetallation from the second part of the molecule because of the electron-seeking effect of the dication. In a similar manner nickel complex VII is also demetallated to complex VIII, which is confirmation of a general mechanism for demetallation of the dimers under these conditions.

Although the electronic spectra of the dimeric compounds obtained are similar to the electronic spectra of meso-substituted porphyrins, they are not a simple sum of component parts, which is an indication of electron interaction in them [10]. The most noticeable changes occur when complex IX is protonated. The appearance of a band at 920 nm indicates the formation of a 'phlorin dication' structure (Fig. 1). In line with such a structure the

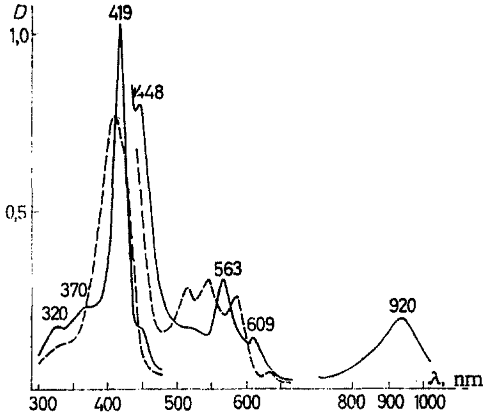
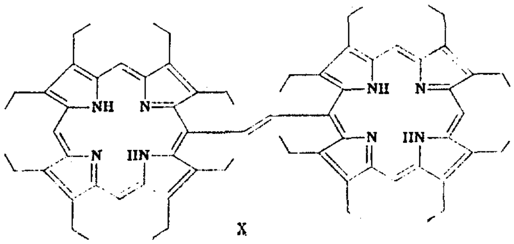


Fig. 1. Electronic absorption spectra of dimer IX in $CHCl_3$ (---) and in $CHCl_3$ + 1% TFA (——).

PMR spectrum of the diamagnetic complex VIII gives signals from protons at meso positions at 10.25 and 10.09 ppm in a region typical for porphyrins, and signals at 6.84 and 6.76 ppm shifted upfield as a result of the disruption of ring conjugation. The 'phlorin' proton appears as a triplet at 4.79 ppm, and the signals from the ethane bridge appear as multiplets at 5.65 and 3.90 ppm (in contrast to the broad singlet at 5.78 ppm in the case of dimer V in TFA).

The data of the PMR spectra of the compounds synthesized are given in the experimental section. It should just be noted that the four groups of signals from the sidechain substituents with the same integral intensity in both the free base and its bisnickel complex indicate that the two rings have a planar configuration. Therefore, a skewed structure for complex VII, reported in [11] with reference to the PMR data in [6], is perhaps typical only for the crystalline state.

The most notable property of the metal-free dimers is their ready spontaneous conversion in solutions of fatty acids to the previously unknown ethylenebisporphyrins. Thus, heating of porphyrin V at 70°C in acetic acid for 20 min gives porphyrin X with a yield of over 80%. A similar process also occurs at 20°C. Degasification of the solvent does not change the course of the reaction. In strong acids (TFA) and in organic solvents (CCl_4, $CHCl_3$) with prolonged reaction times (several weeks) the same conversion occurs. A similar reaction takes place with the etioporphyrin and octapropylporphyrin derivatives synthesized by us, which is an indication of the general nature of the conversion of ethanebisporphyrins to ethylenebisporphyrins [12].



X

The 'phlorin' type of absorption spectrum (510 and 770 nm) of the ethylenebisporphyrins in acidic media is the main feature that distinguishes them from the rest of the porphyrins, which have two bands in the visible region occurring in the range 560-610 nm [13]. At the same time in the PMR spectra additional signals from 'phlorin' protons are not found as in the case of protonation of compound VIII. There is a downfield shift (10.26 ppm) of the signals from the protons of the ethylene bridge. Such a shift is possibly due to the fact that in acidic medium the ethylene bridge is positioned in the plane of the porphyrin molecules to form an overall conjugated system. When the molecule is constructed using Dreiding models, steric hindrance is found for the sidechain substituents adjacent to the ethylene bridge. This is also probably shown in the PMR spectra, where the protons of the ethyl groups adjacent to the ethylene fragment appear as ill-defined signals, in contrast to the usually observed quartet and triplet.

EXPERIMENTAL

Electronic spectra were recorded on UV-5270 (Beckman) and SF-10 (LOMO) spectrophotometers; PMR spectra were recorded on a Bruker WM-360 instrument with TMS as internal standard using $CDCl_3$ solutions. Mass spectra were recorded on a Varian MAT-311 instrument; chromatographic purification of the porphyrins was carried out on silica gel columns 40 × 100 L (Czechoslovakia).

1,2-Di(meso-octaethylporphyrinyl)ethane (V). Complex II (200 mg) was dissolved with shaking in TFA (2 ml), and the mixture was kept at room temperature for 10 min, diluted with water, neutralized with aqueous ammonia, and extracted with 100 ml of chloroform. The organic layer was separated and evaporated, and the residue dissolved in CCl_4 and chromatographed on a silica gel column (3.5 × 15 cm) using carbon tetrachloride. The main mobile zone was separated and evaporated, and the residue was dissolved in 15 ml of conc. H_2SO_4, poured onto ice after 1 h, and neutralized with aqueous ammonia; the porphyrin was extracted with 100 ml of chloroform and chromatographed on a silica gel column (3.5 × 15 cm) using a chloroform–ether (20:1) mixture. The polar fraction containing the main product was eluted with a chloroform–ether (4:1) mixture and evaporated; crystallization from a chloroform–methanol mixture gave 92-98 mg of bisporphyrin V. Yield 53-55%. Mass spectrum, m/z (%): (M^+ not observed), 548 (50), 547 (100), 533 (9), 532 (8), 274 (10), 273 (25). UV spectrum, λ_{max} (log ε) (in $CHCl_3$): 417 (5.36), 516 (4.41), 551 (4.06), 586 (4.08), 638 nm (3.47). PMR spectrum (in $CDCl_3$): 9.87 and 9.76 (2H and 4H, s, meso-H); 5.0 (4H, s, meso-CH_2–CH_2); 4.09 and 1.94 (q, t, 4-C_2H_5); 4.07 and 1.91 (q, t, 4-C_2H_5); 3.73 and 1.67 (m, J_{AB} = 15 Hz, t, 4-C_2H_5); 3.53 and 1.1 (m, J_{AB} = 15 Hz, t, 4-C_2H_5); –2.85 and –3.03 ppm (s, 4H); (in $CDCl_3$ + 1% TFA): 10.23 and 10.07 (4H and 2H, s, meso-H); 5.78 (4H, s, meso-CH_2–CH_2); 3.98 and 1.67 (q, t, 8-C_2H_5); 3.77 and 1.42 (q, t, 4-C_2H_5); 3.38 and 0.99 (q, t, 4-C_2H_5); –1.75 and –2.76 ppm (s, 8-NH).

1,2-Di(meso-octapropylporphyrinyl)ethane. This was obtained in a similar manner, starting from the copper complex of meso-hydroxymethyloctapropylporphyrin and giving a yield of 45-50%. Mass spectrum, m/z (%): (M^+ not observed), 660 (53), 659 (100), 658 (50), 645 (9), 644 (10), 329 (20), 330 (10). UV spectrum, λ_{max} (log ε) (in $CHCl_3$): 416 (5.31), 517 (4.41), 552 (4.07), 586 (4.09), 640 (3.47); (in $CHCl_3$ + 0.1% TFA): 408 shld (232), 426 (282), 440 shld (270), 570 (28.8), 618 nm (16.7). PMR spectrum (in $CDCl_3$ + 1% TFA): 10.22 and 10.06 (4H and 2H, s, meso-H); 5.14 (4H, s, meso-CH_2–CH_2); 3.94; 3.92; 3.78; 3.44 (all t, 16-$CH_2 \cdot CH_2CH_3$); 2.10; 2.07; 1.86; 1.48 (all sext. 16-$CH_2CH_2CH_3$); 1.21; 1.20; 1.07; 0.33 (all t, 16-$CH_2CH_2CH_3$); –1.40 and –2.10 ppm (s, 8-NH).

1,2-Di(meso-octaethylporphyrinatoylcopper)ethane (III). A. Complex II (100 mg) was dissolved in TFA (1 ml), and the mixture was kept at room temperature for 10 min, diluted with water, and neutralized with aqueous ammonia. The precipitate was filtered off, washed with water, dried, dissolved in 20 ml of chloroform, and chromatographed on an alumina (grade II activity) column (3.5 × 40 cm) with a chloroform–hexane (2:1) mixture. After removal of a small quantity (7-9 mg) of ether IV, the main product was eluted with chloroform, and after crystallization from a chloroform–methanol mixture 42-45 mg (43-46%) of complex III was obtained. Mass spectrum, m/z (%): (M^+ not observed), 609 (MH^{2+}, 100), 594 (20). UV spectrum, λ_{max} (relative intensity, %) (in $CHCl_3$): 330 (1.8), 400 (12.5), 550 (1.0), 580 (0.88), 586 shld (0.8).

B. When 100 mg of complex II in 30 ml of TFA was kept for 30 min with subsequent chromatographic treatment of the reaction products according to method A 28 mg of complex III and 29 mg of ether IV were obtained. UV spectrum of ether IV, λ_{max} (log ε) (in $CHCL_3$): 398 (5.59), 537 (4.11), 575 nm (4.28). Mass spectrum, m/z (%): 1232 (M^+, 1), 609 (100), 595 (42).

1-(meso-Octaethylporphyrinyl)-2-(meso-octaethylporphyrinatoylcopper)ethane (IX). A. Complex III (90 mg) was dissolved in TFA (3 ml), after 5 min conc. H_2SO_4 (0.5 ml) was added, and the mixture was agitated for 5 min, poured on to ice, and neutralized with aqueous ammonia. The precipitate was filtered off, dried, dissolved in 50 ml of chloroform, and chromatographed on a silica gel column (3.5 × 20 cm) using chloroform at first, then the main fraction was separated by elution with a chloroform–ether (20:1) mixture. After crystallization from a chloroform–methanol mixture, 45 mg of complex IX was obtained. Yield 57%. Mass spectrum, m/z (%): (M^+ not observed), 609 (62), 608 (57), 607 (45), 594 (21), 593 (17), 592 (17), 578 (11), 563 (15), 549 (45), 548 (72), 547 (100), 543 (25). UV spectrum, λ_{max} (log ε) (in $CHCl_3$): 330 shld (4.40), 412 (5.33), 428 shld (5.19), 516 (4.12), 548 (4.13), 586 (4.08), 640 nm (3.20).

B. Dimer III (78 mg) was dissolved in TFA (5 ml), and the mixture was kept for 5 min, poured onto ice, and neutralized with aqueous ammonia; after chromatographic treatment according to method A, 10 mg of unreacted complex III and 49 mg of dimer IX were isolated. Yield 65%.

1-(meso-Octaethylporphyrinyl)-2-(meso-octaethylporphyrinatoylnickel)ethane (VIII). Complex VII (100 mg), which had been obtained from dimer V and nickel acetate by heating in DMFA to give a quantitative yield, was dissolved in TFA (3 ml), and 9 ml of a TFA–H_2SO_4 (15:1) mixture was added. After 10-12 min the mixture was poured onto ice and neutralized with aqueous ammonia; the porphyrin was extracted with 100 ml of chloroform and chromatographed on a silica gel column (3.5 × 15 cm) with a chloroform–ether (20:1) mixture. The main zone was separated, the solvent was evaporated, and the residue crystallized from a chloroform–methanol mixture to give 69 mg (77%) of complex VIII. Mass spectrum, m/z (%): 1150 (M^+, 1), 604 (90), 547 (100). UV spectrum, λ_{max} (log ε) (in $CHCl_3$): 415 (5.56), 422 (5.57), 515 (4.30), 545 (4.23), 581 (4.25), 638 nm (3.23). PMR spectrum: 9.94, 9.85, 9.51, and 9.34 (2H, 1H, 1H, 2H, all s, meso-H); 4.49 and 4.39 (4H, two m, meso-CH_2CH_2); 4.08-3.32 (overlapping q and m, 16-CH_2CH_3); 1.93; 1.91; 1.87; 1.81; 1.76; 1.66; 1.09; 1.05 (all t, 16-CH_2CH_3); −2.79 and −2.91 ppm (2H, s, NH); (in $CDCl_3$ + 1% TFA): 10.25; 10.10; 6.83; 6.76 (2H, 1H, 2H, 1H, all s, meso-H); 5.65 and 3.90 (4H, two m, meso-CH_2CH_2); 4.79 (1H, t, J = 5.9 Hz); 4.0-3.29 (q, m, 8-CH_2CH_3); 2.74-2.50 (q, m, 8-CH_2CH_3); 1.65-1.07 (overlapping t, 16-CH_2CH_3); −2.28 and −3.35 ppm (4H, two s, NH).

1,2-Di(meso-octaethylporphyrinyl)ethylene (X). A solution of bisporphyrin V (100 mg) in glacial acetic acid (200 ml) was heated for 20 min at 70°C; the mixture was cooled, supplemented with 150 ml of chloroform, and poured onto ice. The organic layer was separated, washed with water until a neutral reaction, and chromatographed on a silica gel column (3.5 × 15 cm) using a chloroform–ether (9:1) mixture. The mobile zone was separated and evaporated, and after crystallization from a chloroform–methanol mixture 83-86 mg (83-86%) of bisporphyrin X was obtained. Mass spectrum, m/z (%): 1092 (M^+, 20), 548 (60), 546 (80), 534 (100). UV spectrum, λ_{max} (log ε) (in $CHCl_3$): 421 (5.41), 480 shld (4.55), 510 (4.52), 546 (4.17), 581 (4.18), 634 nm (3.86); with addition of 1% TFA: 375 (4.95), 402 (4.98), 474 shld (4.74), 510 (5.52), 560 (4.32), 770 nm (4.83). PMR spectrum: 10.12 and 9.93 (4H and 2H, two s, meso-H); 8.56 (2H, s, CH=CH); 4.13; 4.11; 4.08; 3.89 (all q, CH_2CH_3); 1.98; 1.96; 1.93; 1.29 (all t, CH_2CH_3); −2.72 ppm (4H, s, NH); with addition of 1% TFA: 10.26 (2H, s, CH=CH); 10.19 and 9.92 (4H and 2H, two s, meso-H); 3.95; 3.92; 3.73 (all q, CH_2CH_3); 1.67; 1.65; 1.50 (all t, CH_2CH_3); 3.48 and 1.14 (two ill-defined signals, 4-CH_2CH_3); −0.43 and −2.03 ppm (8H, two s, NH).

1,2-Di(meso-octapropylporphyrinyl)ethylene. This was obtained and isolated in a similar manner to derivative X from 1,2-di(meso-octapropylporphyrinyl)ethane. Yield 80%. Mass spectrum, m/z (%): 1316 (M^+, 100), 672 (13), 658 (50), 646 (17). UV spectrum, λ_{max} (log ε) (in $CHCl_3$): 420 (5.40), 480 shld (4.63), 512 (4.53), 545 (4.17), 583 (4.20), 634 nm (3.90); with addition of 1% TFA: 375 shld (4.95), 403 (5.03), 475 shld (4.75), 511 (5.52), 560 shld (4.34), 775 nm (4.85). PMR spectrum (in $CDCl_3$ + 1% TFA): 10.15 (2H, s, CH=CH); 10.14 and 9.86 (4H and 2H, s, meso-H); 3.88; 3.84; 2.03; 1.18 (t, t, sext, t, 8-$CH_2CH_2CH_3$) 3.65; 1.92; 1.14 (t, br. sext, t, 4-$CH_2CH_2CH_3$); 3.47; 1.65; 0.17 (4-$CH_2CH_2CH_3$); −0.38 and −1.88 ppm (8H, all br. s, NH).

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