An Improved Synthesis of Surfactant Porphyrins

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Considerable effort has recently been directed towards finding chemical processes that are capable of conversion and storage of light energy. One approach to this involves the photolysis of water by means of dye-sensitized electron-transfer reactions, as in photosynthesis. Surfactant porphyrins seem to be promising for such reactions across artificial photosynthetic membranes. Preparation of some surface-active porphyrins has been reported\(^1,2\). However, there remained some difficulties in yields and degree of alkylation. We now report the improved preparation and purification of surfactant porphyrins derived from the partial quaternization of meso-tetra(4-pyridyl)-porphyrin (TPyP), and the partial esterification of meso-tetra(4-carboxyphenyl)-porphyrin (TCPPP).

The quaternization of TPyP proceeded smoothly in refluxing dimethylformamide and the products could be separated by gel-permeation chromatography with Sephadex LH-20. By varying the molar ratio of bromohexadecane to TPyP, and the reaction time, the relative proportions of the mono-, di-, tri-, and tetraquaternized porphyrins (designated 1, 2, 3, and 4) can be adjusted. The tetra-derivative (4) was obtained with 83% yield by using a forty-fold excess of bromohexadecane. The porphyrins (1-4) were converted to their metal chelates (9-13) by reacting them with the metal salts. Alternatively, the metallocomplexes (5-8) could be obtained by reacting the metal salts with mixture of 1-4 in dimethylformamide, then separating by chromatography on alumina and Sephadex LH-20.

The mono-hexadecyl ester of TCPPP (14) was prepared by reaction of TCPPP with 1 equiv of potassium hydroxide in methanol and excess i-iodohexadecane.

Thus cationic and anionic surfactant porphyrins can be prepared from commercially available synthetic porphyrins.

The photochemical properties of these porphyrins in aqueous media will be published elsewhere.
Mono-, Di-, Tri-, and Tetraaquatertetrazohibrons (1, 2, 3, 4):
A solution of TPyP (306 mg, 0.49 mmol) and 1-bromohexadecane (2.1 g, 6.8 mmol) in dimethylformamide (300 ml) is refluxed for 4 h under nitrogen. The solvent is removed and the residue is washed with ether (3 × 25 ml) to remove the excess bromide. The solid mixture is dissolved in methanol (∼6 ml) and the unreacted TPyP (negligible) is filtered off. The filtrate is evaporated and the product is purified by repeated gel filtrations over Sephadex LH-20 using methanol as eluent as shown below. After one pass through a short column (1.8 × 24 cm), the first treatment with a 4 × 50 cm column gives three fractions: A, B and C. Fraction A, which moves fastest is a mixture of 3 and 4; it is gel-filtered again to give two new fractions: D and E. Each of the fractions B, D and E which contain predominantly 2, 3, and 4, respectively, is once again gel-filtered individually using the same conditions. Fraction C is mainly the mono-derivative I. Fractions B, C, D, and E are further purified by precipitations from methanol/ether and from ether/ether, and are then dried overnight at 50 °C in vacuo over phosphorus pentoxide.

**Monoaquatetrazohibron Porphyridium 1:** yield: 68 mg (15%) of violet solid.
Ca₈H₁₂Br₈N₄O₄Cl₂Cu calc. C 71.34 H 6.84 N 11.89 (942.1) found 71.62 6.43 11.85
Vis. (ethanol/DMF, 1:1): λmax = 417 (log ε = 5.3), 512 (4.26), 548 (3.80), 588 (3.77), 644 nm (3.38).

**Di-aquatetrazohibron Porphyridium 2:** yield: 157 mg (25%) of a violet solid; mixture of two isomers.
Ca₈H₁₂Br₈N₄O₄Cl₂Cu calc. C 68.30 H 7.58 N 8.85 (1265.4) found 67.88 7.30 8.73
Vis. (ethanol/DMF, 1:1): λmax = 421 (log ε = 5.38), 514 (4.20), 551 (3.84), 589 (3.76), 646 nm (3.32).

**Tetraaquatetrazohibron Porphyridium 3:** yield: 177 mg (23%) of a violet solid.
Ca₈H₁₂Br₈N₄O₄Cl₂Cu calc. C 66.46 H 8.24 N 7.05 (1588.5) found 66.15 8.10 6.95
Vis. (ethanol/DMF, 1:1): λmax = 424 (log ε = 5.36), 516 (4.20), 553 (3.85), 590 (3.78), 647 nm (3.28).

**Tetraaquatetrazohibron Porphyridium 4:** yield: 78 mg (8%) of a violet solid; m.p. > 260 °C.
Ca₈H₁₂Br₈N₄O₄Cl₂Cu calc. C 65.89 H 8.66 N 5.91 (1894.2) found 65.83 8.34 6.08
Vis. (ethanol/DMF, 1:1): λmax = 425 (log ε = 5.36), 516 (4.23), 553 (3.87), 590 (3.82), 646 nm (3.26).
Vis. (methanol): λmax = 426 (log ε = 5.35), 517 (4.29), 557 (4.06), 593 (3.99), 647 nm (3.65).

5,10,15,20-Tetraakis[1-hexadecylpyridinium-4-yl]-2,2′,2′′,2′′′-terphenyl-2,2′,2′′,2′′′-terphenylamine (tetraaquatetrazohibron 4) may be obtained in 83% yield in the same manner using a a 40 fold molar excess of 1-bromohexadecane (2 h at reflux temperature).

5,10,15,20-Tetraakis[1-hexadecylpyridinium-4-yl]-2,2′,2′′,2′′′-terphenyl-2,2′,2′′,2′′′-terphenylamine (tetraaquatertetrazohibron 4) can be used as a source of the porphyrin and free base (1). The reaction may be monitored spectrophotometrically. After 1 h, methanol is evaporated and the residue washed with water (3 × 15 ml). The crude product (20 mg, 78%) is purified by column chromatography over alumina (Woelm, neutral, activity I; 1.8 × 18 cm) using chloroform/methanol (80:20) as eluent and by gel filtration (1.8 × 24 cm) using methanol. The solvent is removed, the residual product dissolved in methanol (∼3 ml), and then precipitated as the perchlorate 8 by addition of an equal volume of aqueous 0.1 M sodium perchlorate solution. The resultant solid red product is isolated by suction, washed with water, and dried overnight over phosphorus pentoxide in vacuo at 50 °C; yield: 21 mg (79%).

C₁₂H₁₉N₅O₈Cl₂Cu calc. C 63.09 H 7.96 N 5.66 (1979.8) found 62.92 7.88 5.63
Vis. (methanol): λmax = 428 (ε, ratios, 100), 549 (5.1), 585 nm (sh, 1.6).

**Copper Complexes 5, 6, and 7:**
A solution of TPyP (101 mg, 0.16 mmol) and 1-bromohexadecane (502 mg, 1.6 mmol) in dimethylformamide (100 ml) is refluxed under nitrogen for 2 h, and then evaporated to dryness. The residue is washed with ether (3 × 15 ml) and dissolved in methanol (∼10 ml), and the unreacted TPyP is filtered off. The filtrate is diluted with methanol (100 ml) and copper(I) bromide (21 mg, 94 μmol) is added. The mixture is refluxed for 1 h and then evaporated. The residue is washed with water (3 × 15 ml) and column-chromatographed on alumina (Woelm, neutral, activity I; 1.8 × 18 cm) using chloroform/methanol (85:15) as eluent to give three fractions. Each fraction is gel-chromatographed on Sephadex LH-20. The solvent is evaporated and the residue dissolved in methanol and precipitated again as the perchlorate (5, 6, 7) by the addition of an equal volume of aqueous 0.1 M sodium perchlorate solution. The resultant solid product is isolated by suction, washed with water, and dried overnight over phosphorus pentoxide in vacuo at 50 °C.

**Copper Complex 5:** yield: 45 mg (27%) of a red solid.
C₃₀H₄₈Cl₃Cu₂N₆O₄ calc. C 66.92 H 5.72 N 11.15 (1005.1) found 66.68 5.76 10.92
Vis. (methanol): λmax = 414 (log ε = 5.37), 543 (4.23), 584 nm (3.54).

**Copper Complex 6:** yield: 29 mg (13%) of a red solid; mixture of two isomers.
C₃₀H₄₈Cl₃Cu₂N₆O₄ calc. C 64.15 H 6.88 N 8.31 (1330.0) found 64.02 7.10 7.70
Vis. (methanol): λmax = 418 (ε, ratios, 100), 544 (8.3), 583 nm (2.4).

**Copper Complex 7:** yield: 9 mg (3.3%) of a red solid.
C₃₀H₄₈Cl₃Cu₂N₆O₄ calc. C 63.87 H 7.49 N 6.77 (1654.9) found 63.88 7.44 7.09
Vis. (methanol): λmax = 422 (ε, ratios, 100), 545 (9.5), 580 nm (sh, 3.3).

5-(6-Hexadecylpyridinium-4-yl)-10,15,20-tris[4-pyridyl]-2,2′,2′′,2′′′-terphenyl-zinc Perchlorate Semihydrate (9): 5-(6-Hexadecylpyridinium-4-yl)-10,15,20-tris[4-pyridyl]-2,2′,2′′,2′′′-terphenyl-zinc bromide (1; 50 mg, 53 μmol) and zinc acetate dihydrate (16 mg, 73 μmol) are added to acetic acid (40 ml), the mixture is refluxed for 9 min, and then evaporated to dryness in vacuo at 40 °C. The residue is taken up in chloroform (∼3 ml) and column-chromatographed on alumina (Woelm, neutral, activity I; 1.8 × 14.5 cm) using chloroform/methanol (95:5) as eluent followed by gel filtration on Sephadex LH-20 (1.8 × 24.5 cm) using chloroform/metha-
nol (50/50) as eluent. The solvent is evaporated, the residual product dissolved in methanol (~6 ml), and an equal volume of aqueous 0.1 molar sodium perchlorate solution is added. The precipitate is isolated by suction, washed with water and methanol, and dried over phosphorus pentoxide in vacuo at 50°C; yield: 40 mg (74%).

C₇H₆ClN₂O₆Zn·½H₂O calc. C 66.20 H 5.76 N 11.03 (1016.0) found 66.44 5.77 10.89
Vis. (methanol): λmax = 423 (log ε = 5.57), 559 (4.26), 606 nm (3.79).

Chloro-(5,10,15,20-tetrakis[1-hexadecylyphyrindinum-4-yl]-21H,23H-porphine)-manganese Tetraphenyl Chloroform Tritylidyne (11): Manganese(II) chloride tetrahydrate (10 mg, 51 μmol) is added to a solution of 5,10,15,20-tetrakis[1-hexadecylyphyrindinum-4-yl]-21H,23H-porphine tetrabromide (4; 49 mg, 26 μmol) in dimethylformamide (100 ml). The mixture is refluxed for 35 min and then evaporated to dryness. The product is column-chromatographed on alumina (Woelm, neutral, activity 1; 1.8 x 13 cm) using chloroform/methanol (80/20) as eluent. The resultant product is dissolved in methanol (~3 ml), and 11 is precipitated by adding an equal volume of aqueous 0.1 molar sodium perchlorate solution. The precipitate is isolated by suction, washed with water and dried in vacuo over phosphorus pentoxide at 50°C; yield: 16 mg (30%).

C₈₀H₁₀₀Cl₂M₄N₆O₁₈ (H₃O)₂ calc. C 60.62 H 7.92 N 5.44 2H₂O (2060.7) found 60.38 7.52 5.45
Vis. (methanol): λmax = 463 (ε, ratios, 100), 571 (8.8), 615 (sh, 3.0), 680 (sh, 0.9), 768 nm (0.8).

Bromo-(5-[1-hexadecylyphyrindinum-4-yl]-10,15,20-tris[4-pyridyl]-21H,23H-porphine)-manganese Porphine Palladium Tetraphenyl Chloroform Tritylidyne (12): A procedure analogous to that for 11 is employed using the monoquinonized porphyrin I (86 mg, 91 μmol) and manganese(II) acetate tetrahydrate (119 mg, 0.49 mmol) in acid (100 ml); yield: 69 mg (67%).

C₆₀H₆₀Br₄Cl₂M₄N₆O₁₈ (H₃O)₂ calc. C 59.50 H 5.61 N 9.91 2H₂O (1130.5) found 59.35 5.26 9.79
Vis. (methanol): λmax = 463 (log ε = 5.07), 560 (4.07), 590 (sh, 3.77), 682 (3.07), 773 nm (3.07).

5,10,15,20-Tetrakis[1-hexadecylyphyrindinum-4-yl]-21H,23H-porphine-Iron(II) Chloroform Tritylidyne (13): Iron(II) chloride dihydrate (6.2 mg, 29 μmol) is added to a solution of 5,10,15,20-tetrakis[1-hexadecylyphyrindinum-4-yl]-21H,23H-porphine tetrabromide (4; 32 mg, 25 μmol) in dimethylformamide (100 ml). The mixture is refluxed under nitrogen for 1 h and then evaporated to dryness. The residue is column-chromatographed on alumina (Woelm, neutral, activity 1; 1.8 x 15 cm). The main fraction is eluted with chloroform/methanol (90/10) and then chloroform/methanol (80/20) and further purified by gel filtration on Sephadex LH-20 (1.8 x 26 cm) using methanol/chloroform (90/10). The solvent is evaporated to give the bromide salt (32 mg, 58%). This salt is dissolved in methanol (~3 ml) and an equal volume of aqueous 0.1 molar sodium perchlorate solution is added. The precipitated porphyrin is isolated by suction, washed with water, and dried in vacuo over phosphorus pentoxide to give 13 as a brown solid; yield: 22 mg (40%).

C₅₀H₄₀Cl₂N₂O₁₈Fe·½Pd calc. C 61.76 H 7.77 N 5.54 (2022.7) found 61.52 7.72 5.47
Vis. (methanol): λmax = 420 (ε, ratios, 100), 525 (10), 560 nm (4.9).

Received: July 19, 1979
(Reduced form: November 26, 1979)

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