

## Meso-functionalized octamethoxyporphyrins: A new class of nonasubstituted porphyrins

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**Abstract.** Octamethoxyporphyrin containing multiple-donor substituents has been functionalized for the first time. A large number of its mono-meso-substituted derivatives with substituents such as nitro, amino, N-methylamino, formyl, hydroxymethyl, oxime, cyano and carboxy functional groups have been synthesized and characterized. They form a new class of nonasubstituted porphyrins. Crystallographic studies on the cyano derivative show that the –C N group is in conjugation with the porphyrin *p*-system. The calculated optical transition energies and the electron densities on the imino nitrogens of the synthesised porphyrins using AMI calculations correlate well with the experimentally observed data. Meso-substituted porphyrins are found to be essentially planar.

**Keywords.** Octamethoxyporphyrin; meso-functionalization; nonasubstituted porphyrins; basicity; AMI semi-empirical correlation.

### 1. Introduction

Porphyrins are an important class of biological pigments and they display remarkable properties that qualify them as advanced materials.<sup>1</sup> The functions of the 22-*p* electron porphyrin core can easily be altered with the nature of the central metal ion in the core and/or by the presence of electron-withdrawing or -donating peripheral substituents. Among the various types of porphyrins, *b*-substituted porphyrins are unique owing to their close resemblance to naturally occurring porphyrins. Also, these porphyrins as well as their suitably substituted derivatives can be employed in designing multi-porphyrinic assemblies. For this it is essential to have an understanding of their reactivity at the meso-position that is influenced by both the electronic and steric nature of the substituents. Thus far, the studies involved have only been related to functionalization of aetioporphyryns<sup>2</sup> and octaethylporphyrin,<sup>3</sup> and this chemistry is little explored beyond the octaalkylporphyrins, owing to the difficulty in synthesizing suitable *b*-octasubstituted porphyrins. Therefore, the recently reported octamethoxyporphyrin,<sup>4</sup> which carries multiple electron-donating substituents, drew our attention to explore their pro-

erties further. The meso-functionalisation of octamethoxyporphyrin **1** with both electron-donor and -acceptor substituents provides a convenient route towards the synthesis of porphyrins that have potential applications in nonlinear optics. Here, we report the synthesis and characterization of a new class of nonasubstituted octamethoxyporphyrin bearing various meso substituents, viz. nitro, amino, N-methylamino, formyl, hydroxymethyl, oxime, cyano and carboxy functional groups.

### 2. Experimental

All the solvents used in this study were procured commercially, purified according to standard proce-



Dedicated to the memory of the late Professor Bhaskar G Maiya

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dures and distilled before use. Chemicals were obtained from Fluka and were purified before use. Reactions have been carried out under a blanket of nitrogen. Sufficient precautions have been taken to avoid exposure to bright light. Zn1 and Ni1 were synthesized using their respective metal acetates following standard procedures.<sup>5</sup> Purity of the synthesized porphyrins was checked by TLC and <sup>1</sup>H NMR spectroscopy.

### 2.1 Synthesis of mesofunctionalized porphyrins

**2.1a 5-Nitro-2,3,7,8,12,13,17,18-octamethoxyporphyrin 2:** Zn1 (100 mg, 0.16 mmol) was dissolved in a mixture of dry solvents containing dichloromethane (200 ml) and acetonitrile (80 ml). A solution of iodine (45 mg, 0.18 mmol) in dry dichloromethane (40 ml) was added to it while stirring, followed by a solution of silver nitrite (25 mg, 0.162 mmol) in dry acetonitrile (15 ml). The reaction mixture was stirred for two minutes during which period the solution color changed from dark pink to light violet. The stirring was then stopped and the reaction mixture was immediately filtered to remove the unreacted AgNO<sub>2</sub> to avoid polynitration. The filtrate was evaporated to dryness. Dissolved in a minimum amount of chloroform and to this concentrated hydrochloric acid was added dropwise while stirring over an ice-bath. After 5 min the green solution was poured into ice-water mixture and extracted with more of chloroform. The organic layer was dried over anhydrous Na<sub>2</sub>SO<sub>4</sub> and stripped of the solvent. The residue was dissolved in a minimum amount of chloroform and chromatographed over a neutral alumina column using chloroform as the eluant. The first reddish brown band collected was the required meso-nitrooctamethoxyporphyrin **2**. The yield based on Zn1 was 74 mg (76%). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) (ppm) *d* = 10.17 (*s*, 2H, CH<sub>meso-adj</sub>), 10.06 (*s*, 1H, CH<sub>meso-opp</sub>), 4.80 (*s*, 6H, OMe), 4.79 (*s*, 6H, OMe), 4.78 (*s*, 6H, OMe), 4.58 (*s*, 6H, OMe), -4.53 (*bs*, 2H, NH). MALDI mass (MH<sup>+</sup>): 596.9, calcd. for MH<sup>+</sup> (C<sub>28</sub>H<sub>30</sub>N<sub>5</sub>O<sub>10</sub>-596.6).

**2.1b 5-Amino-2,3,7,8,12,13,17,18-octamethoxyporphyrin 3:** Metallic tin powder (2.5 g, 21.06 mmol) was added to Zn2 (200 mg, 0.30 mmol) in chloroform (20 ml). This was followed by the addition of conc. hydrochloric acid (15 ml) and the reaction mixture was sonicated for 30 min. The reaction mixture was filtered and washed with water. The organic

layer was extracted with chloroform and dried over anhydrous Na<sub>2</sub>SO<sub>4</sub> and the solvent was removed. The product was dissolved in a minimum amount of chloroform and chromatographed over neutral alumina using chloroform:acetone (95 : 5 v/v) as eluant. The column was protected from light. The yield of **3** was almost quantitative on the basis of starting material, 152 mg (88%). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) (ppm) *d* = 9.30 (*s*, 2H, CH<sub>meso-adj</sub>), 8.92 (*s*, 1H, CH<sub>meso-opp</sub>), 8.18 (*bs*, 2H, -NH<sub>2</sub>), 4.66 (*s*, 6H, OMe), 4.65 (*s*, 6H, OMe), 4

for 30 min, the temperature being maintained around 50–55°C. The reaction mixture was heated and kept at reflux for 2 h, during which period the colour of the solution turned from red to green. The reaction mixture was cooled to room temperature and a saturated solution of sodium acetate (150 ml) was added gradually and then heated as before for another 30 min. At the end of this period, the reaction mixture was cooled and washed with water and the compound extracted in chloroform. The chloroform layer was separated and dried over anhydrous sodium sulphate. The compound was chromatographed on a neutral alumina column with chloroform as the eluant. The first pink band contained Ni (II)-derivative of the meso-formyloctamethoxyporphyrin. The yield was almost quantitative (186 mg, 89%). <sup>1</sup>H NMR in CDCl<sub>3</sub> (*d* in ppm): 12.34 (*s*, 1H, CHO), 9.85 (*s*, 2H, meso-H), 9.82 (*s*, 1H, meso-H), 4.69 (*s*, 12H, OCH<sub>3</sub>), 4.59 (*s*, 6H, OCH<sub>3</sub>), 4.44 (*s*, 6H, OCH<sub>3</sub>).

Free-base formylporphyrin was obtained by acid demetallation reaction of the above Ni(II)-derivative (186 mg) with concentrated H<sub>2</sub>SO<sub>4</sub> (20 ml). The compound was chromatographed on a neutral alumina column with chloroform as the eluant. The first reddish brown fraction collected was the required porphyrin **5**. The yield was almost quantitative (150 mg, 88%). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) (ppm) *d* = 12.49 (*s*, 1H, –CHO), 10.11 (*s*, 2H, CH<sub>meso-adj</sub>), 10.03 (*s*, 1H, CH<sub>meso-opp</sub>), 4.79 (*s*, 12H, OMe), 4.75 (*s*, 6H, OMe), 4.55 (*s*, 6H, OMe), –4.33 (*bs*, 2H, NH). MALDI mass (MH<sup>+</sup>): 579.9, calcd. for MH<sup>+</sup> (C<sub>29</sub>H<sub>31</sub>N<sub>4</sub>O<sub>9</sub>–579.6).

**2.1e 5-Hydroxymethyl-2,3,7,8,12,13,17,18-octamethoxyporphyrin 6:** A solution of sodium borohydride (25 mg, 0.66 mmol) in dry methanol (30 ml) was added to 5-formyloctamethoxyporphyrin, **5** (50 mg, 0.086 mmol) in dry chloroform (25 ml) while stirring, and stirring was continued overnight at room temperature. At the end of this period, the reaction mixture was washed with water and the organic layer extracted with chloroform and dried over anhydrous sodium sulphate, and the solvent finally removed. The residue was dissolved in a minimum amount of chloroform and chromatographed over a neutral alumina column with chloroform as eluant. The first fraction eluted with chloroform gave unreacted formyl derivative and the second fraction eluted with CHCl<sub>3</sub> : acetone (90 : 10 v/v) was the desired hydroxymethyl porphyrin **6** (42 mg, 84%). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) (ppm) *d* = 10.11 (*s*, 2H, CH<sub>meso-adj</sub>),

9.93 (*s*, 1H, CH<sub>meso-opp</sub>), 6.98 (*s*, 1H, –CH<sub>2</sub>–), 6.94 (*s*, 1H, –CH<sub>2</sub>–), 4.80 (*s*, 6H, OMe), 4.79 (*s*, 6H, OMe), 4.78 (*s*, 6H, OMe), 4.74 (*s*, 6H, OMe), –4.07 (*bs*, 1H, NH), –3.95 (*bs*, 1H, NH). MALDI mass (MH<sup>+</sup>): 582.0, calcd. for MH<sup>+</sup> (C<sub>29</sub>H<sub>33</sub>N<sub>4</sub>O<sub>9</sub>–581.6).

**2.1f 2,3,7,8,12,13,17,18-Octamethoxyporphyrin-5-carbaldehyde oxime 7:** Hydroxylamine.hydrochloride (30 mg, 0.43 mmol) was added to 5-formyloctamethoxyporphyrin **5** (50 mg, 0.086 mmol) in pyridine (70 ml). The reaction mixture was heated on a water-bath for 30 min and immediately poured into water (100 ml) and extracted with chloroform. Subsequent to the removal of the solvent, the product was chromatographed over a neutral alumina column. The first band eluted with chloroform was found to be unreacted material. The second band eluted with CHCl<sub>3</sub> : acetone (90 : 10 v/v) was the desired oxime derivative **7**, yield: 45 mg (88%). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) (ppm) *d* = 10.40 (*s*, 1H, CH=N), 10.12 (*s*, 2H, CH<sub>meso-adj</sub>), 10.00 (*s*, 1H, CH<sub>meso-opp</sub>), 7.53 (*bs*, 1H, –NOH), 4.79 (*s*, 12H, OMe), 4.77 (*s*, 6H, OMe), 4.54 (*s*, 6H, OMe), –4.21 (*bs*, 2H, NH). MALDI mass (MH<sup>+</sup>): 594.2, calcd. for MH<sup>+</sup> (C<sub>29</sub>H<sub>32</sub>N<sub>5</sub>O<sub>9</sub>–594.6).

**2.1g 5-Cyano-2,3,7,8,12,13,17,18-octamethoxyporphyrin 8:** The oxime derivative **7** (50 mg, 0.08 mmol) in acetic anhydride (50 ml) was refluxed for 1 h by protecting the reaction mixture from moisture with a CaCl<sub>2</sub> guard tube. At the end of the reaction, the reaction mixture was poured in to water (100 ml) and vigorously stirred for 1 h, extracted with chloroform and dried over anhydrous Na<sub>2</sub>SO<sub>4</sub>. Then the solvent was removed, the product dissolved in a minimum amount of chloroform and chromatographed over neutral alumina column using chloroform as eluant. The bluish-purple first fraction was the desired cyano derivative **8**, yield: 41 mg (84%). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) (ppm) *d* = 10.06 (*s*, 2H, CH<sub>meso-adj</sub>), 9.94 (*s*, 1H, CH<sub>meso-opp</sub>), 4.88 (*s*, 6H, OMe), 4.78 (*s*, 6H, OMe), 4.77 (*s*, 6H, OMe), 4.71 (*s*, 6H, OMe), –4.17 (*bs*, 2H, NH). MALDI mass (MH<sup>+</sup>): 577.0, calcd. for MH<sup>+</sup> (C<sub>29</sub>H<sub>30</sub>N<sub>5</sub>O<sub>8</sub>–576.6).

**2.1h 5-Carboxy-2,3,7,8,12,13,17,18-octamethoxyporphyrin 9:** Meso-cyanoctamethoxyporphyrin **8** (50 mg, 0.087 mmol) was dissolved in concentrated sulphuric acid (4 ml) and glacial acetic acid (4 ml) and heated on a steam bath for 1 h. The reaction mixture was poured into an ice-bath and extracted with chloroform. The organic layer was washed with

saturated sodium bicarbonate solution and dried over anhydrous  $\text{Na}_2\text{SO}_4$ . The solvent was removed and the product was chromatographed over a neutral alumina column with chloroform as eluant. The first two light fractions contained the octamethoxyporphyrin **1** (obtained owing to decarboxylation) and the unreacted starting material whereas the third major fraction eluted with  $\text{CHCl}_3$ : acetone (80 : 20 v/v) contained the desired carboxy derivative **9**. Yield: 41 mg (79%).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ) (ppm)  $\delta$  = 10.07 (*s*, 2H,  $\text{CH}_{\text{meso-adj}}$ ), 9.88 (*s*, 1H,  $\text{CH}_{\text{meso-opp}}$ ), 4.79 (*s*, 6H, OMe), 4.77 (*s*, 12H, OMe), 4.62 (*s*, 6H, OMe), -4.45 (*bs*, 2H, NH). MALDI mass ( $\text{M}^+$ ): 594.9, calcd. for  $\text{M}^+$  ( $\text{C}_{29}\text{H}_{30}\text{N}_4\text{O}_{10}$ -594.6).

## 2.2 Methods

PMR spectra of the porphyrins were recorded on a Bruker AMX 400 MHz FTNMR spectrometer using TMS as internal standard (chemical shifts in  $\delta$ , ppm). Optical absorption spectra were obtained on a Hitachi U-3000 UV-Vis spectrophotometer using a pair of matched quartz cells of 10 mm path length at an ambient temperature of 300 K. MALDI-mass spectra of the porphyrins were recorded on a Kratos PC-Kompact MALDI Data System at room temperature using alpha-cyano-4-hydroxy cinnamic acid or sinnapinic acid matrix. The protonation equilibria of the meso-substituted porphyrins were examined using optical absorption method. The spectra of the porphyrins were recorded on increasing addition of trifluoroacetic acid in a  $\text{CHCl}_3$ :  $\text{CH}_3\text{OH}$  (1 : 1) solvent mixture at room temperature. The decrease in the absorption of the band around 530 nm was monitored as a function of the increasing concentration of the acid. For **3**, **4** and **8**, the bands at 514, 543 and 635 nm were monitored respectively. The pH of the reaction medium was measured using an Elico model L1-120 digital pH meter using a glass electrode. The response of the electrode was calibrated using a standard buffer solution of known pH. The  $\text{p}K_4$  value was obtained from Henderson's plot of  $\log[(A_0 - A)/(A - A_\infty)]$  versus pH, where  $A_0$ ,  $A_\infty$  and  $A$  are the absorbance of the free-base porphyrin, completely protonated species and the mixture of free-base and protonated forms respectively.

AM1 calculations to obtain changes in the spectra and other properties of the porphyrins upon meso-substitution were performed using MOPAC.<sup>6</sup> This method of calculation is known for the validity of prediction both in relation to experimental data and

with respect to elaborate theoretical methods. These semi-empirical calculations include full configuration interaction (CI = 8) within the orbitals of four orbital method (FOM). The optimized structures of all the porphyrins were obtained using AM1 and semi-empirical calculations were performed upon them.

## 2.3 X-ray crystallographic studies

Among the many attempts made to obtain single crystals of the meso-substituted free-base octamethoxyporphyrins, we have been successful in obtaining only the cyano derivative of the free-base octamethoxyporphyrin in the form of single crystals by slow evaporation of chloroform and toluene (1 : 1 v/v) solution of **8** at room temperature. A suitable single crystal was carefully selected under a polarizing microscope and glued to a thin glass fibre with cyanoacrylate (super glue) adhesive. Single crystal structure determination by X-ray diffraction was performed on a Siemens Smart-CCD diffractometer equipped with a normal focus, 2.4 kW sealed tube X-ray source (Mo- $K_\alpha$  radiation,  $\lambda = 0.71073 \text{ \AA}$ ) operating at 50 kV and 40 mA. A hemisphere of intensity data was collected at room temperature in 1321 frames with  $\omega$  scans (width of  $0.30^\circ$  and exposure time of 20s per frame) in the  $2\theta$  range 3 to  $46.5^\circ$ . Relevant crystal data are presented in table 1.

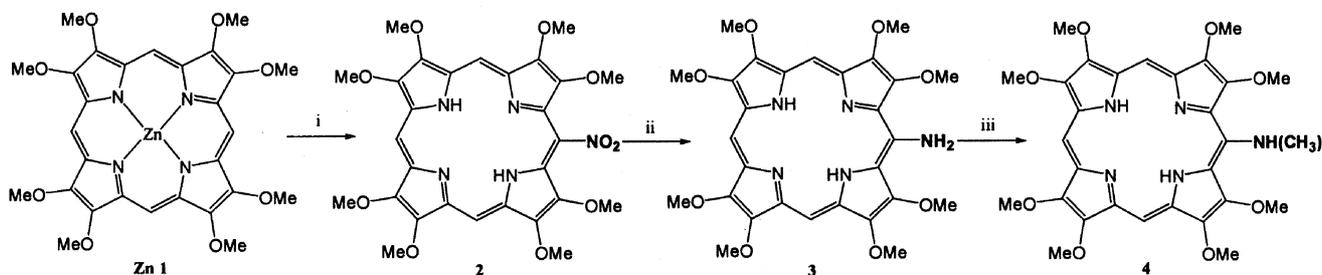
The structure was solved by direct methods using SHELXS-86 and difference Fourier syntheses. All the hydrogen positions were initially located in the difference Fourier maps, but for the final refinement the hydrogen atoms were placed geometrically. No absorption correction was applied. The last cycles of refinement included atomic positions for all the atoms, anisotropic thermal parameters for all non-hydrogen atoms and isotropic thermal parameters for all the hydrogen atoms. Full-matrix-least-squares structure refinement against  $|F^2|$  was carried out using the SHELXL-97 package of programs.<sup>7</sup> Details of CIF files are available from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK on request quoting the deposition number CCDC 260877.

## 3. Results and discussion

Interestingly, **1** does not undergo nitration like other *b*-substituted octaalkylporphyrins with common nitrating agents like concentrated nitric acid either in acetic or sulphuric acids, prolonged reaction time or

**Table 1.** Crystallographic data and structure refinement parameters for **8**.

Identification code	CNOMP	
Empirical formula	C <sub>29</sub> H <sub>29</sub> N <sub>5</sub> O <sub>8</sub>	
Formula weight	575.57	
Temperature	293(2) K	
Wavelength	0.71073 Å	
Crystal system	Monoclinic	
Space group	P2 <sub>1</sub> /c	
Unit cell dimensions	<i>a</i> = 9.0759(6) Å	<i>a</i> = 90°
	<i>b</i> = 13.3631(7) Å	<i>b</i> = 100.871(2)°
	<i>c</i> = 23.3001(15) Å	<i>c</i> = 90°
Volume	2775.2(3) Å <sup>3</sup>	
<i>Z</i>	4	
Density (calculated)	1.378 Mg/m <sup>3</sup>	
Absorption coefficient	0.102 mm <sup>-1</sup>	
<i>F</i> (000)	1208	
Crystal size	0.04 × 0.08 × 0.20 mm <sup>3</sup>	
Theta range for data collection	1.76 to 23.31°	
Index ranges	−9 ≤ <i>h</i> ≤ 10, −14 ≤ <i>k</i> ≤ 13, −20 ≤ <i>l</i> ≤ 25	
Reflections collected	11148	
Independent reflections	3970 [ <i>R</i> (int) = 0.0798]	
Completeness to theta = 23.31°	99.3%	
Refinement method	Full-matrix least-squares on <i>F</i> <sup>2</sup>	
Data/restraints/parameters	3970/0/380	
Goodness-of-fit on <i>F</i> <sup>2</sup>	1.065	
Final <i>R</i> indices [ <i>I</i> > 2 <i>s</i> ( <i>I</i> )]	<i>R</i> 1 = 0.0719, <i>wR</i> 2 = 0.1725	
<i>R</i> indices (all data)	<i>R</i> 1 = 0.1613, <i>wR</i> 2 = 0.2163	
Extinction coefficient	0.0013(6)	
Largest diff. peak and hole	0.410 and −0.232 e.Å <sup>-3</sup>	

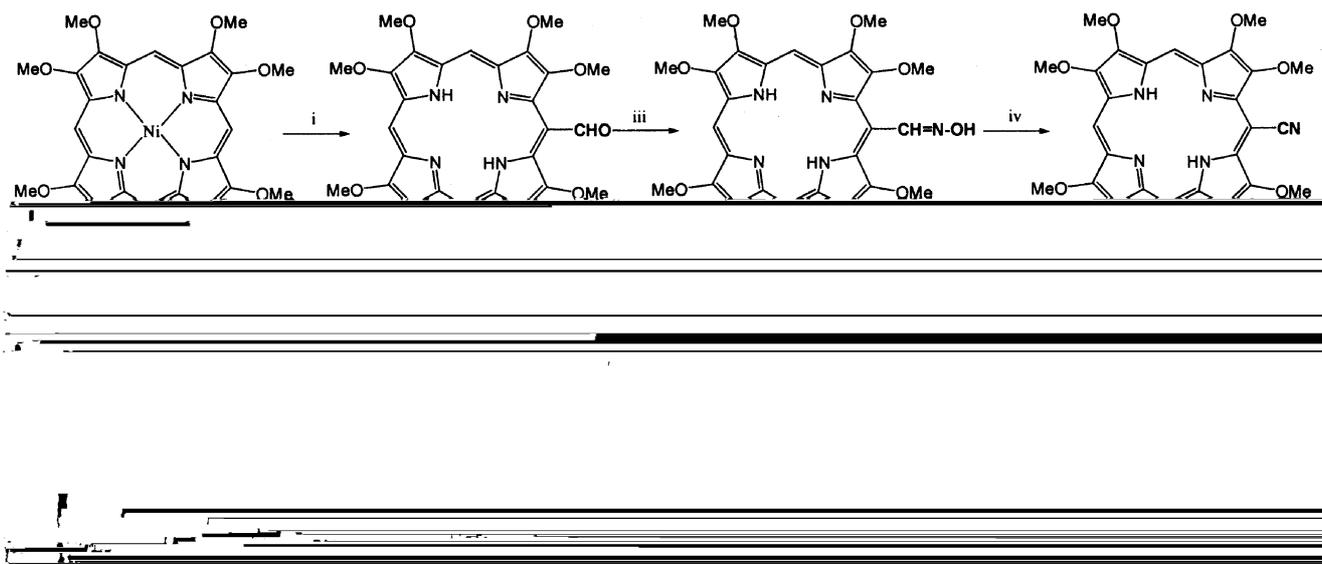


**Conditions:** (i) I<sub>2</sub>/AgNO<sub>3</sub>, CH<sub>2</sub>Cl<sub>2</sub>/CH<sub>3</sub>CN, stir, 2 min, conc. H<sub>2</sub>SO<sub>4</sub>; (ii) Sn/HCl, sonicate, 30 min; (iii) Copper acetate, NaBH<sub>4</sub>, THF, 3M H<sub>2</sub>SO<sub>4</sub>, 40% aq. HCHO, conc. H<sub>2</sub>SO<sub>4</sub>. **Yields:** **2** – 76%; **3** – 88%; **4** – 26%

**Scheme 1.**

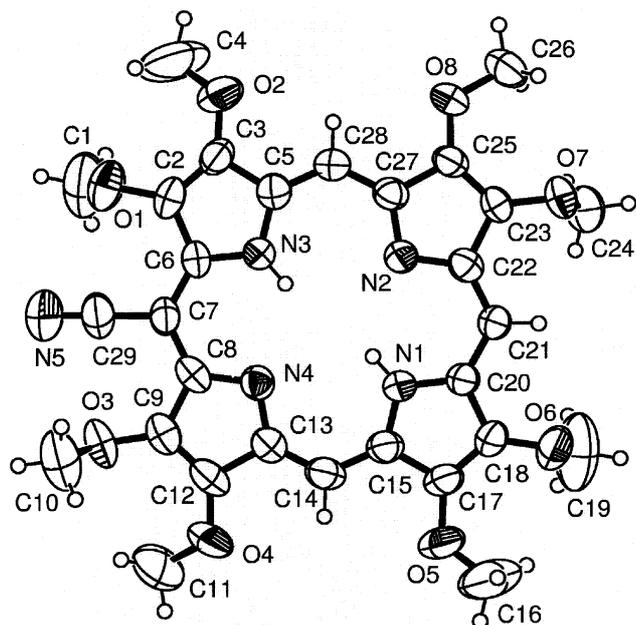
elevated temperature resulting in degradation of the starting material, whereas nitration with copper nitrate in acetic anhydride results in the copper derivative of the nitro-substituted porphyrin **2** in very low yield. However, Zn1 can be readily nitrated with iodine and AgNO<sub>3</sub> in CH<sub>2</sub>Cl<sub>2</sub>/CH<sub>3</sub>CN (scheme 1).<sup>8</sup> The reaction proceeds vigorously and has to be quenched in about 2 min to avoid polynitration. The Sn/HCl

reduction<sup>9</sup> of Cu2 followed by acid demetallation with concentrated sulphuric acid produces the meso-amino derivative **3** in high yield. However, Zn2 undergoes the above reduction process to form **3** directly in quantitative yield. Attempts to N-permethylate **3** remain unsuccessful so far. To avoid methylation of the core imino nitrogens, we used the copper derivative of **3**. With formaldehyde/sodium borohydride in



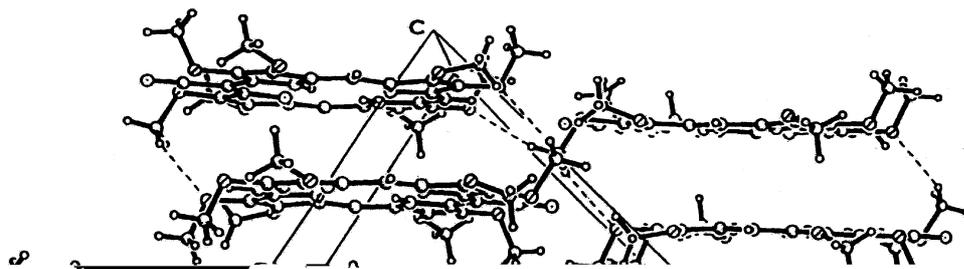
**Conditions:** (i)  $\text{POCl}_3$  to DMF at  $0^\circ$ , dichloroethane, reflux 2 h, sat. NaOAc, reflux 30 min, conc.  $\text{H}_2\text{SO}_4$ ; (ii)  $\text{NaBH}_4$ ,  $\text{CHCl}_3/\text{MeOH}$ , stir, r.t., 12 h; (iii)  $\text{NH}_2\text{OH}\cdot\text{HCl}$ , Pyridine, steam bath, 30 min; (iv)  $\text{Ac}_2\text{O}$ , reflux, 1 h; (v) Glacial  $\text{AcOH}/\text{conc. H}_2\text{SO}_4$  (1 : 1 v/v) steam bath, 1 h. **Yields:** **5** – 89%; **6** – 84%; **7** – 88%; **8** – 84%; **9** – 79%

Scheme 2.



**Figure 1.** ORTEP diagram of free-base meso-substituted cyanooctamethoxyporphyrin **8** showing 50% thermal ellipsoid probability.

aqueous sulphuric acid<sup>10</sup> only mono-methylated derivative **4** could be obtained in lesser yield among with other unidentified products.



**Figure 2.** Crystallographic packing diagram of free-base meso-substituted cyanoctamethoxyporphyrin **8**.

**Table 2.** Selected bond lengths (Å) and bond angles (°) of meso-cyano-substituted octamethoxyporphyrin<sup>a</sup>.

Bond	Distance (Å)	Atoms	Angle (°)
C(1)–O(1)	1.375 (8)	C(3)–C(2)–O(1)	127.6 (5)
C(2)–C(3)	1.348 (6)	C(3)–C(2)–C(6)	

leading to the conclusion that the presence of cyano group does not cause any steric distortion to the porphyrin ring.<sup>4a</sup> The methoxy groups are arranged in a fashion that the planar methoxy groups point away from the meso-hydrogen atoms, forcing the neighbouring methoxy group on the same pyrrole ring out of the plane. The structure of this porphyrin provides a basis for the interpretation of the observed spectral data.

All the porphyrin derivatives were characterized by <sup>1</sup>HNMR, UV–Vis and MALDI–mass spectroscopy techniques. The <sup>1</sup>HNMR data of freebase porphyrins display the characteristic resonances of methine, imino and methoxy protons. Interestingly, the presence of a substituent on one of the meso-carbons results in the splitting of the methine protons resonances and the signals arising from the methoxy protons located at the pyrrole rings become clearly distinguishable. Based on the integrated intensity data, it is found that the methine proton located opposite to the meso-substituent apparently resonates in a shielded region while the two methine protons situated at the neighbouring methine carbons occur at a marginally deshielded region relative to the corresponding resonance of **1**. This shielding and deshielding of methine proton resonances as a consequence of meso-substitution is observed for all the meso-substituted porphyrins. However, in the case of amino and N-methylamino derivatives, both the opposite and adjacent methine proton signals occur in a shielded region relative to that observed for **1**. The methoxy protons, in general, split into four sets of signals, one being more shielded than the others. In case of the cyano-derivative the resonance of one of the methoxy groups occurs in a more deshielded region than the resonances of other methoxy groups. The imino protons, in general, resonate at a lower field compared to the unsubstituted octamethoxy-porphyrin. The deshielding effect experienced by these resonances is found to be more, particularly in case of the amino- and N-methylamino-derivatives. The nitro and carboxy derivatives show a marginal shielding effect. Interestingly, in case of the amino and hydroxymethyl derivatives, an inequivalence of imino protons is observed as revealed by the appearance of two singlets.

The above observations could be interpreted as follows: meso-substitution leads to a depletion of ring current in the porphyrin core. The shielding of the methine protons resonance (located opposite to the meso-substituents) can be ascribed to a conforma-

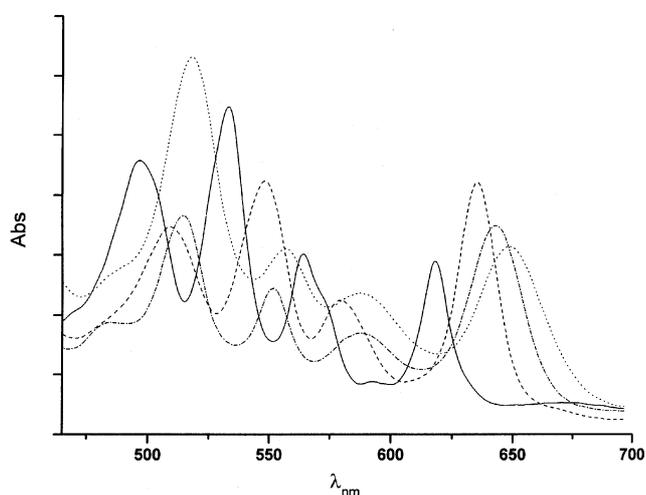
tional change in which the entire molecule is folded across the two opposite meso positions.<sup>13</sup> This results in diminishing the deshielding effects at the substituted meso-position and at the one opposite to it. Protons in the vicinity of the meso-substituents experience an additional shielding effect. This can be understood in terms of the steric influence caused by the nonlinear substituents, which are forced out of the plane of the macrocycle; but magnetic anisotropy associated with the meso-substituents seems to play a predominant role.<sup>14</sup> In case of the formyl, carboxy, oxime and the nitro derivatives, the neighbouring *b*-methoxy substituents are in a region of positive shielding (most shielded resonance) because of the preferred out-of-plane conformation of the meso-substituents. However, the linearity of the cyano-group helps it to align with the plane of the macrocycle and hence the proton resonances arising from neighbouring methoxy groups experience a strong deshielding effect due to the magnetic anisotropy of the cyano-group. The introduction of a meso-amino substituent causes strong shielding of methine and methoxy proton resonances while a deshielding effect is experienced by the imino proton resonances. This apparently arises from the strong electron-donating nature of the amine group ( $s_p$ : -0.66); the amino protons resonating at 8.18 ppm (NH<sub>2</sub> of OEPNH<sub>2</sub> resonates at 6.14 ppm<sup>3c</sup>) support the strong involvement in conjugation with the ring. N-methylation of the amino group shifts the resonance of the NH-proton upfield (8.00 ppm). The formyl proton resonates at 12.49 ppm and shifts upfield on oxime formation (10.40 ppm). It is of interest to note that the methylene protons of **6** resonate as two close-lying singlets (6.94 and 6.98 ppm). This may be attributed to possible hydrogen bonding between substituent and the neighbouring methoxy group (loc. cit) making the methylene protons diastereomeric in nature.

The UV–Vis spectra of some of the substituted porphyrin are presented in figure 3. The absorption spectral data are presented in table 3. All the porphyrins display characteristic Soret band (*B* band) and four *Q* bands in the visible region. These transitions are interpreted in terms of the four-orbital model of Gouterman.<sup>15</sup> It is seen that all the observed bands of the meso-substituted porphyrins are red-shifted relative to the unsubstituted porphyrin **1**. The meso substitution of **1** leads to change in the spectral pattern of the *Q* band region of these porphyrins.

The porphyrins **2**, **5**, **6**, **7**, and **9** show a change from rhodo- to etio-type spectra; **3** has  $Q_4 > Q_1 >$

**Table 3.** Optical absorption data of the free-base meso-substituted octamethoxyporphyrins in dichloromethane at 298 K.

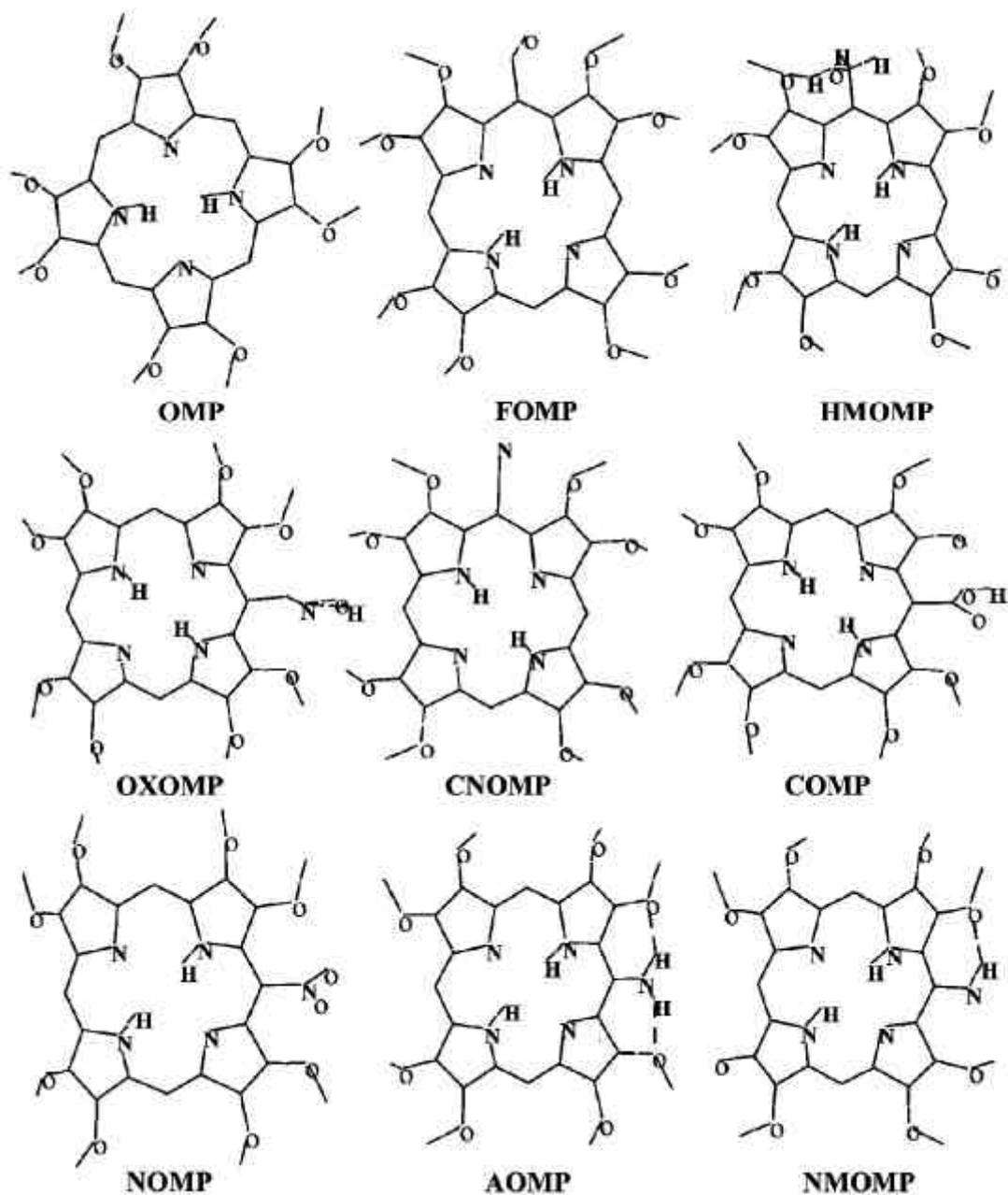
Porphyrins	$I_{\max}$ (nm), log $e$					$Fwhm$ $B_x(0,0)$ ( $\text{cm}^{-1}$ )	$Fwhm$ $Q_x(0,0)$ ( $\text{cm}^{-1}$ )
	$B_x(0,0)$	$Q_y(1,0)$	$Q_y(0,0)$	$Q_x(1,0)$	$Q_x(0,0)$		
<b>1</b>	378.0 (5.21)	496.0 (4.02)	533.0 (4.10)	564.0 (3.84)	618.0 (3.83)	2329	328
<b>2</b>	380.2 (5.22)	499.5 (4.02)	536.0 (4.00)	568.0 (3.82)	622.0 (3.77)	2301	380
<b>3</b>	409.0 (5.29)	515.6 (4.21)	552.0 (4.04)	587.8 (3.88)	643.6 (4.19)	2411	635
<b>4</b>	415.0 (5.30)	518.4 (4.19)	556.4 (3.89)	588.4 (3.77)	647.4 (3.89)	2370	722
<b>5</b>	382.4 (5.23)	499.5 (4.00)	536.0 (3.99)	568.0 (3.79)	622.0 (3.71)	2288	291
<b>6</b>	384.6 (5.20)	501.0 (4.07)	537.5 (3.99)	569.5 (3.84)	624.4 (3.65)	2438	358
<b>7</b>	384.0 (5.34)	500.5 (4.08)	536.5 (4.03)	569.0 (3.83)	623.0 (3.73)	2356	378
<b>8</b>	388.4 (5.26)	509.5 (3.98)	548.0 (4.07)	579.5 (3.80)	635.5 (4.00)	2026	435
<b>9</b>	381.2 (5.12)	498.0 (4.00)	535.0 (3.97)	566.5 (3.79)	620.5 (3.69)	2224	321

**Figure 3.** Electronic absorption spectra (Q-bands) of: **1** (—), **3** (.....), **4** (.....), **8** (- - -) in  $\text{CH}_2\text{Cl}_2$ .

$Q_3 > Q_2$ ; **4** has  $Q_4 > Q_3 = Q_1 > Q_2$  and **8** shows  $Q_3 > Q_1 > Q_4 > Q_2$  pattern. The cyano and amino derivatives show intramolecular charge transfer as evidenced from the strong enhancement of intensity of the longest wavelength  $Q$  bands (figure 3). This is attributed to the presence of substituents like cyano

and amino groups at the meso position that are strongly conjugated to the electron-rich octamethoxyporphyrin skeleton. Methylation of the amino group substantially reduces the intensity of the  $Q$  band possibly due to steric reasons, which diminishes the efficiency of charge-transfer.

In spite of the presence of eight electron-donating methoxy groups, all the porphyrins show poor basi-



**Figure 4.** AM1 optimized structures of the free-base meso-substituted octamethoxyporphyrins (peripheral ring 'H's are removed except for the substituents for clarity).

city in general (table 4). This is similar to those obtained for the aetioporpyrins and OEP.<sup>2b,16</sup> In general, one  $pK_a$  value is observed for these porphyrins which has been denoted as  $pK_4$  by us. The second  $pK_a$  values of **3** at 7.85 was assigned to protonation of the  $NH_2$  functional group. The unexpectedly low basicity of these porphyrins is attributed to their rigid macrocyclic plane, which needs to be distorted in order to undergo protonation. This occurs at a higher acid strength, once deformed the monocation

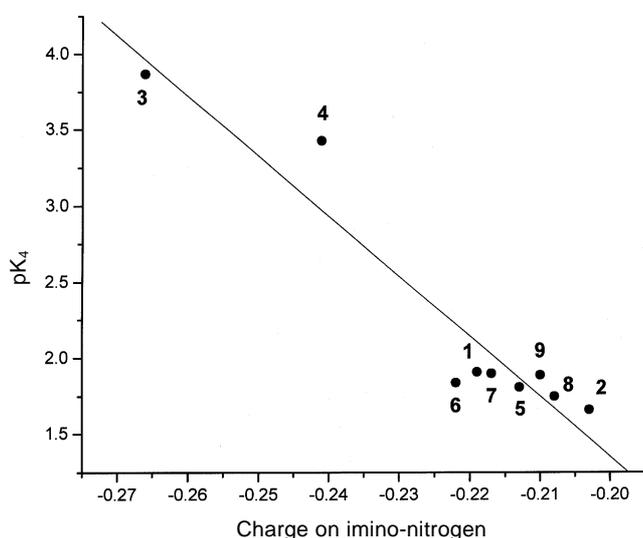
immediately undergoes protonation to form the diprotonated species, thereby making it difficult to separately determine the  $pK_3$  and  $pK_4$  from Henderson's plot.

AM1 calculations on the synthesized porphyrins have been useful in rationalizing the observed transition energies and  $pK$  values. The optimized structure of the mesosubstituted porphyrins is displayed in figure 4. Simple MO theory would ascribe the observed  $B$  and  $Q$  transitions to either ( $a_{2u}e_g$ ) or

**Table 5.** Calculated and experimentally observed transition energies for the meso-substituted octamethoxyporphyrins<sup>a</sup>

Porphyrins	Q-bands (nm) <sup>b</sup>				B-band (nm) <sup>b</sup> $B_x(0,0)$
	$Q_x(0,0)$	$Q_x(0,1)$	$Q_y(0,0)$	$Q_y(0,1)$	
<b>1</b>	618.0 (526.3)	564.0 (415.8)	533.0 (366.7)	496.0 (353.6)	378.0 (322.9)
<b>2</b>	622.0 (522.3)	568.0 (406.1)	536.0 (368.4)	499.5 (360.6)	380.2 (323.5)
<b>3</b>	643.6 (579.9)	587.8 (470.5)	552.0 (378.2)	515.6 (350.8)	409.0 (343.2)
<b>4</b>	647.4 (532.5)	588.4 (424.3)	556.4 (371.4)	518.4 (366.0)	415.0 (344.5)
<b>5</b>	622.0 (527.5)	568.0 (410.3)	536.0 (368.0)	499.5 (355.3)	382.0 (325.7)
<b>6</b>	624.0 (532.5)	569.5 (419.5)	537.5 (367.6)	501.0 (352.7)	384.6 (327.3)
<b>7</b>	623.0 (528.2)	569.0 (417.1)	536.5 (366.2)	500.5 (353.8)	384.0 (322.1)
<b>8</b>	635.5 (524.0)	579.5 (411.0)	548.0 (368.3)	509.5 (360.5)	388.4 (330.3)
<b>9</b>	620.5 (522.3)	566.5 (397.4)	535.0 (370.1)	498.0 (366.5)	381.2 (323.5)

<sup>a</sup>Figures in parentheses refer to the AM1 transition energies; <sup>b</sup>absorption spectra were measured in dichloromethane at 298 K



**Figure 5.** Plot of  $pK_a$  vs AM1 calculated imino nitrogen charge for the free-base meso-substituted octamethoxyporphyrins.

( $a_{1u}e_g$ ) configurations. However, if there is configuration interaction, the  $Q$  and  $B$  transitions must each

be a mixture of such configurations. The excited states of porphyrin are viewed as arising from two configurations which can be mixed to varying degrees. It is found that all excited states are heavily mixed due to configuration interaction but this is restricted to the four orbitals (HOMO-1, HOMO, LUMO, LUMO+1) for the low lying  $S_1$  and  $S_2$  singlet states in the meso-substituted porphyrins, which supports the validity of Gouterman's FOM in predicting the qualitative spectra of porphyrins. The theoretically calculated transition energies faithfully reproduce the experimental trends in energies (table 5).

Several physico-chemical properties can be correlated to the theoretically estimated energy levels and electron densities at different atoms of these porphyrins. It has been possible to relate the average electron densities at the four nitrogens to the  $pK_a$  values. The lowering of the  $pK_a$  value with the decrease in charge density of the inner nitrogens in the series phlorin-porphyrin-chlorin-bacteriochlorin has been rationalized in terms of disruption of  $\pi$ -conjugation resulting in the non-planar conformation of the macrocycle. In general, an electron-donating

group at the periphery of the macrocycle tends to increase the basicity of the nitrogens in the free-base porphyrin, while a decrease is expected for an electron-withdrawing substituent. This is reflected in the electronic charge on the imino nitrogens. Experimentally determined protonation constants ( $pK_a$ ) versus the computed charge densities on the imino nitrogens from AM1 calculations are plotted (figure 5). Experimental  $pK_4$  values correlate quite well (within experimental error) with the computed nitrogen basicities.

#### 4. Conclusion

A new series of nonasubstituted porphyrins in which one of the meso positions was functionalized with various substituents has been synthesized and characterized. These porphyrins, in general, show weak basicity in spite of the presence of eight electron-donating methoxy groups at the *b*-pyrrolic positions. Crystal structure of meso-cyano-octamethoxy-porphyrin reveals a planar core with strongly conjugated cyano group. Meso-functionalization of the octamethoxy-porphyrin results in the red shift of all the *Q* bands of the porphyrin and the magnitude of the red shift is fairly independent of the nature of the substituent. The trend in optical transition energies correlates well with the trend in the calculated values using the semi-empirical AM1 approximation method. UV-Vis spectra indicate red shift in the transitions of all the porphyrins irrespective of the nature of the substituents. Experimental data were well supported by AM1 calculated data.

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