2a were also present in trace amounts, consistent with the isotopic purity of the starting material.

Thermolysis of 4,4-Diethoxy-2,5-cyclohexadien-1-one in Methanol. The thermolysis of the title compound was performed as described for **1a**: 0.2 g (1.1 mmol); CH_3OH (0.5 mL); 4 h. A ^1H NMR spectrum of the reaction mixture indicated that the starting monoketal and **2c** were present; **1a** was not detected.

Thermolysis of 1a in Ethanol. The thermolysis of the title compound was performed as described for **1a**: 0.2 g (1.25 mmol); EtOH (0.5 mL); 4 h. A ^1H NMR spectrum of the reaction mixture indicated that **1a** and **2a** were present; 4,4-diethoxy-2,5-cyclohexadien-1-one was not detected.

Kinetic Procedure. Standardized solutions of **1a** and **1a**-d_6 were prepared at room temperature, and aliquots (0.5 mL) were placed in glass tubes (13 cm × 8 mm). Once filled, the kinetic samples were degassed by a series of four freeze–thaw cycles (0.1 mmHg), and the tubes were then sealed under vacuum. At zero time, all the tubes for a particular kinetic run were placed in a silicon oil kinetic bath maintained at a constant temperature of 180 ± 0.5 °C (except for activation parameter runs). The kinetic samples were retrieved from the bath every 30 min. A typical kinetic run included data points for the first 5 h of reaction with the infinity absorbance sample being pulled from the bath 24 h from zero time (100% conversion to the product phenol). The kinetic samples were analyzed by UV spectroscopy at 293 nm and the rate constants are felt to be reliable to ±5%.

Acknowledgment. We thank the National Science Foundation for partial support of this work.

Registry No. **1a**, 935-50-2; **1a**-d_6, 110614-47-6; **1b**, 73010-55-6; **1c**, 73010-52-3; **1d**, 73010-54-5; **4**, 15791-03-4; **4**-d_{12}, 110614-50-1; **8**, 35357-34-7; 4,4-diethoxy-2,5-cyclohexadien-1-one, 81453-27-2; 4,4-dibutoxy-2,5-cyclohexadien-1-one, 110614-48-7; 1,1,4,4-tetrakis(benzyloxy)-2,5-cyclohexadiene, 110614-49-8; 1,4-benzoquinone bis(ethylene ketal), 35357-33-6; 1,1,4,4-tetraethoxy-2,5-cyclohexadiene, 72205-84-6; 1,1,4,4-tetrabutoxy-2,5-cyclohexadiene, 110614-51-2.

Synthesis of Hydrocarbon-Strapped Porphyrins Containing Quinone and Phenolic Groups

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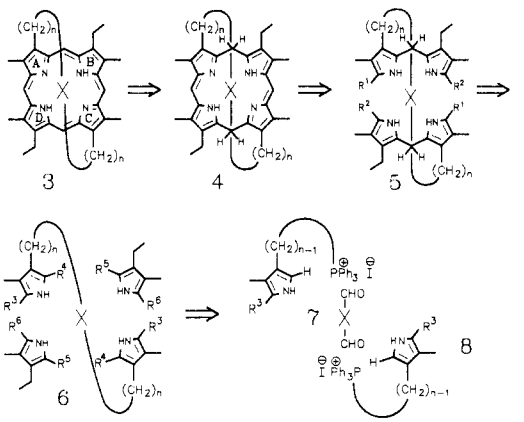
A general synthesis of strapped porphyrins is described and is illustrated for porphyrins bearing quinone and phenol groups in the bridging strap, which is exclusively a polymethylene chain. The NMR and optical spectra of the strapped porphyrins are discussed.

Synthetic metalloporphyrins enjoy continuing popularity as models for metalloenzymes, oxygen transport and storage proteins, and biological electron-transport systems.[1] Covalent attachment of potential ligands, bulky blocking groups, and other interactive species to a porphyrin macrocycle has been a frequently used strategy in the synthesis of heme protein models. This strategy can control coordination of the metalloporphyrin by a steric or neighboring group effect. This allows access to well-defined 5-coordinate iron(II) or 6-coordinate mixed-ligand systems. It can also allow the design of models where the relative orientation and separation of two reaction centers have been predetermined. Iron porphyrins bearing covalently bound imidazole,[2] thioether,[3] and thiolate[4] groups

Scheme I



have been prepared as models for the active centers of hemoglobin, myoglobin, cytochrome *c*, and cytochrome P_{450}. Binucleating porphyrins,[5] which contain a second metal binding site attached to a porphyrin ring, have been

(1) (a) Collman, J. P. *Acc. Chem. Res.* **1977**, *10*, 265–272. (b) Jones, R. D.; Summerville, D. A.; Basolo, F. *Chem. Rev.* **1979**, *79*, 139–179. (c) Scheidt, W. R.; Reed, C. A. *Chem. Rev.* **1981**, *81*, 543–555. (d) Traylor, T. G. *Acc. Chem. Res.* **1981**, *14*, 102–109. (e) Smith, P. D.; James, B. R.; Dolphin, D. H. *Coord. Chem. Rev.* **1981**, *39*, 31–75. (f) Bogatskii, A. V.; Zhilina, Z. I. *Russ. Chem. Rev. (Engl. Transl.)* **1982**, *51*, 592–604.

(2) (a) Traylor, T. G.; Campbell, D.; Sharma, V.; Geibel, J. *J. Am. Chem. Soc.* **1979**, *101*, 5376–5383. (b) Momenteau, M.; Loock, B.; Bisagni, E.; Rougee, M. *Can. J. Chem.* **1979**, *57*, 1804–1813. (c) Goff, H. *J. Am. Chem. Soc.* **1980**, *102*, 3252–3254. (d) Collman, J. P.; Brauman, J. I.; Collins, T. J.; Iverson, B. L.; Lang, G.; Pettman, R. B.; Sessler, J. L.; Walters, M. A. *J. Am. Chem. Soc.* **1983**, *105*, 3038–3052. (e) Momenteau, M.; Loock, B.; Lavalette, D.; Tetreau, C.; Mispelter, J. *J. Chem. Soc., Chem. Commun.* **1983**, 962–964. (f) Battersby, A. R.; Bartholomew, S. A. J.; Nitta, J. *J. Chem. Soc., Chem. Commun.* **1983**, 1291–1293. (g) Chang, C. K.; Young, R. *J. Am. Chem. Soc.* **1985**, *107*, 898–909.

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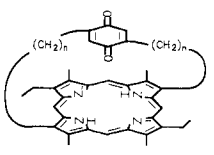
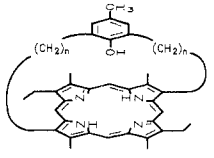
prepared to study metal–metal interactions and to serve as possible models for cytochrome oxidase. In addition, attempts have been made to mimic the light-induced separation of charge in photosynthesis using a variety of porphyrins with covalently bound quinone rings.[6]

We describe here a general synthesis of strapped porphyrins in which a functional group is held above the porphyrin core by a hydrocarbon strap attached to diagonally opposite corners of the porphyrin ring. The advantages of this approach include (i) flexibility in the introduction of different functional groups, (ii) the ability to prepare porphyrins with very short straps (in some cases short enough to cause severe distortion of the porphyrin ring[7]), and (iii) the use of hydrocarbon straps that confer greater stability and solubility than the more common ester- and amide-linked straps.

Syntheses are described for compounds **1** and **2**, which contain a quinone and phenol group, respectively. Although compound **1** has only been prepared with five and six carbons in each strap, a complete range of porphyrin–quinone complexes is possible with strap lengths greater than or equal to four carbons, allowing for intramolecular electron transfer over various distances. Compound **2** may serve as a model for beef liver catalase, in which the fifth proximal ligand of the heme active site is the phenol of Tyr-357,[8] and for certain mutant hemoglobins, where either the proximal or distal histidine is replaced by a tyrosine that may bind to and stabilize the ferric heme.[9]



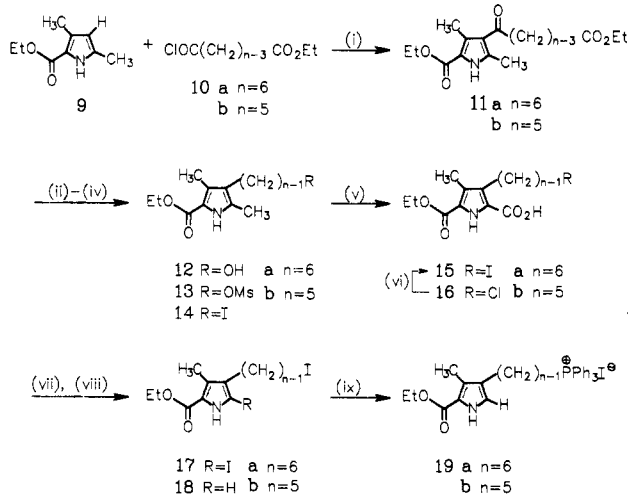
1 a n=6
b n=5



2 a n=6
b n=5

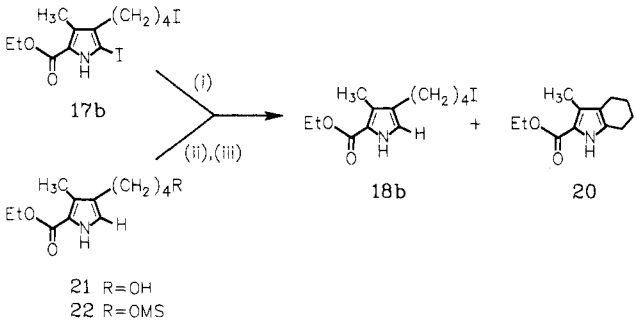
Any attempt to link opposite corners of a preformed porphyrin with hydrocarbon straps would, at best, result in very low yields. Therefore an alternative strategy (Scheme I) was adopted in which the units necessary for the porphyrin macrocycle would be assembled at each end of the bridging strap and the porphyrin ring-forming reaction postponed until the final stages of the synthesis. Thus, intramolecular cyclization of a suitably substituted chain-linked bis(dipyrromethane) **5** would lead to the intermediate porphodimethane **4**, where the flexibility of the two sp^3 meso carbon bridges would minimize any strain

Scheme II[a]



[a] Reagents and conditions: (i) $SnCl_4$, CH_2Cl_2, 0 °C; (ii) $BF_3 \cdot Et_2O$, $NaBH_4$, THF; (iii) CH_3SO_2Cl, Et_3N, CH_2Cl_2, 0 °C; (iv) NaI, Me_2CO; (v) (a) SO_2Cl_2, CH_2Cl_2, Et_2O; (b) H_2O, Me_2CO, reflux; (vi) NaI, Me_2CO; (vii) $NaHCO_3$, KI, I_2, CH_2Cl_2, reflux; (viii) HI, EtOH; (ix) PPh_3, toluene, reflux.

Scheme III[a]



[a] Reagents and conditions: (i) HI, EtOH; (ii) CH_3SO_2Cl, Et_3N, CH_2Cl_2, 0 °C; (iii) NaI, Me_2CO, reflux.

in the system. In situ oxidation would then yield the strapped porphyrins **3**, with any increase in strain energy being compensated by the resonance stabilization of the aromatic porphyrin. The necessary bis(dipyrromethane) **5** could be derived from the corresponding chain-linked bis(pyrrole) **6**, which in turn could be prepared by a Wittig condensation of a suitable dialdehyde **7** and the pyrrole phosphonium salt **8**. Compound **8** would contain all the features required for porphyrin synthesis. The bridging strap would already be anchored to the pyrroles forming rings A and C of the porphyrin, while the pyrrole α-free position would provide the site onto which the eventual rings B and D would be attached. Subject to availability and reactivity, various dialdehydes might be used in the Wittig reaction to produce a series of strapped porphyrins bearing different functionalities in the bridging strap.

Preparation of Pyrrole Phosphonium Iodide 19. Friedel–Crafts acylation of β-free pyrrole **9** with the acid chloride of ethyl hydrogen glutarate **10a** yielded the pyrrole keto ester **11a**, which was reduced to the (hydroxypentyl)pyrrole **12a** with diborane (Scheme II). Conversion to the (iodopentyl)pyrrole **14a** was effected by formation of the mesylate **13a** followed by treatment with sodium iodide in refluxing acetone. Removal of the α-methyl group, to give the corresponding α-free (iodopentyl)pyrrole, was accomplished by trichlorination, followed by hydrolysis and iodinative decarboxylation. Choice of solvent for the trichlorination is important,[10] and the reaction was carried

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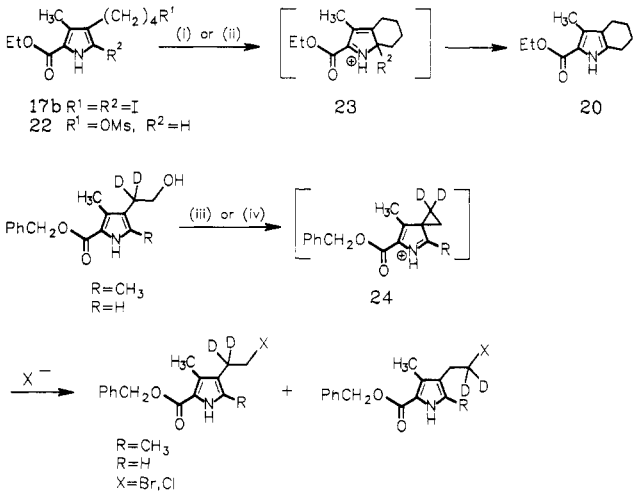
Scheme IV[a]



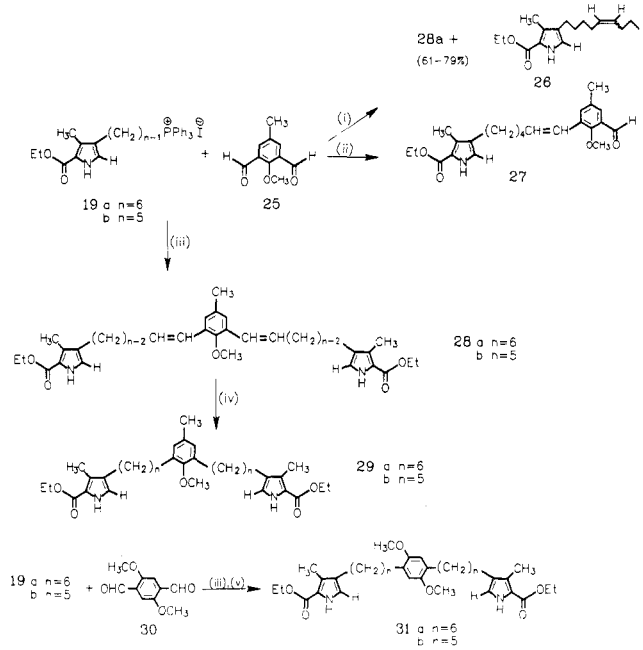
[a] Reagents and conditions: (i) HI, EtOH; (ii) NaI, Me_2CO, reflux; (iii) $SOCl_2$, pyr; (iv) PPh_3, CBr_4. See ref 12.

out by the method of Battersby et al.,[11] using 50:50 CH_2Cl_2/Et_2O. The α-methyl(iodopentyl)pyrrole **14a** was treated with SO_2Cl_2 (10% excess to allow for reaction with ether), and the crude α-(trichloromethyl)pyrrole was immediately hydrolyzed by refluxing in 20% aqueous acetone. The crude α-carboxy(iodopentyl)pyrrole **15a**, which was found to be contaminated with the corresponding α-carboxy(chloropentyl)pyrrole **16a**, was refluxed with sodium iodide in acetone to convert the mixture to the desired product **15a**. Iodinative decarboxylation via the α-iodopyrrole **17a** was followed by deiodination to yield the α-free (iodopentyl)pyrrole **18a**, which was conventiently purified by column chromatography. Treatment of **18a** with PPh_3 in refluxing toluene yielded the phosphonium salt **19a**, which precipitated from solution as a tan powder.

The same sequence of reactions was used to prepare the shorter chain homologue **19b**. The reaction conditions and yields were similar to those for the longer chain homologues, with one exception. Deiodination of the α-iodo(iodobutyl)pyrrole **17b** yielded not only the desired α-free product **18b** but also significant quantities of the cyclohexylpyrrole **20** (Scheme III). Similarly, by using an alternative reaction sequence, formation of **18b** from the α-free (hydroxybutyl)pyrrole **21** via the mesylate **22** was also accompanied by formation of the cyclohexylpyrrole **20**. This was rationalized in terms of a nucleophilic attack on the chain terminus by the electron-rich pyrrole ring to form an intermediate cyclohexylpyrrolium ion **23**, which then collapsed to **20** (Scheme IV). Similar behavior has been reported by Smith et al.,[12] who showed that the transformation of certain (hydroxyethyl)pyrroles into the corresponding (haloethyl)pyrroles involved neighboring group participation by an electron-rich pyrrole to give an ethylenepyrrolium ion **24** and resulted in scrambling of the two carbons in the side chain.

Although contaminated, the crude α-free (iodobutyl)pyrrole **18b** was carried on to the next stage. Upon treatment with PPh_3 in refluxing toluene the desired α-free pyrrole phosphonium iodide **19b** separated from the reaction mixture, while the unreactive cyclohexylpyrrole **20** remained in solution and was easily separated.

Scheme V[a]



[a] Reagents and conditions: (i) *n*-BuLi, THF, −78 °C; (ii) $K_2CO_3 \cdot 1.5H_2O$, **25** (2 equiv), *p*-dioxane, reflux; (iii) $K_2CO_3 \cdot 1.5H_2O$, **25** (3 equiv), *p*-dioxane, reflux; (iv) H_2, 10% Pd/C.

Preparation of the Chain-Linked Bis(pyrroles) 29 and 31. The key reaction for the synthesis of the strapped porphyrins was the double Wittig reaction between the α-free pyrrole phosphonium salt **19** and the corresponding dialdehyde. For the phenol-strap porphyrin **2**, the required dialdehyde 2,6-diformylanisole **25** was prepared by oxidation ($DMSO/COCl_2$)[13] of the readily available 2,6-bis(hydroxymethyl)anisole.[14] Similarly, for the quinone-strap porphyrin **1**, 1,4-diformyl-2,5-dimethoxybenzene (**30**) was obtained by oxidation of 1,4-bis(hydroxymethyl)-2,5-dimethoxybenzene.[15]

The Wittig condensation was carried out under two sets of conditions (Scheme V). The "conventional" reaction using *n*-BuLi as base gave good yields (61–79%) for the reaction of **19a** and **25**. However, separation of the desired bis(alkene) **28a** from unreacted dialdehyde and the side product **26** by column chromatography was tedious. Instead, a simplified Wittig reaction, using a solid–liquid phase-transfer process, was preferred.[16] Initially, treatment of the dialdehyde **25** with 2 equiv of the phosphonium salt **19a** in refluxing *p*-dioxane with K_2CO_3 as base yielded predominantly the monoalkene product **27**. However, addition of **19a** and K_2CO_3 to the dialdehyde **25** in three 1-equiv portions over a period of 38 h yielded the bis(alkene) **28a** in 60–72% yields. Catalytic hydrogenation with 10% Pd/C furnished the required chain-linked bis(pyrrole) **29a**. The shorter chain homologue **29b** was prepared similarly, but in this case the phase-transfer Wittig reaction gave somewhat lower yields (43–52%) of the bis(alkene) **28b**.

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(11) Battersby, A. R.; Hunt, E.; McDonald, E.; Paine, J. B., III; Saunders, J. *J. Chem. Soc., Perkin Trans. 1* **1976**, 1008–1018.
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(14) Koenig, K. E.; Lein, G. M.; Stuckler, P.; Kaneda, T.; Cram, D. J. *J. Am. Chem. Soc.* **1979**, *101*, 3553–3566.
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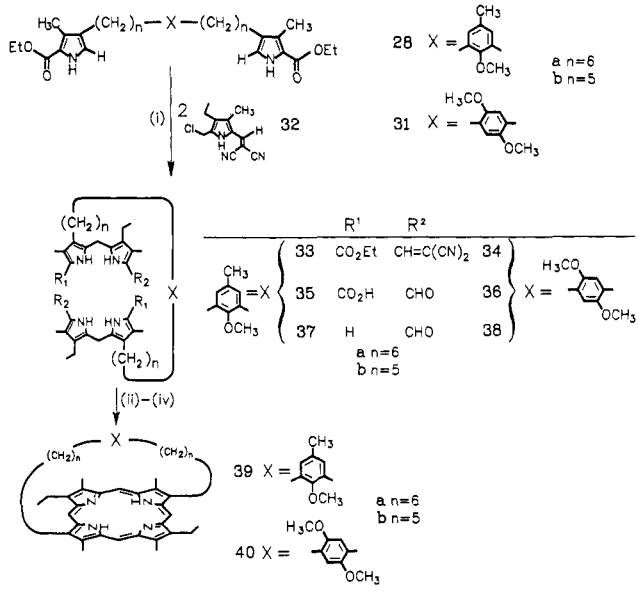
(16) (a) Delmas, M.; Le Bigot, Y.; Gaset, A. *Synth. Commun.* **1982**, *12*, 107–112. (b) Delmas, M.; Le Bigot, Y.; Gaset, A. *Synth. Commun.* **1983**, *13*, 177–182.

Scheme VI[a]



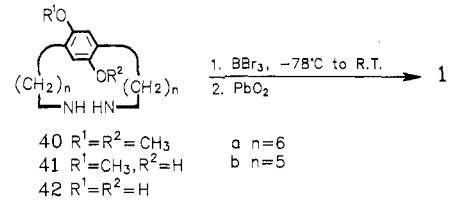
[a] Reagents and conditions: (i) AcOH, 80 °C; (ii) (a) KOH, H_2O, *n*-PrOH, reflux; (b) AcOH; (iii) DMF, reflux.

The chain-linked bis(pyrroles) incorporating a dimethoxybenzene group **31** were also prepared by the phase-transfer Wittig reaction. The bis(alkenes) were somewhat insoluble, so a transfer hydrogenation[17] in refluxing EtOH with 10% Pd/C and cyclohexene was the preferred method of reduction. For the longer chain compound **31a**, the combined yield for the two steps was excellent (67–84%). Again, the shorter chain homologue **31b** was obtained in lower yield (42%).

Preparation of Strapped Porphyrins. To assemble all the necessary units for the porphyrin ring, the chain-linked bis(pyrroles) were reacted with 2 equiv of the α-(chloromethyl)-α′-(dicyanovinyl)pyrrole **32** in glacial acetic acid to form the corresponding bis(dipyrromethanes) (Scheme VI). In the anisole case, **33** was isolated by column chromatography (76–95%). Similar yields (76–88%) of the dimethoxybenzene derivative **34a** were obtained after chromatography, while the less soluble **34b** precipitated from the reaction mixture and could be collected by filtration (91%).

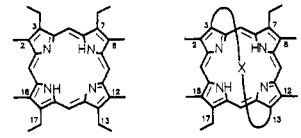
With the chain-linked bis(dipyrromethanes) available, the stage was set for the final condensation to the strapped porphyrins. Hydrolysis under strongly basic conditions removed not only the α-dicyanovinyl groups but also the more resistant α-esters. The resultant α-carboxy-α′-formylbis(dipyrromethanes) **35** and **36** were decarboxylated in refluxing DMF. The course of both reactions could be monitored with visible spectroscopy by observing the disappearance of bands at 406 and 277 nm for the hydrolysis reaction and at 280 nm for the decarboxylation reaction. Since the porphyrin-forming condensation was an intramolecular reaction, it was essential that all four α-positions be deprotected; any unblocked position would prevent intramolecular cyclization, leading to polymer formation and greatly reduced yields. Furthermore, the acid-sensitive α-free, α′-formylbis(dipyrromethanes) **37** and **38** required protection from premature exposure to acid to prevent uncontrolled intermolecular cyclization. The final ring-forming condensation of the α-free, α′-formylbis(dipyrromethanes) **37** and **38** was carried out under high-dilution conditions by the slow dropwise addition of the bis(dipyrromethane) solution (1 mM) to a solution of *p*-TsOH in CH_2Cl_2, using a syringe pump. The strapped porphyrins were conveniently separated from other porphyrin and non-porphyrin material by column chromatography. From four preparations the anisole-strap porphyrin **39a** was obtained in 30.0, 39.7, 40.4, and 43.4% yields from **33a**, while the shorter chain **39b** was obtained in 20.7, 24.1, and 53.0% yields. Similarly, **40a** was prepared in 19.2, 41.3, 49.2, and 60.2% yields, while a single preparation of **40b** yielded 39.5%.

Scheme VII



The final reaction in both cases was demethylation of the methoxy function to yield either a phenol, or a hydroquinone, which was subsequently oxidized to a quinone. The reagent of choice was BBr_3 (Scheme VII). Treatment of **40** with excess BBr_3 at −78 °C for 1.5 h resulted in partial demethylation to a mixture of **41** and **42**; warming to room temperature resulted in complete reaction. Since attempts to purify the crude hydroquinone **42** on alumina invariably led to partial oxidation, the crude product was oxidized by using lead dioxide. Removal of the oxidant by filtration followed by chromatography yielded the quinone porphyrin **1** in good yield (70–87%). Similarly, treating the anisole-strap porphyrin **39** with excess BBr_3 at −78 °C and warming to room temperature yielded the desired phenol-strap porphrin **2** (76–95%).

Visible and NMR Spectroscopy. Both the visible and NMR spectra of the strapped porphyrins **43** were compared with those of the nonstrapped analogue etioporphyrin II (etio II, **44**). Because of its symmetry, etio



44 43

II displays a simple ^1H NMR spectrum with the four ring methyls occurring as a singlet at δ 3.62, while the ethyls appear as a triplet and quartet at δ 1.85 and 4.11, respectively; the two different meso protons appear as a singlet at δ 10.11, and the core NH protons are shifted upfield to δ −3.67 due to shielding by the porphyrin ring current.[18] Introduction of a bridging strap, equivalent to joining the diagonally opposite ethyl groups of etio II, leads to a decrease in symmetry and a splitting of the meso, ring methyl, and methylene resonances. These resonances are shifted upfield and the NH protons shifted downfield as the strap length is decreased and the porphyrin π-cloud is disrupted.[7] For the strapped porphyrins reported here the meso, methyl, and methylenes signals appear close to the values for etio II, indicating that introduction of the strap causes little or no distortion of the porphyrin ring; the NH protons move even further downfield, presumably due to the added shielding by the phenyl or quinone ring in the strap.

For the methylene protons adjacent to the porphyrin ring, introduction of the strap results in a pair of multi-

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Table I. ^{1}H NMR Data (δ) of Strapped Porphyrins (in $CDCl_3$ at 400 MHz)

group	40a	40b	1a	1b	39a	39b	2a	2b
10,20 methine H's	9.98	9.93	10.02	10.05	10.00	10.04	10.04	10.08
5,15 methine H's	10.00	9.97	10.03	10.05	10.02	10.01	10.01	10.22
phenyl 4,6-H's					5.60	5.20	5.51	5.33
CH_2CH_3	4.12	4.17	4.12	4.08–4.25	4.13	4.16	4.09	4.21
	4.04	4.07			4.06	4.07		4.08
phenyl 3,6-H's	3.91	3.80						
CH_3	3.60	3.62	3.68	3.70	3.63	3.64	3.64	3.64
	3.59	3.54	3.60	3.57	3.58	3.52	3.62	3.50
quinone 3,6-H's			2.76	2.94				
CH_2CH_3	1.87	1.88	1.89	1.93	1.88	1.89	1.88	1.88
phenyl 5-CH_3					1.69	1.41	1.51	1.37
phenyl 2,5-OCH_3	1.58	1.91						
phenyl 2-OCH_3					−2.70	−2.07		
NH	−3.99	−3.90	−4.00	−3.91	−3.77	−3.77	−3.68	−3.84
chain 1-CH_2	0.70	0.53	0.27	0.65	0.18	0.20	−0.94	−1.60
	0.21	0.96	−0.70	0.0	0.50	0.68	−0.44	0.15
chain 2-CH_2	−0.10	−1.13	0.05–0.15	−1.29	0.03	−1.10	−0.35	−1.94
	0.11	−0.31		−0.32	0.27	−0.79	0.0	−0.48
chain 3-CH_2	0.82	0.88	0.95	1.14	0.42	0.86	0.47	1.24
		1.07	1.11	1.25	0.71	0.94	0.84	1.40
chain 4-CH_2	1.22	1.91	1.51	1.93	0.84	1.89	1.26	1.60
	1.50	2.22	1.73	2.33	0.89	2.04		2.22
chain 5-CH_2	2.32	3.93	2.51	3.97	2.02	3.88	2.24	4.00
		4.25		4.30	2.19	4.23	2.39	4.24
chain 6-CH_2	3.72		3.63–3.75		3.94		3.95	
	4.43		4.40		4.36		4.46	

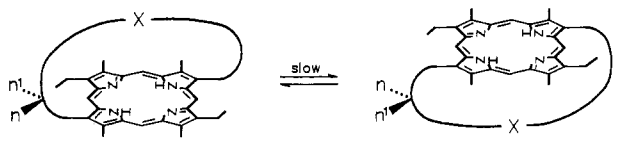

Figure 1. Schematic representation for the flipping of the porphyrin strap.

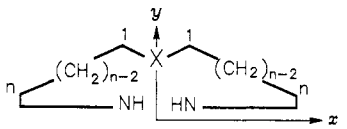

Figure 2. Schematic representation of a strapped porphyrin.

plets. That the protons at the strap's termini appear as complex multiplets indicates that flipping of the strap above and below the porphyrin plane is relatively slow (Figure 1), otherwise the *n,n'* protons would appear as triplets from coupling to its adjacent pair.[19] The asymmetry of the strapped porphyrins also results in an inequivalence of the methylene protons of the 7- and 17-ethyl groups. Similar anisochronous behavior of the ethyl methylene protons has been observed in a number of monomeric and dimeric scandium and thallium porphyrins.[20]

All protons in the strap experience an upfield shift due to shielding by the porphyrin ring current. The effect of this internal shift reagent is to spread the chemical shifts over a wide range, allowing identification of each resonance by simple decoupling experiments (Table I). Since this effect decreases along both *x* and *y* axes (Figure 2), the largest upfield shift should be experienced by protons at the center of the strap. However, the deshielding effect of the strap's functional group, the length and conformation of the strap, and the possible presence of local ring current maxima associated with the pyrrole rings may reinforce or cancel the shielding effect of the porphyrin

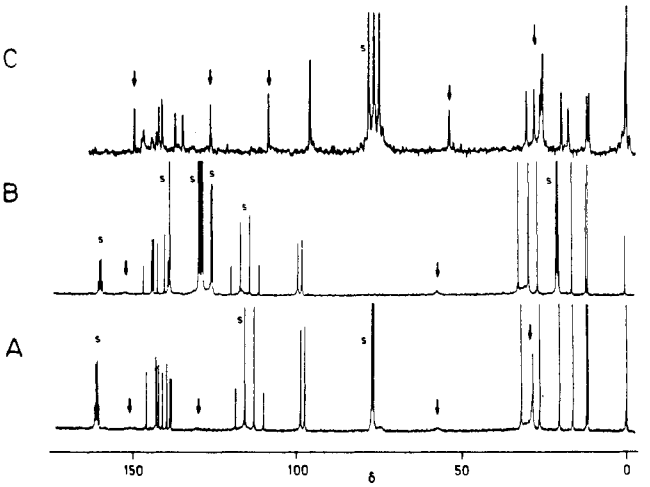

Figure 3. ^{13}C NMR of **40a**: A, in 10% TFA/$CDCl_3$ at room temperature (100 MHz); B, in 10% TFA/toluene-d_8 at 80 °C (100 MHz); C, in $CDCl_3$ at room temperature (20 MHz); S, solvent signals.

ring current, complicating any effort to extract conformational information from chemical shift data alone.

The large upfield shift of the quinone protons in **1a** (δ 2.76) compared with **1b** (δ 2.95) suggests that the longer strap can accommodate a shorter porphyrin–quinone distance, and this is reinforced by examination of CPK space-filling models. A similar situation has been observed for Baldwin's "cap" and "homo-cap" porphyrins[21] and also by Sanders et al.[19] The situation is less clear for the porphyrin–dimethoxybenzene complexes **40**, with the shifts of the phenyl (**40a**, δ 3.91; **40b**, δ 3.80) and the methoxy methyl protons (**40a**, δ 1.58; **40b**, δ 1.91) offering conflicting estimates of the separation of the porphyrin and phenyl rings. However, when the ^{1}H and ^{13}C NMR spectra of **40a** are run in 10% TFA/$CDCl_3$, a broadening or disappearance of the phenyl protons and some of the strap protons

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(21) (a) Clayden, N. J.; Moore, G. R.; Williams, R. J. P.; Baldwin, J. E.; Crossley, M. J. *J. Chem. Soc., Perkin Trans. 2* **1982**, 1693–1698. (b) Clayden, N. J.; Moore, G. R.; Williams, R. J. P.; Baldwin, J. E.; Crossley, M. J. *J. Chem. Soc., Perkin Trans. 2* **1983**, 1863–1868.

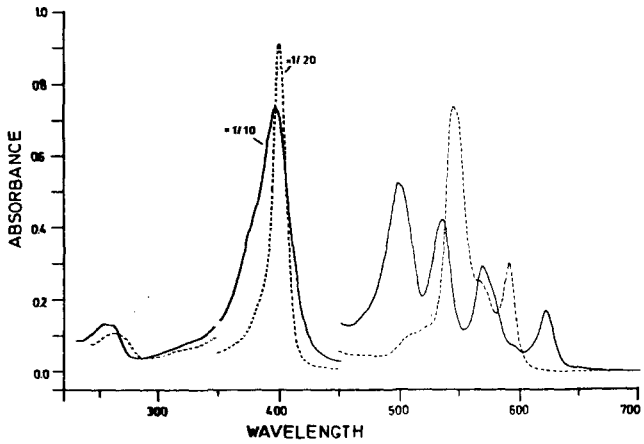

Figure 4. Optical spectra of **1b**: (—) free base in CH_2Cl_2, (- - -) protonated in 10% TFA/CH_2Cl_2.

is observed (Figure 3). When the spectra are run in $CDCl_3$, all the expected resonances are observed. (For the ^{13}C NMR the α-pyrrolic carbons are broadened due to NH tautomerization.[22]) It would appear that for the free-base form of **40a** the strap can rotate freely among a number of conformations, giving rise to sharp signals for the average conformation. On protonation this rotation is restricted, and the signals for the phenyl ring and some of the strap are broadened, due possibly to hydrogen bonding between the methoxy group and the N–H, or due to ruffling of the pyrrole rings on protonation. Observation of all resonances for **40b**, both in the free-base and the protonated forms, suggests that the longer chain in **40a** results in a shorter separation between the phenyl and porphyrin rings.

The chemical shifts of the phenyl and 5-methyl protons in the phenol and anisole porphyrins **2** and **39** suggest that the shorter chain enforces a shorter phenyl–porphyrin separation. That the methoxy group occurs at δ –2.70 in **39a** compared with δ –2.07 in **39b** may be ascribed to steric crowding, with the more crowded **39b** constraining the methoxy methyl into positions outside the cavity bounded by the porphyrin and the strap where it experiences a lesser upfield shift compared with the looser **39a**, which can accommodate this group within the cavity.

All the strapped porphyrins display visible spectra of the etio type,[23] with the intensities of the four bands in the 450–650 nm region being in the order IV > III > II > I (Figure 4). Decreasing the strap length and distorting the porphyrin macrocycle leads to a decrease in intensity of band IV until, in the extreme limit, the spectrum becomes a rhodo type with III > IV > II > I.[7] That this is not observed in the present case suggests that little or no distortion of the porphyrin is caused by introduction of the strap.

Experimental Section

Melting point determinations were obtained using a Thomas-Hoover Unimelt oil bath/capillary tube apparatus and are uncorrected. Elemental analysis was carried out by P. Borda of the Microanalytical Laboratory, U.B.C. A Cary (Model 1756) spectrophotometer was used to record UV and visible spectra. Mass spectra were recorded on a Varian MAT CH 4-B spectrometer or a Kratos/AEI MS-902 spectrometer. High-resolution measurements were obtained on a Kratos/AEI MS-50 spectrometer. In all cases the ionization voltage was 70 eV. ^1H NMR spectra were recorded on a Varian EM-360L or XL-100 spectrometer, a U.B.C. NMR Center modified Nicolet-Oxford H-270 spectrometer, or a Bruker WH-400 spectrometer. ^{13}C NMR spectra were recorded on a Varian CFT-20 or Bruker WH-400 spectrometer. The chemical shifts are recorded relative to tetramethylsilane as an internal standard.

Column chromatography on silica gel was performed using BDH silica gel (60–120 mesh), Merck Kieselgel 60H, or Merck Kieselgel 60 (70–230 mesh). For the final purification of the porphyrin samples Merck aluminum oxide 90 (70–230 mesh, neutral, activity III) was used. Thin-layer chromatography (TLC) was performed using precoated silica gel plates (Analtech-Uniplate, 250 μm), and the compounds were usually detected by UV light (254 nm) and/or exposure to iodine. Mixtures of solvents used in chromatography are expressed as volume/volume percentages. Except where noted, all drying operations were performed over anhydrous sodium sulfate.

Ethyl 5-[5-(Ethoxycarbonyl)-2,4-dimethylpyrrol-3-yl]-5-oxopentanoate (11a). Ethyl hydrogen glutarate (96.0 g, 0.54 mol) and thionyl chloride (120 mL, 1.6 mol) were placed in a round-bottom flask equipped with a reflux condenser and a drying tube and heated on a steam bath for 2 h. The excess thionyl chloride was removed by rotary evaporation with carbon tetrachloride (2 × 100 mL) to give a dark yellow oil, which was added to a solution of **9** (75.0 g, 0.45 mol) in CH_2Cl_2 (750 mL). This mixture was cooled in an ice bath and stirred under nitrogen. Stannic chloride (58.0 mL, 0.50 mol) was added dropwise over a period of 35 min, and the solution was then left stirring for 1.5 h. The reaction mixture was poured into 2 M hydrochloric acid (400 mL), and the dichloromethane layer was separated. This was extracted with sodium bicarbonate solution, dried, and evaporated. The resultant dark red oil was dissolved in ethanol (500 mL). Addition of water precipitated a solid, which was collected by filtration and dried: 116.8 g (84.1%); mp 68.0–70.0 °C; ^1H NMR ($CDCl_3$) δ 1.26 (t, 3 H, J = 7.0 Hz), 1.38 (t, 3 H, J = 7.0 Hz), 2.08 (q, 2 H, J = 7 Hz), 2.43 (t, 2 H, J = 7 Hz), 2.54 (s, 3 H), 2.60 (s, 3 H), 2.80 (t, 2 H, J = 7 Hz), 4.16 (q, 2 H, J = 7.0 Hz), 4.37 (q, 2 H, J = 7.0 Hz), 9.38 (br s, 1 H). Anal. Calcd for $C_{16}H_{23}NO_5$: C, 62.12; H, 7.49; N, 4.53. Found: C, 62.15; H, 7.52; N, 4.59.

Ethyl 4-[5-(Ethoxycarbonyl)-2,4-dimethylpyrrol-3-yl]-4-oxobutanoate (11b). This was prepared from **9** (20.0 g, 0.12 mol) and ethyl succinyl chloride **10b** (23.6 g, 0.14 mol) by the same procedure as for the homologous pyrrole **11a**. The crude product was recrystallized from the minimum amount of hot ethanol to give a white crystalline solid as a first crop: 25.7 g (72.8%); mp 144.0–145.5 °C; ^1H NMR ($CDCl_3$) δ 1.28 (t, 3 H, J = 7.0 Hz), 1.39 (t, 3 H, J = 7.0 Hz), 2.55 (s, 3 H), 2.60 (s, 3 H), 2.72 (t, 2 H, J = 6 Hz), 3.08 (t, 2 H, J = 6 Hz), 4.19 (q, 2 H, J = 7.0 Hz), 4.37 (q, 2 H, J = 7.0 Hz), 9.14 (br s, 1 H). Anal. Calcd for $C_{15}H_{21}NO_5$: C, 61.00; H, 7.17; N, 4.74. Found: C, 61.06; H, 7.26; N, 4.71.

5-[5-(Ethoxycarbonyl)-2,4-dimethylpyrrol-3-yl]-1-pentanol (12a). **11a** (56.3 g, 0.18 mol) was dissolved in freshly distilled tetrahydrofuran (300 mL) and stirred under nitrogen in a 1-L Erlenmeyer flask equipped with a pressure-equalizing addition funnel. Sodium borohydride (14.5 g, 0.38 mol) was added, followed by dropwise addition of boron trifluoride etherate (62.7 mL, 0.51 mol) over a period of 20 min. The reaction was left stirring for 2 h and then quenched by the slow, careful addition of glacial acetic acid (50 mL) followed by the addition of water until the solution became a clear red. The tetrahydrofuran was removed, and the red oil that separated was extracted with dichloromethane (300 mL), which was dried and evaporated to give a dark red oil. Dissolving this in ethanol (100 mL) and adding water precipitated a pink solid that was filtered and air dried: 39.2 g (85.0%); mp 84.0–85.0 °C; ^1H NMR ($CDCl_3$) δ 1.36 (t, 3 H, J = 7.0 Hz), 1.2–1.7 (m, 7 H), 2.21 (s, 3 H), 2.28 (s, 3 H), 2.39 (t, 2 H), 3.69 (t, 2 H, J = 6 Hz), 4.32 (q, 2 H, J = 7.0 Hz), 8.64 (br s, 1 H). Anal. Calcd for $C_{14}H_{23}NO_3$: C, 66.37; H, 9.15; N, 5.53. Found: C, 66.41; H, 9.12; N, 5.50.

4-[5-(Ethoxycarbonyl)-2,4-dimethylpyrrol-3-yl]-1-butanol (12b). This was prepared in the same way as **12a** from **11b** (14.4 g, 0.05 mol), sodium borohydride (7.4 g, 0.2 mol), and boron trifluoride etherate (37.0 mL, 0.3 mol). After workup a yellow oil was obtained, which slowly crystallized to a white solid. The crude product was recrystallized from 50% water/ethanol (100

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(23) Gouterman, M. *The Porphyrins*, Part A; Dolphin, D., Ed.; Academic: New York, 1978; Vol. III, p 16.

mL): 8.4 g (72.1%); mp 117.0–119.0 °C; ^{1}H NMR ($CDCl_3$) δ 1.36 (t, 3 H, J = 7.0 Hz), 1.5–1.7 (m, 5 H), 2.21 (s, 3 H), 2.28 (s, 3 H), 2.40 (t, 2 H), 3.67 (t, 2 H), 4.32 (q, 2 H, J = 7.0 Hz), 8.7 (br s, 1 H). Anal. Calcd for $C_{13}H_{21}NO$: C, 65.25; H, 8.85; N, 5.85. Found: C, 65.24; H, 8.86; N, 5.81.

5-[5-(Ethoxycarbonyl)-2,4-dimethylpyrrol-3-yl]-1-pentyl Methanesulfonate (13a). A solution of **12a** (39.2 g, 0.16 mol) and Et_3N (32.3 g, 0.23 mol) in dichloromethane (500 mL) was stirred under nitrogen and cooled to 0 °C. Methanesulfonyl chloride (18.5 mL, 0.19 mol) was added dropwise over a period of 10 min, and the reaction mixture was then allowed to warm to room temperature. This was extracted in turn with water (200 mL), cold 2 M hydrochloric acid (200 mL), saturated sodium bicarbonate solution, and finally saturated sodium chloride solution. The dichloromethane solution was dried, filtered, and evaporated to give a dark red oil. Dissolving in the minimum amount of hot ethanol and adding water precipitated a pink solid. This was filtered and air dried: 47.1 g (91.8%); mp 68.0–70.0 °C; ^{1}H NMR ($CDCl_3$) δ 1.35 (t, 3 H, J = 7.0 Hz), 1.2–1.9 (m, 6 H), 2.20 (s, 3 H), 2.27 (s, 3 H), 2.39 (m, 2 H), 2.99 (s, 3 H), 4.23 (t, 2 H, J = 7 Hz), 4.24 (q, 2 H, J = 7.0 Hz), 8.79 (br s, 1 H). Anal. Calcd for $C_{15}H_{25}NO_5S$: C, 54.36; H, 7.60; N, 4.23; S, 9.68. Found: C, 54.22; H, 7.66; N, 4.26; S, 9.55.

4-[5-(Ethoxycarbonyl)-2,4-dimethylpyrrol-3-yl]-1-butyl Methanesulfonate (13b). A solution of **12b** (8.4 g, 35 mmol) in dichloromethane (250 mL) was treated with triethylamine (7.3 mL, 52 mmol) and methanesulfonyl chloride (4.8 mL, 48 mmol) as outlined for **13a**. Recrystallization from 50% ethanol/water gave a white flaky solid (8.2 g, 74.0%). A second crop (1.5 g, 13.7%) was obtained from the mother liquors: mp 82.0–83.5 °C; ^{1}H NMR ($CDCl_3$) δ 1.36 (t, 3 H, J = 7.0 Hz), 1.4–1.9 (m, 4 H) 2.21 (s, 3 H), 2.28 (s, 3 H), 2.43 (t, 2 H), 3.00 (s, 3 H), 4.27 (t, 2 H, J = 6 Hz), 4.33 (q, 2 H, J = 7.0 Hz), 8.58 (br s, 1 H). Anal. Calcd for $C_{14}H_{23}NO_5S$: C, 52.98; H, 7.30; N, 4.41; S, 10.10. Found: C, 53.26; H, 7.37; N, 4.32; S, 9.95.

5-[5-(Ethoxycarbonyl)-2,4-dimethylpyrrol-3-yl]-1-iodopentane (14a). 13a (46.6 g, 0.14 mol) and sodium iodide (84.0 g, 0.56 mol) were suspended in acetone (750 mL) and, with vigorous stirring, were refluxed for 16 h. The reaction mixture was cooled to room temperature, and the solid that had precipitated during the course of the reaction was filtered off. The filtrate was reduced in volume to approximately 200 mL, and addition of water (200 mL) precipitated a red solid, which was collected by filtration. While still damp, the crude product was recrystallized from hot ethanol to give a pink solid (40.5 g, 79.3%). A second crop (6.4 g, 12.5%) was obtained by adding water to the mother liquor: mp 79.0–80.0 °C; ^{1}H NMR ($CDCl_3$) δ 1.35 (t, 3 H, J = 7.0 Hz), 1.3–1.5 and 1.7–2.0 (m, 6 H), 2.20 (s, 3 H), 2.27 (s, 3 H), 2.2–2.5 (m, 2 H), 3.19 (t, 2 H, J = 7.0 Hz), 4.31 (q, 2 H, J = 7.0 Hz). Anal. Calcd for $C_{14}H_{22}NO_2I$: C, 46.29; H, 6.11; N, 3.86; I, 34.94. Found: C, 46.50; H, 6.17; N, 3.68; I, 34.71.

4-[5-(Ethoxycarbonyl)-2,4-dimethylpyrrol-3-yl]-1-iodobutane (14b). This was prepared from **13b** (9.2 g, 0.03 mol) by the method outlined for compound **14a**. The crude product was recrystallized from 20% ethanol/water to give a white flaky solid (8.2 g, 80.2%). A second crop (0.8 g, 7.9%) was obtained from the mother liquor: mp 81.0–82.0 °C; ^{1}H NMR ($CDCl_3$) δ 1.36 (t, 3 H, J = 7.0 Hz), 1.4–2.0 (m, 4 H), 2.22 (s, 3 H), 2.28 (s, 3 H), 2.39 (t, 2 H, J = 7.4 Hz), 3.20 (t, 2 H, J = 7.2 Hz), 4.32 (q, 2 H, J = 7.0 Hz), 8.62 (br s, 1 H). Anal. Calcd for $C_{13}H_{20}NO_2I$: C, 44.71; H, 5.77; N, 4.01; I, 36.34. Found: C, 44.96; H, 5.87; N, 4.01; I, 36.22.

5-[5-(Ethoxycarbonyl)-2-carboxy-4-methylpyrrol-3-yl]-1-iodopentane (15a). 14a (30.0 g, 83 mol) was dissolved in dichloromethane (250 mL) and anhydrous diethyl ether (250 mL) was added. With rapid stirring, a solution of sulfuryl chloride (21.2 mL, 270 mmol) in dichloromethane (100 mL) was added dropwise over a period of 15 min. The solution darkened and warmed slightly and was left stirring for a further 15 min. The solvents were removed, and a 20% water/acetone solution (300 mL) was added to the residue. The yellow solution that resulted was refluxed for 45 min. After cooling, the acetone was removed, whereupon the crude product precipitated as a tan solid. This was refluxed with sodium iodide (37 g, 0.25 mmol) in acetone (500 mL) for 12 h. The reaction mixture was then reduced in volume to approximately half, and addition of water (200 mL) precipitated a brown solid. The crude product was filtered off, and while still wet, was dissolved in a mixture of methanol (200 mL) and saturated sodium bicarbonate solution (200 mL) by heating on a steam bath. After cooling, the solution was extracted with ethyl acetate. The aqueous layer was separated, filtered, and acidified with 6 M hydrochloric acid, which precipitated a cream-colored solid. This was collected by filtration, washed with water, and air dried: 27.1 g (83.4%); mp 145.0–147.0 °C; ^{1}H NMR ($CDCl_3$/DMSO-d_6) δ 1.37 (t, 3 H, J = 7.0 Hz), 1.3–2.0 (m, 6 H), 2.29 (s, 3 H), 2.76 (t, 2 H), 3.20 (t, 2 H, J = 7.0 Hz), 4.36 (q, 2 H, J = 7.0 Hz), 9.52 (br s, 1 H). Anal. Calcd for $C_{14}H_{20}NO_4I$: C, 42.76; H, 5.13; N, 3.56; I, 32.27. Found: C, 42.51; H, 5.11; N, 3.44; I, 32.15.

4-[5-(Ethoxycarbonyl)-2-carboxy-4-methylpyrrol-3-yl]-1-iodobutane (15b). This compound was prepared as for compound **15a** with **14b** (8.3 g, 23.6 mmol) and sulfuryl chloride (6.1 mL, 75.6 mmol). The crude product was dissolved in acetone (250 mL), sodium iodide (4 g, 26 mmol) was added and the mixture refluxed for 13 h. After cooling, addition of water (200 mL) precipitated a white solid, which was filtered and dried: 8.1 g (90.5%); mp 157.0–159.0 °C; ^{1}H NMR ($CDCl_3$/DMSO-d_6) δ 1.30 (t, 3 H, J = 7.0 Hz), 1.4–2.0 (m, 4 H), 2.20 (s, 3 H), 2.71 (t, 2 H), 3.14 (t, 2 H), 4.27 (q, 2 H, J = 7.0 Hz), 9.60 (br s, 1 H); mass spectrum, m/z 379 (M^+, 41), 210 (100), 164 (78).

5-[5-(Ethoxycarbonyl)-2-iodo-4-methylpyrrol-3-yl]-1-iodopentane (17a). 15a (13.4 g, 34 mmol) and sodium bicarbonate (11.4 g, 136 mmol) were suspended in a mixture of water (150 mL) and dichloroethane (80 mL) in a 1-L Erlenmeyer flask, and the resultant mixture was heated on a steam bath until all the solid dissolved. The mixture was cooled to room temperature and vigorously stirred, while a solution of potassium iodide (16.9 g, 102 mmol) and iodine (9.5 g, 37 mmol) in water (80 mL) was rapidly added dropwise. The solution was refluxed for 30 min, and the excess iodine was destroyed by the addition of a sodium bisulfite solution. The solution was cooled and dichloromethane (100 mL) added. The organic phase was separated, dried ($MgSO_4$), and evaporated to dryness. The crude product was dissolved in hot ethanol (100 mL), and water was added until crystallization began. The solid that precipitated was filtered, washed with 50% ethanol/water, and air dried to give a slightly yellow solid: 13.6 g (84.3%); mp 92.0–93.5 °C; ^{1}H NMR ($CDCl_3$) δ 1.38 (t, 3 H, J = 7.0 Hz, OCH_2CH_3), 1.3–2.0 (m, 6 H), 2.32 (s, 3 H), 2.39 (t, 2 H), 3.21 (t, 2 H, J = 7.0 Hz), 4.36 (q, 2 H, J = 7.0 Hz), 8.84 (br s, 1 H). Anal. Calcd for $C_{13}H_{19}NO_2I_2$: C, 32.86; H, 4.03; N, 2.95; I, 53.42. Found: C, 32.64; H, 3.84; N, 2.78; I, 53.38.

4-[5-(Ethoxycarbonyl)-2-iodo-4-methylpyrrol-3-yl]-1-iodobutane (17b). This was prepared in the same way as for **17a** from **15b** (6.4 g, 17 mmol). After workup, the crude brown product was crystallized once from hot ethanol to yield 6.6 g (85.5%), which was carried to the next stage without further purification: ^{1}H NMR ($CDCl_3$) δ 1.36 (t, 3 H, J = 7.0 Hz), 1.5–2.0 (m, 4 H), 2.31 (s, 3 H), 2.38 (t, 2 H), 3.21 (t, 2 H, J = 7.0 Hz), 4.33 (q, 2 H, J = 7.0 Hz), 8.86 (br s, 1 H); mass spectrum, m/z 461 (M^+, 83), 292 (60), 246 (100), 207 (69), 166 (60), 120 (39).

5-[5-(Ethoxycarbonyl)-4-methylpyrrol-3-yl]-1-iodopentane (18a). 17a (22.7 g, 47.8 mmol) was dissolved in ethanol (250 mL) by heating on a steam bath. A solution of potassium iodide (12.7 g, 76.5 mmol) in water (20 mL) and concentrated hydrochloric acid (20 mL) was added, the solution darkening as iodine was liberated. Addition of hypophosphorous acid (20 mL) lightened the color as it destroyed the liberated iodine. Heating was continued for a further 15 min. Water (250 mL) was added, and the cloudy pink solution was extracted with ethyl acetate (100 mL). The organic layer was dried ($MgSO_4$), and after filtering and removing the solvent, a pink solid was obtained. The crude product was placed on a silica gel column (Merck Kieselgel 60H, 120 g) and eluted with dichloromethane. The colored impurities remained at the origin, while the product was obtained as a slightly orange solid: 14.6 g (87.5%); mp 74.0–75.0 °C; ^{1}H NMR ($CDCl_3$) δ 1.35 (t, 3 H, J = 7.0 Hz), 1.49 and 1.86 (m, 6 H), 2.28 (s, 3 H), 2.42 (t, 2 H), 3.20 (t, 2 H, J = 7.0 Hz), 4.32 (q, 2 H, J = 7.0 Hz), 6.67 (d, 1 H, J = 3 Hz), 8.76 (br s, 1 H). Anal. Calcd for $C_{13}H_{20}NO_2I$: C, 44.71; H, 5.77; N, 4.01; I, 36.34. Found: C, 44.59; H, 5.66; N, 3.89; I, 36.12.

4-[5-(Ethoxycarbonyl)-4-methylpyrrol-3-yl]-1-iodobutane (18b). 17b (7.3 g, 16 mmol) was dissolved in ethanol (100 mL) by heating on a steam bath. The solution was removed from the

steam bath and hydriodic acid (25 mL) added. The liberated iodine was destroyed by addition of hypophosphorous acid (10 mL). TLC (5% EtOAc/toluene) showed that about 50% reaction had occurred. More hydriodic acid (20 mL) and hypophosphorous acid (10 mL) was added, TLC then showing only a trace of starting material. A third portion of hydriodic acid (10 mL) was added and the solution left standing for 1 h. Water (100 mL) was added to the reaction mixture, and the dark red solid that precipitated was filtered and dried. The crude product was placed on a silica gel column (BDH SiO_2 60–120 mesh, 150 g) and eluted with dichloromethane. At first the eluant was colorless and was shown by TLC to contain only the desired product. These fractions were combined and evaporated: 2.3 g (43.4%); mp 68.5–70.0 °C; ^{1}H NMR ($CDCl_3$) δ 1.38 (t, 3 H, J = 7.0 Hz), 1.5–2.1 (m, 4 H), 2.31 (s, 3 H), 2.47 (t, 2 H), 3.24 (t, 2 H, J = 7.0 Hz), 4.36 (q, 2 H, J = 7.0 Hz), 6.72 (d, 1 H, J = 3 Hz), 8.8 (br s, 1 H). Anal. Calcd for $C_{12}H_{18}NO_2I$: C, 43.00; H, 5.41; N, 4.18; I, 37.86. Found: C, 43.16; H, 5.31; N, 4.14; I, 37.77.

Increasing the polarity of the eluant to 10% EtOAc/CH_2Cl_2 gave fractions that were orange and contained not only the desired product **18b** but also the unwanted contaminant **20**. This impure material (2.1 g) was retained.

[5-[5-(Ethoxycarbonyl)-4-methylpyrrol-3-yl]pentyl]triphenylphosphonium Iodide (19a). A mixture of 5-[5-(ethoxycarbonyl)-4-methylpyrrol-3-yl]-1-iodopentane (**18a**; 7.2 g, 21 mmol) and triphenylphosphine (16.5 g, 60 mmol) in toluene (250 mL) was refluxed under argon for 25 h. The reaction mixture was cooled to room temperature. The solid product was collected by filtration, washed with diethyl ether, and dried: 12.2 g (96.6%); mp 191.0–193.0 °C; ^{1}H NMR ($CDCl_3$) δ 1.34 (t, 3 H, J = 7.0 Hz), 1.4–1.8 (m, 6 H), 2.21 (s, 3 H), 2.36 (m, 2 H), 3.4–3.6 (m, 2 H), 4.30 (q, 2 H, J = 7.0 Hz), 6.76 (d, 1 H, J = 3.0 Hz), 7.6–8.0 (m, 15 H), 8.86 (br s, 1 H); Anal. Calcd for $C_{31}H_{35}NO_2PI$: C, 60.87; H, 5.77; N, 2.29; I, 20.75. Found: C, 60.57; H, 5.80; N, 2.27; I, 20.87.

[4-[5-(Ethoxycarbonyl)-4-methylpyrrol-3-yl]butyl]triphenylphosphonium Iodide (19b). **18b** (3.3 g, 9.7 mmol) and triphenylphosphine (10.2 g, 40 mmol) were dissolved in toluene (70 mL) and refluxed while stirring under nitrogen for 19.5 h. As the reaction proceeded a purple oil separated from solution. The solution was cooled to room temperature, and the supernatant liquid was decanted. The crude product was placed on a silica gel column (Merck Kieselgel, 60, 200 g) and eluted with 5% MeOH/CH_2Cl_2. The colored impurities were retained at the head of the column, and the product was collected as a clear oil, which was dried under vacuum: 5.0 g (86.2%); ^{1}H NMR ($CDCl_3$) δ 1.36 (t, 3 H, J = 7.0 Hz), 1.5–2.0 (m, 4 H), 2.18 (s, 3 H), 2.46 (t, 2 H), 3.5–3.8 (m, 2 H), 4.32 (q, 2 H, J = 7.0 Hz), 6.84 (d, 1 H, J = 3.0 Hz), 7.6–7.9 (m, 15 H), 9.00 (br s, 1 H). Anal. Calcd for $C_{30}H_{33}NO_2PI$: C, 60.31; H, 5.57; N, 2.34; I, 21.24. Found: C, 60.47; H, 5.64; N, 2.14; I, 21.10.

2,6-Diformyl-4-methylanisole (25). Oxalyl chloride (3.5 mL, 10 mmol) was added to freshly distilled dichloromethane (200 mL) and the solution cooled to −78 °C in a dry ice/acetone bath. A solution of dimethyl sulfoxide (5.2 mL, 73 mmol) in dichloromethane (10 mL) was added dropwise over a period of 5 min and the solution left stirring for 5 min. A solution of 2,6-bis(hydroxymethyl)-4-methylanisole[14] (3.01 g, 17 mmol) in dimethyl sulfoxide (5 mL) and dichloromethane (20 mL) was then added dropwise. After the resultant mixture was stirred for 15 min, triethylamine (23 mL, 165 mmol) was added, and the reaction mixture was allowed to warm gradually to room temperature. Addition of water (20 mL) and removal of the dichloromethane led to the precipitation of a waxy solid, which was filtered and dried (2.74 g, 93.1%). The crude product was recrystallized from 1:1 carbon tetrachloride/cyclohexane to yield a first crop of white needles (1.51 g, 51.5%). A second crop (0.57 g, 19.4%) was obtained from the mother liquid: mp 91.5–92.5 °C (lit.[14] 88–89 °C); ^{1}H NMR ($CDCl_3$) δ 2.43 (s, 3 H), 4.07 (s, 3 H), 7.92 (s, 2 H), 10.42 (s, 2 H); mass spectrum, m/z 178 (M^+, 100), 150 (35), 132 (38), 77 (57).

2,5-Diformyl-1,4-dimethoxybenzene (30). Prepared as for **25** from 2,5-bis(hydroxymethyl)-1,4-dimethoxybenzene[15] (2.0 g, 10 mmol). The crude yellow solid (1.83 g, 93.7%) was purified by vacuum sublimation: mp 203.0–205.0 °C (lit.[15] 205–209 °C); mass spectrum, m/z 194 (M^+, 100), 179 (20), 176 (10), 151 (16), 148 (20). Anal. Calcd for $C_{10}H_{10}O_4$: C, 61.85; H, 5.19. Found: C, 61.58; H, 5.20.

2,6-Bis[6-[5-(ethoxycarbonyl)-4-methylpyrrol-3-yl]-1-hexenyl]-4-methylanisole (28a). A mixture of **19a** (0.35 g, 0.58 mmol), **25** (0.10 g, 0.58 mmol), and potassium carbonate (0.10 g, 0.59 mmol) in p-dioxane (50 mL) was refluxed while stirring under nitrogen, and the course of the reaction was followed by TLC (10% EtOAc/toluene). After 20 h, 1 equiv each of **19a** and potassium carbonate was added to the mixture and reflux continued for a further 9 h. By this stage TLC showed two major products, the "monoalkene" **27** and **28a**. An additional 1 equiv each of phosphonium iodide **19a** and potassium carbonate was added and the solution refluxed for a further 15 h. The reaction mixture was cooled and the p-dioxane removed. The residue was dissolved in ethyl acetate (50 mL) and water (50 mL) an the organic layer washed with water, dilute sodium hydroxide solution, and saturated sodium chloride solution. After drying and filtering, the solvent was removed to leave a dirty brown oil. The crude product was placed on a silica gel column (Merck Kieselgel 60H, 30 g) and eluted with dichloromethane. Fractions containing pure product were combined, and the solvent was removed: 0.21 g (60.4%); mp 125.0–128.0 °C; ^{1}H NMR ($CDCl_3$) 1.34 (t, 6 H, J = 7.0 Hz), 1.4–1.6 (m, 8 H), 2.26 (s, 6 H), 2.2–2.3 (m, 4 H), 2.30 (s, 3 H), 2.39 (t, 4 H, J = 7.0 Hz), 3.60 (s, 3 H), 4.30 (q, 4 H, J = 7.0 Hz), 5.70 (dt, 2 H, J_{AB} = 12 Hz, J_{BX} = 8 Hz), 6.51 (d, 2 H, J_{AB} = 12 Hz), 6.62 (d, 2 H, J = 3 Hz), 6.96 (s, 2 H), 8.74 (br s, 2 H). Anal. Calcd for $C_{36}H_{48}N_2O_5$: C, 73.44; H, 8.21; N, 4.76. Found: C, 73.69; H, 8.33; N, 4.57.

2,6-Bis[5-[5-(ethoxycarbonyl)-4-methylpyrrol-3-yl]-1-pentenyl]-4-methylanisole (28b). **28b** was prepared from **25** (0.10 g, 0.56 mmol) by refluxing in p-dioxane (50 mL) for 45 h with **19b** (0.96 g, 1.72 mmol) and potassium carbonate (0.30 g, 1.77 mmol) added in three portions. Workup was as for **28a**. The crude product was placed on a silica gel column (80 g) and eluted with 10% EtOAc/CH_2Cl_2. The front-running byproducts were separated cleanly from the desired product. All the fractions showing a single product spot on TLC were combined and the solvent removed to give a pink oil: 0.15 g (47.1%); ^{1}H NMR ($CDCl_3$) δ 1.34 (t, 6 H, J = 7.0 Hz), 1.6–1.8 (m, 4 H), 2.25 (s, 6 H), 2.27 (s, 3 H), 2.2–2.4 (m, 4 H), 2.41 (t, 4 H, J = 7.0 Hz), 3.61 (s, 3 H), 4.27 (q, 4 H, J = 7.0 Hz), 5.69 (dt, 2 H, J_{AB} = 11 Hz, J_{BX} = 8 Hz), 6.49 (d, 2 H, J_{AB} = 11 Hz), 6.54 (d, 2 H, J = 3 Hz), 6.87 (s, 2 H), 8.76 (br s, 2 H); mass spectrum, m/z 560 (M^+, 5), 514 (54), 206 (81), 167 (100).

2,6-Bis[6-[5-(ethoxycarbonyl)-4-methylpyrrol-3-yl]-hexyl]-4-methylanisole (29a). A solution of **28a** (0.46 g, 0.78 mmol), 10% Pd/C catalyst, and triethylamine (three drops) in tetrahydrofuran (100 mL) was stirred under hydrogen for 24 h. The solution was filtered through Celite to remove the catalyst and then evaporated to yield a yellow oil. The crude product was placed on a silica gel column (Kieselgel 60H, 30 g) and eluted with 10% ethyl acetate/dichloromethane. Fractions exhibiting a single spot on TLC were combined and evaporated to yield a colorless oil, which slowly crystallized: 0.45 g (96.7%); mp 81.0–83.0 °C; ^{1}H NMR ($CDCl_3$) δ 1.34 (t, 6 H, J = 7.5 Hz), 1.2–1.7 (m, 16 H), 2.26 (s, 3 H), 2.27 (s, 6 H), 2.39 (t, 4 H, J = 7.6 Hz), 2.57 (t, 4 H, J = 7.9 Hz), 3.70 (s, 3 H), 4.31 (q, 4 H, J = 7.5 Hz), 6.66 (d, 2 H, J = 2.5 Hz), 6.84 (s, 2 H), 8.96 (br s, 2 H). Anal. Calcd for $C_{36}H_{52}N_2O_5$: C, 72.94; H, 8.84; N, 4.73. Found: C, 73.03; H, 8.83; N, 4.62.

2,6-Bis[5-[5-(ethoxycarbonyl)-4-methylpyrrol-3-yl]-pentyl]-4-methylanisole (29b). **29b** was prepared from **28b** (0.32 g, 0.58 mmol) as described for **29a**: 0.30 g (91.7%); mp 92.0–94.0 °C; ^{1}H NMR ($CDCl_3$) δ 1.33 (t, 6 H, J = 7.2 Hz), 1.4–1.5 (m, 4 H), 1.5–1.7 (m, 8 H), 2.24 (s, 3 H), 2.27 (s, 6 H), 2.39 (t, 4 H, J = 7.7 Hz), 2.56 (t, 4 H, J = 8.0 Hz), 3.67 (s, 3 H), 4.27 (q, 4 H, J = 7.2 Hz), 6.60 (d, 2 H, J = 2.8 Hz), 6.78 (s, 2 H), 8.92 (br s, 2 H). Anal. Calcd for $C_{34}H_{48}N_2O_5$: C, 72.31; H, 8.57; N, 4.96. Found: C, 72.24; H, 8.59; N, 4.96.

2,5-Bis[6-[5-(ethoxycarbonyl)-4-methylpyrrol-3-yl]-hexyl]-1,4-dimethoxybenzene (31a). A solution of **30** (0.21 g, 1.1 mmol) in refluxing p-dioxane (50 mL) under nitrogen was treated with **19a** (1.50 g, 2.50 mmol) and potassium carbonate (0.37 g, 2.3 mmol), and the resultant mixture was then worked up as described for **28a**. The crude product was obtained as a yellow oil, which solidified on standing. Addition of dichloro-

methane (~10 mL) did not dissolved all of the product, and the insoluble material was filtered off and retained. The filtrate was concentrated and placed on a silica gel column (Kieselgel 60H, ~40 g) and eluted with 10% ethyl acetate/dichloromethane. Fractions showing a single product spot on TLC were combined and concentrated to about 50 mL. The solid product was added and the solution diluted with ethanol (150 mL). Cyclohexene (25 mL) and 10% palladium/charcoal catalyst were added, and the mixture was refluxed for 6.5 h. While still hot, the solution was filtered through Celite and the Celite pad washed well with hot ethanol. As the filtrate cooled down a white solid precipitated, which was collected by filtration (0.42 g, 64.1%). Concentration of the filtrate yielded a second crop of product: 0.12 g (18.6%); mp 144.0–145.0 °C; ^{1}H NMR ($CDCl_3$) δ 1.35 (t, 6 H, J = 7.0 Hz), 1.3–1.4 (m, 8 H), 1.4–1.6 (m, 8 H), 2.27 (s, 6 H), 2.39 (t, 4 H, J = 7.0 Hz), 2.56 (t, 4 H, J = 7.7 Hz), 4.30 (q, 4 H, J = 7.0 Hz), 6.64 (s, 4 H), 8.75 (br s, 2 H). Anal. Calcd for $C_{36}H_{52}N_2O_6$: C, 71.02; H, 8.62; N, 4.60. Found: C, 70.70; H, 8.89; N, 4.55.

2,5-Bis[5-[5-(ethoxycarbonyl)-4-methylpyrrol-3-yl]-pentyl]-1,4-dimethoxybenzene (31b). **31b** was prepared from **30** (0.10 g, 0.51 mmol), **19b** (0.92 g, 1.53 mmol), and potassium carbonate (0.25 g, 1.5 mmol) as for **31a**: 0.13 g (42.4%); mp 136.0–137 °C; ^{1}H NMR ($CDCl_3$) δ 1.34 (t, 6 H, J = 7.0 Hz), 1.3–1.5 (m, 4 H), 1.5–1.7 (m, 8 H), 2.27 (s, 6 H), 2.39 (t, 4 H, J = 7.4 Hz), 2.55 (t, 4 H, J = 7.7 Hz), 3.74 (s, 6 H), 4.28 (q, 4 H, J = 7.0 Hz), 6.61 (s, 4 H), 8.76 (br s, 2 H). Anal. Calcd for $C_{34}H_{48}N_2O_6$: C, 70.31; H, 8.33; N, 4.82. Found: C, 70.15; H, 8.19; N, 4.73.

2,6-Bis[6-[5-(ethoxycarbonyl)-2-[[5-(2,2-dicyanovinyl)-3-ethyl-4-methylpyrrol-2-yl]methyl]-4-methylpyrrol-3-yl]-hexyl]-4-methylanisole (33a). A solution of **28a** (0.20 g, 0.34 mmol) and **32** in glacial acetic acid was heated at 80 °C under nitrogen for 1 h. The solution was cooled to room temperature, poured into sodium bicarbonate solution, and extracted with ethyl acetate. The organic layer was dried, filtered, and evaporated to give a dark red oil. The crude product was placed on a column (Kieselgel 60, 50 g) and eluted with 10% ethyl acetate/toluene, the product eluting as a broad yellow band. Those fractions displaying a single yellow spot on TLC were collected. The fractions were combined and evaporated to give an orange oil (0.29 g, 85.2%), which was recrystallized from 50% dichloromethane/methanol to give an orange solid: mp 146.0–150.0 °C; ^{1}H NMR ($CDCl_3$) δ 1.04 (t, 6 H, J = 7.6 Hz), 1.30 (t, 6 H, J = 7.2 Hz), 1.25–1.45 (m, 12 H), 1.48–1.60 (m, 4 H), 2.10 (s, 6 H), 2.26 (s, 9 H), 2.32–2.42 (m, 4 H), 2.42 (q, 4 H, J = 7.8 Hz), 2.54 (br t, 4 H), 3.67 (s, 3 H), 3.97 (s, 4 H), 4.19 (q, 4 H, J = 7.2 Hz), 6.80 (s, 2 H), 7.25 (s, 2 H), 9.26 (br s, 2 H), 9.50 (br s, 2 H); exact mass calcd for $C_{60}H_{74}N_8O_5$ 986.5782, found 986.5849. Anal. Calcd for $C_{60}H_{74}N_8O_5$: C, 72.99; H, 7.56; N, 11.35. Found: C, 73.28; H, 7.42; N, 11.24.

2,6-Bis[5-[5-(ethoxycarbonyl)-2-[[5-(2,2-dicyanovinyl)-3-ethyl-4-methylpyrrol-2-yl]methyl]-4-methylpyrrol-3-yl]-pentyl]-4-methylanisole (33b). This was prepared from **28b** (0.50 g, 0.89 mmol) and **32** (0.44 g, 1.88 mmol) as described for **33a**: 0.78 g (91.7%); mp 181.5–182.5 °C; ^{1}H NMR ($CDCl_3$) δ 1.05 (t, 6 H, J = 7.6 Hz), 1.34 (t, 6 H, J = 7.2 Hz), 1.3–1.5 (m, 8 H), 1.5–1.6 (m, 4 H), 2.14 (s, 6 H), 2.25 (s, 3 H), 2.27 (s, 6 H), 2.38 (t, 4 H), 2.42 (q, 4 H, J = 7.6 Hz), 2.54 (br, t, 4 H), 3.67 (s, 3 H), 3.94 (s, 4 H), 4.27 (q, 4 H, J = 7.2 Hz), 6.79 (s, 2 H), 7.29 (s, 2 H), 8.67 (br s, 2 H), 9.17 (br s, 2 H); exact mass calcd for $C_{58}H_{70}N_8O_5$ 958.5469, found 958.5511. Anal. Calcd for $C_{58}H_{70}N_8O_5$: C, 72.62; H, 7.36; N, 11.68. Found: C, 72.84; H, 7.48; N, 11.38.

2,5-Bis[6-[5-(ethoxycarbonyl)-2-[[5-(2,2-dicyanovinyl)-3-ethyl-4-methylpyrrol-2-yl]methyl]-4-methylpyrrol-3-yl]-hexyl]-1,4-dimethoxybenzene (34a). This was prepared from **31a** (0.30 g, 0.50 mmol) and **32** (0.24 g, 1.03 mmol) as described for **33a**: 0.42 g (85.4%); mp 165.0–168.0 °C; ^{1}H NMR ($CDCl_3$) δ 1.04 (t, 6 H, J = 7.6 Hz), 1.30 (t, 6 H, J = 7.0 Hz), 1.25–1.41 (m, 12 H), 1.45–1.56 (m, 4 H), 2.10 (s, 6 H), 2.25 (s, 6 H), 2.38 (br t, 4 H), 2.41 (q, 4 H, J = 7.6 Hz), 2.51 (br t, 4 H), 3.74 (s, 6 H), 3.94 (s, 4 H), 4.21 (q, 4 H, J = 7.0 Hz), 6.62 (s, 2 H), 7.26 (s, 2 H), 9.15, 9.19 (br s, 4 H); exact mass calcd for $C_{60}H_{74}N_8O_6$ 1002.5731, found 1002.5728. Anal. Calcd for $C_{60}H_{74}N_8O_6$: C, 71.83; H, 7.44; N, 11.17. Found: C, 71.91; H, 7.35; N, 11.06.

2,5-Bis[5-[5-(ethoxycarbonyl)-2-[[5-(2,2-dicyanovinyl)-3-ethyl-4-methylpyrrol-2-yl]methyl]-4-methylpyrrol-3-yl]-pentyl]-1,4-dimethoxybenzene (34b). A solution of **31b** (0.24 g, 0.41 mmol) and **32** (0.20 g, 0.87 mmol) in glacial acetic acid (5 mL) was heated at 80 °C under nitrogen for 1 h. After a few minutes all the solids dissolved to give a dark red solution, but during the course of the reaction an orange solid precipitated from solution. The reaction mixture was cooled to room temperature and methanol (20 mL) added and the resultant mixture cooled overnight in the freezer. The precipitated product was collected by filtration, washed well with methanol, and dried to give a yellow powder: 0.36 g (90.0%); mp >215 °C dec; ^{1}H NMR ($CDCl_3$) δ 1.04 (t, 6 H, J = 7.6 Hz), 1.32 (t, 6 H, J = 7.4 Hz), 1.36–1.47 (m, 8 H), 1.47–1.58 (m, 4 H), 2.12 (s, 6 H), 2.25 (s, 6 H), 2.37 (t, 4 H), 2.40 (q, 4 H, J = 7.4 Hz), 2.50 (br t, 4 H), 3.73 (s, 6 H), 3.93 (s, 4 H), 4.28 (q, 4 H, J = 7.3 Hz), 6.71 (s, 2 H), 7.29 (s, 2 H), 8.81 (br s, 2 H), 9.18 (br s, 2 H); exact mass calcd for $C_{58}H_{70}N_8O_6$ 974.5418, found 974.5402. Anal. Calcd for $C_{58}H_{70}N_8O_6$: C, 71.43; H, 7.24; N, 11.49. Found: C, 71.19; H, 7.32; N, 11.28.

Preparation of Strapped Porphyrins. The α-ester, α'-(dicyanovinyl)bis(dipyrromethane) (e.g., **33a**) and potassium hydroxide (14 g, 0.25 mol) were refluxed in a mixture of water (100 mL) and propanol (50 mL) under argon for 3 h. The propanol was boiled off and more water (200 mL) added and the mixture cooled to room temperature. The cooled solution was filtered, and the material remaining on the filter was washed with water until it all redissolved (final volume ~500 mL). The filtrate was acidified with glacial acetic acid, and the brown precipitate was filtered and dried in vacuo.

The crude α-carboxy-α'-formylbis(dipyrromethane) was dissolved in spectral grade *N,N*-dimethylformamide (150 mL) and refluxed under argon for 3 h. The reaction mixture was cooled under argon and then evaporated almost to dryness under reduced pressure. The residue was dissolved in dichloromethane (100 mL) and extracted with water (3 × 200 mL) and saturated NaCl solution. The organic layer was dried, filtered, and diluted with dichloromethane (250 mL for 0.12–0.8-mmol scale, 500 mL for 1.0–1.7-mmol scale).

The solution was loaded into four 50-mL syringes and, using a syringe pump, was slowly injected into four solutions of *p*-toluenesulfonic acid (4 g) in methanol (25 mL) and dichloromethane (600 mL). After addition was complete, the combined solutions were concentrated to ~200 mL and then extracted with $NaHCO_3$ solution. The organic layer was dried, filtered, and evaporated to dryness (vacuum was used to remove any traces of DMF). The crude strapped porphyrin was purified by chromatography on silica gel and alumina.

7,17-Diethyl-2,8,12,18-tetramethyl-3,13-[(2-methoxy-5-methyl-1,3-phenylene)bis(hexamethylene)]porphyrin (39a). **33a** (0.55 g, 0.55 mmol) was saponified, decarboxylated, and cyclized as described above. The crude product was purified first on a silica gel column (Kieselgel 60, 100 g), eluting with 1% methanol/dichloromethane. The partially purified porphyrin was then placed on an activity III alumina column (Merck 90, neutral, 40 g) and eluted with dichloromethane. The pure porphyrin was collected and evaporated to dryness: 0.16 g (39.7%); mp 233.0–234.0 °C; exact mass calcd for $C_{48}H_{60}N_4O$ 708.4767, found 708.4793; visible spectrum (CH_2Cl_2) [λ_{max}, nm (log ϵ)] 397.2 (5.21), 497.2 (4.13), 530.6 (3.99), 567.2 (3.82), 620.6 (3.70); ^{13}C NMR (10% TFA/$CDCl_3$) δ 150.96 (1 C, phenyl 2-C), 147.01, 144.07, 143.46, 142.19, 141.37, 141.19, 140.13, 139.97 (16 C, α- and β-pyrrolic C), 135.09 (2 C, phenyl 1,3-C), 134.76 (1 C, phenyl 5-C), 128.76 (2 C, phenyl 4,6-C), 100.42, 99.35 (4 C, meso C), 60.64 (1 C, OCH_3), 31.66, 30.52, 29.59, 29.08, 28.40, 26.36 (12 C, chain C), 20.39 (2 C, CH_2CH_3), 20.23 (1 C, phenyl 5-CH_3), 16.65 (2 C, CH_2, CH_3), 12.40, 11.80 (4 C, CH_3); ^{1}H NMR ($CDCl_3$) δ 10.02 (s, 2 H, methine 5, 15-H), 10.00 (s, 2 H, methine 10, 20-H), 5.60 (s, 2 H, phenyl 4, 6-H), 4.36 (m, 2 H, chain 6-CH_2), 4.13 (m, 2H, CH_2CH_3), 4.06 (m, 2 H, CH_2CH_3), 3.94 (m, 2 H, chain 6-CH_2), 3.63 (s, 6 H, 2 CH_3), 3.58 (s, 6 H, 2 CH_3), 2.19 (m, 2 H, chain 5-CH_2), 2.02 (m, 2 H, chain 5-CH_2), 1.88 (t, 6 H, CH_2CH_3), 1.69 (s, 3 H, phenyl 5-CH_3), 0.89 (m, 2 H, chain 4-CH_2), 0.84 (m, 2 H, chain 4-CH_2), 0.71 (m, 2 H, chain 3-CH_2), 0.50 (m, 2 H, chain 1-CH_2), 0.42 (m, 2 H, chain 3-CH_2), 0.27 (m, 2 H, chain 2-CH_2), 0.18 (m, 2 H, chain 1-CH_2), 0.03 (m, 2 H, chain 2-CH_2), −2.70 (s, 3 H, OCH_3), −3.77 (br s, 2 H, NH). Anal. Calcd for $C_{48}H_{60}N_4O$: C, 81.31; H, 8.53; N, 7.90; O, 2.26. Found: C, 81.21; H, 8.62; N, 7.75; O, 2.35.

7,17-Diethyl-2,8,12,18-tetramethyl-3,13-[(2-methoxy-5-methyl-1,3-phenylene)bis(pentamethylene)]porphyrin (39b). **39b** was prepared from **33b** (0.27 g, 0.28 mmol) as described above. Purification was as for **33a**: 0.05 g (24.1%); mp 253–256 °C; exact mass calcd for $C_{46}H_{56}N_4O$ 680.4454, found 680.4439; visible spectrum (CH_2Cl_2) [λ_{max}, nm (log ϵ)] 397.2 (5.18), 497.8 (4.07), 533.6 (3.98), 567.2 (3.78), 620.8 (3.63); ^{13}C NMR (10% TFA/$CDCl_3$) δ 146.44, 143.87, 143.70, 143.32, 141.44, 141.29, 140.02, 139.58 (16 C, α- and β-pyrrolic C), 132.93 (1 C, phenyl 5-C), 131.81 (2 C, phenyl 1,3-C), 126.45 (2 C, phenyl 4,6-C), 100.04, 99.65 (4 C, meso C), 58.89 (1 C, OCH_3), 29.30, 28.65, 27.74, 27.25, 26.97 (10 C, chain C), 20.22 (2 C, CH_2CH_3), 19.81 (1 C, phenyl 5-CH_3), 16.34 (2 C, CH_2CH_3), 12.29, 11.59 (4 C, CH_3). Anal. Calcd for $C_{46}H_{56}N_4O$: C, 81.13; H, 8.29; N, 8.23; O, 2.35. Found: C, 81.28; H, 8.20; N, 8.26; O, 2.16; ^1H NMR ($CDCl_3$) δ 10.04 (s, 2 H, methine 10, 20-H), 10.01 (s, 2 H, methine, 5, 15-H), 5.20 (s, 2 H, phenyl 4,6-H), 4.23 (m, 2 H, chain 5-CH_2), 4.16 (m, 2 H, CH_2CH_3), 4.07 (m, 2 H, CH_2CH_3), 3.88 (m, 2 H, chain 5-CH_2), 3.64 (s, 6 H, 2-CH_3), 3.52 (s, 6 H, 2-CH_3), 2.04 (m, 2 H, chain 4-CH_2), 1.89 (t, m, 8 H, CH_2CH_3, chain 4-CH_2), 1.41 (s, 3 H, phenyl 5-CH_3), 0.94 (m, 2 H, chain 3-CH_2), 0.86 (m, 2 H, chain 3-CH_2), 0.68 (m, 2 H, chain 1-CH_2), 0.20 (m, 2 H, chain 1-CH_2), 0.79 (m, 2 H, chain 2-CH_2), −1.10 (m, 2 H, chain 2-CH_2), −2.07 (s, 3 H, OCH_3), −3.77 (br s, 2 H, NH).

7,17-Diethyl-2,8,12,18-tetramethyl-3,13-[(2,5-dimethoxy-1,4-phenylene)bis(hexamethylene)]porphyrin (40a). **40a** was prepared from **34a** (0.53 g, 0.53 mmol) as described above (0.18 g, 46.9%): mp 271–274 °C; exact mass calcd for $C_{48}H_{60}N_4O_2$, 724.4716, found 724.4695; visible spectrum (CH_2Cl_2) [λ_{max}, nm (log ϵ)] 397.2 (5.19), 496.6 (4.11), 530.0 (3.99), 565.6 (3.80), 620.8 (3.72); ^{13}C NMR (10% TFA/$CDCl_3$) δ 145.89, 142.96, 142.73, 142.12, 140.92, 139.64, 138.67, 138.28 (16 C, α- and β-pyrrolic C), 99.00, 97.72 (4 C, meso C), 31.88, 28.68, 28.43, 26.28 (chain C), 20.28 (2 C, CH_2CH_3), 16.22 (2 C, CH_2CH_3), 12.09, 11.61 (4 C, CH_3); ^1H NMR ($CDCl_3$) δ 10.00 (s, 2 H, methine 5, 15-H), 9.98 (s, 2 H, methine 10, 20-H), 4.43 (m, 2 H, chain 6-CH_2), 4.12 (m, 2 H, CH_2CH_3), 4.04 (m, 2 H, CH_2CH_3), 3.91 (s, 2 H, phenyl 3,6-H), 3.72 (m, 2 H, chain 6-CH_2), 3.60 (s, 6 H, 2 CH_3), 3.59 (s, 6 H, 2 CH_3), 2.32 (m, 4 H, chain 5-CH_2), 1.87 (t, 6 H, CH_2CH_3), 1.58 (s, 6 H, OCH_3), 1.50 (m, 2 H, chain 4-CH_2), 1.22 (m, 2 H, chain 4-CH_2), 0.82 (m, 4 H, chain 3-CH_2), 0.40 (m, 3 H), chain 1-CH_2), 0.21 (m, 2 H, chain 1-CH_2), 0.11 (m, 2 H, chain 2-CH_2), −0.10 (m, 2 H, chain 2-CH_2), −3.99 (br s, 2 H, NH). Anal. Calcd for $C_{48}H_{60}N_4O_2$: C, 79.52; H, 8.34; N, 7.73; O, 4.41. Found: C, 79.64; H, 8.40; N, 7.64; O, 4.44.

7,17-Diethyl-2,8,12,18-tetramethyl-3,13-[(2,5-dimethoxy-1,4-phenylene)bis(pentamethylene)]porphyrin (40b). **40b** was prepared from **34b** (0.26 g, 0.27 mmol) as described above: 0.07 g, (39.5%); mp 264–267 °C; exact mass calcd for $C_{46}H_{56}N_4O_2$ 696.4403, found 696.4365; visible spectrum (CH_2Cl_2) [λ_{max}, nm (log ϵ)] 397.2 (5.19), 496.6 (4.11), 530.0 (3.99), 565.6 (3.80), 620.8 (3.72); ^{13}C NMR (10% TFA/$CDCl_3$) δ 150.01 (1 C, phenyl 2,5-C), 146.29, 143.75, 143.45, 143.30, 141.23, 140.91, 140.11, 139.37 (16 C, α- and β-pyrrolic C), 128.40 (2 C, phenyl 1,4-C), 113.56 (2 C, phenyl 3,6-C), 99.94, 99.42 (4 C, meso C), 57.10 (2 C, OCH_3), 29.70, 28.80, 28.15, 28.08, 27.02 (10 C, chain C), 20.30 (2 C, CH_2CH_3), 16.52 (2 C, CH_2CH_3), 12.34, 11.73 (4 C, CH_3); ^1H NMR ($CDCl_3$) δ 9.97 (s, 2 H, methine 5, 15-H), 9.93 (s, 2 H, methine 10, 10-H), 4.25 (m, 2 H, chain 5-CH_2) 4.17 (m, 2 H, CH_2CH_3), 4.07 (m, 2 H, CH_2CH_3), 3.93 (m, 2 H, chain 5-CH_2), 3.80 (s, 2 H, phenyl 3,6-H), 3.62 (s, 6 H, 2 CH_3), 3.54 (s, 6 H, 2 CH_3), 2.22 (m, 2 H, chain 4-CH_2), 1.91, 1.88 (s, t, m, 14 H, OCH_3, OCH_2CH_3, chain 4-CH_2), 1.07 (m, 2 H, chain 3-CH_2), 0.96 (m, 2 H, chain 1-CH_2), 0.88 (m, 2 H, chain 3-CH_2), 0.53 (m, 2 H, chain 1-CH_2), −3.90 (br s, 2 H, NH). Anal. Calcd for $C_{46}H_{56}N_4O_2$: C, 79.27; H, 8.10; N, 8.04; O, 4.59. Found: C, 79.40; H, 8.11; N, 8.02; O, 4.44.

7,17-Diethyl-2,8,12,18-tetramethyl-3,13-[(2-hydroxy-5-methyl-1,3-phenylene)bis(hexamethylene)]porphyrin (2a). A solution of **39a** (153 mg, 0.22 mmol) in dry dichloromethane (10 mL) was stirred under argon and cooled to −78 °C, and then a solution of boron tribromide (0.3 mL, 3.2 mmol) in dichloromethane was added dropwise over a 5-min period. The reaction mixture was left stirring at −78 °C for 2 h and then at room temperature for a further 1 h. The reaction was quenched with water (10 mL) and extracted with dichloromethane (50 mL). The organic layer was washed with sodium bicarbonate solution and saturated sodium chloride solution, then dried over anhydrous sodium sulfate, filtered, and evaporated to dryness. The crude product was placed on a neutral alumina column (Merck 90, activity III) and eluted with dichloromethane. Fractions containing a single product were combined and evaporated (123 mg, 82.1%). The product was recrystallized from dichloromethane-/hexanes as purple plates: 67 mg (54.3%); mp 260–263 °C; exact mass calcd for $C_{47}H_{58}N_4O$ 694.4606, found 694.4611; visible spectrum (CH_2Cl_2) [λ_{max}, nm (log ϵ)] 398.0 (5.24), 498.0 (4.12), 534.8 (4.00), 564.4 (3.84), 618.0 (3.69); ^{13}C NMR (10% TFA/$CDCl_3$) δ 159.51 (1 C, phenyl 2-C), 145.70, 144.79, 142.91, 142.60, 142.13, 140.91, 138.81, 138.10 (16 C, α- and β-pyrrolic C), 134.08, 132.61, 127.81 (5 C, phenyl C), 98.79, 97.61 (4 C, meso C), 30.89, 30.52, 30.29, 29.64, 28.74, 26.22 (12 C, chain C), 20.25 (3 C, CH_2CH_3, phenyl 5-CH_3), 16.33 (2 C, CH_2CH_3), 11.92, 11.61 (4 C, CH_3); ^1H NMR ($CDCl_3$) δ 10.04, 10.01 (s, 4 H, methine 5,10,15,20-H), 5.51 (s, 2 H, phenyl 4,6-H), 4.46 (m, 2 H chain 6-CH_2), 4.09 (m, 4 H, CH_2CH_3), 3.95 (m, 2 H, chain 6-CH_2), 3.64 (s, 6 H, 2 CH_3), 3.62 (s, 6 H, 2 CH_3), 2.39 (m, 2 H, chain 5-CH_2) 2.24 (m, 2 H, chain 5-CH_2), 1.88 (t, 6 H, CH_2CH_3), 1.51 (s, 3 H, phenyl 5-CH_3), 1.26 (m, 4 H, chain 4-CH_2), 0.84 (m, 2 H, chain 3-CH_2), 0.47 (m, 2 H, chain 3-CH_2), 0.0 (m, 2 H, chain 2-CH_2), −0.35 (m, 2 H, chain 2-CH_2), −0.44 (m, 2 H, chain 1-CH_2), −0.94 (m, 2 H, chain 1-CH_2), −2.56 (br s, 1 H, phenyl OH), −3.68 (br s, 2 H, NH). Anal. Calcd for $C_{47}H_{58}N_4O$: C, 81.22; H, 8.41; N, 8.06; O, 2.30. Found: C, 81.40; H, 8.47; N, 7.97; O, 2.40.

7,17-Diethyl-2,8,12,18-tetramethyl-3,13-[(2-hydroxy-5-methyl-1,3-phenylene)bis(pentamethylene)]porphyrin (2b). The demethylation was carried out on **39b** (0.10 g, 0.15 mmol) exactly as described above. After workup, the crude product was purified by chromatography on a neutral alumina column [Merck 90, activity III] using dichloromethane as eluant (89.8 mg, 88.9%). The product was recrystallized from dichloromethane/hexanes: 72.9 mg (72.2%); mp 295–298 °C; exact mass calcd for $C_{45}H_{54}N_4O$ 666.4298, found 666.4293; visible spectrum (CH_2Cl_2) [λ_{max}, nm (log ϵ)] 397.2 (5.25), 499.2 (4.10), 535.2 (4.01), 563.6 (3.84), 617.6 (3.59); ^{13}C NMR (10% TFA/$CDCl_3$) δ 158.87 (1 C, phenyl 2-C), 146.42, 144.73, 143.42, 143.12, 141.66, 141.37, 140.56, 140.02 (16 C, α- and β-pyrrolic C), 131.32, 127.33, 126.52 (5 C, phenyl C), 100.76, 100.10, (4 C, meso C), 29.08, 28.67, 28.13, 27.77, 27.65 (10 C, chain C), 20.36 (2 C, CH_2CH_3), 19.42 (1 C, phenyl 5-CH_3), 16.65 (2 C, CH_2CH_3), 12.31, 11.85 (4 C, CH_3); ^1H NMR ($CDCl_3$) δ 10.22 (s, 2 H, methine 5,15-H), 10.08 (s, 2 H, methine 15,20-H), 5.33 (s, 2 H, phenyl 4,6-H), 4.24 (m, 2 H, chain 5-CH_2), 4.21, 4.08 (m, 4 H, CH_2CH_3), 4.00 (m, 2 H, chain 5-CH_2), 3.64, 3.50 (s, 12 H, 4 CH_3), 2.22 (m, 2 H, chain 4-CH_2), 3.64, 3.50 (s, 12 H, 4 CH_3), 1.88 (t, 6 H, CH_2CH_3), 1.61 (m, 2 H, chain 4-CH_2), 1.24–1.40 (m, 4 H, chain 3-CH_2), 1.37 (s, 3 H, phenyl 5-CH_3), −0.15 (m, 2 H, chain 1-CH_2), −0.48 (m, 2 H, chain 2-CH_2), −1.60 (m, 2 H, chain 1-CH_2), −1.94 (m, 2 H, chain 2-CH_2), −3.84 (br s, 2 H, NH). Anal. Calcd for $C_{45}H_{54}N_4O$: C, 81.04; H, 8.16; N, 8.40; O, 2.40. Found: C, 78.70; H, 8.27; N, 8.04; O, 4.70. Calcd for $C_{45}H_{54}N_4O{\cdot}1H_2O$: C, 78.91; H, 8.24; N, 8.18; O, 4.67.

7,17-Diethyl-2,8,12,18-tetramethyl-3,13-[(2,5-dioxo-1,4-phenylene)bis(hexamethylene)]porphyrin (1a). Demethylation of **40a** (101 mg, 0.14 mmol) was effected with boron tribromide (0.5 mL, 5.3 mmol) as described above. The crude hydroquinone **42a** was oxidized to the quinone by stirring in dichloromethane with lead dioxide for approximately 10 min. When TLC indicated complete reaction, the oxidant was filtered off. The crude product was placed on a neutral alumina column [Merck 90, activity III]. Elution with dichloromethane yielded **1a** (79.8 mg, 82.2%), which was recrystallized from toluene: 58.8 mg (60.6%); mp >260 °C dec; exact mass calcd for $C_{46}H_{54}N_4O_2$ 694.4247, found 694.4249; visible spectrum (CH_2Cl_2) [λ_{max}, nm (log ϵ)] 258.4 (4.72), 397.2 (5.21), 497.2 (4.08), 530.4 (3.94), 567.2 (3.79), 621.6 (3.63); ^{13}C NMR (10% TFA/$CDCl_3$) δ 188.19 (2 C, C=O), 148.61 (2 C, quinone 1,4-C), 145.71, 142.69, 142.57, 142.21, 141.39, 141.05, 139.39, 138.46 (16 C, α- and β-pyrrolic C), 132.42 (2 C, quinone 3,6-C), 99.14, 98.10 (4 C, meso C) 31.32, 27.51, 27.28, 27.17, 26.93, 26.29 (12 C, chain C), 20.30 (2 C, CH_2CH_3), 16.32 (2 C, CH_2CH_3), 12.27, 11.68 (4 C, CH_3); ^1H NMR ($CDCl_3$) δ 10.03 (s, 2 H, methine 5,15-H), 10.02 (s, 2 H, methine 10,20-H), 4.40 (m, 2 H, chain 6-CH_2), 4.12 (q, 4 H, CH_2CH_3), 3.63–3.75 (m, 2 H, chain 6-CH_2), 3.68, 3.60 (s, 12 H, 4 CH_3), 2.76 (s, 2 H, quinone 3,6-H), 2.51 (m, 4 H, chain 5-CH_2), 1.89 (t, 6 H, CH_2CH_3), 1.73

(m, 2 H, chain 4-CH_2), 1.51 (m, 2 H, chain 4-CH_2), 1.11 (m, 2 H, chain 3-CH_2), 0.95 (m, 2 H, chain 3-CH_2), 0.27 (m, 2 H, chain 1-CH_2), +0.05 to −0.15 (m, 4 H, chain 2-CH_2), −0.72 (m, 2 H, chain 1-CH_2), −4.00 (br s, 2 H, NH). Anal. Calcd for $C_{46}H_{54}N_4O_2$: C, 79.50; H, 7.83; N, 8.06; O, 4.60. Found: C, 79.24; H, 8.00; N, 7.94; O, 4.80.

7,17-Diethyl-2,8,12,18-tetramethyl-3,13-[(2,5-dioxo-1,4-phenylene)bis(pentamethylene)]porphyrin (1b). **1b** was prepared from **40b** (61.6 mg, 0.09 mmol) as described above (41.2 mg, 69.9%): mp >270 °C dec; exact mass calcd for $C_{44}H_{50}N_4O_2$ 666.3934, found 666.3984; visible spectrum (CH_2Cl_2) [λ_{max}, nm (log ϵ)] 260.0 (4.47), 396.8 (95.21), 498.0 (4.07), 534.8 (3.98), 567.2 (3.82), 620.8 (3.58); ^{13}C NMR (10% TFA/$CDCl_3$) δ 186.33 (2 C, quinone 2,5-C), 147.05 (2 C, quinone 1,4-C), 146.15, 142.99, 142.81, 142.05, 141.92, 140.86, 140.17, 139.62 (16 C, α- and β-pyrrolic C), 131.45 (2 C, quinone 3,6-C), 99.85, 98.72 (4 C, meso C), 28.66, 27.00, 26.86, 25.99, 25.92 (10 C, chain C), 20.43 (2 C, CH_2CH_3), 16.54 (2 C, CH_2CH_3), 12.20, 11.80 (4 C, CH_3); ^1H NMR ($CDCl_3$) δ 9.47 (s, 4 H, methine 5,10,15,20-H), 4.30 (m, 2 H, chain 5-CH_2), 4.08–4.25 (m, 4 H, CH_2CH_3), 3.97 (m, 4 H, chain 5-CH_2), 3.70, 3.57 (s, 12 H, 4 CH_3), 2.94 (s, 2 H, quinone 3,6-H), 2.33 (m, 2 H, chain 4-CH_2) 1.93 (t, m, 8 H, CH_2CH_3, chain 4-CH_2), 1.25 (m, 2 H, chain 3-CH_2), 1.14 (m, 2 H, chain 3-CH_2), 0.65 (m, 2 H, chain 1-CH_2), −0.02 (m, 2 H, chain 1-CH_2), −0.32 (m, 2 H, chain 2-CH_2), −1.29 (m, 2 H, chain 2-CH_2), −3.91 (br s, 2 H, NH). Anal. Calcd for $C_{44}H_{50}N_4O_2$: C, 79.24; H, 7.56; N, 8.40; O, 4.80. Found: C, 77.00; H, 7.44; N, 8.00; O, 6.77. Calcd for $C_{44}H_{50}N_4O_2 \cdot 1H_2O$: C, 77.16; H, 7.65; N, 8.18; O, 7.01.

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Registry No. **1a**, 98977-32-3; **1b**, 98977-31-2; **2a**, 110569-90-9; **2b**, 110569-91-0; **9**, 2199-44-2; **10b**, 14794-31-1; **11a**, 68500-90-3; **11b**, 68500-89-0; **12a**, 98977-05-0; **12b**, 98977-04-9; **13a**, 98977-07-2; **13b**, 98977-06-1; **14a**, 98977-09-4; **14b**, 98977-08-3; **15a**, 98977-11-8; **15b**, 98977-10-7; **16a**, 110569-80-7; **16b**, 110569-81-8; **17a**, 98977-13-0; **17b**, 98977-12-9; **18a**, 98977-15-2; **18b**, 98977-14-1; **19a**, 98977-17-4; **19b**, 98977-16-3; **20**, 37945-37-2; **21**, 110569-92-1; **22**, 110569-93-2; **25**, 71128-83-1; **28a**, 110569-82-9; **28b**, 110569-83-0; **29a**, 110569-84-1; **29b**, 110589-04-3; **30**, 7310-97-6; **31a**, 98977-20-9; **31b**, 98977-19-6; **32**, 37789-74-5; **33a**, 110569-85-2; **33b**, 110569-86-3; **34a**, 98977-22-1; **34b**, 98977-21-0; **35a**, 110569-87-4; **37a**, 110589-05-4; **39a**, 110569-88-5; **39b**, 110569-89-6; **40a**, 98977-28-7; **40b**, 98977-27-6; **42a**, 98977-30-1; $CH_3CH_2OCO(CH_2)_3COOH$, 1070-62-8; $CH_3CH_2OCO(CH_2)_3COCl$, 5205-39-0; 2,6-bis(hydroxymethyl)-4-methylanisole, 6327-85-1; 2,5-bis(hydroxymethyl)-1,4-dimethoxybenzene, 51829-43-7; 1,4-bis[6-[2-(ethoxycarbonyl)-3-methylpyrrol-4-yl]hex-1-enyl]-2,5-dimethoxybenzene, 98990-28-4.

Synthesis of Dihydro-1,4-oxathiins by Action of Chlorine on 1,3-Oxathiolanes[1]

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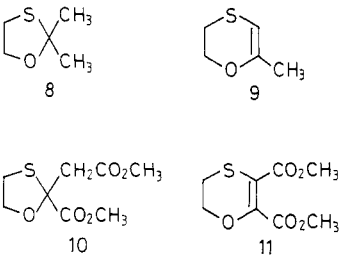
A new convenient synthesis of 5,6-dihydro-2-methyl-1,4-oxathiin-3-carboxylic acid derivatives **1** has been achieved by using the action of chlorine on 2-methyl-*N*-phenyl-1,3-oxathiolane-2-acetamide (**4a**) and 2-methyl-1,3-oxathiolane-2-acetic acid methyl ester (**4b**). From the initially formed chlorosulfonium salts **16** unobserved transient sulfenyl chlorides **5** were generated, followed by cyclization to probable oxonium ion **18** to produce dihydrooxathiins **1**. In the chlorinolysis reactions of **4a** and **4b** minor byproducts were formed: respectively 2,3-dichloro-2-methyl-1,4-oxathiin-3-carboxanilide **12a** and its methyl ester analogue **12b**. While **12b** was stable, **12a** was unstable, transforming to the corresponding 2-chloromethyl compound **13**. The mechanism of formation of **13** as well as relative stability of dichlorides **12a**, **12b**, and related compounds is also discussed.

Introduction

In our previous paper[2] we reported a new synthesis of dihydro-1,4-oxathiins **1** by rearrangement of 1,3-oxathiolane *S*-oxides **2** involving sulfenic acid **3** (Scheme I, path a). As an inevitable extension of this work we now report a possibly simpler synthesis of **1** by chlorinolysis of readily available 1,3-oxathiolanes **4** involving sulfenyl chlorides **5** (Scheme I, path b).

Wilson[3] previously reported the chlorinolysis of 2,2-dimethyloxathiolane (**8**) in refluxing methylene chloride–carbon tetrachloride to obtain 5,6-dihydro-2-methyl-1,4-oxathiin (**9**) in fair yield. Another paper by ten Haken[4] described ring expansion of 2-carbomethoxy-1,3-oxathiolane-2-acetic acid methyl ester (**10**) by action of chlorine to 5,6-dihydro-1,4-oxathiin-2,3-dicarboxylic acid, bis(methyl ester) (**11**) in low yield. The reaction was carried out initially at −20 °C to ambient temperature and at 120 °C in the last stage. No mechanistic considerations were given in this report.



A salient feature of the 1,3-oxathiolanes **4** is the presence of both carbonyl-activated methylene and unactivated methyl hydrogens β to the C–S bond being ruptured.

(1) A part of this work was presented (a) at the 28th International Union of Pure and Applied Chemistry Congress, Vancouver, Canada, August 16–21, 1981, and (b) in Lee, W. S.; U.S. Pat. 4 230 871, 1980; Can. Pat. 1 035 778, 1978; *Chem. Abstr.* **1979**, *90*, 102970d.

(2) Lee, W. S.; Hahn, H. G.; Nam, K. D. *J. Org. Chem.* **1986**, *51*, 2789–2795.

(3) Wilson, G. E., Jr. *J. Am. Chem. Soc.* **1965**, *87*, 3785–3786.

(4) ten Haken, P. *J. Heterocycl. Chem.* **1970**, *7*, 1211–1213.

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