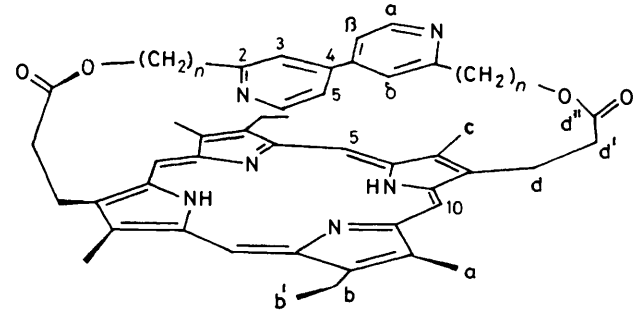
Synthesis of Bipyridyl-, Viologen-, and Quinone-bridged Porphyrins

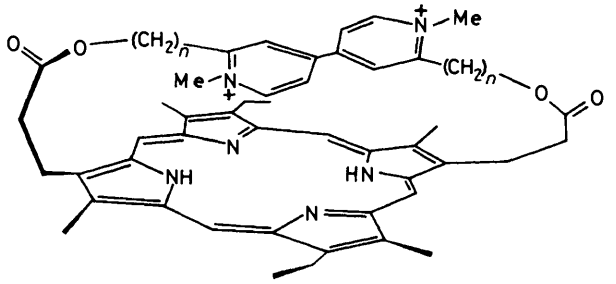
Philip Leighton and Jeremy K. M. Sanders *
University Chemical Laboratory, Lensfield Road, Cambridge CB2 1EW

Mesoporphyrin-II has been bridged by several 2,2′-hydroxymethyl-substituted 4,4′-bipyridine compounds. *N*-Methylation of the bipyridine bridge groups yielded viologen-bridged porphyrins which have unusual aggregation and fluorescence properties. An improved route to quinone-bridged porphyrins is also reported.

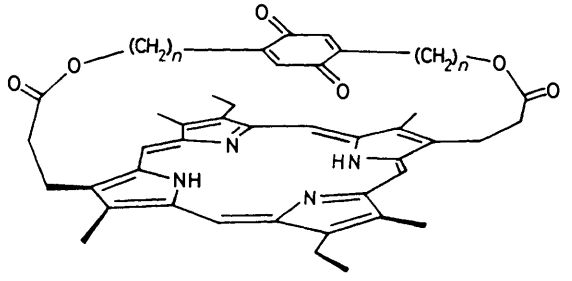
We have recently described in detail the geometries and co-ordination chemistry of the bipyridine-bridged porphyrins (**1**)—(**3**)[1,2] and the photophysical properties of the viologen- and quinone-bridged porphyrins (**4**)—(**7**).[3–5] However, we have so far given only preliminary accounts of the synthesis of compounds (**1**)—(**5**)[1,3] and details of an early synthetic route to (**6**) and (**7**).[6] In this paper, we present details of the synthesis of the bipyridyl- and viologen-bridged materials and of an improved approach to some of the quinone-bridged porphyrins. The compounds described in this paper form part of a larger set of porphyrin derivatives designed to possess model photosynthetic or enzymatic properties.[7–10] For the sake of easy reading metallated derivatives are not given separate compound numbers; they are indicated by Mg or Zn prefixes as appropriate.



(**1**) *n* = 2
(**2**) *n* = 3
(**3**) *n* = 4

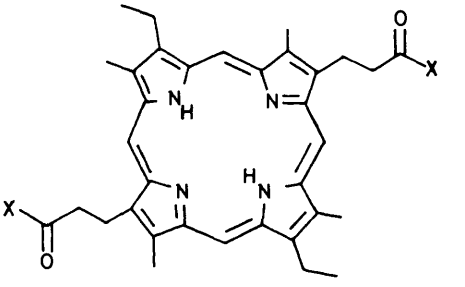


(**4**) *n* = 3
(**5**) *n* = 4



(**6**) *n* = 2
(**7**) *n* = 3

In devising a synthesis of bridged porphyrins our main concern has been to adopt a synthetically flexible route which should allow easy alteration of the bridging group and, if desired, of the porphyrin. Battersby[11] has developed a versatile approach in which a diol is esterified in high dilution with the bisacid chloride of mesoporphyrin-II. This is an elegant convergent synthesis bringing together the porphyrin and bridging group close to, or in, the final step. It is therefore only necessary to synthesize homologous diols to prepare a homologous series of bridged porphyrins. We have been fortunate to have in this laboratory access to a supply of mesoporphyrin-II bismethyl ester (**8**) from which the bisacid chloride (**9**) can be prepared in two straighforward steps.

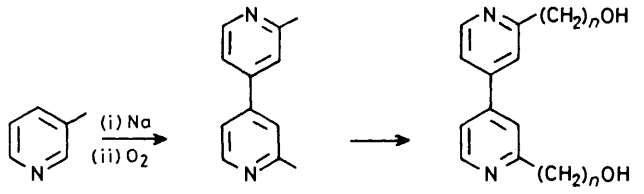


(**8**) X = OMe
(**9**) X = Cl

We therefore decided to pursue the synthesis of our bridged compounds by this route. It thus only remained to devise syntheses of the diols and to perform transformations of the bridging group where appropriate.

Results and Discussion

Bipyridyl-bridged Porphyrins.—Our route to the 4,4′-bipyridine-2,2′-diyl-bridged porphyrins (**1**)—(**3**) was designed to lead to viologen derivatives such as (**4**) and (**5**), but also would allow for the use of alternative quaternising groups other than methyl; to date only the methylated derivatives have been investigated. Inspection of CPK models suggested that connecting chains containing 2, 3, and 4 methylene groups

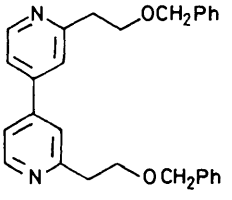


(13) (10) n = 2 (11) n = 3 (12) n = 4

Scheme 1.

would give a suitable range of strained and floppy bridges. It was hence necessary to synthesise the diols (**10**)—(**12**).

Scheme 1 illustrates the synthetic strategy. The first step was the reductive coupling of 2-methylpyridine with sodium[12] to give, on oxidation, the 2,2′-dimethyl-4,4′-bipyridine (**13**) in 59% yield. The product was inevitably contaminated with small amounts of isomeric bipyridines and higher pyridines. The dianion of (**13**) could be generated by treatment of a THF/TMEDA solution of (**13**) with either butyl-lithium or lithium di-isopropylamide (LDA). Quenching of the dianion with gaseous formaldehyde gave compound (**10**) in poor yield (6.7%). Better yields of (**10**) were subsequently achieved by reaction of the dianion of (**13**) with benzyl chloromethyl ether to give the dibenzyl ether (**14**) in 83% yield; (**14**) was not readily de-

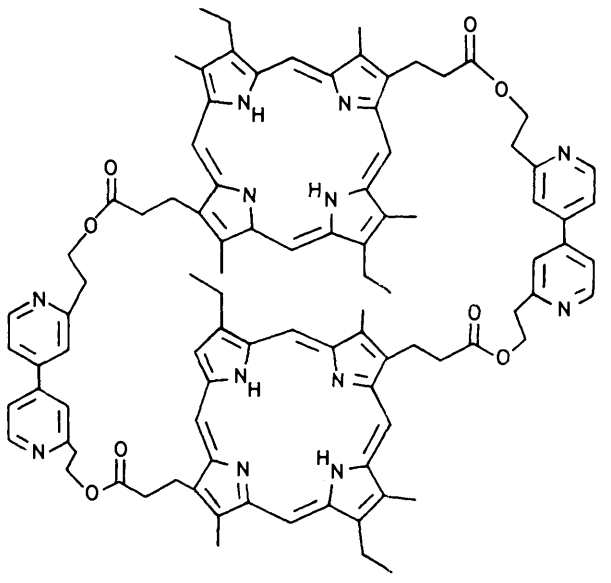


(14)

protected by hydrogenolysis (Pd on carbon, PtO_2), trimethylsilyl iodide, or anhydrous HI, but HBr in acetic acid cleanly deprotected the alcohols and gave (**10**) in 70% yield. Reaction of the dianion solution with ethylene oxide gave (**11**) in 51% yield while reaction with the THP ether of 3-bromopropan-1-ol in THF/DMPU gave compound (**12**) in 47% yield. In each case the asymmetric diol and the mono-substituted compounds were significant by-products (up to 50%).

Reaction of these diols with mesoporphyrin-II bisacid chloride (**9**) (formed by the reaction of the porphyrin bisacid with oxalyl chloride in dichloromethane containing a trace of dimethylformamide (DMF), under high dilution conditions gave the bridged compounds (**1**)—(**3**) in yields in the range 32—44%. The reactions producing bridged porphyrins (**2**) and (**3**) gave these compounds as the only cyclic product. However the coupling of (**9**) and (**10**) to give (**1**) also yielded the cyclic dimer (**15**) in *ca.* 10% yield.

It is interesting to note that high yields in these macrocyclisation reactions are observed when the diol contains large aromatic groups. Thus, the presence of anthracene,[11] bipyridine, dimethoxybenzene,[6] pyromellitimide,[9] and porphyrin[8] groups in the diol have all been observed to have a beneficial effect on the yield compared with a straight methylene chain of approximately equal length. This would suggest that π–π interactions play a significant part in holding the diol and DMAP adduct of the porphyrin acid together in a suitable geometry for reaction. It would seem that this effect is



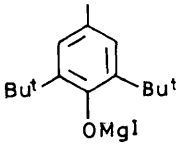
(15)

independent of whether the aromatic system is a net electron donor such as dimethoxybenzene or is electron deficient, as is the case for pyromellitimide. The deciding factors would appear to be as follows.

(1) The overall size of the aromatic system. Thus diols containing pyromellitimide, anthracene, or porphyrin give higher yields than, for example, dimethoxybenzenediols.

(2) The length of the diol chain. Very short chains will produce tight bridges and hence give low yields. However very long chains have so many more degrees of freedom that the two reactive ends have a statistically lower chance of reacting intramolecularly and hence the yield of linear polymer increases with a commensurate decrease in the yield of desired bridged compound.

The bridged porphyrins (**1**)—(**3**) could be metallated with zinc acetate in dichloromethane–methanol to give the zinc porphyrins Zn(**1**)—Zn(**3**) or with the magnesium phenoxide (**16**) in ether–dichloromethane to give the magnesium por-



(16)

phyrins Mg(**1**)—Mg(**3**). Metallations with zinc were effectively quantitative; those with magnesium were variable, presumably as a result of the more complicated procedure and the labile nature of the metal in the macrocycle.

These bipyridinediyl-bridged materials possess remarkable properties as conformational 'switches', dramatic conformational changes being induced on protonation or titration with external ligands.[1,2] These conclusions result from the detailed investigations of the n.m.r. and electronic spectral properties of the compounds as previously reported. The Experimental section of this report, therefore, contains only brief descriptions of these spectroscopic data.

The dimer (**15**) is a flexible molecule with the porphyrin moieties easily able to rotate through the cavity: its ^1H n.m.r. spectrum shows all methylenes in the strap as triplets unlike the double-double-doublets for the corresponding protons in (**1**). It

might, therefore, be expected that the time-averaged orientation of each porphyrin with respect to the other should be the same as for monomers in free solution. Hence, unless the porphyrins stack in some manner in solution due to π–π interactions, the molecule should have properties essentially identical to unlinked porphyrins. However this is observed not to be the case. The u.v./visible, fluorescence, and n.m.r. spectroscopic properties display characteristics quite unlike monomeric porphyrins or indeed (**1**) itself. U.v./visible spectroscopy shows a broadened, blue-shifted, and considerably hypochromic Soret band compared with (**8**). This effect, which has been observed in other, closely linked, co-facial, porphyrin dimers, is caused by a close association of two porphyrins lying with their transition dipoles parallel to each other.[7] The emission spectrum shows 75% quenching of the steady-state fluorescence and a slight shift in the emission wavelength. Such effects have been observed in other tightly stacked porphyrin dimers,[7,13] and are not due to the presence of the bipyridinediyl moiety. Finally, the ^{1}H n.m.r. spectrum of (**15**) shows substantial upfield shifts of protons from both porphyrin and bipyridyl components. Since the molecule is very flexible it is impossible to determine any 'preferred geometry' for this system. However the data clearly indicate that one or more of such conformations exist.

Addition of trifluoroacetic acid to a solution of compound (**15**) in dichloromethane gives the octacation. This shows virtually normal u.v./visible and n.m.r. spectra by comparison with protonated compound (**8**), indicating, as expected, that mutual repulsion of the charged components destroys any significant porphyrin-porphyrin or porphyrin-bipyridyl interaction.

Viologen-bridged Porphyrins.—The viologen-bridged porphyrins (**4**) and (**5**) were prepared by the action of methyl iodide at room temperature on dichloromethane solutions of compounds (**2**) and (**3**) respectively. Yields were typically 70—80%. The chloride salts were obtained by ion exchange over an anion exchange resin in the chloride form.

Compounds (**4**) and (**5**) were difficult to handle and purify since it was not possible to chromatograph them on either normal or reversed-phase silica. High-pressure liquid chromatography on a reverse-phase column was also unsuccessful. On a cellulose column they were eluted with dichloromethane–methanol (1:1) but streaked badly. It is possible that the extensive aggregation of these materials (see below) causes this bizarre behaviour. However, in view of this the compounds were purified by extraction into water, evaporation, and subsequent precipitation by vapour diffusion of pentane into a solution of the porphyrin in chloroform–5% methanol.

The viologen-bridged porphyrins were also difficult to characterise satisfactorily by methods other than f.a.b. mass spectrometry. These difficulties are a result of strong aggregation. Thus, aqueous solutions do not obey Beer's Law even at concentrations below 10^{-6}M. Attempts to disperse the aggregates by addition of an excess of methyl viologen or sodium iodide failed. Only in acetonitrile, using dilute solutions of the chloride salts, was it possible to obtain well-behaved solutions. Under these conditions, both the Soret and visible bands are substantially shifted and hypochromic (Table). These changes presumably reflect the proximity of the viologen electric field gradient.

The ^{1}H n.m.r. spectra of compounds (**4**) and (**5**) also indicate extensive aggregation. Linewidths are typically 20 Hz or more, being largest in polar solvents and minimised in acetonitrile. Again, added viologen or sodium iodide were ineffective.* The large linewidths precluded the use of decoupling or COSY methods of spectral assignment. However, aggregation could be abolished by addition of trifluoroacetic acid. Protonation of the basic porphyrin nitrogens leads to electrostatic repulsion between the porphyrin and viologen moieties and completes disaggregation. The resulting spectra show sharp lines. The porphyrin-induced ring current shifts of the viologen protons are also reduced because of the greater inter-chromophore distance; precisely the same repulsion effects are seen when the bipyridyl-bridged porphyrins are protonated.[2]

Table. Electronic spectra of compounds (**4**) and (**8**) in acetonitrile

$\lambda_{max.}$/nm (ε × 10^{-3})		
(**4**)	(**8**)	% Hypochromicity
397 (102)	393 (168)	39
496 (7.9)	495 (13.9)	43
529 (5.9)	528 (9.9)	40
564 (4.5)	564 (6.6)	31
617 (2.2)	619 (4.3)	49

Small-scale experiments demonstrated that it is possible to methylate the metallated bipyridinediyl-bridged porphyrins, u.v./visible spectroscopy showing no evidence of demetallation. The unstable products were characterised solely by f.a.b. mass spectrometry and ^{1}H n.m.r. spectroscopy: aggregation in Mg(**5**) is so strong that it cannot be broken by addition of an excess of pyridine (which would be expected to co-ordinate to the metal). These compounds were not pursued further.

Viologen-bridged porphyrins are almost totally non-fluorescent, in contrast to conventional porphyrins and the bipyridyl analogues.[3] This is a result of fast electron transfer from the porphyrin excited state to the viologen acceptor. Our motive in synthesising these compounds was precisely the search for such an intramolecular electron transfer. Detailed results have been presented elsewhere.[5]

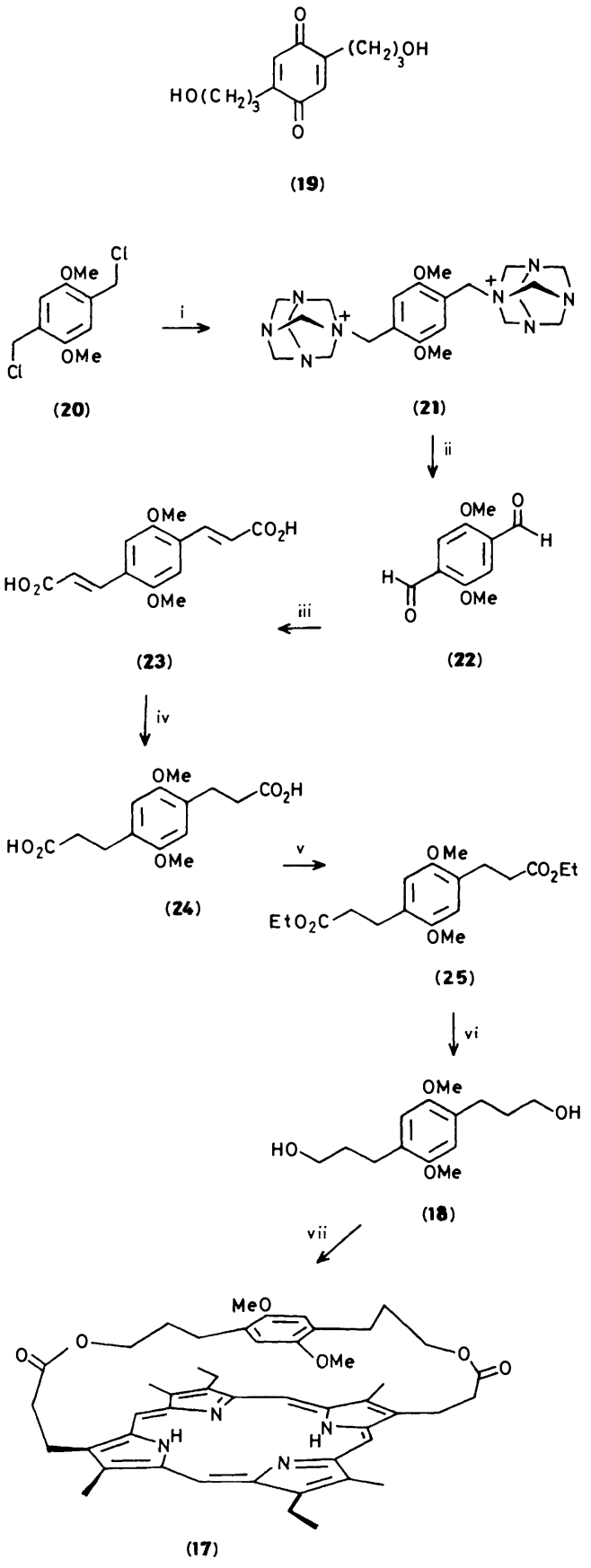
Compound (**1**) was not methylated by the conditions described above, nor by more vigorous conditions, *e.g.* refluxing in neat methyl iodide or reaction with methyl tosylate–DMF. F.a.b. mass spectroscopy showed no evidence of viologen-bridged material. N.m.r. studies of the conformation of compound (**1**) show that the pyridine nitrogens are actually inaccessible, being shielded by the methylene linking chain; this is in contrast to the longer chained analogues which have freely-accessible pyridyl nitrogens.[2]

Quinone-bridged Porphyrins.—We have previously reported the quinone-bridged porphyrins (**6**) and (**7**) and their magnesium derivatives.[6] However, our spectroscopic studies[5] required more material than was at that time available, particularly of compound (**7**) which appeared to show considerably more inter-chromophore interactions than the shorter chain compound (**6**).

The previously reported scheme was rather tortuous, particularly in its need for a messy change of hydroquinone protecting group midway. This change was necessary because of initial failure to deprotect the dimethoxybenzene-bridged porphyrin (**17**).[6,14] This did not seem to be an insurmountable problem since the methoxy group has been successfully removed from other, similar, molecules.[15] We therefore decided to synthesise more of (**17**) *via* the diol (**18**). A direct route to compound (**7**) *via* the quinone diol (**19**) is not feasible due to intramolecular nucleophilic attack by the hydroxy group on the quinone moiety.

A new route to the diol (**18**) was also devised (Scheme 2),

* This line broadening does not appear to result from electron transfer exchange effects: linewidths are similar for all proton resonances, including those that arise from sites that are several bonds removed from any unpaired spin density in a porphyrin or viologen radical.



Scheme 2. *Reagents:* i, Hexamine; ii, CH_2O–H_2O; iii, $CH(CO_2H)_2$ iv, Raney nickel–N_2H_4; v, EtOH–H^+; vi, $LiAlH_4$; vii, compound (**9**)

although in the event it offers no great advantage over the previous one. Compound (**20**) reacted with hexamine in chloroform to give the hexamine salt (**21**) quantitatively. Oxidation of (**21**) by heating in aqueous formaldehyde gave the dialdehyde (**22**) in 62% yield.[16] Reaction of (**22**) with malonic acid in pyridine containing a trace of piperidine gave, in 75% yield, the diacid (**23**).[17] Solutions of (**23**) had a spectacular green fluorescence. Reduction with Raney nickel/hydrazine[18] gave the diacid (**24**) in 85% yield. Esterification with acidic ethanol to give the diethyl ester (**25**) and subsequent reduction with lithium aluminium hydride gave the diol (**18**) in 81% yield over two steps.

Compound (**18**) was converted into (**17**) in 23% yield by the high dilution procedure described above. Deprotection of compound (**17**) was achieved by treatment of a dichloromethane solution of the porphyrin with fresh trimethylsilyl iodide under scrupulously dry conditions. The degradation reported previously[6,14] would appear to be caused by the presence of significant amounts of HI. Addition of pyridine prevents this degradation but lengthens reaction times to the order of days rather than hours. In the absence of pyridine the reaction was quantitative, the hydroquinone appearing as a cherry-red spot of lower R_F than the starting material. The hydroquinone was not characterised but was oxidised directly to compound (**7**) by the addition of an excess of lead dioxide. The oxidation was also quantitative. The material so obtained was spectroscopically identical with previously prepared samples.

The successful deprotection of compound (**17**) has thus allowed a substantial shortening of the synthesis of the quinone-bridged porphyrins which may now be prepared in significantly larger quantities (many milligrams). Metallation to the Zn and Mg derivatives is straightforward.

Experimental

Analytical thin-layer chromatography was performed with Merck Kieselgel 60 F_{254} plates, pre-coated with silica gel. Preparative thin-layer chromatography was performed on plates coated with 1 mm thickness Whatman 513F 230—400 mesh silica gel.

Anhydrous tetrahydrofuran (THF) was freshly distilled from lithium aluminium hydride prior to use, and anhydrous dichloromethane was distilled from phosphorus pentaoxide prior to use. Chloroform and dichloromethane were shaken with basic alumina to remove any acidic impurities.

Unless otherwise stated all reactions were performed under an atmosphere of dry nitrogen. All organic extracts were dried with anhydrous magnesium sulphate. M.p.s were recorded in a glass capillary tube using a Büchi 510 melting point apparatus, and are uncorrected. I.r. spectra were recorded as Nujol mulls on a Perkin-Elmer 297 infrared spectrophotometer. U.v./visible absorption spectra were recorded on a Pye Unicam PU 8800 spectrometer in dichloromethane solution unless otherwise stated. ^{1}H N.m.r. spectra were recorded at 60 MHz (Varian EM-360), 80 MHz (Bruker WP80), 90 MHz (Varian EM-390), 250 MHz (Bruker WM250), 400 MHz (Bruker WH400), or 500 MHz (Bruker AM500). The Bruker instruments operated in the Fourier transform mode, and the Varian instruments in the continuous wave mode. Continuous wave spectra are referenced to tetramethylsilane as internal standard. Fourier transform spectra are referenced to the residual protons of the solvent. Fourier transform spectra were typically recorded over either 11 or 16 p.p.m. using 8 or 16 K data points. N.O.e. difference spectra were recorded using standard software. Typically an irradiation time of 1 s was employed, with a relaxation delay of 1.5 s between transients. 512 Free induction decays were normally acquired for each frequency irradiated.

COSY-45 spectra were acquired in the absolute value mode

using standard software. Typically 1 or 2 K data points over 5 p.p.m. were acquired in f2 and 256 or 512 increments acquired in f1. Normally 16 or 32 free induction decays were acquired for each increment. Suitable apodisation, normally a shifted sine bell squared function, was applied in both dimensions. No zero filling was used in f2, but f1 was normally zero filled until the data matrix was square.

^{13}C N.m.r. proton broadband decoupled spectra were acquired in deuteriodichloromethane or deuteriochloroform solution at 62.9 MHz (Bruker WM250). 32K Data points were collected over 200 p.p.m. Chemical shifts are referenced to deuteriodichloromethane or to deuteriochloroform. More detailed n.m.r. parameters and assignments for compounds (**1**)—(**3**) are given in ref. 1, and for compound (**7**) in ref. 19.

Low-resolution e.i. mass spectra were obtained with a Kratos/AEI MS12 or with a Kratos/AEI MS902 spectrometer. High-resolution mass spectra were recorded with a Kratos/AEI MS30 double-beam spectrometer. Fast-atom bombardment (f.a.b.) ionisation mass spectra were recorded on a Kratos/AEI MS50 spectrometer using an 8 KeV beam of neutral xenon atoms to effect ionisation. Compounds were dispersed in a matrix of thioglycerol–diglycerol. Mass spectra of zinc porphyrins are quoted based upon ^{64}Zn.

Typical Macrocyclisation Reaction.—Mesoporphyrin-II bis-acid (300 mg, 0.53 mmol) was dispersed in dry dichloromethane (50 ml). Oxalyl chloride (2 ml) and DMF (1 drop) were added and the mixture was stirred in the dark for 1 h. During this time the solid dissolved and a clear pink solution remained. The solvent and excess oxalyl chloride were removed under reduced pressure to yield (**9**) as a purple gum. This was dissolved in dry dichloromethane (500 ml) and transferred, under an atmosphere of dry nitrogen, to a dry dropping funnel.

The diol (0.53 mmol) was similarly dissolved in dry dichloromethane (500 ml) and transferred to an identical dropping funnel. These two solutions were added with stirring to a solution of freshly recrystallised *N,N*-dimethylaminopyridine (DMAP) (0.7 g) in dry dichloromethane (500 ml) over 8 h. The whole apparatus was maintained under a positive pressure of dry nitrogen throughout the addition.

The solvent was then evaporated under reduced pressure. The resultant purple solid was dissolved in a minimum amount of dichloromethane (*ca.* 50 ml) and filtered through a short column of Fluorisil to remove polymers and DMAP hydrochloride. The solution was then washed with 0.1M hydrochloric acid to remove residual DMAP, and then with water. The organic layer, after drying with magnesium sulphate, was flash chromatographed on silica with dichloromethane–5% methanol eluant. The first band eluted was the bridged porphyrin. All free-base bridged porphyrins were recrystallised from dichloromethane solution by the slow diffusion of hexanes into the solution.

2,2-*Dimethyl*-4,4′-*bipyridine* (**13**).—Sodium (10 g, 0.435 mol) was cut into small pieces and added to 2-methylpyridine (850 ml) under a nitrogen atmosphere. The reaction was frequently sonicated in an ultrasound bath. After 48 h the solution was a deep blue colour and most of the sodium had dissolved. Digestion of the sodium was completed by heating on a water-bath for 8 h at 90 °C. Oxygen was then bubbled into the hot mixture, and a vigorous reaction occurred. After several seconds the reaction quietened, the blue colour was discharged, and a pale orange solution remained. The excess of 2-methylpyridine was distilled off leaving a brown viscous residue. This was passed through a column of Fluorisil eluted with ethyl acetate–3% triethylamine to remove most of the higher pyridines. Evaporation of the solvent gave a semicrystalline orange solid containing the desired compound contaminated with isomeric bipyridines and higher pyridines. The 4,4′-bipyridine could be obtained in satisfactory purity by recrystallisation firstly from hexane and then from diethyl ether. This gave a yellow solid (23.66 g, 59%), m.p. 79—80 °C (lit.,[20] m.p. 84 °C); δ_H (60 MHz, $CDCl_3$), 8.62 (2 H, d, 5 Hz, α-H), 7.40 (2 H, d, 5 Hz, β-H), 7.45 (2 H, s, δ-H), and 2.63 (6 H, s, Me); δ_C($CDCl_3$) 159.53 (C-2), 120.86 (C-3), 146.00 (C-4), 118.56 (C-5), 149.95 (C-6), and 24.4 (Me); *m/z* 184 (M^+).

2,2′-*Bis*(*benzyloxyethyl*)-4,4′-*bipyridine* (**14**).—Dimethylbipyridine (**13**) (2.2 g, 12 mmol) was dissolved in dry THF (70 ml) containing TMEDA (0.2 ml) and cooled to −78 °C in a solid CO_2 acetone bath. Butyl-lithium in hexane (15% solution; 15 ml) was added by syringe over 10 min to give a dark red dianion. The solution was allowed to warm to 0 °C, and was stirred at this temperature for 1 h. The solution was then cooled to −78 °C and benzyl chloromethyl ether (3.3 ml, 24 mmol) was added by syringe. The flask was then removed from the solid CO_2 bath and allowed to warm slowly to room temperature. After 2 h the colour of the dianion had been discharged and saturated aqueous ammonium chloride (50 ml) was added, followed by 2M hydrochloric acid (20 ml). This was then extracted with dichloromethane (3 × 50 ml). The dichloromethane extracts were discarded and the aqueous layer was neutralised with sodium hydrogen carbonate. The aqueous layer was further extracted with dichloromethane (2 × 50 ml). The organic layers were combined, dried, and evaporated to yield a pale yellow oil. Chromatography of this over silica (eluted dichloromethane–10% methanol) gave the dibenzyl ether as a colourless oil (3.3 g, 83%); δ_H(90 MHz, $CDCl_3$) 8.7 (2 H, d, *J* 5 Hz, α-H), 7.5 (2 H, s, δ-H), 7.45 (2 H, d, *J* 5 Hz, β-H), 7.4 (10 H, s, phenyl ring), 4.6 (4 H, s, benzylic methylene), 3.95 (4 H, t, *J* 7 Hz, CH_2O), and 3.2 (4 H, t, *J* 7 Hz, ArCH_2) (Found: M^+ − Bz, 333.1599. $C_{21}H_{21}N_2O_2$ requires M^+ − Bz, 333.1599).

2,2′-(4,4′-*Bipyridine*-2,2′-*diyl*)*diethanol* (**10**).—*Method 1.* Dimethylbipyridine (**13**) (1.1 g, 6 mmol) was converted into the dianion by the procedure described above and brought to 0 °C. Paraformaldehyde (1 g, 36 mmol), previously dried *in vacuo*, was heated in a stream of dry nitrogen, the vapour being passed through the dianion solution. The anion colour was rapidly discharged and work-up was performed as described above. Chromatography over silica using ethyl acetate–10% methanol–3% triethylamine as eluant gave a tan solid, recrystallisation of which from ethyl acetate–hexane provided the diol as a light brown powder (98 mg, 6.7%).

Method 2. The dibenzyl ether (**14**) (1 g, 3 mmol) was mixed with HBr in acetic acid (5 ml). The mixture was stirred for 5 min after which it was diluted with water (20 ml) and extracted with dichloromethane (2 × 20 ml). The aqueous layer was neutralised with sodium hydrogen carbonate and again extracted with dichloromethane (2 × 20 ml). The latter extracts were dried and evaporated to dryness. Chromatography and recrystallisation of the residue as above gave the diol as light brown powder (0.5 g, 70%), m.p. 147—148 °C: δ_H (60 MHz, $CDCl_3$) 8.65 (2 H, d, *J* 5 Hz, α-H), 7.45 (2 H, s, δ-H), 7.43 (2 H, d, *J* 5 Hz, β-H), 3.9 (4 H, t, *J* 7 Hz, CH_2O), and 2.9 (4 H, t, 7 Hz, ArCH_2) (Found: M^+, 244.1209. $C_{14}H_{16}N_2O_2$ requires *M*, 244.1209).

3,3′-(4,4′-*Bipyridine*-2,2′-*diyl*)*dipropanol* (**11**).—The bipyridine (**13**) (0.55 g) was converted into the dianion as described above for the preparation of (**14**). Addition of ethylene oxide (135 mg) to the dianion solution at −78 °C, followed by work-up and subsequent purification as above gave the diol (410 mg, 51%) as a light brown powder, m.p. 97—98 °C; $\lambda_{max.}$(CH_2Cl_2) 269—271infl nm (ε 8 900); δ_H (80 MHz, CD_2Cl_2) 8.65 (2 H, d, 5 Hz, α-H), 7.45 (2 H, s, δ-H), 7.42 (2 H, d, 5 Hz, β-H), 3.71 (4 H, t, 7 Hz, CH_2O), 3.0 (4 H, t, 7 Hz, ArCH_2), and 2.12 (4 H, quint., 7

Hz, CH_2CH_2OH); $\delta_C(CD_2Cl_2)$ 163.12 (C-2), 121.12 (C-3), 146.65 (C-4), 119.23 (C-5), 149.85 (C-6), 62.06 (CH_2OH), 35.35 ($ArCH_2$), and 32.30 ($ArCH_2CH_2$) (Found: $M^+ - OH$, 255.1496. $C_{16}H_{20}N_2O_2$ requires $M - OH$, 255.1496).

4,4'-(4,4'-*Bipyridine*-2,2'-*diyl*)*dibutanol* (**12**).—The dimethylbipyridine (**13**) (1.1 g, 6 mmol) was dissolved in dry THF (20 ml) containing DMPU (12 g) and LiI (30 mg). This was cooled in a solid CO_2–acetone bath and THF (10 ml) containing lithium diisopropylamide (LDA) (3 mmol) [LDA (6 mmol) was prepared from di-isopropylamine (0.84 ml) and butyl-lithium (15% hexane soln.; 3.75 ml) in THF (20 ml) were added by syringe. A red anion formed. The solution was warmed to 0 °C, stirred for 1 h, and then cooled to −78 °C; the THP ether of 3-bromopropan-1-ol (3 mmol, 0.67 g) was then added. The solution was allowed to warm to room temperature and when the anion colour had been discharged the flask was again cooled to −78 °C and a further portion of LDA (3 mmol) was added. The procedure was repeated as above, the anion thus formed being again quenched with a further equivalent of the THP ether. When the second anion had been quenched, water (20 ml) was added, followed by 2M hydrochloric acid (120 ml). The THF was evaporated under reduced pressure. The aqueous layer was extracted with dichloromethane, and the extracts discarded, neutralised with sodium hydrogen carbonate and re-extracted with dichloromethane (3 × 40 ml). Evaporation of the dichloromethane under reduced pressure gave a solution of the desired compound in residual DMPU. The DMPU was distilled off under reduced pressure to leave a brown viscous residue. This was taken up in ethyl acetate and passed down a column of Fluorisil eluted with ethyl acetate–5% methanol. Evaporation of the solvent gave a brown solid which was recrystallised from chloroform-hexane to give the diol as an off-white solid (0.85 g, 47%), m.p. 124—126 °C; δ_H (80 MHz, CD_2Cl_2) 8.65 (2 H, d, 5 Hz, α-H), 7.45 (2 H, s, δ-H), 7.42 (2 H, d, 5 Hz, β-H), 3.7 (4 H, t, 7 Hz, CH_2OH), 3.0 (4 H, t, Hz, $ArCH_2$), and 1.8—2.0 (8 H, m, $CH_2CH_2CH_2OH$); $\delta_C(CD_2Cl_2)$ 163.65 (C-2), 120.86 (C-3), 146.66 (C-4), 119.18 (C-5), 150.22 (C-6), 62.63 (CH_2OH), 38.15 ($ArCH_2$), 32.27 (CH_2CH_2OH), and 26.2 ($ArCH_2CH_2$) (Found: M^+, 300.1845. $C_{18}H_{24}N_2O_2$ requires M, 300.1844).

Mesoporphyrin-II 2,2'-(4,4'-*Bipyridine*-2,2'-*diyl*)*diethanol Diester* (**1**) *and Dimer* (**15**).—By the macrocyclisation procedure outlined above, the diol (**10**) (100 mg, 0.4 mmol) was allowed to react with compound (**9**) derived from the diacid (230 mg, 0.4 mmol). After work-up, chromatography revealed the presence of two bridged materials. These were separated by flash chromatography over silica eluted with dichloromethane–2% methanol. Evaporation of the solvent and subsequent recrystallisation gave the diester (**1**) (100 mg, 32%) as large purple cubes and (**15**) (40 mg, 10%) as fine purple microcrystals. Compound (**1**), m.p. >300 °C, $\lambda_{max.}$ (CH_2Cl_2) 400 (ε 142 000), 498 (12 000), 531 (8 500), 567 (5 600), and 622 nm (4 100); δ_H (400 MHz, CD_2Cl_2) 9.89 (2 H, s, 10-H), 9.87 (2 H, s, 5-H), 6.57 (2 H, d, 5 Hz, α-H), 4.5—4.65 (2 H, m, H_d), 4.55 (2 H, s, δ-H), 4.10—4.25 (6 H, overlapping multiplets, CH_2O and H_b), 3.88 (2 H, dt, 12,6 Hz, CH_2O), 3.63 (6 H, s, H_a), 3.48 (6 H, s, H_c), 3.40 (2 H, d, 5 Hz, β-H), 3.18—3.35 (4 H, m, $H_{d'}$), 2.08 (2 H, t, *J* 6 Hz, $ArCH_2$), 1.95 (6 H, t, *J* 7 Hz, $H_{b'}$), and −4.40 (2 H, s, NH); $\delta_C(CD_2Cl_2)$ 173.97 ($C_{d''}$), 157.44 (bipy C-2), 148.01 (bipy C-6), 143.88 (bipy C-4), 142.04, 139.12, 137.64, 135.19 (C-2, 3, 6, 7), 118.73 (bipy C-3), 116.97 (bipy C-5), 96.93, 96.73 (C-5, 10), 63.45 (CH_2O), 37.95 ($C_{d'}$), 36.44 ($ArCH_2$), 23.07 (C_d), 20.15 (C_b), 17.66 ($C_{b'}$), 11.83, and 11.59 ($C_{a,c}$); *m*/*z* 774 (M^+) (Found: C, 69.15; H, 6.2; N, 9.95%; $C_{48}H_{50}N_6O_4 \cdot 3/2\ CH_2Cl_2$ requires C, 69.21; H, 6.09; N, 9.94%).

Compound (**15**), m.p. 207—209 °C; $\lambda_{max.}$ (CH_2Cl_2) 394 (ε 196 000), 498 (18 000), 532 (15 000), 565 (11 000), and 618 nm (7 800); δ_H (250 MHz, CD_2Cl_2) 9.44 (4 H, s, 5-H), 9.64 (4 H, s, 10-H), 7.88 (4 H, d, *J* 5 Hz, α-H), 6.62 (4 H, d, *J* 2 Hz, δ-H), 6.22 (4 H, dd, *J* 5, 2 Hz, β-H), 4.27 (8 H, t, *J* 7 Hz, CH_2O), 3.80 (8 H, q, *J* 7 Hz, H_b), 3.79 (8 H, t, *J* 7 Hz, H_d), 3.23 (12 H, s, H_a), 3.19 (12 H, s, H_c), 2.89 (8 H, t, *J* 7 Hz, $H_{d'}$), 2.68 (8 H, t, *J* 7 Hz, $ArCH_2$), 1.70 (12 H, t, *J* 7 Hz, $H_{b'}$); δ_H (CD_2Cl_2 + d-TFA) 10.66 (4 H, s, meso), 10.63 (4 H, s, meso), 8.76 (4 H, d, 5 Hz, α-H), 7.65 (4 H, s, δ-H), 7.58 (4 H, d, *J* 5 Hz, β-H), 4.45 (8 H, t, *J* 7 Hz, CH_2O), 4.13 (8 H, q, *J* 7 Hz, H_b), 4.03 (8 H, t, *J* 7 Hz, H_d), 3.59 (12 H, s, porphyrin methyl), 3.58 (12 H, s, porphyrin methyl), 3.02 (8 H, t, *J* 7 Hz, $H_{d'}$), 2.66 (8 H, t, 7 Hz, $ArCH_2$), and 1.68 (12 H, t, *J* 7 Hz, $H_{b'}$); *m*/*z* (f.a.b.) 1 549 (M^+).

Mesoporphyrin-II 3,3'-(4,4'-*Bipyridine*-2,2'-*diyl*)*dipropanol Diester* (**2**).—By the above procedure the diol (**11**) (145 mg, 0.53 mmol) was allowed to react with mesoporphyrin-II-diacid chloride (0.53 mmol) to give the title compound (**2**) (190 mg, 44%) as purple microcrystals from dichloromethane–hexane; m.p. 237—239 °C; $\lambda_{max.}$ (CH_2Cl_2) 400 (ε 154 000), 497 (12 900), 532 (9 200), 567 (6 300), and 620 nm (4 100); δ_H (400 MHz, CD_2Cl_2) 9.99 (2 H, s, 5-H), 10.05 (2 H, s, 10-H), 7.90 (2 H, d, *J* 5 Hz, α-H), 6.12 (2 H, dd, *J* 5, 2 Hz, β-H), 5.25 (2 H, d, *J* 2 Hz, δ-H), 4.63 (2 H, ddd, *J* 14, 9, 5 Hz, H_d), 4.18 (2 H, ddd, *J* 14, 9, 5 Hz, H_d), 4.08 (4 H, q, *J* 7 Hz, H_b), 3.85 (2 H, ddd, *J* 14, 9, 5 Hz, CH_2O), 3.63 (6 H, s, H_c), 3.58 (6 H, s, H_a), 3.6 (2 H, m, CH_2O), 3.15—3.35 (4 H, m, $H_{d'}$), 1.86 (6 H, t, 7 Hz, $H_{b'}$), 1.6 (2 H, m, $ArCH_2$), 1.1—1.4 (6 H, m, $ArCH_2CH_2$), and −3.95 (2 H, s, NH); $\delta_C(CD_2Cl_2)$ 173.56 ($C_{d''}$), 161.37 (bipy C-2), 149.09 (bipy C-6), 144.75 (bipy C-4), 141.79, 139.65, 137.91, 134.88 (C-2, 3, 7, 8), 119.01 (bipy C-3), 117.79 (bipy C-5), 97.00, 96.71 (C-5, 10), 64.28 (CH_2O), 37.47 ($C_{d'}$), 33.83 ($ArCH_2$), 27.78 ($ArCH_2CH_2$), 22.34 (C_d), 20.02 (C_b), 17.60 ($C_{b'}$), and 11.91 and 11.44 ($C_{a,c}$); *m*/*z* 802 (M^+) (Found: C, 75.2; H, 6.85; N, 10.35. $C_{50}H_{54}N_6O_4$ requires C, 74.8; H, 6.73; N, 10.47%).

Mesoporphyrin-II 4,4'-(4,4'-*Bipyridine*-2,2'-*diyl*)*dibutanol Diester* (**3**).—By the same macrocyclisation reaction the diol (**12**) (160 mg, 0.53 mmol) was converted into the title compound (**3**) (164 mg, 37%) as purple microcrystals, m.p. 209—210 °C; $\lambda_{max.}$ (CH_2Cl_2) 398 (ε 122 000), 497 (10 000), 531 nm (6 600), 566 nm (4 400), and 620 nm (2 700); δ_H (400 MHz, CD_2Cl_2) 10.12 (2 H, s, 10-H), 10.09 (2 H, s, 5-H), 7.80 (2 H, d, *J* 5 Hz, α-H), 6.35 (2 H, dd, *J* 5, 2 Hz, β-H), 5.89 (2 H, d, *J* 2 Hz, δ-H), 4.62 (2 H, ddd, *J* 15, 9, 5 Hz, H_d), 4.21 (2 H, ddd, *J* 15, 9, 5 Hz, H_d), 4.12 (4 H, q, *J* 7 Hz, H_b), 3.79 (2 H, dt, *J* 11, 6.5 Hz, CH_2O), 3.63 (12 H, s, porphyrin methyls), 3.60 (2 H, m, CH_2O), 3.34 (2 H, ddd, *J* 14, 9, 5 Hz, $H_{d'}$), 3.20 (2 H, ddd, *J* 14, 9, 5 Hz, $H_{d'}$), 1.88 (6 H, t, *J* 7 Hz, $H_{b'}$), 1.74 (4 H, m, $ArCH_2$), 0.75—0.9 (8 H, m, bridge methylenes), and −3.92 (2 H, s, NH); $\delta_C(CD_2Cl_2)$ 173.52 ($C_{d''}$), 162.24 (bipy C-2), 149.22 (bipy C-6), 145.34 (bipy C-4), 141.98, 139.64, 137.85, 137.07 (C-2, 3, 7, 8), 119.49 (bipy C-3), 118.06 (bipy C-5), 97.00, 96.81 (C-5, 10), 64.29 (CH_2O), 38.1 ($ArCH_2$), 37.2 ($C_{d'}$), 28.2 (CH_2CH_2O), 25.8 ($ArCH_2CH_2$), 22.9 (C_d), 20.5 (C_b), 18.0 ($C_{b'}$), and 11.9 and 11.4 ($C_{a,c}$); *m*/*z* 830 (M^+) (Found: C, 66.05%; H, 6.35; N, 8.75. $C_{52}H_{58}N_6O_4 \cdot 3/2CH_2Cl_2$ requires C, 65.8; H, 6.15; N, 8.6%).

Zinc Mesoporphyrin-II 2,2'-(4,4'-*Bipyridine*-2,2'-*diyl*)*diethanol Diester* Zn(**1**).—Compound (**1**) (20 mg) was dissolved in dichloromethane (10 ml) and a saturated solution of zinc acetate in methanol (0.5 ml) was added. The mixture was stirred at room temperature until u.v./visible spectroscopy showed complete metallation (less than 5 min). The solvent was removed under reduced pressure and the pink residue taken up in dichloromethane. Chromatography over neutral alumina (grade-II) using dichloromethane–0.25% methanol as eluant gave a blueish pink band of the metallated porphyrin. This method was used for all metallations with zinc. Recrystallisation

from dichloromethane–pentane gave purple prisms of Zn(**1**) (20 mg, *ca.* 100%), m.p. >250 °C; δ_H (250 MHz, CD_2Cl_2–[$^2H_5$]pyridine) 9.98 (2 H, s, meso), 9.92 (2 H, s, meso), 6.92 (2 H, d, 5 Hz, α-H), 4.72 (2 H, m, H_d), 4.46 (2 H, s, δ-H), 4.15—4.35 (4 H, m, β-H and H_d), 4.10 (4 H, q, *J* 7 Hz, H_b), 3.80 (2 H, dt, *J* 11, 4.5 Hz, CH_2O), 3.63 (6 H, s, porphyrin methyl), 3.55 (6 H, s, porphyrin methyl), 3.6 (2 H, m, CH_2O), 3.2—3.45 (4 H, m, $H_{d'}$), 1.9—2.15 (4 H, m, $ArCH_2$), and 1.86 (6 H, t, *J* 7 Hz, $H_{b'}$); *m/z* 836 (M^+).

Zinc Mesoporphyrin-II 3,3′-(4,4′-*Bipyridine*-2,2′-*diyl*)*dipropanol Diester* Zn(**2**).—By the above method compound (**2**) (20 mg) gave Zn(**2**) (18 mg, 83%) as purple plates from dichloromethane–pentane; δ_H (250 MHz, CD_2Cl_2) 9.53 (2 H, s, meso), 9.60 (2 H, s, meso), 6.05 (2 H, br, α-H), 5.38 (2 H, br, β-H), 5.00 (2 H, s, δ-H), 4.58 (2 H, ddd, *J* 14, 8, 5 Hz, H_d), 4.15 (2 H, ddd, *J* 14, 8, 5 Hz, H_d), 3.95 (4 H, q, 7 Hz, H_b), 3.4—3.6 (4 H, m, CH_2O), 3.55 (6 H, s, porphyrin methyl), 3.47 (6 H, s, porphyrin methyl), 3.05—3.35 (4 H, m, $H_{d'}$), 1.79 (6 H, t, *J* 7 Hz, $H_{b'}$), 0.6—0.8 (6 H, m, $ArCH_2CH_2$), and 0.3 (2 H, m, $ArCH_2$); *m/z* 865 (M^+ + H).

Zinc Mesoporphyrin-II 4,4′-(4,4′-*Bipyridine*-2,2′-*diyl*)*dibutanol Diester* Zn(**3**).—In a similar manner, compound (**3**) (20 mg) gave Zn(**3**) (20 mg, 93%) as small purple plates from dichloromethane–pentane; δ_H (400 MHz, CD_2Cl_2) 10.15 (2 H, s, meso), 9.93 (2 H, s, meso), 5.98 (2 H, s, δ-H), 5.87 (2 H, d, *J* 5 Hz, β-H), 4.83 (2 H, br, α-H), 4.60 (2 H, m, H_d), 4.25 (2 H, m, H_d), 4.12 (6 H, overlapping multiplets, H_b and CH_2O), 3.69 (6 H, s, porphyrin methyl), 3.62 (6 H, s, porphyrin methyl), 3.6 (2 H, m, CH_2O), 3.0—3.25 (4 H, m, $H_{d'}$), 1.87 (6 H, t, 7 Hz, $H_{b'}$), 0.8—1.05 (6 H, m, $ArCH_2CH_2CH_2$), and 0.0—0.2 (6 H, m, $ArCH_2CH_2$); *m/z* 894 (M^+).

Zinc Mesoporphyrin-II *Dimethyl Diester* Zn(**8**).—Mesoporphyrin-II dimethyl ester (**8**) (0.5 g) was converted into the zinc derivative by the above procedure. Recrystallisation from dichloromethane–hexane gave a gelatinous mass of bright red microcrystals (0.55 g, 100%), m.p. 286—288 °C; δ_H (250 MHz, CD_2Cl_2 + [$^2H_5$]pyridine) 10.09 (2 H, s, meso), 10.07 (2 H, s, meso), 4.44 (4 H, t, *J* 7 Hz, H_d), 4.11 (4 H, q, *J* 7 Hz, H_b), 3.67 (6 H, s, porphyrin methyl), 3.66 (6 H, s, OMe), 3.64 (6 H, s, porphyrin methyl), 3.29 (4 H, t, 7 Hz, $H_{d'}$), and 1.87 (6 H, t, *J* 7 Hz, $H_{b'}$); δ_C ($CDCl_3$ + [$^2H_5$]pyridine) 173.78 ($C_{d'}$), 148.54, 148.06, 147.59, 147.06 (C-1, 4, 6, 9), 142.68, 138.42, 136.44, 135.44 (C-2, 3, 7, 8), 96.70, 96.45 (C-5, 10), 51.48 (OMe), 37.47 (C_d), 22.26 (C_b), 19.95 ($C_{d'}$), 17.74 ($C_{b'}$), and 11.75 and 11.62 ($C_{a,c}$); *m/z* 658 (M^+).

Magnesium Mesoporphyrin-II 3,3′-(4,4′-*Bipyridine*-2,2′-*diyl*)*dipropanol Diester* Mg(**2**).—Freshly sublimed 4-hydroxy-3,5-di-t-butyltoluene (BHT) (2.3 g) was dissolved in dry dichloromethane (25 ml) and the solution was cooled to 10 °C. Ethylmagnesium iodide [prepared from magnesium (286 mg) and ethyl iodide (2.4 ml) in dry ether (15 ml)] was added and the solution was stirred for 10 min in the dark. To this reagent (**16**) was added compound (**1**) (59 mg) in dry dichloromethane (15 ml). The metallation was followed by u.v./visible spectroscopy and was essentially complete in 10 min. Saturated aqueous disodium hydrogen phosphate (50 ml) was added to quench the excess of reagent and this was followed by THF (100 ml). The organic layers were washed with aqueous saturated disodium hydrogen phosphate, distilled water, and brine, dried ($MgSO_4$), and evaporated to provide a pink oil. This was passed through a column of neutral alumina (activity grade 3) eluting first with light petroleum (b.p. 60—80 °C) and then increasing amounts of dichloromethane to give the excess of BHT and some minor bands. The column was then thoroughly washed with dichloromethane until all of the minor bands were eluted and only a pink band at the top of the column remained. Addition of methanol (0.5%) slowly eluted this band. This material was then recrystallised from dichloromethane–pentane to give Mg(**2**) (32 mg, 52%) as purple crystals; $\lambda_{max.}$ (CH_2Cl_2) 336 (22 800), 410 (316 000), 544 (15 600), and 581 nm (12 700); δ_H (250 MHz, CD_2Cl_2–[$^2H_5$]pyridine) 10.00 (2 H, s, meso), 10.06 (2 H, s, meso), 7.90 (2 H, d, 5 Hz, α-H), 6.12 (2 H, d, 5 Hz, β-H), 5.25 (2 H, s, δ-H), 4.63 (2 H, ddd, *J* 14, 9, 5 Hz, H_d), 4.18 (2 H, ddd, *J* 14, 9, 5 Hz, H_d), 4.08 (4 H, q, *J* 7 Hz, H_b), 3.85 (2 H, ddd, *J* 13, 8, 5 Hz, CH_2O), 3.65 (6 H, s, porphyrin methyl), 3.60 (6 H, s, porphyrin methyl), 3.6 (2 H, m, CH_2O), 3.20—3.35 (4 H, m, $H_{d'}$), 1.86 (6 H, t, *J* 7 Hz, $H_{b'}$), 1.63 (2 H, m, $ArCH_2$), and 1.1—1.4 (6 H, m, $ArCH_2CH_2$); *m/z* (f.a.b.) 825 (M^+ + H).

Magnesium Mesoporphyrin-II 4,4′-(4,4′-*Bipyridine*-2,2′-*diyl*)*dibutanol Diester* Mg(**3**).—In an analogous manner compound (**3**) (10 mg) was converted into the title compound Mg(**3**) (5.8 mg, 53%); $\lambda_{max.}$ (CH_2Cl_2) 410, 545, and 580 nm; δ_H (250 MHz, CD_2Cl_2) 10.18 (2 H, s, meso), 9.99 (2 H, s, meso), 6.04 (2 H, d, *J* 2 Hz, δ-H), 5.96 (2 H, dd, *J* 5, 2 Hz, β-H), 4.85 (2 H, d, *J* 5 Hz, α-H), 4.63 (2 H, dt, *J* 14.7, H_d), 4.0—4.35 (8 H, overlapping multiplets, H_b, H_d, and CH_2O), 3.72 (6 H, s, porphyrin methyl), 3.63 (6 H, s, porphyrin methyl), 3.55 (2 H, m, CH_2O), 3.12 (2 H, m, $H_{d'}$), 3.25 (2 H, m, $H_{d'}$), 1.86 (6 H, t, *J* 7 Hz, $H_{b'}$), 0.8—1.1 (6 H, m, $ArCH_2CH_2CH_2$), and 0.0—0.25 (6 H, m, $ArCH_2CH_2$); *m/z* 854 (M^+).

Mesoporphyrin-II 3,3′-(N,N′-*Dimethyl*-4,4′-*bipyridine*-2,2′-*diyl*)*dipropanol Diester Chloride Salt* (**4**).—Compound (**2**) (10 mg) was dissolved in dichloromethane (5 ml) and methyl iodide (1 ml) was added. The reaction was kept in the dark and allowed to stand overnight. A precipitate of the methylated material formed; t.l.c. (alumina eluted with methanol) of the supernatant showed no material which moved from the baseline. Water (10 ml) was added and the aqueous layer was extracted with several portions of dichloromethane. The aqueous solution of porphyrin was concentrated to 2 ml and passed through an ion exchange column (Amberlite IR 45) in the chloride form. Evaporation of solvent yielded a purple glass which was sparingly soluble in chloroform but freely soluble in chloroform–5% methanol. It was taken up into this latter solvent and placed in a vial immersed in a beaker of pentane. This was covered and allowed to stand in the dark overnight. A purple gum (occasionally mixed with some crystals) precipitated. The slightly purple supernatant was removed and the latter procedure was repeated. This gave the viologen-bridged porphyrin (**4**) (8 mg, 80%); δ_H (400 MHz, CD_2Cl_2) 10.05 (2 H, s, meso), 10.15 (2 H, s, meso), 6.9 (2 H, d, *J* 5 Hz, α-H), 6.0 (2 H, d, *J* 5 Hz, β-H), 6.05 (2 H, s, δ-H), 4.6 (2 H, m, H_d), 4.1—4.3 (6 H, overlapping multiplets, H_b and H_d), 3.9—3.6 (4 H, m, CH_2O), 3.67 (6 H, s, porphyrin methyl), 3.60 (6 H, s, porphyrin methyl), 3.25 (6 H, s, NMe), 3.2—3.5 (4 H, m, $H_{d'}$), 1.9 (6 H, t, *J* 7 Hz, $H_{b'}$), 0.8—2.0 (8 H, m, bridge methylenes), −4.88 (2 H, s, NH); δ_H (400 MHz, CD_2Cl_2—[^2H]TFA) 10.78 (2 H, s, meso), 10.81 (2 H, s, meso), 8.45 (2 H, d, *J* 5 Hz, α-H), 7.72 (2 H, d, *J* 5 Hz, β-H), 7.08 (2 H, s, δ-H), 4.88 (2 H, m, H_d), 4.52 (2 H, m, H_d), 4.18 (4 H, q, *J* 7 Hz, H_b), 4.05 (6 H, s, NMe), 3.76 (6 H, s, porphyrin methyl), 3.70 (6 H, s, porphyrin methyl), 3.61 (2 H, m, CH_2O), 3.28 (2 H, m, CH_2O), 3.15 (4 H, m, $H_{d'}$), 2.55 (4 H, m, $ArCH_2$), 1.75 (6 H, t, *J* 7 Hz, $H_{b'}$), and 0.2—0.4 (4 H, m, $ArCH_2CH_2$); *m/z* (f.a.b.) 832 (M^+).

Mesoporphyrin-II 4,4′-(N,N′-*Dimethyl*-4,4′-*bipyridine*-2,2′-*diyl*)*dibutanol Diester Chloride Salt* (**5**).—By a similar procedure compound (**3**) (10 mg) was converted into the title compound (**5**) (7 mg, 70%); δ_H (250 MHz, CD_2Cl_2) 10.10 (2 H, s, meso), 10.20 (2 H, s, meso), 6.9 (2 H, d, *J* 5 Hz, α-H), 6.0 (2 H, d, *J* 5 Hz, β-H), 6.05 (2 H, s, δ-H), 4.6 (2 H, m, H_d), 4.1—4.3 (6 H, overlapping multiplets, H_b and H_d), 3.9—3.6 (4 H, m,

CH_2O), 3.67 (6 H, s, porphyrin methyl), 3.60 (6 H, s, porphyrin methyl), 3.25 (6 H, s, NMe), 3.2—3.5 (4 H, m, $H_{d'}$), 1.9 (6 H, t, J 7 Hz, $H_{b'}$), 1.5—2.0 and 0.8—1.1 (12 H, overlapping multiplets, bridge methylenes), and −4.8 (2 H, s, NH); m/z (f.a.b.) 860 (M^+).

Magnesium Mesoporphyrin-II 3,3′-(N,N′-*Dimethyl*-4,4′-*bipyridine*-2,2′-*diyl*)*dipropanol Diester Chloride Salt* Mg(**4**).—Compound Mg(**2**) (10 mg) was similarly converted into Mg(**4**) (7 mg, 70%). The *methyl* iodide was shaken with barium oxide to remove traces of acid prior to use. Pyridine (5%) was added to the water used for ion exchange to prevent demetallation. U.v./visible spectroscopy was used to monitor for possible demetallation; $\lambda_{max.}$ (CH_2Cl_2 + 1% pyridine) 412 (ε 98 000), 542 (5 300), and 578 nm (4 300); δ_H (400 MHz, D_2O) 10.1 (2 H, s, meso), 10.3 (2 H, s, meso), 7.3 (2 H, br, α-H), 5.4 (4 H, overlapping signals, β-H and δ-H), 4.2 (2 H, m, H_d), 3.9 (2 H, overlapping multiplets, H_b and H_d), 3.77 (6 H, s, NMe), 3.65 (12 H, s, porphyrin methyls), 3.25—3.8 (8 H, overlapping multiplets, $H_{d'}$ and CH_2O), 1.87 (6 H, t, J 7 Hz, $H_{b'}$), 0.5—1.3 (8 H, overlapping multiplets, bridge methylenes); m/z (f.a.b.) 856 (M^+).

2,5-*Dimethoxybenzene*-1,4-*dicarbaldehyde* (**22**).—A suspension of 1,4-bis(chloromethyl) 2,5-dimethoxybenzene (22.5 g 95 mmol) in chloroform (125 ml) was added to a solution of hexamine (28.8 g, 0.2 mmol) in chloroform (125 ml). The resultant mixture was refluxed for 16 h and then cooled to room temperature. The precipitated hexamine salt (**21**) was collected and dried *in vacuo* to yield a yellowish crystalline material (46.66 g, 95 mmol, 100%), m.p. 204 °C (decomp.) (lit.,[16] 204 °C).

This salt (37.5 g) was dissolved in water (230 ml) and treated with 40% formalin solution (20 ml). This mixture was refluxed for 21 h, during which time a yellow precipitate formed. The precipitate was collected and recrystallised from ethanol to give the *dialdehyde* (**22**) as yellow needles (7.8 g, 62%), m.p. 207—209 °C (lit.,[16] 207 °C); δ_H (60 MHz, $CDCl_3$) 3.85 (6 H, s, OMe), 7.3 (2 H, s, ArH), 10.5 (2 H, s, CHO); $\nu_{max.}$ 1 670 cm^{-1}; m/z 194 (M^+).

3,3′-(2,5-*Dimethoxy*-p-*phenylene*)*bispropenoic Acid* (**23**).—The dialdehyde (**22**) (5.28 g, 30 mmol) was dissolved in pyridine (36 ml) containing piperidine (0.5 ml) and malonic acid (12.5 g). This mixture was heated for 1 h at 80 °C, 2 h at 100 °C, and then finally under reflux for 20 h. After the mixture had cooled to room temperature, aqueous hydrochloric acid (100 ml, 12%) was added. The resultant precipitate was washed with dilute hydrochloric acid and twice recrystallised from pyridine as yellow prisms. Pyridine of crystallisation was removed by drying in a pistol (200 °C, 0.1 mmHg) for several hours to give the *diacid* (**23**) as yellow crystals (6.32 g, 75%) which gave highly fluorescent solutions in pyridine, m.p. > 300 °C; $\lambda_{max.}$ (CH_2Cl_2) 243 (ε 9 700), 308 (26 300), and 390 nm (15 000); δ_H (90 MHz, [$^2H_5$]pyridine) 3.8 (6 H, s, OMe), 7.2 (2 H, d, 18 Hz, CH=C*H*CO_2H), 7.36 (2 H, s, ArH), and 8.6 (2 H, d, J 18 Hz, C*H*=CHCO_2H); ν 2 900br, 1680s, and 1 615s cm^{-1}; m/z 278 (M^+) (Found: C, 60.7; H, 5.2. $C_{14}H_{14}O_6$ requires C, 60.40; H, 5.0%).

3,3′-(2,5-*Dimethoxy*-p-*phenylene*)*dipropionic Acid* (**24**).—The diacid (**23**) (1.39 g, 5 mmol) was dissolved in 1M aqueous sodium hydroxide (50 ml) and a suspension of Raney nickel in ethanol (*ca.* 1 ml) was added. The mixture was heated to 90 °C and hydrazine hydrate was added until the yellow colour was completely discharged. After all evolution of gas had ceased the solution was cooled and the acid was precipitated by the addition of an excess of hydrochloric acid. The precipitate was filtered off, and the *diacid* was recrystallised from water as colourless needles which slowly yellowed on exposure to air (1.19 g, 85%), m.p. 200—201 °C; δ_H [60 MHz, $(CD_3)_2SO$] 2.25—2.9 (8 H, m, CH_2CH_2), 3.7 (6 H, s, OMe), 5.7 (2 H, s, COOH), and 6.6 (2 H, s, ArH); $\nu_{max.}$ 3 000br and 1 700s; m/z 282 (M^+) (Found: C, 59.4; H, 6.35. $C_{14}H_{18}O_6$ requires C, 59.6; H, 6.4%).

Diethyl 3,3′-(2,5-*Dimethoxy*-p-*phenylene*)*dipropionate* (**25**).—A suspension of the diacid (**24**) (2.4 g, 8.5 mmol) in ethanol (150 ml) containing concentrated sulphuric acid (0.5 ml) was refluxed for 4 h. The solution was evaporated to dryness and the residue recrystallised from ethanol to yield the diester as needles (2.34 g, 81%), m.p. 61 °C; δ_H (60 MHz, $CDCl_3$) 1.2 (6 H, t, 7 Hz, CH_2CH_3), 2.4—3.0 (8 H, m, $CH_2CH_2CO_2Et$), 3.7 (6 H, s, OMe), 4.0 (4 H, q, 7 Hz, CH_2CH_3), and 6.48 (2 H, s, Ar*H*); m/z 338 (M^+) (Found: C, 64.05%; H, 7.8%. $C_{18}H_{26}O_6$ requires C, 63.9%; H, 7.69%).

3,3′-(2,5-*Dimethoxy*-p-*phenylene*)*dipropanol* (**18**).—A solution of the diethyl ester (**25**) (1.71 g, 5 mmol) in dry THF (25 ml) was added to a well stirred slurry of lithium aluminium hydride (0.5 g, 13 mmol) in dry THF (25 ml). The mixture was stirred at room temperature for 1 h and then worked up with cold water (10 ml), saturated aqueous ammonium chloride (20 ml), and dilute sulphuric acid (20 ml). The mixture was extracted with diethyl ether (3 × 50 ml), and the combined extracts dried ($MgSO_4$) and evaporated to dryness to yield the *diol* (**18**) as a solid. Recrystallisation from water gave needles (1.28 g, 100%), m.p. 93 °C; δ_H (90 MHz, $CDCl_3$) 1.75 (4 H, q, J 6 Hz, $CH_2CH_2CH_2OH$), 2.05 (2 H, s, OH), 2.6 (4 H, t, J 6 Hz, $ArCH_2$), 3.45 (4 H, t, J 6 Hz, CH_2OH), 3.65 (6 H, s, OMe), and 6.5 (2 H, s, ArH); $\nu_{max.}$ 3 290br, 1 220s, and 880m; m/z 254 (M^+) (Found: M^+, 254.1517. $C_{14}H_{22}O_4$ requires M, 254.1517).

Mesoporphyrin-II 3,3′-(2,5-*Dimethoxy*-p-*phenylene*)*dipropanol Diester* (**17**).—By the standard macrocyclisation procedure outlined above the diol (**18**) (134 mg, 0.53 mmol) was converted into the dimethoxybenzene-bridged porphyrin (**17**). Recrystallisation from dichloromethane–hexane gave fine purple crystals (95 mg, 23%), m.p. 254—256 °C; δ_H (250 MHz, CD_2Cl_2) 10.10 (2 H, s, meso), 9.99 (2 H, s, meso), 4.73 (2 H, ddd, 13, 8, 4 Hz, H_d), 4.20 (2 H, ddd, J 13, 8, 4 Hz, H_d), 4.09 (4 H, q, J 7 Hz, H_b), 3.7—3.9 (4 H, m, OCH_2), 3.75 (2 H, s, ArH), 3.66 (6 H, s, porphyrin methyl), 3.63 (6 H, s, porphyrin methyl), 3.2—3.55 (4 H, m, $H_{d'}$), 1.84 (6 H, t, J 7 Hz, $H_{b'}$), 0.9—1.05 (6 H, m, $ArCH_2CH_2CH_2O$), and 0.4—0.6 (2 H, m, $ArCH_2$); m/z 786 (M^+).

Mesoporphyrin-II 3,3′-(2,5-*Dioxo*-p-*phenylene*)*dipropanol Diester* (**7**).—The dimethoxybenzene-bridged porphyrin (**17**) (50 mg) was dissolved in dry dichloromethane (20 ml). Trimethylsilyl iodide (0.15 ml) was added and the mixture was stirred in the dark under nitrogen. The reaction was followed by thin layer chromatography (t.l.c.). Normally, the dimethoxybenzene-bridged porphyrin had fully reacted after 2—8 h. At this stage the t.l.c. (eluant dichloromethane–2% methanol) showed a cherry-red spot of lower R_F due to the hydroquinone. The reaction was worked up by the addition of water (50 ml). The organic layer was separated and the aqueous layer was extracted with dichloromethane (1 × 10 ml). The combined organic extracts were treated with lead dioxide (20 mg). T.l.c. (same solvent) after 5 min showed quantitative conversion into the quinone-bridged porphyrin, which gives a non-fluorescent purple spot of higher R_F than compound (**17**). The reaction mixture was filtered through Celite and evaporated under reduced pressure to yield a purple glass, recrystallisation of which from dichloromethane–hexane gave (**17**) (48 mg, 100%) as large prisms, m.p. 231—233 °C; spectroscopic and analytical properties as previously described.[6]

Zinc Mesoporphyrin-II 3,3′-(2,5-*Dioxo*-p-*phenylene*)*dipropanol Diester* Zn(7).—By the usual metallation procedure described above compound (7) (5 mg) was metallated with zinc acetate in dichloromethane–methanol. Recrystallisation from dichloromethane–hexane gave a mixture of fine pink powder and larger purple crystals (5 mg, *ca.* 100%), m.p. >250 °C; δ_H (250 MHz, CD_2Cl_2) 10.10 (2 H, s, meso), 9.96 (2 H, s, meso), 4.78 (2 H, m, H_d), 4.0—4.2 (10 H, m, H_b, $H_{d'}$ and CH_2O–), 3.78 (6 H, s, porphyrin methyl), 3.76 (6 H, s, porphyrin methyl), 3.3—3.5 (4 H, m, H_d), 2.76 (2 H, s, quinone proton), 1.89 (6 H, t, 7 Hz, $H_{b'}$), 0.3—0.55 (6 H, m, quinone CH_2CH_2), −0.35 (2 H, m, quinone CH_2); *m/z* 818 (M^+ + 2).

Acknowledgements

We are grateful to A. R. Battersby and C. Sporikou for supplies of mesoporphyrin-II bismethyl ester, the S.E.R.C. for a studentship (P. L.) and the Royal Society of Chemistry for a Hickinbottom Award (J. K. M. S.).

References

1 P. Leighton and J. K. M. Sanders, *J. Chem. Soc., Chem. Commun.*, 1984, 854.
2 R. J. Abraham, P. Leighton, and J. K. M. Sanders, *J. Am. Chem. Soc.*, 1985, **107**, 3472.
3 P. Leighton and J. K. M. Sanders, *J. Chem. Soc., Chem. Commun.*, 1984, 856.
4 P. Leighton and J. K. M. Sanders, *J. Chem. Soc., Chem. Commun.*, 1985, 24.
5 M. P. Irvine, R. J. Harrison, G. S. Beddard, P. Leighton, and J. K. M. Sanders, *Chem. Phys.*, 1986, **104**, 315.
6 K. N. Ganesh and J. K. M. Sanders, *J. Chem. Soc., Perkin Trans. 1*, 1982, 1611.
7 P. Leighton, J. A. Cowan, R. J. Abraham, and J. K. M. Sanders, in preparation.
8 J. A. Cowan and J. K. M. Sanders, following paper.
9 J. A. Cowan and J. K. M. Sanders, *J. Chem. Soc., Perkin Trans. 1*, 1985, 2435.
10 J. A. Cowan, J. K. M. Sanders, R. J. Harrison, and G. S. Beddard, *J. Chem. Soc., Chem. Commun.*, 1987, 55.
11 A. R. Battersby and A. D. Hamilton, *J. Chem. Soc., Chem. Commun.*, 1981, 117.
12 C. R. Smith, *J. Am. Chem. Soc.*, 1924, **46**, 414.
13 J. P. Collman, C. M. Elliot, T. R. Halbert, and B. S. Tovrog, *Proc. Natl. Acad. Sci. USA*, 1977, **74**, 18.
14 K. N. Ganesh, Ph.D. Thesis, University of Cambridge, 1980.
15 J. L. Y. Kong and P. A. Loach, *J. Heterocycl. Chem.*, 1980, **17**, 737.
16 J. H. Wood, C. C. Tuns, M. A. Perry, and R. E. Gibson, *J. Am. Chem. Soc.*, 1950, **72**, 2992.
17 R. Livshitz, G. I. Bazilevskaya, M. S. Bainova, O. E. Dobsovinskaya, and N. A. Preobrazhenskii, *J. Gen. Chem. USSR*, 1947, **17**, 1671.
18 N. S. Hjelte, *Acta Chem. Scand.*, 1961, **15**, 1200.
19 K. N. Ganesh, J. K. M. Sanders, and J. C. Waterton, *J. Chem. Soc. Perkin Trans. 1*, 1982, 1617.
20 A. Heuser and C. Stoehr, *J. Prakt. Chem.*, (2), 1890, **42**, 429.

Received 3rd *October* 1986; *Paper* 6/1952