A new synthesis of pyrroles and porphyrins fused with aromatic rings

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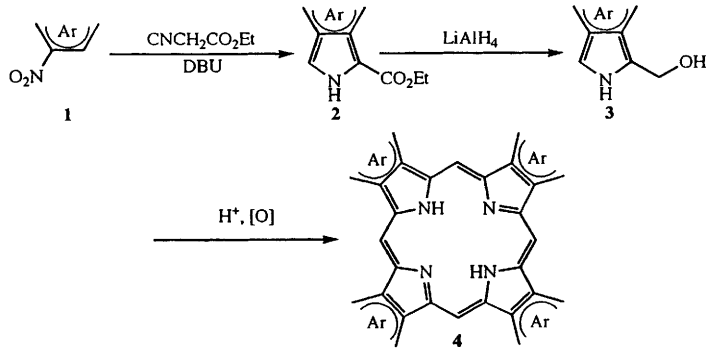
Pyrroles fused with aromatic rings (isoindole derivatives) have been readily prepared by the reaction of aromatic nitro compounds with ethyl isocyanoacetate in the presence of DBU. The ease of this reaction depends on the aromaticity of the starting nitro aromatics. Polycyclic aromatic nitro compounds such as 1-nitroacenaphthylene or 9-nitrophenanthrene are more reactive than simple nitro aromatics such as nitrobenzene or nitronaphthalenes and give the corresponding pyrroles in good yields. Pyrroles prepared by this method have been converted into porphyrins fused with various aromatic rings by the reduction with $LiAlH_4$ followed by treatment with an acid catalyst and oxidation with chloranil or oxygen. Tetra-1,2-naphthoporphyrin has been prepared by the reaction of 2-nitro-3,4-dihydronaphthalene or 1-nitronaphthalene with ethyl isocyanoacetate followed by reduction, tetramerization and oxidation. Thus, highly conjugated porphyrins are readily prepared starting from aromatic nitro compounds, and their electronic and optical properties can be controlled by choice of the starting aromatic nitro compound.

Highly conjugated porphyrins such as benzoporphyrins or naphthoporphyrins have been the subject of numerous studies in recent years.[1] These molecules are relatives of phthalocyanines and naphthocyanines and have potential values as conducting materials, near infrared dyes, nonlinear optical materials, or sensitizers for photo dynamic therapy (PDT). Compared to phthalocyanines and naphthocyanines, the corresponding porphyrins have been little studied, and syntheses of them have not been well developed. As conjugated porphyrin systems have larger calculated odd-α-electron band widths than the corresponding phthalocyanines, highly conjugated porphyrins are thought to be the most promising p-type semiconductors.[2] Furthermore, porphyrins or related pigments with red-shifted absorption bands are potentially useful as sensitizers for PDT as a result of the enhanced penetration of red light in tissue. Thus, compounds absorbing strongly in the red region are currently of interest in the field of PDT for tumours.[3] Recently, because of the potential value of such highly conjugated porphyrin systems, several improved syntheses of monobenzoporphyrins,[4] dibenzoporphyrins,[5] mononaphthoporphyrins,[6] dinaphthoporphyrins[7] and tetraphenanthroporphyrins[8] have been added to the established routes to tetrabenzoporphyrins[9] and tetra-2,3-naphthoporphyrins.[10] In order to synthesize such conjugated porphyrins, pyrroles fused with various aromatic rings (isoindoles) are the requisite starting materials. Although several routes are available for such pyrroles, they lack generality and are multistep.[11] In the previous communication we reported a simple solution to this problem. Namely, pyrroles fused with aromatic rings can be prepared by the reaction of aromatic nitro compounds with ethyl isocyanoacetate,[12] which will open a new route to highly conjugated porphyrins as outlined in Scheme 1. Here we report the experimental detail for the preparation of pyrroles fused with aromatic ring and their conversion into the corresponding porphyrins.

Results and discussion

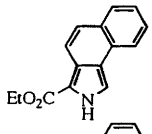
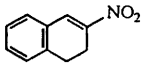
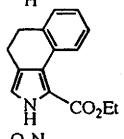
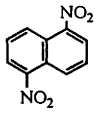
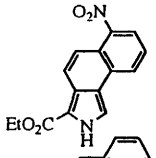
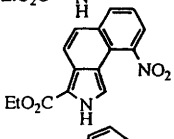
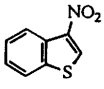
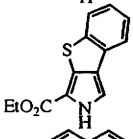
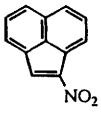
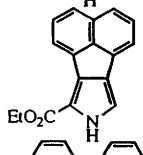
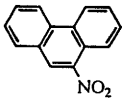
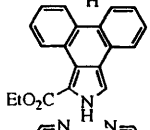
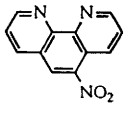
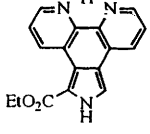
Preparation of the pyrroles 2

A variety of aromatic nitro compounds **1** were allowed to react with ethyl isocyanoacetate in the presence of DBU (see Table 1) to give the pyrroles **2** fused with various aromatic rings in 10–90% yield. The reactivity of **1** and the yield of **2** depend on the structure of the nitro aromatic component. Polycyclic nitro aromatics such as 1-nitroacenaphthylene **1f**, 9-nitrophenanthrene **1g**, and 5-nitro-1,10-phenanthroline **1h** reacted smoothly with ethyl isocyanoacetate under mild conditions to give the corresponding pyrroles **2f**, **2g** and **2h**, respectively, in good yields. Since the double bonds substituted with nitro groups in these compounds have alkene character, they behave as nitroalkenes towards the carbanion derived from ethyl isocyanoacetate to give pyrroles in good yield.[12] However, simple nitro aromatics such as nitrobenzene or its derivatives were less reactive toward ethyl isocyanoacetate than **1f**, **1g** and **1h**. For example, nitrobenzene was completely inert to the carbanion derived from ethyl isocyanoacetate under the conditions shown in Table 1. *m*- or *p*-Dinitrobenzene reacted with ethyl isocyanoacetate under the same conditions to give several products including the desired pyrroles. However, these reactions are useless for the preparation of fused pyrroles owing to the low yield and difficult separation of pure pyrroles from the products. On the other hand, the reaction of nitronaphthalenes with ethyl isocyanoacetate proceeded more cleanly than that of nitrobenzene or its derivatives, which gave the pure pyrroles in reasonable yields (See Table 1). 1-Nitronaphthalene **1a** gave the desired compound **2a** in 12% yield with 80% recovery of starting material; similarly, 2-nitronaphthalene gave the pyrrole in *ca.* 10% yield. Various efforts to improve the yield of **2a** have been unsuccessful. Dinitronaphthalenes **1c** and **1d** were much more reactive than **1a** to give the desired pyrroles **2c** and **2d** in 40 and 34% yield, respectively. Considering the simplicity of the procedure and availability of these nitro aromatics, the reaction of dinitronaphthalenes with ethyl isocyanoacetate may be useful for the direct synthesis of pyrroles fused with the naphthalene rings. Thus, simple aromatic nitro compounds such as nitrobenzene or 1- or 2-nitronaphthalene are not reactive enough to afford the corresponding pyrroles in good yields by this procedure. As an alternative route, the Barton pyrrole synthesis using nitroalkenes and ethyl isocyanoacetate might be considered.[13] In fact, 2-nitro-3,4-dihydronaphthalene **1b** reacted cleanly with ethyl isocyanoacetate to afford the corresponding pyrrole **2b** in 92% yield, which can be used as an equivalent of **2a** for the synthesis of porphyrin **4a** (see Scheme



Scheme 1

Table 1 Preparation of fused pyrroles

Nitro Compounds		Conditions[a]	Product		Yield (%)[b]
	**1a**	60°C, 48h		**2a**	12
	**1b**	RT, 24h		**2b**	92
	**1c**	RT, 12h		**2c**	43
	**1d**	RT, 12h		**2d**	32
	**1e**	RT, 8h		**2e**	60
	**1f**	RT, 7h		**2f**	70
	**1g**	RT, 8h		**2g**	75
	**1h**	RT, 8h		**2h**	87

[a] Solvent: THF. [b] Yields refer to pure isolated product.

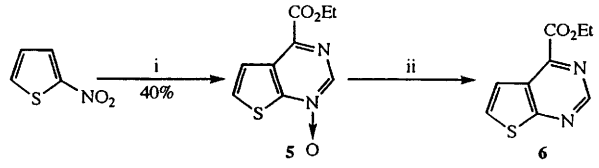
3). The requisite starting material **1b** was readily prepared by the nitration of the corresponding alkene.[14] Pyrrole **2b** is an excellent precursor to mononaphthoporphyrins and dinaphthoporphyrins, which have been recently reported.[6,7,15] In a similar way, the pyrroles prepared by the reaction of nitrocyclohexadienes with ethyl isocyanoacetate are also expected to be good precursors to benzoporphyrins. However, the realization of this transformation has encountered unexpected difficulties owing to the instability of nitrocyclohexadienes. The direct nitration of cyclohexadienes followed by the reaction with ethyl isocyanoacetate gave the desired pyrroles in low yield. We are now trying another approach to get nitrocyclohexadienes. The Diels–Alder reaction of β-sulfinylnitroethylene with dienes gave nitrocyclohexadienes,[16] which afforded the pyrroles fused with various cyclohexene rings on treatment with ethyl isocyanoacetate and 1,8-diazabicyclo-[4.4.0]undec-7-ene (DBU). Although this method requires more steps than the direct route, it offers the merit of the easy introduction of various substituents into fused cyclohexenes. The details for the preparation of benzoporphyrins by this route will be discussed in a separate paper.

If the present isoindole synthesis is extended to nitro heteroaromatics, we can prepare many pyrroles fused with various heteroaromatics. Since the aromaticity of nitro heteroaromatics is less than that of nitrobenzenes, nitro heteroaromatics are expected to be more reactive to the nucleophilic reagents in the present type of aromatic substitution reaction than nitrobenzenes. In fact, 3-nitrobenzothiophene **1e** was reactive enough to give the corresponding pyrrole **2e** in 60% yield by the present reaction (see Table 1). However, the DBU-catalysed reaction of 2-nitrothiophene with ethyl isocyanoacetate proceeded in the completely different way to give pyrimidine *N*-oxide **5** in 40% yield, the desired pyrrole not being formed (Scheme 2). The structure of **5** was confirmed by conversion of **5** into the pyrimidine **6** on treatment with PCl_3. We shall discuss the formation of pyrimidines from other nitro aromatics in a separate paper. Although there have been a variety of nucleophilic aromatic substitutions of hydrogen,[17] the present reaction is novel in that its driving force is the recovery of resonance energy by annulation. It should be noted that not all nitro aromatics give pyrroles fused with aromatic rings by a base-catalysed reaction with ethyl isocyanoacetate.

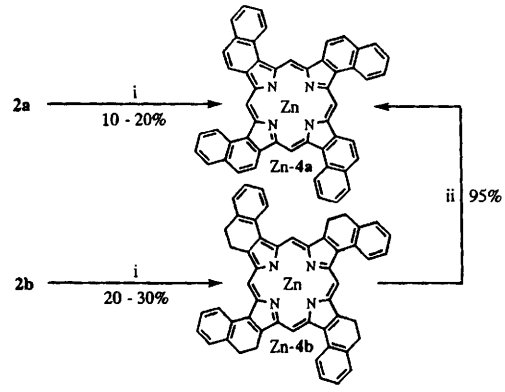
Porphyrin synthesis

The pyrroles **2** listed in Table 1 have potential as precursors for porphyrins fused with various aromatic rings. Such a conversion starts with the reduction of **2** to a 2-hydroxymethylpyrrole **3** followed by tetramerization and oxidation (see Scheme 1).[18] Thus **2a** was converted into the naphthoporphyrin **4a** as shown in Scheme 3. Initially, reduction of **2a** with $LiAlH_4$ at 0 °C for 1 h gave the corresponding alcohol and subsequent treatment of this alcohol with silica gel and zinc acetate in dichloromethane followed by oxidation with chloranil gave Zn-**4a** as a green powder (10–20%). The conditions for the reduction of the ethoxycarbonyl function of the pyrrole into the hydroxymethyl group with $LiAlH_4$ are crucial steps for the success of this conversion.† The same porphyrin was prepared in 20–30% yield by reduction of **2b** with $LiAlH_4$ followed by treatment with silica gel and zinc acetate and then oxidation with chloranil and DDQ. Demetallation of Zn-**4a** by treatment with hydrochloric acid gave **4a**, which was readily converted into the nickel complex Ni-**4a** by treatment with nickel acetate. In general, the chemical tetramerization of

† The reaction conditions for the conversion of ethyl 3,4-diethylpyrrole-2-carboxylate into octaethylporphyrin by reduction with $LiAlH_4$ have been re-investigated, and the importance of controlled reduction has been emphasized.[19]

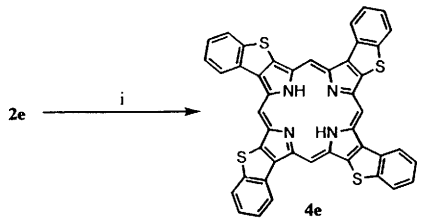


Scheme 2 *Reagents and conditions:* i, $CNCH_2CO_2Et$, DBU, THF, RT, 24 h; ii, PCl_3, $CHCl_3$, reflux, 2 h

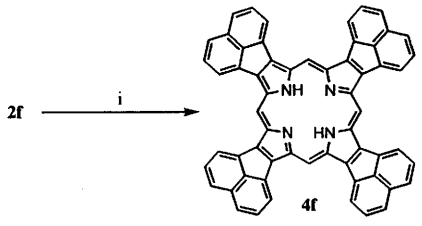


Scheme 3 *Reagents and conditions:* i, $LiAlH_4$, THF, 0 °C, 1 h; SiO_2, $Zn(OAc)_2$, CH_2Cl_2, RT, 24 h; chloranil, RT; ii, DDQ, benzene, 80 °C, 4 h

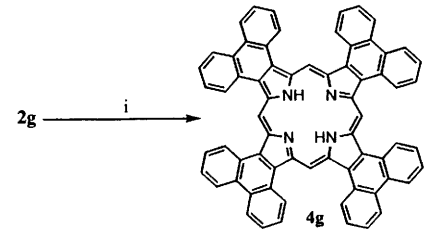
monopyrroles substituted with 2-hydroxymethyl- or related groups results in a mixture of the four possible regioisomeric porphyrins.[20] The scrambling can be minimized by the use of solid catalysts such as silica gel[21] or montmorillonite clay K-10 as the acid catalyst.[22] Thus, porphyrins prepared by the present procedure have a symmetrical structure (C_{4h}), which can be assigned on the basis of the 400 MHz proton NMR spectra of Zn-**4a** (see Fig. 1). The *meso* protons appear at δ 10.03 as a sharp singlet and protons of the naphthalene rings appear at δ 9.10 (d), 8.11 (d), 7.94 (d), 7.74 (d), 7.70 (m), 7.62 (m) which supports a proposed symmetrical structure. When *p*-TsOH was used as an acid, serious scrambling of porphyrins occurred to give a mixture of four isomers, whose *meso* protons appeared as a multiplet. The former method starting from 1-nitronaphthalene is very attractive as a general synthetic method for porphyrins fused with aromatic rings, since aromatic nitro compounds are more readily available than cyclic nitro dienes. The choice of these methods depend on the availability of starting nitro compounds and the yield of the annulated pyrroles. In this sense, conversion of **2e–h** into the corresponding porphyrins is very attractive, since the requisite nitroaromatics are readily available and the yields of the pyrroles **2e–h** are good. The pyrroles **2e**, **2f** and **2g** were converted into the corresponding porphyrins **4e**, **4f** and **4g** in a similar way to that described in the preparation of **4a**; the conversion of **2h** was unsuccessful however. In the case of **4e**, montmorillonite clay K-10 was the most effective acid catalyst among those tested (silica gel, K-10, and *p*-TsOH).[23] Nevertheless, complete suppression of scrambling proved difficult and a mixture of four regioisomers was formed, the type I porphyrin (illustrated as **4e** in Scheme 4) being the main product. Since it was impossible to separate the four regioisomers of **4e** by column chromatography or recrystallization, only suitably controlled conditions for tetramerization will allow isolation of pure regioisomers of **4e**. For **4f** and **4g**, where regioisomers are not a problem, their preparation is quite simple. After the reduction of **2f** or **2g** with $LiAlH_4$, addition of *p*-TsOH to the reaction mixture effectively induced tetramerization, to give, after the final oxidation with chloranil or oxygen, **4f** and **4g** in 10–20% yield (Schemes 5 and 6). Since these porphyrins are highly conjugated, even during the tetramerization step partial oxidation takes place and is completed by passage of oxygen through the reaction mixture. Such a process avoids



Scheme 4 *Reagents and conditions:* i, $LiAlH_4$, 0 °C, 1 h, THF; K-10, RT, 10 h; chloranil



Scheme 5 *Reagents and conditions:* i, $LiAlH_4$, 0 °C, 1 h, THF; *p*-TsOH, $CHCl_3$, RT, 48 h; O_2



Scheme 6 *Reagents and conditions:* i, $LiAlH_4$, 0 °C, 1 h, THF; *p*-TsOH, $CHCl_3$, RT, 48 h; O_2

the tedious procedures necessary to remove chloranil and its reduced material from the product mixture. Recently, Lash has reported the synthesis of **4g** by a similar procedure,[8] in which $BF_3{\cdot}Et_2O$ is recommended as an acid catalyst; neither use of *p*-TsOH nor $BF_3{\cdot}Et_2O$ influenced the product yields. The insolubility of the porphyrins **4f** and **4g** in most organic solvents, precluded their characterization as neutral entities. However, since on treatment with trifluoroacetic acid (TFA) they gave diprotonated species which were soluble in $CHCl_3$, they were characterized in this form by UV-VIS and NMR spectroscopy in the presence of 1% TFA in $CHCl_3$ or $CDCl_3$. In order to increase the solubility of these porphyrins in organic solvents, porphyrins with long alkyl substituents are necessary, and efforts to introduce these into the acenaphthylene or phenanthrene rings of **4g** and **4f** are now being pursued. Since a porphyrin fused with a 1,10-phenanthroline ring may both serve as a versatile ligand and play an important role in molecular recognition and self-assembling systems,[24] the synthesis of such porphyrins is of interest; we are, therefore, now seeking a further approach to the conversion of **2h** into a porphyrin.

The electronic absorption spectra of compounds **4a** and **4b** are shown in Figs. 2 and 3, respectively, and the data are summarized in Table 2. The electronic spectrum of **4b** is of the rhodo-type (the intensity of the Q bands is III > IV > II > I), but that of **4a** is quite different; namely, the lowest energy band (band I) has λ_{max} 672 nm with a high molar extinction. In Fig. 3, the electronic spectra of **4a** are compared with those of the conventional porphyrins such as the zinc complex of *meso*-tetraphenylporphyrin (TPP) and β-octaphenylporphyrins (OPP). Because of the extended π-electron system of naphthoporphyrins, both Soret and Q bands are red shifted. Furthermore, the intensity of the Q (0,0) bands of **4a** and Zn-**4a** are much stronger than those of TPP and ZnTPP. These properties are desirable in a sensitizer for PDT applications. The similar trends were also observed in **4e**, and these properties

Table 2 Absorption spectra of **4a** and **4e** in CH_2Cl_2

Compound	λ/nm (log ε)			
4a	438 (5.28)	568 (4.13)	601 (4.76)	611 (4.61) 672 (4.57)
Zn-**4a**	452 (5.36)	585 (3.12)		634 (4.90)
Ni-**4a**	464 (5.21)	592 (3.05)		635 (4.98)
4b	416	521	560	588 645
4e	432	558	586	597 659
Zn-**4e**	438 (4.74)	572 (3.83)		616 (4.03)
Ni-**4e**	452	575		614
TPP	417 (5.65)	515 (4.15)	548(3.65)	588 (3.34) 647 (3.33)
Zn-TPP	422 (5.79)	552 (4.72)		593 (4.56)

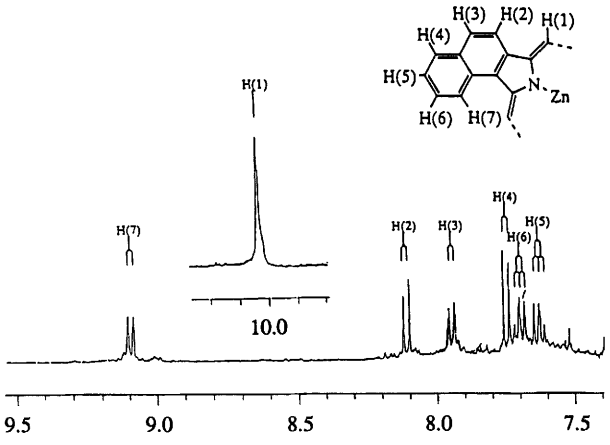


Fig. 1 ^1H NMR spectrum of Zn-**4b**

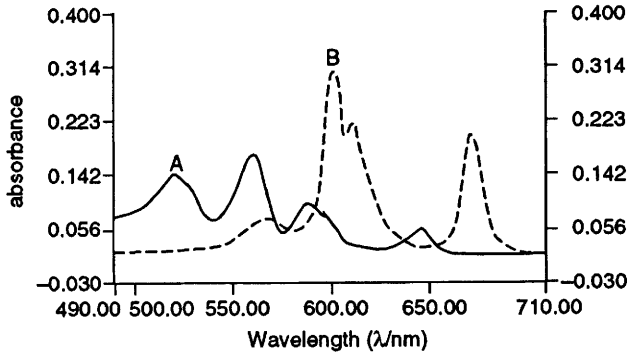


Fig. 2 Visible or Q band region of the electronic spectra for **4b** (A) and **4a** (B) in dichloromethane. The Soret bands for **4b** and **4a** appear at 416 and 438 nm, respectively, which are omitted.

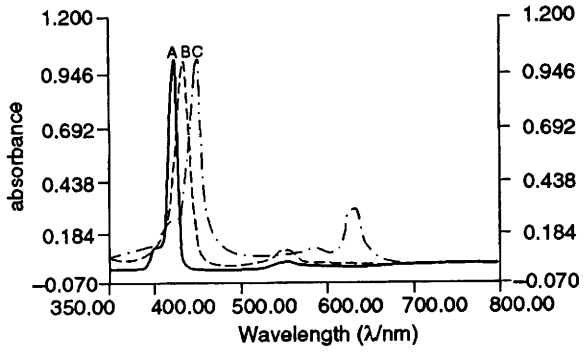


Fig. 3 Electronic spectra for ZnTPP (A), ZnOPP (B) and Zn-**4a** (C) in dichloromethane

were common in porphyrins fused with aromatic rings (Table 2). Since neutral porphyrins **4f** and **4g** were not soluble enough to show clean absorption spectra, a direct comparison of these with other porphyrins was difficult. Thus, the electronic spectra of the diprotonated porphyrins of **4a**, **4e**, **4f** and **4g** were compared in order to estimate the extent of π-conjugation

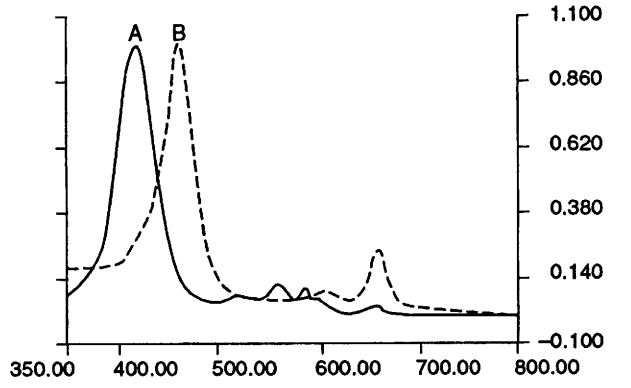


Fig. 4 Electronic spectra of **4e** in CH_2Cl_2 (A) and $CHCl_3$ containing 1% TFA (B)

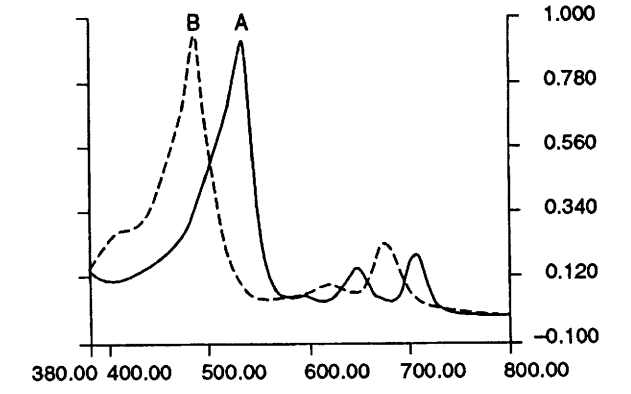


Fig. 5 Electronic spectra of **4f** (A) and **4g** (B) in $CHCl_3$ containing 1% TFA

between the porphyrin ring and the fused aromatics (Figs. 4, 5 and Table 3). The electronic spectrum of diprotonated **4e** (Fig. 4) shows that both the Soret band and the Q bands are red-shifted, but the latter less than the former. The aggregation of porphyrins must be taken into account when comparing their electronic spectra. In general, the Soret bands are blue-shifted and the Q bands are red-shifted when porphyrins are aggregated in a face-to-face fashion. Compared to neutral porphyrins, diprotonated ones are less aggregated and their absorption spectra become sharp and shifted. Since aggregation of neutral porphyrins of **4f** and **4g** is considerable, their electronic spectra show very broad, ill-defined absorption; in the presence of 1% TFA in $CHCl_3$, however, these sharpen (see Fig. 4). The Soret band of diprotonated **4f** was observed at 528 nm, which was red-shifted by *ca.* 30 nm compared to that of diprotonated **4g**. The Q bands of diprotonated **4f** were also red-shifted by 20–30 nm compared to those of diprotonated **4g**. Although it is difficult to predict the exact Soret and Q bands of neutral **4f** from the present data, the λ_{max} of **4f** should, compared with those of the other porphyrins prepared, be at the longest wavelength of the new porphyrins presented, here π-conjugation of the aromatic rings with the porhyrin rings is most effective in **4f**.

Table 3 Absorption spectra of diprotonated porphyrins in 1% CF_3CO_2H–$CHCl_3$

Compound	λ/nm		
4a	462	614	670
4b	460	580	625
4e	462	604	659
4f	528	647	702
4g	482	615	668

Table 4 Redox potentials of **4a**, **4e** and Zn-TPP

Compound	E_{Ox}^1	E_{Ox}^2	E_{Rd}^1	E_{Rd}^2	$E_{Ox}^1 - E_{Rd}^1$
Zn-**4a**	0.32	0.71	−1.65	−1.89	1.97
Ni-**4a**	0.59	0.94	−1.39	−1.68	1.98
Zn-**4e**	0.46	0.79	−1.60		2.06
Ni-**4e**	0.71	0.92	−1.30		2.01
Zn-TPP	0.65	0.95	−1.67	−2.20	2.32

Potentials (V *vs.* SCE) were measured by CV with 0.1 mol dm^{-3} Bu_4NClO_4 in CH_2Cl_2 at room temperature (scan rate, 50 mV/s).

In order to elucidate the redox properties of these new porphyrins, cyclic voltammetry of Zn-**4a**, Ni-**4a**, Zn-**4e**, Ni-**4e** and ZnTPP was carried out under identical conditions, the redox potentials depending on the solvent and concentration; the results are summarized in Table 4. The first oxidation potential (E^1_{ox}) of Zn-**4a** is 0.32 V *vs.* SCE and much lower than that of ZnTPP (0.65 V), while the first reduction potentials (E^1_{re}) of Zn-**4a** and ZnTPP are almost the same, −1.65 and −1.67 V, respectively. Thus, the difference $E^1_{ox} - E^1_{re}$ (HOMO-LUMO difference) was substantially lowered by the extension of the π-conjugation in the naphthoporphyrins. Although the HOMO-LUMO difference of **4f** and **4g** was expected to be further lowered, their redox potentials could not be measured by the CV method because of their low solubility in organic solvents. However, their absorption spectra suggest that π-electrons of **4f** are the most highly conjugated.

Thus, the redox properties of compounds **4** can be finely tuned by selection of an appropriate aromatic ring fused to the β-position of the pyrrole rings and a variety of such compounds may be envisaged.[25]

In summary, we present a new strategy for the preparation of highly conjugated porphyrin systems starting from aromatic nitro compounds. Namely, aromatic nitro compounds react with ethyl isocyanoacetate to give pyrroles fused with aromatic rings. Pyrroles thus prepared are converted into porphyrins fused with aromatic rings by reduction, tetramerization and oxidation. This method opens a new way to control the intrinsic electronic and optical properties of porphyrins, for the π-electrons of the porphyrins fused with aromatic rings are effectively conjugated through the whole π-electron systems. The degree of π-conjugation of these new porphyrins depends on the fused aromatic rings. At present, the acenaphthylene ring is the best aromatic component for conjugation with the porphyrin rings. The scope and limitations of the present porphyrin synthesis and applications of highly conjugated porphyrin systems to electronic and optical devices are now under investigation.

Experimental

Mps were measured by a Yanaco micro melting point apparatus and are uncorrected. ^{1}H NMR spectra were recorded on a JEOL-JNM-GSX270 or JNM-EX 400 spectrometer and *J* values are given in Hz. IR and UV–VIS spectra were recorded with a Hitachi 270-30 and Shimadzu UV-2200 spectrometer, respectively. Mass spectra were taken on a Hitachi M-80B and FAB mass spectra of porphyrins were measured with a JEOL JMS-DX-300 spectrometer; samples were dissolved in $CHCl_3$ and *m*-nitrobenzyl alcohol was used as the matrix. The cyclic voltammetry was carried out at room temperature under nitrogen using a Yanagimoto P-1100 under the conditions described in Table 4.

Nitro aromatics which were not commercially available were prepared by the conventional methods using HNO_3–Ac_2O. 3-Nitrobenzothiophene **1e**: mp 46–48 °C, 1-nitroacenaphthylene **1f**: mp 123–124 °C (lit.,[26] 124–125 °C), 9-nitrophenanthrene **1g**: mp 117–118 °C (lit.,[27] 118 °C), and 5-nitro-1,10-phenanthroline **1h**: mp 202–204 °C (lit.,[28] 202–204 °C) were prepared.

Ethyl 2*H*-benz[*e*]isoindole-3-carboxylate 2a
A solution of 1-nitronaphthalene **1a** (1.73 g, 10 mmol), ethyl isocyanoacetate (1.24 g, 11 mmol) and DBU (1.67 g, 11 mmol) in THF (50 cm^3) was heated at 60 °C for 48 h. Work-up followed by column chromatography (silica gel, ethyl acetate–hexane) gave **2a** (0.28 g, 12%), mp 215–217 °C; $\delta_H(CDCl_3)$ 1.48 (t, 3 H, *J* 7.0), 4.47 (q, 2 H, *J* 7.0), 7.31–7.35 (m, 2 H), 7.81 (d, 1 H, *J* 7.6), 7.86 (d, 1 H, pyrrole α-H, *J* 3.6), 8.02 (d, 1 H, *J* 8.2), 8.14 (d, 1 H, *J* 8.1) and 9.99 (s, NH); ν_{max}/cm^{-1} 3450 (NH) and 1750 (CO_2Et) (Found: M^+, 239.0991. $C_{15}H_{13}NO_2$ requires *M*, 239.0993).

Ethyl 4,5-dihydro-2*H*-benz[*e*]isoindole-1-carboxylate 2b
To a solution of **1b** (1.75 g, 10 mmol) and ethyl isocyanoacetate (1.24 g, 11 mmol) in THF (20 cm^3) was added a solution of DBU (1.67 g, 11 mmol) in THF (5 cm^3) at 0 °C. The resulting solution was stirred at room temperature for 24 h. Work-up followed by column chromatography (silica gel, ethyl acetate–hexane) gave **2b** (2.2 g, 92%), mp 68–70 °C; $\delta_H(CDCl_3)$ 1.37 (t, 3 H, *J* 7), 2.63 (m, 2 H), 2.83 (m, 2 H), 4.36 (q, 2 H, *J* 7), 6.71 (d, 1 H, *J* 2), 7.16–7.26 (m, 4 H) and 9.06 (s, NH) (Found: C, 74.8; H, 6.3; N, 5.7%; M^+, 241. $C_{15}H_{15}NO_2$ requires C, 74.7, H, 6.3; N, 5.8%; M^+, 241).

The pyrroles **2c–h** were prepared by the same procedures as described in the preparation of **2a** and under the conditions shown in Table 1.

Ethyl 6-nitro-2*H*-benz[*e*]isoindole-3-carboxylate 2c. Mp 257–259 °C; $\delta_H(CDCl_3)$ 1.50 (t, 3 H, *J* 7.0), 4.50 (q, 2 H, *J* 7.0), 7.60 (t, 1 H, *J* 7.9), 7.92 (d, 1 H, *J* 3.4), 8.04 (dd, 1 H, *J* 7.3, 1.2), 8.09 (d, 1 H, *J* 9.8), 8.23 (d, 1 H, *J* 9.4), 8.39 (d, 1 H, *J* 8.0) and 10.22 (br s, 1 H); ν_{max}/cm^{-1} 3432 (NH), 1680 (C=O), 1520 and 1360 (NO_2) (Found: C, 64.67; H, 4.24; N, 9.66. $C_{15}H_{12}N_2O_4$ requires C, 63.38; H, 4.26; N, 9.86%).

Ethyl 9-nitro-2*H*-benz[*e*]isoindole-3-carboxylate 2d. Mp 252–254 °C; $\delta_H(CDCl_3)$ 1.42 (t, 3 H, *J* 7.0), 4.49 (d, 2 H, *J* 7.0), 7.60 (t, 1 H, *J* 8.0), 7.92 (d, 1 H, *J* 3.8), 8.04 (dd, 1 H, *J* 7.3, 1.2), 8.09 (d, 1 H, *J* 8.7), 8.23 (d, 1 H, *J* 9.4), 8.39 (d, 1 H, *J* 7.6) and 10.17 (br s, 1 H); ν_{max}/cm^{-1} 3432 (NH), 1664 (C=O), 1510 and 1324 (NO_2) (Found: C, 64.7; H, 4.3; N, 9.8. $C_{15}H_{12}N_2O_4$ requires C, 63.38; H, 4.26; N, 9.86%).

Ethyl 2*H*-[1]benzothieno[2,3-*c*]pyrrole-2-carboxylate 2e. Mp 213–214 °C; $\delta_H(CDCl_3)$ 1.54 (t, 3 H, *J* 7.0), 4.42 (q, 2 H, *J* 7.0), 7.30–7.38 (m, 2 H), 7.46 (d, 1 H, *J* 3.1), 7.71–7.75 (m, 1 H), 7.80–7.84 (m, 1 H), 9.65 (br s, 1 H); ν_{max}/cm^{-1} 3200 (NH) and 1640 (C=O) (Found: C, 63.35; H, 4.5; N, 6.0. $C_{13}H_{11}NO_2S$ requires C, 63.65; H, 4.52; N, 5.71%).

Ethyl acenaphtho[1,2-*c*]pyrrole-7-carboxylate 2f. Mp 182–184 °C; $\delta_H(CDCl_3)$ 1.55 (t, 3 H, *J* 7.0), 4.53 (q, 2 H, *J* 7.0), 7.18 (d, 1 H, *J* 3.1), 7.50–6.80 (m, 5 H), 8.10 (d, 1 H, *J* 8.5) and 9.07 (br s, 1 H); ν_{max}/cm^{-1} 3290 (NH) and 1680 (C=O) (Found: C, 77.5; H, 4.7; N, 5.4. $C_{17}H_{13}NO_2$ requires C, 77.55; H, 4.72; N, 5.32%).

Ethyl phenanthro[9,10-*c*]pyrrole-2-carboxylate 2g. Mp 147–149 °C; $\delta_H(CDCl_3)$ 1.46 (t, 3 H, *J* 7.0), 4.46 (q, 2 H, *J* 7.0), 7.48–7.58 (m, 2 H), 7.62 (d, 1 H, *J* 3.1), 8.12 (d, 2 H), 8.53 (d, 2 H) and 8.93 (br s, 1 H); ν_{max}/cm^{-1} 3456 (NH) and 1706 (C=O) (Found: M^+, 289.1093. $C_{19}H_{15}NO_2$ requires *M*, 289.1099).

Ethyl 2*H*-dibenz[*e*,*g*]isoindole-1-carboxylate 2h. Mp > 300 °C; $\delta_H([^2H_6]$-DMSO) 1.49 (t, 3 H, *J* 7.0), 4.49 (q, 2 H, *J* 7.0), 7.77 (m, 2 H), 8.43 (d, 1 H, *J* 3.66), 8.86 (d, 1 H, *J* 8.2), 8.95

(d, 1 H, *J* 4.3), 8.99 (d, 1 H, *J* 4.6), 10.14 (d, 1 H, *J* 8.2) and 13.14 (br s, 1 H); ν_{max}/cm^{-1} 3436 (NH) and 1698 (C=O) (Found: M$^+$, 291.0891. $C_{17}H_{13}N_3O_2$ requires *M*, 291.0893).

Reaction of 2-nitrothiophene with ethyl isocyanoacetate

A solution of DBU (1.6 g, 10 mmol) in THF (10 cm^3) was added to a stirred solution of 2-nitrothiophene (1.3 g, 10 mmol) and ethyl isocyanoacetate (1.2 g, 10 mmol) in THF (20 cm^3) at room temperature and the resulting mixture was stirred for 24 h. After work-up, the crude product was subjected to a column chromatography (silica gel/hexane–ethyl acetate) to give **5** (0.8 g, 40%), mp 133–134 °C; δ_H($CDCl_3$) 1.50 (t, 3 H), 4.60 (q, 2 H, *J* 2), 7.77 (d, 1 H, *J* 3.1), 8.16 (d, 1 H, *J* 3.1) and 9.84 (s, 1 H); *m*/*z* 224 (M$^+$). The structure of **5** was confirmed by the conversion of **5** into **6** on treatment with PCl_3. Compound **6**: mp 79–80 °C; δ_H($CDCl_3$) 1.52 (t, 3 H, *J* 7.0), 4.60 (q, 2 H, *J* 7.0), 7.76 (d, 1 H, *J* 2.1), 8.09 (d, 1 H, *J* 3.2) and 9.28 (s, 1 H) (Found: C, 51.95; H, 3.8; N, 13.6. $C_9H_8N_2O_2S$ requires C, 51.91; H, 3.87; N, 13.45%).

Tetranaphtho[1,2-*b*; 1′,2′-*g*; 1″,2″-*l*; 1‴,2‴-*q*]porphyrin 4a

A solution of **2a** (0.82 g, 3.4 mmol) in THF (5 cm^3) was added to a stirred mixture of $LiAlH_4$ (0.2 g, 5.2 mmol) in THF (30 cm^3) at 0 °C under N_2 and the resulting mixture was stirred for 1 h at 0–5 °C. It was then poured into saturated aqueous NH_4Cl, and extracted with CH_2Cl_2 (100 cm^3 × 3). The combined extracts were mixed with silica gel (for column chromatography, 5 g) and zinc acetate (10 mmol) and the resulting mixture was stirred in the dark for 24 h at room temperature before chloranil (0.4 g) was added to it. After the mixture had been stirred for 8 h it was filtered and the collected solid was washed with CH_2Cl_2. The combined extracts were concentrated and the residue subjected to column chromatography (silica gel, CH_2Cl_2) to give crude Zn-**4a**. This was purified by recrystallization from MeOH–$CHCl_3$ to give Zn-**4a** (0.07 g, 12%) as a green powder. Conversion of Zn-**4a** into **4a** and Ni-**4a** was carried out by a literature procedure.[29] Compound **4a**: green powder, ν_{max}/cm^{-1} 3408, 2916, 1580, 1530, 1482, 1352, 1092, 1048, 810, 734 and 676; λ_{max}/nm 438 (log ε 5.28), 563 (4.13), 601 (4.76), 611 (4.61) and 672 (4.57) [Found (HRMS): [M + H]$^+$, 711.2472. $C_{52}H_{30}N_4$ requires 710.2464]. Compound Zn-**4a**: green powder, δ_H($CDCl_3$) 7.62 (m, 4 H), 7.70 (m, 4 H), 7.74 (d, 4 H), 7.94 (m, 4 H), 8.11 (d, 4 H), 9.10 (d, 4 H) and 10.03 (s, 4 H); ν_{max}/cm^{-1} 3408, 2916, 1580, 1530, 1482, 1352, 1092, 1048, 810, 734 and 676; λ_{max}/nm 452 (log ε 4.59), 588 (3.55) and 634 (4.07) [Found (LRMS): (M + H)$^+$, 773. $C_{52}H_{28}N_4Zn$ requires 772]. Compound Ni-**4a**: green powder, ν_{max}/cm^{-1} 3640, 3410, 2956, 2920, 2868, 1728, 1646, 1462, 1436, 1392, 1366, 1248, 1160, 1120, 790 and 670; λ_{max}/nm 438 (log ε 4.92), 592 (3.10) and 635 (4.01) [Found (LRMS): (M + H)$^+$, 767. $C_{52}H_{28}N_4Ni$ requires 766].

8,9,17,18,26,27,35,36-Octahydrotetranaphtho[1,2-*b*; 1′,2′-*g*; 1″,2″-*l*; 1‴,2‴-*q*]porphyrin 4b

The pyrrole **2b** gave **4b** as a purple powder in 20–30% yield by a similar procedure to that adopted in the preparation of **4a**; δ_H($CDCl_3$) −3.4 (s, 4 H, NH), 5.23 (t, 8 H), 7.34 (t, 3 H), 7.7–8.2 (m, 12 H), 9.01 (d, 4 H) and 10.9 (s, 4 H); λ_{max}/nm (CH_2Cl_2) 416, 521, 560, 588 and 645; ν_{max}/cm^{-1} 3428, 3304, 3040, 2924, 2828, 1728, 1604, 1542, 1488, 1436, 1328, 1184, 1160, 1002, 972, 952, 920, 834, 796, 764, 730, 674 and 652 [Found (HRMS): (M + H)$^+$, 719.3092. $C_{52}H_{38}N_4$ requires 718.3088]. Compound Zn-**4b**: purple powder, ν_{max}/cm^{-1} 3524, 3036, 2924, 2880, 1600, 1492, 1446, 1292, 1160, 1112, 1018, 974, 936, 836, 798, 764, 732, 688, 674 and 538; λ_{max}/nm (CH_2Cl_2) 432, 556 and 594 [Found (LRMS): (M + H)$^+$, 781. $C_{52}H_{36}N_4Zn$ requires 780].

A mixture of Zn-**4b** (0.078 g, 0.1 mmol) and DDQ (0.12 g, 0.5 mmol) in benzene (10 cm^3) was refluxed for 4 h and the subsequent column chromatography (silica gel, CH_2Cl_2) gave Zn-**4a** (0.073 g, 95%).

Tetra[1]benzothieno[2,3-*b*; 2′,3′-*g*; 2″,3″-*l*; 2‴,3‴-*q*]porphyrin 4e

The pyrrole **2e** (2.45 g, 10 mmol) was reduced to the corresponding alcohol with $LiAlH_4$ (0.9 g) in THF (150 cm^3) by a similar procedure to that adopted in the preparation of **4a**. Montmorillonite clay K-10 (5 g) was added to a solution of the crude alcohol in $CHCl_3$ (100 cm^3) and the mixture was stirred for 12 h at room temperature in the dark. Chloranil (2.5 g, 10 mmol) was added to the reaction mixture after which it was filtered and the collected solid washed with THF. The combined filtrate and washings were concentrated and the residue was subjected to column chromatography (silica gel, $CHCl_3$). The crude porphyrin was purified by recrystallization from $CHCl_3$–MeOH to give **4e** (0.37 g, 20% yield) as a green powder; δ_H($CDCl_3$) −3.7 (s, 2 H), 7.8–7.92 (m, 12 H), 8.05 (m, 4 H) and 10.5 (s, 4 H). NMR results showed the presence of other isomers; δ_H 10–11 (m, *meso* H); ν_{max}/cm^{-1} 3640, 3436, 3060, 2956, 1722, 1668, 1646, 1532, 1434, 1392, 1364, 1314, 1234, 1216, 1200, 1160, 1120, 1058 and 1008; λ_{max}/nm (CH_2Cl_2) 432, 558, 586, 597 and 659 [Found (HRMS): (M + H)$^+$, 735.0736. $C_{44}H_{22}N_4S_4$ requires 734.0724]. Compounds Zn-**4e** and Ni-**4e** were prepared by the reaction of **4e** with the corresponding metal acetates in $CHCl_3$. Compound Zn-**4e**: green powder; λ_{max}/nm (log ε) in CH_2Cl_2 438 (4.74), 572 (3.83) and 616 (4.03) [Found (LRMS): (M + H)$^+$, 797. $C_{44}H_{20}N_4S_4Zn$ requires 796]. Compound Ni-**4e**: green powder, λ_{max}/nm in CH_2Cl_2 452, 575 and 614 [Found (LRMS): (M + H)$^+$, 791. $C_{44}H_{20}N_4S_4Ni$ requires 790].

Tetraacenaphtho[1,2-*b*; 1′,2′-*g*; 1″,2″-*l*; 1‴,2‴-*q*]porphyrin 4f

The pyrrole **2f** (1.17 g, 4.4 mmol) was reduced to the corresponding alcohol with $LiAlH_4$ (0.34 g, 8.8 mmol) in THF (70 cm^3) at 0 °C in a similar manner to that adopted in the preparation of **4a**. *p*-TsOH (0.08 g) was added to a solution of the crude alcohol in $CHCl_3$ (500 cm^3) and the mixture was stirred for 48 h at room temperature in the dark. Oxygen was then passed through the reaction mixture for 30 min after which crude product **4f** was precipitated and filtered off. Recrystallization of the crude product from MeOH–$CHCl_3$ containing 1% TFA gave diprotonated **4f** (0.08 g, 10% yield) as a dark green powder: δ_H($CDCl_3$–TFA) −2.2 (br, 4 H, NH), 8.20 (t, 8 H), 8.41 (d, 8 H), 9.31 (d, 2 H) and 12.0 (s, 4 H); λ_{max}/nm ($CHCl_3$–TFA) 528, 647 and 702 [Found (LRMS): (M + H)$^+$, 807. $C_{60}H_{30}N_4$ requires 806].

Tetraphenanthro[9,10-*b*; 9′,10′-*g*; 9″,10″-*l*; 9‴,10‴-*q*]porphyrin 4g

After the pyrrole **2g** (1.16 g, 4 mmol) had been reduced with $LiAlH_4$ (0.34 g, 8.8 mmol) in THF at 0 °C the product was treated by similar procedures to those adopted in the preparation of **4f** to give diprotonated **4g** (0.18 g, 20% yield) as a dark green powder: δ_H($CDCl_3$–TFA) −0.55 (br, 4 H, NH), 8.10 (t, 8 H), 8.23 (t, 8 H), 9.22 (d, 8 H), 9.68 (d, 8 H) and 12.0 (s, 4 H); λ_{max}/nm ($CHCl_3$–TFA) 482, 615 and 668 [Found (LRMS): (M + H)$^+$, 911. $C_{68}H_{38}N_4$ requires 910]. These spectra data were in good agreement with those reported in the literature.[8]

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