Selective preparation of polycyclic aromatic hydrocarbons. Part 5.[1] Bromination of 2,7-di-*tert*-butylpyrene and conversion into pyrenoquinones and their pyrenoquinhydrones

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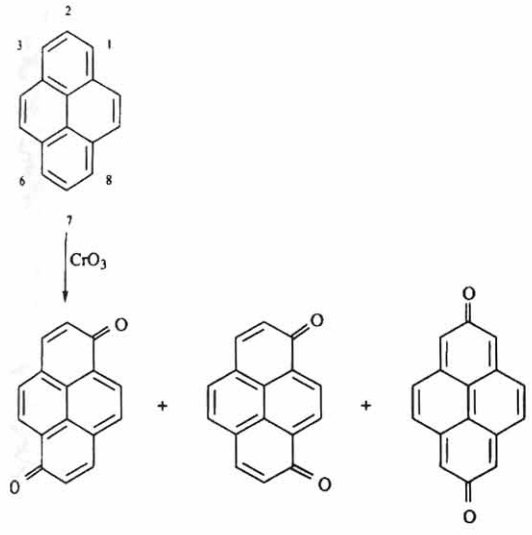
The bromination of 2,7-di-*tert*-butylpyrene 1 with 1.1 mol equiv. and 2.2 mol equiv. of bromine in a carbon tetrachloride solution afforded 1-bromo-2,7-di-*tert*-butylpyrene 2a and a mixture of 1,6-dibromo- (3a) and 1,8-dibromo-2,7-di-*tert*-butylpyrene (3b) in 85 and 73% yield, respectively. On the other hand, when the same reaction was carried out with 6.0 mol equiv. of bromine in the presence of iron powder, an acid-catalysed rearrangement of bromine atoms was observed to give 4,5,9,10-tetrabromo-2,7-di-*tert*-butylpyrene 4 in 90% yield. The same orientation in the chlorination of substrate 1 was also observed to afford 2,7-di-*tert*-butyl-1-chloropyrene 2b. The conversion of tetrabromide 4 into 2,7-di-*tert*-butylpyrene-4,5,9,10-tetraone 15 was carried out by the reaction of compound 4 with sodium methoxide in the presence of copper(I) iodide, followed by demethylation of the corresponding 4,5,9,10-tetramethoxy derivative 12 with boron tribromide. The strong charge-transfer complex of tetraone 15 and its hydroquinone 13 was observed as being due to the pyrene skeleton. The mechanism of the above novel bromination is also discussed.

Introduction

There are numerous reports concerning the quinhydrone type of charge-transfer complex such as those between *p*-benzoquinones and hydroquinones. However, to our knowledge (surprisingly), none of the pyrenoquinones appears to have been studied with respect to their abilities as charge-transfer complexation acceptors despite the fact that the expanded π-conjugation system would provide a strong charge-transfer interaction with potential donors. There is therefore substantial interest in investigating the charge-transfer complexation between expanded π-conjugation systems such as pyrenes and pyrenoquinones.

The regioselective oxidation of pyrene seems to be quite difficult in spite of the fact that electrophilic substitution of pyrene itself occurs at the 1-, 3-, 6- and 8-positions.[2,3] For example, Vollmann *et al.* reported[3] that the oxidation of pyrene with chromic acid afforded 1,6- and 1,8-pyrenoquinones as major products along with lesser amounts of the 2,7-analogue [see eqn. (1)]. Therefore, the selective preparation of pyrenoquinones by direct oxidation would be very difficult because of the low product yields as well as the necessity of their separation from the reaction mixture. On the other hand, pyrene-4,5,9,10-tetraone was prepared by oxidation of pyreno-4,5-quinone with chromic acid in 71% yield.[3] However, the preparation of pyreno-4,5-quinone itself was accomplished in only a low total yield from phenanthrene *via* several steps using alkaline fusion of 4-formylphenanthrene-5-carboxylic acid to construct a pyrene ring.[3]



(1)

Electrophilic substitution of pyrene occurred at the 1-, 3-, 6- and 8-positions (as previously mentioned), but not at the other positions (2, 4, 5, 7, 9 and 10).[2-7] Therefore, pyrenes substituted at the latter positions must be prepared in ways other than by direct electrophilic substitution of pyrene itself.[8,9] Quite recently, we have found[10] that the $AlCl_3$-catalysed acetylation of 2,7-di-*tert*-butylpyrene **1** with acetyl chloride, using the *tert*-butyl group as a positional protective group, afforded only the 4,9-diacetylated product, 4,9-diacetyl-2,7-di-*tert*-butylpyrene. This strategy is also suitable for the preparation of 4,5,9,10-tetrasubstituted pyrenes, which themselves afforded convenient starting materials for the attempted preparation of pyrene-4,5,9,10-tetraone.

We now report the bromination of hydrocarbon **1** to enable us to study the behaviour of electrophilic reagents in further detail and the application of this method to the preparation of hydroxypyrenes as well as to 2,7-di-*tert*-butylpyrene-4,5,9,10-tetraone and its quinhydrone.

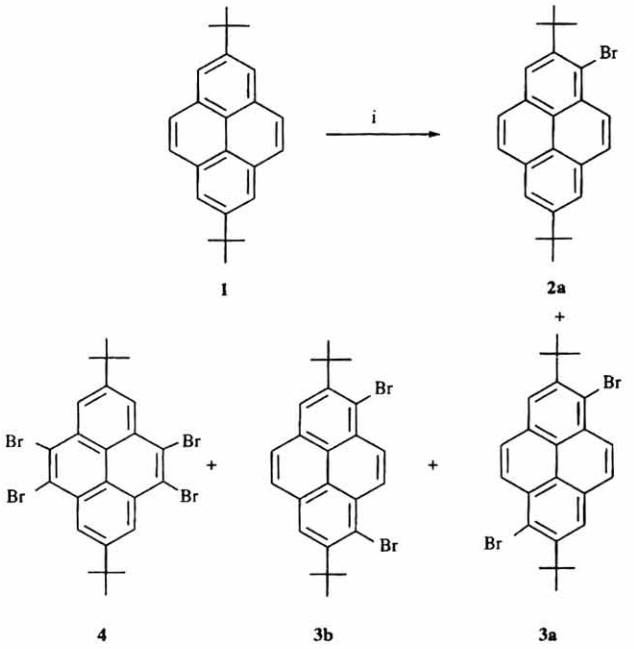
Results and discussion

The bromination of 2,7-di-*tert*-butylpyrene **1** with 1.1 mol equiv. of bromine in a carbon tetrachloride solution afforded 1-bromo-2,7-di-*tert*-butylpyrene **2a** in 85% yield (Scheme 1; Table 1). Friedel–Crafts acetylation of hydrocarbon **1** occurred selectively at the 4-position to afford the corresponding 4-acetylpyrene in good yield,[10b,10c] whereas in other electrophilic substitutions such as nitration[6] the same selectivity was not observed. Only 2,7-di-*tert*-butyl-1-nitropyrene was obtained. The difference in regioselectivity (4 *versus* 1) between the acetylation and the above electrophilic aromatic substitution

Table 1 Bromination of 2,7-di-*tert*-butylpyrene **1** with various bromination reagents

Run	Substrate	Reagents	Reagents/**1** (mol/mol)	Products (%)[a]
1	**1**	Br_2	1.1	**2a** (85)
2	**1**	Br_2–Fe	1.1	**2a** (80)
3	**1**	NBS	1.1	**2a** (90)
4	**1**	BTMA Br_3	1.2	**2a** (80)
5	**1**	Br_2	2.2	**3a**, **3b** (73)[b]
6	**1**	BTMA Br_3	2.4	**3a**, **3b** (80)[b]
7	**1**	Br_2–Fe	6.0	**4** (90)
8	**2a**	Br_2–Fe	6.0	**4** (85)
9	**3a**, **3b**	Br_2–Fe	6.0	**4** (90)

[a] The isolated yields are shown. [b] A mixture of compounds **3a** and **3b** was obtained in the ratio 50:50 (^{1}H NMR).



1 **2a** **4** **3b** **3a**

Scheme 1 (see Table 1) *Reagents and conditions:* i, Bromination reagents, room temperature, 1 h

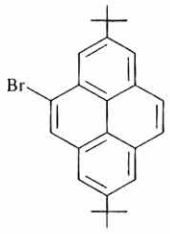
such as bromination and nitration of compound **1** may be due to steric hindrance from the electrophiles in normal aromatic systems.[12]

^{1}H NMR spectral data (270 MHz; $CDCl_3$) of bromide **2a** show 2 sets of doublets with the *ortho*-coupling constant (J 9.2 and 9.5 Hz) at δ 7.97,8.02 and 8.12,8.70, as well as sets of doublets with the *meta*-coupling constant (J 1.8 Hz) at δ 8.20 and 8.22, which are assigned to the protons of positions 4,5,9,10 and 6,8, respectively, on the pyrene ring. These data strongly support the structural assignment of 1-bromo-2,7-di-*tert*-butylpyrene **2a**.

The same results were obtained in the presence of iron powder, *N*-bromosuccinimide, and benzyltrimethylammonium tribromide (BTMA Br_3).[13] Similarly, the bromination of compound **1** with 2.2 mol equiv. of bromine was carried out to afford a mixture of 1,6-dibromo- (**3a**) and 1,8-dibromo-2,7-di-*tert*-butylpyrene (**3b**) in 73% yield in the ratio 50:50 (^{1}H NMR). Fractional recrystallization from methanol and hexane furnished the complete separation to give pure regioisomers **3a** and **3b**, respectively. The structures of compounds **3a** and **3b** were assigned by spectral data and elemental analysis. Thus, ^{1}H NMR spectral data (270 MHz; $CDCl_3$) of compound **3a** show 2 sets of doublets with the *ortho*-coupling constant (J 9.5 Hz) at δ 8.09 and 8.74 as well as a singlet at δ 8.31, which are assigned to the protons at positions 4, 5, 9, 10 and 3, 8, respectively, on the pyrene ring. On the other hand, ^{1}H NMR spectral data (270 MHz; $CDCl_3$) of isomer **3b** show three singlets (relative intensity 1:1:1) at δ 8.01, 8.30 and 8.78. These data strongly support the assignment of structures 1,6-dibromo-2,7-di-*tert*-butylpyrene **3a** and 1,8-dibromo-2,7-di-*tert*-butylpyrene **3b**.

The relatively easy electrophilic substitution at a position *ortho* to a *tert*-butyl group (6- or 8-position) on the pyrene ring is remarkable because usually the steric bulkiness of a *tert*-butyl group might be expected to direct the substitution towards other positions on the pyrene ring. This result is strongly attributable to the high reactivity of the 1-, 3-, 6- and 8-positions on the pyrene ring.

On the other hand, when the same reaction was carried out with 6.0 mol equiv. of bromine in the presence of iron powder, the acid-catalysed rearrangement of bromine atoms was observed to give 4,5,9,10-tetrabromo-2,7-di-*tert*-butylpyrene **4** in 90% yield. It seems that compound **5** might be formed by isomerization of compound **2a** catalysed by $FeBr_3$, which should be produced from bromine and Fe powder present during the bromination. In fact, when 1-bromo-2,7-di-*tert*-butylpyrene **2a** was treated with $FeBr_3$ in a carbon tetrachloride solution at room temperature for 3 h, the expected product, 4-bromo-2,7-di-*tert*-butylpyrene **5**[14] was obtained in 80% yield. However, attempted isomerization of compound **2a** with other Lewis acids, such as $TiCl_4$, $AlCl_3$ or $FeCl_3$, performed under the same reaction conditions failed. The starting compound **2a** was recovered quantitatively.



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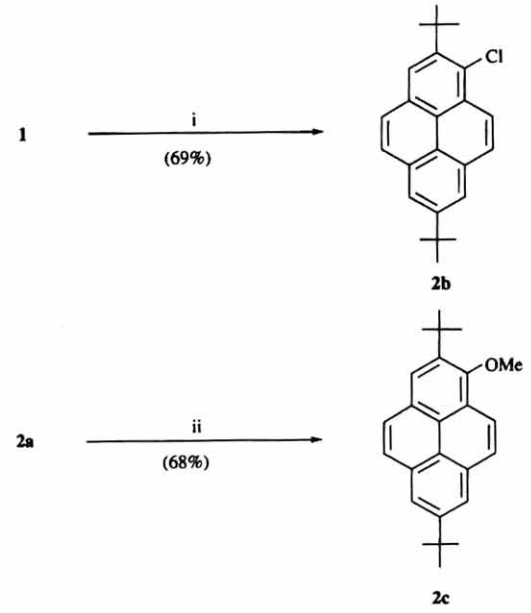
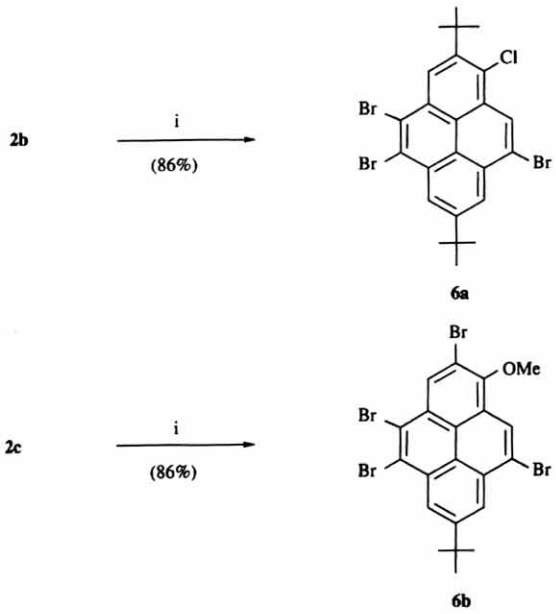
The same $FeBr_3$-catalysed rearrangement to afford tetrabromide **4** was observed in the bromination of a mixture of dibromopyrenes **3a** and **3b** in the presence of iron powder. The above results strongly suggest that compounds **2a**, **5**, **3a** and **3b** were the intermediates for the formation of the tetrabromopyrene **4**.

In order to study this novel $FeBr_3$-catalysed isomerization of bromide **2a** in more detail, we have attempted to prepare 1-substituted 2,7-di-*tert*-butylpyrenes **2** and to try to get them to react with bromine in the presence of iron powder. The preparation of 1-chloro- (**2b**) and 1-methoxy-2,7-di-*tert*-butylpyrene **2c** is shown in Scheme 2. Thus, chlorination of hydrocarbon **1** with sulfuryl chloride in the presence of BF_3–diethyl ether at 0 °C for 4 h afforded the corresponding 1-chloro derivative **2b** in 69% yield. The conversion of bromide **2a** into 1-methoxy derivative **2c** can be furnished by reaction with NaOMe in the presence of copper(I) iodide in 68% yield.

The bromination of 2,7-di-*tert*-butyl-1-chloropyrene **2b**[14] with Br_2 in carbon tetrachloride was carried out under the same conditions as described above. Formation of the rearrangement product corresponding to tetrabromide **4** has not been observed, but tribrominated pyrene **6a** was obtained in 86% yield (Scheme 3). In the case of 2,7-di-*tert*-butyl-1-methoxypyrene **2c**, *ipso*-bromination of the *tert*-butyl group at the 2-position occurred to give 2,4,5,9-tetrabromo-7-*tert*-butyl-1-methoxypyrene **6b** in 86% yield. These results seem to suggest that the present $FeBr_3$-induced isomerization of a substituent from the 1- to the 4-position is limited to the bromine group. It was also found that when 2,7-di-*tert*-butyl-1-chloropyrene **2b** was treated with $FeBr_3$ under the same conditions as the 1-bromo derivative **2a**, the starting compound was recovered almost quantitatively. Although the detailed mechanism of formation of the 4,5,9,10-tetrabromopyrene **4** is not clear, one



Scheme 2 *Reagents and conditions:* i, SO_2Cl_2, $BF_3{\cdot}Et_2O$, 0 °C, 4 h; ii, NaOMe, CuI, MeOH–DMF, reflux, 30 h

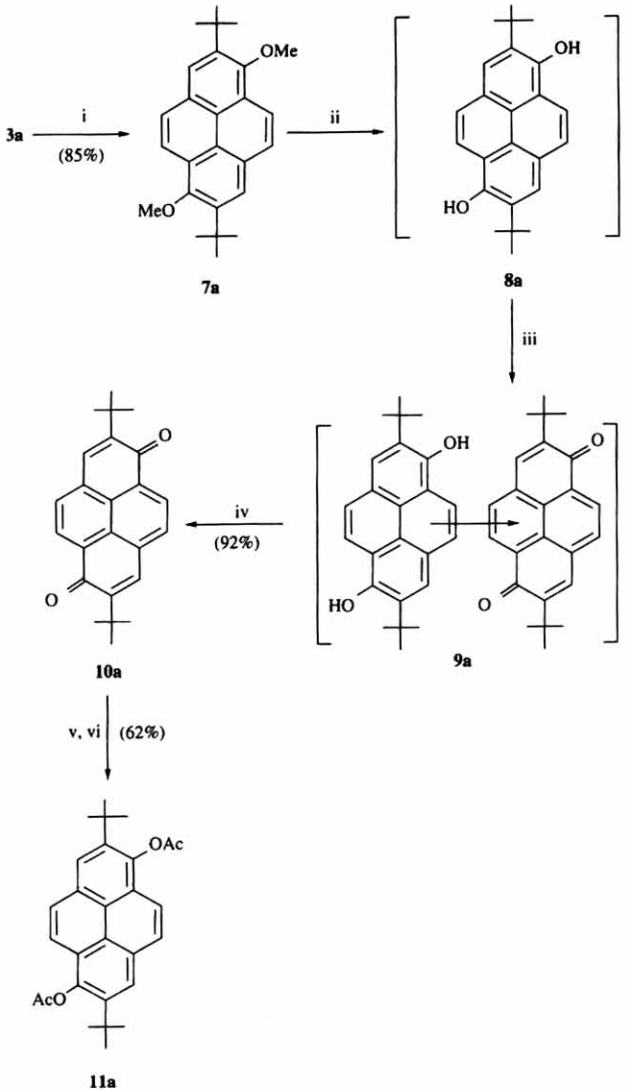


Scheme 3 *Reagents and conditions:* i, Br_2, CCl_4, Fe powder, room temperature, 1 h

might assume the reaction pathway. As mentioned previously, the highly reactive electrophilic substitution at a position *ortho* to a *tert*-butyl group (1-, 3-, 6- or 8-position) on the pyrene ring is remarkable in spite of steric hindrance from the bulky *tert*-butyl group. This result is strongly attributable to the high reactivity of the 1-, 3-, 6- and 8-positions on the pyrene ring. However, owing to the increased steric crowdedness between the 1-bromo group and the *tert*-butyl group at the 2-position of the pyrene ring in the kinetically controlled intermediate with bromophilic attack at the 1-position of pyrene ring, the bromine rearranges to the 4-position *via* a bromonium intermediate. This would be driven by the release of steric strain between the *tert*-butyl group and can be demonstrated by molecular models. Subsequently bromine addition to the pyrene ring at the 4-position is much more favourable than to that at the 1-position. The present bromine rearrangement is strongly accelerated by $FeBr_3$ generated in the system.

It is concluded that the above novel isomerization is strongly affected by the bulkiness of the electrophiles which increases strain in the molecule and the value of the carbon–halogen bond energy.

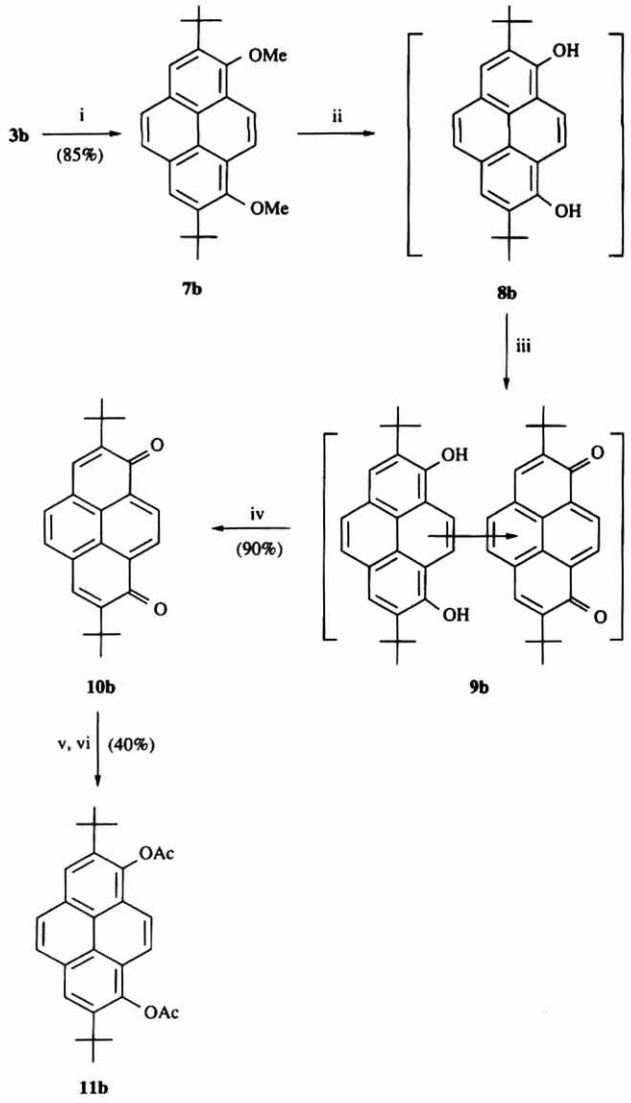
Von Braun reaction[15] of 1,6-dibromo- (**3a**) and 1,8-dibromo-2,7-di-*tert*-butylpyrene (**3b**) with NaOMe in the presence of CuI afforded the desired 1,6-dimethoxy- (**7a**) and 1,8-dimethoxy-2,7-di-*tert*-butylpyrene (**7b**) both in 85% yield (Schemes 4, 5).



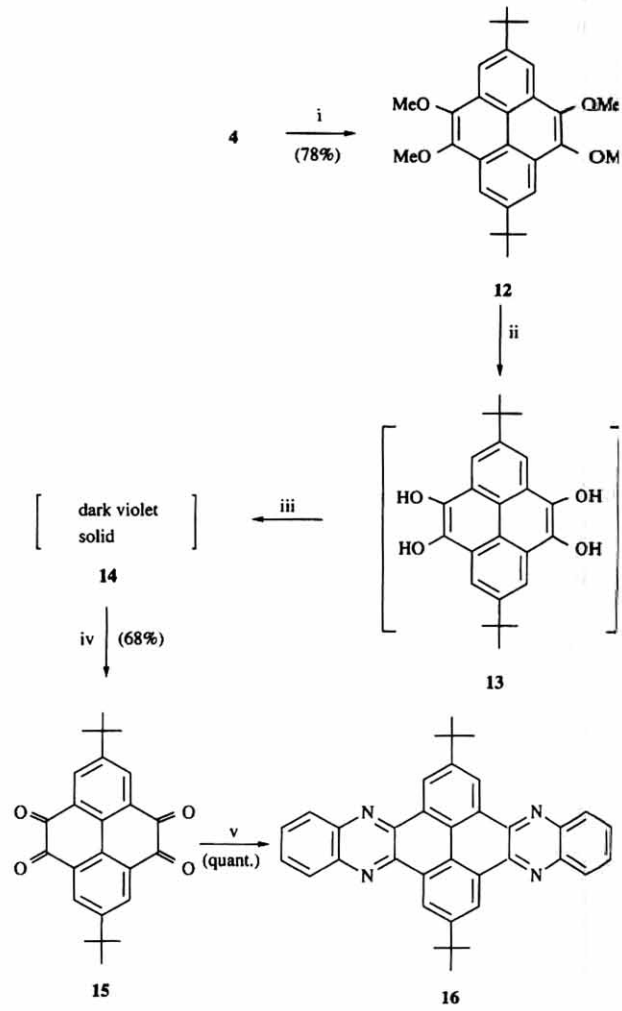
Scheme 4 *Reagents and conditions:* i, NaOMe, CuI, MeOH–DMF, reflux, 30 h; ii, BBr_3, CH_2Cl_2, room temperature, 3 h; iii, air oxidation; iv, SiO_2; v, Zn, HOAc, 80 °C; vi, Ac_2O–HCl, 80 °C, 5 min

Attempted demethylation of 2,7-di-*tert*-butyl-1,6-dimethoxypyrene **7a** with BBr_3[16] in methylene dichloride to give 2,7-di-*tert*-butyl-1,6-dihydroxypyrene **8a** failed. Only 2,7-di-*tert*-butylpyrene-1,6-dione **10a** was obtained, as reddish brown prisms in 92% yield. This finding suggests that aerial oxidation of diol **8a** to 1,6-dione **10a** occurred rapidly during the demethylation reaction.

When zinc powder was added to a solution of 1,6-dione **10a** in acetic acid, the solution changed colour rapidly from brown to reddish purple in a few minutes. After prolonged reaction the reaction mixture became pale yellow. Then, to the reaction mixture were added acetic anhydride and a small amount of conc. HCl to afford diacetate **11a** as prisms in 62% yield. Thus, partial hydrogenation of 1,6-dione **10a** gives the coloured quinhydrone **9a**, which can be reduced further in a few minutes to pale yellow 1,6-diol **8a**. Attempted isolation of 1,6-diol **8a** again failed. Only 1,6-dione **10a** was obtained by aerial oxidation.



Scheme 5 *Reagents and conditions:* as for Scheme 4



Scheme 6 *Reagents and conditions:* i, NaOMe, CuI, MeOH–DMF, reflux, 30 h; ii, BBr_3, CH_2Cl_2, room temperature, 3 h; iii, air oxidation; iv, SiO_2; v, *o*-phenylenediamine, EtOH, room temperature, 2 h

The ^{1}H NMR spectrum of dione **10a** shows 2 sets of doublets with the *ortho*-coupling constant (J 7.3 Hz) at δ 7.72 and 8.40 as well as a singlet at δ 7.49, which are assigned to the protons at positions 4, 5, 9, 10 and 3, 8 on the pyrene ring.

The same treatment of 2,7-di-*tert*-butyl-1,8-dimethoxypyrene **7b** with BBr_3 in methylene dichloride gave the corresponding pyrenoquinhydrone **9b** as a dark violet solid, which was found to be a mixture of 1,8-diol **8b** and 1,8-dione **10b** in the ratio 50:50 by ^{1}H NMR spectroscopy in $CDCl_3$. On SiO_2 column chromatography treatment the pyrenoquinhydrone **9b** was easily converted into 1,8-dione **10b** completely. A similar phenomenon to that mentioned for dione **10a** was observed during the reduction of 1,8-dione **10b** with zinc in the presence of acetic anhydride and conc. HCl to afford diacetate **11b**.

Von Braun reaction of 4,5,9,10-tetrabromo-2,7-di-*tert*-butylpyrene **4** with NaOMe in the presence of CuI afforded the desired 2,7-di-*tert*-butyl-4,5,9,10-tetramethoxypyrene **12** in 78% yield (Scheme 6).

Attempted demethylation of 2,7-di-*tert*-butyl-4,5,9,10-tetramethoxypyrene **12** with BBr_3 in methylene dichloride to give 2,7-di-*tert*-butyl-4,5,9,10-tetrahydroxypyrene **13** also failed. Only the corresponding pyrenoquinhydrone **14** was obtained, as a dark violet solid. On SiO_2 column chromatography treatment the pyrenoquinhydrone **14** was easily converted into 4,5,9,10-tetraone **15** completely, as orange prisms. This finding suggests that aerial oxidation of tetraol **13** to 4,5,9,10-tetraone **15** occurred during the demethylation.

The ^{1}H NMR spectrum of tetraone **15** shows a singlet at δ 8.40, which is assigned to the protons at positions 1, 3, 6 and 8 on the pyrene ring. It was also found that the reaction of tetraone **15** with *o*-phenylenediamine afforded the desired bis(quinoxaline) **16** in almost quantitative yield. This finding strongly supports the bis(*o*-quinone) structure of tetraone **15**.

When zinc powder was added to a solution of 4,5,9,10-tetraone **15** in acetic acid, the solution changed colour rapidly from orange to reddish brown in a few minutes, and then to colourless with prolonged time. Subsequently, acetic anhydride and a small amount of conc. HCl were added to the reaction mixture to afford diacetate **17** as pale yellow prisms in 94% yield (Scheme 7). Thus, partial hydrogenation of 4,5,9,10-tetraone **15** gives the coloured quinhydrone **14**, which can be reduced further in a few minutes to colourless 4,5,9,10-tetraol **13**. Attempted isolation of 4,5,9,10-tetraol **13** failed. Only 4,5,9,10-tetraone **15** was obtained by aerial oxidation.

The lower frequency band in the IR spectrum (1628 cm^{-1}) of 1,8-dione **10b** in comparison with those of 1,6-dione **10a** (1680 cm^{-1}) and tetraone **15** presumably reflects the expanded conjugation of the π-electron system in spite of the expanded OCC bond angles ascribed to an increase in the sterically crowded environment between the *tert*-butyl groups of this system by analogy to the highly strained [2.2]paracyclophan-1-one[17] and the corresponding [2.2]metacyclophane analogue.[18]

The UV spectra of diones **10a**, **10b**, tetraone **15** and 2,7-di-*tert*-butyl-1,8-dimethoxypyrene **7b** in cyclohexane are shown in

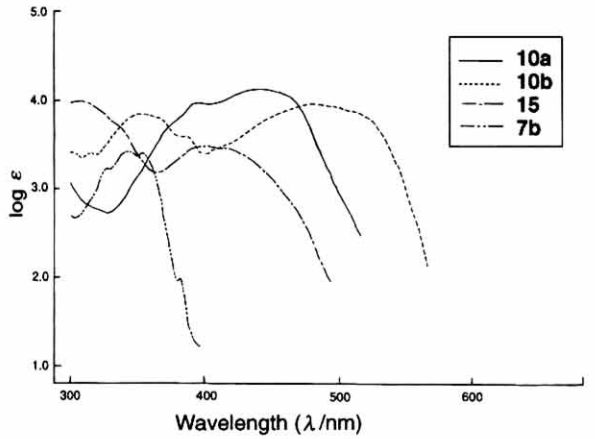
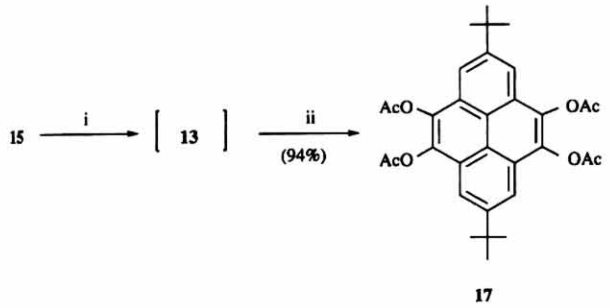


Fig. 1 UV absorption spectra of pyrenoquinones **10a**, **10b** and **15** and pyrene **7b** in cyclohexane



Scheme 7 *Reagents and conditions:* i, Zn, HCl, HOAc, 80 °C, 5 min; ii, Ac_2O, 80 °C, 5 min

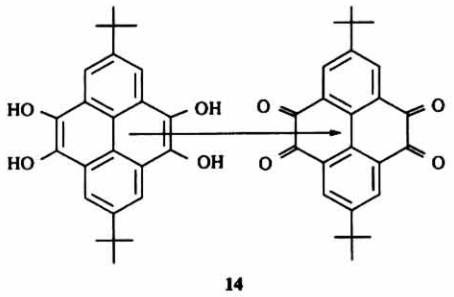


Fig. 1. Bathochromic shifts were observed in 1,8-dione **10b** (λ_{max} 515 nm) in comparison with those of 1,6-dione **10a** (λ_{max} 450 nm) and 4,5,9,10-tetraones **15** (λ_{max} 420 nm), which are ascribed to the expanded conjugation of the π-electron system, similar to the observation in the IR spectrum. The lack of a benzoquinone-type chromophore in the UV spectrum of diones **10a** and **10b** confirms the nonplanarity of the aromatic ring and carbonyl group.

The electronic spectrum of pyrenoquinhydrone **14** shows a larger charge-transfer interaction than that seen in quinhydrones such as *p*-benzoquinones and hydroquinones. The charge-transfer band of compound **14** was observed at λ_{max} 570 nm with a large bathochromic shift. This observation is ascribed to a strong charge-transfer interaction between the acceptor and donor in the expanded π-conjugation system of such species as pyrenoquinones and tetrahydroxypyrenes.

In conclusion, the different directive effects of 1-substituents on the pyrene ring on the position of electrophilic bromination were first observed with 1-substituted 2,7-di-*tert*-butylpyrenes. The acid-catalysed rearrangement of bromine atoms from positions 1, 3, 6 and 8 to positions 4, 5, 9 and 10 on the pyrene ring was observed to give 4,5,9,10-tetrabromo-2,7-di-*tert*-butylpyrene **4** in 90% yield. The present isomerization might be strongly affected by the bulkiness of the bromo groups in the 1-, 3-, 6- and 8-position, which increases the strain in the molecule due to the sterically crowded environment between the *tert*-butyl groups. These results will open up new mechanistic aspects for condensed aromatic compounds.

The conversion of bromo-2,7-di-*tert*-butylpyrenes into pyrenoquinones was carried out by the reaction of bromo-2,7-di-*tert*-butylpyrenes with sodium methoxide in the presence of copper(I) iodide, followed by demethylation of the corresponding methoxy-substituted derivatives with boron tribromide. The strong charge-transfer complex of pyrenoquinone **15** and its hydroquinone **13** was observed due to the expanded π-electron deficiency in the acceptor pyrenoquinone. Further studies on the chemical properties of pyrenoquinones are now in progress.

Experimental

All mps and bps are uncorrected. Mps were measured on a Yanagimoto MP-S1 instrument. NMR spectra were determined at 270 MHz with a Nippon Denshi JEOL FT-270 NMR spectrometer with $SiMe_4$ as internal reference: *J*-values are given in Hz. IR spectra were measured for samples as KBr pellets or a liquid film on NaCl plates in a Nippon Denshi JIR-AQ2OM spectrophotometer. Mass spectra were obtained on a Nippon Denshi JMS-01SA-2 spectrometer at 75 eV using a direct-inlet system through GLC.

Materials

The preparation of **2,7-di-*tert*-butylpyrene 1** was previously described.[10c]

Bromination of 2,7-di-*tert*-butylpyrene 1. Typical procedure

To a solution of 2,7-di-*tert*-butylpyrene **1** (200 mg, 0.64 mmol) in CCl_4 (20 cm^3) was added a solution of Br_2 (112 mg, 0.70 mmol) in CCl_4 (5 cm^3) at 0 °C. After the reaction mixture had been stirred for 1 h at room temperature, it was poured into water (50 cm^3). The organic layer was extracted with CH_2Cl_2 (20 $cm^3 \times 2$). The extract was washed successively with 10% aq. sodium thiosulfate (10 cm^3) and water (10 cm^3), dried (Na_2SO_4), and concentrated. The residue was subjected to column chromatography over silica gel (Wako, C-300; 200 g) with hexane as eluent to afford a solid. Recrystallization from methanol gave 1-*bromo*-2,7-*di*-tert-*butylpyrene* **2a** (213 mg, 85%) as prisms, mp 165–168 °C; $\delta_H(CDCl_3)$ 1.57 (9 H, s), 1.80 (9 H, s), 7.97 (1 H, d, *J* 9.2), 8.02 (1 H, d, *J* 9.2), 8.12 (1 H, d, *J* 9.5), 8.20 (1 H, d, *J* 1.8), 8.22 (1 H, d, *J* 1.8), 8.27 (1 H, s) and 8.70 (1 H, d, *J* 9.5); *m/z* 392 and 394 (M^+) (Found: C, 73.67; H, 6.75. $C_{24}H_{25}Br$ requires C, 73.28; H, 6.41%).

Compounds **3a** and **3b** were obtained in a 1:1 ratio (^1H NMR) by the bromination of hydrocarbon **1** with 2 mol equiv. of bromine under the conditions compiled in Table 1. The crude product was subjected to column chromatography over silica gel (Wako, C-300; 200 g) with hexane as eluent to afford a solid in 73% yield. Recrystallization from methanol or from hexane gave compounds **3a** and **3b**, respectively.

1,6-*Dibromo*-2,7-*di*-tert-*butylpyrene* **3a** was obtained as prisms (from methanol), mp >300 °C; $\delta_H(CDCl_3)$ 1.80 (18 H, s), 8.09 (2 H, d, *J* 9.5), 8.31 (2 H, s) and 8.74 (2 H, d, *J* 9.5); *m/z* 470, 472 and 474 (M^+) (Found: C, 60.94, 5.22. $C_{24}H_{24}Br_2$ requires C, 61.04; H, 5.12%).

1,8-*Dibromo*-2,7-*di*-tert-*butylpyrene* **3b** was obtained as prisms (from hexane), mp 239–241 °C; $\delta_H(CDCl_3)$ 1.57 (18 H, s), 8.01 (2 H, s), 8.30 (2 H, s) and 8.78 (2 H, s); *m/z* 470, 472 and 474 (M^+) (Found: C, 60.85, 5.16%).

When bromination of compounds **1**, **2a**, and a mixture of dibromides **3a** and **3b** was carried out with 6.0 mol equiv. of bromine in the presence of iron powder at room temperature for 1 h, compound **4** was obtained in 90, 85 and 90% yield, respectively. 4,5,9,10-Tetrabromo-2,7-di-*tert*-butylpyrene **4** was

obtained as prisms [from hexane–benzene (1:1)], mp 286–288 °C (lit.,[19] 287–288 °C).

Preparation of 2,7-di-*tert*-butyl-1-methoxypyrene 2c

To methanol (18 cm^3) was added sodium (580 mg, 25.2 mmol), and then a mixture of CuI (177 mg, 0.93 mmol) and bromide **2a** (523 mg, 1.27 mmol) in dimethylformamide (DMF) (5 cm^3) was added. After the reaction mixture had been refluxed for 30 h, it was poured into ice–water (100 cm^3) and extracted with CH_2Cl_2 (70 cm^3 × 2). The extract was washed with water (40 cm^3 × 2), dried (Na_2SO_4), and concentrated. The residue was subjected to column chromatography over silica gel (Wako, C-300; 100 g) with hexane as eluent to afford a solid. Recrystallization from methanol gave the desired 2,7-*di*-tert-*butyl*-1-*methoxypyrene* **2c** (310 mg, 68%) as prisms, mp 119–122 °C; $\delta_H(CDCl_3)$ 1.57 (9 H, s), 1.64 (9 H, s), 4.12 (3 H, s), 7.92 (1 H, d, *J* 9.3), 7.96 (1 H, d, *J* 9.3), 8.02 (1 H, d, *J* 9.3), 8.12 (1 H, s), 8.14 (1 H, d, *J* 2.0), 8.15 (1 H, d, *J* 2.0) and 8.24 (1 H, d, *J* 9.3); *m/z* 344 (M^+) (Found: C, 86.96, 8.25. $C_{25}H_{28}O$ requires C, 87.16; H, 8.19%).

Chlorination of 2,7-di-*tert*-butylpyrene 1

To a solution of compound **1** (100 mg, 0.32 mmol) in CH_2Cl_2 (100 cm^3) were added SO_2Cl_2 (1.0 cm^3) and boron trifluoride–diethyl ether (0.5 cm^3) at 0 °C. After the reaction mixture had been stirred for 4 h at room temperature, it was poured into water (50 cm^3). The organic layer was extracted with CH_2Cl_2 (70 cm^3 × 2). The extract was washed with water (40 cm^3 × 2), dried (Na_2SO_4), and concentrated. The residue was subjected to column chromatography over silica gel (Wako, C-300; 100 g) with hexane as eluent to afford a solid. Recrystallization from ethanol gave 2,7-di-*tert*-butyl-1-chloropyrene **2b** (95 mg, 86%) as prisms, mp 171–174 °C (lit.,[14] 172–175 °C).

Bromination of 2,7-di-*tert*-butyl-1-chloropyrene 2b

To a solution of compound **2b** (100 mg, 0.29 mmol) and a small amount of iron powder in CCl_4 (10 cm^3) was added a solution of Br_2 (276 mg, 1.72 mmol) in CCl_4 (2.5 cm^3) at 0 °C. After the reaction mixture had been stirred for 1 h at room temperature, it was poured into water (30 cm^3). The organic layer was extracted with CH_2Cl_2 (10 cm^3 × 2). The extract was washed successively with 10% aq. sodium thiosulfate (5 cm^3) and water (5 cm^3), dried (Na_2SO_4), and concentrated. The residue was subjected to column chromatography over silica gel (Wako, C-300; 100 g) with hexane as eluent to afford a solid. Recrystallization from hexane gave 4,5,9-*tribromo*-2,7-*di*-tert-*butyl*-1-*chloropyrene* **6a** (146 mg, 86%) as prisms, mp 258–260 °C; $\delta_H(CDCl_3)$ 1.63 (9 H, s), 1.76 (9 H, s), 8.67 (1 H, d, *J* 2.0), 8.78 (1 H, d, *J* 2.0), 8.81 (1 H, s) and 8.96 (1 H, s); *m/z* 586, 588 and 590 (M^+) (Found: C, 49.17, 3.76. $C_{24}H_{22}Br_3Cl$ requires C, 49.22; H, 3.79%).

Bromination of 2,7-di-*tert*-butyl-1-methoxypyrene 2c

To a solution of compound **2c** (200 mg, 0.58 mmol) and a small amount of iron powder in CCl_4 (10 cm^3) was added a solution of Br_2 (550 mg, 3.43 mmol) in CCl_4 (10 cm^3) at 0 °C. After the reaction mixture had been stirred for 1 h at room temperature, it was poured into water (30 cm^3). The organic layer was extracted with CH_2Cl_2 (10 cm^3 × 2). The extract was washed successively with 10% aq. sodium thiosulfate (5 cm^3) and water (5 cm^3), dried (Na_2SO_4), and concentrated. The residue was subjected to column chromatography over silica gel (Wako, C-300; 100 g) with hexane as eluent to afford a solid. Recrystallization from hexane gave 2,4,6,9-*tetrabromo*-7-*di*-tert-*butyl*-1-*methoxypyrene* **6b** (295 mg, 86%) as prisms, mp 195–198 °C; $\delta_H(CDCl_3)$ 1.63 (9 H, s), 4.13 (3 H, s), 8.62 (1 H, s), 8.75 (2 H, s) and 8.84 (1 H, s); *m/z* 588, 590, 592 and 594 (M^+) (Found: C, 40.88, 2.82. $C_{20}H_{16}Br_4O$ requires C, 40.58; H, 2.72%).

Preparation of 2,7-di-*tert*-butyl-1,6-dimethoxypyrene 7a

To methanol (10 cm^3) was added sodium (900 mg, 39.15 mmol), and then a mixture of CuI (400 mg, 2.1 mmol) and 1,6-dibromo-2,7-di-*tert*-butylpyrene **3a** (100 mg, 0.21 mmol) in DMF (5 cm^3) was added. After the reaction mixture had been refluxed for 30 h, it was poured into ice–water (200 cm^3) and extracted with CH_2Cl_2 (100 cm^3 × 2). The extract was washed with water (50 cm^3 × 2), dried (Na_2SO_4), and concentrated. The residue was column chromatographed over silica gel (Wako, C-300; 100 g) with hexane as eluent to afford a solid. Recrystallization from methanol gave the *title compound* **7a** (94.5 mg, 85%) as prisms, mp 230–233 °C; $\delta_H(CDCl_3)$ 1.63 (18 H, s), 4.10 (6 H, s), 7.97 (2 H, d, *J* 9.3), 8.10 (2 H, s) and 8.16 (2 H, d, *J* 9.3); *m/z* 374 (M^+) (Found: C, 83.14, 7.84. $C_{26}H_{30}O_2$ requires C, 83.38; H, 8.07%).

Compound **7b** was prepared in the same manner as described above, starting from the 1,8-dibromide **3b**, in 85% yield. 2,7-*Di*-tert-*butyl*-1,8-*dimethoxypyrene* **7b** was obtained as prisms (from methanol), mp 113–116 °C; $\delta_H(CDCl_3)$ 1.63 (18 H, s), 4.12 (6 H, s), 7.87 (2 H, s), 8.08 (2 H, s) and 8.24 (2 H, s); *m/z* 374 (M^+) (Found: C, 83.28, 8.01%).

Demethylation of compound 7a with BBr_3

To a solution of bis-ether **7a** (30 mg, 0.08 mmol) in CH_2Cl_2 (2 cm^3) was added a solution of BBr_3 (0.3 cm^3) in CH_2Cl_2 (1 cm^3) at 0 °C. After the reaction mixture had been stirred at room temperature for 3 h, it was poured into ice–water (10 cm^3) and extracted with CH_2Cl_2 (20 cm^3 × 2). The extract was washed with water (10 cm^3 × 2), dried (Na_2SO_4), and concentrated. The residue was dissolved in a small volume of CH_2Cl_2 and subjected to column chromatography over silica gel (Wako, C-300; 50 g) with $CHCl_3$ as eluent to afford a brown solid (25.3 mg, 92%). Recrystallization from hexane–benzene (1:1) gave 2,7-*di*-tert-*butylpyrene*-1,6-*dione* **10a** as reddish brown prisms, mp >300 °C; ν_{max}(KBr)/cm^{-1} 1680 (C=O); $\delta_H(CDCl_3)$ 1.44 (18 H, s), 7.49 (2 H, s), 7.72 (2 H, d, *J* 7.3) and 8.40 (2 H, d, *J* 7.3); *m/z* 344 (M^+) (Found: C, 83.50, 6.73. $C_{24}H_{24}O_2$ requires C, 83.69; H, 7.02%).

Demethylation of compound 7b with BBr_3

To a solution of bis-ether **7b** (30 mg, 0.08 mmol) in CH_2Cl_2 (2 cm^3) was added a solution of BBr_3 (0.3 cm^3) in CH_2Cl_2 (1 cm^3) at 0 °C. After the reaction mixture had been stirred at room temperature for 3 h, it was poured into ice–water (10 cm^3) and extracted with CH_2Cl_2 (20 cm^3 × 2). The extract was washed with water (10 cm^3 × 2), dried (Na_2SO_4), and concentrated. The residue was washed with hot $CHCl_3$ to afford pyrenoquinhydrone **9b** (26 mg) as a dark violet solid, mp >300 °C; ν_{max}(KBr)/cm^{-1} 3400 (OH) and 1625 (C=O); $\lambda_{max}(CHCl_3)$ 356 and 480 nm; $\delta_H(CDCl_3)$ (diol) 1.67 (18 H, s), 5.78 (2 H, s, OH, replaced by D_2O), 7.79 (2 H, s), 8.04 (2 H, s) and 8.11 (2 H, s); (dione) 1.44 (18 H, s), 7.48 (2 H, s), 7.54 (2 H, s) and 8.56 (2 H, s).

The solid was dissolved in a small amount of methanol and subjected to column chromatography over silica gel (Wako, C-300; 50 g) with $CHCl_3$ as eluent to afford a brown solid. Recrystallization from hexane–benzene (1:1) gave 2,7-*di*-tert-*butylpyrene*-1,8-*dione* **10b** as reddish brown prisms, mp 282–284 °C; ν_{max}(KBr)/cm^{-1} 1628 (C=O); $\delta_H(CDCl_3)$ 1.44 (18 H, s), 7.48 (2 H, s), 7.54 (2 H, s) and 8.56 (2 H, s); *m/z* 344 (M^+) (Found: C, 83.77, 6.95. $C_{24}H_{24}O_2$ requires C, 83.69; H, 7.02%).

Preparation of 1,6-diacetoxy-2,7-di-*tert*-butylpyrene 11a

To a solution of dione **10a** (23 mg, 0.067 mmol) in acetic acid (3 cm^3) was added zinc powder (310 mg, 4.71 mmol), resulting in the formation of a brown colour that immediately turned reddish purple. After the reaction mixture had been stirred at room temperature for a few minutes until it became pale yellow, acetic anhydride (2 cm^3) and one drop of conc. HCl were added to the reaction mixture, which was then stirred at 80 °C for 5 min, filtered, and poured into water (10 cm^3). After the aqueous solution had been stirred at room temperature for 1.5 h, it was

extracted with CH_2Cl_2 (20 cm^3), washed with water, dried (Na_2SO_4), and concentrated *in vacuo* to leave the crude product as a solid. Recrystallization from hexane–benzene (1:1) gave the *title compound* **11a** (18 mg, 62.3%) as prisms, mp 294–296 °C; ν_{max}(KBr)/cm^{-1} 1735 (C=O); δ_H($CDCl_3$) 1.59 (18 H, s), 2.60 (6 H, s), 7.74 (2 H, d, *J* 9.3), 8.01 (2 H, d, *J* 9.3) and 8.19 (2 H, s); *m/z* 430 (M^+) (Found: C, 78.34; H, 6.93. $C_{28}H_{30}O_4$ requires C, 78.11; H, 7.02%).

Compound **11b** was prepared in the same manner as described above, starting with dione **10b**, in 40% yield. 1,8-*Diacetoxy*-2,7-*di*-tert-*butylpyrene* **11b** was obtained as prisms (from hexane–benzene, 1:1), mp 240–242 °C; ν_{max}(KBr)/cm^{-1} 1735 (C=O); δ_H($CDCl_3$) 1.59 (18 H, s), 2.57 (6 H, s), 7.78 (2 H, s), 8.01 (2 H, s) and 8.19 (2 H, s); *m/z* 430 (M^+) (Found: C, 78.28; H, 6.83%).

Preparation of 2,7-di-*tert*-butyl-4,5,9,10-tetramethoxypyrene 12

To methanol (30 cm^3) was added sodium (1.5 g, 65.2 mmol), and then a mixture of CuI (400 mg, 2.1 mmol) and 4,5,9,10-tetrabromo-2,7-di-*tert*-butylpyrene **4** (300 mg, 0.45 mmol) in DMF (10 cm^3) was added. After the reaction mixture had been refluxed for 30 h, it was poured into ice–water (200 cm^3) and extracted with CH_2Cl_2 (100 cm^3 × 2). The extract was washed with water (50 cm^3 × 2), dried (Na_2SO_4), and concentrated. The residue was subjected to column chromatography over silica gel (Wako, C-300; 100 g) with hexane–benzene (1:1) as eluent to afford a solid. Recrystallization from hexane gave the desired 2,7-*di*-tert-*butyl*-4,5,9,10-*tetramethoxypyrene* **12** (150 mg, 78%) as prisms, mp 253–255 °C; ν_{max}(KBr)/cm^{-1} 3050, 2960, 1600, 1370, 1230 and 1200; δ_H($CDCl_3$) 1.60 (18 H, s), 4.20 (12 H, s) and 8.45 (4 H, s); *m/z* 434 (M^+) (Found: C, 77.52, 8.20. $C_{28}H_{34}O_4$ requires C, 77.39; H, 7.89%).

Demethylation of compound 12 with BBr_3

To a solution of tetrakis-ether **12** (34 mg, 0.078 mmol) in CH_2Cl_2 (5 cm^3) was added a solution of BBr_3 (0.6 cm^3) in CH_2Cl_2 (2 cm^3) at 0 °C. After the reaction mixture had been stirred at room temperature for 3 h, it was poured into ice–water (10 cm^3) and extracted with CH_2Cl_2 (20 cm^3 × 2). The extract was washed with water (10 cm^3 × 2), dried (Na_2SO_4), and concentrated. The residue was washed with hot $CHCl_3$ to afford pyrenoquinhydrone **14** (30 mg) as a dark violet solid, mp >300 °C; ν_{max}(KBr)/cm^{-1} 3400, 2980, 1660, 1600 and 1230; λ_{max}($CHCl_3$) 570 nm.

The solid was dissolved in a small amount of methanol and subjected to column chromatography over silica gel with $CHCl_3$ as eluent to afford an orange solid. Recrystallization from benzene gave 2,7-*di*-tert-*butylpyrene*-4,5,9,10-*tetraone* **15** (20 mg, 68%) as orange prisms, mp >300 °C; ν_{max}(KBr)/cm^{-1} 1670 (C=O); δ_H($CDCl_3$) 1.35 (18 H, s) and 8.40 (4 H, s); *m/z* 374 (M^+) (Found: C, 77.49, 6.08. $C_{24}H_{22}O_4$ requires C, 76.98; H, 5.92%).

Reaction of tetraone 15 with *o*-phenylenediamine to give the fused bisphenazine 16

A solution of tetraone **15** (10 mg, 0.027 mmol) in ethanol (5 cm^3) was treated with *o*-phenylenediamine (6.5 mg, 0.06 mmol) and was stirred at room temperature for 2 h. The precipitate was filtered off and washed with hot $CHCl_3$ to give *octacycle* **16** (25 mg, 90%) as pale brown prisms, mp >300 °C; ν_{max}(KBr)/cm^{-1} 3020, 2980 and 1600; *m/z* 518 (M^+) (Found: C, 83.09; H, 5.55; N, 10.33. $C_{36}H_{30}N_4$ requires C, 83.37; H, 5.83; N, 10.80%).

Preparation of 4,5,9,10-tetraacetoxy-2,7-di-*tert*-butylpyrene 17

To a solution of tetraone **15** (34 mg, 0.091 mmol) in acetic acid (3 cm^3) was added 20 mg (0.31 mmol) of zinc powder, resulting in formation of an orange colour that immediately turned reddish brown. After the reaction mixture had been stirred at room temperature for a few minutes until it became colourless, acetic anhydride (2 cm^3) and one drop of conc. HCl were added. The reaction mixture was stirred at 80 °C for 5 min, filtered, and poured into water (10 cm^3). After the aqueous solution had been stirred at room temperature for 1.5 h, it was extracted with CH_2Cl_2 (20 cm^3); the extract was washed with water, dried (Na_2SO_4), and concentrated *in vacuo* to leave 55 mg of crude tetraacetate **17**. Recrystallization from benzene gave the *title compound* **17** (47 mg, 94%) as pale yellow prisms, mp >300 °C; ν_{max}(KBr)/cm^{-1} 1735 (C=O); δ_H($CDCl_3$) 1.52 (18 H, s), 2.56 (12 H, s) and 8.18 (4 H, s); *m/z*, 546 (M^+) (Found: C, 70.57; H, 6.45. $C_{32}H_{34}O_8$ requires C, 70.31; H, 6.27%).

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