Naphthoquinone Mono- and Di-methide Lactones

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Monolactones which are derivatives of 7-hydroxynaphtho[1,8-*bc*]pyran-2,6-dione are obtained by reaction of simple juglones with ethyl chloroformylacetate, and by condensation of mandelic acid with 2,6-dibromo-1,5-dihydroxynaphthalene. Dilactones are formed by condensation of mandelic acid with 1,5-dihydroxynaphthalene, which yields 3,8-diphenylnaphtho[1,2-*b*:5,6-*b'*]difuran-2,7-dione and/or 3,8-diphenylnaphtho[1,8-*bc*:4,5-*b'c'*]dipyran-2,7-dione; with 2,3-dihydroxynaphthalene it gives 3,8-diphenylnaphtho[2,1-*b*:3,4-*b'*]difuran-2,9-dione.

Few quinone methide lactones are known apart from certain natural pigments,[1] *e.g.* xylerythrin (**1**),[2] and the synthetic benzodifuranones of type (**2**) reported previously.[3] As the latter are highly coloured it was of interest to investigate related naphthoquinone methide lactones as potential dyes for synthetic fibres.

In the naphthoquinone series the *peri*-position permits the formation of δ-lactones of type (**3**) as well as γ-lactones analogous to (**2**). A convenient synthetic approach to the quinone methide system (**3**) appeared to be the intramolecular condensation of the malonate ester (**4**). However, attempts to esterify juglone (5-hydroxy-1,4-naphthoquinone) with malonic acid half-ester using dicyclohexylcarbodi-imide, polyphosphoric acid, or polyphosphate ester,[4] or with the half ester acid chloride using triethylamine,[5] and other basic and acidic catalysts, all failed. When juglone, in benzene, was treated with ethyl chloroformylacetate and aluminium chloride at room temperature a new orange compound (*ca.* 10%) was formed, and by changing the solvent to a mixture of nitromethane and carbon disulphide the yield was increased to 45%. However the new compound was not the expected ester (**4**) nor the quinone methide (**3**; R = CO_2Et) but the hydroxy derivative (**5**).

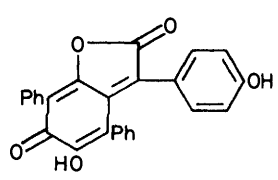
The quinone methide (**5**), $C_{15}H_{10}O_6$, shows i.r. absorption at 1 722, 1 712, 1 639, and 1 615 cm^{-1}, the ^1H n.m.r. spectrum comprises signals for a *peri*-hydroxy group, two AB systems, and an ethyl group, and the ^{13}C n.m.r. spectrum is fully consistent with structure (**5**). The new compound formed an acetate, and after reduction followed by acetylation the product sublimed to yield the diacetate (**6**) [δ(CH_2) 4.25]; the ^1H n.m.r. spectrum showed that the ethoxycarbonyl group was lost before sublimation.

The formation of (**5**) rather than (**3**; R = CO_2Et) from juglone at first suggested that an 'extra' oxygen atom had been inserted, possibly from air or water. However the result of the reaction was the same when it was performed under nitrogen, and when carried out under scrupulously dry conditions followed by quenching with ^{18}O-enriched water (containing hydrochloric acid) it gave (**5**) devoid of ^{18}O (mass spectrum). Thus the three oxygen atoms of juglone are retained in the quinone methide (**5**). Similarly the reaction of ethyl chloroformylacetate with 3-bromo- and 2,3-dibromo-juglone gave (**7**; R = H) and (**7**; R = Br), respectively, but 8-chlorojuglone and 8-hydroxyjuglone (naphthazarin) do not undergo this reaction. The assignment of structures (**7**) is consistent with their ^1H n.m.r. spectra. In (**5**), H-4 and H-5 resonate at δ 7.76 and 6.88, respectively, and there is little change when bromine is present in the benzenoid ring (**7**). If the monobromo compound (**5**) had the alternative structure (with Br at C-5), the H-4 signal would be appreciably shifted downfield. That the benzenoid ring of a juglone becomes the quinonoid ring of a quinone methide lactone is most clearly seen in (**8**), derived from 7-methyljuglone, where the methyl signal in the ^1H n.m.r. spectrum is a doublet coupled to a quartet from H-5.

It is now evident that the synthesis of (**5**) entails formation of a bond between C-8 of juglone and the central methylene carbon of the chloroformyl ester; furthermore the chloroformyl group must react with the juglone oxygen at C-1. This implies that juglone is reduced, at least in part, to hydrojuglone, whence reaction with the acid chloride could form (**9**) which looks like a likely precursor of (**5**). However, when (**9**) (synthesised from juglone) was treated under the original conditions, and variations thereof, (**5**) could not be detected. Further investigations are in progress. That (**9**) can be oxidised to the quinone methide (**5**) was demonstrated by leaving it, adsorbed on silica gel, exposed to air for some hours, but not surprisingly the yield of (**5**) was very small.

As the colour intensities of the quinone methide lactones (**5**), (**7**), and (**8**) were not remarkable, we then turned our attention to naphthoquinone dimethide dilactones. In principle malonates of the type (**9**) could be readily cyclised if they carried a suitable leaving group on the central methylene, and the reaction would be an intramolecular alkylation. For convenience, and eventual dyestuff stability we used phenylacetates rather than malonates, and from diesters of 1,5-dihydroxynaphthalene of type (**10**) we envisaged the formation of dilactones by either *peri*- or *ortho*-cyclisation. As the dimandelate (**10**; R = OH) is not easily prepared, we then condensed 1,5-dihydroxynaphthalene directly with mandelic acid[3] in a preliminary trial by fusion with zinc chloride. The crude product was a mixture which contained prominent blue and violet compounds. These were isomers of molecular formula $C_{26}H_{14}O_4$ which we regard as the dilactones (**12**) and (**13**), respectively. They are distinguished by their intense visible spectra (blue, $\lambda_{max.}$ 592 and 634 nm; violet, 552 nm), and i.r. carbonyl absorption (blue, 1 694 cm^{-1}; violet, 1 750 cm^{-1}) [*c.f.* (**2**; Ar = Ph) which shows ν_{CO} 1 760 cm^{-1}]. Reaction must proceed by condensation to form initial dilactones, *e.g.* (**11**) for the blue compound, followed by aerial oxidation. The crude violet product was incompletely oxidised and was therefore treated with manganese dioxide before final purification. However the yields of (**12**) and (**13**) were extremely low.

Variation of the conditions, with and without acidic reagents (see Experimental section) usually gave only the violet dilactone (**13**) in poor yield. The blue dilactone (**12**) was extremely difficult to form; best results were obtained by heating 1,5-dihydroxynaphthalene and mandelic acid in molten toluene-*p*-sulphonic acid, which gave (**12**) (*ca.* 5%) only and no (**13**). In contrast when the diol and mandelic acid were heated in boiling 1,2,4-trichlorobenzene with removal of water azeotropically,



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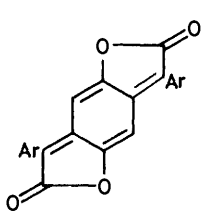

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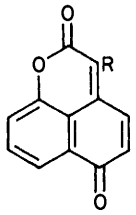

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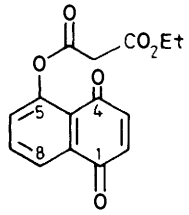

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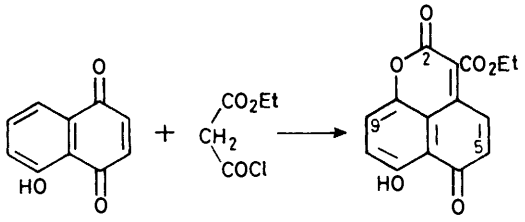

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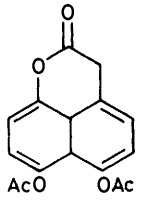

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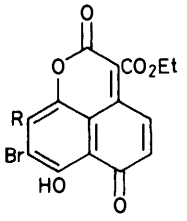

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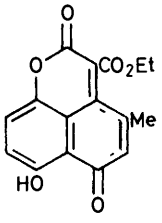

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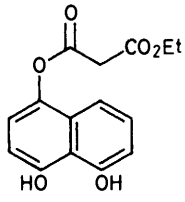

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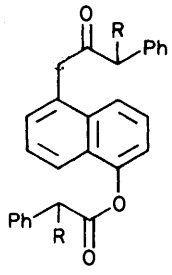

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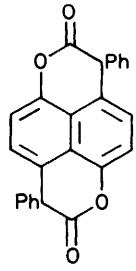

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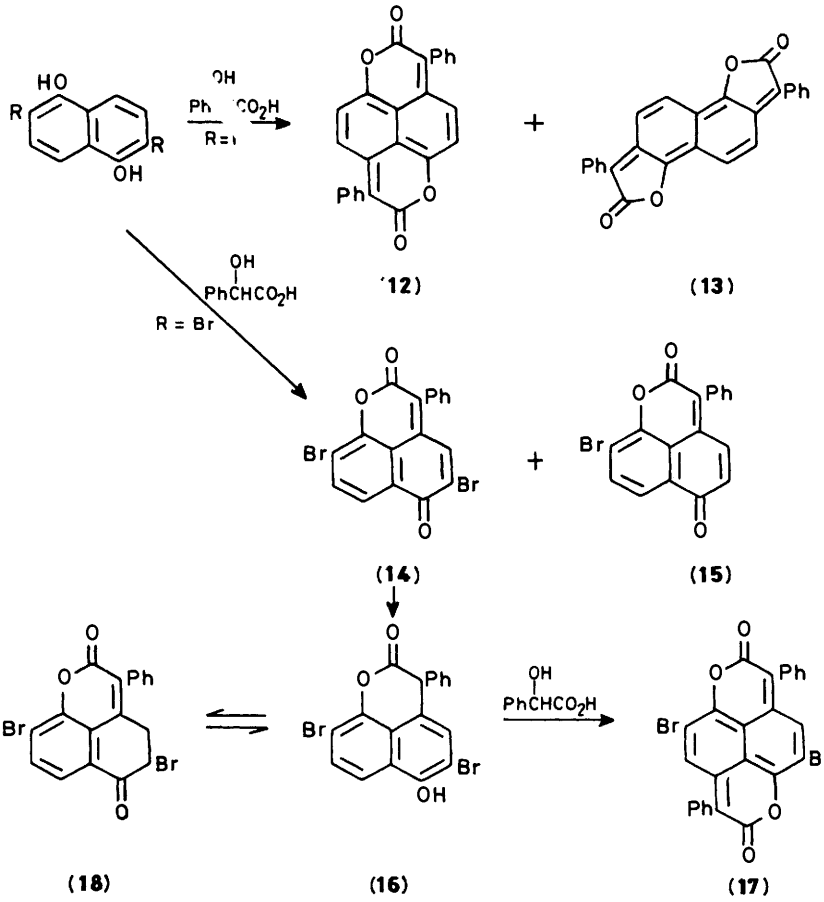
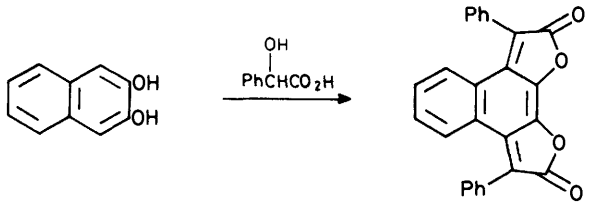


Scheme 1.



(19)

Scheme 2.

the violet dilactone (**13**) crystallised on cooling in around 50% yield and (**12**) was not observed. Initial attempts to cyclise the esters (**10**; R = OAc and Br) were unsuccessful, but we found later that the ditosyl derivative (**10**; R = OTs) could be converted into the violet dilactone (**13**) either by heating alone, or better by heating in polyphosphoric acid. The latter method gave (**13**) in 51% yield but the preparation of (**10**; R = OTs) requires several steps.

Structures (**12**) and (**13**) are distinguished mainly by their visible and i.r. carbonyl absorption, and to obtain further evidence we carried out a dilactone synthesis starting with 2,6-dibromo-1,5-dihydroxynaphthalene. The bromine atoms were introduced to block *ortho*-cyclisation and encourage the more difficult *peri*-cyclisation, and so lead to a blue dilactone analogous to (**12**). In fact condensation of the dibromo diol with mandelic acid in molten toluene-*p*-sulphonic acid gave only a trace of a blue compound, the main products being the two yellow monolactones (**14**) ($C_{18}H_8Br_2O_2$, ν_{CO} 1 720sh, 1 712, and 1 656 cm^{-1}) and (**15**) ($C_{18}H_9BrO_2$, ν_{CO} 1 723 and 1 650 cm^{-1}). In the ^{1}H n.m.r. spectrum of the monobromo compound the quinonoid proton signals are doublets at δ 6.48 and 7.45 (this shifting to 7.91 in the dibromo analogue) while H-7 and H-8 resonate as a singlet (2 H) at 7.97 in deuteriochloroform solution which was resolved into a pair of doublets on addition of deuteriobenzene. Neither (**14**) nor (**15**) would react further with mandelic acid in molten toluene-*p*-sulphonic acid but the naphthol (**16**) produced by reducing (**14**) then condensed with mandelic acid under the same conditions, with spontaneous oxidation, to give the blue dibromodilactone (**17**) ($\lambda_{max.}$ 598 and 639 nm; ν_{CO} 1 693 cm^{-1}), which was very similar to (**14**). Evidently in the melt produced during reaction between mandelic acid and the dibromo diol (**16**) is an intermediate which is oxidised to the quinone methide (**14**) more rapidly than it condenses with mandelic acid. A similar condensation of the dibromo diol with *p*-methoxymandelic acid gave the corresponding methoxy analogues of (**14**) and (**15**), and again dilactone formation was not observed. All these *peri*-cyclisations proceeded in low yield.

As the starting 2,6-dibromo-1,5-dihydroxynaphthalene did not contain monobromo material the formation of a monobromo lactone (**15**) was unexpected. A possible explanation is that some of the intermediate compound (**16**) tautomerises to the ketone (**18**) (in toluene-*p*-sulphonic acid at 120 °C), which then eliminates hydrogen bromide; in fact, when (**16**) was heated alone in molten toluene-*p*-sulphonic acid it was converted into a mixture of (**14**) and the monobromo lactone (**15**). The elimination of halogen from halogenonaphthohydroquinones which are known to tautomerise to diketones provides a parallel.[6]

In principle, dilactones analogous to the violet compound (**13**) should be obtainable from other naphthalenediols; indeed the yellow dilactone (**19**) was easily prepared simply by melting 2,3-dihydroxynaphthalene with mandelic acid. However, similar procedures with the 1,7- and 2,6-diols were unsuccessful as were attempted stepwise syntheses using ditosyl derivatives corresponding to (**10**; R = OTs).

Experimental

U.v. and n.m.r. spectra were measured for chloroform and deuteriochloroform solutions, respectively, and i.r. spectra for KBr discs, unless otherwise stated.

3-*Ethoxycarbonyl*-7-*hydroxynaphtho*[1,8-bc]*pyran*-2,6-*dione* (**5**).—Anhydrous aluminium chloride (4.04 g, 30.0 mmol) was added to a stirred solution of juglone (0.87 g, 5.0 mmol) in nitromethane (50 ml) and carbon disulphide (25 ml). To the red, two-phase solution ethyl chloroformylacetate (3.01 g, 20.0 mmol) was added and stirring was continued at room temperature for 16 h. The mixture was poured into dilute hydrochloric acid (150 ml; 10%), stirred for 1 h, and extracted with chloroform; the extract was washed and dried ($MgSO_4$). Evaporation gave an oil which after dry column chromatography on silica in chloroform–methanol (9:1) gave the *quinone methide*, which crystallised from ethanol in orange needles, m.p. 158—159 °C (0.65 g, 45%) (Found: C, 62.6; H, 3.6. $C_{15}H_{10}O_6$ requires C, 62.9; H, 3.5%); $\lambda_{max.}$ 250, 289, 323, and 484 nm (log ε 3.54, 3.90, 4.00, and 3.71); $\nu_{max.}$ 1 722, 1 712, 1 639, and 1 615 cm^{-1}; δ_H 12.30 (1 H, s, exchangeable, OH), 7.76 (1 H, d, *J* 10 Hz, 4-H), 7.58 (1 H, d, *J* 10 Hz, 9-H), 7.31 (1 H, d, *J* 10 Hz, 8-H), 6.88 (1 H, d, *J* 10 Hz, 5-H), 4.52 (2 H, q, *J* 7 Hz, CH_2CH_3), and 1.43 (3 H, t, *J* 7 Hz, CH_2CH_3); δ_C 187.4 (s), 162.7 (s), 160.5 (s), 157.0 (s), 145.4 (s), 137.3 (s), 135.4 (d), 135.3 (d), 125.0 (d), 123.7 (d), 122.7 (s), 114.2 (s), 110.6 (s), 63.0 (t), and 14.0 (q); *m/z* 286 (M^+, 100%), 258 (35), 241 (28), 230 (59), 214 (21), 186 (41), 157 (19), 129 (12), 101 (11), and 75 (13). When the reaction was carried out at 40 °C for 24 h the yield was 36%. The *acetate* crystallised from ethanol in yellow needles, m.p. 160—161 °C (Found: C, 61.9; H, 3.4. $C_{17}H_{12}O_7$ requires C, 62.2; H, 3.7%); $\nu_{max.}$ 1 753, 1 720, 1 650, and 1 615 cm^{-1}; δ 7.48 (3 H, m, 4-, 8-, and 9-H), 6.68 (1 H, d, *J* 10 Hz, 5-H), 4.50 (2 H, q, *J* 7 Hz, CH_2CH_3), 2.44 (3 H, s, OAc), and 1.42 (3 H, t, *J* 7 Hz, CH_2CH_3); *m/z* 328 (M^+, 0.1%), 286 (100), 258 (22), 241 (13), 230 (25), 214 (14), and 157 (6).

6,7-*Diacetoxynaphtho*[1,8-bc]*pyran*-2(3H)-*one* (**6**).—An orange solution of (**5**) (286 mg) in ether (50 ml) was shaken with saturated aqueous sodium dithionite (4 × 50 ml) until colourless, then dried and evaporated. The residual off-white solid [δ 7.32—6.48 (4 H, m, ArH), 5.04 (1 H, s, 3-H), 4.20 (2 H, q, *J* 7 Hz, CH_2CH_3), and 1.23 (3 H, t, *J* 7 Hz, CH_2CH_3); *m/z* 288 (M^+, 63%), 286 (8), 243 (25), 242 (100), 216 (45), 215 (94), 187 (56), 186 (63), and 174 (79)] was dissolved in acetic anhydride (10 ml) containing pyridine (0.1 ml). After 6 h acetic acid (10 ml) was added, and the mixture was poured into water (100 ml) and stirred for 3 h. The solid was collected, dried, sublimed at 190 °C and 0.1 mmHg, and crystallised from ethanol to give the *lactone* as plates, m.p. 155—156 °C (60 mg, 40%) (Found: C, 64.1; H, 4.3. $C_{16}H_{12}O_6$ requires C, 64.0; H, 4.0%); $\nu_{max.}$ 1 755 and 1 733 cm^{-1}; δ 7.19 (4 H, m, ArH), 4.25 (2 H, s, CH_2), and 2.38 (6 H, s, OAc); *m/z* 300 (M^+, 3.5%), 258 (8), 216 (100), and 188 (15).

8-*Bromo*-3-*ethoxycarbonyl*-7-*hydroxynaphtho*[1,8-bc]*pyran*-2,6-*dione* (**7**; R = H).—The preparation was carried out as for (**5**), using aluminium chloride (400 mg, 3.0 mmol), 3-bromojuglone (126 mg, 0.5 mmol), nitromethane (10 ml), carbon disulphide (5 ml), and ethyl chloroformylacetate (150 mg, 1.0 mmol). The mixture was stirred at 40 °C for 3 h, cooled, and stirred vigorously for 1 h while dilute hydrochloric acid (25 ml; 10%) was added. The product was purified by p.l.c. on silica in chloroform–methanol (19:1), and crystallised from ethanol in orange needles, m.p. 187—188 °C (100 mg, 55%) (Found: C, 49.5; H, 2.2; Br, 30.1. $C_{15}H_9BrO_6$ requires C, 49.3; H, 2.5; Br, 29.1%); $\lambda_{max.}$ 250, 300, 322, and 470—486 nm (log ε 3.82, 4.00, 4.07, and 3.86); $\nu_{max.}$ 1 739, 1 723, 1 710, 1 650, and 1 615 cm^{-1}; δ 12.90 (1 H, s, exchangeable, OH), 7.79 (1 H, d, *J* 10 Hz, 4-H), 7.69

(1 H, s, 9-H), 6.90 (1 H, d, *J* 10 Hz, 5-H), 4.50 (2 H, q, *J* 7 Hz, CH_2CH_3), and 1.44 (3 H, t, *J* 7 Hz, CH_2CH_3); *m/z* 364 (M^+, 100%), 336 (25), 308 (50), 252 (56) (all doublets), and 173 (79).

8,9-*Dibromo*-3-*ethoxycarbonyl*-7-*hydroxynaphtho*[1,8-bc]-*pyran*-2,6-*dione* (7; R = Br).—This was prepared as for (**5**), using 2,3-dibromojuglone (110 mg) and ethyl chloroformylacetate (100 mg), with stirring at 40 °C for 8 h. The *quinone methide* crystallised from ethanol in orange needles, m.p. 197—198 °C (90 mg, 62%) (Found: C, 40.4; H, 1.7; Br, 36.1. $C_{15}H_8Br_2O_6$ requires C, 40.6; H, 1.8; Br, 36.0%); $\lambda_{max.}$ 251, 298, 320, and 468—490 nm (log ε 4.09, 3.96, 4.04, and 3.86); $\nu_{max.}$ 1 720br, 1 638, and 1 615 cm^{-1}; δ 13.35 (1 H, s, exchangeable, OH), 7.81 (1 H, d, *J* 10 Hz, 4-H), 6.93 (1 H, d, *J* 10 Hz, 5-H), 4.51 (2 H, q, *J* 7 Hz, CH_2CH_3), and 1.44 (3 H, t, *J* 7 Hz, CH_2CH_3); *m/z* 442 (M^+ for ^{79}Br, 100%), 414 (22), 397 (9), 386 (22), 342 (14) (all triplets), and 307 (18) (doublet).

3-*Ethoxycarbonyl*-4-*methyl*-7-*hydroxynaphtho*[1,8-bc]*pyran*-2,6-*dione* (**8**) (*with* **G. Harvey**).—This was similarly prepared using 7-methyljuglone (372 mg) and ethyl chloroformylacetate (750 mg), with stirring in the cold for 24 h. The product was purified by p.l.c. on silica followed by p.l.c. on oxalated silica (both in chloroform). The *quinone methide* crystallised from ethanol in tiny orange plates, m.p. 204—206 °C (45 mg, 8%) (Found: M^+, 300.0638. $C_{16}H_{12}O_6$ requires *M*, 300.0634); $\lambda_{max.}$ 247, 293, 320, 452sh, and 470 nm (log ε 3.83, 4.10, 4.23, 3.91, and 3.92); $\nu_{max.}$ 1 745, 1 734, 1 710, and 1 638 cm^{-1}; δ 12.65 (1 H, s, exchangeable, OH), 7.57 (1 H, d, *J* 10 Hz, 9-H), 7.30 (1 H, d, *J* 10 Hz, 8-H), 6.72 (1 H, q, *J* 1.5 Hz, 5-H), 4.51 (2 H, q, *J* 7 Hz, CH_2CH_3), 2.48 (3 H, d, *J* 1.5 Hz, Me), and 1.47 (3 H, t, *J* 7 Hz, CH_2CH_3); *m/z* 300 (M^+, 100%), 272 (50), 271 (54), 254 (57), 244 (73), 200 (30), and 115 (39).

Ethyl 4,5-*Dihydroxy*-1-*naphthyl Malonate* (**9**).—5-Benzyloxy-1,4-naphthoquinone 1.05 g) in dichloromethane (15 ml) and ether (50 ml) was reduced[7] by shaking with aqueous sodium dithionite. The organic phase was shaken with brine, filtered through a layer of magnesium sulphate, and evaporated. The hydroquinone was dissolved in dichloromethane (90 ml) under nitrogen, cooled in ice, ethyl chloroformylacetate (1.65 ml) and triethylamine (1.8 ml) were added, and the mixture was left overnight at room temperature. After work-up the crude product was dissolved in ether–hexane and left to crystallise at −10 °C. Recrystallisation in the same way yielded *ethyl* 5-*benzyloxy*-4-*hydroxy*-1-*naphthyl malonate* as plates, m.p. 57—59 °C (0.52 g, 35%) (Found: C, 68.1; H, 5.4. $C_{22}H_{20}O_6$ requires C, 67.8; H, 5.6%); δ 9.34 (1 H, s, exchangeable, OH), 7.60—6.75 (11 H, m, ArH), 5.27 (2 H, s, OCH_2), 4.32 (2 H, q, *J* 7 Hz, CH_2CH_3), 3.74 (2 H, s, $COCH_2CO$), and 1.38 (3 H, t, *J* 7 Hz, CH_2CH_3); *m/z* 380 (M^+, 4%), 266 (7), 176 (38), 175 (32), 115 (15), and 91 (100). Hydrogenolysis of the benzyl ether in ethyl acetate over Pd–C afforded *ethyl* 4,5-*dihydroxy*-1-*naphthyl malonate* (**9**), δ 8.22 (2 H, br, exchangeable, OH), 7.40—6.50 (6 H, m, ArH), 4.34 (2 H, q, *J* 7 Hz, CH_2CH_3), 3.80 (2 H, s, $COCH_2CO$), and 1.38 (3 H, t, *J* 7 Hz, CH_2CH_3); *m/z* 290 (M^+, 2%), 176 (100), 120 (9), and 92 (7), which was used directly without purification.

Preparation of Naphthalenediol Diacetates.—General methods. (a) To a stirred solution of the diol (10 mmol), triethylamine (22 mmol), and 4-dimethylaminopyridine (2 mmol) in tetrahydrofuran (20 ml) the appropriate acid chloride (22 mmol) was added, dropwise, during 15 min. After being stirred for several hours the mixture was filtered and evaporated. Trituration of the residual oil with a little solvent gave a solid diester which was crystallised.

(b) The appropriate acid (30 mmol) was added to a mixture of the diol (10 mmol), dicyclohexylcarbodi-imide (40 mmol), and pyridine (30 mmol) in tetrahydrofuran (50 ml), and stirred for 24 h. After removal of dicyclohexylurea, the solvents were evaporated off leaving the crude diester which was crystallised.

The following were obtained by both methods: *naphthalene*-1,5-*diyl bisphenylacetate* (**10**; R = H), plates, m.p. 149—150 °C (from ethanol) (Found: C, 78.9; H, 5.0. $C_{26}H_{20}O$ requires C, 78.8; H, 5.1%); ν_{CO} 1 755 cm^{-1}; δ 7.65—7.04 (16 H, m, ArH) and 3.94 (4 H, s, 2 × CH_2); *m/z* 396 (M^+, 0.3%), 278 (6), 160 (100), and 91 (60): *naphthalene*-1,7-*diyl bisphenylacetate*, plates, m.p. 77—78 °C [from petroleum (b.p. 60—80 °C)] (Found: C, 78.6; H, 4.9%); ν_{CO} 1 744 and 1 755 cm^{-1}; δ 7.85—7.10 (16 H, m, ArH), 3.99 and 3.90 (each 2 H, s, 2 × CH_2); *m/z* 396 (M^+, 0.6%), 278 (25), 160 (100), and 91 (79); *naphthalene*-2,6-*diyl bisphenylacetate*, plates, m.p. 152—153 °C (from ethanol) (Found: C, 78.6; H, 5.2%); ν_{CO} 1 748 cm^{-1}; δ 7.82—7.10 (6 H, m, ArH), and 3.88 (4 H, s, 2 × CH_2); *m/z* 396 (M^+, 0.8%), 278 (9), 160 (100), and 91 (25); *naphthalene*-1,5-*diyl bis*[(*acetoxy*)-(*phenyl*)*acetate*] (**10**; R = OAc), needles, m.p. 188—189 °C (from toluene) (Found: C, 70.4; H, 5.0. $C_{30}H_{24}O_8$ requires C, 70.3; H, 4.7%); ν_{CO} 1 770 and 1 740 cm^{-1}; δ 7.70—7.05 (16 H, m, ArH), 6.22 (2 H, s, CHOAc), and 2.21 (6 H, s, CH_3); *m/z* 512 (M^+, 0.4%), 337 (7), 202 (9), 177 (25), 160 (100), 149 (100), 131 (9), 118 (11), and 107 (100).

Naphthalenediyl Bistosylacetates.—A solution of naphthalene-1,5-diyl bisphenylacetate (1.96 g, 5 mmol), *N*-bromosuccinimide (1.96 g, 11 mmol), and benzoyl peroxide (0.1 g) in carbon tetrachloride (50 ml) was boiled under reflux. After 16 h, more *N*-bromosuccinimide (0.45 g, 2.5 mmol) and benzoyl peroxide (0.1 g) were added, and refluxing was continued for 4 h. The mixture was then cooled, filtered and evaporated, and the residue was crystallised from toluene to give *naphthalene*-1,5-*diyl bis*[(*bromo*)(*phenyl*)*acetate*] (**10**; R = Br) as plates, m.p. 161—162 °C (2.6 g, 94%) (Found: C, 56.1; H, 3.4; Br, 28.9. $C_{26}H_{18}Br_2O_4$ requires C, 56.4; H, 3.3; Br, 28.8%); ν_{CO} 1 775 cm^{-1}; δ 7.80—7.10 (16 H, m, ArH) and 5.71 (2 H, s, 2 × CHBr); *m/z* 552 (M^+ for ^{79}Br, 0.3%) and 160 (100). The dibromo ester (0.554 g, 1 mmol) in dry acetonitrile (25 ml) was boiled under reflux with silver toluene-*p*-sulphonate (0.59 g, 2.2 mmol) for 3 h, and the mixture was filtered hot. *Naphthalene*-1,5-*diyl bis*[(*phenyl*)(*tosyl*)*acetate*] (**10**; R = OTs) separated on cooling. It crystallised from acetonitrile as needles, m.p. 195—205 °C (decomp. to a violet solid) (0.35 g, 47%) (Found: C, 65.0; H, 4.2; S, 8.6. $C_{40}H_{32}O_{10}S_2$ requires C, 65.2; H, 4.4; S, 8.7%); ν_{CO} 1 780 cm^{-1}; δ 7.81 (4 H, d, *J* 8 Hz, ArH), 7.85—7.02 (20 H, m, ArH), 6.12 (2 H, s, 2 × PhCH), and 2.40 (6 H, s, 2 × CH_3); *m/z* 736 (M^+, 0.1%), 261 (6), 247 (6), 172 (45), 160 (4.5), 155 (45), 118 (11), 107 (20), and 91 (100).

The following were obtained by the same procedure: *naphthalene*-1,7-*diyl bis*[(*bromo*)(*phenyl*)*acetate*], plates, m.p. 86—87 °C [after dry column chromatography in chloroform and crystallisation from petroleum (b.p. 60–80 °C)] (Found: C, 56.3; H, 3.2; Br, 28.7%); ν_{CO} 1 773 and 1 765 cm^{-1}; δ 7.36 (16 H, m, ArH), 5.72 and 5.61 (each 1 H, s, 2 × CHBr); *m/z* 552 (M^+ for ^{79}Br, 0.3%), 356 (10), 169 (11), and 160 (100): *naphthalene*-1,7-*diyl bis*[(*phenyl*)(*tosyl*)*acetate*], plates, m.p. 52—53 °C (decomp.) [from ether–petroleum (b.p. 40—60 °C)] (Found: C, 65.1; H, 4.6; S, 8.6%); ν_{CO} 1 780 and 1 769 cm^{-1}; δ 7.80 (4 H, d, *J* 8 Hz, ArH), 7.48 (20 H, m, ArH), 6.12 and 6.05 (each 1 H, s, 2 × PhCH), and 2.41 (6 H, s, 2 × CH_3); *m/z* 736 (M^+, 0.1%), 261 (5), 247 (6), 172 (50), 160 (3.5), 155 (45), 118 (10), and 91 (100): *naphthalene*-2,6-*diyl bis*[(*bromo*)(*phenyl*)*acetate*], plates, m.p. 142—143 °C [from petroleum (b.p. 100—120 °C)] (Found: C, 56.1; H, 3.5; Br, 29.0%); ν_{CO} 1 766 cm^{-1}; δ 7.88—7.10 (16 H, m, ArH) and 5.60 (2 H, s, 2 × CHBr); *m/z* 552 (M^+ for ^{79}Br, 0.6%), 356 (10), 169 (10), and 160 (100): *naphthalene*-2,6-*diyl bis*[(*phenyl*)(*tosyl*)*acetate*], plates, decomp. 135—140 °C (from

propan-2-ol) (Found: C, 65.0; H, 4.5; S, 8.6%); ν_{CO} 1 774 cm^{-1}; δ 7.82 (4 H, d, *J* 8 Hz, ArH), 7.69 (4 H, d, *J* 8 Hz, ArH), 7.00—6.96 (16 H, m, ArH), 6.02 (2 H, s, 2 × PhC*H*), and 2.40 (6 H, s, 2 × CH_3); *m/z* 736 (M^+, 0.1%), 247 (6), 172 (45), 160 (3.5), 155 (45), and 91 (100).

Condensation of 1,5-*Dihydroxynaphthalene with Mandelic Acid.*—(*a*) To a rapidly stirred melt of 1,5-dihydroxynaphthalene (8.0 g, 0.05 mol) and mandelic acid (30.4 g, 0.2 mol) at 180—185 °C was added finely divided zinc chloride (54.4 g, 0.4 mol) during 5 min. After being stirred for 1 h at 180—185 °C the blue melt was poured carefully into water (250 ml). The solid was collected, triturated with water, re-collected, and dried. The crude material was extracted (Soxhlet) with toluene until no more colour was removed, the solvent was evaporated off, and the residue re-extracted in the same way with chloroform. This extract was then evaporated. The residual mixture was complex but contained major blue and violet components which were isolated by dry column chromatography, followed by p.l.c., both in chloroform–ethyl acetate (19:1).

The blue compound, 3,8-*diphenylnaphtho*[1,8-bc:4,5-b′c′]*dipyran*-2,7-*dione* (**12**), crystallised from ethoxyethanol as blue-grey needles, m.p. > 300 °C (114 mg, 0.6%) (Found: C, 79.7; H, 3.6%; M^+, 390.0889. $C_{26}H_{14}O_4$ requires C, 80.0; H, 3.9% *M*, 390.0892); $\lambda_{max.}$ 270, 592, and 634 nm (log ε 4.50, 4.37, and 4.46); ν_{CO} 1 694 cm^{-1}; δ 7.49 (14 H, m, ArH + 4 × –CH=); *m/z* 390 (M^+, 100%), 362 (50), 334 (14), 305 (14), 276 (18), and 167 (22).

The pale violet product was dissolved in dichloromethane (5 ml) and stirred with manganese dioxide (0.1 g) for 1 h. After filtration and evaporation the dark violet solid was crystallised from ethoxyethanol to give 3,8-*diphenylnaphtho*[1,2-b:5,6-b′]-*difuran*-2,7-*dione* (**13**) as brown needles, m.p. > 300 °C (50 mg, 0.3%) (Found: C, 79.7; H, 3.9%; M^+, 390.0893. $C_{26}H_{14}O_4$ requires C, 80.0; H, 3.6%; *M*, 390.0892); $\lambda_{max.}$ 267.5 and 552 nm (log ε 5.00 and 4.81); ν_{CO} 1 750 cm^{-1}; δ 7.55 (14 H, m, ArH); *m/z* 390 (M^+, 100%), 363 (5), 335 (5.5), 305 (28), 276 (11), and 167 (5).

When the melt of 1,5-dihydroxynaphthalene and mandelic acid was stirred at 165 °C for 1 h without zinc chloride and then heated to 250 °C during 2 h, subsequent work up yielded (**13**) (0.6%) but no (**12**).

(*b*) 1,5-Dihydroxynaphthalene (1.6 g, 10 mmol) and mandelic acid (4.56 g, 30 mmol) were melted and stirred at 190—200 °C for 1 h. After cooling, the solid was dissolved in pyridine (50 ml), potassium persulphate (5.4 g, 20 mmol) was added, and the mixture was stirred on a steam-bath for 1 h, then filtered hot. A violet solid deposited on cooling crystallised from ethoxyethanol in brown needles, m.p. > 300 °C (0.2 g, 5.1%) identical with (**13**) obtained in (*a*).

(*c*) 1,5-Dihydroxynaphthalene (1.6 g, 10 mmol) and mandelic acid (4.56 g, 30 mmol) were heated in boiling trichlorobenzene (50 ml) for 15 h in a Dean–Stark apparatus. After cooling, the crystalline mass was collected, washed with toluene and petroleum, and recrystallised from 2-ethoxyethanol to give (**13**) as brown needles, m.p. > 300 °C (1.9 g, 49%).

(*d*) A mixture of 1,5-dihydroxynaphthalene (1.6 g, 10 mmol) and mandelic acid (4.56 g, 30 mmol) was added to molten toluene-*p*-sulphonic acid (20 g) stirred at 120 °C; the melt soon became blue. After being stirred at 120—130 °C for 1 h, it was poured into water (250 ml) and the precipitate was collected, and washed with water. After purification by dry column chromatography in chloroform–methanol (19:1) it crystallised from 2-ethoxyethanol to give (**12**) as blue needles, m.p. > 300 °C (210 mg, 5.4%), spectroscopically identical with those described in (*a*).

When toluene-*p*-sulphonic acid was replaced by methanesulphonic acid, stirring the mixture for 24 h at room temperature gave (**12**) in 4.6% yield (180 mg).

Cyclisation of Naphthalene-1,5-*diyl Bis*[(*phenyl*)(*tosyl*)-*acetate*].—(*a*) The diester (**10**; R = OTs) (184 mg) was stirred in polyphosphoric acid (10 g) at 120—130 °C for 3 h. After cooling, the violet mixture was diluted with water (100 ml), and stirred on a steam-bath for 30 min and then at room temperature for 2 h. The product was extracted with chloroform to yield a violet solid, which crystallised from 2-ethoxyethanol in brown needles, m.p. > 300 °C (50 mg, 51%) spectroscopically identical with (**13**) described above.

(*b*) The diester (**10**; R = OTs) (184 mg) was melted and stirred at 230 °C for 1 h. The product was purified by p.l.c. on silica in chloroform followed by crystallisation from 2-ethoxyethanol to give (**13**) (11 mg, 11.2%) identical with that described above.

Condensation of 2,6-*Dibromo*-1,5-*dihydroxynaphthalene with Mandelic Acid.*—A mixture of 2,6-dibromo-1,5-dihydroxynaphthalene [8] (3.18 g, 10 mmol) and mandelic acid (4.56 g, 30 mmol) was added to molten toluene-*p*-sulphonic acid (20 g) at 120 °C. After being stirred at 120—130 °C for 4 h the yellow melt was poured into water (250 ml). The precipitate was collected, washed with water, dried, and extracted (Soxhlet) with toluene until the extract was colourless. Evaporation left a mixture of two yellow compounds (and a trace of a blue one) which were separated by dry column chromatography in toluene. 5,9-*Dibromo*-3-*phenylnaphtho*[1,8-bc]*pyran*-2,6-*dione* (**14**) crystallised from toluene in yellow needles, m.p. 274 °C (0.3 g, 7.0%) (Found: C, 49.9; H, 1.8; Br, 36.9. $C_{18}H_8Br_2O_3$ requires C, 50.0; H, 1.9; Br, 37.0%); $\lambda_{max.}$ 254, 279, 323, and 384 nm (log ε 3.96, 3.81, 4.04, and 4.12); ν_{CO} 1 720sh, 1 712, and 1 656 cm^{-1}; δ 8.06 (1 H, d, *J* 8 Hz, 7-H), 7.95 (1 H, d, *J* 8 Hz, 8-H), 7.91 (1 H, s, 4-H), and 7.70—7.32 (5 H, m, ArH); *m/z* 432 (t, M^+, 40%), 404 (t, 100), 351 (d, 27), 323 (d, 15), 295 (d, 30), 267 (d, 18), 216 (41), 187 (61), and 94 (29). 9-*Bromo*-3-*phenylnaphtho*[1,8-bc]*pyran*-2,6-*dione* (**15**) formed yellow needles, m.p. 266 °C (from toluene) (0.4 g, 12.3%) (Found: C, 61.0; H, 2.5; Br, 22.6. $C_{18}H_9BrO_3$ requires C, 61.2; H, 2.6; Br, 22.6%); $\lambda_{max.}$ 249, 266sh, 277, 294, 305sh, and 376 nm (log ε 3.97, 3.99, 4.04, 4.05, 4.04, and 4.12); ν_{CO} 1 723 and 1 650 cm^{-1}; δ 7.97 (2 H, s, 7-H and 8-H), 7.65—7.35 (6 H, m, Ph + 4-H), 6.72 (1 H, d, *J* 8 Hz, 5-H) [the singlet at 8.00 resolves into a pair of doublets at 7.62 and 7.82 (*J* 7 Hz) on adding 10% C_6D_6]; *m/z* 352 (d, M^+, 100%), 324 (d, 50), 296 (6), 217 (5), 189 (80), 163 (14), and 95 (46).

The dibromo dilactone (**14**) (10 mg) in ether (8 ml) was shaken with aqueous sodium dithionite until colourless; the ether layer was separated, shaken with brine, and evaporated. To the residual white solid (m.p. > 300 °C) toluene-*p*-sulphonic acid (2 g) was added, and the mixture was heated at 120 °C for 2 h. The orange-red melt was cooled, diluted with water, and extracted with ether. Work-up gave a yellow solid which was separated by p.l.c. ($CHCl_3$; SiO_2) into (**14**) (3 mg) and (**15**) (4 mg), identified by t.l.c., mass spectrometry, and i.r.

5,10-*Dibromo*-3,8-*diphenylnaphtho*[1,8-bc:4,5-b′c′]*dipyran*-2,7-*dione* (**17**).—The dibromo dione (**14**) (0.43 g, 1 mmol) in ether (100 ml) was shaken with a saturated aqueous sodium dithionite (3 × 50 ml) until the yellow solution became colourless. The ether layer was washed with water, dried ($MgSO_4$), and evaporated. The residue, mixed with mandelic acid (0.63 g, 2 mmol), was added to molten toluene-*p*-sulphonic acid (20 g) at 120 °C. After being stirred for 1 h at 120 °C the melt was poured into water (100 ml) and extracted with chloroform. The *product* was purified by p.l.c. on silica in chloroform–methanol (9:1), and crystallised from 2-ethoxyethanol as dark blue needles, m.p. > 300 °C (90 mg, 4.9%) (Found: C, 57.0; H, 2.1; Br, 29.3. $C_{26}H_{12}Br_2O_4$ requires C, 57.0; H, 2.2; Br, 29.2%); $\lambda_{max.}$ 272.5, 598, and 639 nm (log ε 4.48, 4.36, and 4.45); ν_{CO} 1 693 cm^{-1}; δ 7.52 (12 H, m, ArH); *m/z* 546 (M^+ for

^{79}Br, 40%), 520 (47.5), 413 (5), 411 (5), 304 (6), 276 (10), and 274 (9).

Condensation of 2,6-*Dibromo*-1,5-*dihydroxynaphthalene with* 4-*Methoxymandelic Acid.*—A mixture of 2,6-dibromo-1,5-dihydroxynaphthalene (3.18 g, 10 mmol) and 4-methoxymandelic acid (4.0 g, 22 mmol) was added to toluene-*p*-sulphonic acid (20.0 g) at 120 °C; the melt was stirred at 120—130 °C for 30 min and poured into water (250 ml). The precipitate was collected, washed with water, dried and extracted (Soxhlet) with toluene until the extract was colourless. Evaporation left a yellow solid which was separated into two components by dry column chromatography in toluene. 5,9-*Dibromo*-3-(4-*methoxyphenyl*)*naphtho*[1,8-bc]*pyran*-2,6-*dione* crystallised from toluene in orange needles, m.p. 277 °C (0.2 g, 4.4%) (Found: C, 49.2; H, 2.1; Br, 34.4. $C_{19}H_{10}Br_2O_4$ requires C, 49.3; H, 2.2; Br, 34.6%); $\lambda_{max.}$ 256, 324, 333, and 444 nm (log ε 4.10, 4.16, 4.16, and 4.13); ν_{CO} 1 720 and 1 650 cm^{-1}; δ 8.08 (1 H, d, *J* 8 Hz, 7-H), 8.01 (1 H, s, 4-H), 7.95 (1 H, d, *J* 8 Hz, 8-H), 7.46 (2 H, d, *J* 9 Hz, 2′-H and 6′-H), 7.10 (2 H, d, *J* 9 Hz, 3′-H and 5′-H), and 3.95 (3 H, s, OMe); *m/z* 460 (M^+ for ^{79}Br, 40%), 433 (7), 418 (11), and 175 (5). 9-*Bromo*-3-(4-*methoxyphenyl*)*naphtho*[1,8-bc]*pyran*-2,6-*dione* crystallised from toluene in red needles, m.p. 279 °C (0.25 g, 6.5%) (Found: C, 59.3; H, 2.9; Br, 20.8. $C_{19}H_{11}BrO_4$ requires C, 59.5; H, 2.9; Br, 20.9%); $\lambda_{max.}$ 254, 280, 305, and 429 nm (log ε 3.98, 4.07, 4.10, and 4.11); ν_{CO} 1 726 and 1 645 cm^{-1}; δ 8.00 (2 H, s, 7-H and 8-H), 7.60 (1 H, d, *J* 10 Hz, 4-H), 7.42 (2 H, d, *J* 9 Hz, 2′-H and 6′-H), 7.08 (2 H, d, *J* 9 Hz, 3′-H and 5′-H), 6.72 (1 H, d, *J* 10 Hz, 5-H), and 3.92 (3 H, s, OMe) (the singlet at 8.00 resolves into a pair of doublets on adding 10% C_6D_6); *m/z* 382 (M^+, ^{79}Br%), 354 (10), 339 (11), and 176 (10).

Condensation of 2,3-*Dihydroxynaphthalene with Mandelic Acid.*—A mixture of 2,3-dihydroxynaphthalene (6.4 g, 40 mmol) and mandelic acid (18.24 g, 120 mmol) was melted and stirred at 180—181 °C for 2 h. The deep yellow liquid was cooled to 80 °C, ethanol (150 ml) was added, and the mixture was boiled under reflux for 1 h. After cooling, the yellow powder was collected and crystallised from petroleum (b.p. 100—120 °C) to give 3,8-*diphenylnaphtho*[2,1-b:3,4-b′]*difuran*-2,9-*dione* (**19**) (8.5 g, 54.5%) (Found: C, 80.1; H, 3.7. $C_{26}H_{14}O_4$ requires C, 80.0; H, 3.6%); $\lambda_{max.}$ 276 and 422 nm (log ε 4.23 and 4.53); ν_{CO} 1 767 cm^{-1}; δ 7.88 (2 H, m, ArH), 7.52 (8 H, m, ArH), and 7.25 (8 H, m, ArH); *m/z* 390 (M^+, 100%) and 277 (18).

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