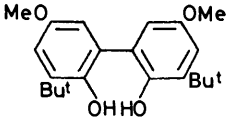
Oxidation of Alkoxyphenols. Part 23.[1] A Re-examination of the Reaction of 5,5′-Dimethoxy-3,3′-di-t-butylbiphenyl-2,2′-diol with Lead Tetra-acetate: Crystal Structure of the Product

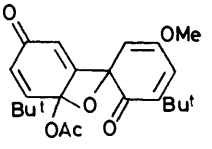
By F. Richmond Hewgill,* David G. Hewitt, Graeme B. Howie, Colin L. Raston, Rauleigh J. Webb, and Allan H. White, School of Chemistry, University of Western Australia, Nedlands, Western Australia 6009

The major product of the reaction, previously described as an acetoxybenzoxet, is now shown to be 4,10a-dihydro-7-methoxy-4-oxo-2,9-di-t-butyloxepino[2,3-*b*]benzofuran-10a-yl acetate (4). This assignment is based on *X*-ray crystallographic analysis of the corresponding benzoate. The biphenyl system is re-formed on reduction of the acetate, and reaction with acid converts the acetate into benzofuran-3(2*H*)-one derivatives.

In an earlier paper [2] structure (2) was assigned to the major product of the reaction of lead tetra-acetate with



(1)



(2)

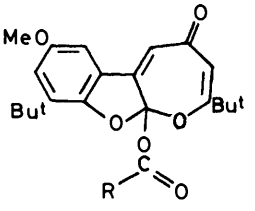
5,5′-dimethoxy-3,3′-di-t-butylbiphenyl-2,2′-diol (1). This assignment was based on spectroscopic evidence, and on the products of catalytic hydrogenation and reductive acetylation. Although treatment with acetic acid gave two crystalline products, Rast molecular-weight determination suggested that these were derived from two and three molecules of the original acetate, and they were not further investigated at the time. Mass spectroscopy has now shown that these acid degradation products are not polymeric, and further investigation here described has resulted in the elucidation of their structures.

RESULTS AND DISCUSSION

As these new structures were not easily reconciled with the formulation of the acetate as (2), the latter was examined by *X*-ray crystallography, but without success. We therefore prepared the corresponding benzoate by reaction of the diol (1) with lead tetra-benzoate. This gave the same hydrogenation product, 5-methoxy-3,3′-di-t-butylbiphenyl-2,2′,5′-triol, as did the acetate, and had essentially similar n.m.r., i.r., and u.v. spectra to those of the acetate, and we therefore conclude that the acetate and benzoate differ only in the nature of the acyl group. *X*-Ray crystallography of the benzoate was more successful and showed it to be the unusual orthoanhydride (3). The acetate must therefore have structure (4). This is consistent with the previously published [2] n.m.r., i.r., and u.v. spectroscopic data for the acetate, and with its mass spectrum.

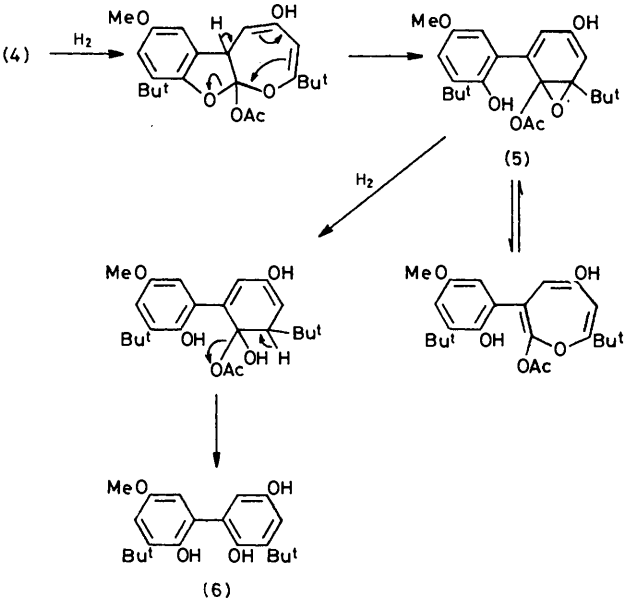
Reduction products of the acetate (4) all contain the biphenyl nucleus, and this reversion of the oxepin to an aromatic ring is difficult to explain except in terms of valence tautomerism [3,4] between oxepins and arene oxides, which in solution are in equilibrium. Hydrogenation to the biphenyltriol (6) may be rationalised as in Scheme 1, where initial 1,4-addition of hydrogen to the oxepinone system is postulated. Reduction of the epoxide (5) in the alternative mode would lead to the same triol. The three products (9)—(11) isolated from the reductive acetylation of the acetate (4) can be similarly accounted for by the various transformations of the radical anion (7) shown in Scheme 2.

Analogy for the ring contraction in these reductions is provided by the reaction of the dibenzoxepinone (12) with 3 mol. equiv. of Grignard reagent to give the dihydroanthracenediol (13), which is also believed to involve an epoxide intermediate.[4]



(3) R = Ph
(4) R = Me

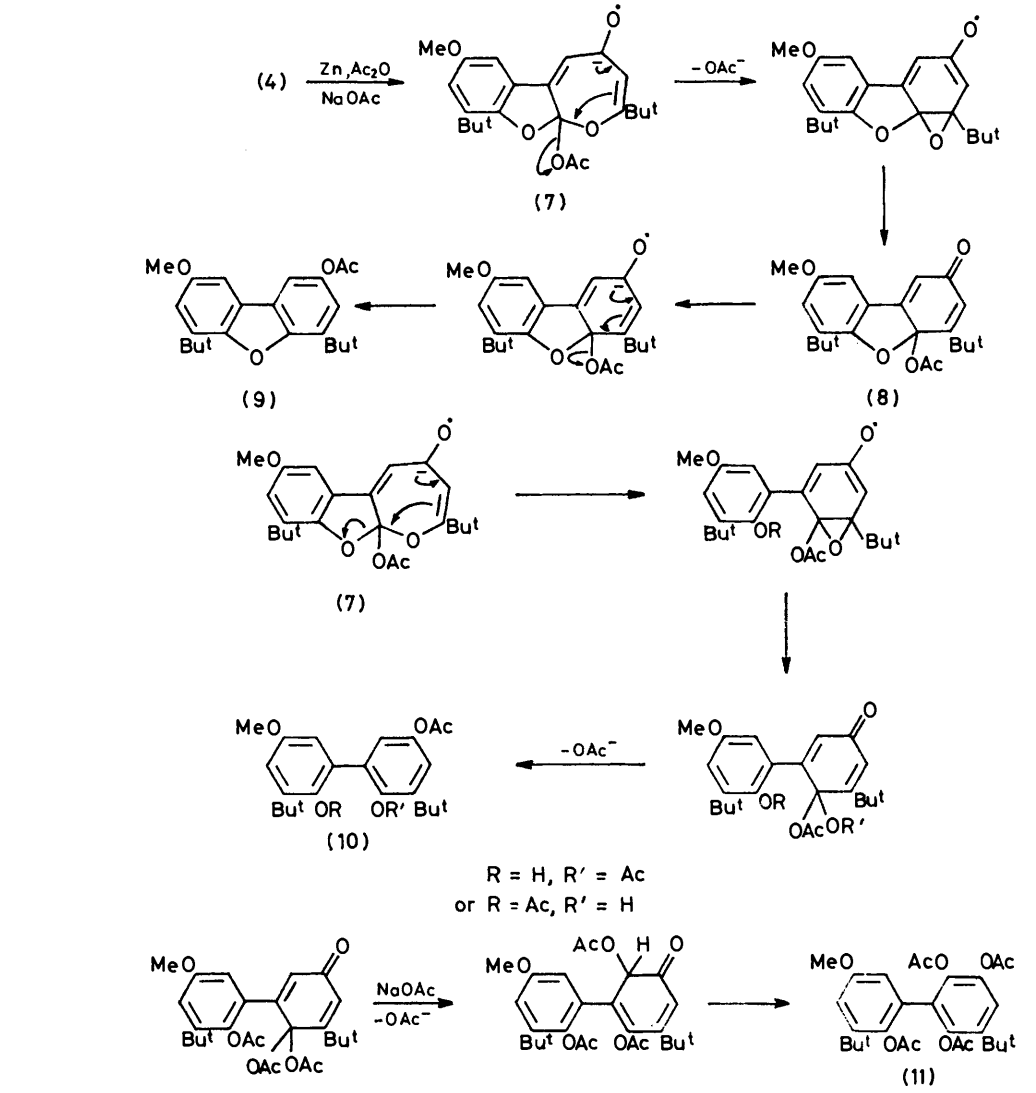
In our earlier paper [2] we showed that the reaction of 1 mol. equiv. of lead tetra-acetate with the diol (1) in



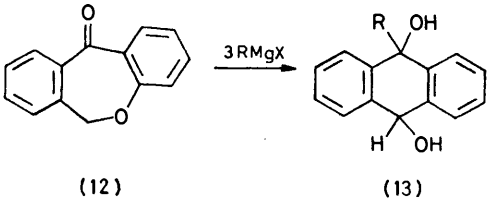
SCHEME 1

benzene gave the compound there described as the benzoxet (16). This was believed to be formed by the sequence

(14)→(16), where the quinone (15) could be generated from (1) either through the cyclic intermediate (14) or by any of the various mechanisms proposed for the oxidation of phenols by this reagent. On this basis we recently proposed [5] a rationalisation for the formation of the geometrically isomeric lactones (17) and (18), which were isolated as minor products in the oxidation of (1) by lead tetra-acetate, involving hydration of the benzoxet (16) to a glycol, followed by cleavage with lead tetra-acetate.



SCHEME 2

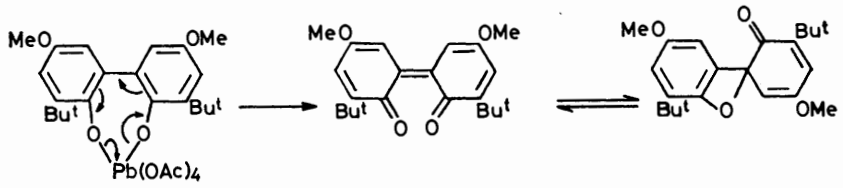


Still more recently,* however, Meier *et al.*[6] have shown that the true valence isomers of 2,2′-diphenoquinones such as (15) are not benzoxets but oxepinobenzofurans. Our previous explanation for the formation of (17) and (18) is thus incorrect. Both these compounds as well as the acetate (4) can be derived quite simply from the oxepinobenzofuran valence isomer (19) of the quinone (15) as in Scheme 3. Electrophilic addition of lead tetra-acetate to (19) would be expected to involve the most stable carbocation and result in the adduct (20). After loss of lead diacetate and acetate anion the resulting carbocation (21) could be hydrolysed as shown, either to the acetate (4), or *via* (22) and (23) to the minor products (17) and (18).

The two products isolated earlier [2] on treatment of the acetate (4) with acetic acid formed red prisms, m.p. 149—154 °C, and colourless plates, m.p. 121—126 °C.

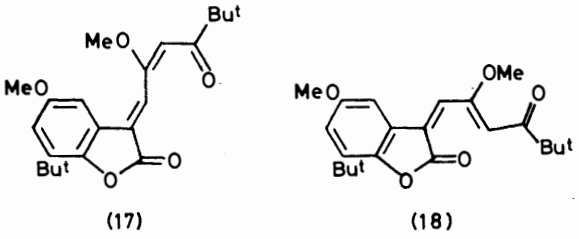
* The paper by Meier *et al.* appeared after acceptance of the present paper. Scheme 3 has been changed in accordance with their revised structure for compound (16).

Mass spectrometry showed that both had a molecular weight of 358, and almost identical fragmentation



patterns, and the analytical data were consistent with the formula $C_{21}H_{26}O_5$.

The n.m.r. spectrum of the red material showed the presence of two t-butyl groups, one methoxy group, two

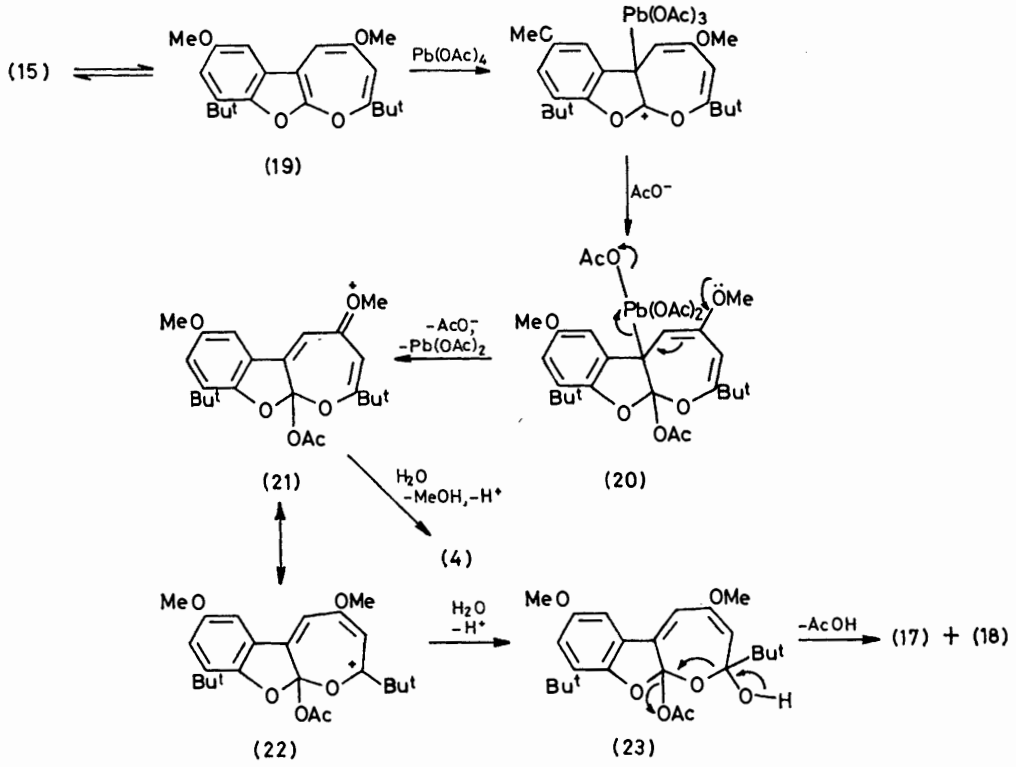


uncoupled olefinic hydrogens, a pair of *meta*-coupled aromatic hydrogens, and a broad singlet at extremely low field, δ 15.72, which did not exchange with D_2O. The i.r. spectrum showed a broad, intense carbonyl absorption at 1 530—1 610 cm^{-1}, with a sharper band at 1 790 cm^{-1}, as well as a broad, hydrogen-bonded hydroxy absorption at 2 500—3 300 cm^{-1}. This information is consistent with the enolized β-diketone structure (24).

The high carbonyl frequency at 1 790 cm^{-1} is typical of a benzofuran-2(3*H*)-one with an exocyclic double bond.[5] The broad carbonyl absorption at 1 530—1 610 cm^{-1} is similar to that described by Rassmusen *et al.*[7] for compounds such as acetylacetone, and which is attributed to conjugate chelation. Moreover, the enolic hydrogen resonance at δ 15.72 is also typical of such systems: for example, that of 5,5-dimethylhexane-2,4-dione (26) has a chemical shift of δ 15.9.[8]

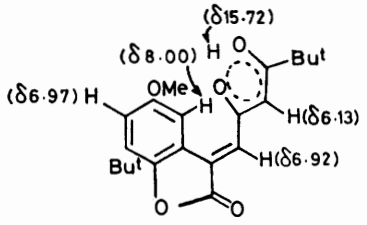
The stereochemistry of the side chain is revealed by the low-field resonance at δ 8.00 of one of the aromatic hydrogens, which is very similar to that of the analogous hydrogen of the ester (25) at δ 8.08 which is deshielded by the ester carbonyl group.[5] Comparison with compound (25) and with the diketone (26) [8] also allowed the assignment of chemical shifts to the olefinic hydrogens of (24).

The n.m.r. spectrum of the colourless isomer again contained resonances from the aromatic ring sub-



SCHEME 3

stituents, another t-butyl group, and one olefinic hydrogen at δ 5.43, and a doublet of doublets at δ 4.10 and 4.98 (J 2.3 Hz); the i.r. spectrum had ν(CO) 1 815 and 1 710 cm^{-1}. The fact that this compound was colourless indicated loss of the extensive conjugation present in (24), and this, together with the other spectroscopic data, suggested structure (27). The high carbonyl frequency at 1 815 cm^{-1} is consistent with a benzofuran-2(3*H*)-one structure lacking α,β-unsaturation at C-3. Several 5-alkylfuran-3(2*H*)-ones prepared by Casnati and Ricca [9] had ν(CO) 1 700 cm^{-1} and u.v. absorption at 260 nm (log ε 4.03—4.11). In comparison compound (27) showed u.v. absorption at 260 nm (log ε 4.06). The chemical shifts of the two vicinal hydrogens



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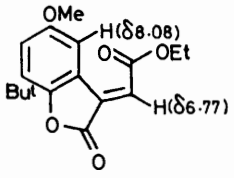

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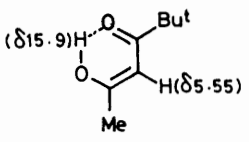

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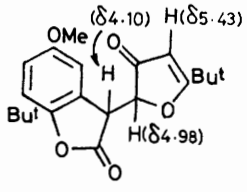
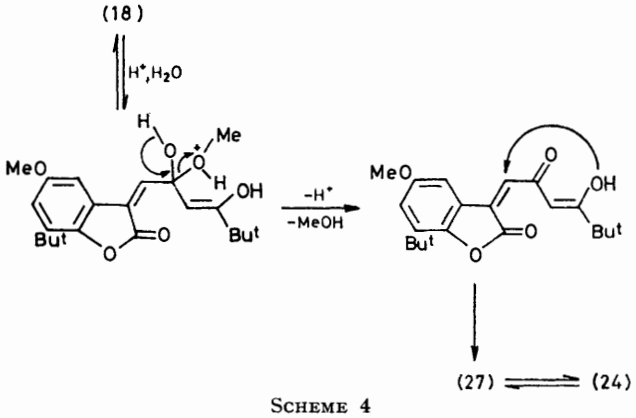


(27)

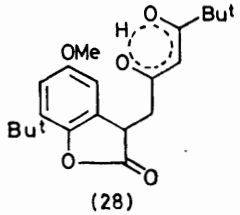
were assigned on the basis of the slight broadening of the doublet at δ 4.10 due to benzylic coupling with the aromatic protons. Becker has observed similar coupling in a related benzofuran-2(3*H*)-one.[10]

Compound (27) is isomerised to (24) on prolonged boiling in hexane or chloroform, presumably by reverse Michael addition. As the isomers (17) and (18) are enol ethers of the pair of isomers (24) and (27), hydrolysis of



Scheme 4

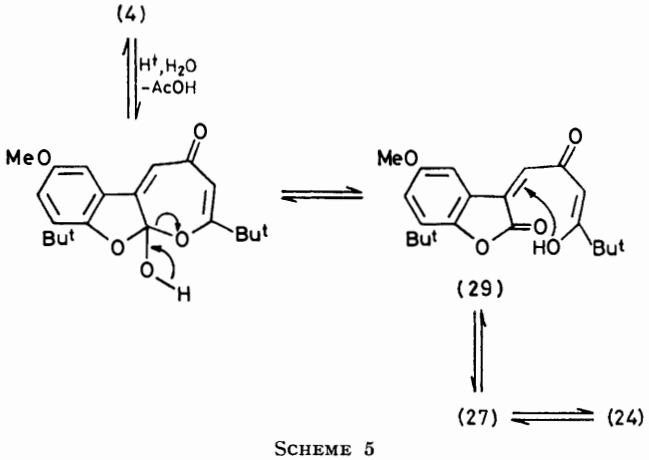
the former should lead to the latter. Although no crystalline material could be isolated from hydrolysis of the *E*,*E*-isomer (17), the *Z*,*Z*-isomer (18) gave a 60% yield of (24), which can be represented as in Scheme 4. A small amount of the isomer (27) was present in the crude reaction mixture. The reverse reaction, methylation of (24) to (17) or (18), could not be accomplished.



(28)

No reaction occurred when (24) was treated with diazomethane in methanol, and attempted base-catalysed methylation led to extensive decomposition. These results emphasise the strength of the hydrogen bond in compound (24).

On catalytic reduction compound (24) absorbed 1 mol. equiv. of hydrogen giving colourless material, $C_{21}H_{28}O_5$. The same product was obtained using zinc in acetic acid. On the basis of spectroscopic data, which included an n.m.r. signal at δ 15.3 indicating that the enolised β-diketone moiety was still present, and i.r. absorption at 1 805 cm^{-1}, consistent with a benzofuran-2(3*H*)-one carbonyl, structure (28) is proposed. The u.v. spectrum also showed absorption at 281 nm (log ε 3.92) in close agreement with the calculated value of 279 nm (log ε 4.1) for an enolised β-diketone.[11]



Scheme 5

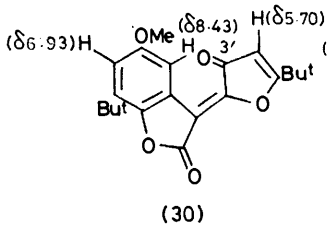
Formation of the benzofuran-2(3*H*)-ones (24) and (27) from the acetate (4) can be explained as in Scheme 5,

where hydrolysis of the acetate generates the ortho acid, which can open to the enol (29), and undergo Michael addition to give (24) and (27). This rearrangement was monitored by n.m.r. spectrometry. In moist acetic acid (*ca.* 8% H_2O) 90% of the acetate (4) was converted after 1.2 h into a mixture of (24) and (27), in the ratio 1.0 : 2.6. By contrast, analysis of a solution of (4) in dry acetic acid containing acetic anhydride (5%) showed negligible rearrangement after 2 h at 80—90 °C.

The ease of hydrolysis of the acetate (4) is demonstrated by the fact that the solid slowly decomposes into (24) and acetic acid. The pure acetate crystallises as bright yellow prisms (m.p. 168—171 °C). After storage for 2 weeks in the dark the crystals were orange-brown (m.p. 142—153 °C), and after 2 months the colour had changed to a dull red (m.p. 131—145 °C). At this stage a strong odour of acetic acid could be detected. Recrystallisation of this sample from hexane gave 40% of the acetate (4), and from the mother liquors (24) was obtained in 45% yield. The decomposition is negligible when the acetate is stored over phosphorus pentaoxide.

Originally, when it was thought that the acetate (4) had structure (2), it was treated with sulphuric acid and acetic anhydride in an attempt to induce a dienone–phenol rearrangement. A dark red product, $C_{21}H_{24}O_5$, was isolated, for which spectroscopic evidence indicates structure (30). The n.m.r. spectrum shows the loss of the acetate group, and apart from the aromatic ring substituents only a t-butyl group and a singlet at δ 5.70. The *Z*-stereochemistry of the C-3 exocyclic double bond and the substitution pattern in the furan-3(2*H*)-one ring are defined by the low-field resonance at δ 8.43 of the C-4 aromatic hydrogen, which is deshielded by the carbonyl group at C-3′. The i.r. spectrum showed αβ-unsaturated carbonyl absorption at 1 690 cm^{-1} and αβ-unsaturated benzofuran-2(3*H*)-one carbonyl absorption at 1 790 cm^{-1}. This transformation of (4) into (30) probably involves the dihydrobenzofuran-2(3*H*)-one (27) as an intermediate, since under the same conditions (30) was also formed from (27), but the detailed reaction path is not clear as an oxidation is involved and no hydrogen acceptor could be identified.

The structural relationship between the dihydrobenzofuran-2(3*H*)-one (27) and the (*Z*)-benzofuran-2(3*H*)-one (30) was proved by dehydrogenation of (27) with DDQ in benzene, which gave (30) in low yield (9%). The major product (55%) was the *E*-isomer (31). The i.r.,



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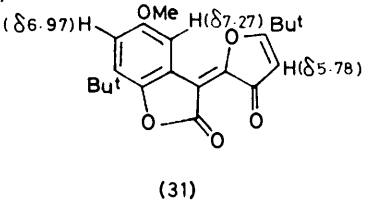
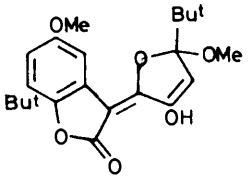


(31)

u.v., and mass spectra of the two isomers were almost identical, and the *E*-configuration of (31) is revealed by the higher chemical shift (δ 7.27) of the C-4 proton. Presumably the *E*-isomer is the thermodynamically less stable, and its preferential formation in the DDQ oxidation may be the result of a kinetic preference.

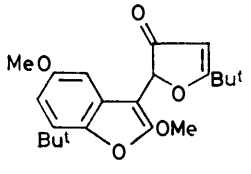
Oxidation of (27) with DDQ in methanol gave the dimethoxybenzofuran-2(3*H*)-one (32). The *E*-con-



(32)

figuration assigned to the C-3 exocyclic double bond is based on the low chemical shift of the enolic hydroxy proton at δ 11.53. Compound (32) is similar to the benzofuran-2(3*H*)-ones obtained on oxidation of 2,4-di-t-butylphenol with methanolic DDQ.[12]

On treatment with methanol both the benzoate (3) and the acetate (4) gave a compound, $C_{22}H_{28}O_5$. Spectroscopic data are consistent with the formulation of this as (33), and its formation can be rationalised as



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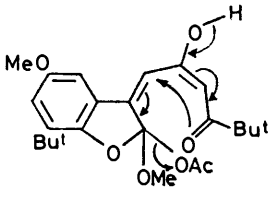

(34)

shown in (34). With ethanol the analogous ethoxy-compound was formed.

EXPERIMENTAL

M.p.s were taken with a Kofler hot-stage apparatus. Microanalyses were performed by the Australian Microanalytical Service. N.m.r. spectra were measured with a Varian A-60, mass spectra with a Varian MAT-CH7, u.v. spectra with a Beckman Acta MIV, and i.r. spectra with a Perkin-Elmer 283 spectrometer. Extracts were dried with magnesium sulphate.

4,10a-*Dihydro*-7-*methoxy*-4-*oxo*-2,9-*di*-t-*butyloxepino*-[2,3-b]*benzofuran*-10a-*yl Benzoate* (3).—A solution of 5,5′-dimethoxy-3,3′-di-t-butylbiphenyl-2,2′-diol (5 g) in hot moist benzene (100 ml) was added dropwise during 15 min to a vigorously stirred suspension of lead tetrabenzoate (20 g) in dry benzene (150 ml). After further stirring for 1 h water (15 ml) was added and stirring was continued for 30 min. After filtration the organic layer was washed with water, sodium hydrogen carbonate, and water, and dried. Removal of the solvent left a yellow oil which crystallised from hexane to give the *benzoate* (3) as yellow prisms, m.p. 186—188 °C (Found: C, 72.7; H, 6.4. $C_{28}H_{30}O_6$ requires C, 72.7; H, 6.5%); δ($CDCl_3$) 1.28 (Bu^t), 1.32 (Bu^t), 3.67 (OMe), 5.76 (d, 1 H, $J_{3,5}$ 2.0 Hz), 6.59 (d, 1 H, $J_{3,5}$ 2.0 Hz), 6.77 (d, 1 H, ArH, $J_{6,8}$ 2.5 Hz), 6.93 (d, 1 H, ArH, $J_{6,8}$ 2.5 Hz), and 7.42 (5 H, ArH); $\nu_{max.}$ ($CHCl_3$) 1 750 and 1 615 cm^{-1}; $\lambda_{max.}$ (log ε) (cyclohexane) 229 (4.28), 273 (3.87),

284 (3.88), 297 (3.90), and 386 nm (3.65); *m/e* 462, 434, 377, 357, 341, 329, 301, 273, 259, 231, and 105.

Hydrogenation of the Benzoate (3).—The benzoate (3) (150 mg) was hydrogenated over Pd–C in ethanol, consuming 2 mol. equiv. of hydrogen. Filtration and concentration gave an oil which was taken up in ethyl acetate and washed with sodium hydrogen carbonate solution to remove benzoic acid. After washing with water and drying the solvent was removed. Addition of hexane gave 5-methoxy-3,3′-di-t-butylbiphenyl-2,2′,5′-triol, m.p. and mixed m.p. 184—186 °C (lit.,[2] 185.5—186.5 °C).

Mass Spectrum of the Acetate (4).—*m/e* 400 (26%), 358 (40), 330 (11), 301 (43), 274 (42), 259 (100), 57 (69), 55 (18), 43 (48), and 41 (30). Other spectroscopic data are given in ref. 2.

Reaction of the Acetate (4) *with Acetic Acid.*—The acetate (4) (600 mg) in acetic acid (40 ml) was heated on a steam-bath for 1 h. The cooled solution was poured into water and extracted with ethyl acetate. Concentration of the washed and dried extract gave a red gum which crystallised on cooling. Recrystallisation from hexane gave 3-(2,3-*dihydro*-3-*oxo*-5-*t*-*butylfuran*-2-*yl*)-5-*methoxy*-7-*t*-*butylbenzofuran*-2(3H)-*one* (27) (83 mg, 15%) as plates. m.p. 121—123 °C (decomp.) (lit.,[2] 121—126 °C); δ(CCl_4) 0.92 (5-Bu^t), 1.38 (7-Bu^t), 3.68 (5-OMe), 4.10 (d, 3-H, $J_{3.2}$ 2.3 Hz), 4.98 (d, 2-H, $J_{3.2}$ 2.3 Hz), 5.43 (4-H), 6.39 (d, 1 H, ArH, $J_{4.6}$ 2.5 Hz) and 6.73 (d, 1 H, ArH, $J_{4.6}$ 2.5 Hz); $\nu_{max.}$ (CCl_4), 1 710 (furanone CO) and 1 815 cm^{-1} (benzofuranone CO); $\lambda_{max.}$ (log ε) (cyclohexane), 260 (4.06), 296 (3.43), and 368 nm (2.78); *m/e* 358 (32%), 330 (9), 301 (28), 274 (32), 259 (100), 57 (48), 43 (12), and 41 (18).

From the mother liquors (E)-3-[(Z)-4(*or* 2)-*hydroxy*-5,5-*dimethyl*-2(*or* 4)-*oxohex*-3(*or* 2)-*enylidene*]-5-*methoxy*-7-*t*-*butylbenzofuran*-2(3H)-*one* (24) (315 mg, 59%) crystallised as red prisms, m.p. 146—150 °C (lit.,[2] 149—154 °C); δ(CCl_4) 1.23 (4-Bu^t), 1.40 (7-Bu^t), 3.83 (5-OMe), 6.13 (3-H), 6.92 (1-H), 6.97 (d, 6-ArH, $J_{4.6}$ 3.0 Hz), 8.00 (d, 4-ArH, $J_{4,6}$ 3.0 Hz), and 15.72 (br, enolic OH); $\nu_{max.}$ (CCl_4) 1 630 (αβ-unsaturated CO), 1 790 (αβ-unsaturated benzofuranone CO) and 2 950—3 300 cm^{-1} (enolic OH); (Nujol) 1 530—1 610 (br, conjugated H-bonded CO); $\lambda_{max.}$ (log ε) (EtOH), 266 (4.05), 294 sh (3.45), and 372 nm (3.43); *m/e* 358 (34%), 330 (7), 301 (29), 274 (31), 259 (100), 57 (50), 55 (33), 43 (17), and 41 (21).

When a solution of (27) (85 mg) in chloroform was heated under reflux for 10 h, and then evaporated to dryness (24) (61 mg) was obtained on crystallisation of the residue from hexane.

Hydrolysis of the Benzofuranone (18).—A solution of (18) (239 mg) in acetone (20 ml) containing water (5 ml) and concentrated HCl (5 ml) was heated under reflux for 2 h. The cooled solution was poured into water and extracted with ethyl acetate. Concentration of the washed and dried extract gave a gum which crystallised on addition of methanol. Recrystallisation from hexane gave (24) (171 mg), m.p. and mixed m.p. 146—150 °C. The i.r. spectra of the two samples were identical .

Reduction of the Benzofuranone (24).—(*a*) Catalytic reduction of (24) (365 mg) in ethanol over Pd–C required 1 mol. equiv. of hydrogen. Concentration of the filtered solution gave a colourless gum which crystallised on cooling. Recrystallisation from hexane gave (Z)-3-[4(*or* 2)-*hydroxy*-5,5-*dimethyl*-2(*or* 4)-*oxohex*-3(*or* 2)-*enyl*]-5-*methoxy*-7-*t*-*butylbenzofuran*-2(3H)-*one* (28) (215 mg) as needles, m.p. 92—93 °C (Found: C, 70.2; H, 8.1. $C_{21}H_{28}O_5$ requires C, 70.0; H, 7.8%); δ(CCl_4) 1.17 (4-Bu^t), 1.38 (7-Bu^t), 2.3—4.2 (m, 3 H, 3-H and 1-H_2), 3.70 (5-OMe), 5.62 (3-H), 6.57 (dd, ArH, $J_{benzylic}$ 0.8, $J_{4.6}$ 2.8 Hz), 6.62 (d, ArH, $J_{4.6}$ 2.8 Hz) and 15.3 (br, enolic OH), $\nu_{max.}$ (CCl_4) 1 805 and 2 500—3 300; (Nujol) 1 570—1 640 cm^{-1}; $\lambda_{max.}$ (log ε) (EtOH) 243 (3.74) and 281 nm (3.92); *m/e* 360 (26%), 346 (13), 276 (44), 261 (6), 233 (42), 219 (12), 217 (9), 206 (16), 191 (9), 189 (5), 127 (7), 91 (7), 85 (8), 57 (100), 43 (27), and 41 (25).

(*b*) A solution of (24) (329 mg) in acetic acid (15 ml) was heated on a steam-bath with zinc dust (500 mg) for 30 min. The filtered mixture was poured into water and extracted with ethyl acetate. Concentration of the washed and dried extract and crystallisation from hexane gave (28) (161 mg), m.p. and mixed m.p. 92—93 °C.

Reaction of the Acetate (4) *with Acetic Anhydride and Concentrated Sulphuric Acid.*—A solution of the acetate (4) (260 mg) in acetic anhydride (30 ml) containing sulphuric acid (10 drops) was set aside for 12 h, then poured into dilute aqueous sulphuric acid and extracted with ether. Concentration of the washed and dried extract gave a red gum which crystallised on addition of hexane. Recrystallisation from hexane gave (Z)-3-(2,3-*dihydro*-3-*oxo*-5-*t*-*butylfuran*-2-*ylidene*)-5-*methoxy*-7-*t*-*butylbenzofuran*-2(3H)-*one* (30) (170 mg, 74%) as brick-red needles, m.p. 161.5—162.5 °C (Found: C, 71.0; H, 6.9. $C_{21}H_{24}O_5$ requires C, 70.8; H, 6.8%); δ(CCl_4) 1.43 (2 Bu^t), 3.88 (5-OMe), 5.70 (4-H), 6.93 (d, 6-ArH, $J_{4.6}$ 3.0 Hz), and 8.43 (d, 4-ArH, $J_{4.6}$ 3 Hz); $\nu_{max.}$ (CCl_4) 1 785 and 1 790 (αβ-unsaturated benzofuranone CO), and 1 690 cm^{-1} (furanone CO); $\lambda_{max.}$ (log ε) (EtOH) 275 (4.03), 357 (3.96), 290 sh (3.88), and 455 nm (3.50); *m/e* 356 (100%), 341 (43), 299 (33), 272 (17), 231 (18), 67 (14), 57 (40), and 41 (22).

Similar treatment of (27) (98 mg) gave (30) (59 mg, 62%), m.p. and mixed m.p. 161.5—162.5 °C.

Dehydrogenation of the Benzofuranone (27).—A solution of (27) (273 mg) in dry benzene (10 ml) containing DDQ (182 mg) was heated under reflux for 3 h. Filtration of the cooled mixture gave $DDQH_2$ (161 mg). Concentration of the filtrate gave a red gum which was found by n.m.r. to be a mixture of (30) and (31) in the ratio 1 : 6. The two components were separated by preparative t.l.c. on silica plates developed in chloroform. The fraction of higher R_F was (30) (24 mg, 9%), which after crystallisation from hexane had m.p. and mixed m.p. 161.5—162.5 °C.

The fraction of lower R_F was the E-*isomer* (31) (150 mg, 55%), which crystallised from ethanol as red needles, m.p. 172—173 °C (Found: C, 70.4; H, 6.9. $C_{21}H_{24}O_5$ requires C, 70.7; H, 6.8%); δ($CDCl_3$) 1.38 (5-Bu^t), 1.42 (7-Bu^t), 3.85 (5-OMe), 5.78 (4-H), 6.97 (d, 6-ArH, $J_{4.6}$ 2.9 Hz), and 7.27 (d, 4-ArH, $J_{4.6}$ 2.9 Hz); $\nu_{max.}$ (CCl_4) 1 705 (αβ- and α′β′-unsaturated CO) and 1 790, 1 800 cm^{-1} (αβ-unsaturated benzofuranone CO); $\lambda_{max.}$ (log ε) (EtOH) 271 (4.01), 365 (4.09), and 455 nm (3.60); *m/e* 356 (100%), 341 (43), 299 (41), 272 (22), 231 (28), 67 (28), 57 (59), 43 (15), and 41 (35).

Reaction of the Acetate (4) *with Methanol.*—A solution of the acetate (4) (300 mg) in methanol (20 ml) was heated under reflux for 3 h. The solvent was removed under reduced pressure and the residue was crystallised from hexane giving 2-(2,5-*dimethoxy*-7-*t*-*butylbenzofuran*-3-*yl*)-5-*t*-*butylfuran*-3(2H)-*one* (33) (157 mg) as needles, m.p. 124—127 °C (decomp.) (Found: C, 70.5; H, 7.6. $C_{22}H_{28}O_5$ requires C, 70.9; H, 7.6%); δ($CDCl_3$) 1.33 (5-Bu^t), 1.43 (7-Bu^t), 3.75 (OMe), 4.13 (OMe), 5.58 (1 H), 5.65 (1 H), 6.68 (d, 6-ArH, $J_{4.6}$ 2.5 Hz), and 7.02 (d, 4-ArH, $J_{4.6}$ 2.5

Hz); $\nu_{max.}$ (CCl_4) 1 650 (C=C) and 1 710 cm^{-1} (furanone CO); $\lambda_{max.}$ (log ε) (cyclohexane) 253 (4.33), 289 (3.71), and 297 nm (3.69); M^+ 372.

TABLE 1

Fractional cell parameters H × 10^3; others × 10^4

Atom	x	y	z
C(1)	3 263(4)	3 480(3)	3 556(2)
C(2)	2 237(4)	3 906(3)	3 436(2)
H(2)	225(4)	446(3)	328(2)
C(3)	1 208(4)	3 557(3)	3 585(2)
O(3)	0 101(3)	3 892(2)	3 493(2)
C(31)	0 024(7)	4 645(5)	3 254(3)
H(31α)	046(5)	506(4)	349(2)
H(31β)	040(5)	451(4)	292(2)
H(31γ)	−087(5)	469(4)	329(2)
C(4)	1 191(4)	2 810(3)	3 825(2)
H(4)	042(4)	256(3)	390(2)
C(5)	2 191(4)	2 360(3)	3 939(2)
C(51)	2 146(4)	1 518(3)	4 172(2)
C(52)	2 770(7)	0 898(5)	3 838(3)
H(52α)	219(5)	094(4)	356(2)
H(52β)	358(5)	108(3)	379(2)
H(52γ)	271(5)	036(3)	400(2)
C(53)	0 889(7)	1 231(6)	4 258(4)
H(53α)	050(5)	165(4)	452(2)
H(53β)	058(6)	116(4)	392(2)
H(53γ)	094(5)	071(4)	441(2)
C(54)	2 804(7)	1 519(5)	4 681(3)
H(54α)	363(4)	173(3)	464(2)
H(54β)	224(5)	181(3)	486(2)
H(54γ)	293(5)	092(3)	478(2)
C(6)	3 219(4)	2 740(3)	3 795(2)
O(6)	4 337(2)	2 405(2)	3 879(1)
C(7)	5 154(4)	2 921(3)	3 653(2)
O(7)	6 066(2)	3 115(2)	4 008(1)
C(8)	4 478(4)	3 629(3)	3 432(2)
C(9)	4 974(5)	4 204(3)	3 160(2)
H(9)	448(4)	462(3)	306(2)
C(10)	6 197(4)	4 221(3)	3 000(2)
O(10)	6 602(3)	4 866(2)	2 847(1)
C(11)	6 895(4)	3 481(3)	2 967(2)
H(11)	757(4)	356(3)	281(2)
C(12)	6 677(4)	2 696(3)	3 062(2)
C(121)	7 410(4)	1 978(3)	2 911(2)
C(122)	6 639(6)	1 416(4)	2 590(3)
H(122α)	594(5)	116(3)	277(2)
H(122β)	641(5)	172(3)	227(2)
H(122γ)	715(4)	089(3)	250(2)
C(123)	7 821(6)	1 534(5)	3 391(3)
H(123α)	842(5)	196(3)	355(2)
H(123β)	718(5)	129(3)	362(2)
H(123γ)	828(5)	110(4)	333(2)
C(124)	8 476(6)	2 227(5)	2 616(3)
H(124α)	813(5)	240(4)	228(2)
H(124β)	895(5)	264(4)	283(2)
H(124γ)	886(5)	170(4)	249(2)
O(12)	5 701(2)	2 425(2)	3 307(1)
C(13)	5 834(4)	3 636(3)	4 390(2)
O(13)	4 874(3)	3 911(2)	4 459(1)
C(14)	6 889(4)	3 809(3)	4 700(2)
C(15)	7 961(6)	3 492(5)	4 583(3)
H(15)	801(5)	308(4)	435(2)
C(16)	8 950(6)	3 680(6)	4 875(3)
H(16) *	978(—)	349(—)	477(—)
C(17)	8 844(6)	4 177(5)	5 284(3)
H(17)	953(5)	433(4)	546(2)
C(18)	7 788(6)	4 500(4)	5 394(2)
H(18)	774(5)	489(3)	566(2)
C(19)	6 810(5)	4 318(4)	5 106(2)
H(19)	600(4)	454(3)	516(2)

* Constrained.

Similar treatment of the benzoate (3) (250 mg) also gave (33) (200 mg), m.p. and mixed m.p. 124—127 °C.

Reaction of the acetate (4) with boiling ethanol gave the corresponding 2-*ethoxy compound*, m.p. 115—116.5 °C

TABLE 2

Non-hydrogen molecular geometry

(*a*) Bond lengths (Å)

C(1)–C(2)	1.393(7)	C(9)–C(10)	1.468(7)
C(1)–C(6)	1.375(7)	C(10)–O(10)	1.232(6)
C(1)–C(8)	1.452(6)	C(10)–C(11)	1.455(8)
C(2)–C(3)	1.373(7)	C(11)–C(12)	1.338(8)
C(3)–O(3)	1.391(6)	C(12)–C(121)	1.506(7)
O(3)–C(31)	1.395(10)	C(121)–C(122)	1.525(9)
C(3)–C(4)	1.385(8)	C(121)–C(123)	1.540(9)
C(4)–C(5)	1.385(7)	C(121)–C(124)	1.523(9)
C(5)–C(51)	1.518(7)	C(12)–O(12)	1.381(6)
C(51)–C(52)	1.542(9)	O(7)–C(13)	1.364(6)
C(51)–C(53)	1.530(9)	C(13)–O(13)	1.201(6)
C(51)–C(54)	1.540(9)	C(13)–C(14)	1.471(7)
C(5)–C(6)	1.391(6)	C(14)–C(15)	1.372(9)
C(6)–O(6)	1.400(5)	C(15)–C(16)	1.388(10)
O(6)–C(7)	1.407(5)	C(16)–C(17)	1.375(12)
C(7)–O(7)	1.427(5)	C(17)–C(18)	1.354(10)
C(7)–C(8)	1.507(6)	C(18)–C(19)	1.370(8)
C(7)–O(12)	1.394(5)	C(19)–C(14)	1.378(7)
C(8)–C(9)	1.327(7)		

(*b*) Bond angles (°)

C(2)–C(1)–C(6)	120.7(6)	C(1)–C(8)–C(9)	131.9(5)
C(2)–C(1)–C(8)	131.4(4)	C(7)–C(8)–C(9)	122.9(4)
C(6)–C(1)–C(8)	107.6(4)	C(8)–C(9)–C(10)	126.5(5)
C(1)–C(2)–C(3)	116.1(5)	C(9)–C(10)–C(10)	118.7(5)
C(2)–C(3)–C(4)	121.8(5)	C(9)–C(10)–C(11)	121.7(5)
C(2)–C(3)–O(3)	124.0(5)	O(10)–C(10)–C(11)	119.2(5)
C(4)–C(3)–O(3)	114.1(4)	C(10)–C(11)–C(12)	133.5(5)
C(3)–O(3)–C(31)	118.5(5)	C(11)–C(12)–C(121)	126.6(4)
C(3)–C(4)–C(5)	123.6(5)	O(12)–C(12)–C(121)	109.5(4)
C(4)–C(5)–C(6)	113.1(4)	C(11)–C(12)–O(12)	123.8(4)
C(4)–C(5)–C(51)	122.7(4)	C(12)–C(121)–C(122)	108.1(4)
C(6)–C(5)–C(51)	124.1(4)	C(12)–C(121)–C(123)	107.8(5)
C(5)–C(51)–C(52)	109.9(5)	C(12)–C(121)–C(124)	112.6(5)
C(5)–C(51)–C(53)	112.6(5)	C(122)–C(121)–C(123)	110.1(5)
C(5)–C(51)–C(54)	110.1(5)	C(122)–C(121)–C(124)	108.9(5)
C(52)–C(51)–C(53)	109.4(6)	C(123)–C(121)–C(124)	109.4(5)
C(53)–C(51)–C(54)	107.5(1)	C(12)–O(12)–C(7)	120.5(4)
C(52)–C(51)–C(54)	107.6(5)	C(7)–O(7)–C(13)	119.2(3)
C(1)–C(6)–C(5)	124.5(4)	O(7)–C(13)–O(13)	123.1(4)
C(1)–C(6)–O(6)	112.2(4)	O(7)–C(13)–C(14)	111.9(4)
C(5)–C(6)–O(6)	123.2(4)	O(13)–C(13)–C(14)	125.0(5)
C(6)–O(6)–C(7)	107.6(3)	C(13)–C(14)–C(15)	121.1(5)
O(6)–C(7)–C(8)	107.3(3)	C(13)–C(14)–C(19)	119.7(4)
O(6)–C(7)–O(7)	109.0(3)	C(15)–C(14)–C(19)	119.2(5)
O(6)–C(7)–O(12)	104.2(3)	C(14)–C(15)–C(16)	120.1(7)
C(8)–C(7)–O(7)	116.5(4)	C(15)–C(16)–C(17)	119.6(7)
C(8)–C(7)–O(12)	115.0(4)	C(16)–C(17)–C(18)	120.3(6)
O(7)–C(7)–O(12)	104.1(3)	C(17)–C(18)–C(19)	120.4(6)
C(1)–C(8)–C(7)	105.1(4)	C(18)–C(19)–C(14)	120.5(5)

TABLE 3

Some equations for least-squares planes in the right-handed orthogonal Å frame (X, Y, Z), X parallel to a, Z in the ac plane [atom deviations (Å) in parentheses]

(*a*) C(1—6, 8, 51) O (3, 6)

$0.0580X + 0.4600Y + 0.8860Z = 11.24$ (σ 0.04 Å)

[C(1), 0.03; C(2), 0.00; C(3), 0.02; O(3), −0.02; C(4), 0.02; C(5), 0.02; C(6), 0.03; O(6), 0.05; C(7), −0.04; C(8), −0.07; C(51), −0.07; C(9), −0.25; O(7), 1.01; O(12), −1.20]

(*b*) C(1, 7—10)

$0.1616X + 0.5500Y + 0.8194Z = 11.56$ (σ 0.05 Å)

[C(1), −0.05; C(7), 0.01; C(8), 0.04; C(9), 0.06; C(10), −0.05; O(10), 0.27]

(*c*) C(9—11) O(10)

$0.3144X + 0.1768Y + 0.9327Z = 10.84$ (σ 0.02 Å)

C(9), −0.01; C(10), 0.04; C(11), −0.01; O(10), −0.01

(*d*) C(10—12, 121) O(12)

$0.4810X + 0.1208Y + 0.8684Z = 11.18$ (σ 0.07 Å)

[C(10), −0.07; C(11), 0.09; C(12), 0.03; C(121), −0.06; O(12), 0.01; O(10), −0.07; C(7), 0.60; C(9), −0.38]

(Found: C, 71.2; H, 7.9. $C_{23}H_{30}O_5$ requires C, 71.5; H, 7.8%); δ($CDCl_3$) 1.33 (5-Bu^t), 1.45 (7-Bu^t), 1.48 (t, OCH_2-CH_3, J 7.0 Hz), 3.75 (OMe), 4.49 (q, OCH_2CH_3, J 7.0 Hz),

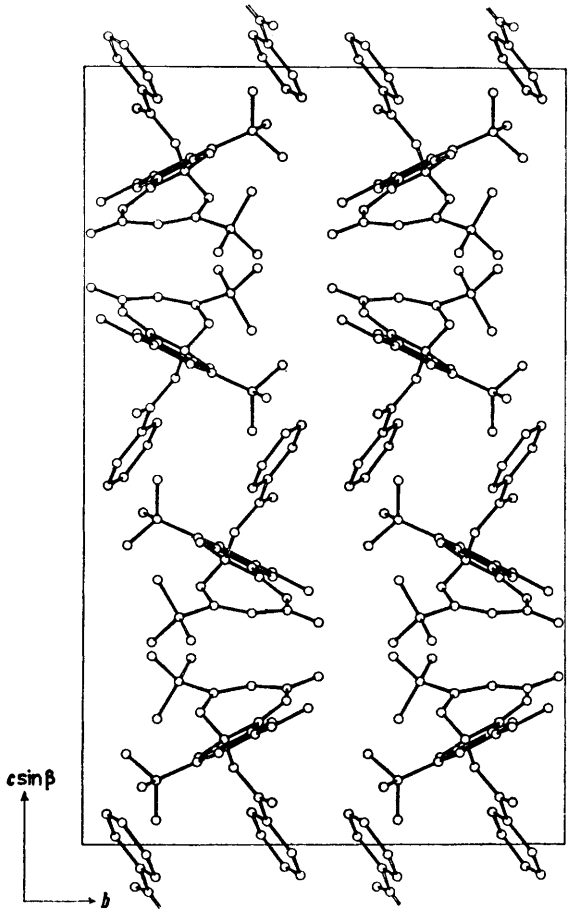

FIGURE 1 Unit-cell contents projected down *a* (non-hydrogen atoms only)

5.61 (1 H), 5.67 (1 H), 6.46 (d, 6-ArH, $J_{4,6}$ 2.5 Hz) and 6.67 (d, 4-ArH, $J_{4,6}$ 2.5 Hz); $\nu_{max.}$ (CCl_4) 1 710 cm^{-1}; M^+ 386.

Crystal Data.—$C_{28}H_{30}O_6$, M 462.6. Monoclinic, space group $C2/c$ (C_{2h}^6, No. 15), a = 11.388(7), b = 16.42(1), c = 26.80(2) Å, β = 91.51(7)°, U = 5 010(7) Å^3, D_m = 1.23 g cm^{-3}, Z = 8, D_c 1.23 g cm^{-3}, $F(000)$ 1 968. μ = 0.92 cm^{-1} (Mo-K_α radiation, monochromatic, λ 0.710 69 Å), polyhedral specimen *ca.* 0.4 mm diameter.

Structure Determination.—Data collection: Syntex $P\bar{1}$ four-circle diffractometer in 2θ—θ mode, $2\theta_{max.}$ 40°, yielding 2 368 independent reflections, 1 604 with $I > 2\sigma(I)$ considered ' observed ' and used in the refinement, uncorrected for absorption. Refinement: 9 × 9 block-diagonal least squares, but where hydrogen atoms were attached to any carbon, their parameters were also included in that block. Thermal parameters: C, O anisotropic; U_H isotropic, constrained at $< U_{ii} + 0.01 >$ Å^2, U_{ii} pertaining to parent carbon. Hydrogen atoms: all except H(16) refined in positional co-ordinates only. Residuals: R 0.054, R' 0.055 {reflection weights, $w = [\sigma^2(F_o) + 0.000\ 3(F_o)^2]^{-1}$}. Computation: ' X-RAY '76 ' program system,[13] CYBER 73 computer. Scattering factors: neutral atom, C, O corrected for anomalous dispersion ($\Delta f'$, $\Delta f''$).[14-16] Material deposited:* structure-amplitude tables, thermal parameters, hydrogen geometries.

The structure determination establishes the molecular composition to be as described above; the unit-cell contents are comprised of discrete molecules with no unusually short intermolecular contacts and with one molecule in the asymmetric unit.

The benzoate geometry is usual and will not be discussed further. In the context of the substituents about the benzofuran entity, the distortions observed therein are also ' normal ' [17] and do not warrant further comment; the sequence C(1—6,8,51)O(3,6) is substantially planar. Some equations for least-squares planes are in Table 3. Selected angles between these planes are a—b, 8.7; b—c, 24.2; and c—d, 10.7°, clearly reflecting the substantial distortions from planarity of the seven-membered ring and its substituents. The benzene ring and the carboxylate group are substantially planar and lie at an angle of 82° to the benzofuran plane (a). The geometry within the seven-membered ring is of interest. The ketonic C=O bond is appreciably longer (1.23_2 Å) than is usual and this together with the rather short C(9)–C(10) and C(10)–C(11) distances (1.46_8 and 1.45_5 Å) suggests that the whole ring exhibits some conjugation; the distances about O(12) are shorter, also, than the usual aliphatic C–O distances. The angular geometry within the ring exhibits substantial deviations from the 128.6° angles expected for an (unlikely) regular planar system. Those at the benzofuran ring fusion are approximately as expected for the trigonal and tetrahedral geometries involved; at O(12), the angle is 120.5°, typical of aromatic oxygen substituents and in keeping with the reduced bond lengths on either side. At C(12), the distortion of the exocyclic angles from the trigonal values is greater than usual and, together with the t-butyl disposition

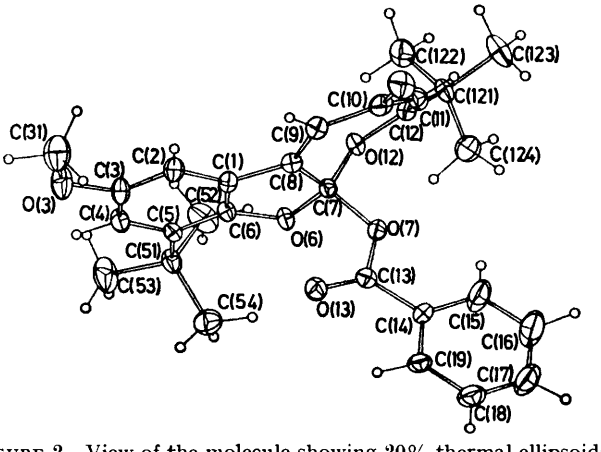

FIGURE 2 View of the molecule showing 20% thermal ellipsoids (hydrogen atom radii are set arbitrarily at 0.1 Å). The non-systematic skeletal numbering used for the crystallographic work is given; methyl hydrogen atoms are distinguished by suffixes α, β, γ given in the text

(Figures 1 and 2) is suggestive of interaction of the latter with H(11); the angle C(10–C(11)–C(12) is very large indeed (133.5°).

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