

Cyclisation of Arylpropioyl Chloro-oxalyl Anhydrides: the Chemistry of Aryl(chloro)methylenetetrahydrofuran-2,4,5-triones and the X-ray Crystal Structure of a 3,4-Methylenedioxybenzylidene Representative

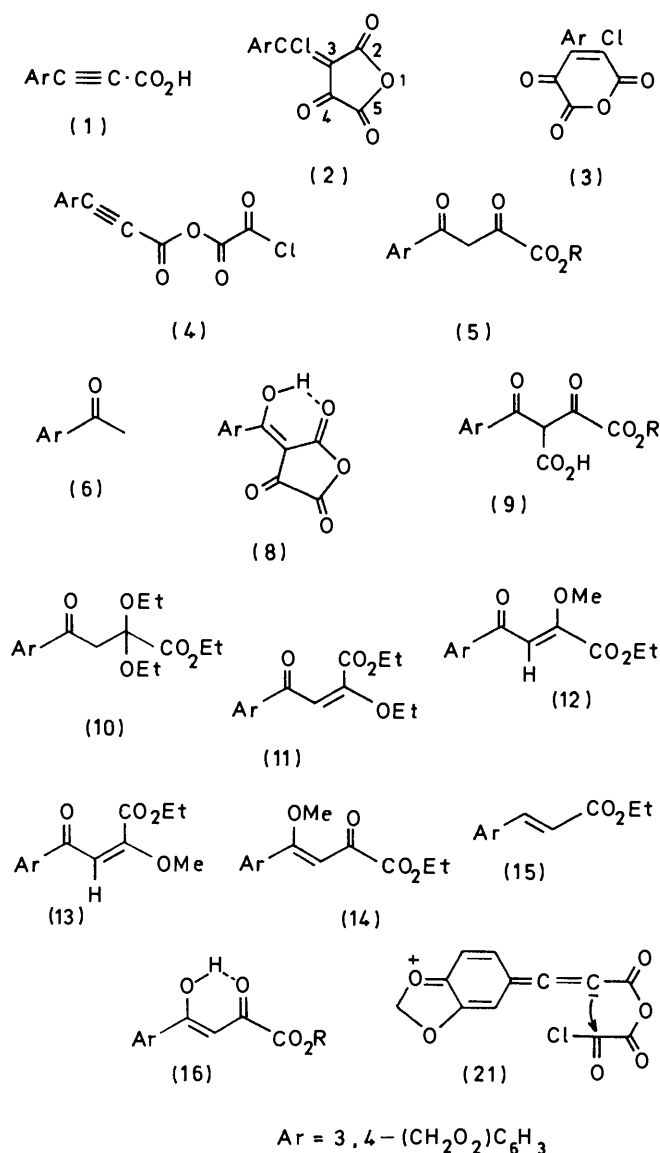
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3,4-Methylenedioxyphenylpropionic acid and oxalyl chloride form a mixed anhydride which cyclises to give a red, water-sensitive aryl(chloro)methylenetetrahydrofuran-2,4,5-trione: its mixed *Z,E*-geometry has been investigated by single crystal X-ray methods. Arylpropionic acids with substituents providing sufficient electron release undergo the cyclisation, but in other cases arylnaphthalenedicarboxylic anhydrides and arylpropioyl chlorides are formed. The mechanism of the cyclisation is considered, and some reactions of the trione are described.

TREATMENT of a suspension of 3,4-methylenedioxyphenylpropionic acid (1) in benzene with oxalyl chloride gives little of the expected propioyl chloride: instead,

red crystals of a new compound, $C_{12}H_5ClO_6$, are formed. In this paper the chemistry and structure of the compound are discussed, and the scope and mechanism of the

reaction considered.¹ The following paper deals with the thermal rearrangement which it undergoes.



The red compound showed n.m.r. signals for three aromatic and two methylenedioxy protons, and had ν_{\max} 1 869, 1 838, 1 788, and 1 723 cm⁻¹, accommodating an oxo-anhydride structure (2) or (3) which might be formed by cyclisation of a mixed anhydride (4). Structure (2) was shown to be correct by basic hydrolysis to 3,4-methylenedioxybenzoylpyruvic acid (5; R = H; enolised). The latter could be degraded thermally to 3',4'-methylenedioxyacetophenone (6) with loss of CO and CO₂, or, by further treatment with base, to (6) and oxalic acid. Alcohols reacted with (2) to give the esters (5; R = Me or Et), and the latter was resynthesised by Claisen condensation between (6) and diethyl oxalate.

ZE-Isomerism is possible for the vinylogous acid chloride structure (2), and the stereochemistry was

examined by X-ray methods. The compound formed orthorhombic crystals, space-group *Pbca*, with unit cell dimensions $a = 7.95$, $b = 23.78$, and $c = 11.93$ Å, containing 8 molecules in the unit cell (one molecule per asymmetric unit). The structure was solved by the heavy-atom technique (664 reflections) and refined by block-diagonal least-squares methods. Two views of the structure arrived at, which has *Z*-geometry, are shown in Figure 1, and Figure 2 shows the crystallographic numbering.

However, a difference map calculated after apparent convergence (R 0.077) revealed an additional peak in the neighbourhood of the ring oxygen atom [O(5)] together with a 'hole' at the oxygen atom of the carbonyl [O(4)]. This was interpreted as indicating the presence of a limited amount of *E*-isomer which had co-crystallised with the *Z*-. The two isomers are superimposable in a space-filling sense, except for the carbonyl

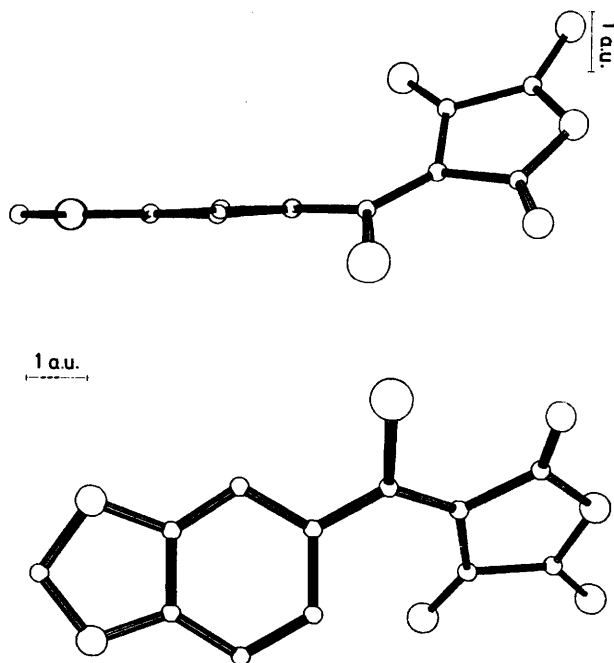


FIGURE 1 (*Z*)- α -Chloro-3,4-methylenedioxybenzylidene-tetrahydrofuran-2,4,5-trione

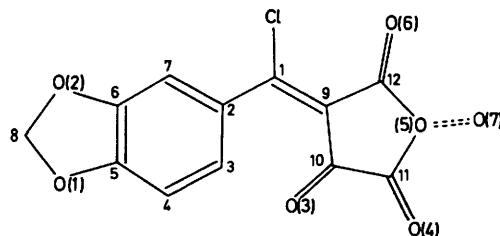


FIGURE 2 Crystallographic numbering scheme

oxygen [O(4)] which has to be moved between O(4) and O(7) with interchange between O(5) and C(11) (Figure 2). Refinement was therefore continued with an 'extra'

¹ Preliminary account, L. Crombie, R. Havard, and D. P. Reynolds, *J.C.S. Chem. Comm.*, 1973, 265.

atom, O(7), attached to O(5), and the occupation fractions of O(4) and O(7) were allowed to vary. Refinement converged to R 0.056 (anisotropic temperature factors were used). The occupation fractions of O(4) and O(7) had a sum of unity within one standard deviation, thus confirming the model of co-crystallised stereoisomers. Bond-length and -angle calculations showed no contact distances to O(7) less than 3.0 Å, the sum of the van der Waals radii: this indicates that the crystal structure of the *Z*-isomer contains enough space

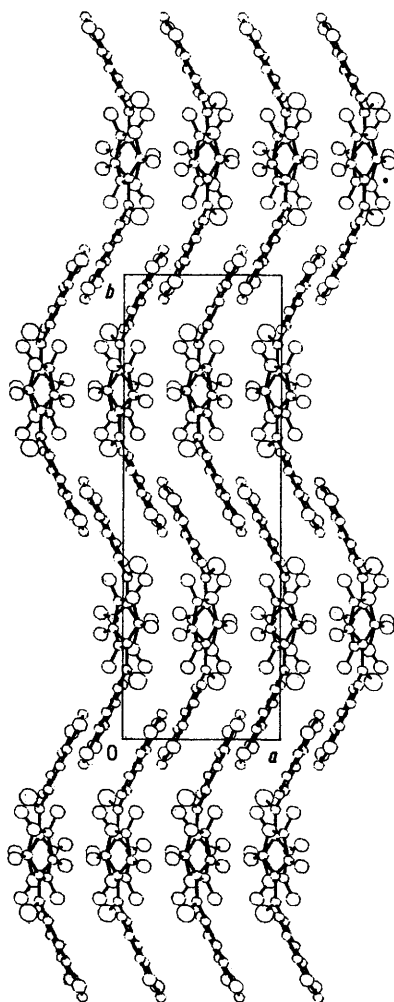


FIGURE 3 Molecular packing; view perpendicular to the c axis

to accommodate the additional atom O(7) of the *E*-isomer without distortion of the close-packing of the molecules. The crystal structure thus consists of the *Z*-isomer shown in Figure 1 with $17 \pm 5\%$ of *E*-isomer in the lattice.

Whether the observed isomer ratio in the crystal is representative of the total reaction product is uncertain. It is also uncertain whether the mixture reflects kinetic or thermodynamic control, though the latter seems probable (2 h reflux in benzene). Proton n.m.r. does not adequately differentiate between the *Z*- and *E*-isomers,

there being insufficient perturbation to alter the chemical shifts of the aromatic protons, and a ^1H solution study of the isomerisation could not be undertaken.

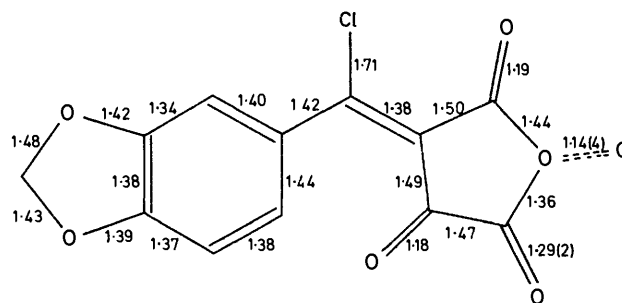


FIGURE 4 Bond length (Å); e.s.d.s 0.01 Å unless otherwise indicated in parentheses

The arrangement of molecules in the unit cell is shown in Figure 3 which confirms the availability of space within the crystal structure to accommodate the additional atom of the *E*-isomer without distortion. Bond lengths and angles are displayed in Figures 4 and 5; these adopt expected values if allowance is made for the larger uncertainties in those positions which are fractionally occupied. The benzene ring is planar within 0.03 Å (χ^2 13.93) as are also both the five-membered rings, with $\chi^2 = 1.03$ for the cyclic acetal ring and $\chi^2 = 3.77$ for the trione ring. As expected, the benzene and acetal rings are coplanar: however, the central section of the molecule [C(1),C(2),C(9)] is distorted out of conjugation, presumably to avoid close contact of O(3) and C(3). The torsion angle about the C(1)-C(2) bond is 33° , and, surprisingly, the C(1)-C(9) double bond has a torsion angle of 11° . The resulting twist in the molecule allows the O(3)-C(3) contact distance to expand to 2.41 Å and the Cl-O(6) contact distance is 2.89 Å. Short intermolecular carbonyl contacts were observed as follows: O(3)-C(9'), 2.93 Å; O(3)-C(12'), 2.99 Å; O(4)-C(8'), 3.00 Å; O(6)-C(10'), 2.84 Å; O(6)-C(11'), 2.95 Å; O(7)-C(8'), 2.99 Å.

Treatment of the red trione (2) in ethyl acetate with an excess of water led to the acid (5; R = H), but with 1 mol. equiv. of water the tetraone, $\text{C}_{12}\text{H}_6\text{O}_7$ (7) could be isolated in 70% yield. The mass spectrum (Scheme 1)

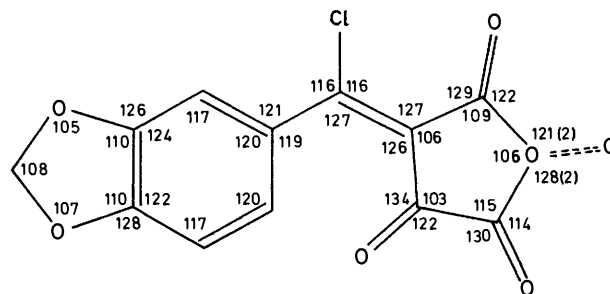
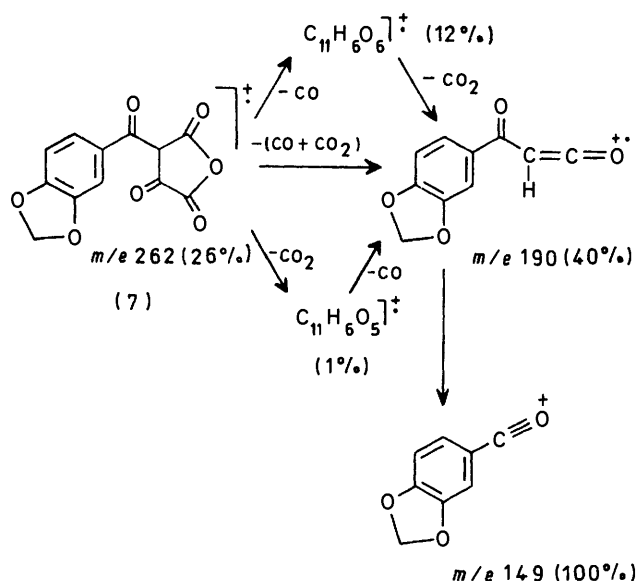


FIGURE 5 Bond angles ($^\circ$); e.s.d.s 1° unless otherwise indicated in parentheses

supported the structure, and u.v. data [λ_{max} (CHCl_3) 250 (ϵ 7 510), 292 (6 820), 332 (6 180), and 408 nm (13 300)] suggested that it is largely enolised, as in (8),

in this solvent. Treatment of (8) with water or sodium hydroxide solution gave the acid (5; R = H), and



treatment with ethanol gave the ester (5; R = Et), by cleavage of the anhydride and decarboxylation of (9; R = Et).

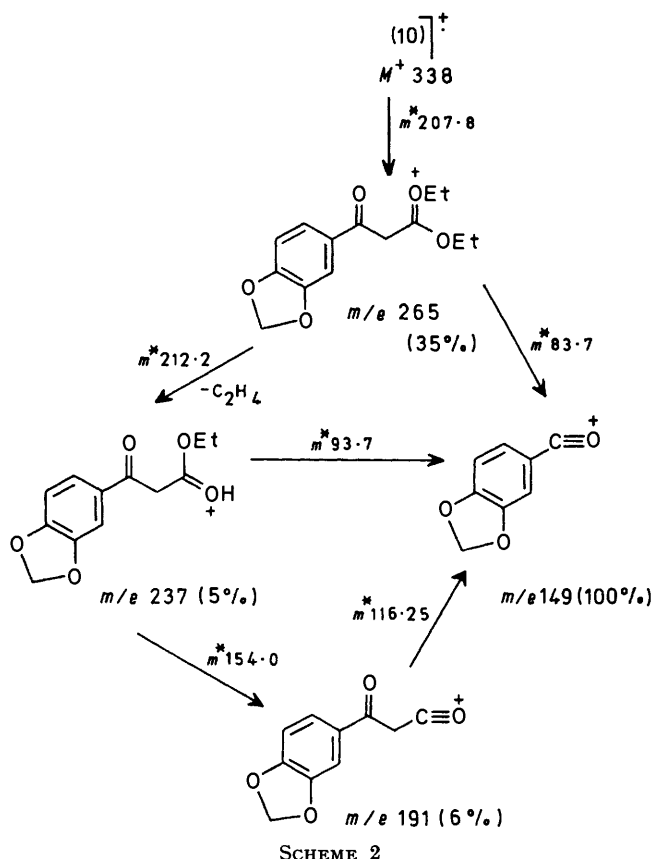
Addition of an excess of ethanol to the red trione (2) itself, in the absence of organic diluent, resulted in an exothermic reaction with evolution of carbon dioxide. If, after effervescence had ceased, water was added, the ester (5; R = Et) was obtained. However, if the mixture was set aside, two further products, (10) and (11), could be isolated from the acidic solution. The n.m.r. spectrum of (10) showed signals for three ethyl groups (two equivalent), a methylene singlet, and the methylene singlet and three aromatic protons of the methylenedioxyphenyl group. Comparison of u.v. data showed a chromophore closely similar to that of 3,4-methylenedioxyacetophenone, but substantially different from models for the 4-monoacetal chromophore, e.g. the lignan asarinin. Assignment of structure (10) is also supported by the mass spectral data (Scheme 2).

The n.m.r. spectrum of the second product showed signals for two ethyl groups, an olefinic proton, and the methylenedioxyphenyl group: this led to the enol ether structure (11). Its stereochemistry was explored as follows. Treatment of (5; R = Et) with diazomethane in the presence of a catalytic quantity of boron trifluoride gave (12), showing τ 3.16 for the olefinic 3-proton. On treatment with trifluoroacetic acid, this isomer underwent stereomutation to give (13), τ 3.82; the upfield shift suggests that the methoxycarbonyl group is in this case *trans* to the olefinic proton.² This geometry was confirmed when a 21% enhancement of the H-3 signal was observed on irradiation at τ 6.18

(OMe). Since H-3 in (11) resonates at 3.88 the compound is the *E*-isomer. Assignment of the 2-alkoxy-structures (11)—(13) as opposed to the 4- (14) is supported by u.v. data. Since an alkoxy-group produces a shift of ca. 30 nm when substituted in the β -position of an α -unsaturated ketone,³ the principal absorption of (14) would be expected to be at longer wavelength than that of 3,4-methylenedioxyacetic ester (15). Compounds (11)—(13) absorb at shorter wavelengths (though longer than that of 3',4'-methylenedioxyacetophenone).

N.m.r. data show that, in the solvents examined, none of the compounds of type (5) actually exhibits resonances attributable to the dioxo-form: all appear entirely enolised, with the chelated proton signal near τ -5. Since the u.v. spectra show maxima at longer wavelengths than that of the corresponding cinnamic acid (15), the predominant tautomer appears to be (16).

Following this examination of the chemistry of the red trione (2), the reactions of a series of substituted arylpropionic acids with oxalyl chloride were studied, to assess the scope of the synthesis. The results are summarised in Table 1: yields refer to the amounts of pure compounds isolated by crystallisation or distillation.



In the cases (a)—(d), the i.r. spectra of the crude products showed absorptions at 2200 cm^{-1} assigned to

³ A. I. Scott, 'Interpretation of the Ultraviolet Spectra of Natural Products,' Pergamon, Oxford, 1964.

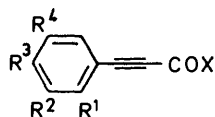
² L. H. Jackman and S. Sternhell, 'Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry,' 2nd edn., Pergamon, Oxford, 1969.

$\text{C}\equiv\text{C}$ stretching of the corresponding acid chlorides (18), which are minor products. For case (a) quantitative i.r. estimation showed the presence of 92% of the trione (19) and 8% of the acid chloride (18); amounts for (b)–(d) are expected to be similar. The ratio of (19) to (18) remained unchanged on prolonged refluxing, and both pure compounds were unchanged by refluxing with oxalyl chloride in benzene: the two are produced in competing pathways, neither being an intermediate in the formation of the other.

TABLE 1

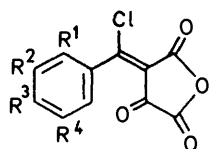
Reaction of arylpropionic acids (17) with oxalyl chloride

	R ¹	R ² R ³		R ⁴	Product isolated (%)		
		O-CH ₂ -O			(19)	(18)	(20)
a	H			H	75		
b	H	OMe	OMe	OMe	70		
c	H	OMe	OMe	H	75		
d	H	H	OMe	H	73		
e	OMe	H	H	H		41	5
f	H	H	Me	H		44	16
g	H	H	H	H		41	40
h	H	H	Cl	H		35	52

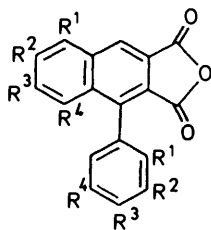


(17) X = OH

(18) X = Cl



(19)



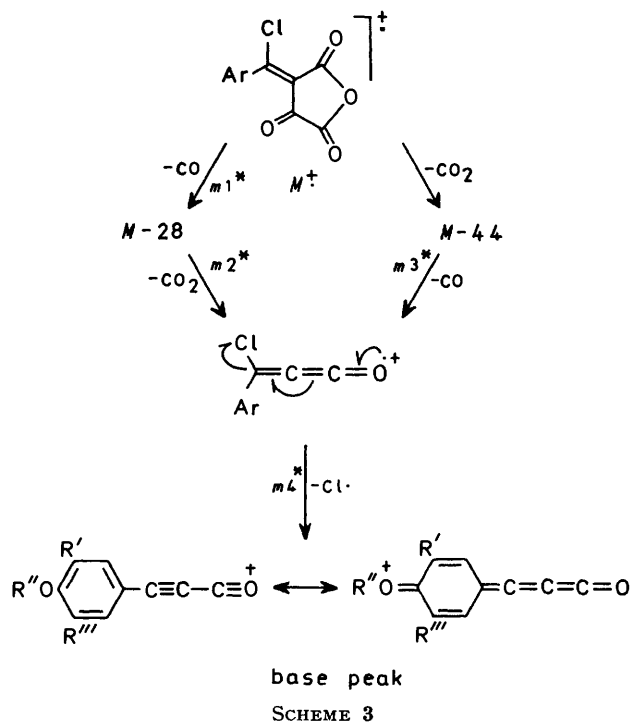
(20)

All the triones (19) exhibit deep red solutions showing strong absorption (ϵ 12 000–20 000) in the 420–480 nm region, and their i.r. spectra are very similar in the carbonyl region. The mass spectral fragmentation patterns all follow that summarised in Scheme 3.*

Arylnaphthalenes (20), all identical with authentic specimens,⁴ were important products in reactions (e)–(h). These arise from the corresponding acetylenic acid anhydrides⁵ which, along with the acid chlorides, are well known products from oxalyl chloride and carboxylic acids.⁶ However in none of these reactions did a red colour develop, indicative of trione formation, with the exception of (e), and here no trione was isolated.

* This contrasts with the mass spectrum of the thermal rearrangement products (following paper), which fragment by direct decomposition of M^+ to $\text{ArC}\equiv\text{O}$. Minor peaks corresponding to the latter were observed even under conditions of strict exclusion of moisture to avoid contamination by (8): this tends to imply some isomerisation in the mass spectrometer.

Formation of the triones must involve nucleophilic displacement by C-2 of the acetylene in the mixed



anhydride [see (21)]. In the transition state for the cyclisation the aromatic ring is envisaged as being orthogonal to the forming trione ring. Overlap of the aromatic orbitals with the shaded orbitals of the rehybridising acetylene (Figure 6) implies that the electronic effect of substituents in the aromatic ring is of cardinal importance in stabilising the developing positive charge at C-3; carbonyl overlap with the unshaded orbitals has little influence. Thus only examples (a)–(d) in Table 1, all of which possess a *p*-alkoxy-group gave chlorotriones. When suitable electron release is not available, *i.e.* (e)–(h), the reaction takes another course leading to aryl-naphthalenes and acid

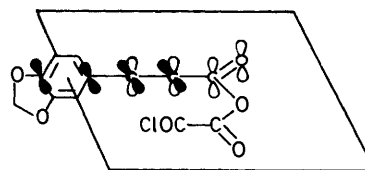


FIGURE 6

chlorides. Other aspects of the mechanism are discussed with the mechanism of the thermal rearrangement of the chloro-triones in the following paper.

⁴ (a) F. G. Baddar, *J. Chem. Soc.*, 1947, 224; (b) F. G. Baddar and L. S. El-Assal, *ibid.*, 1848, 1267; (c) 1951, 1844; (d) F. G. Baddar, L. S. El-Assal, and N. A. Doss, *ibid.*, 1955, 465; (e) 1959, 1027; (f) F. G. Baddar, G. E. M. Moussa, and M. T. Omar, *J. Chem. Soc. (C)*, 1968, 110.

⁵ J. Cley and J. F. Arens, *Rec. Trav. chim.*, 1959, 78, 929.

⁶ R. Adams and L. H. Ulich, *J. Amer. Chem. Soc.*, 1920, 42, 599.

EXPERIMENTAL

α -Chloro-3,4-methylenedioxybenzylidenetetrahydrofuran-2,4,5-trione (2).—Oxalyl chloride (10 g, 80 mmol) was added to a finely ground suspension of 3,4-methylenedioxyphenylpropionic acid (5.7 g, 30 mmol) in anhydrous benzene (10 cm³). The mixture was refluxed for 2 h. Benzene and the excess of oxalyl chloride were removed under reduced pressure, and the residue crystallised from anhydrous benzene to give the *tetrahydrofurantrione* (2) (6.2 g, 75%), red plates, m.p. 170–172° (decomp.) (Found: C, 51.3; H, 1.8; Cl, 12.6%; M^+ , 279.977. $C_{12}H_5ClO_6$ requires C, 51.3; H, 1.8; Cl, 12.65%; M , 279.977), ν_{\max} . (CHCl₃) 1 869, 1 838, 1 788, and 1 723 cm⁻¹, λ_{\max} . 274sh (ϵ 7 020), 288 (8 200), 364 (5 300), 425sh (8 700), and 473 nm (13 000), τ [(CD₃)₂CO] 2.45 (1 H, dd, $J_{5,6}$ 8, $J_{2,6}$ 2 Hz, arom. H-6), 2.70 (1 H, d, $J_{2,6}$ 2 Hz, arom. H-2), 2.95 (1 H, d, $J_{5,6}$ 8 Hz, arom. H-5), and 3.78 (2 H, s, CH₂O₂).

Reactions of the Trione (2) with Water and Alcohols.—(a) *With aqueous sodium hydroxide.* The trione (2) (0.5 g) was shaken with aqueous sodium hydroxide (5%; 10 cm³). When the red colour had been discharged (a few minutes), the solution was acidified with hydrochloric acid. The precipitate, on crystallisation from aqueous ethanol, gave pale yellow crystals of 3,4-methylenedioxybenzoylpyruvic acid (16; R = H) (348 mg, 83%), m.p. 197–199° (decomp.) (Found: C, 55.7; H, 3.35%; M^+ , 236. $C_{11}H_8O_6$ requires C, 56.0; H, 3.4%; M , 236), ν_{\max} . (mull) 3 200–2 400 (carboxylic acid), 1 730 and 1 723 (carbonyl), and 1 633 cm⁻¹ (enolic β -diketone), ν_{\max} . (EtOH) 352 (ϵ 15 000), 306inf (8 100), and 244 nm (7 300), τ [(CD₃)₂SO] -1.05 (2 H, s), 2.23 (1 H, dd, $J_{5,6}$ 8, $J_{2,6}$ 2 Hz, H-6), 2.45 (1 H, d, $J_{2,6}$ 2 Hz, H-2), 2.92 (1 H, d, J 8 Hz, H-5), 2.93 (1 H, s, olefinic), and 3.78 (2 H, s, CH₂O₂). An ethanolic solution gave a red colour with iron(III) chloride.

(b) *With an excess of water.* The trione (2) (533 mg) was refluxed with ethyl acetate (10 cm³) and water (1 cm³) for 1.5 h. Evaporation, and crystallisation from aqueous ethanol, yielded 3,4-methylenedioxybenzoylpyruvic acid (16; R = H) (236 mg, 54%), m.p. 196–198° (decomp.).

(c) *With 1 mol. equiv. of water.* A solution of water in ethyl acetate (19.976 g l⁻¹; 3 cm³) was added to a hot solution of the trione (2) (932 mg) in anhydrous ethyl acetate (7 cm³). On cooling the solution deposited yellow needles of α -hydroxy-3,4-methylenedioxybenzylidenetetrahydrofuran-2,4,5-trione (8) (621 mg, 71%), m.p. 179° (decomp.), not raised by crystallisation (ethyl acetate) (Found: C, 54.7; H, 2.45; M^+ , 262. $C_{12}H_6O_7$ requires C, 54.95; H, 2.3%; M , 262), ν_{\max} . (CHCl₃) 1 850, 1 780, and 1 695 cm⁻¹, λ_{\max} . (CHCl₃) 250 (ϵ 7 510), 292 (6 820), 332 (6 180), and 408 nm (13 300), τ [(CD₃)₂CO] 2.15 (1 H, dd, $J_{5,6}$ 8, $J_{2,6}$ 2 Hz, arom. H-6), 2.43 (1 H, d, $J_{2,6}$ 2 Hz, arom. H-2), 2.97 (1 H, d, $J_{5,6}$ 8 Hz, arom. H-5), and 3.81 (2 H, s, CH₂O₂).

(d) *With an excess of ethanol.* The trione (2) (710 mg) in anhydrous chloroform (300 cm³) was treated with ethanol (500 mg) and kept for 60 h. The solution was evaporated and the residue crystallised from aqueous ethanol to give ethyl 3,4-methylenedioxybenzoylpyruvate (16; R = Et) (511 mg, 65%) as pale yellow microcrystals, m.p. 70–71° (Found: C, 59.0; H, 4.5%; M^+ , 264. $C_{13}H_{12}O_6$ requires C, 59.1; H, 4.55%; M , 264), ν_{\max} . (CCl₄) 3 200–2 500 (chelated OH), 1 758, 1 738, and 1 045 cm⁻¹, λ_{\max} . (EtOH) 248 (ϵ 6 640), 309 (7 890), and 360 nm (14 700), τ (CCl₄) -4.7br (1 H, s, chelated OH), 2.43 (1 H, dd, $J_{5,6}$ 8, $J_{2,6}$ 2 Hz, H-6), 2.62 (1 H, d, $J_{2,6}$ 2 Hz, H-2), 3.16 (1 H, s, olefinic), 3.20 (1 H, d, $J_{5,6}$ 8 Hz, H-5), 3.95 (2 H, s, CH₂O₂),

5.68 (2 H, q, J 7 Hz), and 8.60 (3 H, t, J 7 Hz). An ethanolic solution gave a red colour with iron(III) chloride.

Prior to evaporation the mixture was analysed by g.l.c. (column 5 ft by $\frac{1}{4}$ in of 10% squalane on Celite) in order to determine whether ethyl chloride was a product. Sensitivity was adequate to detect a less than 1% yield, but none was observed.

(e) *With 1 mol. equiv. of ethanol.* A solution of ethanol in chloroform (45.9 g l⁻¹; 0.85 cm³) was added to the trione (2) (237 mg) in anhydrous chloroform (100 cm³). After 60 h g.l.c. showed no ethyl chloride. Evaporation and crystallisation from anhydrous ethyl acetate gave α -hydroxy-3,4-methylenedioxybenzylidenetetrahydrofuran-2,4,5-trione (8) (79 mg, 36%), m.p. 178–179° (decomp.).

(f) *With ethanol in the absence of an inert solvent.* (i) *With quenching after a short period.* Anhydrous ethanol (0.5 cm³) was added in one portion to the trione (2). After an induction period (minutes) an exothermic reaction began, and the red compound dissolved with effervescence. As soon as dissolution was complete, water (10 cm³) was added. The precipitated oil solidified; crystallisation from aqueous ethanol gave ethyl 3,4-methylenedioxybenzoylpyruvate (16; R = Et) (154 mg, 80%), m.p. 71–72°.

(ii) *Over a prolonged period.* Anhydrous ethanol (10 cm³) was added to the trione (2), and the resulting solution kept for 24 h. The mixture was separated by p.l.c. on silica with benzene-ethyl acetate (7:1) as eluant. Three bands formed and were extracted with ethyl acetate. That of highest R_F gave the *enol ethyl ether* of ethyl 3,4-methylenedioxybenzoylpyruvate (11) (69 mg), needles (benzene), m.p. 128–130° (Found: C, 61.7; H, 5.5%; M^+ , 292. $C_{15}H_{16}O_6$ requires C, 61.65; H, 5.5%; M , 292), ν_{\max} . (CHCl₃) 1 735 ($\alpha\beta$ -unsaturated ester), 1 655 (aryl and $\alpha\beta$ -unsaturated ketone), 1 604, and 1 582 cm⁻¹, λ_{\max} . (EtOH) 238 (ϵ 13 400), 280 (11 800), and 322 nm (12 050), τ (CDCl₃) 2.50 (1 H, dd, $J_{5,6}$ 8, $J_{2,6}$ 2 Hz, H-6), 2.59 (1 H, d, $J_{2,6}$ 2 Hz, H-2), 3.20 (1 H, d, $J_{5,6}$ 8 Hz, H-5), 4.01 (2 H, s, CH₂O₂), 3.88 (1 H, s, olefinic), 5.68 (2 H, q, J 7 Hz), 5.97 (2 H, q, J 7 Hz), 8.58 (3 H, t, J 7 Hz), and 8.70 (3 H, t, J 7 Hz). The band of intermediate R_F gave the *diethyl acetal* of ethyl 3,4-methylenedioxybenzoylpyruvate (10) (715 mg), blades, m.p. 89–90° (aqueous ethanol) (Found: C, 60.7; H, 6.6%; M^+ , 338. $C_{17}H_{22}O_7$ requires C, 60.35; H, 6.55%; M , 338), ν_{\max} . (mull) 1 750 (ester) and 1 660 cm⁻¹ (aryl ketone), λ_{\max} . (EtOH) 231 (ϵ 17 800), 275 (7 050), and 310 nm (8 320), τ (CDCl₃) 2.43 (1 H, dd, $J_{5,6}$ 8, $J_{2,6}$ 2 Hz, H-6), 2.58 (1 H, d, $J_{2,6}$ 2 Hz, H-2), 3.17 (1 H, d, $J_{5,6}$ 8 Hz, H-5), 3.96 (2 H, s, CH₂O₂), 6.38 (2 H, s, CH₂), 5.75 (2 H, q, J 7 Hz), 8.73 (3 H, t, J 7 Hz), 6.45 (4 H, q, J 7 Hz), and 8.81 (6 H, t, J 7 Hz).

The band of lowest R_F gave ethyl 3,4-methylenedioxybenzoylpyruvate (16; R = Et) (242 mg), m.p. 70–72° (from ethanol).

Reactions of α -Hydroxy-3,4-methylenedioxybenzylidenetetrahydrofuran-2,4,5-trione (8) with Water and Alcohols.—

(a) *With aqueous sodium hydroxide.* Aqueous sodium hydroxide (5%; 2 cm³) was added to the hydroxy-trione (8) (92 mg). When effervescence had ceased the solution was acidified. The precipitate crystallised from aqueous ethanol to give 3,4-methylenedioxybenzoylpyruvic acid (16; R = H) (69 mg, 84%), m.p. 197–198° (decomp.).

(b) *With water.* The hydroxy-trione (8) (169 mg), water (0.5 cm³), and ethyl acetate (4 cm³) were refluxed for 1 h. Evaporation and crystallisation from aqueous ethanol yielded 3,4-methylenedioxybenzoylpyruvic acid (16; R = H) (135 mg, 88%), m.p. 197–198°.

(c) *With ethanol.* The hydroxy-trione (9) (202 mg) was warmed with ethanol (0.5 cm³) until effervescence had ceased and dissolution had taken place. On cooling, ethyl 3,4-methylenedioxybenzoylpyruvate (165 mg, 81%) crystallised; m.p. 71–72°.

Enol Methyl Ethers of Ethyl 3,4-Methylenedioxybenzoylpyruvate.—Ethyl 3,4-methylenedioxybenzoylpyruvate (264 mg, 1 mmol) in ether (10 cm³) was treated with boron trifluoride-ether (0.06 cm³, 0.05 mmol) and an excess of ethereal diazomethane. After 20 h the solution was washed with aqueous sodium hydrogen carbonate, then water, dried (MgSO₄), and evaporated. The predominant product (12) was separated from contaminating *E*-isomer and starting material (both of lower *R_F*) by p.l.c. on silica, with benzene-ethyl acetate (9:1) as eluant. Molecular distillation (60 °C; 0.1 mmHg) gave the (*Z*)-*enol methyl ether of ethyl 3,4-methylenedioxybenzoylpyruvate* (12) (143 mg) as an oil (Found: C, 60.55; H, 5.0%; *M*⁺, 278. C₁₄H₁₄O₆ requires C, 60.54; H, 5.05%; *M*, 278), ν_{\max} (CHCl₃) 1 725 ($\alpha\beta$ -unsaturated ester), 1 656 (aryl, $\alpha\beta$ -unsaturated ketone), 1 620sh, 1 608, and 1 590 cm⁻¹, λ_{\max} (EtOH) 239 (ϵ 13 300), 281 (10 600), and 324 nm (11 300), τ (CDCl₃) 2.50 (1 H, dd, *J*_{5,6} 8, *J*_{2,6} 2 Hz, H-6), 2.63 (1 H, d, *J*_{2,6} 2 Hz, H-2), 3.22 (1 H, d, *J*_{5,6} 8 Hz, H-5), 4.0 (2 H, s, CH₂O₂), 3.16 (1 H, s, olefinic), 6.23 (3 H, s, OCH₃), 5.70 (2 H, q, *J* 7 Hz), and 8.65 (3 H, t, *J* 7 Hz).

Trifluoroacetic acid (0.5 cm³) was added to a solution of the *Z*-isomer (12) (140 mg) in chloroform (5 cm³). After 10 min, the solution was evaporated, and the residue crystallised from benzene-hexane to give needles of the *E*-isomer (13) (96 mg), m.p. 132–133° (Found: C, 59.9; H, 5.2%; *M*⁺, 278), ν_{\max} (CHCl₃) 1 733 ($\alpha\beta$ -unsaturated ester), 1 656 (aryl, $\alpha\beta$ -unsaturated ketone), 1 605, and 1 583 cm⁻¹, λ_{\max} (EtOH) 238 (ϵ 13 600), 281 (11 400), and 323 nm (12 100), τ (CDCl₃) 2.49 (1 H, dd, *J*_{5,6} 8, *J*_{2,6} 2 Hz, H-6), 2.60 (1 H, d, *J*_{2,6} 2 Hz, H-2), 3.18 (1 H, d, *J*_{5,6} 8 Hz, H-5), 3.99 (2 H, s, CH₂O₂), 3.82 (1 H, s, olefinic), 6.18 (3 H, s, OCH₃), 5.67 (2 H, q, *J* 7 Hz), and 8.70 (3 H, t, *J* 7 Hz). A 10% solution in CDCl₃ was degassed by five freeze-pump-thaw cycles, and tetramethylsilane was added for field frequency locking. With irradiation at τ 6.17 (OMe) the olefinic signal at τ 3.82 showed 21% greater integrated intensity than observed with the irradiating field offset to τ 6.5.

Arylpropionic Acids.—The acids (17a–c) and (17f) were prepared from the corresponding cinnamic acids, by esterification followed by bromination and dehydrobromination. The cinnamic acids were made by Doebner condensation. The acids (17d) and (17g and h) were prepared from the appropriately substituted benzoic acids by the Wittig method.⁷

Reactions of Oxalyl Chloride with Arylpropionic Acids.—The arylpropionic acid in anhydrous benzene was refluxed with an excess of oxalyl chloride (2–3 mol. equiv.) and, after evaporation, the crude product was purified (see below). Products and their solutions are moisture sensitive; exposure to the atmosphere was kept to a minimum, and all the solvents were anhydrous.

In reactions with the acids (17a–d) crystallisation gave coloured aryl(chloro)methylenetetrahydrofuran-2,4,5-triones (19a–d). With (17f and g) the crude product was a yellow solid suspended in an oil. The solid was filtered off and washed with a little benzene to give the naphthalene-

dicarboxylic anhydride (20f or g). Evaporation of the filtrate and distillation gave the arylpropionyl chloride (18f or g). For (1h), sublimation at 55 °C and 0.2 mmHg gave the acid chloride (18h) and crystallisation of the involatile residue afforded the naphthalenedicarboxylic anhydride (20h).

Unlike reactions with (17f and g), with (17e) the reaction mixture developed a red colour but no aryl(chloro)methylenetetrahydrofurantrione (19e) was isolated. Sublimation (75 °C and 0.1 mmHg) of the crude product yielded the acid chloride (18e), and crystallisation of the involatile residue gave the naphthalene (19e).

The naphthalenedicarboxylic anhydrides (20e–h) were identical (mixed m.p. and i.r. spectrum) with authentic samples.⁴ The arylpropionyl chlorides (18e–h) were identical (i.r. spectrum) with samples prepared by the action of thionyl chloride on the corresponding acids. Products and yields are summarised in Table 1. Properties of compounds (18)–(20) are given in Table 2.

For the reaction involving 3,4-methylenedioxyphenylpropionic acid (17a), the ratio of (19a) to (18a) was estimated from the absorbances of the i.r. bands at 2 200 and 1 790 cm⁻¹, by using a calibration graph.

Crystallographic Analysis of α -Chloro-3,4-methylenedioxybenzylidenetetrahydrofuran-2,4,5-trione (2).—Suitable specimens of the trione were grown from ethyl acetate solution. Oscillation and Weissenberg photographs were taken about the *a* axis to establish approximate unit cell dimensions and space group. For intensity measurement, a crystal of dimensions ca. 0.6 × 0.3 × 0.05 mm was mounted about the *a* axis on a Hilger and Watts linear diffractometer. Unit-cell dimensions were refined on the diffractometer. With Mo-*K α* radiation, intensity data were collected on the levels 0–7*kl* by the moving-crystal stationary-counter scan method. Each reflection was measured twice and the mean taken in data reduction. Reflections with a mean net count < 3 σ were considered unobserved, leaving 664 observed reflections which were used in the subsequent refinement. No absorption corrections were made. Data reduction and subsequent crystallographic calculations were performed by using the National Research Council (Ottawa) programs of Ahmed, Hall, Pippy, and Saunders. Atomic scattering factors were taken from ref. 8.

Crystal data. C₁₂H₅ClO₆, *M* = 280.6. Orthorhombic, *a* = 7.95 ± 0.02, *b* = 23.87 ± 0.04, *c* = 11.93 ± 0.02 Å, *U* = 2 255.4 Å³, *Z* = 8, *D_c* = 1.65 g cm⁻³, *F*(000) = 1 136. Space group *Pbca* uniquely from systematic absences. Mo-*K α* radiation, λ = 0.710 69 Å, μ (Mo-*K α*) = 3.67 cm⁻¹.

Structure solution and refinement. The atomic coordinates of the chlorine atom were found from a Patterson synthesis using the observed intensity data, sharpened by 1/*L*² corrections. A three-dimensional Fourier summation phased on the chlorine atom enabled a further 9 atoms to be located. After a structure-factor calculation with the new model, a second Fourier synthesis revealed the positions of all the non-hydrogen atoms.

Initially five cycles of block-diagonal least-squares refinement of atomic positions and isotropic temperature factors were carried out with all the data and unit weight. After the fifth cycle the value of the agreement factor *R* was 0.15. Analysis of the agreement between *F_o* and *F_c* indicated a slight rescaling of the data between the reciprocal lattice levels 0–7*kl*. A weighting scheme was also adopted

⁷ G. Markl, *Chem. Ber.*, 1961, **94**, 3005; S. T. D. Gough and S. Trippett, *J. Chem. Soc.*, 1962, 2333.

⁸ 'International Tables for X-Ray Crystallography,' vol. III, Kynoch Press, Birmingham, 1962.

of the form $w = 1$ for $|F_o| \leq 30.0$ and $w = (30.0/|F_o|)^2$ for $|F_o| > 30.0$. Two further cycles of refinement were then carried out, after which the atomic temperature factors were allowed to vary anisotropically. Three more cycles reduced the value of R to 0.077.

A difference synthesis was then calculated whose main feature was the presence of a peak within bonding distance

TABLE 2
(a) Data for triones (19)

	R ²	R ³	R ⁴	Reflux time	Cryst. solvent	Form	M.p. (°C)
(19b)	OMe	OMe	OMe	2 h	PhH	Orange needles	152—154 (decomp.)
(19c)	OMe	OMe	H	2.5 h	PhMe	Brown needles	158—160 (decomp.)
(19d)	OMe	H	H	10 min	PhH-C ₆ H ₁₄	Orange needles	138—139 (decomp.)

	Found (%)			Formula	Required (%)		
	C	H	Cl		C	H	Cl
(19b)	51.4	3.5	10.65	C ₁₄ H ₁₁ ClO ₇	51.45	3.4	10.9
(19c)	52.65	3.15	11.65	C ₁₂ H ₉ ClO ₆	52.6	3.05	11.95
(19d)	53.95	2.75	13.2	C ₁₂ H ₇ ClO ₅	54.1	2.6	13.3

$\lambda_{\max.}(\text{CHCl}_3)/\text{nm} (\epsilon)$

(19b)	298 (7 710), 464 (12 500)
(19c)	293 (8 030), 381 (5 880), 430 (9 600), 477 (15 100)
(19d)	264sh (6 410), 287 (8 930), 422 (19 900), 434sh (17 700)

$\nu_{\max.}/\text{cm}^{-1}$ (carbonyl region)

(19b)	1 870, 1 830, 1 786, 1 723
(19c)	1 870, 1 845, 1 786, 1 720
(19d)	1 861, 1 788, 1 725

$\tau [(\text{CD}_3)_2\text{CO}]$

(19b)	τ 2.78 (2 H, s, H-2 and -6), 6.08 (3 H, s, 4-OMe), and 6.13 (6 H, s, 3- and 5-OMe)
(19c)	τ 2.34 (1 H, dd, $J_{5,6}$ 8, $J_{2,6}$ 2 Hz, H-6), 2.51 (1 H, d, $J_{2,6}$ 2 Hz, H-2), 2.82 (1 H, d, $J_{5,6}$ 8 Hz, H-5), 6.00 (3 H, s, OMe), and 6.14 (3 H, s, OMe)
(19d)	τ ca. 2.05 and ca. 2.85 (4 H, AB ₂ multiplet, symmetrical about τ 2.47, H-2, -3, -4, and -6), and 6.03 (3 H, s, OMe)

(b) Data for aryl-naphthalenes and arylpropionyl chlorides

R ¹	R ²	Products	M.p. or [b.p.] (°C)	Lit. m.p. (°C)	Ref.
OMe	H	(18e)	91—93	93—94	4c
OMe	H	(20e)	247—249	254—246	4a
H	Me	(18f)	[80 at 0.2 mmHg]		
H	Me	(20f)	272—273	268—269	4d
H	H	(18g)	[46 at 0.1 mmHg]		
H	H	(20g)	258—259	255—256	4b
H	Cl	(18h)	65—67	68—69	4e
H	Cl	(20h)	266—267	266—267	4e

of O(5). This corresponded to the presence of a minor amount of the *E*-isomer of the trione which had co-crystallised. In confirmation the difference map also showed a large depression in the neighbourhood of O(4). The difference map also revealed the approximate positions of all the hydrogen atoms. The additional atom was designated O(7) and included in the structure factor calculation. The temperature factor for O(4) reverted to being isotropic and O(4) and O(7) were included in the

calculations with isotropic temperature factors, and their occupation fractions were also refined. Five further cycles of least-squares refinement were carried out to allow the refined occupation fractions of these two atoms to settle down, which reduced R to 0.065. The positions of the hydrogen atoms were calculated accurately from bond length and angle considerations and found to correspond approximately to their peaks in the difference map. Three final rounds of least-squares refinement, including the hydrogen atoms but without refinement, and allowing O(4) and O(7) to vibrate anisotropically, reduced the agreement factor R to 0.056 after a total of 18 cycles, the largest parameter shifts being of the order 0.4σ , indicating that the refinement had converged. The accuracy of the structure was confirmed by computing a final difference map which showed no peaks or depressions $>0.3 \text{ e}\text{\AA}^{-3}$. Final atomic co-ordinates are listed in Table 3 together with their

TABLE 3

Atom	x/a	y/b	z/c
Cl	0.594 8(4)	0.375 0(1)	-0.024 1(2)
O(1)	0.321 4(10)	0.515 6(3)	0.398 1(6)
O(2)	0.270 5(11)	0.530 9(3)	0.206 3(6)
O(3)	0.360 4(8)	0.272 8(3)	0.285 3(5)
O(4)	0.411 2(15)	0.156 0(5)	0.215 7(9)
O(5)	0.562 9(10)	0.194 4(3)	0.078 5(6)
O(6)	0.681 4(9)	0.257 3(3)	-0.045 4(5)
C(1)	0.525 1(10)	0.350 3(4)	0.102 5(7)
C(2)	0.469 9(10)	0.391 4(4)	0.181 0(6)
C(3)	0.501 1(11)	0.382 4(4)	0.298 2(7)
C(4)	0.451 9(13)	0.422 0(4)	0.376 3(8)
C(5)	0.381 2(13)	0.470 4(4)	0.336 7(7)
C(6)	0.352 2(12)	0.478 7(4)	0.223 5(7)
C(7)	0.398 7(12)	0.442 1(4)	0.144 4(7)
C(8)	0.249 1(17)	0.554 4(5)	0.320 2(9)
C(9)	0.527 6(10)	0.292 7(4)	0.116 4(7)
C(10)	0.440 2(10)	0.260 3(4)	0.205 5(7)
C(11)	0.473 4(12)	0.201 7(4)	0.174 7(8)
C(12)	0.602 3(11)	0.250 0(5)	0.038 3(7)
O(7)	0.641 7(52)	0.156 5(15)	0.052 1(29)
H(3)	0.566	0.344	0.326
H(4)	0.467	0.415	0.465
H(7)	0.383	0.451	0.056
H(8a)	0.314	0.595	0.327
H(8b)	0.118	0.561	0.340

standard deviations. Temperature factors and observed and calculated structure factors are listed in Supplementary Publication No. SUP 21879 (16 pp., 1 microfiche).† The final values for the occupation fractions of O(4) and O(7) were 0.85(2) and 0.19(2), respectively. These add up to unity, within one standard deviation, and were taken to indicate the presence of $17 \pm 5\%$ of the minor *E*-isomer co-crystallised with the major *Z*-isomer of the trione (2).

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† For details of Supplementary Publications see Notice to Authors No. 7 in *J.C.S. Perkin I*, 1975, Index issue.