Flavonoid Synthesis based on Photolysis of Flavan-3-ols, 3-Hydroxyflavanones, and 2-Benzylbenzofuranones

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Irradiation of flavan-3-ols, 3-hydroxyflavanones, and 2-benzylbenzofuranones in methanol leads mainly to photochemical opening of the heterocyclic ring, or to its complete photofragmentation, the products being trapped by reaction with the solvent. Fission of exocyclic C–O bonds also occurs, accompanied by intramolecular rearrangements. The course of these reactions is often dependent on the position and nature of substituents.

The conversions provide novel routes to 1,3-diaryl-1-methoxypropan-2-ols, 1,3-diaryl-2,2-dimethoxypropan-1-ones, *cis*-3-methoxyflavanones, isoflavones, flavanones, and *trans*-chalcones, and hence to α-hydroxychalcones, *cis*- and *trans*-α-methoxychalcones, and 2-methoxy-2-(α-methoxybenzyl)benzofuranones.

REARRANGEMENTS and fragmentations which result from the photolysis of stilbenes,[1] hydroxyflavones,[2] 3-methoxyflavones,[3,4] flavanones,[5] chalcones,[6] isoflavones,[7] and 4-phenylchroman-3-ones [8] have hitherto been studied mainly with unsubstituted flavonoid compounds in non-polar solvents. In the last-mentioned instance [8] the course of rearrangements leading to either 2-phenylchroman-3-ones or 4-phenyldihydrocoumarins has been shown to be solvent-dependent and subject to tautomeric control. During the present extension of photolysis to other flavonoids the sequence of homolyses and the dependence of the rearrangements on the position and type of substitution have been examined, with a view to synthetic applications.

Irradiation of the flavan-3-ol (−)-fisetinidol (Ia) and its methyl ether (Ib) in methanol at 300 nm results in homolysis of the heterocyclic 1,2- (O–C) and 3,4- (C–C) bonds [see (I) ⟶ (VI)]. This is reflected by the formation of optically active 1-(3,4-dimethoxyphenyl)-3-(2-hydroxy-4-methoxyphenyl)-1-methoxypropan-2-ol (IV; R^1 = Me, R^2 = H) and 5-methoxy-2-methoxymethylphenol (VI; R^1 = Me) from the methyl ether, whereas the parent compound gives the 1,3-diarylpropan-2-ol only. The latter was identified as the phenolic methyl ether after methylation with diazomethane. Irradiation of (+)-catechin (Ic) under identical conditions gave the corresponding 1,3-diarylpropan-2-ol only, similarly identified as the phenolic ether of (IV; R^1 = Me, R^2 = OMe). Since in possible competing radical processes the free dissociation energy of the MeO–H bond (102 kcal mol^{-1}) of methanol is high in comparison with its $HOCH_2$–H bonds (93 kcal mol^{-1}),[9] 1,3-diarylpropan-2-ols (IV) could arise from the diradicals (II) through reactions of the elements of methanol with carbocations and phenoxide anions (III) formed by intramolecular electron transfer, *i.e.* through 'decomposition' of the diradical, rather than by radical coupling. The benzyl ether (VI) may be formed from addition of methanol to the *ortho*-quinone methide intermediate (V), originating from the same diradical. The apparent ease of initial homolysis of the 1,2- (O–C) bond could be related to the stability of the phenoxyl and benzylic radical systems (II) formed, presumably after $\pi \longrightarrow \pi^*$ transitions as indicated by the relatively short wavelength (300 nm) employed.

Whereas the course of photolytic fragmentation is not

[1] F. B. Mallory and C. W. Mallory, *J. Amer. Chem. Soc.*, 1972, **94**, 6041; J. H. M. Cuppen and W. H. Laarhoven, *ibid.*, p. 5914.
[2] T. Matsuura, T. Takemoto, and R. Nakashima, *Tetrahedron Letters*, 1971, 1539.
[3] A. C. Waiss, R. E. Lundin, A. Lee, and J. Corse, *J. Amer. Chem. Soc.*, 1976, **89**, 6213.
[4] T. Matsuura and H. Matsushima, *Tetrahedron*, 1968, **24**, 6615.
[5] P. O. L. Mack and J. T. Pinhey, *J.C.S. Chem. Comm.*, 1972, 451.
[6] F. R. Stermitz, J. A. Adamovics, and J. Geigert, *Tetrahedron*, 1975, **31**, 1595; D. Dewar and R. G. Sutherland, *Chem. Comm.*, 1970, 272.
[7] U. Ishibe, S. Yutaka, J. Masui, and Y. Ishida, *J.C.S. Chem. Comm.*, 1975, 241.
[8] A. Padwa and G. A. Lee, *J. Amer. Chem. Soc.*, 1974, **96**, 1634; A. Padwa and A. Au, *J.C.S. Chem. Comm.*, 1975, 58; A. Padwa, A. Au, G. A. Lee, and O. Williams, *J. Org. Chem.*, 1975, **40**, 1142.
[9] S. W. Benson, *J. Chem. Educ.*, 1965, **42**, 503.

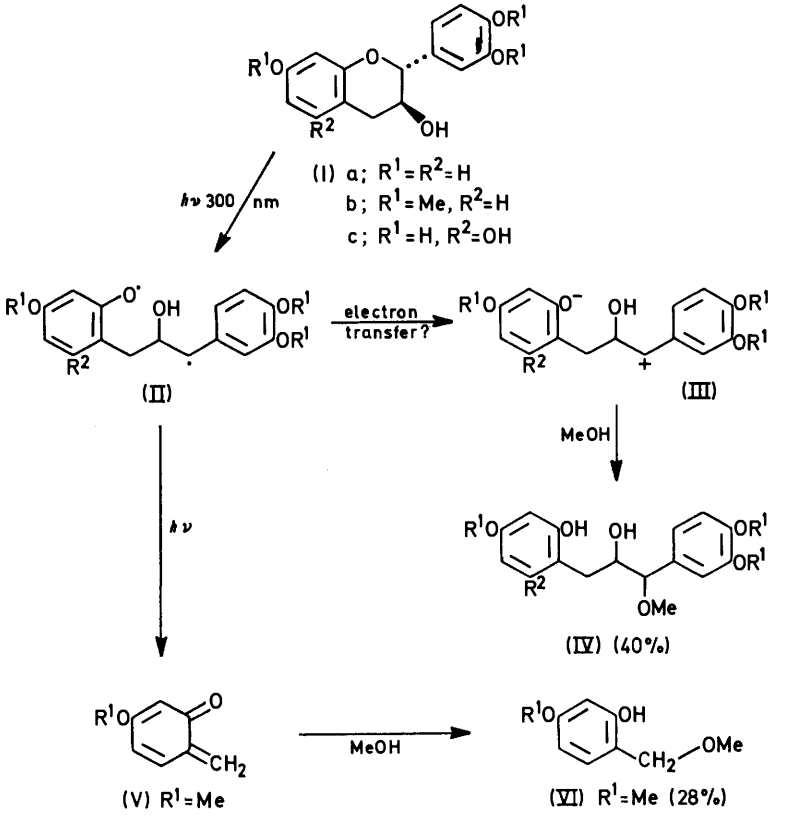
appreciably affected by the degree or type of substitution of the flavan-3-ols examined, the reverse pertains in the case of hydroxyflavanones. Thus, (±)-2,3-*trans*-fustin (VIIa) irradiated in methanol gives the thermodynamically less stable (±)-3,3′,4′,7-tetra-*O*-methyl-2,3-*cis*-fustin (IX),[10] and also the isoflavone analogue (XI), after methylation of the products with diazomethane.

Since prior to methylation of the products the hydroxyflavanone fraction gave no evidence of a 3-*O*-methyl group, and also since the 3-hydroxy-function of 2,3-*trans*-fustin is not methylated by diazomethane under the conditions used,[10] enolization of fustin to a flav-3-ene-3-diol intermediate (VIII) appears feasible as it permits inversion at C-3 to give 2,3-*cis*-fustin (IX) and also oxidative rearrangement *via* a spirodienone (X) to the isoflavone (XI). However, these conversions presuppose complete methylation of 2,3-*cis*-fustin with diazomethane, and also final reduction in a redox equilibrium, respectively.

An alternative but more remote possibility would be homolysis of the C(3)–OH bond of fustin (*cf.* ref. 11 for the unusual β-fission of chloroacetone) succeeded either by inversion on recombination of hydroxyl and resonance-stabilized flavanone radicals, or by a 1,2-shift[12] of the 2-phenyl group to furnish the same products [(IX) and (XI)].

Tri-*O*-methylfustin (VIIb), irradiated under precisely the same conditions, gave methyl 2-hydroxy-4-methoxybenzoate (XIII), implying homolysis of both heterocyclic C–O and α-carbonyl bonds (Norrish type I process). The resultant keten (XII) would undergo 1,4-addition of the elements of methanol.

Tetra-*O*-methylfustin (VIIc), when irradiated under identical conditions, gives both the *trans*-chalcone (XIV) and the flavanone (XV), in high yields. Since the *trans*-chalcone ⇌ flavanone equilibrium is well known, their formation implies abstraction of a hydrogen atom from the 3-methoxy-group of (VIIc), followed by loss of formaldehyde from the intermediate diradical[13] to form the enolic form of the flavanone (Norrish type II process). Formation of the *trans*- rather than the anticipated *cis*-chalcone indicates that *trans* ⇌ *cis*-isomerisation of 'conventional' chalcones does not occur as readily as with α-methoxychalcones.



Similar differences in photoinduced behaviour with variation in the position and type of substituents on both rings A and B and also on hetero-rings are evident amongst derivatives of 2-benzyl-2-hydroxybenzo[*b*]-furan-3(2*H*)-ones (2-benzyl-2-hydroxycoumaranones). Thus 2-(3,4-dimethoxybenzyl)-2-hydroxy-6-methoxybenzo[*b*]furan-3(2*H*)-one (XVIa) suffers photofragmentation of the heterocyclic C–O and α-carbonyl bonds to

[10] D. Ferreira, J. P. van der Merwe, and D. G. Roux, *J.C.S. Perkin I*, 1974, 1492.

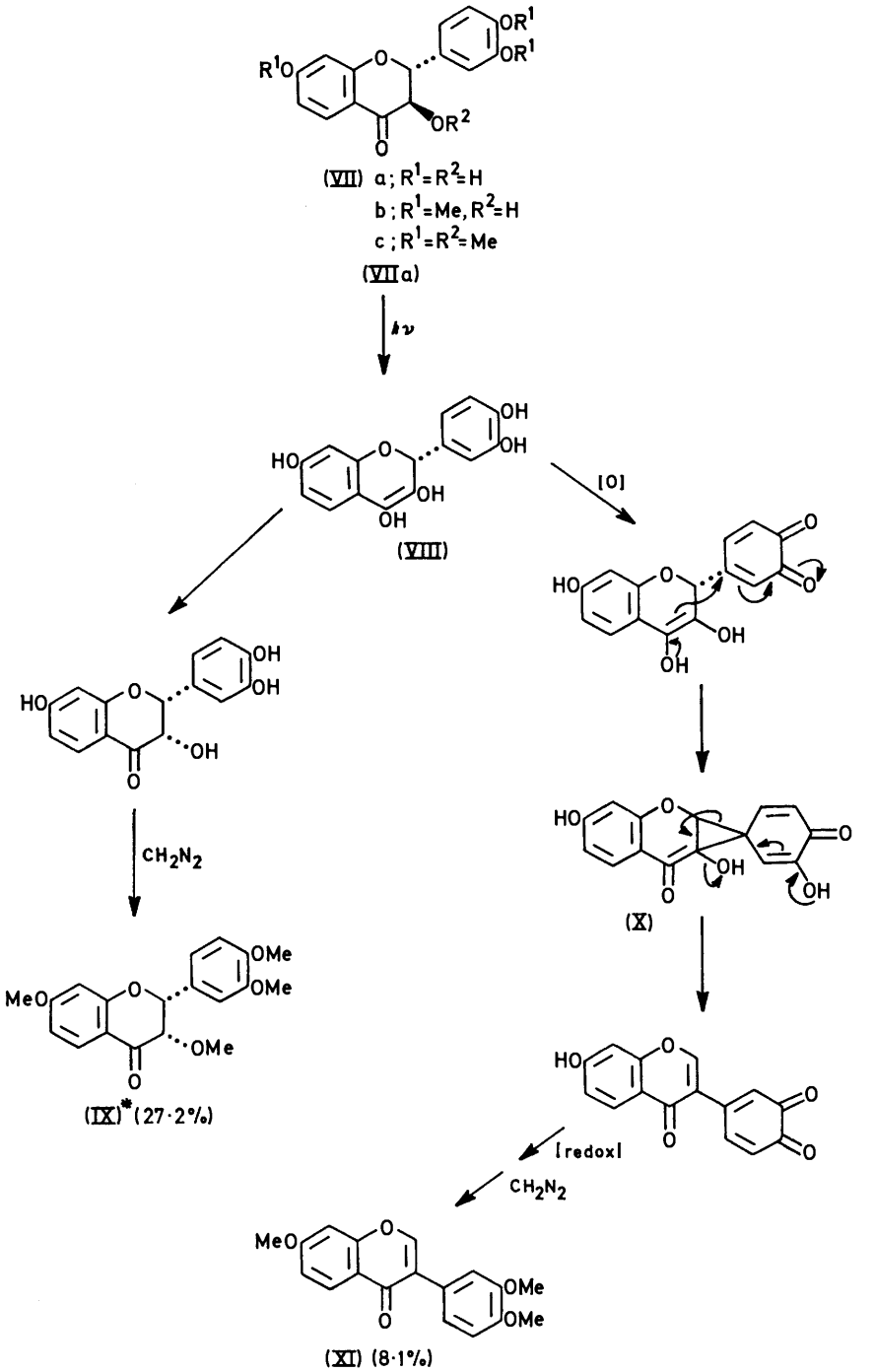
[11] A. N. Strachan and F. E. Blacet, *J. Amer. Chem. Soc.*, 1955, **77**, 5254.

[12] F. H. Seubold, *J. Amer. Chem. Soc.*, 1953, **75**, 2532.

[13] M. Yoshida and R. G. Weiss, *Tetrahedron*, 1975, **31**, 1801.

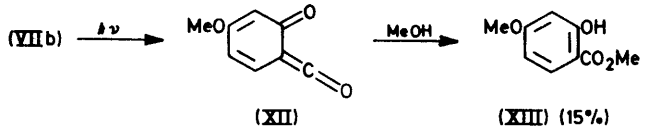
form methyl 2-hydroxy-4-methoxybenzoate (XIII), as in the case of (±)-tri-*O*-methylfustin.

By contrast, photofragmentation under the same conditions is confined to the heterocyclic C–O bond in the case of 2-(3,4-dimethoxybenzyl)-2,6,7-trimethoxybenzo[*b*]furan-3(2*H*)-one (XVIb). Solvolysis could presumably occur through the net equivalent of a heterolytic mechanism following decomposition of the diradical (as discussed for flavan-3-ols) to form 1-(2-hydroxy-3,4-dimethoxyphenyl)-2,2-dimethoxy-3-(3,4-dimethoxyphenyl)propan-1-one (XVIII). Where ring B of the 2-benzylfuranone has 4-methoxy- rather than 3,4-dimethoxy-substitution while ring A is of the phloroglucinol type, as in 2-(4-methoxybenzyl)-2,4,6-trimethoxybenzo-[*b*]furan-3-(2*H*)-one (XVIIIa), a substantial yield of the *cis*-α-methoxychalcone analogue (XIX) accompanies the corresponding acetal (XX). Formation of the *cis*-α-methoxychalcone suggests that the incipient benzylic



* Only one enantiomer indicated.

radical in the intermediate is better stabilized by 4-methoxy- than by 3,4-dimethoxy-substitution as in the



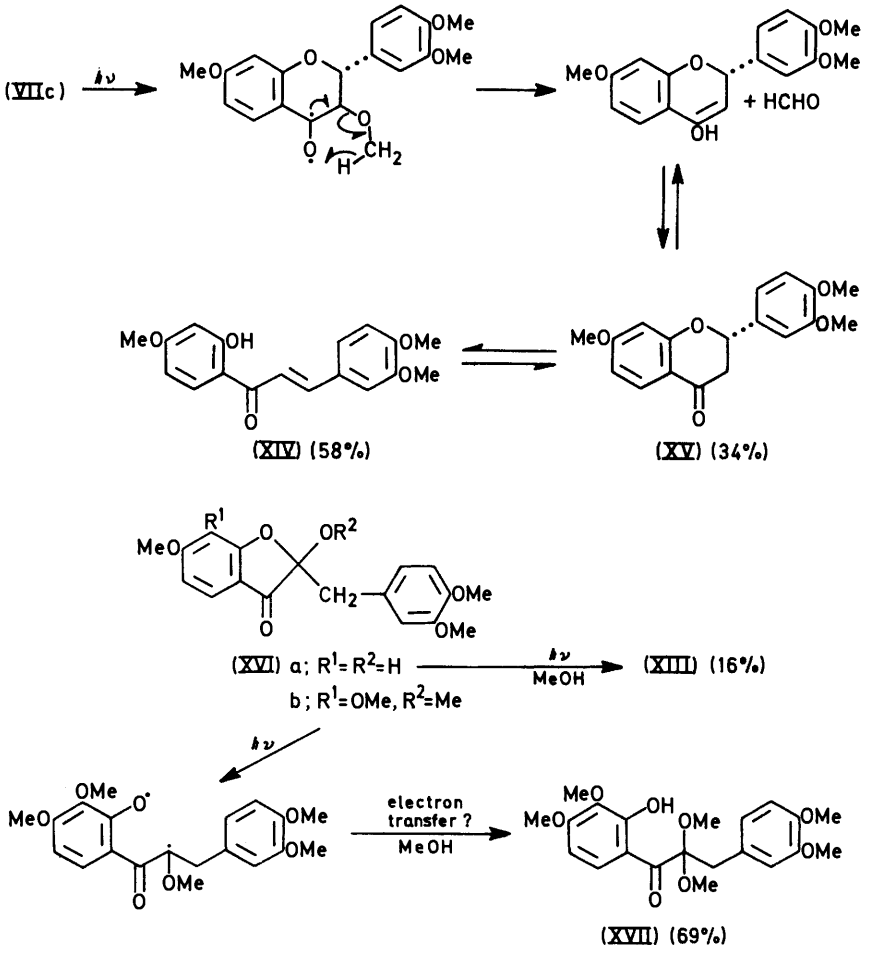
(XII) (XIII) (15%)

previous scheme. Remarkably, irradiation of the 2-acetoxy-derivative (XVIIIb) gives the same products [(XIX) and (XX)], whereas the 2-hydroxy-compound (XVIIIc) undergoes no reaction under identical conditions. Replacement of the acetoxy- by a methoxy-function at an early stage in the conversions of the former is indicated.

Conversions of the Photolysis Products.—Formation of the acetals (XVII) and (XX) in relatively high yields (69 and 52%) by photolysis of 2-benzyl-2-methoxybenzofuranones offers useful routes to *trans*- and *cis*-α-methoxychalcones and to α-hydroxychalcones.[14]

Hydrolysis of (XX) with 0.1N-acetic acid on a water-bath, aimed at forming α,2′-dihydroxychalcones, gave both *trans*- and *cis*-α-methoxychalcones, (XXI) and (XIX), respectively (2 : 1) in addition to maesopsin tetra- (XXII) and tri-methyl ethers (XXIII). Even the very mild conditions are apparently sufficient to induce cyclization of the desired α-hydroxy-chalcone to give (XXIII), but useful yields of the isomeric α-methoxy-chalcones result. The course of hydrolysis as indicated is based on the knowledge that under such weakly acidic conditions very low conversions of (XXI) into (XXII) and of (XXI) into (XXIII) occur.

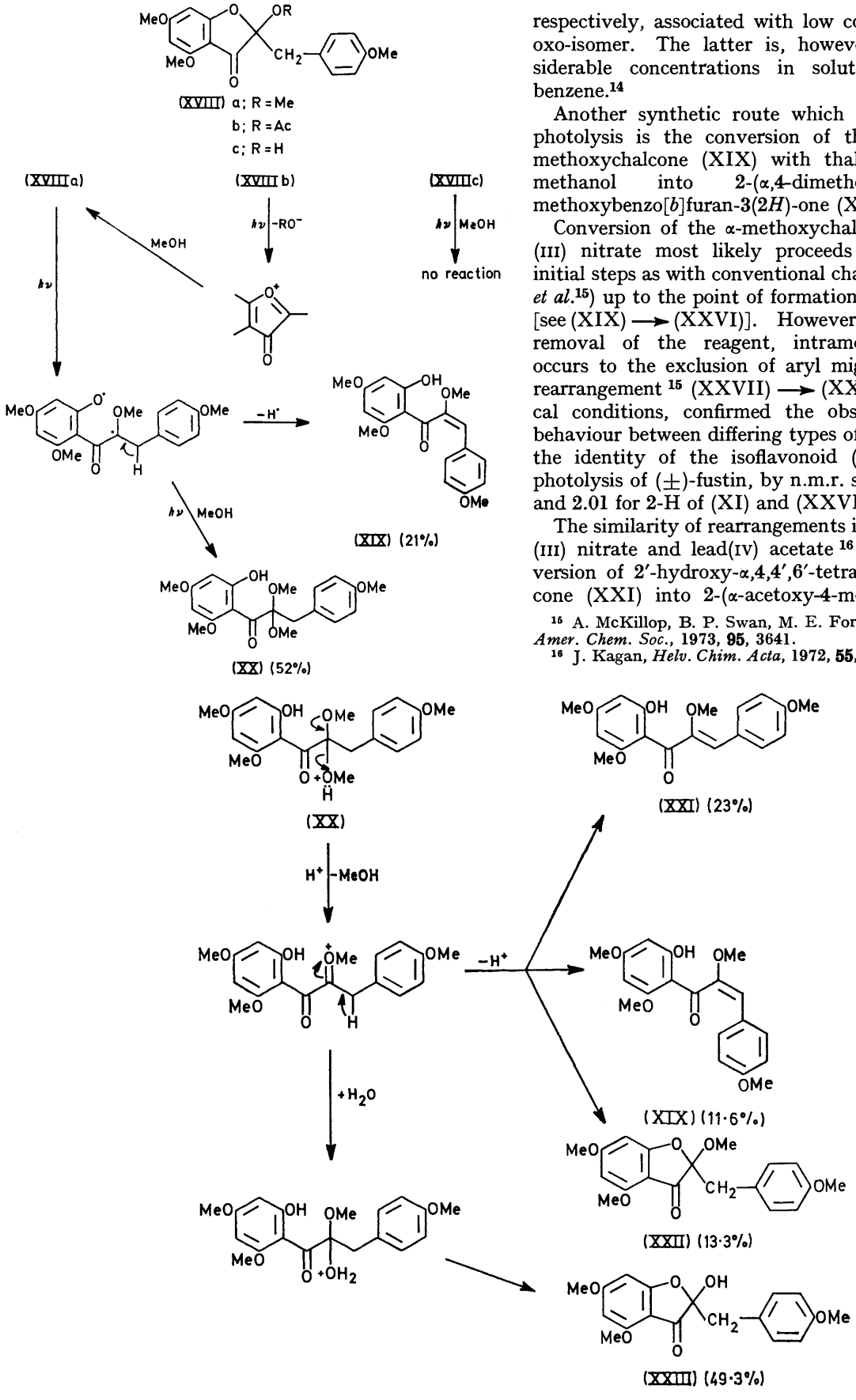
Protection of the 2-hydroxy-group of the acetal (XX) by methylation as in (XXIV) to prevent cyclization permits formation of fully substituted α-hydroxy-chalcones (XXV) under much stronger hydrolytic conditions (3N-H_2SO_4). Estimation of proportions of the two enolic and α-dioxo-forms, in organic solutions, by n.m.r. spectrometry is complicated by the observations that β-proton resonances of the former pair often overlie benzenoid proton absorption, and that the methylene signal of the latter apparently underlies methoxy resonances. Partial overlap of methoxy and methylene resonances occurs, for example, at 60 MHz in a simple compound such as methyl phenylacetate [τ ($CDCl_3$) 6.45 (OMe) and 6.47 (CH_2)]. In deuteriated chloroform, acetone, and pyridine the proportions of *cis*- to *trans*-enol are approximately 1 : 4, 1 : 5, and 1 : 3



(XIV) (58%) (XV) (34%)

(XVII) (69%)

[14] T. G. Fourie, D. Ferreira, and D. G. Roux, *J.C.S. Chem. Comm.*, 1974, 760.



respectively, associated with low concentrations of the oxo-isomer. The latter is, however, present in considerable concentrations in solution in deuteriated benzene.[14]

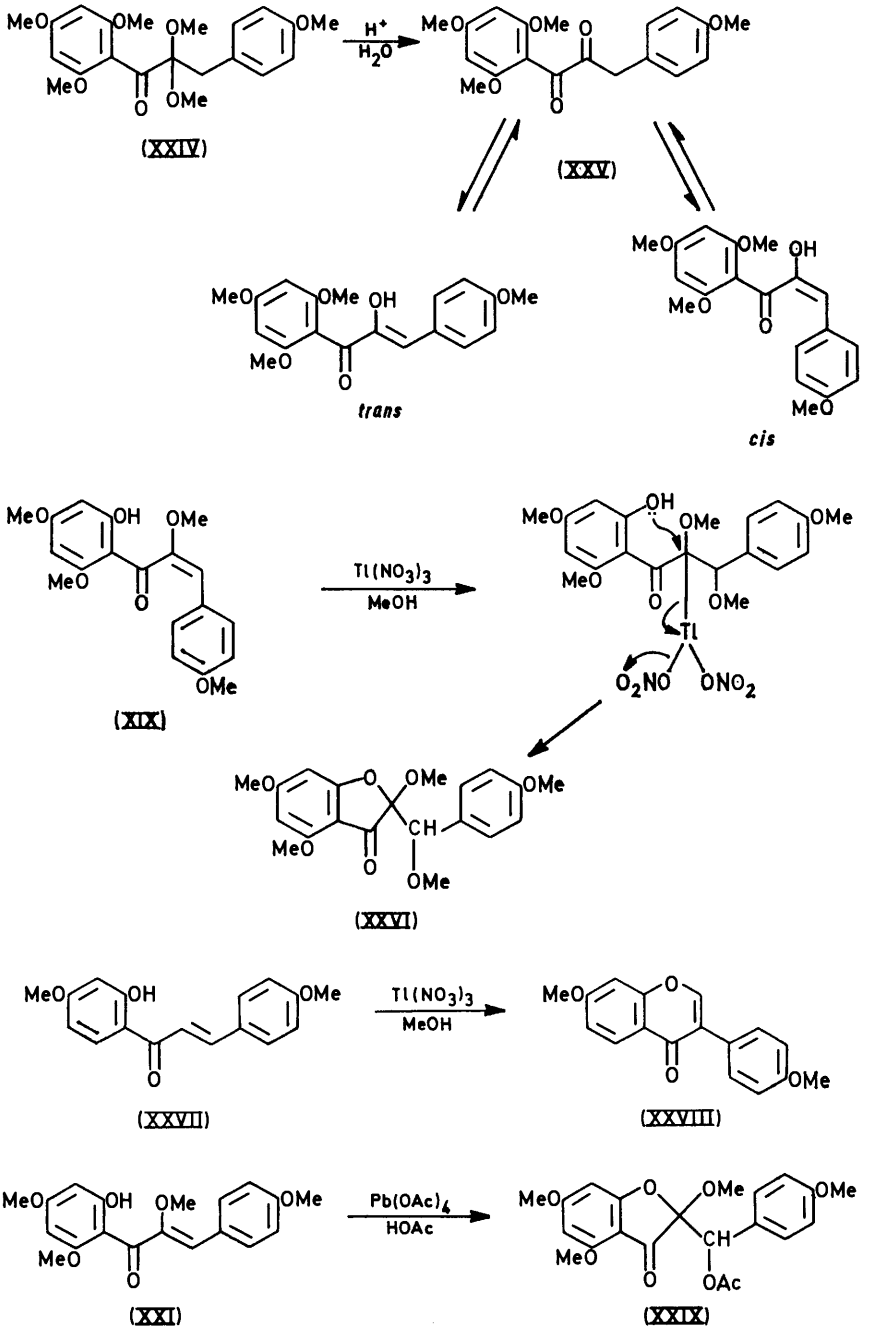
Another synthetic route which follows from initial photolysis is the conversion of the *cis*-2′-hydroxy-α-methoxychalcone (XIX) with thallium(III) nitrate in methanol into 2-(α,4-dimethoxybenzyl)-2,4,6-trimethoxybenzo[*b*]furan-3(2*H*)-one (XXVI).

Conversion of the α-methoxychalcone with thallium(III) nitrate most likely proceeds through the same initial steps as with conventional chalcones (*cf.* McKillop *et al.*[15]) up to the point of formation of the intermediate [see (XIX) ⟶ (XXVI)]. However, with acid-catalysed removal of the reagent, intramolecular cyclization occurs to the exclusion of aryl migration. The latter rearrangement [15] (XXVII) ⟶ (XXVIII) under identical conditions, confirmed the observed difference in behaviour between differing types of chalcones, and also the identity of the isoflavonoid (XI) resulting from photolysis of (±)-fustin, by n.m.r. spectrometry [τ 2.05 and 2.01 for 2-H of (XI) and (XXVIII) respectively].

The similarity of rearrangements induced by thallium(III) nitrate and lead(IV) acetate [16] indicates that conversion of 2′-hydroxy-α,4,4′,6′-tetramethoxy-*trans*-chalcone (XXI) into 2-(α-acetoxy-4-methoxybenzyl)-2,4,6-

[15] A. McKillop, B. P. Swan, M. E. Ford, and E. C. Taylor, *J Amer. Chem. Soc.*, 1973, **95**, 3641.
[16] J. Kagan, *Helv. Chim. Acta*, 1972, **55**, 2356.

trimethoxybenzo[*b*]furan-3(2*H*)-one [17] (XXIX) by a mechanism parallel to that outlined above [(XIX) ⟶ (XXVI)] represents a more plausible alternative to the free radical mechanism previously suggested.[17]



EXPERIMENTAL

Irradiation of compounds in methanolic solution in a quartz vessel was carried out in a slow current of N_2 (*ca.* 1 ml min^{-1}) in a Rayonet Photochemical Reactor. T.l.c. was performed on Kieselgel PF_{254} (0.25 mm); for preparative scale experiments (p.l.c.) the same material (1 mm) was used. Plates were air-dried and unactivated, and sprayed with H_2SO_4–40% HCHO (40 : 1). Colours indicated are those obtained with this reagent. Evaporations were carried out under reduced pressure with a water-bath temperature of 60 °C. Acetylations were performed with acetic anhydride in pyridine solution, and methylation with an excess of diazomethane in methanol–diethyl ether at −15 °C for 48 h. Mass spectral data were recorded with a Varian CH-5 spectrometer, and n.m.r. spectra with a Varian T-60 spectrometer. Analyses (C and H) were performed by Alfred Bernhardt (Bonn).

[17] D. Ferreira, E. V. Brandt, F. du R. Volsteedt, and D. G. Roux, *J.C.S. Perkin I*, 1975, 1437.

Irradiation of Flavan-3-ols.—(i) (−)-3′,4′,7-Trimethoxy-2,3-*trans*-flavan-3-ol (Ib) (300 mg) derived from *Colophospermum mopane*,[18] m.p. 121°, in methanol (400 ml) was irradiated at 300 nm for 5 h and the mixture was separated by p.l.c. with benzene–ethyl acetate–acetone (45 : 5 : 1). Two bands, R_F 0.26 (119 mg; purple) and 0.50 (84 mg; red), were obtained. The former gave 1-(3,4-*dimethoxyphenyl*)-3-(2-*hydroxy*-4-*methoxyphenyl*)-1-*methoxypropan*-2-*ol* (IV; R^1 = Me, R^2 = H) as a *light brown oil*, M^+ 348 (21%), *m/e* 317 (5.0), 316 (19), 256 (7.1), 181 (100), 179 (4.3), 167 (29), 165 (17.9), 151 (22), 149 (4.3), 137 (41), 136 (4.3), 121 (6.4), and 108 (4.3), τ (C_6D_6) 3.08 (d, 3-H, *J* 2.5 Hz), 3.10—3.26 (3 × arom. H), 3.28 (d, 6-H, *J* 8.5 Hz), 3.53 (dd, 5-H), 5.7—6.0 (m, 2-H), 6.13 (d, $J_{1.2}$ 9.8 Hz, 1-H), 6.40 (s, 3 × OMe), 6.50 (s, OMe), 6.99 (s, 1-OMe), and 7.10—7.42 (m, CH_2). Acetylation of the propan-2-ol (100 mg) and separation by p.l.c. in benzene–ethyl acetate–acetone (45 : 5 : 1) gave a band (R_F 0.37; dark purple) which yielded the *diacetate* as a pale yellow oil (72 mg) (Found: C, 64.1; H, 6.6. $C_{19}H_{24}O_6$ requires C, 63.9; H, 6.5%), M^+ 432 (23%), *m/e* 390 (1.3), 372 (4.6), 358 (1.3), 330 (1.3), 181 (100), 167 (8.3), 166 (17.9), 165 (11.7), 151 (9.2), 149 (4.6), 137 (24), and 121 (2.5), τ ($CDCl_3$) 2.77 (d, 6-H, *J* 8.5 Hz), 3.16br (s, 2-, 5-, and 6-H), 3.23 (dd, 5-H), 3.34 (d, 3-H), 4.65—5.00 (m, 2-H), 5.93 (d, 1-H, $J_{1.2}$ 4.5 Hz), 6.12 (s, 2 × OMe), 6.21 (s, OMe), 6.73 (s, 1-OMe), 7.05—7.30 (d, CH_2, *J* 7.0 Hz), 7.73 (s, OAc), and 8.05 (s, OAc). The shift (Δτ *ca.* −1.0 p.p.m.) of the 2-H multiplet on acetylation is consistent with the propan-2-ol assignment. The R_F 0.50 band gave 5-*methoxy*-2-*methoxymethylphenol* (VI) as a light yellow oil, M^+ 168 (51%), *m/e* 151 (15.6), 138 (8.9), 137 (56), 136 (100), 135 (6.7), 122 (8.9), 109 (11.1), and 108 (56); τ ($CDCl_3$–C_6D_6, 8 : 2) 3.17 (d, 6-H, *J* 8.5 Hz), 3.48 (d, 3-H, *J* 2.5 Hz), 3.63 (dd, 5-H), 5.58 (s, CH_2), 6.43 (s, 4-OMe), and 6.82 (s, OMe).

(ii) Irradiation of (−)-3′,4′,7-trimethoxy-2,3-*trans*-flavan-3-ol (Ib) (30 mg) in benzene (40 ml) at 300 nm over 20 h did not give any prominent conversion products.

(iii) Irradiation of (−)-2,3-*trans*-flavan-3,3′,4′,7-tetraol [(−)-fisetinidol] (Ia) (250 mg) in methanol (335 ml) at 300 nm for 4 h, and separation of the products by p.l.c. with benzene–ethyl acetate–acetone (5 : 4.5 : 0.5) gave three bands, R_F 0.58 (70 mg; red), 0.47 (161 mg; purple), and 0.33 (65 mg; purple). These were methylated and the products purified by p.l.c. The methylated product from the middle band was separated in benzene–ethyl acetate (9 : 1) to give 3-(2,4-*dimethoxyphenyl*)-1-(3,4-*dimethoxyphenyl*)-1-*methoxypropan*-2-*ol* as a *yellow oil*, M^+ 362 (15.9%), *m/e* 316 (25), 182 (76), 181 (100), 180 (53), 167 (32), 166 (38), 165 (35), 152 (32), 151 (70), 138 (14.3), 137 (67), and 121 (45) (Found: M^+, 362.170. $C_{20}H_{26}O_6$ requires *M*, 362.173), τ ($CDCl_3$) 2.85—3.25 (m, 4 × arom. H), 3.50 (d, 3-H), 3.55 (dd, 5-H), *ca.* 6.08 (m, 1- and 2-H), 6.10 (s, 2 × OMe), 6.25 (s, OMe), 6.32 (s, OMe), 6.74 (s, 1-OMe), and 7.20—7.55 (m, CH_2). Acetylation of the propan-2-ol gave the optically active *monoacetate* as a pale yellow oil $[\theta]_{280}^{MeOH}$ −1.80 × 10^{-4}, $[\theta]_{259}^{MeOH}$ 0, $[\theta]_{233}^{MeOH}$ +2.98 × 10^{-4}, $[\theta]_{226}^{MeOH}$ 0, M^+ 404 (1.0%), *m/e* 390 (14.3), 344 (6.9), 330 (38.5), 302 (3.4), 181 (5.2), 168 (59), 167 (100), 166 (42), 165 (4.9), 151 (28), and 137 (63) (Found: M^+, 404.181. $C_{22}H_{28}O_7$ requires *M*, 404.184), τ ($CDCl_3$) 2.90 (d, 6-H, *J* 8.5 Hz), 3.05—3.15 (m, 2-, 5-, and 6-H), 3.55 (d, 3-H, *J* 2.5 Hz), 3.60 (dd, 5-H), 4.4—4.7 (m, 2-H), 5.86 (d, 1-H, $J_{1.2}$ 4.5 Hz), 6.10 (s, 2 × OMe), 6.22 (s, 2 × OMe), 6.73 (s, 1-OMe), 7.0—7.43 (m, CH_2), and 8.10 (s, OAc). The remaining fractions (R_F 0.58 and 0.33) did not provide discrete bands after methylation with diazomethane.

(iv) Irradiation of (+)-catechin [(+)-2,3-*trans*-flavan-3,3′,4′,5,7-pentaol (Ic)] (300 mg) in methanol (400 ml) at 300 nm for 4.5 h followed by methylation and p.l.c. (benzene–ethyl acetate–acetone 45 : 5 : 1) gave a single prominent band (R_F 0.43; red brown), which afforded 1-(3,4-*dimethoxyphenyl*)-1-*methoxy*-3-(2,4,6-*trimethoxyphenyl*)*propan*-2-*ol* as a pale yellow oil (62 mg), M^+ 392 (15.0%), *m/e* 358 (6.4), 225 (15.0), 212 (28), 211 (48), 210 (13), 195 (18.0), 183 (29), 182 (75), 181 (100), 180 (20), 167 (35), 165 (31), 152 (18.6), 151 (40), 137 (25), and 121 (32) (Found: M^+, 392.176. $C_{21}H_{28}O_7$ requires *M*, 392.184), τ ($CDCl_3$) 2.93—3.23 (m, 2-, 5-, and 6-H), 3.85 (s, 3- and 5-H), 5.80—6.40 (m, 1- and 2-H), 6.08 (s, 2 × OMe), 6.20 (s, OMe), 6.23 (s, 2 × OMe), 6.70 (s, 1-OMe), and 7.00—7.40 (m, CH_2). Acetylation of the propan-2-ol gave the *monoacetate* as a pale yellow oil, M^+ 434 (24%), *m/e* 376 (3.5), 375 (20), 374 (42), 344 (15.7), 343 (39), 253 (20), 193 (3.5), 182 (45), 181 (100), 175 (22), 167 (25), 165 (36), 151 (35), 137 (14.8), and 121 (32) (Found: M^+, 434.189. $C_{22}H_{30}O_8$ requires *M*, 434.195), τ ($CDCl_3$) 3.0—3.3 (m, 2-, 5-, and 6-H), 3.90 (s, 3- and 5-H), 4.4—4.7 (m, 2-H), 5.90 (d, 1-H, $J_{1.2}$ 5.5 Hz), 6.12 (s, OMe), 6.15 (s, OMe), 6.25 (s, 3 × OMe), 6.77 (s, 1-OMe), 7.05—7.30 (m, (CH_2), and 8.15 (s, OAc). Deshielding of the 2-proton acetylation is consistent with the propan-2-ol structure.

(v) Irradiation of (+)-catechin (Ic) (100 mg) in water (134 ml) at 300 nm for 18 h resulted in a pale brown solution. Two-dimensional paper chromatography in water-saturated butan-2-ol and then 2% acetic acid showed the formation of a complex mixture of phenolic products.

Irradiation of 3-Hydroxyflavanones.—(i) (±)-Fustin (VIIa), m.p. 211° (320 mg), from the wood of *Rhus glabra*,[19] in methanol (430 ml) was irradiated at 300 nm for 8 h. The product was methylated, and the methyl ethers were resolved by p.l.c. in benzene–acetone (9 : 1). Three bands were isolated: (*a*) (±)-3′,4′,7-tri-*O*-methyl-2,3-*trans*-fustin (VIIb), R_F 0.43, crystallized from ethanol as pale yellow needles (27 mg), m.p. 142° (lit.,[17] 141—142°); identity confirmed by n.m.r. spectrometry ($J_{2.3}$ 12.0 Hz); (*b*) (±)-3,3′,4′,7-tetra-*O*-methyl-2,3-*cis*-fustin (IX), R_F 0.53, obtained as a yellow oil (87 mg), M^+ 334 (22%); n.m.r. ($J_{2.3}$ 2.0 Hz) and mass spectra identical with those of the compound isolated from *Trachylobium verrucosum* and synthesised;[10] (*c*) 3′,4,7-trimethoxyisoflavone (XI), R_F 0.48 (40 mg), exhibiting a pale blue fluorescence under u.v. light, and a pale yellow with the spray reagent, crystallizing from ethanol as white plates (25.5 mg), m.p. 161° (lit.,[20] 161° (Found: C, 69.3; H, 5.2. Calc. for $C_{18}H_{16}O_5$: C, 69.2; H, 5.2%), M^+ 312 (100%), *m/e* 298 (5.0), 297 (18.3), 281 (3.3), 269 (14.2), 267 (4.2), 238 (5.0), 226 (10.0), 162 (9.2), 150 (5.8), 147 (7.5), 127 (7.5), and 119 (16.7), τ ($CDCl_3$) 1.73 (d, 5-H, *J* 8.5 Hz), 2.01 (s, 2-H), 2.75 (d, 2′-H), 2.80—3.00 (m, 5′- and 6′-H), 3.00 (dd, 6-H), 3.13 (d, 8-H), and 6.07 (s, 3 × OMe).

The products of similar irradiation of (±)-fusion were fractionated by means of preparative paper chromatography in 2% acetic acid (*cf.* ref. 18). None of the bands, including the hydroxyflavanone fraction, showed the presence of a methoxy-function (n.m.r. spectrometry).

(ii) (±)-3′,4′,7-Tri-*O*-methyl-2,3-*trans*-fustin (VIIb), m.p.

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142° (210 mg), derived from the same source as above, was irradiated in methanol (280 ml) at 300 nm for 4.5 h. P.l.c. separation in benzene–ethyl acetate (97 : 3) gave methyl 2-hydroxy-4-methoxybenzoate (XIII) (R_F 0.26; green) as a pale yellow oil (31 mg). The n.m.r. spectrum [τ ($CDCl_3$) 0.27 (s, 2-OH), 2.61 (d, 3-H), 2.80 (dd, 5-H), 3.53 (d, 6-H), and 6.65 and 6.68 (s, 2 × OMe)] was consistent with the structure and identical with that of the synthetic product.

(iii) (±)-3,3′,4′,7-Tetra-*O*-methyl-2,3-*trans*-fustin (VIIc) (60 mg), obtained by methylation of (±)-*trans*-fustin with dimethyl sulphate–potassium carbonate in anhydrous acetone,[10] was irradiated in methanol (80 ml) at 300 nm for 2 h. P.l.c. in benzene–acetone (17 : 3) gave two bands: (*a*) 2′-hydroxy-3,4,4′-trimethoxy-*trans*-chalcone (XIV) (38 mg), R_F 0.63 (red brown), crystallized from ethanol as fine needles, m.p. 154° (lit.,[21] 156°), M^+ 314 (6.1%), τ ($CDCl_3$) −1.93 (s, 2′-OH), 2.06 (d, α-H, $J_{\alpha\beta}$ 15 Hz), 2.11 (d, 6′-H, J 8.5 Hz), 2.55 (d, β-H, $J_{\alpha\beta}$ 15 Hz), 2.70 (dd, 6-H), 2.80 (d, 2-H), 3.06 (d, 5-H, J 8.5 Hz), 3.46 (dd, 5′-H), 3.50 (d, 6′-H), and 6.05, 6.08, and 6.17 (s, 3 × OMe), ^{1}H n.m.r. spectrum identical with that of the corresponding synthetic compound; acetate obtained as a non-crystalline solid (lit.,[21] m.p. 88°), M^+ 356 (67%), τ ($CDCl_3$) 2.19 (d, 6′-H), 2.37 (d, α-H, J 16 Hz), 2.6—3.0 (2-, 5-, and 6-H), 2.86 (d, β-H, J 16 Hz), 3.11 (dd, 5′-H), 3.29 (d, 3′-H), 6.06 (s, 2 × OMe), 6.11 (OMe), and 7.71 (s, OAc); (*b*) (±)-3′,4′,7-trimethoxyflavanone (XV) (22 mg), R_F 0.54 (red-brown), M^+ 314 (25%), with n.m.r. and mass spectra identical with those of (±)-tri-*O*-methylbutin from *Acacia saxatilis*,[22] and optically inactive.

Irradiation of 2-*Benzylbenzo*[b]*furan*-3(2H)-*ones* (2-*Benzylcoumaranones*).—(±)-3′,4′,7-Tri-*O*-methylfustin (220 mg) in methanolic 15% potassium hydroxide (25 ml) was heated for 3 min on a water-bath (96 °C) under reflux. After rapid cooling the mixture was acidified (3N-HCl), extracted with chloroform, and dried (Na_2SO_4). P.l.c. (benzene–acetone 9 : 1) gave (±)-2-(3,4-*dimethoxybenzyl*)-2-*hydroxy*-6-*methoxybenzo*[b]*furan*-3(2H)-*one* (XVIa), R_F 0.41 (purple), as a pale yellow oil (200 mg) (Found: C, 65.6; H, 5.7. $C_{18}H_{18}O_6$ requires C, 65.4; H, 5.5%), M^+ 330 (50%), τ ($CDCl_3$) 2.53 (d, 4-H), 3.07—3.20 (2′-, 5′-, and 6′-H), 3.44 (dd, 5-H), 3.57 (d, 7-H), 6.17 (s, 3 × OMe), and 6.80 (s, CH_2).

(i) Irradiation of the benzofuranone (XVIa) (200 mg) in methanol (270 ml) at 300 nm for 2 h, followed by p.l.c. (benzene–acetone 9 : 1), gave four bands, R_F 0.72 (yellow; 6.4 mg), 0.65 (yellow; 6.4 mg), 0.58 (purple; 32.5 mg), and 0.50 (yellow; 9.8 mg). The R_F 0.58 band gave a yellow oil which had a n.m.r. spectrum identical with that of methyl 2-hydroxy-4-methoxybenzoate (XIII) from the irradiation of tri-*O*-methyl-*trans*-fustin. The remaining bands were not examined.

(ii) (+)-2-(3,4-Dimethoxybenzyl)-2,6,7-trimethoxybenzo[*b*]furan-3(2*H*)-one (XVIb) (60 mg), derived from *Acacia nigrescens*,[23] in methanol (70 ml) was irradiated at 300 nm for 3 h. P.l.c. (benzene–ethyl acetate, 8 : 2) gave two bands, R_F 0.26 (42 mg) and 0.41 (8.5 mg) (both purple). Only the former was investigated, and gave 3-(3,4-*dimethoxyphenyl*)-1-(2-*hydroxy*-3,4-*dimethoxyphenyl*)-2,2-*dimethoxypropan*-1-*one* (XVII) as a pale yellow oil (Found: C, 62.1; H, 6.5. $C_{21}H_{26}O_8$ requires C, 62.0; H, 6.5%), M^+ 406 (16.4%), *m/e* 375 (5.7), 374 (10.0), 344 (5.7), 343 (15.7), 283 (14.3), 255 (39), 225 (100), 224 (17.9), 223 (23), 209 (21), 208 (13.6), 195 (12.9), 193 (5.7), 181 (17.9), 165 (40), 151 (46), and 137 (8.6), τ ($CDCl_3$) −2.50 (2-OH), 1.78 (6-H), 3.15—3.40 (m, 5- and 6-H), 3.55 (d, 2-H), 3.50 (d, 5-H, J 8.5 Hz), 6.04, 6.13, 6.20, and 6.30 (s, 4 × OMe), 6.55 (s, 2 × 2-OMe), and 6.71br (s, CH_2).

(iii) Irradiation of (±)-2,4,6-trimethoxy-2-(4-methoxybenzyl)benzo[*b*]furan-3(2*H*)-one [(±)-tetra-*O*-methylmaesopsin[24,25] (XVIIIa)] (800 mg) in methanol (1 l) at 300 nm for 4.5 h was followed by p.l.c. (benzene–ethyl acetate, 23 : 2). Three bands, R_F 0.44 (160 mg; red), 0.35 (403 mg; red), and 0.25 (179 mg; red; unchanged starting material) were obtained. The first afforded 2′-*hydroxy*-α,4,4′,6′-*tetramethoxy*-cis-*chalcone* (XIX), crystallized from ethanol as fine yellow needles, m.p. 116° (Found: C, 66.4; H, 6.0. $C_{19}H_{20}O_6$ requires C, 66.3; H, 5.9%), M^+ 344 (80%), *m/e* 329 (79), 314 (67), 313 (79), 301 (17.5), 273 (12.3), 237 (81), 181 (100), 180 (15.6), 164 (30), 163 (12.3), 149 (42), 135 (74), and 121 (84), τ ($CDCl_3$) −3.03 (s, 2′-OH), 2.88 (d, 2- and 6-H), 3.23 (d, 3- and 5-H), 3.89 (d, 3′-H), 4.07 (d, 5′-H), 4.24 (s, β-H), 6.19 and 6.22 (s, 2 × OMe), and 6.25 (2 × OMe). The second (R_F 0.35) gave 1-(2-*hydroxy*-4,6-*dimethoxyphenyl*)-2,2-*dimethoxy*-3-(4-*methoxyphenyl*)-*propan*-1-*one* (XX) (403 mg), crystallized from ethanol as fine white needles, m.p. 114° (Found: C, 63.8; H, 6.4. $C_{20}H_{24}O_7$ requires C, 63.8; H, 6.4%), $\nu_{max.}$ ($CHCl_3$) 1 627 cm^{-1}, M^+ 376 (<1%), *m/e* 345 (8.3), 344 (10.0), 314 (3.7), 313 (15.3), 255 (80), 196 (90), 195 (100), 182 (32), 181 (43), 180 (31), 166 (19), 152 (8.3), 151 (13.0), 150 (7.0), 149 (10.0), and 121 (43), τ ($CDCl_3$) −1.30 (s, 2-OH), 2.85 (d, 2- and 6-H, J 8.5 Hz), 3.20 (d, 3- and 5-H, J 8.5 Hz), 3.91 (d, 3-H, J 2.0 Hz), 3.97 (d, 5-H, J 2.0 Hz), 6.10, 6.20, and 6.24 (s, 3 × OMe), 6.58 (s, CH_2), and 6.67 (s, 2 × 2-OMe). The *monoacetate* afforded fine white needles (from ethanol), m.p. 108° (Found: M^+, 418.175. $C_{22}H_{26}O_8$ requires M, 418.171), τ ($CDCl_3$) 2.75 (d, 2- and 6-H, J 8.5 Hz), 3.20 (d, 3- and 5-H), 3.67 (d, 3-H, J 2 Hz), 3.73 (d, 5-H), 6.22, 6.25, and 6.27 (s, 3 × OMe), 6.72 (2 × 2-OMe), 6.80 (s, CH_2), and 7.90 (s, OAc). Methylation of the 2-hydroxy-2,2-dimethoxypropanone (XX) and p.l.c. (benzene–ethyl acetate, 23 : 2) gave the *fully methylated ether* (XXIV) (R_F 0.41; red), crystallized from ethanol as fine white needles (195 mg), m.p. 141° (Found: C, 64.7; H, 6.2. $C_{21}H_{26}O_7$ requires C, 64.6; H, 6.4%), $\nu_{max.}$ ($CHCl_3$) 1 698 cm^{-1}, M^+ 390 (<1%), *m/e* 358 (6.5), 345 (9.8), 344 (44), 223 (4.6), 195 (100), 181 (13.7), 180 (46), 163 (10.4), 152 (46), 151 (9.8), 149 (49), 137 (55), and 121 (88), τ ($CDCl_3$) 2.73 (d, 2- and 6-H), 3.14 (d, 3- and 5-H), 3.84 (s, 3- and 5-H), 6.15 and 6.19 (s, 2 × OMe), 6.24 (s, 2 × OMe), 6.70 (s, 2 × 2-OMe), and 6.80 (s, CH_2).

α-*Hydroxy*-2′,4,4′,6′-*tetramethoxy*-cis- *and* -trans-*chalcones* [3-(4-*Methoxyphenyl*)-1-(2,4,6-*trimethoxyphenyl*)*propane*-1,2-*dione* (XXV)].—The fully methylated acetal (XXIV) (180 mg) in a mixture of 3N-sulphuric acid (10 ml), water (10 ml), and dioxan (10 ml) was heated for 2 h under reflux on a water-bath (96 °C). After neutralization with 10% sodium hydrogen carbonate the solution was extracted with

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chloroform, and solids were recovered from the organic phase at 60 °C under vacuum. P.l.c. (benzene–ethyl acetate, 23 : 2) gave only one band (R_F 0.38; red). The α-hydroxy-chalcone (α-diketone) crystallizes from ethanol as fine white needles, m.p. 136° (Found: C, 66.5; H, 5.8. $C_{19}H_{22}O_6$ requires C, 66.3; H, 5.9%), $\nu_{max.}$ (KBr) 1 680 and 1 720sh cm^{-1}, M^+ 344 (13.6%), *m/e* 195 (100), 180 (40), 167 (12.3), 166 (33), 152 (27), 149 (39), 148 (99), 139 (24), 138 (6.8), 124 (8.0), 121 (19.8), and 120 (38), τ [$(CD_3)_2CO$] 2.20 (d, 2- and 6-H), 3.05 (d, 3- and 6-H), 3.63 (s, 3′- and 5′-H), 3.70 (s, β-H *cis*), 3.79 (s, β-H *trans*), 6.10 and 6.19 (s, 2 × OMe), and 6.25 (s, 2 × OMe), τ (C_6D_6) 2.19 (d, 2- and 6-H), 2.37 (d, 2- and 6-H, oxo-form), 3.27 (d, 3- and 5-H), 3.35 (d, 3- and 5-H, oxo-form), 3.40 (s, β-H *trans*), 3.90 (s, 3′- and 5′-H), 4.05 (s, β-H *cis*), 6.60 and 6.75 (s, 2 × OMe), 6.79 (s, 2 × OMe), and 6.67 and 6.72 (s, small peaks, either OMe or CH_2 of oxo-form). The approximate proportions of *cis*- and *trans*-isomers were estimated from the integrals of their β-proton signals, and that of the α-diketone by difference from unity (high-field benzenoid absorption as reference).

Hydrolysis of 1-(2-*Hydroxy*-4,6-*dimethoxyphenyl*)-2,2-*dimethoxy*-3-(4-*methoxyphenyl*)*propan*-1-*one* (XX).—Hydrolysis of the 2-hydroxy-acetal, m.p. 114° (230 mg), in 0.1N-acetic acid (25 ml) and dioxan (30 ml) was carried out as for the fully methylated hemiacetal (XXIV). P.l.c. (benzene–ethyl acetate, 23 : 2) gave three bands, R_F 0.43, 0.31, and 0.10 (all red).

(±)-2,4,6-Trimethoxy-2-(4-methoxybenzyl)benzo[*b*]-furan-3(2*H*)-one (XXII) (maesopsin tetramethyl ether) (34 mg) crystallized from the contents of the R_F 0.31 band as white needles from ethanol, m.p. 130° (lit.,[25] 131°). The structure was confirmed by n.m.r. spectrometry.[24] (±)-2-Hydroxy-4,6-dimethoxy-2-(4-methoxybenzyl)benzo[*b*]-furan-3(2*H*)-one (XXIII) (4,4′,6-tri-*O*-methylmaesopsin) (R_F 0.10; 126 mg) crystallized from ethanol as fine white needles, m.p. 161° (lit.,[25] 158—159°; lit.,[26] 144—145°), M^+ 330 (25%), τ ($CDCl_3$) 2.79 (d, 2- and 6-H), 3.25 (d, 3- and 5-H), 3.96 (d, 7-H), 4.16 (d, 5-H), 6.20 (s, 2 × OMe), 6.27 (s, OMe), 6.37br (m, OH), and 6.85 (s, CH_2). Acetylation of 4,4′,6-tri-*O*-methylmaesopsin (100 mg) gave a ***monoacetate*** (90 mg) which crystallized from ethanol as fine white needles, m.p. 139°, M^+ 372 (14.6%), τ ($CDCl_3$) 2.74 (d, 2- and 6-H), 3.17 (d, 3- and 5-H), 3.89 (d, 7-H), 3.99 (s, 5-H), 6.12, 6.16, and 6.21 (s, 3 × OMe), 6.68 and 6.95 (dd, CH_2, *J* 14 Hz), and 7.90 (s, OAc). The R_F 0.43 band (103 mg) was resolved by p.l.c. (1,2-dichloroethane–ethyl acetate, 49 : 1) into two compounds, R_F 0.54 and 0.48. 2′-Hydroxy-α,4,4′,6′-tetramethoxy-*trans*-chalcone (XXI) (R_F 0.54; 59 mg) crystallized from ethanol as fine needles, m.p. 120° (lit.,[25] 120—121°), M^+ 344 (87%), τ ($CDCl_3$) −1.53 (s, 2′-OH), 2.25 (d, 2- and 6-H), 3.06 (d, 3- and 5-H), 3.80 (d, 3′-H), 3.86 (s, β-H), 3.96 (d, 5′-H), and 6.12, 6.15, 6.23, and 6.28 (s, 4 × OMe). 2′-Hydroxy-α,4,4′,6′-tetramethoxy-*cis*-chalcone (XIX) (R_F 0.48) crystallized from ethanol as fine yellow needles (30 mg), m.p. 116°, identical (n.m.r. and mass spectra and mixed m.p.) with the product derived from (±)-tetra-*O*-methylmaesopsin by photolysis.

Irradiation of 2-*Hydroxy*-4,6-*dimethoxy*-2-(4-*methoxybenzyl*)*benzo*[b]*furan*-3(2H)-*one* (XVIIIc) *and its Acetate* (XVIIIb).—Compound (XVIIIc) (10 mg) in methanol (13 ml) was irradiated at 300 nm over 12 h. T.l.c. then showed no conversion products. Irradiation of the acetate, m.p. 139° (100 mg), in methanol (134 ml) at 300 nm for 4 h gave two products, each in low concentration. P.l.c. (benzene–ethyl acetate, 23 : 2) gave two bands [R_F 0.41 (5 mg) and 0.31 (14.5 mg); both red]. N.m.r. and mass spectral t.l.c., and m.p. comparisons indicated that these bands represent 2′-hydroxy-α,4,4′,6′-tetramethoxy-*cis*-chalcone (XIX) and 1-(2-hydroxy-4,6-dimethoxyphenyl)-2,2-dimethoxy-3-(3,4-dimethoxyphenyl)propan-1-one (XX), respectively.

Conversion of 2′-*Hydroxy*-α,4,4′,6′-*tetramethoxy*-cis-*chalcone* (XIX) *into* (±)-2-(α,4-*Dimethoxybenzyl*)-2,4,6-*trimethoxybenzo*[b]*furan*-3(2H)-*one* (XXVI) *with Thallium*(III) *Nitrate*.—The α-methoxy-*cis*-chalcone (60 mg) and thallium(III) nitrate (80 mg) in methanol (10 ml) were stirred at ambient temperature for 2 h. After addition of 10% hydrochloric acid (10 ml) the mixture was refluxed for 3 h on a water-bath (96 °C). Methanol was removed under reduced pressure at 60 °C, water (10 ml) was added, and the organic components were extracted with chloroform (3 × 25 ml). The recovered solids crystallize from ethanol as fine white *needles* (38 mg), m.p. 165° (Found: C, 64.4; H, 5.7. $C_{20}H_{22}O_7$ requires C, 64.2; H, 5.9%), $\nu_{max.}$ ($CHCl_3$) 1 718 cm^{-1}, M^+ 374 (8.9%), *m/e* 344 (4.4%), 343 (4.4), 315 (7.8), 224 (11.1), 223 (48), 209 (8.1), 195 (7.8), 194 (5.6), 181 (18.9), 180 (28), 164 (5.6), 163 (6.7), 152 (83), and 121 (28), τ ($CDCl_3$) 2.51 (d, 2′- and 6′-H), 3.04 (d, 3′- and 5′-H), 3.74 (d, 7-H), 3.94 (d, 5-H), 5.47 (s, α-H), 6.05, 6.11, and 6.16 (s, 3 × OMe), 6.81 (s, 2-OMe), and 6.87 (s, α-OMe).

Conversion of 2′-*Hydroxy*-4,4′-*dimethoxy*-trans-*chalcone* (XXVII) *into* 4′,7-*Dimethoxyisoflavone* (XXVIII).—The chalcone (50 mg) and thallium(III) nitrate (80 mg) in methanol (10 ml) were treated as above (*cf.* ref. 13) to give the isoflavone (33 mg), m.p. 162° (lit.,[27] 162—163°), M^+ 282 (100%), τ ($CDCl_3$) 1.74 (d, 5-H), 2.05 (s, 2-H), 2.44 (d, 2′- and 6′-H), 3.00 (dd, 6-H), 3.02 (d, 3′- and 5′-H), 3.15 (d, 8-H), and 6.09 and 6.15 (s, 2 × OMe).

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