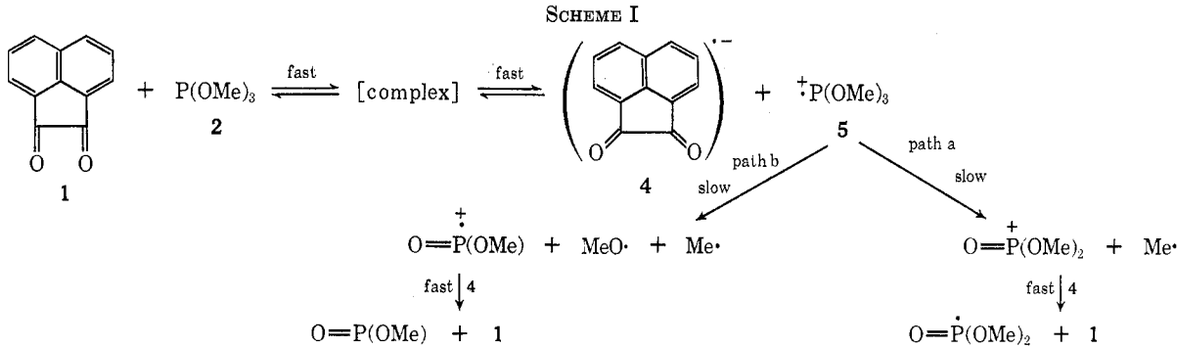
TABLE III

RATE OF DISAPPEARANCE OF DPPH IN THE REACTION OF VARIOUS QUINONES WITH TRIMETHYL PHOSPHITE IN DIOXANE AT 30.0°

Quinones	Initial concn, M: 10^3[Quinone]$_0$	10^3[P(OMe)$_3$]$_0$	10^4[DPPH]$_0$	Rate constant 10^6 k', $M^{0.5}$ sec^{-1}	Reduction potential, V
5,6-Dinitroacenaphthenequinone (6)	4.33	1.59	1.49	5.96	
5-Nitroacenaphthenequinone (7)	4.67	1.59	1.49	4.75	
Chloranil (8)	4.93	7.93	1.49	4.30[a]	0.712[b]
Acenaphthenequinone (1)	7.87	7.50	12.7	1.64	0.78
p-Benzoquinone (9)	4.67	507	1.49	0.312	0.698[c]
Phenanthrenequinone (10)	6.07	507	1.49	7.30×10^{-4}	0.458[d]
Anthraquinone (11)	6.57	507	1.49	Too slow to measure	0.157[e]

[a] Rate constant after induction period. [b] K. Wallenfels and W. Möhle, *Ber.*, 76, 924 (1943). [c] J. B. Conant and L. F. Fieser, *J. Amer. Chem. Soc.*, 44, 2480 (1922). [d] L. F. Fieser, *ibid.*, 51, 3101 (1929). [e] J. B. Conant and L. F. Fieser, *ibid.*, 46, 1855 (1924).

SCHEME I



The rate of one-electron transfer reaction seems to correlate with the reduction potential of quinones; *i.e.*, a plot of log k' *vs.* reduction potential fits well a straight line, whose slope is 12. This shows that the energy barrier for this reaction correlates with the reduction potential of quinone (Table III). The substitution by a nitro group seems to afford a little higher reduction potential to acenaphthenequinone.[16]

Experimental Section

Materials.—Trimethyl phosphite [bp 58° (116 mm)], acenaphthenequinone (mp 261°), chloranil (mp 299°), phenanthrenequinone (mp 210°), *p*-benzoquinone [mp 115.5° (lit.[17] mp 115.7°)], anthraquinone [mp 286–287° (lit.[18] mp 286°)], 5-nitroacenaphthenequinone [mp 210° (lit.[19] mp 218°)], and 5,6-dinitroacenaphthenequinone [mp > 300° (lit.[19] mp >300°)] were used.

Product.—The reaction of **1** with excess **2** was carried out at 25° under N_2. After distillation of unreacted **2** *in vacuo*, the product was analyzed by nmr ($CDCl_3$), τ 1.5–2.5 (multiplet, 12 H), 6.28 (doublet, J_{PH} = 10.6 Hz, 9 H). The yield of **3** was almost quantitative.

Kinetics.—The disappearance of color of DPPH [$\lambda_{max}^{dioxane}$ 515 nm (ϵ 5310)] was followed by means of spectrophotometry. Each 1-ml portion of dioxane solution of **1**, **2**, and DPPH was introduced separately into a three-necked quartz uv cell. After air was substituted by N_2, the three solutions were mixed and the cell was placed in a thermostated cell chamber of an Hitachi EPU-2A spectrophotometer. The consumption of DPPH was determined spectrophotometrically at appropriate intervals of time.

On the other hand, the disappearance of color of **1** [$\lambda_{max}^{dioxane}$ 473 nm (ϵ 17.9)] was followed by almost the same procedure as above.

Esr Spectra.—Esr spectra were observed by mixing a dioxane solution of trimethyl phosphite and acenaphthenequinone in an esr tube at the temperature of the melting point of dioxane. Field and modulation width were 3150 ± 100 and 20 G, respectively.

(16) L. F. Fieser, *J. Amer. Chem. Soc.*, **51**, 3101 (1929).
(17) J. M. Robertson, *Proc. Roy. Soc., Ser. A*, **150**, 106 (1935).
(18) (a) R. Kempf, *J. Prakt. Chem.*, [2] **78**, 257 (1908); (b) H. R. Snyder and F. X. Werber, *J. Amer. Chem. Soc.*, **72**, 2965 (1950).
(19) F. Rowe and J. S. Herbert, *J. Chem. Soc.*, **117**, 1344 (1920).

Reduction Potential.—The reduction potential of quinones was measured in 50% aqueous ethanol containing 0.1 *N* HCl as a 10^{-4}–10^{-3} *M* solution of substrate at 20° by a Yanagimoto P8-DPR polarograph potentiostated with a calomel electrode.

Registry No.—**1**, 82-86-0; **2**, 121-45-9; **3**, 40782-66-9; **6**, 27471-02-9; **7**, 24040-42-4; **8**, 2435-53-2; **9**, 106-51-4; **10**, 84-11-7; **11**, 84-65-1.

Conversion of *o*-Acylphenylacetic Acids to Naphthalene and Chrysene Derivatives[1]

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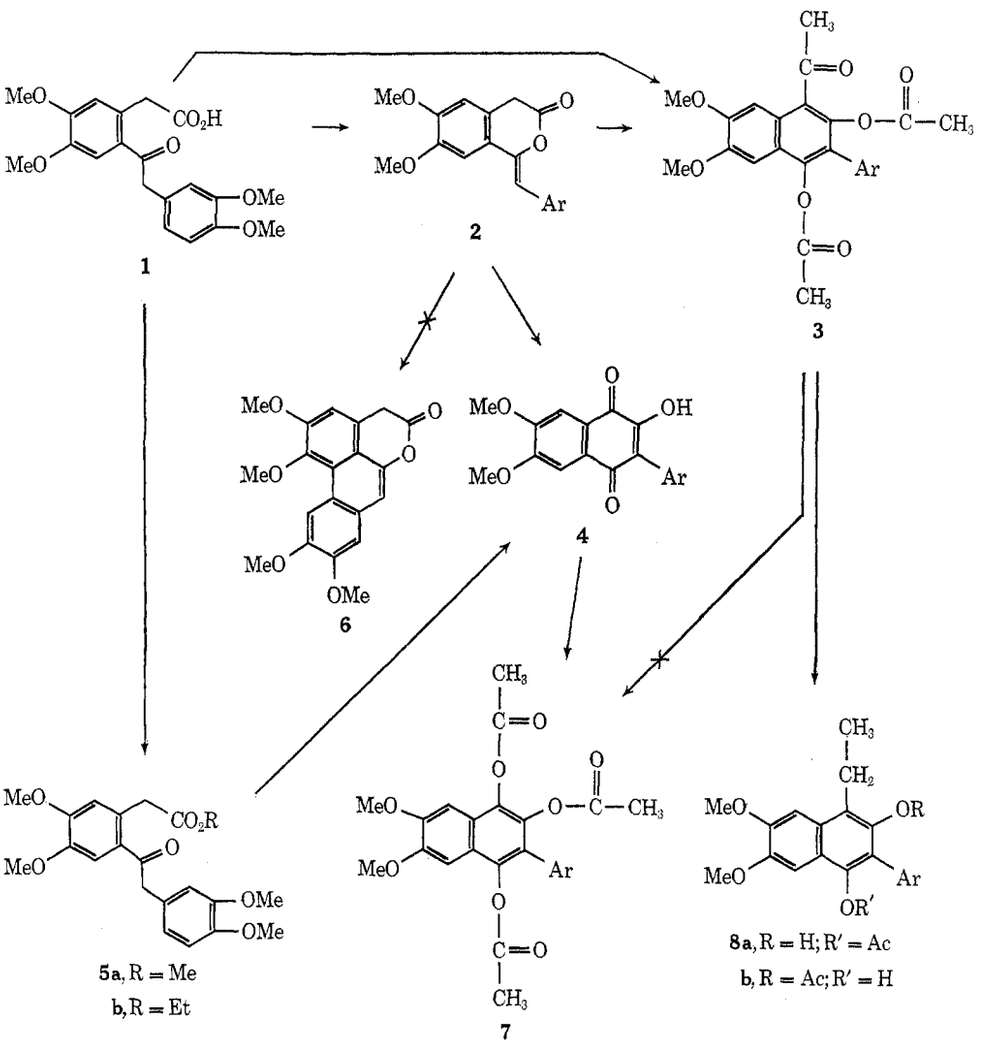
2-[(3,4-Dimethoxyphenylacetyl)-4,5-dimethoxyphenyl]acetic acid (**1**) has been used in a new total synthesis of 1-benzylisoquinoline alkaloids, and one of key intermed:ates in that work was 1-(3,4-dimethoxybenzylidene)-6,7-dimethoxy-3-isochromanone (**2**) obtained by thermal dehydration of **1**.[2] The present work was undertaken in an effort to find a milder reaction to convert **1** to **2**, and in the initial attempts the keto acid **1** was heated for 1 hr in a solution of acetic anhydride in pyridine. The purified product, obtained in about 52% yield, was identified as 1-acetyl-2,4-diacetoxy-3-(3,4-dimethoxyphenyl)-6,7-dimethoxynaphthalene (**3**). The structure proof of **3** rested on the elemental analysis and on the uv, ir, nmr, and mass spectra (see Experimental Section) as well as on the chemical conversion to the known 1,4-naphthoquinone derivative **4**.

(1) This study was supported in part by a grant from the National Science Foundation (GY 6169).
(2) I. W. Elliott, Jr., *J. Heterocycl. Chem.*, **9**, 853 (1972).

SCHEME I



Ar = 3,4-dimethoxyphenyl

In subsequent reactions we have found that heating **1** in pyridine–acetic anhydride for a shorter period resulted in the formation of a mixture of **3** and the isochromanone **2**. From a reaction of **1** in acetic anhydride alone, the substituted 3-isochromanone **2** was isolated in moderate yield, but compound **3** was not detected under these conditions. Moreover, when **2** was subjected to treatment with hot pyridine and acetic anhydride it was converted to the naphthalene derivative **3**. These results suggest that **2** is a possible intermediate in the cyclization of **1** to **3**; these transformations are outlined in Scheme I.

Both **2** and **3** are readily oxidized by alcoholic sodium hydroxide and air to the 1,4-naphthoquinone derivative **4**. Compound **4** has been prepared earlier from the keto ester **5**,[3,4] and its structure was established by Bentley. The formation of **4** from **3** requires the loss of the 1-acetyl group from the aromatic ring by carbon–carbon bond cleavage; although there are reports for loss of aryl and alkoxy groups from 4-substituted 1,2-naphthoquinones under mild conditions to give the 2-hydroxy-1,4-naphthoquinone system,[5] probably the nearest analogy for the oxidation of **3** to **4** is the transformation of the keto ester **5** to **4** in which Bentley and coworkers offered evidence that an intermediate 1,3-dihydroxynaphthalene was oxidized by air to the 1,4-naphthoquinone **4**.

The same 1,4-naphthoquinone **4** was also prepared from **2** by an oxidative photochemical reaction of **2**. The photochemical reaction was originally undertaken in an attempt to couple the two benzene rings in **2** to synthesize a tetracyclic oxygen analog (**6**) of certain of the aporphine alkaloids. Under the conditions used none of compound **6** has been obtained.

Two additional reactions of **3** were tried, based on known functional group reactions. Although a triacetoxynaphthalene compound (**7**) was readily prepared by reductive acetylation of **4** using zinc and acetic anhydride, we were not able to oxidize the naphthyl ketone **3** to **7** under Baeyer–Villiger conditions. The reaction of sodium borohydride with **3** did not lead to the anticipated carbinol; rather the product of this mild reduction is assigned the structure **8** for the several

(3) H. R. Bentley, W. Dawson, and F. S. Spring, *J. Chem. Soc.*, 1763 (1952).

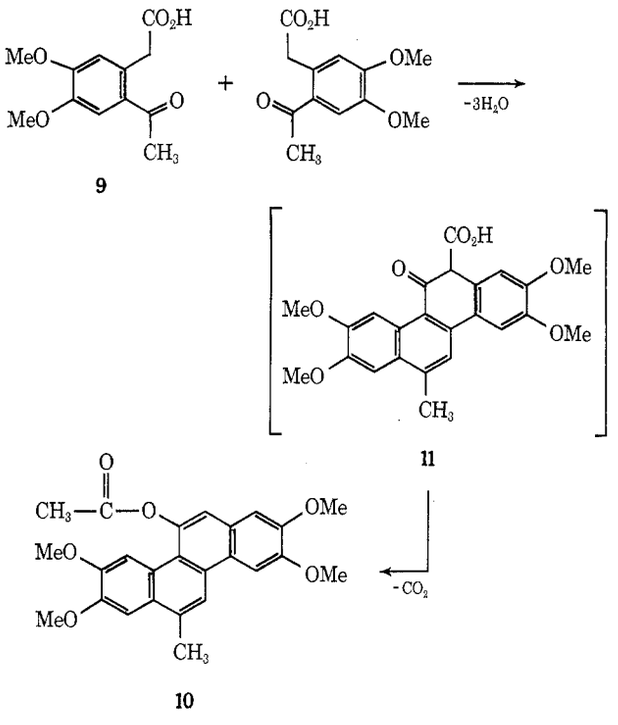
(4) I. W. Elliott, *J. Heterocycl. Chem.*, **7**, 1229 (1970).

(5) S. C. Hooker and J. G. Walsh, Jr., *J. Chem. Soc.*, **65**, 321 (1894); L. F. Fieser, *J. Amer. Chem. Soc.*, **48**, 2922 (1926).

following reasons: (1) the elemental analysis fit a formula $C_{24}H_{26}O_7$ but not $C_{26}H_{28}O_9$; (2) the mass spectrum shows a peak for the parent ion at *m/e* 426; (3) the nmr spectrum clearly shows the pattern of an ethyl group, in addition to one acetyl and an OH group. Either **8a** or **8b** fits this description, and since this compound was peripheral to our investigation we have made no detailed study of it. However, the reduction by borohydride of a carbonyl group to the methylene stage[6] and facile hydrolysis of one specific ester linkage suggest a proximity effect that would favor the formation of **8a** over **8b**.

By contrast with the *o*-(phenylacetyl)phenylacetic acid (**1**), when 6-acetyl-3,4-dimethoxyphenylacetic acid (6-acetylhomoveratric acid) was heated in pyridine–acetic anhydride solution, the major compound isolated proved to be 11-acetoxy-6-methyl-2,3,8,9-tetramethoxychrysene. The elemental analysis and spectral data support the constitution **10** for this product, and its formation from 2 mol of 6-acetylhomoveratric acid (**9**) can be rationalized by Scheme II. An intermediate

SCHEME II



such as **11**, with a β-keto acid unit, provides an explanation for the ready decarboxylation required in the final formulation of the chrysene derivative **10**. The examples whereby 2-hydroxy-1-naphthoic acid[7] and to a lesser extent 1-hydroxy-2-naphthoic acid[8] are decarboxylated in boiling water serve as models for the chrysene case. The sketchy trend in ease of decarboxylation from salicylic acid through the hydroxy naphthoic acids to the hypothetical chrysene intermediate **11** may parallel the greater relative importance of the keto tautomers in each of these compounds.

(6) Reductions have been reported of acetyl to ethyl groups in other substituted naphthalenes: R. E. Moore, H. Singh, C. W. J. Chang, and P. J. Scheuer, *J. Org. Chem.*, **31**, 3638 (1966); H. Singh, T. L. Folk, and P. J. Scheuer, *Tetrahedron*, **25**, 5301 (1969). We thank one of the referees for calling this work to our attention.

(7) G. Kaufmann, *Ber.*, **15**, 804 (1882).

(8) R. Schmitt and E. Burkard, *Ber.*, **20**, 2699 (1887).

Experimental Section

1-Acetyl-2,4-diacetoxy-3-(3,4-dimethoxyphenyl)-6,7-dimethoxynaphthalene (3). A. From the Keto Acid.—The keto acid (**1**, 2 g) in pyridine (12 ml) and acetic anhydride (10 ml) was heated to boiling for 10 min and allowed to stand for 18 hr. The solution was stirred into aqueous 10% HCl (150 ml), and the solid which separated was collected and immediately recrystallized from EtOH. The solution deposited 1.5 g (52%) of pale golden crystals: mp 200–201°; *m/e* 482 (M^+); uv λ_{max}^{EtOH} 247 nm (log ε 4.75), 289 sh (4.08), 337 (3.07); ir (paraffin oil mull) 1760, 1690 cm^{-1} (C=O); nmr ($CDCl_3$) δ 1.99, 2.15, 2.70 (each 3 H, s, $COCH_3$), 4.00 (12 H, m, 4 OCH_3), 6.99–7.40 (5 H, m).

Anal. Calcd for $C_{26}H_{26}O_9$: C, 64.74; H, 5.43. Found: C, 64.47; H, 5.44.

B. From 1-(3,4-Dimethoxybenzylidene)-6,7-dimethoxy-3-isochromanone (2).—The lactone **2** (2 g) in pyridine (15 ml) and acetic anhydride (10 ml) was allowed to reflux for 30 min and to stand for 20 hr. When the solution was added to 10% HCl solution (150 ml) a solid was obtained. Recrystallization from EtOH gave a golden crystalline product (1.2 g), mp 200–201°. An infrared spectral comparison showed that this product was identical with compound **3** in part A.

2-(3,4-Dimethoxyphenyl)-3-hydroxy-6,7-dimethoxy-1,4-naphthoquinone (4). A. From the Keto Ester 5b.—To a mixture of the keto acid (1.5 g) in absolute EtOH (150 ml) was added ethyl chloroformate (10 ml). The mixture was warmed for 10 min and allowed to stand overnight. The ester **5b** (4.8 g) separated on cooling and was recrystallized from EtOH as a colorless solid, mp 106–107°.

Anal. Calcd for $C_{22}H_{26}O_7$: C, 65.66; H, 6.51. Found: C, 65.84; H, 6.56.

The ester **5b** (2 g) was suspended in EtOH (50 ml) and treated with 20% sodium hydroxide solution (20 ml). A deep purple color developed immediately and the solid gradually dissolved. After standing exposed to the air for 18 hr the solution was poured into 10% HCl solution (200 ml) and a red solid (2 g) was collected. The naphthoquinone **4** was recrystallized from a mixture of MeOH and $CHCl_3$ as orange needles, mp 230–231° (lit.[3] mp 226°).

B. From the Naphthyl Ketone 3.—A suspension of **3** (1 g) in EtOH (30 ml) was mixed with 20% NaOH solution (10 ml). The characteristic violet color (see part A) developed within 1 min but not so quickly as with the keto ester **5b**. Within 2 hr all of the solid has dissolved and the solution was dark purple. After 24 hr the reaction mixture was poured into 10% HCl (150 ml) and a red solid (1 g) precipitated. The naphthoquinone was recrystallized from $CHCl_3$–MeOH as orange crystals, mp 229–230°, that had an infrared spectrum identical with that of the product from part A.

C. From the Isochromanone 2 by Reaction with Base.—The isochromanone **2** (1 g) reacted with NaOH in EtOH in the same proportions as in part B, and within 3 min a purple color had developed. After 30 hr the naphthoquinone was isolated quantitatively from HCl solution and recrystallized from $CHCl_3$–MeOH as orange crystals, mp 230–231°, *m/e* 370 (M^+). The infrared spectrum showed that the product was identical with Bentley's naphthoquinone.[3]

Anal. Calcd for $C_{20}H_{18}O_7$: C, 64.86; H, 4.90. Found: C, 65.08; H, 5.02.

D. From the Isochromanone 2 by Photolysis.—A solution of **2** in *t*-BuOH (200 ml)–C_6H_6 (60 ml) was irradiated with exposure to air for 24 hr in a Rayonet Model RPR-100 reactor equipped with 3000-Å lamps. Evaporation of the dark red solution gave a gum which was washed several times with petroleum ether (bp 30–60°) to leave a red solid (0.2 g), mp 222–223°. Recrystallization of the crude product from $CHCl_3$–MeOH gave orange crystals, mp 228–229°. The ir spectrum of this product was superimposable on that of Bentley's naphthoquinone (**4**).[3]

Sodium Borohydride Reduction of 3.—A suspension of the naphthyl ketone **3** (1 g) in EtOH (20 ml) was allowed to react with sodium borohydride (0.4 g). After 20 min at room temperature the mixture was boiled for 3 min and diluted with water (20 ml). Acetic acid was added dropwise until the evolution of gas ceased, and the mixture was diluted to 100 ml with water. After cooling, the supernatant liquid was decanted, and the solid was recrystallized from EtOH (15 ml)–THF (5 ml) as nearly colorless plates (0.35 g): mp 190–191°; *m/e* 426 (M^+); ir 3440 (OH) and 1760 cm^{-1} (ester C=O), there was no band at

1690 cm^{-1} that was assigned to the ketone C=O in the starting compound **3**; nmr δ 1.3 (3 H, t, CH_3 of Et), 2.1 (3 H, s, $COCH_3$), 3.1 (2 H, q, CH_2 of Et), 3.9 (12 H, m, 4 OCH_3), 5.0 (1 H, s, OH), 7.0–7.3 (5 H, m, ArH).

Anal. Calcd for $C_{24}H_{26}O_7$: C, 67.59; H, 6.15. Found: C, 67.70; H, 6.23.

1,3,4-Triacetoxy-2-(3,4-dimethoxyphenyl)-6,7-dimethoxynaphthalene (**7**).—Reductive acetylation of the naphthoquinone **4** with zinc dust in acetic anhydride after the procedure described by Bentley[4] gave the triacetyl derivative **7**, mp 221–222°.

Anal. Calcd for $C_{28}H_{26}O_{10}$: C, 62.65; H, 5.26. Found: C, 62.63; H, 5.42.

An attempt to prepare **7** by oxidation of **3** by *m*-chloroperbenzoic acid led to 60% recovery of **3** and *m*-chlorobenzoic acid (83%) but, there was no evidence for the formation of **7**.

6-Acetylhomoveratric Acid (**9**).—3,4-Dimethoxyphenylacetic acid (15 g, homoveratric acid) was dissolved in warm acetic acid (25 ml) and the solution was stirred into polyphosphoric acid (200 g). After standing at room temperature for 2 days with occasional stirring, the reaction mixture was added to water (1500 ml) and the aqueous solution was extracted continuously with ether (1300 ml) for 18 hr. Evaporation of the ether extract left 12 g of colorless solid that after recrystallization from water (3 parts)–EtOH (1 part) had mp 175–176° (lit.[3] mp 175°). The identification of the product was by comparison with a sample prepared by Bentley's method and by oxidation to the known 3,4-dimethoxyhomophthalic acid.[3] Compound **9** could also be isolated in several crops from the water solution on long standing (1–3 weeks).

11-Acetoxy-6-methyl-2,3,8,9-tetramethoxychrysene (**10**).—A mixture of 6-acetylhomoveratric acid (**9**, 2 g) in pyridine (16 ml) and acetic anhydride (12 ml) was heated under reflux conditions for 1 hr. After standing for 12 hr, the red solution was added to 300 ml of 10% HCl solution and the crude product (1.8 g, mp 120°) was collected. Extraction of the solid with hot MeOH left a residue (0.75 g), mp 253–258°. The chyrsene derivative was purified by recrystallization from $CHCl_3$–petroleum ether: mp 263–265°; *m/e* 420 (M^+); ir 1750 cm^{-1} (C=O); uv λ_{max}^{EtOH} 231 nm (log ε 4.81), 259 sh (4.60), 279 sh (5.02), 287 (5.15), 307 (4.54), 319 (4.34), 334 (4.26), 362 (4.00), 380 (4.08); nmr δ 2.51 (3 H, s, CH_3), 2.75 (3 H, s, CH_3CO), 4.14 (12 H, m, OCH_3), 7.20–8.75 (6 H, m, ArH).

Anal. Calcd for $C_{25}H_{24}O_6$: C, 71.42; H, 5.75. Found: C, 71.09; H, 5.70.

Registry No.—1, 26954-85-8; 2 30034-55-0; 3, 40940-67-8; 4, 40940-48-5; **5b**, 40940-49-6; **7**, 40940-50-9; **8a**, 40940-51-0; **9**, 38210-84-3; **10**, 40940-53-2; homoveratric acid, 93-40-3.

A Convenient Preparation of Tetrahydrofurylidene Acetates

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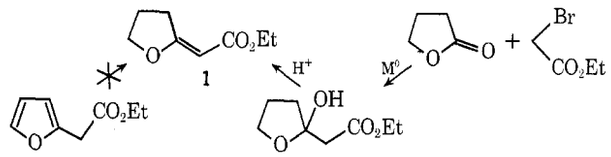
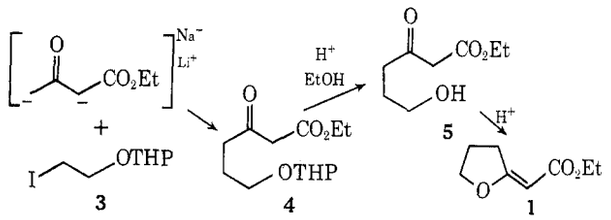
Recent heterocyclic studies have required reduced derivatives of furan for synthetic building blocks. This had led to a convenient preparation of ethyl α-(tetrahydro-2-furylidene)acetate (**1**) by a novel epoxide ring cleavage. The preparation of this compound (**1**) by the reduction of furan esters seemed unlikely. The reaction of organometallics with γ-butyrolactone proved to be a complex process but did, on treatment with acid, afford furylidene acetate **1** in 24% yield from γ-butyrolactone.[1] Use of the dianion of ethyl acetoacetate (**2**), following the procedure of Weiler,[2]

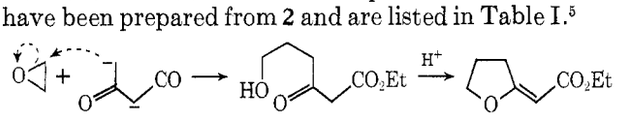


proved a very simple approach to the formation of the carbethoxymethylene tetrahydrofuran **1**.



Initially, the dianion of ethyl acetoacetate (**2**) was alkylated with the tetrahydropyranyl ether (THP) of iodoethanol (**3**), forming a new β-keto ester, **4**, alkylation occurring at the methyl rather than methylene position of ethyl acetoacetate. This was converted into **1** in 34% yield (from ethyl acetoacetate) by treatment with first aqueous ethanol and acid (**4** → **5**) and then benzene and *p*-toluenesulfonic acid (**5** → **1**). The same alkylation procedure with the THP of chloro- or bromoethanol failed to yield keto ester **4** in any usable quantities.

Improvement in the preparation of ester **1** was facilitated by the discovery that the dianion of ethyl acetoacetate (**2**) would undergo smooth epoxide ring opening[3] in a manner analogous to the above-cited alkylation reaction (bond formation occurring at the methyl position of ethyl acetoacetate). When approximately 1 equiv of ethylene oxide was added to litho sodio ethyl acetoacetate (**2**) a crude alcohol **5** was formed which was readily transformed into tetrahydrofuran **1** on treatment with oxalic acid in methylene chloride (54% yield). The generality of this novel dianion epoxide ring opening and enol etherification is apparent from the reduced furan and thiophene derivatives that have been prepared from **2** and are listed in Table I.[5]



The product of initial epoxide (sulfide) ring opening (*i.e.*, **5**) was never purified. However, the spectral data (ir, nmr) from these crude products, **5**, and the analogous compounds from propylene oxide and butylene oxide (propylene sulfide) suggest these alcohols (mercaptans) could be isolated and used for synthetic transformations other than simple intramolecular enol etherification.

The stereochemistry about the double bond of these esters is as shown in Table I (E or trans). This is apparent from shift reagent studies which confirm the close proximity of the ester carbonyl and allylic, methylene ring protons. That is, assuming proton deshielding decreases as the intramolecular distance

(1) F. F. Blick and B. A. Brown, *J. Org. Chem.*, **26**, 3685 (1961), and references cited therein.

(2) L. Weiler, *J. Amer. Chem. Soc.*, **92**, 6707 (1970); L. Weiler, *Tetrahedron Lett.*, 4809 (1971).

(3) For examples of sodio ethyl acetoacetate epoxide ring opening see ref 4; to our knowledge this study represents the first report of a dianion epoxide ring cleavage.

(4) A. Graham, A. Millidge, and D. Young, *J. Chem. Soc.*, 2180 (1954); T. Temnikova, G. Markina, V. Borodavko, and N. Yaskina, *Zh. Org. Khim.*, **6**, 739 (1970); G. El Naggar and B. Ershov, *ibid.*, **5**, 1368 (1969).

(5) All products were characterized by ir, nmr, uv, mass spectra and C, H analysis.