sium sulfate, and evaporated in vacuo. The residual solid (0.175 g, 93%) had mp 94–95 °C (lit.[3] 96.5–97 °C), after crystallization from ethyl acetate, and was indistinguishable from an authentic specimen[3] of $PGF_{2\beta}$.

B. Hydrolysis of $PGF_{2\beta}$ Methyl Ester (1c). The hydrolysis of **1c** was effected in the same manner as described for **1b**, with the exception that the quantity of potassium carbonate was halved. $PGF_{2\beta}$ was obtained in 94% yield and had mp 93–95 °C after crystallization from ethyl acetate.

11-*epi*-$PGF_{2\alpha}$ (2a). The hydrolysis of **2b** or **2c** was accomplished in exactly the same way as described above for **1b** and **1c**. 11-*epi*-$PGF_{2\alpha}$ (**2a**) was thus obtained in 93% yield and had mp 117–118 °C (lit.[9] 117–119 °C) after crystallization from acetonitrile. This material was indistinguishable from an authentic sample prepared according to White.[5]

Registry No.—**1a,** 4510-16-1; **1b,** 58282-71-6; **1c,** 28977-26-6; **2a,** 38432-87-0; **2b,** 61158-80-3; **2c,** 58407-22-0; **5a,** 42161-56-8; aluminum hydride, 7784-21-6.

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Synthesis of 3-Substituted Furans

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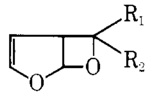
A considerable number of naturally occurring furans bear a substituent in position 3.[1] The synthetic access to them is usually not easy because of known difficulties in preparation of 3-furyl type synthons.[2] Although in recent years a number of methods for the synthesis of 3-substituted furans were reported,[3] there is still a need for further, possibly uncomplicated synthetic routes. We would like to present here a new synthesis of 3-substituted furans which is simple, does not require any special reagents or reaction conditions, and can be performed on a fairly large scale.

It is known since 1963 that carbonyl compounds can be photochemically added to furan furnishing in a remarkably regioselective reaction derivatives of 2,7-dioxabicyclo[3.2.0]hept-3-ene.[4,5] The outcome of the photochemical cycloaddition is strongly dependent on the carbonyl compound used; the yields vary from 1% for acetophenone to 35% for benzaldehyde.[6] In this way oxetanes **1–7** were prepared (with the exception of **3**, cf. Experimental Section).

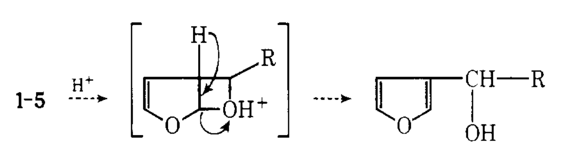
Table I. 3-Furylmethanols from Isomerization of 2,7-Dioxabicyclo[3.2.0]hept-3-enes

Compd	Yield, %	Bp, °C (mm)	Anal., % Calcd C	Calcd H	Found C	Found H
8	58	65–70 (0.2)	64.3	7.2	63.9	7.5
9	73	80–83 (0.15)	60.6	7.1	60.3	7.4
10	63	98–100 (0.2)	56.5	5.9	56.4	6.2
11	68	80–85 (0.2)	71.4	9.6	71.5	9.6
12	68	80–85 (0.2)	75.8	5.8	75.6	5.7



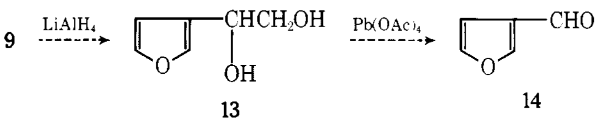
1, $R_1 = H; R_2 = CH_3$
2, $R_1 = H; R_2 = CO_2C_4H_9$
3, $R_1 = H; R_2 = CH_2OCOCH_3$
4, $R_1 = H; R_2 = CH_2CH_2CH(CH_3)_2$
5, $R_1 = H; R_2 = C_6H_5$
6, $R_1 = R_2 = CO_2C_2H_5$
7, $R_1 = H; R_2 = \text{2-furyl}$

We have now found that oxetanes **1–5** can be isomerized in the presence of acids (e.g., *p*-toluenesulfonic acid) in aprotic solvents such as diethyl ether or carbon tetrachloride at room temperature to 3-furylmethanols **8–12** in good yields. There can be little doubt that the gain in stabilization on return to the furan system is the driving force of this isomerization. In Table I are shown the yields, boiling points, and analytical data of 3-furylmethanols obtained.

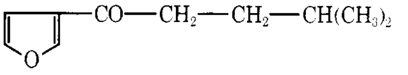


8, $R = CH_3$
9, $R = CO_2C_4H_9$
10, $R = CH_2OCOCH_3$
11, $R = CH_2CH_2CH(CH_3)_2$
12, $R = C_6H_5$

Compound **9** was reduced with lithium aluminum hydride to diol **13**, which, in turn, was cleaved with lead tetraacetate to 3-furylaldehyde **14** in 65% yield:



Compound **11** was oxidized with Sarett or Jones reagents to perilla ketone **15**.



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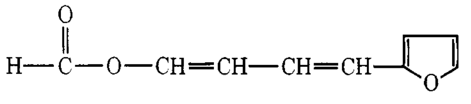
These examples show that 3-furylmethanols can be exploited in the synthesis of naturally occurring furans either directly by employing a suitable aldehyde for photocycloaddition or by means of convenient synthons, e.g., **9**, **13**, or **14**.

The behavior of oxetanes **6** and **7** toward acids was different from that of compounds **1–5**. Whereas oxetane **6** remained unchanged under the conditions employed, oxetane **7** was very unstable; the acidity of silica gel for chromatography was sufficient to convert **7** into a new compound for which the constitution of the formate of 1-hydroxy-4-(2-furyl)-1,3-butadiene (**16**) was deduced from the spectral and analytical data. This is a new manner of oxetane ring cleavage in the 2,7-dioxabicyclo[3.2.0]hept-3-ene system.



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Experimental Section

6-Carbobutoxy-2,7-dioxabicyclo[3.2.0]hept-3-ene (2). A solution of *n*-butyl glyoxylate (37.0 g) in furan (450 ml) was irradiated with a 400-W high-pressure mercury lamp under argon atmosphere in a Pyrex photochemical reactor. After 25 h the mixture was distilled and afforded 43.5 g (77.3%) of oxetane **2:** bp 86–88 °C (0.2 Torr); IR 1750, 1610 cm^{-1}; ^{1}H NMR (CCl_4) δ 6.59 (m, 1 H, $J_{1,3}$ = 1, $J_{3,4}$ = 2.3 Hz, H-3), 6.34 (d, 1 H, $J_{1,5}$ = 4.2 Hz, H-1), 5.34 (t, 1 H, $J_{4,5}$ = 2.8 Hz, H-4), 4.69 (d, 1 H, $J_{5,6}$ = 2.9 Hz, H-6). 3.69 (m, 1 H, H-5), signals of the *n*-butoxy group at 4.13 (t, 2 H) and 1.1–1.8 (m, 7 H). Anal. Calcd for $C_{10}H_{14}O_4$: C, 60.6; H, 7.1. Found: C, 60.8; H, 7.1.

6-Acetoxymethyl-2,7-dioxabicyclo[3.2.0]hept-3-ene (3) was obtained from **2** by lithium aluminum hydride reduction followed by acetylation with acetic anhydride and pyridine in 53% overall yield: bp 83–86 °C (0.2 Torr); IR 1745, 1605 cm^{-1}; ^{1}H NMR (CCl_4) δ 6.65 (m, 1 H, $J_{3,4}$ = 3, $J_{3,5}$ = 1.3 Hz, H-3), 6.05 (d, 1 H, $J_{1,5}$ = 4.4 Hz, H-1), 5.34 (t, 1 H, $J_{4,5}$ = 3 Hz, H-4), 4.60 (pt, 1 H, $J_{5,6}$ = 2.9 Hz, H-6), 4.23 (d, 2 H, CH_2OAc), 3.57 (m, 1 H, H-5), 2.08 (s, 3 H, OAc). Anal. Calcd for $C_8H_{10}O_4$: C, 56.5; H, 5.9. Found: C, 56.5; H, 6.2.

6-(3-Methylbutyl)-2,7-dioxabicyclo[3.2.0]hept-3-ene (4) was prepared in 66.4% yield from 4-methylpentanal and furan according to the method described for oxetane **2:** bp 135 °C (53 Torr); IR 1610 cm^{-1}; ^{1}H NMR (CCl_4) δ 6.60 (m, 1 H, $J_{3,4}$ = 2.8 Hz, H-3), 6.21 (d, 1 H, $J_{1,5}$ = 4.5 Hz, H-1), 5.27 (t, 1 H, $J_{4,5}$ = 3 Hz, H-4), 4.45 (pt, 1 H, $J_{5,6}$ = 3.2 Hz, H-6), 3.37 (m, 1 H, H-5), signals of the 3-methylbutyl group at 0.9–2.0 (m, 11 H). Anal. Calcd for $C_{10}H_{16}O_2$: C, 71.4; H, 9.6. Found: C, 71.6; H, 9.8.

6,6-Dicarbethoxy-2,7-dioxabicyclo[3.2.0]hept-3-ene (6) was obtained similarly in 30% yield from diethyl ketomalonate and furan. The crude product was purified by column chromatography: IR 1760, 1605 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 6.56 (m, 1 H, $J_{3,4}$ = 3, $J_{3,5}$ = 1 Hz, H-3), 6.33 (d, 1 H, $J_{1,5}$ = 4.2 Hz, H-1), 5.18 (t, 1 H, $J_{4,5}$ = 2.5 Hz, H-4), 4.26 (m, 5 H, H-5 and two CH_2O), 1.30 (t, 6 H, two CH_3). Anal. Calcd for $C_{11}H_{14}O_6$: C, 54.5; H, 5.8. Found: C, 54.6; H, 6.0.

Oxetanes **1, 5** and **7** were prepared according to ref 5.

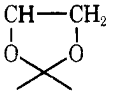
Isomerization of 6-Substituted 2,7-Dioxabicyclo[3.2.0]hept-3-enes. A 1% solution of oxetane **1** (or **2–5**) in diethyl ether or carbon tetrachloride was treated with 0.02–0.04% of *p*-toluenesulfonic acid and left at room temperature for 10–24 h. After neutralization with triethylamine the product was isolated by distillation. Yields, boiling points, and elemental analyses of 3-furylmethanols **8–12** are collected in Table I. All compounds exhibited ^{1}H NMR low-field signals at δ 7.3–7.4 (2 H) and 6.3–6.4 (1 H) typical for 3-monosubstituted furans. Also their IR spectra displayed bands specific for the furan ring at 1510 and 870–880 cm^{-1}.

Isomerization of 6-substituted 2,7-dioxabicyclo[3.2.0]hept-3-enes with higher concentration of catalyst led to retro cleavage; after addition of 5% *p*-toluenesulfonic acid to compound **5** only benzaldehyde could be detected after 10 h. From oxetane **1** tars were formed under similar conditions. On the other hand, oxetane **6** remained unchanged after standing with 1% hydrogen chloride for 140 h.

3-(1,2-Dihydroxyethyl)furan (13). Butyl 3-furylglycolate (**9**) was reduced with lithium aluminum hydride in ether solution at 0 °C. After typical workup 67% of diol **13** was obtained. The compound solidified after distillation at 110 °C (0.2 Torr): mp 54.5–55 °C; IR 3350, 1510, 875 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 7.36 (m, 2 H, furan H-2 and H-5), 6.30 (s, 1 H, furan H-4), 4.70 (pd, 1 H, J_{AX} = 4.2, J_{BX} = 6.8 Hz, C**H**OHCH$_2$OH), 3.65 (m, 2 H, CHOHC**H**$_2$OH). Anal. Calcd for $C_6H_8O_3$: C, 56.2; H, 6.3. Found: C, 56.3; H, 6.6.

Oxidation of diol **13** with lead tetraacetate in benzene solution gave, after workup, 65% of 3-furylaldehyde, mp of phenylhydrazone 147.5 °C (lit.[7] 149.5°C).

1,2-*O*-Isopropylidene derivative of 3-(1,2-dihydroxyethyl)furan was obtained in 81% yield from **13** and acetone to which a catalytic amount of concentrated sulfuric acid was added: distilled at 45–50 °C (0.2 Torr); IR 1510, 880 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 7.38 (m, 2 H, furan H-2 and H-4), 6.36 (m, 1 H, furan H-4), 5.00 (pd, 1 H, J_{AX} = 6.0, J_{BX} = 7.8 Hz, fragment a), 4.16 (pd, 1 H, J_{AB} = 7.7 Hz, fragment b), 3.75 (t, 1 H, fragment c), 1.43 and 1.47 (two s, 6 H, two CH_3). Anal. Calcd for $C_9H_{12}O_3$: C, 64.3; H, 7.1. Found: C, 64.7; H, 7.4.



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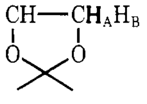

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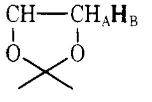

c

1-(3-Furyl)-4-methyl-1-pentanone (Perilla Ketone, 15). A solution of 1-(3-furyl)-4-methyl-1-pentanol (**11**, 100 mg) in 3 ml of acetone was treated with Jones reagent[8] until persistent yellow coloration. The excess of the oxidizing reagent was destroyed with a few drops of methanol whereupon the mixture was diluted with 2 ml of water and extracted several times with chloroform. Evaporation of the dried ($MgSO_4$) chloroform solution and distillation of the remaining liquid at 60–70 °C (10 Torr) afforded 61 mg (61.7%) of the perilla ketone: mp of 2,4-dinitrophenylhydrazone 149.5 °C (lit.[9] 149.5 °C); IR 1680, 1570, 1520, 875 cm^{-1}; ^{1}H NMR (CCl_4) δ 8.67, 7.83, and 6.81 (three m, 3 H, furan H-2, H-4, and H-5), 2.69 (t, 2 H, $J_{2,3}$ = 7.6 Hz, $COCH_2$–), signals of the 2-methylpropyl group at 0.93–1.8 (m, 9 H). Anal. Calcd for $C_{10}H_{14}O_2$: C, 72.3; H, 8.5. Found: C, 72.5; H, 8.7.

Essentially the same result was obtained on oxidation of **11** with Sarett reagent.

Formate of 1-Hydroxy-4-(2-furyl)-1,3-butadiene (16). 6-(2-Furyl)-2,7-dioxabicyclo[3.2.0]hept-3-ene (**7**, 1 g) was chromatographed on a silica gel (Merck) column in a mixture of light petroleum (bp 60–80 °C) and benzene (10:3 v/v). The main fraction (0.63 g) was distilled at 80 °C (0.02 Torr): IR 1730, 1640, 1625, 1555, 1220, 1150, 970, 925, 885, and 738 cm^{-1}; ^{1}H NMR (CCl_4) δ 8.12 (s, 1 H, HCOO–), 5.43–7.53 (m, 7 H, vinylic and furan H); UV (cyclohexane) λ_{max} 293 nm (ϵ 36 100), 304.5 (45 500), and 317.5 (34 200). Anal. Calcd for $C_9H_8O_3$: C, 65.9; H, 4.9. Found: C, 65.8; H, 4.8.

Registry No.—**1,** 7555-25-1; **2,** 61063-39-6; **3,** 61063-40-9; **4,** 61063-41-0; **5,** 1915-16-8; **6,** 61063-42-1; **7,** 7555-27-3; **8,** 13129-26-5; **9,** 61063-43-2; **10,** 61063-44-3; **11,** 60122-21-6; **12,** 40358-49-4; **13,** 61063-45-4; **13** 1,2-*O*-isopropylidene derivative, 61063-46-5; **14,** 498-60-2; **15,** 553-84-4; **16,** 61063-47-6; *n*-butyl glyoxylate, 6295-06-3; furan, 110-00-9; 4-methylpentanal, 1119-16-0; diethyl ketomalonate, 609-09-6; acetone, 67-64-1.

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Anodic and Chemical Oxidation of 1-Benzyl-3-isochromanone and 1-Benzyl-1,4-dihydro-3(2*H*)-isoquinolone Derivatives

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Electrochemical oxidation is a useful method for biaryl coupling of phenols and phenol eithers. These laboratory reactions offer attractive synthetic procedures that parallel a wide range of important biosynthetic processes. Simple me-