133–135° (760 mm). Glc analysis of the product on column A showed the product to be >99% pure: ir (neat) 6.02 (conjugated C=O), 6.14 mμ (C=C); nmr δ 10.05 (d, 1 H, aldehydic proton), 5.92 (d, 1 H, olefinic), 2.17 (d, 3 H, J = 1 Hz, methyl), 1.98 (d, 3 H, J = 1 Hz, methyl).

2-Bromomethyl-1,3-butadiene (4a). This compound was prepared by the method of Krug and Yen[7] in 18% over-all yield. Glc analysis on column B showed the product to be 90% pure: ir (neat, glc pure) 6.28 (conjugated C=C), 11.05 mμ (olefinic C–H bend); nmr δ 6.42 (dd, 1 H, J = 17.5, 11.0 Hz, olefinic), 5.16–5.66 (m, 4 H, olefinic), 4.12 (s, 2 H, CH_2); mass spectrum m/e 146, 148 (M^+), 41, base peak ($C_3H_5^+$), 67 ($M^+ - Br$).

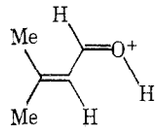
3-Methyl-3,4-oxido-1-butene (5). This epoxide was prepared according to a modification of the procedure of Reist, Junga, and Baker.[8] Isoprene (76.1 g, 1.12 mol) was emulsified by rapid stirring in 250 ml of water and the emulsion was cooled to 0°. *N*-Bromosuccinimide (200 g, 1.12 mol) was added slowly over a period of 0.5 hr and stirred for an additional 3 hr at 0°, and the organic phase was separated, combined with an ether extract of the aqueous phase, and dried ($MgSO_4$). Removal of solvent under reduced pressure gave a yellow oil containing crystals of succinimide which were removed by filtration; yield 160 g (87%) of a mixture of bromohydrins which was not further characterized.

The total bromohydrin product (160 g) was added over a 20-min period to 300 g of a rapidly stirred solution of 30% aqueous sodium hydroxide at 0°, and was stirred for an additional 2 hr at 0°. The organic phase was removed, combined with an ether extract of the aqueous layer, dried ($MgSO_4$), and fractionally distilled. A fraction (32.5 g, 34.5% overall yield) boiling at 78.0–82.1° (lit.[8] bp 79–82°) contained the desired epoxide **5**: nmr (CCl_4) δ 1.35 (s, 3 H), 2.58 (dd, J = 10.0, 6.0 Hz, 2 H), 4.98–5.80 (m, 3 H, olefinic).

2-Hydroxymethyl-1,3-butadiene (4b). Lithium diisopropylamide (18.0 g, 0.168 mol) was dissolved in 300 ml of anhydrous ether, and the epoxide **5** (11.0 g, 0.130 mol) was added over a 10-min period. After reflux had ceased, the solution was cooled to room temperature and poured into 200 ml of 2.0 M HCl. The organic layer was isolated, washed with 5% sodium bicarbonate, and dried ($MgSO_4$). Solvent was removed under vacuum to give 8.3 g (0.099 mol, 76% yield) of the desired alcohol **4b** as a brown oil. This material was used without purification, because its purification is difficult. However, distillation from 0.5 g of hydroquinone gave 3.3 g (0.039 mol, 30% yield) of **4b**, bp 69° (35 mm), as a clear liquid. Glc analysis on column C showed the product to be 99% pure, and its spectroscopic properties (nmr) were identical with those of a sample prepared from 2-bromomethyl-1,3-butadiene (**4a**) by the method of Thomas.[11]

2-Bromomethyl-1,3-butadiene (4a) from 2-Hydroxymethyl-1,3-butadiene (4b). The alcohol **4b** (2.0 g, 0.0238 mol) was dissolved in 50 ml of ether and cooled in an ice–salt bath. Phosphorus tribromide (2.16 g, 0.008 mol) was added dropwise over a 20-min period; the reaction mixture was then stirred in the absence of light at ice–salt temperatures for 30 min and then for 2 hr at 25°. The organic layer was extracted with 100 ml of 5% bicarbonate solution and dried ($MgSO_4$), and the solvent was removed to give 1.5 g (0.0102 mol, 43% yield) of the bromide **4a**. This material was 97% pure by glc analysis (column C) and had the same spectroscopic properties (nmr, ir) as the material prepared by the method of Krug and Yen[7] (see above).

2-Methyl-6-methylene-2,7-octadien-4-ol (1). To 30 ml of dry THF was added 2.43 g (0.037 mol) of zinc (99% pure, dried under vacuum over P_2O_5), 4.16 g (0.026 mol based on 90% purity by glc) of **4a**, and 2.36 g (0.028 mol) of **3c**. Compounds **4a** and **3c** had been dried overnight over molecular sieves. The mixture was refluxed with stirring for 4 hr (oil bath at 68°), cooled to room temperature, and hydrolyzed by addition to a stirred mixture of ether and water. The salts were filtered, and the ether layer was washed once with 25 ml of H_2O and transferred to a flask containing 4A molecular sieves. Salt was added to the combined water layers and this layer was extracted with 50 ml of ether. The ether extracts were combined, dried for 36 hr over 4A molecular sieves, and concentrated, and the remaining traces of solvent were removed in a micro distillation apparatus at room temperature by slowly reducing the pressure from 760 to 2 mm. The remaining oil was warmed to 30° and the pressure was reduced to 0.15 mm. The temperature of the oil bath was slowly increased. The product was collected in an ice-cooled trap, yield 2.57 g (65%) of **1**: bp 54–59° (0.15 mm); ir (CCl_4) 3605 (OH), 3085 (C=C), 901 cm^{-1} (olefinic C–H bend); nmr δ 6.41 (dd, 1 H, J = 18, 9 Hz, olefinic), 5.36–4.90 (m, 5 H, olefinic protons), 4.52 (m, 1 H, methine proton), 1.74 (d, 3 H, J = 1 Hz, CH_3), 1.69 (d, 3 H, J = 1 Hz, CH_3), 1.56 (s, 1 H, OH); mass spectrum m/e 152 (M^+), 85, base peak.



These spectra were identical with those of an authentic sample of **1** obtained from Chemical Samples Co. Glc analysis of a sample of distilled **1** on column B (column temperature 140°, injection temperature 140°) showed the sample to be >95% pure.

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Registry No.—**1**, 14434-41-4; **3a**, 3350-78-5; **3b**, 556-82-1; **3c**, 107-86-8; **4a**, 23691-13-6; **4b**, 13429-21-5; **5**, 1838-94-4; 3-methyl-2-butenoic acid, 541-47-9; isoprene, 78-79-5; *N*-bromosuccinimide, 128-08-5.

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A Practical Synthesis of α-Methylene-γ-butyrolactone

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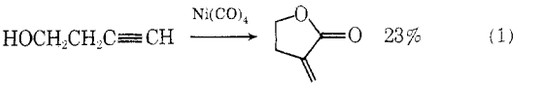
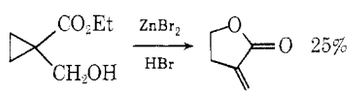
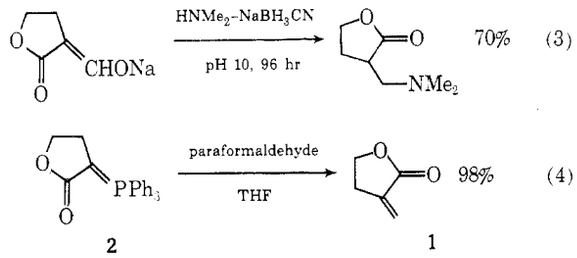
The unsubstituted α-methylene-γ-butyrolactone **1** was isolated by hydrolysis of a glycosidic substance occuring in *Erythronium americanum*.[1] More recently a fungitoxic substance identified as **1** has been isolated from tulips.[2] The structure of **1** has been confirmed by spectral data and synthesis. The primary interest in **1** stems from the presence of the α-methylene-γ-butyrolactone ring system in many natural products of biological interest[3] and the need for new efficient synthetic methods for the introduction of the α-methylene unit from lactone precursors.[4] Previous syntheses of **1** have involved as the key step (a) the reaction of a β,γ-acetylenic carbinol with nickel carbonyl (eq 1),[5] (b) the zinc bromide treatment of ethyl 1-hydroxymethylcyclopropanecarboxylate in hydrobromic acid (eq 2),[6] and (c) the reductive animation of an α-formyl lactone (eq 3).[4f]



(1)



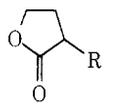
(2)



2 1

These approaches either suffer from low yields or require tedious, long chemical operations.[7] We wish to report a practical synthesis of α-methylene-γ-butyrolactone which employs as the key step a previously unreported method for the introduction of the α-methylene unit. We have observed that γ-butyrolactonylidene triphenylphosphorane (2) reacts with paraformaldehyde in refluxing anhydrous tetrahydrofuran, providing a near-quantitative yield of α-methylene-γ-butyrolactone (1) (eq 4).[8,9]

The required phosphorane 2 is readily available from the corresponding phosphonium bromide 3c in yields of 85–95% (crystalline) upon treatment of 3c with sodium carbonate in aqueous methanol.[10] The phosphonium salt 3c is obtained by treatment of α-bromo-γ-butyrolactone (3b) with triphenylphosphine in refluxing tetrahydrofuran.[10] Yields for this reaction are 40–50% of crystalline material. Attempts to brominate[11] the lithium enolate[12] of 3a at low temperature have resulted in disappointingly low yields (20–30%) of 3b. However, the classical method of Price and Judge[13] provides reproducible yields (55%) of 3b which can be carried out on a very large scale.



3a, R = H
b, R = Br
c, R = $\overset{+}{P}Ph_3Br^-$

The synthesis of 1 *via* readily available crystalline intermediates represents the most convenient route to 1 in comparison with previously reported syntheses. Furthermore, it permits large-scale production and facile isotopic labeling of the α-methylene unit for biochemical studies. We believe that the present method offers some obvious advantages over the existing methods for the preparation of α-methylene-γ-butyrolactone.

Experimental Section[14]

α-Methylene-γ-butyrolactone. A suspension of 3.46 g (0.01 mol) of α-(γ-butyrolactonylidene)triphenylphosphorane[10] and 0.6 g (0.02 mol) of paraformaldehyde in 150 ml of freshly distilled tetrahydrofuran under an atmosphere of nitrogen was heated at gentle reflux. After 2.5 hr, the contents of the flask were cooled to room temperature and the solvent was removed on a rotary evaporator, reducing the total volume of the reaction mixture by two-thirds. After addition of pentane, the contents of the flask were passed through a very short column of silica gel to remove triphenylphosphine oxide. After removal of the solvent *in vacuo*, there was obtained 974 mg of α-methylene-γ-butyrolactone (98% yield) which was pure by nmr analysis. Vacuum distillation afforded an analytical sample of 1: bp 60–53° (0.45 mm); ir ($CHCl_3$) 1765 (C=O) and 1670 cm^{-1} (=CH_2); nmr (CCl_4) 6.08 (t, J = 3 Hz, 1 H), 5.63 (t, J = 3 Hz, 1 H), 4.30 (t, J = 7 Hz, 2 H), 2.97 (m, 2 H); M^+ m/e 98. Ir and nmr spectra of 1 were identical with those previously reported for the natural product.[1,2] *Anal.* Calcd for $C_5H_6O_2$: C, 61.21; H, 6.17. Found: C, 61.09; H, 6.10.

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Registry No.—1, 547-65-9; 2, 34932-07-5.

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i ii

at −78°) with bromine in 60–70% isolated yields: P. A. Grieco and J. J. Reap, unpublished results.
(12) We have demonstrated that lactone enolates undergo high-yield α-hydroxymethylation,[4a,b] α-carboxylation,[4c] α-phenylselenenylation,[4d] and α-phenylsulfenylation.[4e]
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New Routes for the Degradation of the Lanosterol Side Chain

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Recent reports[2,3a] describe the degradation of the lanosterol side chain with overall yields of approximately 4–10%. Other steroid side-chain degradations have also been reported,[4,5] but none of them seem to give particularly attractive yields. In view of this, we decided that it would be of considerable interest to apply a newly developed method of degradation[6] to these substrates, in the hope of improving the yields. This method, originally applied to the side-chain degradation of cholic acids,[6] utilizes as the key step a Norrish type II photoelimination reaction of a phenyl ketone which is easily obtained by means of an established rearrangement procedure.[7] Application of this photoelimination method[6] to lanosterol (Scheme I) resulted in a 23% overall yield.

Similarly, the modification of the original Briggs procedure[2] (Scheme II) gave a 15% overall yield, *i.e.*, approximately three times that obtained by the original method. Thus it appears that the photolysis of ketonic in-