α-Methoxy-β-methyl-γ-ethyl-$\Delta^{\alpha\beta}$-butenolide-γ-carboxylic Acid Methyl Ester (2d).—A solution of 500 mg (0.0028 mole) of **2a** in 30 ml of ether was gradually added with swirling to an ether solution containing 360 mg (50% excess) of diazomethane. After standing for 3 hr the excess diazomethane was decomposed with 4 drops of glacial acetic acid. The ethereal solution was then washed with sodium bicarbonate solution to remove the acetic acid. The ether was dried, filtered, and evaporated leaving 510 mg of the enol ether methyl ester (**2d**). An analytical sample was isolated by preparative glpc: infrared (CCl_4), 1780 (γ-lactone), 1740 (ester CO) and 1680 cm^{-1} (C=C); nmr, 3 H singlet δ 3.97 (enol $-OCH_3$), 3 H singlet 3.74 (ester $-OCH_3$), 2 H multiplet 1.99 (methylene), 3 H singlet 1.80 (vinyl methyl) and 3 H triplet 0.87 (methyl); ultraviolet, λ_{max} 234 mμ (ε 7540).

Anal. Calcd for $C_{10}H_{14}O_5$: C, 56.07; H, 6.59. Found: C, 56.21; H, 6.48.

α-Methoxy-γ-methyl-$\Delta^{\alpha,\beta}$-butenolide-γ-carboxylic Acid Methyl Ester (3b).—An ethereal solution of 350 mg (50% excess) of diazomethane was gradually added with shaking to a solution of 400 mg (0.0025 mole) of **3a** in 25 ml of ether until the yellow color persisted. The reaction mixture stood for 3 hr at room temperature after which time it was washed with saturated sodium bicarbonate solution. The ether was dried, filtered, and evaporated leaving 420 mg of a yellow oil. An analytical sample was isolated by preparative glpc: infrared (CCl_4), 1795 (γ-lactone), 1745 (ester CO) and 1660 cm^{-1} (C=C); ultraviolet, λ_{max} 230 mμ (ε 4740); nmr, 1 H singlet δ 6.12 (vinyl H), 3 H singlet 3.72 (enol $-OCH_3$), 3 H singlet 3.67 (ester $-OCH_3$), and 3 H singlet 1.61 (methyl).

Registry No.—**1**, 15023-79-7; **1** 2,4-dinitrophenylhydrazone, 15023-80-0; **2a**, 15023-81-1; **2b**, 15023-82-2; **2c**, 15023-83-3; **2d**, 15023-84-4; **3b**, 15023-85-5; di-*t*-butyl succinate, 926-26-1; benzyl *t*-butyl succinate, 15026-16-1; *t*-butyl hydrogen succinate, 15026-17-2.

Methylation of 10-Methyl-1(9)-octal-2-ones by Organocopper Reagents

James A. Marshall[1] and Heide Roebke[2]

Department of Chemistry, Northwestern University, Evanston, Illinois 60201

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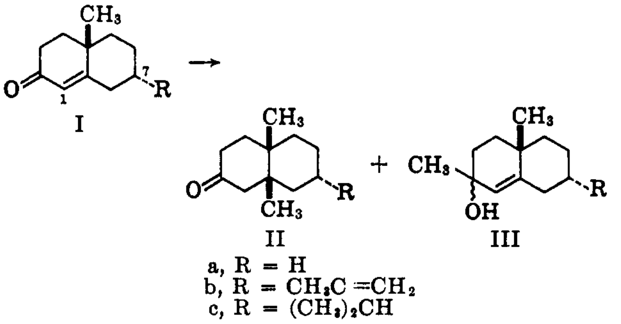
In connection with a project aimed at the synthesis of the naturally occurring sesquiterpene valeranone, we examined the stereochemistry of 1,4 additions to 10-methyl-1(9)-octal-2-ones (I) by methylmagnesium iodide in the presence of cuprous salts.[3] The parent compound Ia afforded the *cis*-decalone IIa as the sole 1,4 adduct, whereas the 7α-substituted homologs Ib and Ic gave only the 1,2 adducts IIIb and IIIc.

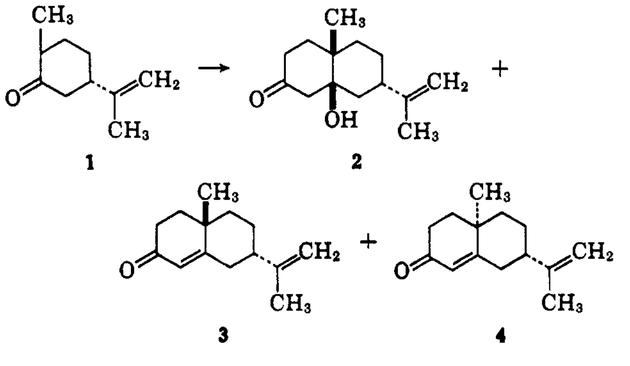


a, R = H
b, R = $CH_2C{=}CH_2$
c, R = $(CH_3)_2CH$

These findings suggested to us that with Ib and Ic, unfavorable interactions between C-1 and the respective C-7 substituent increased the energy of the transition state for 1,4 addition relative to that for the competing 1,2 addition reaction. We now describe some additional studies along these lines which reinforce this viewpoint.

Octalone **4** has an equatorial isopropenyl grouping at C-7 and, according to the aforementioned postulate, would be expected to undergo the 1,4 addition reaction. This octalone was prepared *via* Robinson annelation of (−)-dihydrocarvone and methyl vinyl ketone.[3] As previously noted,[3,4] this reaction affords principally the crystalline ketol **2** with *trans*-oriented methyl and isopropenyl groups. However, the material remaining after collection of the crystalline product contained a fair amount of octalone **4** and, presumably, its ketol and dione precursors. Treatment of this residue with refluxing aqueous base led to a mixture of the isomeric octalones **3** and **4** with the former predominating 2.5 to 1. The latter isomer was obtained *via* fractional crystallization of the semicarbazone derivatives followed by preparative gas chromatography and column elution chromatography of the ketonic mixture regenerated from the enriched semicarbazone fractions.

Having previously found that octalone **3** gives no conjugate methylation products with the cupric acetate–methylmagnesium iodide reagent of Birch and Smith,[5] we felt that we could carry out our present studies on mixtures of octalones **3** and **4** with the expectation of obtaining 1,4 adducts related only to **4**.



This was indeed the case. Decalone **5** could be isolated in 16–21% yield, based on octalone **4**, from such addition reactions. The by-products of these reactions consisted largely of the expected tertiary alcohols which were readily separated from decalone **5** by column chromatography. Lithium dimethylcopper, a reagent recently employed by House and coworkers[6] for similar 1,4 additions, afforded decalone **5** in 40% yield. In this case, a substantial portion of the octalone **3** initially present was recovered unchanged and a small amount of what appears to be the 1,4 adduct of octalone **3** was detected by gas chromatography. The recovery of ketonic materials is concordant with the results of House, *et al.*,[6] who found that lithium dimethylcopper adds only slowly to ketonic carbonyl groups.

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(1) Fellow of the Alfred P. Sloan Foundation, 1966–1968.

(2) National Institutes of Health Predoctoral Fellow, Institute of General Medical Sciences, 1965–1968.

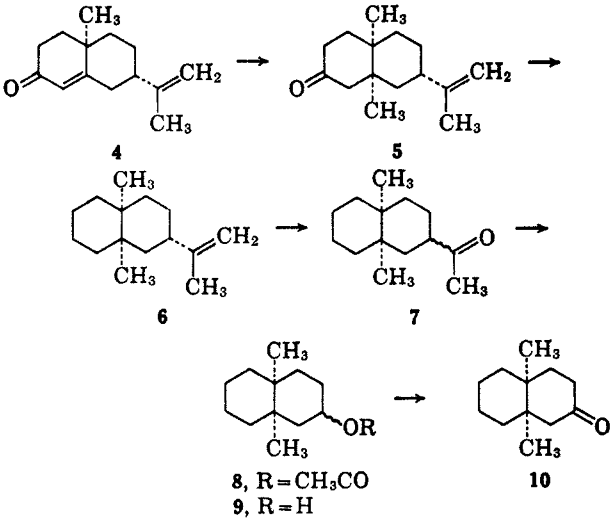
(3) J. A. Marshall, W. I. Fanta, and H. Roebke, *J. Org. Chem.*, **31**, 1016 (1966).

(4) *Cf.* D. W. Theobald, *Tetrahedron Letters*, No. 9, 969 (1966).

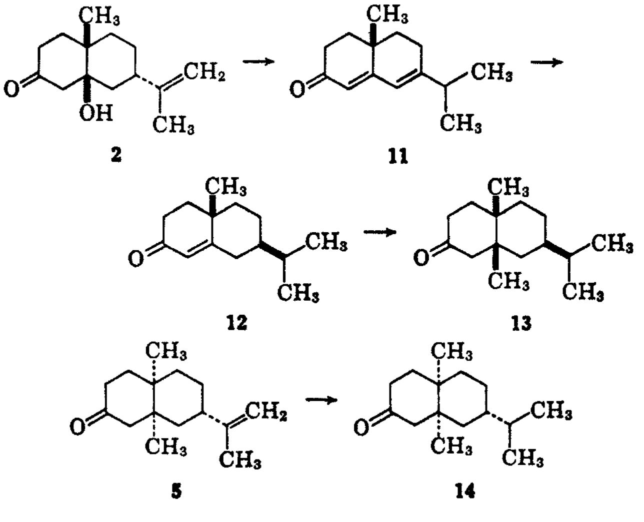
(5) A. J. Birch and M. Smith, *Proc. Chem. Soc.*, 356 (1962).

(6) H. O. House, W. L. Respess, and G. M. Whitesides, *J. Org. Chem.*, **31**, 3128 (1966).

The stereochemistry of decalone **5** was established through its degradation to *cis*-9,10-dimethyldecalone **10** and comparison with racemic material of established structure.[3] The degradation, which is outlined below, proceeded *via* Wolff-Kishner reduction of decalone **5** to the isopropenyldecalin **6** followed directly by ozonation. A 40:60 mixture of epimeric ketones **7** was thus obtained after chromatography on basic alumina. This mixture was treated with *m*-chloroperoxybenzoic acid affording a 1:1 mixture of epimeric acetates **8** in 80% yield along with one of the ketone **7** epimers in 20% yield. Apparently, the recovered ketone is oxidized less readily than its epimeric counterpart. Saponification of the 1:1 mixture of acetates followed by oxidation of the resulting alcohol mixture (**9**) afforded the decalone **10**. The infrared and nmr spectra and the gas chromatographic retention time of this substance were identical with the corresponding properties of the racemic decalone previously prepared from octalone Ia. Like its racemic counterpart, decalone **10** exhibited a wide melting range, even after recrystallization and sublimation. We attribute this behavior to polymorphism since the material appeared homogeneous by other criteria.



We next examined the reaction of lithium dimethylcopper with the isopropyloctalone **12**. This material was prepared from the crystalline ketol **2** which afforded the conjugated dienone **11** upon treatment with *p*-toluenesulfonic acid in refluxing toluene. Selective reduction with lithium in ammonia containing a small amount of ethanol, followed by chromatographic purification of the resulting ketonic mixture afforded octalone **12**. This material, like its unsaturated counterpart **4**, smoothly afforded a 1,4 adduct (decalone **13**) upon treatment with lithium dimethylcopper. The structure of this 1,4 adduct was ascertained through hydrogenation of the isopropenyldecalone **5** whereupon a substance with identical infrared and nmr spectra was obtained.



These studies show that the orientation of an alkyl substituent at C-7 in octalones such as I controls the conjugate methylation of these compounds. Axial groups block the 1,4 addition and equatorial groups exert a negligible effect. Since octalones Ia, **4**, and **12** all lead to *cis*-fused addition products, steric interactions between C-1 and C-7 in the transition state rather than steric hindrance to the attacking reagent would appear to account best for the observed reactivity differences between Ib and **4** and Ic and **12**.

Experimental Section[7]

10α-Methyl-7α-isopropenyl-1(9)-octal-2-one (4).—A solution containing 6.25 ml of 3 *M* ethanolic sodium ethoxide in 171 g of (−)-dihydrocarvone (**1**) was maintained at −10 to −20° while a solution of 39.5 g of methyl vinyl ketone in 171 g of (−)-dihydrocarvone was added dropwise with stirring over 6 hr.[7a] After an additional 6 hr at −10 to −20°, the product was isolated with ether[7b] and distilled affording three fractions: (1) 99 g, bp 87 (5 mm)–62° (0.1 mm), mainly recovered (−)-dihydrocarvone (**1**); (2) 1 g, bp 62° (0.1 mm)–110° (0.15 mm); (3) 81 g, bp 110–145° (0.15 mm), a mixture of ketol **2** and octalones **3** and **4**.

Fraction 3 was allowed to crystallize from 125 ml of hexane containing a small amount of ether whereupon 33.5 g (27%) of crystalline ketol **2**, mp 103–104° (lit.[3] mp 106–107°) was secured. The solvent was removed from the mother liquor and the residue (56 g) was heated at reflux with 800 ml of 10% aqueous potassium hydroxide for 10 hr.[7a] The product was isolated with ether[7b] and distilled affording 42.4 g of material, bp 90° (0.04 mm)–93° (0.02 mm), containing 5% of (−)-dihydrocarvone (**1**), 57% of octalone **3**, and 38% of octalone **4** according to the gas chromatogram.[8]

A portion of this mixture was converted to the semicarbazone derivative which was fractionally recrystallized from methanol–ethyl acetate. The early fractions, mp 204.5–205.5° dec, consisted of the 10β-methyl-7α-isopropenyloctalone **3** derivative.

Anal. Calcd for $C_{15}H_{23}N_3O$: C, 68.93; H, 8.87; N, 16.08. Found: C, 69.1; H, 8.9; N, 16.2.

The later fractions consisted largely of the 10α-methyl-7α-isopropenyloctalone **4** derivative. The octalone **4** was secured *via* hydrolysis[9] of the latter semicarbazone fractions and preparative gas chromatography[10] of the resulting mixture of octalones **3** and **4**, enriched in the latter isomer. In this manner octalone **4** of 92% purity could be isolated. Careful column elution chromatography of the aforementioned material on silica gel afforded a sample containing 98% of octalone **4**: bp 80° (bath temperature) at 0.1 mm; $\lambda_{\max}^{\text{film}}$ 3.24 (vinyl H), 5.98 (CO), 6.19 (C=C), 8.02, 8.30, 10.31, 11.20, and 12.93 μ; $\delta_{\text{TMS}}^{\text{CCl}_4}$ 5.73 (C-1 H), 4.82 ($C{=}CH_2$), 1.78 (vinyl CH_3), and 1.27 ppm (C-10 CH_3); $\lambda_{\max}^{\text{EtOH}}$ 241.5 mμ (ε 15,000). The semi-

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[7] (a) The apparatus described by W. S. Johnson and W. P. Schneider [*Org. Syn.*, **30**, 18 (1950)] was used to maintain a nitrogen atmosphere over reaction mixtures. (b) The isolation procedure consisted of thoroughly extracting the reaction mixture with the specified solvent, washing the combined extracts with saturated brine, and drying the organic phase over anhydrous magnesium sulfate. (c) Melting points were determined on a Fisher-Johns hot stage. (d) Microanalyses were performed by Micro-Tech Laboratories, Inc., Skokie, Ill.

[8] A 0.25 in. × 10 ft column of 10% Ucon 75H 90,000 Polar on 60–80 Gas Pack W was used at 197° with a helium flow of 100 cc/min.

[9] The procedure of A. St. Pfau and Pl. A. Plattner, *Helv. Chim. Acta.* **22**, 202 (1939).

[10] A 3/8 in. × 18 ft column of 12% D.C. 550 Silicone Oil on 60–80 Chromosorb W was used at 205°.

carbazone derivative exhibited mp 202.5–203° dec after two recrystallizations from methanol and one recrystallization from ethyl acetate.

Anal. Calcd for $C_{13}H_{23}N_3O$: C, 68.93; H, 8.87; N, 16.08. Found: C, 69.0; H, 8.7; N, 16.0.

9α,10α-Dimethyl-7α-isopropenyl-2-decalone (5). A. Using Methylmagnesium Iodide–Cupric Acetate.—The Grignard reagent prepared from 1.08 g of magnesium turnings and 7.0 g of methyl iodide in 75 ml of ether was maintained at −10° while a solution of 1.97 g of octalones **3** and **4** (6% of an impurity, 55% of **3**, and 39% of **4**) and 0.45 g of cupric acetate monohydrate in 35 ml of tetrahydrofuran was added with rapid stirring over 0.5 hr.[7a] The yellow slurry was allowed to reach room temperature over 2 hr and refluxed for 15 min. Aqueous ammonium chloride was added and the product was isolated with ether[7b] and chromatographed on 150 g of alumina. Elution with benzene afforded 0.17 g of material, bp 80° (bath temperature) at 0.05 mm, which according to the gas chromatogram[11] contained 76% of decalone **5** and 24% of a substance arising from an impurity in the starting material.[12]

Preparative gas chromatography[13] was employed to purify ketone **5**: $\lambda_{\max}^{\mathrm{KBr}}$ 5.85 (CO), 7.99, 8.77, 11.22, and 11.34 μ; $\delta_{\mathrm{TMS}}^{\mathrm{CCl_4}}$ 4.78 (C=CH₂), 1.73 (vinyl CH₃ doublet, *J* = 1 Hz), 1.00 and 0.87 ppm (angular CH₃'s). This material was recrystallized twice from pentane affording white plates, mp 51–52°.

Anal. Calcd for $C_{15}H_{24}O$: C, 81.76; H, 10.98. Found: C, 81.6; H, 10.8.

B. Using Methyllithium–Cuprous Iodide.—A solution of lithium dimethylcopper was prepared from 15.6 ml of 1.6 *N* methyllithium in ether, and 2.4 g of cuprous iodide in 35 ml of ether according to House and coworkers.[6] This solution was maintained at 0° while 1.29 g of octalone (a mixture containing 35% of **3** and 65% of **4**) was added.[7a] After 1 hr at 0° the yellow mixture was poured into aqueous ammonium chloride and the product was isolated with ether.[7b] Analysis by gas chromatography indicated the presence of decalone **5**, a small amount (*ca.* 3%) of what appears to be the 1,4 adduct of octalone **3**, unreacted octalone **3**, and alcoholic materials. This mixture was chromatographed on 120 g of alumina. The material eluted with benzene was recrystallized from pentane at −78° affording 0.57 g of decalone **5**, mp 51–52°, identified by comparison of its infrared spectrum and gas chromatographic retention time with those of the material prepared in part A.

9α,10α-Dimethyl-2-acetyldecalin (7).—A 0.56-g sample of decalone **5**, 0.5 g of potassium hydroxide, and 0.45 ml of hydrazine hydrate (85% in water) was stirred at 120° for 12 hr and at reflux for 3 hr.[7a] The product was isolated with pentane[7b] and filtered through 50 g of alumina (Woelm, activity I). The material eluted with pentane (0.18 g) was dissolved in 30 ml of 1:1 methylene chloride–pyridine, cooled in a Dry Ice-acetone bath, and treated with excess ozone. Formaldehyde (0.7 ml) was added, the mixture was allowed to stand at room temperature for 3 hr, and the product was isolated with ether[7b] and chromatographed on 75 g of alumina. Elution with benzene afforded 106 mg of ketone **7**, a 60:40 mixture of epimers according to the gas chromatogram: $\lambda_{\max}^{\mathrm{film}}$ 5.85 (CO), 7.38, 8.46, and 8.59 μ; $\delta_{\mathrm{TMS}}^{\mathrm{CCl_4}}$ 2.00 (CH₃CO), 0.88, and 0.90 ppm (angular CH₃'s). The analytical sample, bp 37° (bath temperature) at 0.05 mm, was secured after two successive distillations.

Anal. Calcd for $C_{14}H_{24}O$: C, 80.71; H, 11.61. Found: C, 80.6; H, 11.5.

9α,10α-Dimethyl-2-decalone (9).—A solution containing 90 mg of ketone **7** (a 60:40 mixture of epimers) and 200 mg of *m*-chloroperoxybenzoic acid in 3 ml of 1:1 chloroform–methylene chloride was stirred at room temperature for 45 hr. The mixture was poured into ether and washed with 5% aqueous sodium hydroxide, saturated brine, and dried over anhydrous magnesium sulfate. The material obtained after removal of the solvent contained 20% of one epimer of the starting ketone **7**, and 80% of a 1:1 epimeric mixture of acetate **8**. Chromatography on 20 g of silica gel afforded 60 mg of acetate **8** as a 1:1 mixture of epimers eluted with benzene: $\lambda_{\max}^{\mathrm{film}}$ 5.76 (CO), 7.31, 8.02, and 9.68 μ; $\delta_{\mathrm{TMS}}^{\mathrm{CCl_4}}$ 1.94 (CH₃CO), 0.97, 0.93, and 0.89 ppm (angular CH₃'s).

The above mixture of acetates was saponified with 1 ml of 5% sodium hydroxide in 1:1 ethanol–water.[7a] The solution was heated to boiling on a steam bath and allowed to reach room temperature over a 2-hr period. The product was isolated with ether[7b] affording 49 mg of semisolid decalol **9**: $\lambda_{\max}^{\mathrm{film}}$ 3.04 (OH), 9.44, 9.61, 9.90, and 10.72 μ; $\delta_{\mathrm{TMS}}^{\mathrm{CCl_4}}$ 3.05 (broad >CHOH), 0.90, and 0.87 ppm (angular CH₃'s).

The above decalol was dissolved in 5 ml of acetone, the solution was cooled to 0°, and 0.12 ml of standard chromic acid reagent[14] was slowly added with rapid stirring. After 5 min, the excess reagent was discharged with isopropyl alcohol and the product was isolated with ether.[7b] The material was sublimed twice at 30° (0.05 mm) affording 21 mg of white solid decalone **10**: mp 95–102°; $\lambda_{\max}^{\mathrm{KBr}}$ 5.84 (CO), 7.22, 8.05, 8.55, 8.90, 9.93, 10.57, 12.45, and 13.05 μ; $\delta_{\mathrm{TMS}}^{\mathrm{CCl_4}}$ 1.04 and 0.90 ppm (angular CH₃'s).

Anal. Calcd for $C_{12}H_{20}O$: C, 79.94; H, 11.18. Found: C, 80.1; H, 11.2.

A gas chromatogram[15] of this material showed a single peak. The above spectra were identical with the spectra of a sample of racemic decalone **10**[3] as was the gas chromatographic retention time (peak enhancement).

10β-Methyl-7-isopropyl-1(9),7-hexal-2-one (11).—A solution containing 5 g of 10β-methyl-9β-hydroxy-7α-isopropenyldecal-2-one (**2**)[3] and 140 mg of *p*-toluenesulfonic acid in 210 ml of toluene was refluxed for 96 hr.[7a] After cooling, the brown solution was stirred for 10 min with barium oxide and filtered. The filtrate was distilled at 90° (0.05 mm) affording 4.03 g (89%) of yellow oil which contained 98% of dienone **11** according to the gas chromatogram:[16] $\lambda_{\max}^{\mathrm{film}}$ 6.01 (CO), 6.17, 6.30 (C=C), 7.81, 8.01, 8.22, and 11.10 μ; $\delta_{\mathrm{TMS}}^{\mathrm{CCl_4}}$ 5.92, 5.50 (singlets, two vinyl H), 1.11 (angular CH₃), and 1.06 ppm (isopropyl doublet, *J* = 6 Hz); $\lambda_{\max}^{\mathrm{EtOH}}$ 293 mμ (ε 25,300). The 2,4-dinitrophenylhydrazone derivative had mp 171–172.5° after three recrystallizations from ethanol.

Anal. Calcd for $C_{20}H_{24}N_4O_4$: C, 62.49; H, 6.29; N, 14.57. Found: C, 62.3; H, 6.4; N, 14.3.

10β-Methyl-7β-isopropyl-1(9)-octal-2-one (12).—To a solution of 780 mg (111 mmoles) of lithium wire in 1 l. of liquid ammonia was added a solution of 3.9 g (19 mmoles) of 10β-methyl-7-isopropyl-1(9),7-hexal-2-one (**11**) and 3 ml of ethanol in 50 ml of ether over 10 min. The mixture was stirred an additional 20 min and then 15 g of ammonium chloride was added. After the ammonia had evaporated, the residue was taken up in brine and the product was isolated with ether[7b] affording a yellow oil which contained alcohol, a small amount of saturated ketone, and conjugated enone according to the infrared spectrum. This material was chromatographed on 400 ml of alumina. Elution with hexane and 25% benzene in hexane afforded olefinic material and a small amount of saturated ketone. Elution with 50% benzene and benzene afforded 1.2 g (30%) of octalone **12**: bp 65° (bath temperature) at 0.05 mm; $\lambda_{\max}^{\mathrm{film}}$ 5.98 (CO), 6.18 (C=C), 7.51, 8.00, 8.27, and 11.62 μ; $\delta_{\mathrm{TMS}}^{\mathrm{CCl_4}}$ 5.62 (vinyl H), 1.21 (angular CH₃) and 0.93 ppm (isopropyl doublet, *J* = 6 Hz); $\lambda_{\max}^{\mathrm{EtOH}}$ 239 mμ (ε 15,600). The 2,4-dinitrophenylhydrazone had mp 154.5–155.5° after three recrystallizations from ethanol.

Anal. Calcd for $C_{20}H_{26}N_4O_4$: C, 62.16; H, 6.78; N, 14.50. Found: C, 62.1; H, 6.8; N, 14.4.

9β,10β-Dimethyl-7β-isopropyldecal-2-one (13).—A solution of lithium dimethylcopper was prepared from 3.91 ml of 1.6 *N* methyllithium in ether and 600 mg of cuprous iodide in 8.5 ml of ether according to House and coworkers.[6] This solution was maintained at 0° while 322 mg (1.58 mmoles) of octalone **12** was added.[7a] After 1 hr at 0° the yellow mixture was poured into aqueous ammonium chloride and the product was isolated with ether[7b] and chromatographed on 40 g of alumina. Elution with 25 and 50% benzene in hexane afforded 215 mg (60%) of white crystals (mp 38.5–40°) after sublimation at 30° (0.05 mm). This material gave a single peak on gas chromatog-

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[11] The Ucon Polar column[3] was employed at 195°.

[12] We have previously shown that octalone **3** gives only 1,2 addition products under the reaction conditions employed in this experiment.[3]

[13] A 0.5 in. × 12 ft column of 20% Carbowax 20M on 60–80 Chromosorb W was employed.

[14] K. Bowden, I. M. Heilbron, E. R. H. Jones, and B. C. L. Weedon, *J. Chem. Soc.*, 39 (1946).

[15] A 0.25 in. × 13 ft column of 20% Carbowax 20M on 60–80 Chromosorb W was employed at 220°.

[16] A 0.25 in. × 6 ft column of 10% DC550 on 60–80 Chromosorb W was used at 180°.

raphy:[17] λ_{max}^{KBr} 5.81 (CO), 6.77, 7.17, 7.70, 7.98, 8.18, 8.68, and 9.81 μ; $\delta_{TMS}^{CCl_4}$ 0.95 (singlet, 6 H) and 0.84 ppm (singlet, 6 H).

Anal. Calcd for $C_{15}H_{26}O$: C, 81.02; H, 11.79. Found: C, 81.2; H, 12.0.

9α,10α-Dimethyl-7α-isopropyldecal-2-one (14).—A solution containing 90 mg of ketone **5** in 5.0 ml of ethanol was stirred with 50 mg of palladium on charcoal in an atmosphere of hydrogen. After 11 ml of gas was taken up, the mixture was filtered and the product was isolated with ether[7b] and sublimed at room temperature (0.05 mm) affording moist white crystals, mp 33-36°, which were 97% pure by vpc.[18] The infrared and nmr spectra were superimposable on those of decalone **13** and the vpc retention times were identical by peak enhancement.

Registry No.—**1**, 15188-30-4; **2**, 4895-25-4; **3**, 5208-62-8; **4**, 13085-23-9; **5**, 15188-34-8; **7**, 15188-35-9; **8**, 15215-81-3; **9**, 15188-36-0; **10**, 15188-37-1; **11**, 5208-63-9; **11** 2,4-dinitrophenylhydrazone, 5208-64-0; **12**, 15188-39-3; **13**, 15188-40-6; **14**, 15188-41-7.

Acknowledgments.—We thank the Public Health Service for a Research Grant (AI-04965, Division of Allergy and Infectious Diseases) and a Predoctoral Fellowship (5-F1-GM-29, 696 to H. R.).

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[17] A 0.25 in. × 15 ft column of 5% Carbowax 20 M on acid-washed DMCS 70-80 Chromosorb G was employed at 190°.

[18] The carbowax column was employed.[17]

Concerning the Kinetics of the Acid-Catalyzed Dehydration of α-Methyl-β-hydroxy-β-arylpropionic Acids[1]

Donald S. Noyce and Sharon K. Brauman

Department of Chemistry, University of California at Berkeley, Berkeley, California 94720

Received August 9, 1967

There has been a great deal of study devoted to the solvolytic behavior of alkyl halides and alkyl sulfonates, as influenced by numerous structural parameters.[2] However, there is somewhat less information regarding structural effects on the rates of E1 elimination. We have previously reported the results of studies of the kinetics of the acid-catalyzed dehydration of a variety of β-hydroxy acids[3-5] and β-hydroxy ketones.[6-9] These studies delineated the sensitivity of the dehydration reaction to electronic effects, and to structural changes at the alcoholic carbon. The present report is concerned with a brief examination of the effect of branching at the carbon β to the alcoholic moiety on the rate of dehydration of hydroxy acids. For this purpose we have examined the rates of dehydration of α-methyl-β-hydroxy-β-arylpropionic acids in moderately concentrated sulfuric acid. In each case the product is the *trans*-α-methylcinnamic acid.

In the solvolysis of tertiary halides chain branching generally leads to a modest increase in reactivity. Studies of the concomitant elimination reaction are somewhat less extensive. It has been reported that in 80% ethanol[10] *t*-butyl chloride gives 16% elimination, *t*-amyl chloride gives 33% elimination,[11] and 2,3-dimethyl-2-chlorobutane gives 62% elimination.[12] These results suggest that branching increases the rate of E1 reactions in aliphatic systems even more than it increases the rate of SN1 reactions. These strain interactions are more fully discussed by Brown and Fletcher.[12]

However, the situation appears to be different for benzyl systems. Baddeley, Chadwick, and Taylor[13,14] have observed that both for secondary and tertiary chlorides, branching reduces the rate of solvolysis. 2-Methyl-1-phenyl-1-chloropropane solvolyzes more slowly than 1-phenyl-1-chloropropane,[13] and 2-phenyl-2-chlorobutane solvolyzes more slowly than cumyl chloride.[14] These authors attributed these changes to steric hindrance to fully developed resonance interaction on ionization. A related situation is that discussed by Curtin.[15] In the study of elimination and rearrangement reactions which prefer a *trans* coplanar arrangement for the transition state, Curtin has observed a decreased rate of reaction for the *cis* isomer, and has attributed this "*cis*" effect to developing crowding in the transition state.

We have measured the rates of dehydration of **1**, **2**, and **3**. The results are given in Table I.

ArCHOHCH(CH_3)COOH
1, Ar = C_6H_5
2, Ar = p-$CH_3C_6H_4$
3, Ar = p-$CH_3OC_6H_4$

TABLE I
RATES OF DEHYDRATION OF
α-METHYL-β-ARYL-β-HYDROXYPROPIONIC ACIDS AT 25.0°

Compd	% H_2SO_4	$-H_0$	10^5k_{obs}, sec^{-1}
1[a]		4.61	0.50[b]
	63.60	4.90	1.10
	68.71	5.60	6.64
	72.66	6.21	32.1
	73.22	6.29	39.3
	75.72	6.66	135
	78.87	7.17	492
2[c]	60.30	4.61	15.0[d]
	61.89	4.79	23.4
	64.08	5.07	52.3
	66.66	5.50	142
	69.01	5.90	366
3[c]	60.30	4.61	1030

[a] In aqueous sulfuric acid. [b] Extrapolated using $\log k + H_0 = -10.60$. [c] In aqueous sulfuric acid containing 5% ethanol. [d] Extrapolated value.

The acid-catalyzed dehydrations of **1**, **2**, and **3** show typical carbonium ion characteristics. The rates increase sharply with increasing sulfuric acid concentration. They are extremely sensitive to the electron-

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