

## Carbonyl-Olefin Reactions. The Cyclization of 3-Isopropenyl-6-oxoheptanoic Acid

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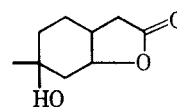
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3-Isopropenyl-6-oxoheptanoic acid (I) is converted slowly on standing or rapidly on heating with a trace of acid into a mixture of *trans*-2,4-dihydroxy-2,4-dimethyl-*trans*-1-acetic acid  $\gamma$ -lactone (V) and *trans*-2,4-dihydroxy-2,4-dimethyl-*cis*-1-acetic acid  $\gamma$ -lactone (VI). The mechanism of the conversion of I into V and VI is briefly discussed. It is suggested that a similar olefin-carbonyl cyclization reaction is involved at one stage in the conversion of pinonic acid, by the action of bromine and hydrochloric acid, into 2,4-dimethylphenylacetic acid.

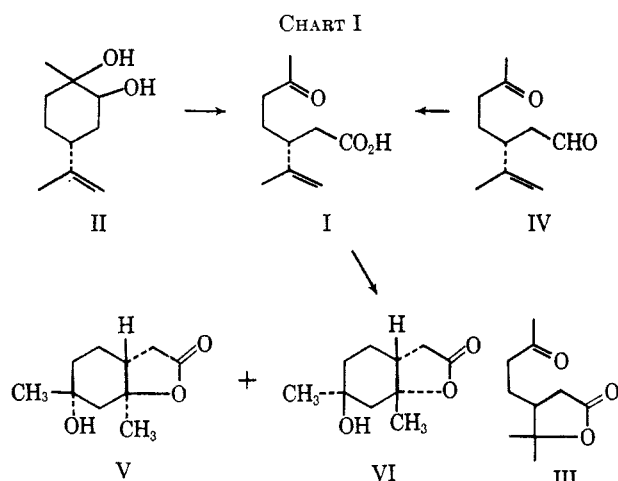
3-Isopropenyl-6-oxoheptanoic acid (I) was desired as a starting material for a projected synthesis<sup>1</sup> of the D-E ring fragment of the triterpene lupeol.<sup>2</sup> Schmidt<sup>3</sup> reported that chromic acid oxidation of 8-*p*-menthene-1,2-diol (II) afforded keto acid I contaminated by a lactone which was alleged to be homoterpenyl methyl ketone (III). In our hands, the keto acid I could not be isolated in high yield by this method and was found to be contaminated with lactones V and VI and not homoterpenyl methyl ketone (III) as originally suggested.<sup>3</sup> Keto acid I was readily obtained in high yield by silver oxide oxidation of 3-isopropenyl-6-oxo-1-heptanal (IV).<sup>4</sup> The pure keto acid I is a liquid which is converted slowly on standing or rapidly on heating with a trace of acid into a mixture of crystalline hydroxy lactones V and VI (Chart I). The de-

were rich in lactone V; later fractions were rich in lactone VI.

A close structural relationship between V and VI was inferred from the relative similarity of their infrared spectra. The presence of  $\gamma$ -lactone rings and monomeric hydroxyl groups in both isomers was confirmed by absorption at 5.70 and 2.76 and 2.86  $\mu$  (sh), respectively. Two methyl groups and the absence of olefinic protons was dictated by their nmr spectra. These data and mechanistic considerations led to the conclusion that the lactones were best represented by gross structure A. The conversion of lactones V and



A



VI into 2,4-dimethylphenylacetic acid by the action of bromine and hydrochloric acid<sup>5</sup> provided unequivocal evidence for the carbon skeleton represented in structure A.

The stereochemistry of each hydroxy lactone was established on the basis of the following chemical and spectral considerations. Dehydration of hydroxy lactone V with phosphorus oxychloride in pyridine gave an unsaturated lactone VII (Chart II) which displayed a broad nmr signal at 5.47 ppm characteristic of a single olefinic proton. Dehydration of hydroxy lactone VI using the same conditions led to an isomeric unsaturated lactone VIII which also exhibited a signal at 5.32 ppm characteristic of a lone olefinic proton. Gas chromatographic analysis of each crude dehydration product demonstrated the absence of other isomers. The exclusive formation of endocyclic olefins from V and VI suggests the presence of axial hydroxyl groups in both isomers.<sup>6</sup>

Conclusive evidence for the location of the double bonds in each unsaturated lactone were provided by their behavior toward catalytic hydrogenation. Hydrogenation of VII gave dihydro lactones IX and X in a ratio of 64:36, whereas lactone VIII afforded, beside 42% of dihydro lactones XI and XII in 80:20 ratio, 58% of a C<sub>10</sub>H<sub>18</sub>O<sub>2</sub> acid, XIII.

termination of the structure and stereochemistry of these lactones and a discussion of the mode of their formation serve as a basis for this communication.

The hydroxy lactones V and VI were best separated by careful fractional crystallization and "hand-picking" of crystals. In this manner there were obtained two pure solids, mp 145–146° (V) and mp 119–120° (VI), in addition to a mixture, mp 100–117°, whose infrared spectrum showed only those peaks present in V and VI. Elution chromatography of the crude lactone mixture on neutral or acid-washed alumina gave only partial separation of the lactones; early fractions

(1) D. Chan, Ph.D. Thesis, Purdue University, Jan 1965.

(2) J. Simonsen and W. C. J. Ross, "The Terpenes," Vol. IV, University Press, 1957, p 328.

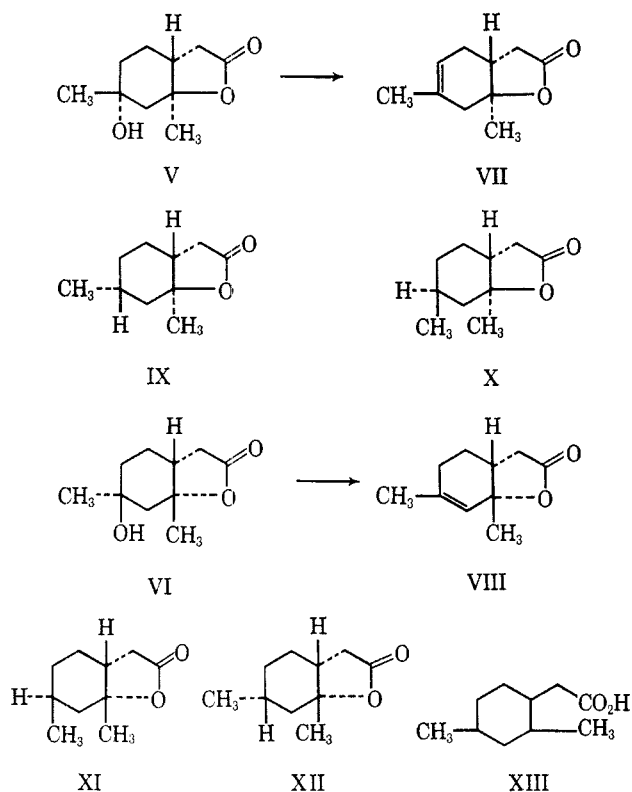
(3) H. Schmidt, *Ber.*, **82**, 11 (1949).

(4) J. Wolinsky and W. Barker, *J. Am. Chem. Soc.*, **82**, 636 (1960).

(5) C. L. Arcus and G. J. Bennett, *J. Chem. Soc.*, 3180 (1958).

(6) Dehydration of tertiary alcohols in cyclohexane ring systems has been thoroughly investigated. S. Beckmann, R. Schaber, and R. Bamberger [*Ber.*, **87**, 997 (1954)], D. H. R. Barton, A. daS. Campos-Neves, and R. C. Cookson [*J. Chem. Soc.*, 3500 (1956)], and H. Heusser, N. Wahba, and F. Winternitz [*Helv. Chim. Acta*, **37**, 1052 (1954)] have shown that equatorial alcohols gave predominantly exocyclic olefins, whereas axial alcohols afforded endocyclic olefins.

CHART II



The formation of acid XIII is a result of hydrogenolysis and indicates that the oxygen of the lactone group in unsaturated lactone VIII is allylic to the carbon-carbon double bond. The exclusive formation of dihydro lactones IX and X from VII argues that the double bond in VII must be at least two carbon atoms removed from the oxygen of the lactone group.

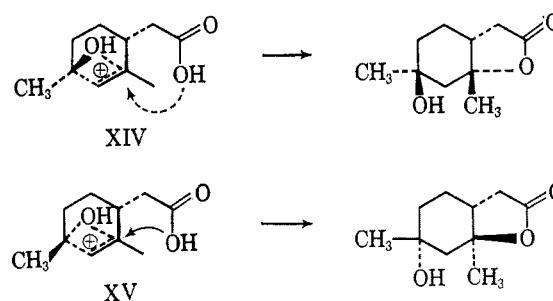
The demonstration of the position of the double bond in each unsaturated lactone permits an assignment of stereochemistry to the ring fusion of their lactone rings. Bucourt<sup>7a</sup> has analyzed the perhydroindane ring system and concluded that for *cis*-bicyclo[4.3.0]nonenes the 2-nonene is more stable than the 3-nonene, while for the *trans*-bicyclo[4.3.0]nonenes the 3-nonene is more stable than the 2 isomer.<sup>7b</sup> On this basis a *cis*-ring fusion is assigned lactone VI and a *trans*-ring fusion is indicated for lactone V.

### Discussion

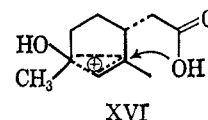
3-Isopropenyl-6-oxoheptanoic acid (I) undergoes an extremely facile intramolecular carbonyl-olefin (Prins) cyclization reaction, accompanied by participation of the carboxylic acid group. Examination of the crude hydroxy lactone mixture gives no indication for the presence of lactones other than V and VI. Dehydration of the *crude* hydroxy lactone mixture with phos-

phorus oxychloride in pyridine gives the unsaturated lactones VII and VIII and no trace of isomeric unsaturated lactones. The over-all conversion of keto acid I to the hydroxy lactones V and VI is, therefore, highly stereoselective. It should be further noted that both products exhibit a *trans* relationship between the two oxygen atoms. The stereochemistry of the products is best accounted for by assuming an over-all *trans* addition of the protonated carbonyl group and the carboxylic acid group to the terminal carbon-carbon double bond with the intervention of the intramolecularly solvated cations<sup>8</sup> XIV and XV which result from a transition state in which there is maximum orbital overlap between the protonated carbonyl and the terminal methylene group (Chart III). Examination

CHART III



of molecular models makes it difficult to reconcile the high selectivity of this cyclization reaction with the intermediacy of a free carbonium ion or a three-membered cyclic ion<sup>9,10</sup> such as XVI.



The remarkable conversion of pinonic acid into 2,4-dimethylphenylacetic acid by the action of bromine<sup>11</sup> or bromine and hydrochloric acid<sup>12</sup> has recently been reinvestigated by Arcus and Bennett.<sup>5</sup> Convincing evidence was provided for the mechanism shown in Chart IV.

The manner in which bromohomoterpenyl methyl ketone XVII was converted into the cyclohexene derivative XVIII was not defined by Arcus and Bennett. The facile conversion of keto acid I into the hydroxyl

(7) (a) R. Bucourt, *Bull. Soc. Chim. France*, 1983 (1962); 1262 (1963).  
 (b) Justification for these conclusions is found in the fact that chlorination of *cis*-5-perhydroindanone [R. Granger, M. Corbier, and P. Nau, *ibid.*, 479 (1955); 247 (1956); R. Granger and J. P. Girard, *ibid.*, 695 (1962)] leads exclusively to 4-chloro-*cis*-5-perhydroindanone, whereas chlorination of *trans*-5-perhydroindanone affords the 6-chloro isomer. Oxidation [A. H. Cook and R. P. Linstead, *J. Chem. Soc.*, 946 (1934)] of *cis*-5-perhydroindanone gives exclusively *cis*-2-carboethoxycyclopentane-1-propionic acid. These reactions depend upon the direction of enolization of the ketone and suggest that in the *cis* compounds enolization occurs toward the ring junction, whereas in the *trans* system enolization occurs away from the ring junction.

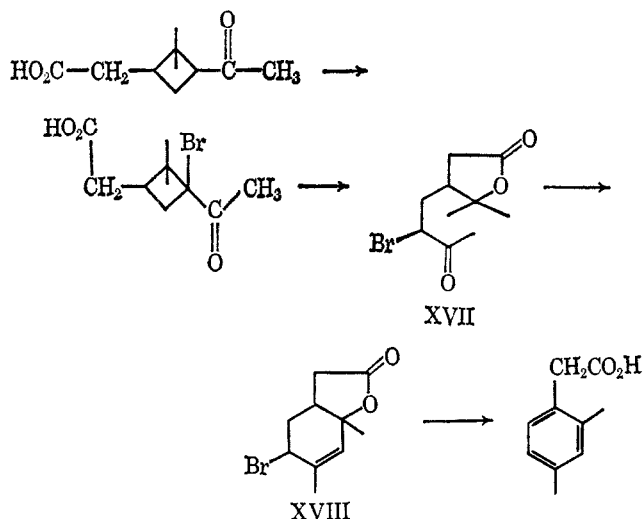
(8) A similar intermediate has been suggested by H. E. Zimmerman and J. English, Jr., [*J. Am. Chem. Soc.*, **75**, 2367 (1953)] to explain the predominance of *cis*-isopulegol hydrate in the cyclization of *d*-citronellal. J. Meinwald and J. A. Yankelev, Jr., *ibid.*, **80**, 5266 (1958)] rejected an intramolecularly solvated cation in the formation of *cis*- and *trans*-1,3-dimethyl-1,3-cyclohexanediol in the acid-catalyzed cyclization of  $\alpha$ -methylheptenone in favor of a concerted *trans*-addition mechanism. Partial conversion of the intramolecularly solvated cation to a "free" cation [N. A. LeBel, R. N. Liesemer, and E. Mehmedbasich, *J. Org. Chem.*, **28**, 615 (1963)] can also account for the formation of both *cis* and *trans* diols.

(9) L. J. Dolby, *ibid.*, **27**, 2971 (1962).  
 (10) Dolby<sup>9</sup> has assumed that the importance of cyclic intermediates in addition reactions is related to the ability of the moiety in question to act as a neighboring group. An oxygen atom with its unshared electrons should certainly be better than a saturated carbon atom to solvate a carbonium ion. The high net retention observed in the solvolysis of *trans*-2-hydroxymethylcyclohexyl brosylate in aqueous dioxane [L. J. Dolby, C. N. Lieske, D. R. Rosencrantz, and M. J. Schwarz, *J. Am. Chem. Soc.*, **85**, 47 (1963)] can be explained by oxygen participation and removes the only argument originally presented by Dolby<sup>9</sup> against a cyclic onium ion.

(11) A. Barbier and V. Grignard, *Compt. Rend.*, **148**, 646 (1909).

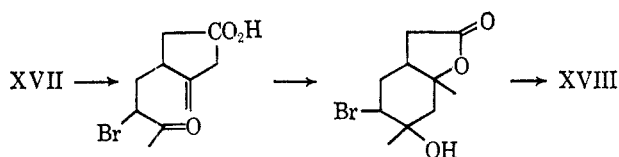
(12) J. Harispe, *Ann. Chim.*, **6**, 249 (1936).

CHART IV



lactones V and VI and these, in turn, to the unsaturated lactones VII and VIII now provides strong support for the following intermediates in the conversion of XVII to XVIII (Chart V).

CHART V



### Experimental Section<sup>13</sup>

**8-*p*-Menthene-1,2-diol.**<sup>4</sup>—To 1920 ml of 1% sulfuric acid, kept at ice temperature, was added dropwise with vigorous stirring 250 g (1.64 moles) of limonene monoxide. Stirring was continued for 5 hr. The product was collected by filtration, washed with water, and dried *in vacuo* for 3 days: 191 g (68%), mp 72.5–73.5°.

In one experiment the crude diol was distilled *in vacuo* and gave carvenone,  $\lambda_{\max}$  6.00 and 6.17  $\mu$ , identified as its 2,4-DNP derivative, mp 163–165°, lit.<sup>14</sup> mp 164°. This dehydration and rearrangement of *p*-menthenediol was undoubtedly brought about by the presence of a trace of sulfuric acid.

**3-Isopropenyl-6-oxoheptanal (IV).**—To a cold solution of 191 g (1.12 moles) of 8-*p*-menthene-1,2-diol in 475 ml of tetrahydrofuran was added slowly 240 g (1.12 moles) of sodium metaperiodate in 1100 ml of water. The exothermic reaction was accompanied by the precipitation of sodium iodate. The mixture was kept in the refrigerator overnight and the precipitate was removed by filtration and washed thoroughly with ether. The volatile solvents were removed under diminished pressure and the aqueous residue was extracted with ether. Distillation of the ether extracts afforded 148.8 g (80%) of the ketoaldehyde IV: bp 82–84° (0.50 mm);  $n_D^{25}$  1.4595;  $\lambda_{\max}$  3.70, 5.85, 6.10, and 11.20  $\mu$ ; nmr signals at 1.63 (CH<sub>3</sub>-C=C-), 2.02 (CH<sub>2</sub>-CO-), multiplets at 2.12–2.64 (-CH<sub>2</sub>-CO- and -CH-), 4.74 (CH<sub>2</sub>=C), and 9.42 (CHO) ppm.

**3-Isopropenyl-6-oxoheptanoic Acid (I). Oxidation of 8-*p*-Menthene-1,2-diol. A. Chromium Trioxide in Acetic Acid.**—A solution of 20 g (0.1184 mole) of 8-*p*-menthene-1,2-diol in 30 g of glacial acetic acid was added to 12 g (0.12 mole) of chromium trioxide in 70 g of 75% acetic acid. The mixture was kept at 53° for 90 min and the dark purple solution was poured into 150 ml of water and extracted thoroughly with chloroform. The

chloroform extracts were washed with aqueous sodium bicarbonate solution and dried. Distillation of the dried chloroform solution gave a low-boiling fraction, bp 74–76° (1 mm), which was largely 2-hydroxy-5-isopropenyl-2-methylcyclohexanone,  $\lambda_{\max}$  2.90, 5.84, 6.10, and 11.20  $\mu$ , and a higher boiling fraction, bp 84–86° (1 mm), which was a mixture of acyloin and starting diol.

The sodium bicarbonate washings obtained above were acidified with 10% hydrochloric acid and extracted with chloroform. Distillation afforded 4.67 g of keto acid I, bp 120–124° (1 mm),  $n_D^{25}$  1.4690. In other experiments the acidic fraction was a mixture of the keto acid I and lactones V and VI.

**B. Jones Procedure.**—To a cold solution of 10 g (58.8 mmoles) of diol II in 80 ml of purified acetone was added dropwise 35.2 ml of chromium trioxide in sulfuric acid–water. The dark green mixture was filtered and the solid was washed thoroughly with methylene chloride. The filtrate was extracted with saturated sodium carbonate solution. The basic extract was acidified with 10% hydrochloric acid and extracted with methylene chloride. The methylene chloride solution was dried and distilled to give after 0.83 g of forerun, bp 118–130° (1 mm), 3.73 g of keto acid I contaminated by lactones V and VI, bp 130–132° (1 mm),  $n_D^{25}$  1.4798.

Distillation of the methylene chloride neutral fraction obtained above afforded 0.55 g of 2-hydroxy-5-isopropenyl-2-methylcyclohexanone. When the oxidation of diol II was repeated using a smaller quantity of oxidant 5.9 g of a mixture of acyloin and diol II was obtained. Careful fractional distillation of this mixture gave the pure acyloin: bp 80–82° (0.50 mm);  $n_D^{25}$  1.4795; nmr signals at 1.20 (CH<sub>3</sub>-C-O-), 1.70 (CH<sub>3</sub>-C=C-), multiplets centered at 2.40 (-CH<sub>2</sub>- and -CH-), 3.64 (-OH), and 4.74 (CH<sub>2</sub>=C) ppm.

*Anal.* Calcd for C<sub>10</sub>H<sub>16</sub>O<sub>2</sub>: C, 71.39; H, 9.59. Found: C, 71.34; H, 9.84.

**Oxidation of Ketoaldehyde IV. A. Jones Procedure.**—A cold solution of 1.98 g (0.012 mole) of aldehyde IV in 100 ml of purified acetone was treated with 31.6 ml of Jones reagent. The reaction was worked up in the usual fashion and gave on distillation 1.20 g (55%) of the keto acid I, bp 142–144° (1.5 mm),  $n_D^{25}$  1.4715. The infrared spectrum indicated the presence of a lactone impurity,  $\lambda_{\max}$  5.65  $\mu$ .

When conducted on a larger scale the keto acid I was contaminated by appreciable amounts of the lactones V and VI.

**B. Chromium Trioxide in Acetic Acid.**—To a solution of 10 g (5.95 mmoles) of ketoaldehyde IV in 15 ml of acetic acid was added a solution of 3.96 g (2.97 mmoles) of chromium trioxide in 15 ml of 75% acetic acid. The mixture was stirred at room temperature for 2 hr and heated at 65° for 1 hr. Water was added and the mixture was extracted with methylene chloride. The methylene chloride solution was extracted with 5% sodium bicarbonate solution. The resulting basic solution was acidified with dilute hydrochloric acid and then extracted with methylene chloride. Distillation gave 2.36 g of a mixture of keto acid I and lactones V and VI, bp 134–138° (1 mm),  $n_D^{25}$  1.4774.

**C. Silver Oxide.**—To a solution, protected by a stream of nitrogen gas, of 15.52 g (0.0925 mole) of ketoaldehyde IV and 40 g (0.24 mole) of silver nitrate in 200 ml of ethanol and 80 ml of water was slowly added a 10% aqueous solution of potassium hydroxide until the pH of the reaction mixture reached 11–12. Stirring under nitrogen was continued for another 4–5 hr, with care being taken to maintain the pH at 11–12. The precipitated silver and silver oxide were removed by filtration and washed thoroughly with 10% aqueous potassium hydroxide. The alkaline solution was extracted with ether, acidified with cold 6 *N* hydrochloric acid, and rapidly extracted with methylene chloride. Distillation afforded 11.50 g (68%) of keto acid I: bp 128–130° (2 mm);  $n_D^{25}$  1.4671; nmr signals at 1.67 (CH<sub>3</sub>-C-C-), 2.07 (CH<sub>2</sub>-CO-), and 4.77 (CH<sub>2</sub>=C) ppm.

*Anal.* Calcd for C<sub>10</sub>H<sub>16</sub>O<sub>3</sub>: C, 65.19; H, 8.76. Found: C, 65.20; H, 9.00.

The 2,4-dinitrophenylhydrazone of keto acid I showed mp 130–131° after being recrystallized from benzene–petroleum ether.

*Anal.* Calcd for C<sub>16</sub>H<sub>20</sub>N<sub>4</sub>O<sub>6</sub>: C, 52.75; H, 5.41; N, 15.37. Found: C, 52.80; H, 5.38; N, 15.17.

**Methyl ester of keto acid I** was prepared in quantitative yield by reaction of the acid with ethereal diazomethane and showed bp 93–94° (2 mm);  $n_D^{25}$  1.4516;  $\lambda_{\max}$  5.78, 5.82, 6.10, and 11.20  $\mu$ ; and nmr signals at 1.63 (CH<sub>3</sub>-C=C-) overlapping a multiplet (-CH<sub>2</sub>-), 2.05 (CH<sub>2</sub>-CO-), multiplets centered at 2.35 (-CH<sub>2</sub>-CO-, -CH-CO-), 3.60 (CH<sub>3</sub>O-), and 4.73 (CH<sub>2</sub>=C) ppm.

(13) All boiling and melting points are uncorrected. Nmr spectra were measured at 60 Mc by W. E. Baitinger, J. R. Barnes, and A. K. Moreland with the Varian Associates A-60 spectrometer. Chemical shifts are given with reference to tetramethylsilane. Microanalyses were performed by Dr. C. S. Yeh and associates.

(14) H. Pines and H. E. Eschinazi, *J. Am. Chem. Soc.*, **77**, 6314 (1955).

*Anal.* Calcd for  $C_{11}H_{13}O_3$ : C, 66.64; H, 9.15. Found: C, 66.50; H, 8.90.

The semicarbazone derivative of the keto methyl ester exhibited mp 135–136° after several recrystallizations from aqueous ethanol.

*Anal.* Calcd for  $C_{12}H_{21}N_3O_3$ : C, 56.45; H, 8.29; N, 16.46. Found: C, 56.49; H, 8.26; N, 16.45.

**2,4-Dihydroxy-2,4-dimethylcyclohexane-1-acetic Acid  $\gamma$ -Lactones V and VI.**—Keto acid I solidified completely on standing at room temperature for 2 months. The same solid was obtained when acid I was heated for 4 hr with a trace of *p*-toluenesulfonic acid in chloroform.<sup>15,16</sup> A 2.45-g sample of the crude solid, mp 97–118°, was placed on an acid-washed alumina column. Elution with petroleum ether–benzene (30:70) gave 0.125 g of lactones V and VI contaminated with a small amount of unsaturated lactone VII; benzene afforded 0.995 g of a lactone mixture rich in V; benzene–ether and ether gave 0.682 g of a lactone mixture rich in VI; and methanol yielded 0.460 g of acidic material.

Slow crystallization of 11.0 g of the crude mixture from ethyl acetate–methylene chloride (95:5), afforded a first crop composed of prisms and a second and third crop consisting of prisms and needles. The needles and prisms were separated by hand picking. The needles were recrystallized from petroleum ether–diethyl ether (95:5), whereas the prisms were recrystallized from methylene chloride–diethyl ether (5:95). Laborious recrystallization finally afforded 2.0 g of prisms, mp 145–146°, 3.59 g of needles, mp 119–120°, and 4.30 g of a mixture of V and VI whose infrared spectrum exhibited only those peaks found in V and VI.

The hydroxy lactone V, mp 145–146°, displayed  $\lambda_{\max}^{CHCl_3}$  2.79, 2.90, 3.40, 5.70, 6.99, 7.10, 7.30, 7.50, 7.70, 7.80, 8.72, 9.10, 9.20, 9.65, 9.90, 10.40, 10.60, 10.85, 11.02, 11.32, and 11.75  $\mu$ ; and nmr signals at 1.32 ( $CH_3-C-O-$ ), 1.47 ( $CH_3-C-O-$ ), 1.65, 1.70 ( $-CH_2-$ ), 1.87, 2.06 ( $-OH$ ), and 2.37 ppm.

*Anal.* Calcd for  $C_{10}H_{16}O_3$ : C, 65.19; H, 8.76. Found: C, 65.08; H, 8.86.

The hydroxy lactone VI, mp 119–120°, exhibited  $\lambda_{\max}^{CHCl_3}$  2.75, 2.85, 5.70, 6.90, 6.95, 7.08, 7.25, 7.54, 8.80, 9.00, 9.13, 9.35, 9.41, 9.65, 10.00, 10.38, 10.59, 10.99, and 11.70  $\mu$ ; and nmr signals at 1.32 and 1.57 ( $2CH_3-C-O-$ ), multiplets centered at 1.60 and 1.81, and a singlet at 2.47 ( $-OH$ ) overlapping a multiplet at 2.47 ppm.

*Anal.* Calcd for  $C_{10}H_{16}O_3$ : C, 65.19; H, 8.76. Found: C, 65.27; H, 8.81.

**Dehydration of Hydroxy Lactone V.**—To a cold solution of 1.00 g (0.00542 mole) of hydroxy lactone V in 3 ml of anhydrous pyridine was added dropwise 1.66 g (0.0108 mole) of phosphorus oxychloride. The mixture was allowed to warm to room temperature and was then stirred for 12 hr. Ice–water was added cautiously to the cooled mixture and the resulting solution was extracted with ether. The combined ether extracts were washed with 6 *N* hydrochloric acid and the ether solution was dried over anhydrous magnesium sulfate. The ether was removed under diminished pressure to afford 0.84 g of crude 2-hydroxy-2,4-dimethylcyclohex-4-ene-1-acetic acid  $\delta$ -lactone (VII) which showed only one component on gas phase chromatography. Recrystallization of the unsaturated lactone from petroleum ether (bp 35–37°) at  $-78^\circ$  afforded 0.362 g of crystalline solid which when further purified by sublimation showed mp 45–47°. A sample of the unsaturated lactone VII purified by vpc showed a carbonyl peak at 5.65  $\mu$ ; and nmr signals at 1.20 ( $CH_3-C-O-$ ), 1.74 ( $CH_3-C=C-$ ), a multiplet centered at 2.27, and a broad singlet at 5.47 ( $-CH=C-$ ) ppm.

*Anal.* Calcd for  $C_{10}H_{14}O_2$ : C, 72.20; H, 8.45. Found: C, 72.40; H, 8.62.

**Hydrogenation of Unsaturated Lactone VII.**—A solution of 0.739 g (4.46 mmoles) of lactone VII in ethanol containing a few drops of acetic acid was hydrogenated using platinum oxide as catalyst. The mixture was filtered through Celite and the solvent was removed under diminished pressure. Gas chromatographic analysis of the residual oil, 0.81 g, indicated the presence of dihydro lactones IX and X in a ratio of 64:36. The crude oil was crystallized from petroleum ether to give 0.312 g of semicrystal-

line solid, mp 42–48°. Chromatography of this solid using silica gel and 90:10 petroleum ether–ether as an eluant gave only partial separation, but from which 20 mg of pure liquid dihydro lactone IX and 65.4 mg of crystalline dihydro lactone X, mp 47–49.5°, were obtained. Further purification of X by recrystallization and sublimation afforded a sample, mp 50–51°, which exhibited nmr signals at 0.97, 1.07 ( $CH_3CH$ ), 1.30 ( $CH_3-C-C-$ ), 1.38–2.13, 2.22, and 2.26 ppm.

*Anal.* Calcd for  $C_{10}H_{16}O_2$ : C, 71.39; H, 9.59. Found: C, 71.35; H, 9.76.

The liquid dihydro lactone IX showed a carbonyl peak at 5.65  $\mu$ ; and nmr signals at 0.94, 1.03 ( $CH_3CH$ ), 1.34 ( $CH_3-C-O-$ ), 1.37–2.00, and 2.20 ppm.

**Dehydration of Hydroxy Lactone VI.**—To a cooled solution of 1.00 g (5.42 mmoles) of hydroxy lactone VI in 3 ml of anhydrous pyridine was added dropwise 1.66 g (10.84 mmoles) of phosphorus oxychloride. The reaction was allowed to warm to room temperature and was stirred for 10 hr. Ice–water was added to the cooled reaction mixture and the resulting solution was extracted with ether. The combined ether extracts were washed with 1 *N* hydrochloric acid and then dried. The solvent was removed under diminished pressure to leave 0.85 g of a slightly yellow oil which showed a single peak on gas chromatographic analysis. Repeated recrystallization of the oil from petroleum ether at  $-78^\circ$  gave 0.192 g of waxy solid. A sample further purified by sublimation showed mp 36–37.5°; 5.70  $\mu$ ; and nmr signals at 1.34 ( $CH_3-C-O-$ ), 1.67 ( $CH_3-C=C-$ ), 1.74–2.47, and 5.32 ( $-CH=C-$ ) ppm.

*Anal.* Calcd for  $C_{10}H_{14}O_2$ : C, 72.20; H, 8.45. Found: C, 72.18; H, 8.65.

**Hydrogenation of Unsaturated Lactone VIII.**—A solution of 0.354 g (2.14 mmoles) of unsaturated lactone VIII in ethanol was hydrogenated using platinum oxide as catalyst. The catalyst and solvent were removed leaving an oil which exhibited absorption at 3.0–3.9 and 5.90  $\mu$  characteristic of a carboxylic acid and 5.70  $\mu$  ( $\gamma$ -lactone). The oil was dissolved in ether and the ether solution was extracted with saturated sodium carbonate solution. The ether was distilled leaving 0.156 g of a neutral oil which was shown to be a mixture of XI and XII in a 4:1 ratio.

Dihydro lactone XI, which had the longer retention time on a Carbowax 20M column, showed mp 42–42.5°; 5.65  $\mu$ ; and nmr signals at 0.97 ( $CH_3-CH$ ), 1.44 ( $CH_3-C-O-$ ), 1.70, and 2.32 ppm.

*Anal.* Calcd for  $C_{10}H_{16}O_2$ : C, 71.39; H, 9.59. Found: C, 71.10; H, 9.56.

Dihydro lactone XII, isolated by vpc, showed a carbonyl peak at 5.65  $\mu$  and nmr signals at 0.87, 0.97 ( $CH_3-CH$ ), 1.32 ( $CH_3-C-O-$ ), and multiplets from 1.42–2.38 ppm.

The sodium carbonate extracts obtained as described above were acidified with dilute hydrochloric acid and then extracted with ether. Removal of the ether under diminished pressure gave 0.218 g of acid XIII:  $n_D^{20}$  1.4672; 5.90  $\mu$ ; and nmr signals at 0.80, 0.90, 1.90, 1.00 ( $2CH_3-CH-$ ), 1.12–2.0, 2.17, and 11.88 ( $CO_2H$ ) ppm.

The action of diazomethane on the acid XIII afforded its methyl ester which was purified by vpc and showed  $n_D^{20}$  1.4489, 5.78  $\mu$ , and an nmr spectrum identical with that of acid XIII except for the absence of the carboxylate proton signal at 11.88 and the presence of a methoxy signal at 3.60 ppm.

*Anal.* Calcd for  $C_{11}H_{20}O_2$ : C, 71.69; H, 10.94. Found: C, 71.90; H, 11.11.

**Conversion of Hydroxyl Lactone VI into 2,4-Dimethylphenylacetic Acid.**—A solution of 0.15 g (0.815 mmole) of hydroxy lactone VI and 0.13 g (0.815 mmole) of bromine in 5 ml of concentrated hydrochloric acid was shaken until a yellow oil separated. The mixture was heated to 93° for 4 hr. The resulting colorless solution was cooled, water was added, and the solution was extracted with methylene chloride. The methylene chloride solution was washed with water and then extracted with 10% ammonium hydroxide solution. The basic extracts were acidified and extracted with methylene chloride. The methylene chloride was distilled and the residue was sublimed at 85° and 1 mm. The sublimate, 50 mg, mp 81–97°, was recrystallized from cyclohexane to afford colorless needles, mp 100–103°, which were identical in all respects with an authentic sample of 2,4-dimethylphenylacetic acid prepared according to the procedure of Arcus and Bennett.<sup>5</sup>

(15) The infrared spectrum of this crude product showed only those peaks present in pure V and VI.

(16) When keto acid I was refluxed with trichloroacetic acid for 3 hr, there was obtained a mixture of hydroxy lactones V and VI and unsaturated lactones VII and VIII, the unsaturated lactones predominating.