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Synthesis Studies Relating to Guaiane Sesquiterpenes

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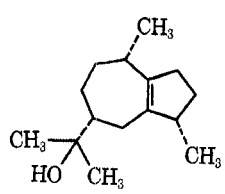
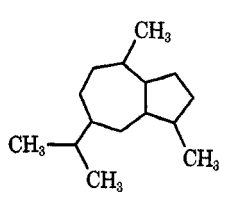
Acetolysis of the methanesulfonate derivative of 7a-hydroxymethyl-5,6,7,7a-tetrahydroindan (**5**) proceeds smoothly to give the expected hydroazulenic homoallylic acetate **6**. Stereoselective methods for the synthesis of methyl-substituted homologs of carbinol **4** are discussed. One of these entails ozonolysis of the benzyl ether of 10-hydroxymethyl-1,9-octalin (**29**) followed by aldol cyclization of the resulting keto aldehyde. Reductive deconjugation of this aldol product proceeds stereoselectively to give the hydrindanol derivative **31** in which the angular carbinyl and the newly introduced carbinyl center are cis related. This point was established by cyclization of the corresponding diol to the tricyclic ether **34** *via* the monomesylate derivative.

The sesquiterpene alcohol guaiol was one of the first authentic naturally occurring hydroazulenes to be structurally elucidated.[2] It also represents the structural prototype of the guaiane family of sesquiterpenes.[3] Despite its apparent simplicity, guaiol presents a number of difficult synthesis problems. Foremost of these is the general need for stereochemically unambiguous routes to asymmetrically substituted hydroazulenes. In this report we present some preliminary studies relating to this problem which serve to define guidelines for future synthetic work.

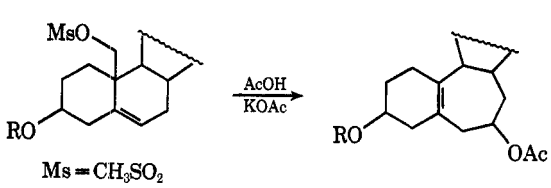


guaiol



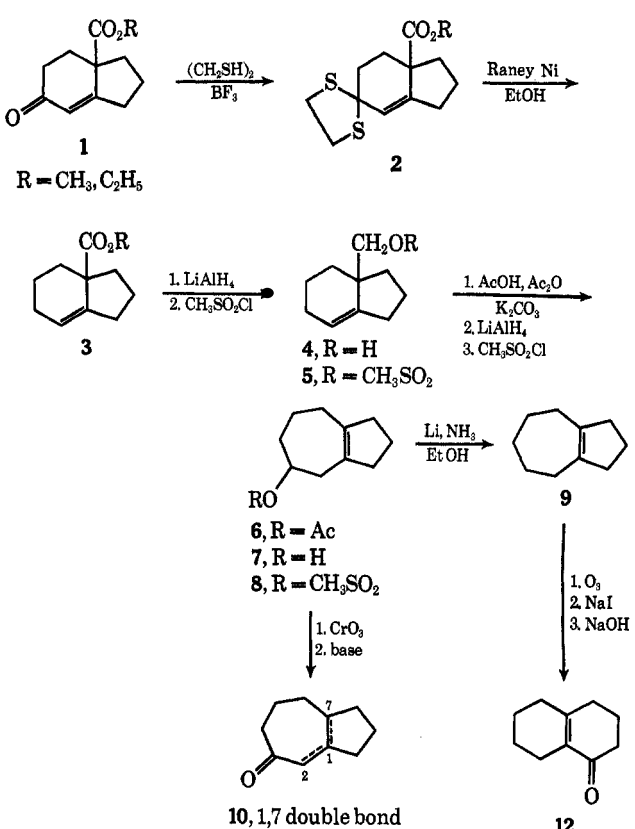
guaiane

The synthetic route that we chose to explore in these studies is based on the work of Tadanier[4] who found that C-19 functionalized Δ^5 steroids of the type depicted below undergo the indicated rearrangement upon acetolysis in a buffered medium. Our initial goal was to examine this rearrangement–solvolysis reaction in the hydrindan system **5** in order to determine its applicability to hydroazulene synthesis. Chart I summarizes our findings.



Ms = CH_3SO_2

CHART I



(1) National Institutes of Health Predoctoral Fellow, Institute of General Medical Sciences, 1967–1970.

(2) H. Minato, *Tetrahedron Lett.*, 280 (1961).

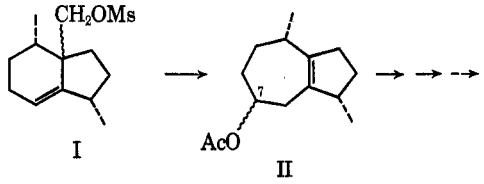
(3) *Cf.* T. Nozoe and S. Itô in "Fortschritte der Chemie Organischer Naturstoffe," L. Zechmeister, Ed., Springer-Verlag, Vienna, 1961, pp 52–61; P. de Mayo, "Mono and Sesquiterpenoids," Interscience, New York, N. Y., 1959, pp 244–262.

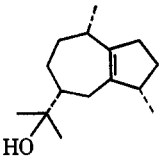
(4) J. Tadanier, *J. Org. Chem.*, **31**, 3204 (1966).

The hydrindanone **1** was prepared *via* base-catalyzed annelation of the commercially available mixture of the methyl and ethyl esters of cyclopentanone-2-carboxylate[5] with methyl vinyl ketone. Desulfurization of the thioketal derivative **2** with W-2 Raney nickel afforded the unsaturated ester mixture **3**. The experimental conditions for this step had to be carefully defined as prolonged heating effected reduction of the double bond, and insufficient Raney nickel or shorter reaction times led to recovery of starting material. Reduction with lithium aluminum hydride yielded the alcohol **4**, an easily purified substance, in 78% overall yield. Solvolysis of the methanesulfonate derivative **5** under the conditions of Tadanier[4] gave the hydroazulenic acetate **6** in nearly 80% yield. The structure of this product was ascertained through its conversion to the hydrocarbon **9** *via* hydrogenolysis of the methanesulfonate derivative **8** with lithium in ammonia and subsequent ozonolysis, followed by aldol cyclization of the resulting 1,5-cyclodecanedione to the known octalone **12**.[6] This sequence establishes the hydroazulenic carbon skeleton and places the double bond. The location of the acetoxyl group was confirmed by oxidation of the corresponding alcohol **7** with Collins' bispyridinechromium(VI) oxide reagent[7] to an unsaturated cycloheptanone **10** which yielded the conjugated isomer **11** upon treatment with base or acid.

Having established the feasibility of the hydrindan rearrangement route (**5** → **6**) to hydroazulenes, we next turned our attention to the synthesis of a suitable intermediate for subsequent conversion to guaiol along those lines. It should be noted at this point that one intrinsic advantage of the above hydrindan rearrangement route is the opportunity for stereochemical control through the use of conformationally defined cyclohexane derivatives as intermediates with subsequent conversion to the conformationally ambiguous hydroazulene system[8] being effected under nonequilibrating conditions.

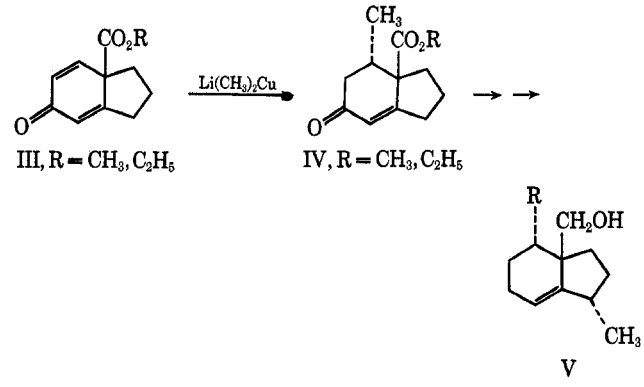
Since our synthetic approach called for the final conversion of the acetoxyl substituent in the solvolysis product **6** to the isopropylol substituent of guaiol, we ultimately required a hydrindan such as I for our intended synthesis. The important feature of this intermediate is a cis relationship between the two methyl substituents. At this point we were not concerned with the relative stereochemistry of the angular carbinyl





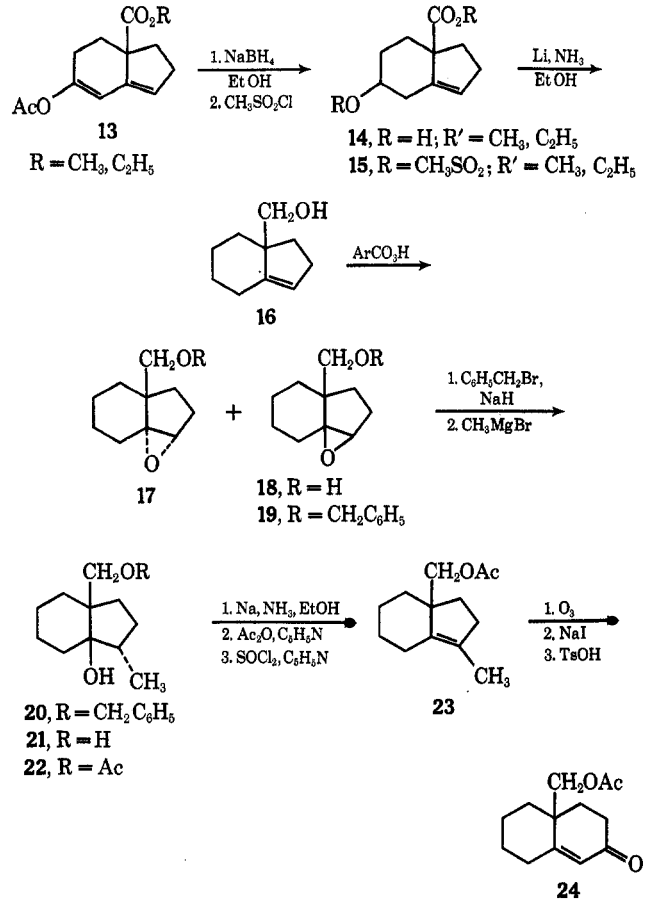
grouping, as this center becomes trigonal in the rearrangement product II. Of course, the relative stereochemistry of the carbinyl carbon (C-7) in acetate II would be determined by the angular carbinyl orientation in I, and this relationship could determine our eventual choice of methodology for introduction of the isopropylol substituent.

In preliminary experiments we were able to establish that the addition of lithium dimethylcopper to the dienone ester III proceeds in a highly selective fashion to give the enone IV with trans-related methyl and carboxyl groups.[9] In light of this finding we directed our attention to the synthesis of the intermediate V



(R = CH_3). Our initial efforts in this direction (Chart II) were carried out on the demethyl analog **1** of enone IV.

CHART II



(5) Secured fron the Aldrich Chemical Co., Milwaukee, Wis.

(6) A. L. Wilds and N. A. Nelson, *J. Amer. Chem. Soc.*, **75**, 5360 (1953).

(7) J. C. Collins, W. W. Hess, and F. J. Frank, *Tetrahedron Lett.*, 3363 (1968).

(8) *Cf.* J. B. Hendrickson, *Tetrahedron*, **19**, 1387 (1963); M. Hanack, "Conformation Theory," Academic Press, New York, N. Y., 1965, p 158 ff; E. L. Eliel, N. L. Allinger, S. J. Angyal, and G. A. Morrison, "Conformational Analysis," Interscience, New York, N. Y., 1965, p 206 ff.

(9) A. E. Greene, unpublished results.

Reduction of the enol acetate derivative **13** (mixture of ethyl and methyl esters) of enone **1** with sodium borohydride afforded the homoallylic alcohol **14**. Hydrogenolysis of the derived methanesulfonate **15** with lithium in ammonia–ethanol proceeded with concomitant reduction of the ester grouping to give the unsaturated alcohol **16**. We expected the hydroxyl function of this intermediate to exert a cis-directing effect on the epoxidation of olefin **16** under appropriate conditions[10] to afford the cis isomer **18**. In fact this was found to be the case when the reaction was carried out at low temperature in chloroform or chloroform–methylene chloride (Table I). Under comparable conditions

TABLE I

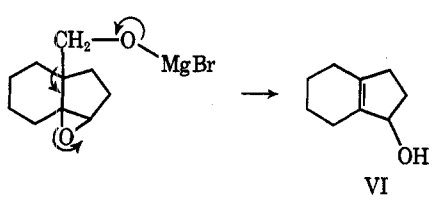
EPOXIDATION OF HOMOALLYLIC ALCOHOL **16** WITH *m*-$ClC_6H_4CO_3H$

Solvent	Temp, °C	β (18)/α (17)[a]
THF–H_2O[b]	0	15/85
DME–H_2O[b]	0	25/75
Ether	25	33/67
Acetonitrile	0	50/50
Cyclohexane	12	67/33
Chloroform	0	75/25
	−20	80/20
Chloroform–methylene chloride	−78	85/15
Chloroform[c]	0	30/70

[a] The ratio was determined by gas chromatography. [b] Buffered with K_2HPO_4. [c] Epoxidation of the acetate of **15**.

the acetate derivative of alcohol **16** afforded mainly (see Table I) the trans epoxy acetate derivative **17** (R = Ac).[9] Interestingly, the epoxidation of unsaturated alcohol **16** showed a marked solvent dependence even with aprotic solvents.

The requisite trans methyl grouping was introduced *via* treatment of the benzyl ether derivative **19** of epoxide **18** with methylmagnesium bromide in refluxing tetrahydrofuran to give the alcohol **20**. When the epoxy alcohol **18** was similarly treated, a fragmentation reaction took place leading to the alcohol VI.[9] The

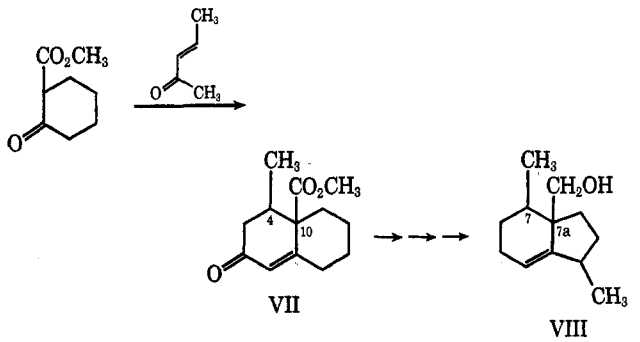


VI

same alcohol was produced upon similar treatment of the trans epoxy acetate **17** (R = Ac).[9]

At this point our projected synthesis of the trans alcohol V (R = H) took an unexpected turn. We had hoped that the hydroxy acetate **22**, secured from alcohol **20** *via* hydrogenolysis with sodium in ammonia–ethanol followed by selective acetylation of the resulting diol **21**, would undergo a specific trans dehydration leading to the desired trisubstituted olefin.[11] However, our efforts to effect this conversion were to no avail. The tetrasubstituted olefin **23** was the only detectable product of various dehydration attempts. The structure of this material was confirmed through its conversion, *via* ozonolysis and acid-catalyzed aldol cyclization, to the known acetoxy enone **24**.[12]

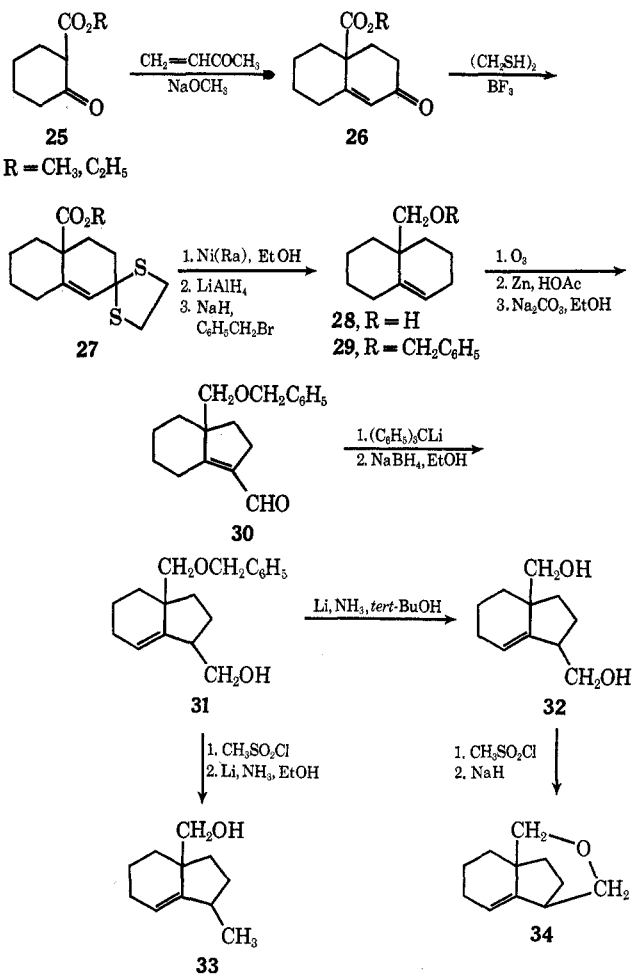
In view of the foregoing results we decided to abandon our efforts to prepare the alcohol V (R = CH_3) and study instead the synthesis of the all-cis isomer VIII along the general lines depicted below. The stereo-



VII VIII

chemical groundwork for the C-4/C-10 relationship in VII (and thus the C-7/C-7a relationship in VIII) had been established by some of our earlier work.[13] We therefore needed only to devise a method for introducing the second *cis*-methyl group. For studies on this point (Chart III) we employed as a model com-

CHART III



(10) H. B. Henbest, *Proc. Chem. Soc.*, 159 (1963).

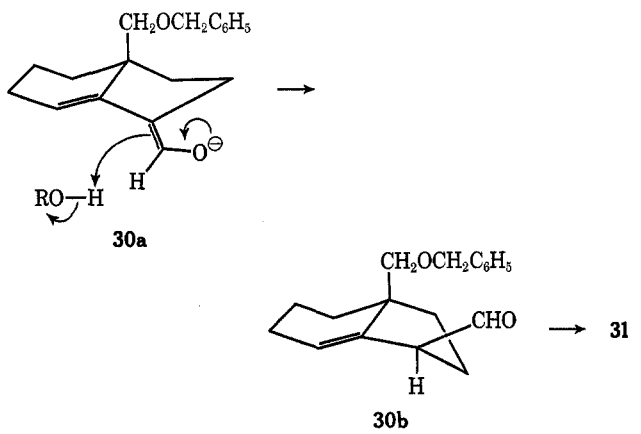
(11) *Cf.* J. A. Marshall, N. Cohen, and A. R. Hochstetler, *J. Amer. Chem. Soc.*, **88**, 3408 (1966); J. A. Marshall and A. R. Hochstetler, *ibid.*, **91**, 684 (1969).

(12) T. M. Warne, Jr., unpublished results.

(13) T. Warne, Jr., Ph.D. Dissertation, Northwestern University, 1970.

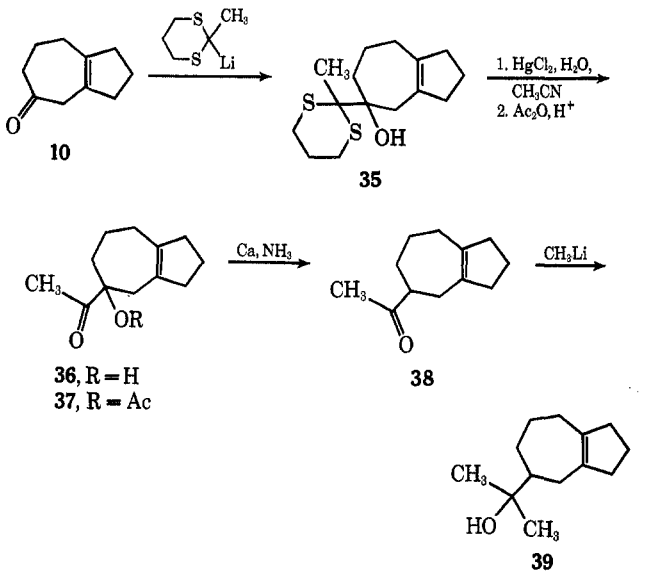
pound the methyl vinyl ketone adduct **26** of the commercially available mixture of methyl and ethyl esters of cyclohexanone-2-carboxylate (**25**).[5] Our projected guaiol synthesis would of course require the aforementioned methyl propenyl ketone Michael-aldol adduct VII as the starting material.

The known homoallylic alcohol **28**[14] was prepared *via* desulfurization of the thioketal derivative **27** and reduction of the resulting mixture of methyl and ethyl esters. The benzyl ether derivative **29**, obtained through treatment of alcohol **28** with sodium hydride and benzyl bromide, was subjected to ozonolysis followed by a reductive work-up. The resulting keto aldehyde cyclized upon stirring with ethanolic sodium carbonate to give the unsaturated aldehyde **30**. Conversion to the homoallylic alcohol **31** was effected by addition of the enolate, secured *via* treatment of aldehyde **30** with triphenylmethyllithium, to ethanolic sodium borohydride. The indicated stereochemical outcome was predicted on the assumption that protonation of the enolate **30a** by ethanol would occur from the less hindered face of the trigonal α position to give the β,γ-unsaturated aldehyde **30b**, which would then be reduced by sodium borohydride before epimerization could take place. In fact, a 9:1 mixture of alcohol **33** and its presumed epimer was obtained from this sequence. The stereochemistry of alcohol **31** was confirmed through hydrogenolysis of the benzyl ether using lithium in ammonia–*tert*-BuOH and cyclization of the resulting diol **32** to the tricyclic ether **34** *via* basic treatment of the monomesylate derivative. The desired methyl compound **33** was secured from alcohol **31** by hydrogenolysis of the methanesulfonate derivative with lithium in ammonia–ethanol.



In considering the applicability of the hydrindanylcarbinol rearrangement to a synthesis of guaiol we had to provide for some means of introducing the isopropylol substituent at the appropriate cycloheptane ring position. Our initial plan was to conduct the solvolysis–rearrangement reaction (*e.g.*, **5** → **6**) in liquid HCN containing KCN as a buffer, whereupon the cyano counterpart of the hydroazulenic acetate **6** might have been formed directly. Unfortunately initial experiments along these lines looked unpromising.[9] Likewise, attempts to prepare organometallic derivatives[15] and efforts to effect displacement reactions[16] on the appropriate halo compound proved unsuccessful. We were thus forced to consider less direct routes to the requisite isopropylol compound (*e.g.*, **39**). A successful scheme which evolved from our preliminary studies is outlined in Chart IV.

CHART IV



The β,γ-unsaturated ketone **10** condensed with the lithio derivative of 2-methyl-1,3-dithiane[17] to give alcohol **35**. This product could not be obtained free of starting material despite the use of excess organolithium reagent (enolate formation?). Fortunately the crude product contained none of the conjugated ketone **11** and the mixture could thus be recycled. Hydrolysis of the thioketal **35** proceeded smoothly to give the ketol **36**. Acetylation followed by hydrogenolysis with calcium in ammonia afforded the ketone **38**, provided the excess calcium was destroyed with bromobenzene[18] before work-up. Otherwise, further reduction of ketone **38** to the corresponding alcohol took place. Treatment of this ketone with methyllithium gave the desired alcohol **39**.

The work described in this report provides a reasonable basis for a potential synthesis of guaiol. Further work toward the end is in progress.

Experimental Section[19]

7a-Hydroxymethyl-5,6,7,7a-tetrahydroindan (4).—A solution of 5.28 g (*ca.* 26 mmol) of keto ester **1** (methyl, ethyl mixture), 5.8 ml (68.9 mmol) of 1,2-ethanedithiol, and 1.4 ml (11.0 mmol) of boron trifluoride etherate in 12 ml of acetic acid was stirred at 0° for 2 hr and stored at 5° for 8 hr. The product was isolated with ether and the residual ethanedithiol was removed under high vacuum affording 7.36 g of thioketal **2** (methyl, ethyl

(14) J. W. Rowe, A. Melera, D. Arigoni, O. Jeger, and L. Ruzicka, *Helv. Chim. Acta*, **40**, 1 (1957).

(15) *Cf.* (a) C. H. Heathcock and T. R. Kelly, *Tetrahedron*, **24**, 1801 (1968); (b) L. F. Fieser and M. Fieser, "Reagents for Organic Synthesis," Wiley, New York, N. Y., 1967, pp 618–619, 711–712.

(16) *Cf.* H. Normant, *Bull. Soc. Chim. Fr.*, 791 (1968); *Angew. Chem., Int. Ed. Engl.*, **6**, 1046 (1967); ref 15b, pp 297–298, 696.

(17) E. J. Corey and D. Seebach, *Angew. Chem., Int. Ed. Engl.*, **4**, 1075 (1965); E. J. Corey and D. Crouse, *J. Org. Chem.*, **33**, 298 (1968); D. Seebach, N. R. Jones, and E. J. Corey, *ibid.*, **33**, 300 (1968).

(18) E. S. Rothman and M. E. Wall, *J. Amer. Chem. Soc.*, **79**, 3228 (1957).

(19) Reactions were carried out under an atmosphere of nitrogen. The isolation procedure involved adding the reaction mixture to water or saturated brine followed by thorough extraction with the specified solvent. Anhydrous magnesium sulfate or potassium carbonate was used to dry the combined extracts and the solvent was subsequently removed on a rotary evaporator under reduced pressure. Microanalyses were performed by Microtech Inc., Skokie, Ill.

mixture): λ_{max}^{film} 5.80, 6.90, 7.82, 8.00, 8.45, 9.28, 9.73, 11.45, and 11.72 μm.

The above material was stirred with 120 ml (*ca.* 72 g) of W-2 Raney nickel in 1.7 l. of ethanol at reflux for 55 min. The cooled mixture was filtered and concentrated by distillation and the product was isolated with ether, affording 4.21 g of ester **3** (methyl, ethyl mixture): λ_{max}^{film} 5.81, 6.90, 7.69, 8.08, 8.55, 9.25, 9.72, 10.50, and 11.55 μm. Longer reflux periods afforded material contaminated with the product of double bond reduction.

The above ester mixture in 50 ml of ether was added to a solution of 2.50 g (65.8 mmol) of lithium aluminum hydride in 300 ml of ether. The mixture was stirred for 8 hr and treated with 5 ml of water and 4 ml of 10% aqueous NaOH. After 1 hr of continued stirring a small amount of anhydrous magnesium sulfate was added and the mixture was filtered, concentrated under reduced pressure, and distilled, affording 3.12 g (*ca.* 78% overall yield) of alcohol **4**, bp 110° (bath temperature) at 0.1 mm: λ_{max}^{film} 3.00, 3.29, 6.85, 9.20, 9.60, 9.75, 10.38, 11.25, and 12.32 μm; $\delta_{TMS}^{CCl_4}$ 5.38 (broad, H-4), and 3.35 ppm (broad, CH_2OH). The analytical sample, mp 35.5–37°, was prepared by preparative gas chromatography[20] and short-path distillation.

Anal. Calcd for $C_{10}H_{16}O$: C, 78.90; H, 10.59. Found: C, 78.8; H, 10.3.

Bicyclo[5.3.0]dec-1(7)-en-3-yl Acetate (6).—A stirred solution of 1.30 g (8.6 mmol) of alcohol **4** in 9 ml of pyridine was treated dropwise with 3.9 ml (51.5 mmol) of methanesulfonyl chloride at 0°. After 20 min the mixture was slowly poured into a solution containing 75 ml of pyridine and 10 ml of water at 0°, and the product was isolated with ether, affording 1.88 g (96%) of mesylate **5**: λ_{max}^{film} 3.30, 6.87, 7.38, 8.50, 10.25, 10.58, 11.85, and 12.37 μm; $\delta_{TMS}^{CCl_4\text{-}CDCl_3}$ 5.65 (broad, H-4), 4.05 (CH_2O, AB, J = 10 Hz, $\Delta\nu$ = 11 Hz), and 3.04 ppm (CH_3SO_3).

The above product in 130 ml of a solution prepared from 250 ml of acetic acid, 5 ml of acetic anhydride, and 3.50 g of potassium carbonate (previously heated at reflux overnight) was stirred at reflux for 5 hr.[4] The product was isolated with ether and distilled, affording 1.32 g (83%) of acetate **6**, bp 85° (bath temperature) at 0.1 mm (*ca.* 90% pure according to gas chromatography[21]): λ_{max}^{film} 5.77, 6.91, 7.30, 8.03, 9.74, 10.22, and 10.59 μm; $\delta_{TMS}^{CCl_4}$ 4.75 (broad, H-3), 2.40 and 2.28 (broad, allylic H's), and 1.94 ppm (CH_3CO).

The analytical sample was prepared *via* preparative gas chromatography[20] and short-path distillation.

Anal. Calcd for $C_{12}H_{18}O_2$: C, 74.19; H, 9.34. Found: C, 74.1; H, 9.5.

Bicyclo[5.3.0]dec-1(7)-en-3-ol (7).—A solution of 1.32 g (6.8 mmol) of acetate **6** in 25 ml of ether was added dropwise with stirring to a solution of 1.50 g (39.5 mmol) of lithium aluminum hydride in 225 ml of ether. After 3 hr, 3 ml of water and 2.4 ml of 10% aqueous NaOH were added and stirring was continued for 1 hr. A small amount of anhydrous magnesium sulfate was added and the mixture was filtered and distilled, affording 1.02 g (99%) of alcohol **7**, bp 80° (bath temperature) at 0.4 mm (90% pure according to gas chromatography[21]): λ_{max}^{film} 3.00, 6.91, 9.58, 9.77, 9.95, and 10.75 μm; $\delta_{TMS}^{CCl_4}$ 3.65 (broad, H-3), 2.38, and 2.25 ppm (allylic H's). The analytical sample, mp 47.5–49.5°, was secured *via* preparatuve gas chromatography,[20] followed by short-path distillation and sublimation (25° at 0.2 mm).

Anal. Calcd for $C_{10}H_{16}O$: C, 78.90; H, 10.59. Found: C, 79.1; H, 10.6.

Bicyclo[5.3.0]dec-1(7)-ene (9).—A stirred solution of 0.38 g (2.5 mmol) of alcohol **7** in 2.7 ml of pyridine of 0° was treated dropwise with 1.17 ml (15.4 mmol) of methanesulfonyl chloride. After 20 min the mixture was slowly added to a solution of 5 ml of water in 20 ml of pyridine at 0° and the product was isolated with ether, affording 0.33 g (57%) of mesylate **8**: λ_{max}^{film} 6.91, 7.37, 8.34, 8.49, 10.25, 10.55, 10.95, 11.93, and 13.15 μm; $\delta_{TMS}^{CCl_4\text{-}CDCl_3}$ 2.99 ppm (CH_3SO_3).

The above mesylate in 1.7 ml of ethanol was added dropwise to a stirred solution of 0.41 g (59 mg-atoms) of lithium in 30 ml of ammonia at −78°. After 1 hr at −78° and 0.5 hr at −33° (reflux) ethanol was added dropwise to discharge the blue color, followed by solid ammonium chloride. The ammonia was allowed to evaporate through a mercury bubbler and the product was isolated with ether, affording 0.18 g of olefin **9** (55% pure according to gas chromatography[22]): λ_{max}^{film} 6.91, 7.65, 7.82, 8.12, and 9.35 μm: $\delta_{TMS}^{CDCl_3}$ 2.38 and 2.27 ppm (allylic H's).

The analytical sample, bp 70° (bath temperature) at 20 mm, was secured *via* preparative gas chromatography[23] followed by short-path distillation.

Anal. Calcd for $C_{10}H_{16}$: C, 88.16; H, 11.84. Found: C, 88.1; H, 12.1.

Bicyclo[5.3.0]dec-1(7)-en-3-one (10).—A stirred solution of 64 mg (0.42 mmol) of alcohol **7** in 10 ml of methylene chloride was treated with 640 mg (2.48 mmol) of Collins bispyridinechromium(VI) oxide reagent.[7] After 1 hr ether was added and the mixture was washed with aqueous sodium bicarbonate, water, and 10% aqueous HCl, dried over anhydrous potassium carbonate, and distilled, affording 53 mg (84%) of ketone **10**, bp 70° (bath temperature) at 0.05 mm (90% pure according to gas chromatography[21]): λ_{max}^{film} 5.86, 6.00, 6.97, 7.11, 7.49, 7.58, 7.78, 7.99, 8.21, 9.43, 9.80, and 10.08 μm.

The analytical sample was secured *via* preparative gas chromatography,[23] followed by short-path distillation.

Anal. Calcd for $C_{10}H_{14}O$: C, 79.96; H, 9.39. Found: C, 79.7; H, 9.2.

Bicyclo[5.3.0]dec-1-en-3-one (11).—A stirred mixture containing 120 mg of ketone **10**, comparable to that described above, and 0.25 g of sodium carbonate in 20 ml of methanol and 2 ml of water was heated at reflux for 3.75 hr. The product was isolated with ether, affording material shown by gas chromatography[24] to contain 65% of starting β,γ-unsaturated ketone **10** and 30% of conjugated ketone **11**. The latter component was isolated *via* preparative gas chromatography[23] and short-path distillation (80° at 0.05 mm): λ_{max}^{film} 3.32, 6.03, 6.90, 7.39, 7.98, 8.48, 9.53, 11.47, and 12.05 μm: $\delta_{TMS}^{CCl_4}$ 5.89 ppm (H-2).

Anal. Calcd for $C_{10}H_{14}O$: C, 79.96; H, 9.39. Found: C, 79.7; H, 9.5.

Treatment of the β,γ-unsaturated ketone **10** with ethanolic oxalic acid (15 mg/ml of 95% ethanol) at 66° for 15.5 hr afforded a mixture containing 51% of starting ketone **10** and 34% of conjugated ketone **11**.

9-Octal-1-one (12).—A solution of 100 mg of crude olefin **9** in 2.5 ml of pentane was treated at −78° with a stream of ozonized oxygen until the appearance of a blue coloration. The excess ozone was allowed to evaporate and the mixture was added to a stirred solution of 0.6 g of NaI and 0.7 ml of acetic acid in 1 ml of methanol at 0°. After 15 min at 0° and 1.5 hr at room temperature the mixture was shaken with aqueous sodium bisulfite and the product was isolated with ether.

The resulting dione (λ_{max}^{film} 5.87 μm) was stirred with 5 ml of 10% aqueous NaOH at 70° for 1.5 hr. The product was isolated with ether and purified *via* preparative gas chromatography,[20] affording the enone **12**: λ_{max}^{film} 6.02, 6.12, 6.88, 6.97, 7.20, 7.39, 7.56, 7.78, 7.91, 8.36, 8.86, 8.99, 9.62, 10.96, and 11.80 μm. This material was identified by spectral and gc comparison with an independently prepared sample.[6]

7a-Hydroxymethyl-2,4,5,6,7,7a-hexahydroindene (16).—A solution of 10.0 g (*ca.* 50 mmol) of keto ester **1**[25] (methyl, ethyl mixture) in 927 ml of ethyl acetate containing 185 μl of 70% perchloric acid and 89 ml of acetic anhydride[26] was allowed to stand for 8 min. The solution was washed with aqueous sodium bicarbonate and the product was isolated with ethyl acetate and distilled, affording 10.8 g (*ca.* 90%) of enol acetate **13**, bp 100° (0.05 mm): λ_{max}^{film} 5.67, 5.80, 6.00, 6.10, 6.94, 7.32, 8.30, 8.95, 9.30, 9.85, and 10.85 μm.

The above product in 250 ml of ethanol was added dropwise to a stirred solution containing 29 g of sodium borohydride in 1.21 l. of ethanol and 188 ml of water at 0°. After 45 min at 0° the mixture was stored at 5° for 35 hr and poured into 200 ml of 10% aqueous NaOH. The product was isolated with ether–benzene, affording 8.6 g (*ca.* 95%) of alcohol **14**: λ_{max}^{film} 3.00, 3.26, 5.80, 5.98, 6.90, 8.45, 9.35, and 9.69 μm.

An 8.0-g sample of the above alcohol in 25 ml of pyridine was stirred at 0° during the addition of 8.3 ml (109 mmol) of methanesulfonyl chloride. After 6 hr at room temperature the stirred

(20) A 13.5 ft × 0.5 in. column of 9% FFAP on 70–80 mesh Chromosorb G was used.

(21) A 22 ft × 0.12 in. column of 4% FFAP on 70–80 mesh Chromosorb G was used.

(22) A 22 ft × 0.12 in. column of 1% Carbowax 20M on 80–100 mesh Chromosorb G was used.

(23) A 13.5 ft × 0.5 in. column of 9% Dow Corning silicone oil 550 on 70–80 mesh Chromosorb G was used.

(24) A 15 ft × 0.12 in. column of 4% Dow Corning silicone oil 550 on 60–70 mesh Chromosorb G was used.

(25) W. G. Dauben, J. W. McFarland, and J. B. Rogan, *J. Org. Chem.*, **26**, 297 (1961).

(26) B. E. Edwards and P. N. Rao, *ibid.*, **31**, 324 (1966).

mixture was cooled to 0° and small chips of ice were added to destroy the excess acid chloride. The product was isolated with ether, affording 8.7 g (*ca.* 80%) of semisolid mesylate **15**: λ_{max}^{film} 3.29, 5.80, 5.98, 6.90, 7.40, 7.92, 8.20, 8.50, 9.10, 9.69, 10.10, 10.35, 11.92, and 13.16 μm.

The above product in 91 ml of ethanol and 48 ml of tetrahydrofuran was added with stirring to a solution of 16.1 g (2.31 g-atoms) of lithium in 1.35 l. of ammonia at −78°. After 1 hr at −78° and 1.5 hr at −33° (reflux) ethanol was added to discharge the blue color and solid ammonium chloride was added to destroy the basic alkoxides. The ammonia was allowed to evaporate through a mercury bubbler and the product was isolated with ether and distilled twice, affording 3.01 g (*ca.* 65%) of alcohol **16**, bp 90° (bath temperature) at 0.07 mm (95% pure according to gas chromatography[27]): λ_{max}^{film} 2.98, 3.28, 6.00, 6.90, 9.57, 9.80, and 12.60 μm; $\delta_{TMS}^{CCl_4-CDCl_3}$ 5.45 (broad, vinylic H) and 3.50 ppm (CH_2OH).

Anal. Calcd for $C_{10}H_{16}O$: C, 78.90; H, 10.59. Found: C, 79.2; H, 10.7.

Epoxidation of Unsaturated Alcohol 16.—A stirred solution of 0.80 g (5.26 mmol) of olefin **16** in 370 ml of chloroform and 75 ml of methylene chloride at −78° was treated with 4.0 g (17.9 mmol) of *m*-chloroperoxybenzoic acid (77% peroxy acid by titration). After 108 hr at −78° the mixture was poured into 10% aqueous NaOH and the product was isolated with chloroform and distilled, affording 0.71 g (80%) of oil, bp 120° (bath temperature) at 0.15 mm, shown to be an 85:15 mixture of the β-epoxide **18** and the α-epoxide **17** by gas chromatography:[27] λ_{max}^{film} 2.90, 6.92, 8.98, 9.52, 9.67, 10.82, 11.68, and 12.60 μm; $\delta_{TMS}^{CCl_4}$ 3.65 (CH_2OH) and 3.40 and 3.20 ppm (carbinyl H's of the α and β-epoxides, respectively).

Anal. Calcd for $C_{10}H_{16}O_2$: C, 71.39; H, 9.59. Found: C, 71.2; H, 9.5.

***trans*-3-Methyl-7a-acetoxymethyl-3a,4,5,6,7,7a-hexahydro-*cis*-indan-3a-ol (22).**—A solution of 100 mg (0.60 mmol) of alcohol **18** (15% **17**) in 3 ml of dioxane was added to hexane-washed NaH [from 50 mg (1.2 mmol) of 57% oil dispersion] and the mixture was stirred at reflux for 1 hr. The cooled solution was treated with 0.14 g (0.82 mmol) of benzyl bromide in 2 ml of dioxane and reflux was resumed for 12 hr. The product was isolated with ether and distilled, affording 112 mg (73%) of ether **19**, bp 140° (bath temperature) at 0.1 mm: λ_{max}^{film} 3.30, 6.87, 7.31, 9.05, 11.59, 13.55, and 14.31 μm; $\delta_{TMS}^{CCl_4}$ 7.34 (aromatic H's), 4.55 (benzylic H's), 3.55 (CH_2O, AB, J = 9, $\Delta\nu$ = 26.5 Hz), and 3.09 ppm (carbinyl H).

To 330 mg (1.28 mmol) of epoxide **19**, comparable to that described above, in 18 ml of tetrahydrofuran (THF) was added a solution of methylmagnesium bromide (from 6.6 g of Mg in 60 ml of THF) and the mixture was stirred at reflux for 66 hr. The product was isolated with ether–ethyl acetate and distilled, affording 362 mg of crude alcohol **20**, bp 130° (bath temperature) at 1.5 mm: λ_{max}^{film} 2.95, 3.31, 6.88, 7.31, 9.28, 9.74, 13.55, and 14.30 μm; $\delta_{TMS}^{CCl_4}$ 7.20 (aromatic H's), 4.40 (benzylic H's), 3.60 ($-CH_2O-$ multiplet), and 0.85 ppm (CH_3 doublet, J = 6 Hz).

To a 100-mg sample of the above alcohol in 1 ml of ether and 15 ml of ammonia at −33° (reflux) was added 120 mg of Na. After 1 hr ammonium chloride was added, the ammonia was allowed to evaporate through a mercury bubbler, and the product was isolated with ethyl acetate, affording 70 mg of diol **21** (70% pure according to gas chromatography[27]): λ_{max}^{film} 2.99, 6.85, 7.26, 9.45, and 9.78 μm.

A 400-mg sample of diol **21** comparable to that described above was stirred at room temperature overnight with 14 ml of pyridine and 10 ml of acetic anhydride. The product was isolated with ethyl acetate and distilled, affording 414 mg of white solid, bp 120° (bath temperature) at 0.05 mm. Crystallization from chloroform–hexane afforded 110 mg (24%) of acetate **22**, white needles, mp 104.5–107°: λ_{max}^{KBr} 2.87, 5.84, 6.85, 7.18, 7.30, 7.88, 9.60, 9.88, and 10.18 μm; $\delta_{TMS}^{CCl_4-CDCl_3}$ 4.07 (carbinyl CH_2), 2.05 (CH_3CO), and 0.90 ppm (CH_3 doublet, J = 6 Hz).

A second crop of 54 mg (12%) was obtained.

Anal. Calcd for $C_{13}H_{22}O_3$: C, 68.99; H, 9.80. Found: C, 69.0; H, 10.0.

Dehydration of Alcohol 22.—A solution of 46 mg (0.20 mmol) of alcohol **22** in 1.35 ml of pyridine was stirred at 0° and 0.12 ml of thionyl chloride was added dropwise. After 25 min, the solution was poured onto crushed ice and the product was isolated with ether and distilled, affording 37 mg (87%) of acetate **23** (98% pure according to gas chromatography),[22,27] bp 80° (bath temperature) at 0.03 mm: λ_{max}^{film} 5.75, 6.88, 7.25, 8.08, and 9.60 μm; $\delta_{TMS}^{CCl_4}$ 3.97 (carbinyl CH_2), 1.97 (CH_3CO), and 1.60 ppm (vinylic CH_3).

The same results were obtained when the dehydration was carried out for 1 hr at −30 to −40°.

Anal. Calcd for $C_{13}H_{20}O_2$: C, 74.96; H, 9.68. Found: C, 74.8; H, 9.8.

10-Acetoxymethyl-1(9)-octal-2-one (24).—A solution of 37 mg of olefin **23**, comparable to that described above, in 2.5 ml of pentane at −78° was treated with a stream of ozonized oxygen until the solution became blue. The excess ozone was allowed to evaporate and the precipitated ozonide was added to a stirred solution containing 0.3 g of NaI and 0.35 ml of acetic acid in 1 ml of methanol at 0°. After 1 hr at 0° and 1 hr at room temperature, the mixture was shaken with aqueous sodium bisulfite and the product was isolated with ethyl acetate and distilled, affording 30 mg of dione, bp 150° (bath temperature) at 0.1 mm (80% pure according to gas chromatography[27]): λ_{max}^{film} 5.74, 5.84, 6.90, 7.27, 7.35, 8.10, and 9.63 μm.

The above sample was refluxed with 18 mg of *p*-toluenesulfonic acid monohydrate in 12 ml of benzene for 17.5 hr, with removal of water *via* a Dean–Stark trap. The product was isolated with ethyl acetate and distilled (short path), affording 21 mg of enone **24** (85% pure according to gas chromatography[27]): λ_{max}^{film} 3.30, 5.75, 5.98, 6.16, 6.89, 7.29, 8.10, 9.55, 11.53, and 12.92 μm; $\delta_{TMS}^{CCl_4}$ 5.75 (vinylic H), 4.25 (carbinyl CH_2, AB, J = 12, $\Delta\nu$ = 13 Hz), and 2.00 ppm (CH_3CO).

The spectral properties and gas chromatographic behavior of this material were indistinguishable from those of an authentic sample.[12]

10-Hydroxymethyl-1(9)-octalin (28).—To a solution of 55.39 g (*ca.* 0.34 mol) of keto ester **25** (methyl, ethyl mixture) in 108 ml of 0.074 *M* sodium methoxide at −5 to −15° was added dropwise over a period of 3 hr a solution of 23.4 g (0.339 mol) of methyl vinyl ketone in 75 ml of methanol. After addition was complete 10 ml of 1 *M* sodium methoxide was added and the mixture was allowed to reach room temperature. An additional 250 ml of 1 *M* methoxide was then added and, after 12 hr, acetic acid was added to neutralize the base and the product was isolated with benzene and distilled, affording 60.3 g (*ca.* 83%) of keto ester **26**, bp 110–125° at 0.25 mm: λ_{max}^{film} 3.31, 5.79, 5.98, 6.15, 6.92, 7.00, 7.52, 7.75, 7.96, 8.14, 8.27, 8.50, 9.20, 9.72, 9.88, 10.25, 10.67, and 11.65 μm.

A 5.68-g sample of the above keto ester, 5.8 ml of 1,2-ethanedithiol, and 1.4 ml of boron trifluoride etherate in 12 ml of acetic acid was stirred at 0° for 2 hr and kept at 5° for 9 hr. The product was isolated with ether and freed of excess ethanedithiol under vacuum, affording 7.60 g of thioketal **27**: λ_{max}^{film} 3.27, 5.80, 6.95, 7.02, 7.78, 8.00, 8.20, 8.45, 8.89, 9.21, 9.90, 10.15, and 11.62 μm.

The above-described thioketal in 500 ml of ethanol was stirred at reflux with 75 ml (45 g) of W-2 Raney nickel for 2 hr. The cooled mixture was filtered and concentrated by distillation, and the product was isolated with ether and distilled, affording 4.26 g (*ca.* 80%) of ester, bp 90° (bath temperature) at 0.06 mm: λ_{max}^{film} 3.29, 5.78, 6.92, 7.72, 7.91, 8.21, 8.61, 8.83, 9.18, 9.75, 9.98, and 12.35 μm.

The above sample in 50 ml of ether was added to 2.50 g of lithium aluminum hydride in 300 ml of ether with stirring. After 12 hr, 5 ml of water and 4 ml of 10% aqueous NaOH were added and the mixture was stirred for 1 hr, treated with anhydrous magnesium sulfate, and filtered. Distillation afforded 3.49 g (99%) of alcohol **28**, bp 100° (bath temperature) at 0.02 mm, mp 67–68° (lit.[14] mp 69.5–70°): λ_{max}^{KBr} 3.00, 3.29, 6.90, 7.30, 7.88, 8.00, 8.73, 9.54, 9.67, 10.01, 10.18, 10.99, 11.25, 11.50, 11.87, 12.28, and 12.67 ppm; $\delta_{TMS}^{CCl_4-CDCl_3}$ 5.55 (vinylic H) and 3.60 ppm (CH_2OH).

7a-Benzyloxymethyl-2,4,5,6,7,7a-hexahydroindene-3-carboxaldehyde (30).—A solution of 3.33 g (20.1 mmol) of alcohol **28** in 170 ml of dioxane was added to heptane-washed NaH (from 1.93 g of 57% oil dispersion) and the mixture was stirred at reflux for 2 hr. The cooled solution was treated with 3.48 ml (5.00 g, 29.2 mmol) of benzyl bromide and refluxing was continued for 16 hr whereupon the product was isolated with ether and distilled, affording 5.83 g of ether **29** contaminated with benzyl bromide, bp 140° (bath temperature) at 0.01 mm: λ_{max}^{film} 3.30, 6.71, 6.91, 7.39, 8.35, 9.15, 9.78, 11.02, 11.52, 13.68, and 14.41 μm; $\delta_{TMS}^{CCl_4}$ 7.20 (aromatic H's), 5.35 (vinylic H), 4.40

(27) A 6 ft × 0.12 in. column of 10% UCON W-98 on 80–100 mesh Diatoport-S was used.

(benzylic H's), and 3.40 ppm (carbinyl CH_2, AB, $J = 9$, $\Delta\nu = 12$ Hz). The analytical sample was obtained by two successive short-path distillations.

Anal. Calcd for $C_{18}H_{24}O$: C, 84.32; H, 9.44. Found: C, 84.4; H, 9.6.

A 240-mg sample of the above olefin in 16 ml of methylene chloride at −78° was treated with a stream of ozonized oxygen until the solution became blue. The excess ozone was allowed to evaporate and 1.6 ml of acetic acid followed by 0.8 g of zinc powder were added with stirring at −78°. The mixture was allowed to reach room temperature, stirred for 10 min, and filtered. The product was isolated with ether, affording 242 mg of crude keto aldehyde: λ_{max}^{film} 3.30, 3.69, 5.80, 5.86, 6.71, 6.91, 7.35, 7.91, 8.33, 9.11, 9.76, 13.62, and 14.38 μm; $\delta_{TMS}^{CCl_4}$ 9.58 (CHO triplet, $J = 2$ Hz), 7.20 (aromatic H's), 4.42 (benzylic H's), and 3.47 ppm (carbinyl CH_2, AB, $J = 9$, $\Delta\nu = 11$ Hz).

The above material was stirred at 60° with 240 mg of sodium carbonate and 2 ml of water in 40 ml of ethanol for 22 hr. The product was isolated with ether–benzene and chromatographed on silica gel to give 120 mg (54%) of unsaturated aldehyde **30**: λ_{max}^{film} 3.28, 3.65, 5.98, 6.10, 6.68, 6.88, 7.38, 7.89, 8.28, 9.12, 9.72, 11.81, 13.60, and 14.35 μm; $\delta_{TMS}^{CCl_4}$ 9.88 (aldehyde CH), 7.20 aromatic H's), 4.43 (benzylic H's), and 3.37 ppm (carbinyl CH_2).

3,7a-Bishydroxymethyl-5,6,7,7a-tetrahydroindan (32).—To a solution of triphenylmethyllithium[28] (from 1.54 g of triphenylmethane and 3.8 ml of 1.5 *M* methyllithium) in 1,2-dimethoxyethane (7 ml) was added 0.400 g of aldehyde **30**, comparable to that described above, in 7 ml of 1,2-dimethoxyethane dropwise with stirring over a 0.5-hr period. After 1 hr the solution was added to a well-stirred solution containing 20 g of sodium borohydride and 20 ml of water in 152 ml of ethanol. The solution was stirred for 3.5 hr and poured into 10% aqueous NaOH, and the product was isolated with ether–benzene. The triphenylmethane was removed by precipitation from cold pentane and filtration through a column of silica gel, affording 233 mg of alcohol **31** contaminated with the isomeric allylic alcohol: λ_{max}^{film} 2.92, 3.31, 6.70, 6.91, 7.38, 8.32, 9.15, 9.33, 9.72, 11.26, 13.62, and 14.35 μm; $\delta_{TMS}^{CCl_4}$ 7.15 (aromatic H's), 5.40 (vinylic H), 4.35 (benzylic H's), 3.4–3.2 (C-3 carbinyl CH_2), and 3.11 ppm (C-7a carbinyl CH_2). The analytical sample was prepared by preparative layer chromatography (silica) followed by short-path distillation (120° at 0.03 mm).

Anal. Calcd for $C_{18}H_{24}O_2$: C, 79.37; H, 8.88. Found: C, 79.7; H, 9.1.

To a stirred solution of 0.37 g of Li wire in 70 ml of ammonia at −78° was added 0.23 g of alcohol **31**, comparable to that described above, in 3 ml of tetrahydrofuran and 2 ml of *tert*-butyl alcohol. After 1 hr at −78° and 2 hr at −33° (reflux) ethanol was slowly added to discharge the blue color and the ammonia was allowed to evaporate. The product was isolated with ethyl acetate, purified by preparative layer chromatography (silica), and distilled to give 0.11 g (41% based on aldehyde **30**) of diol **32**, bp 160° (bath temperature) at 0.10 mm: λ_{max}^{film} 3.00, 5.98, 6.88, 8.00, 8.65, 9.75, 10.45, and 11.33 μm; $\delta_{TMS}^{CCl_4-CDCl_3}$ 5.53 (vinylic H) and 3.8–3.3 ppm (−CH_2OH multiplet).

Anal. Calcd for $C_{11}H_{18}O_2$: C, 72.49; H, 9.95. Found: C, 72.4; H, 10.2.

3-Methyl-7a-hydroxymethyl-5,6,7,7a-tetrahydroindan (33).—To a stirred solution of 82 mg (0.30 mmol) of alcohol **31**, comparable to that described above, in 0.7 ml of pyridine at 0° was added 0.135 ml (1.78 mmol) of methanesulfonyl chloride. After 0.5 hr at 0° and 2 hr at room temperature, the mixture was cooled to 0° and was added slowly to a solution containing 2 ml of water in 5 ml of pyridine at 0°. The product was isolated with ether, affording 79 mg of mesylate: λ_{max}^{film} 3.28, 6.90, 7.40, 8.52, 9.15, 9.75, 10.30, 10.63, 11.24, 12.00, 13.45, and 14.36 μm; $\delta_{TMS}^{CCl_4}$ 7.20 (aromatic H's), 5.55 (vinylic H), 4.42 (benzylic H's), 4.02 and 3.92 (CH_2OMs, two doublets, $J = 1$–2 Hz), 3.17 (C-7a carbinyl CH_2), and 2.75 ppm (CH_3SO_3).

The above mesylate in 0.67 ml of ethanol and 0.35 ml of tetrahydrofuran was added dropwise to a stirred solution of 0.124 g of lithium in 10 ml of ammonia at −78°. After 1.5 hr at −78° and 1 hr at −33° (reflux) ammonium chloride was added, the ammonia was allowed to evaporate through a mercury bubbler, and the product was isolated with ether and distilled, affording 35 mg of alcohol **33**, bp 95° (bath temperature) at 0.04 mm (87% pure according to gas chromatography[22]): λ_{max}^{film} 2.96, 3.29, 6.89, 7.31, 8.00, 9.76, 10.33, 10.43, 10.71, 11.04, 11.35, 11.61, and 12.95 μm; $\delta_{TMS}^{CCl_4}$ 5.50 (vinylic H), 3.40 (carbinyl CH_2), and 1.04 ppm (CH_3 doublet, $J = 7$ Hz). The anaytical sample, mp 27–33°, was prepared by preparative layer chromatography (silica) and two successive short-path distillations.

Anal. Calcd for $C_{11}H_{18}O$: C, 79.46; H, 10.91. Found: C, 79.6; H, 10.9.

Cyclization of Diol 32 to Ether 34.—A stirred solution of 0.103 g of diol **32** in 2 ml of pyridine at −40° was treated dropwise with 47 μl (71 mg) of methanesulfonyl chloride. After 4 hr at −10° and 6 hr at room temperature the mixture was cooled to 0° and ice chips were slowly added. The product was isolated with ether, affording 0.128 g of crude hydroxy mesylate: λ_{max}^{film} 2.94, 3.31, 6.87, 7.45, 8.53, 9.72, 10.27, 10.65, and 11.95 μm; $\delta_{TMS}^{CCl_4-CDCl_3}$ 5.68 (vinylic H) and 3.00 ppm (CH_3SO_3).

The above material in 35 ml of dioxane was treated with pentane-washed NaH (from 0.35 g of 57% mineral oil dispersion) and the mixture was stirred at room temperature for 2 hr, at 70° for 1 hr, and at reflux for 3 hr. The cooled mixture was poured onto ice and the product was isolated with pentane and distilled, affording 35 mg of ether **34**, bp 90° (bath temperature) at 20 mm: λ_{max}^{film} 6.90, 7.84, 8.28, 8.73, 9.03, 9.28, 10.02, 10.16, 10.28, 10.43, 11.14, 11.82, 12.07, and 12.48 μm; $\delta_{TMS}^{CCl_4}$ 5.35 (vinylic H, unresolved triplet) and 3.6–3.3 ppm (−CH_2O− multiplet). The analytical sample was obtained by preparative layer chromatography (silica) and short-path distillation.

Anal. Calcd for $C_{11}H_{16}O$: C, 80.44; H, 9.82. Found: C, 80.2; H, 10.0.

3-Acetylbicyclo[5.3.0]dec-1(7)-en-3-ol (36).—The method of Corey was employed.[17] A solution of 1.8 g of 1,3-dithiane in 60 ml of tetrahydrofuran was cooled to −30° and 5.4 ml of 2.8 *M* butyllithium was added with stirring. After 1.5 hr, the solution was allowed to reach −5° and 2.26 g of methyl iodide was added dropwise. The mixture was kept at −5° for 20 hr and a 20-ml aliquot was removed, cooled to −30°, and treated with 2 ml of 2.8 *M* butyllithium with stirring. After 2.25 hr, a solution of 0.59 g of ketone **10** in 5 ml of tetrahydrofuran was added. After 36 hr at −5° the reaction mixture was concentrated under reduced pressure and the product was isolated with ether, affording 1.15 g of crude alcohol **35** whose infrared spectrum showed unreacted ketone **10**. Accordingly the mixture was subjected to the above procedure (54 hr at −5°) whereupon 1.3 g of alcohol **35** was obtained nearly free of ketone **10** but contaminated with 2-methyl-1,3-dithiane: λ_{max}^{film} 2.88, 5.88 (trace), 6.95, 7.08, 7.32, 7.89, 8.10, 8.42, 9.49, 9.93, and 11.02 μm; $\delta_{TMS}^{CCl_4}$ 3.0–2.6 (−SCH_2− multiplet) and 1.60 ppm (CH_3).

The above thioketal alcohol in 56 ml of acetonitrile and 2.9 ml of water containing 3.3 g of mercuric chloride and 1.96 g of cadmium carbonate was stirred at 55° for 11 hr.[17] An additional 0.3 g of mercuric chloride and 0.2 g of cadmium carbonate were then added (an aliquot showed the presence of starting material) and heating was continued for 3 hr. The mixture was filtered and the product was isolated with ether and distilled, affording 0.49 g of keto alcohol **36**, bp 120° (bath temperature) at 0.05 mm: λ_{max}^{film} 2.90, 5.86, 6.97, 7.44, 8.50, 9.10, and 9.85 μm; $\delta_{TMS}^{CCl_4}$ 2.35 (allylic H's) and 2.16 ppm (CH_3CO). The analytical sample was prepared by preparative layer chromatography (silica) and short-path distillation.

Anal. Calcd for $C_{12}H_{18}O_2$: C, 74.19; H, 9.34. Found: C, 74.0; H, 9.4.

3-Acetylbicyclo[5.3.0]dec-1(7)-en-3-yl Acetate (37).—The procedure of Saucy was employed.[29] A 0.19-g sample of the crude keto alcohol **36** was stirred with 0.59 ml of acetic anhydride and 5.5 μl of phosphoric acid for 0.5 hr. The product was isolated with ether and partially purified by preparative layer chromatography (silica) and distillation, affording 0.11 g of material, bp 120° (bath temperature) at 0.2 mm, which contained 80% of acetoxy ketone **37** and 18% of ketone **10** according to the gas chromatogram:[27] λ_{max}^{film} 5.74, 5.81, 6.97, 7.32, 7.42, 8.01, 8.11, 8.41, 9.26, and 9.83 μm. The analytical sample was prepared from comparable material by preparative layer chromatography (silica) and two successive short-path distillations.

Anal. Calcd for $C_{14}H_{20}O_3$: C, 71.16; H, 8.53. Found: C, 71.2; H, 8.5.

3-Acetylbicyclo[5.3.0]dec-1(7)-ene (38).—To a stirred solution of 1.48 g of Ca turnings in 150 ml of ammonia at −78° was added 110 mg of 80% pure (see above) acetoxy ketone **37** dissolved in 6 ml of tetrahydrofuran. After 10 min sufficient bromo-

(28) H. O. House and B. M. Trost, *J. Org. Chem.*, **30**, 1341 (1965).

(29) G. Saucy, *Helv. Chim. Acta*, **42**, 1945 (1959).

benzene was added dropwise to discharge the blue color and excess ammonium chloride was added. The ammonia was allowed to evaporate and the product was isolated with ether and purified by short-path distillation, preparative layer chromatography (silica), and short-path distillation (100° at 0.15 mm) to give 49 mg (74%) of ketone **38**: λ_{max}^{film} 5.83, 6.94, 7.42, 8.18, 8.33, and 9.61 μm; $\delta_{TMS}^{CCl_4-CDCl_3}$ 2.05 ppm (CH_3CO).

Anal. Calcd for $C_{12}H_{18}O$: C, 80.85; H, 10.18. Found: C, 80.8; H, 10.2.

2-(3-Bicyclo[5.3.0]dec-1(7)-enyl)-2-propanol (39).—To a stirred solution containing 34 mg of ketone **38** in 3 ml of ether at 0° was added 1.0 ml of 1.5 *M* methyllithium. After 3.5 hr at room temperature, the mixture was poured onto ice and the product was isolated with ether. The material thus secured still contained 15% of ketone **38**.[27] The above procedure was thus repeated and the product distilled, affording 35 mg (94%) of alcohol **39**, bp 85° (bath temperature) at 0.2 mm, shown to be 85% pure by gas chromatography:[27] λ_{max}^{film} 2.97, 6.95, 7.32, 7.67, 8.87, 10.50, 11.02, 11.32, and 11.61 μm; $\delta_{TMS}^{CCl_4}$ 1.10 ppm (CH_3). The analytical sample secured by preparative layer chromatography (silica) and distillation exhibited mp 54–55.5° after sublimation at 25° (0.04 mm).

Anal. Calcd for $C_{13}H_{22}O$: C, 80.35; H, 11.41. Found: C, 80.4; H, 11.4.

Registry No.—**2** methyl ester, 29494-06-2; **2** ethyl ester, 29494-34-6; **3** methyl ester, 29494-07-3; **3** ethyl ester, 29494-35-7; **4**, 29494-08-4; **5**, 29494-09-5; **6**, 29494-10-8; **7**, 29494-11-9; **8**, 29494-12-0; **9**, 7125-60-2; **10**, 29494-14-2; **11**, 29494-15-3; **13** methyl ester, 29494-16-4; **13** ethyl ester, 29494-36-8; **14** methyl ester, 29494-17-5; **14** ethyl ester, 29576-49-6; **15** methyl ester, 29494-18-6; **15** ethyl ester, 29494-37-9; **16**, 29494-19-7; **17**, 29478-14-6; **18**, 29478-15-7; **19**, 29478-16-8; **20**, 29478-17-9; **21**, 29478-18-0; **22**, 29478-19-1; **23**, 29494-20-0; **26** methyl ester, 29494-21-1; **26** ethyl ester, 7478-39-9; **27** methyl ester, 29494-22-2; **27** ethyl ester, 2088-98-4; desulfurized **27** methyl ester, 29494-24-4; desulfurized **27** ethyl ester, 29494-25-5; **29**, 29494-26-6; **30**, 29494-27-7; **31**, 29478-20-4; **31** mesylate, 29576-48-5; **32**, 29478-21-5; **32** monomesylate, 29472-24-0; **33**, 29478-22-6; **34**, 29494-28-8; **35**, 29494-29-9; **36**, 29494-30-2; **37**, 29494-31-3; **38**, 29494-32-4; **39**, 29494-33-5.

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The Acid-Catalyzed Alkylation and Cyclialkylation of the Cymenes with Isobutylene and Related Olefins[1a]

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The acid-catalyzed reactions of *o*-, *m*-, and *p*-cymene with isobutylene, diisobutylene, and triisobutylene give complex mixtures of hydrocarbon products. *o*-Cymene forms only alkylation products, whereas *p*-cymene gives predominantly cyclialkylation products, with only one case of alkylation. *m*-Cymene occupies an intermediate position, providing both alkylation and cyclialkylation products. The reactions of *m*- and *p*-cymene with these olefins afford indans and tetralins as cyclialkylation products. In the cyclialkylation products from *m*-cymene, the point of ring closure (ortho or para position to the methyl group) is strongly influenced by an alkyl group at the 5 position of *m*-cymene. Several acidic materials were used to catalyze the reactions of *p*-cymene with isobutylene, diisobutylene, and triisobutylene, and their effectiveness is compared. Some new hydrocarbons were isolated and identified. These are obtained from alkylation and cyclialkylation of the starting olefin or result from olefins produced in the reaction system *via* polymerization, rearrangement, and fragmentation.

Cyclialkylation reactions initiated by hydride ion abstraction were discovered by Pines and coworkers.[2a] They found that aromatic hydrocarbons having α tertiary hydrogens may undergo hydride ion abstraction by carbonium ions generated in the reaction medium. Their mechanism[2a] is shown in Scheme I using isobutylene as the olefin to give 1,1,3,3,5-pentamethylindan (**2**), first identified by Schlatter.[2b] As pointed out by Barclay,[2c] alkylation competes with cyclialkylation. Alkylation will predominate unless the aromatic hydrocarbons used are substituted so as to sterically hinder alkylation reactions. In addition, branched olefins (or compounds such as branched-chain alcohols which can generate such olefins in acidic media) seem necessary since straight-chain alcohols have been reported[2c,d] to react with *p*-cymene to give only alkylation products.

A variety of substituted indans, hydrindacenes, and tetralins have been prepared[2c] with *p*-cymene, whereas Barclay[2e] used 1,3,5-triisopropylbenzene and diisobutylene to prepare a neopentylindan. Most of the work has been with *p*-cymene, *m*- and *o*-cymene[2c,f] having been used in only a few cases, and no previous studies have dealt extensively with minor products.

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