mp 115 °C); $[\alpha]^{25}_J$ -7.5° (c 0.01, CH_3OH); lit.[5] $[\alpha]^{20}_D$ -9.2°; ^{13}C NMR (15.08 MHz, D_2O) δ 181.67, 177.77, 38.40, 36.90, 17.15.

Stereochemistry of the 2,5-Dimethylcyclopentanones. Commercial 2,5-dimethylcyclopentanone was reduced by $LiAlH_4$ by usual method.[9] 1,3-Dimethylcyclopentene was prepared by the method of Rei.[3] The hydroboration was carried out by the procedure of Brown et al.[8]

^1H NMR (250 MHz) (δ) follow.

cis,cis-2,5-Dimethylcyclopentanol: 3.71 (t, 3.7, 1-H), 2-CH_3 and 5-CH_3 are not visible (too small concentration).

trans,trans-2,5-Dimethylcyclopentanol: 3.00 (t, 3.0, 1-H), 1.03 (d, 6.5, 2-CH_3 and 5-CH_3).

cis,trans-2,5-Dimethylcyclopentanol: 3.57 (q, 4.5 and 6, 1-H), 0.97 (d, 7, 2-CH_3), 0.99 (d, 7, 5-CH_3).

Acknowledgment. We thank Mme M. Bon (Laboratoire des Composés Azotés Polyfonctionnels, Université P. Sabatier, Toulouse) for NMR spectra at 250 MHz and Dr. A. Collet (Collège de France) for CD curve.

Registry No. (±)-**3**, 93301-81-6; **3**, 66166-86-7; **3'**, 93184-37-3; **4**, 6672-39-5; **5**, 93301-79-2; **5'**, 93301-80-5; *cis,cis*-2,5-dimethylcyclopentanol, 65404-79-7; *trans,trans*-2,5-dimethylcyclopentanol, 63057-29-4; *cis,trans*-2,5-dimethylcyclopentanol, 65378-78-1.

(8) Brown, H. C.; Zweifel, C. *J. Am. Chem. Soc.* **1959**, *91*, 4106.
(9) Gannon, W. F.; House, H. O. "Organic Syntheses"; Wiley: New York, 1973; Collect. Vol. 5, p 294.

Intramolecular Simmons-Smith Reaction and Other Synthetic Alternatives to Cyclopropanation of Dienic Diazoketones. Parallel Decomposition Pathways of a Sterically Congested Diazoketone and Its Vinylcyclopropane under Thermal, Photolytic, Acid-Catalyzed, and Radical-Release Conditions

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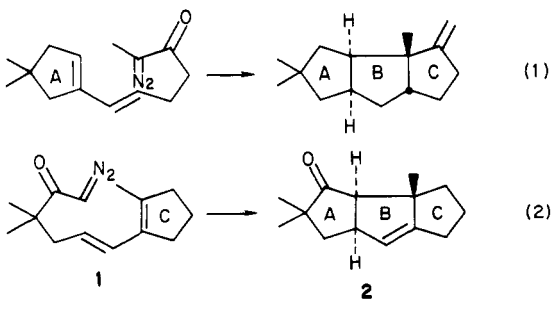
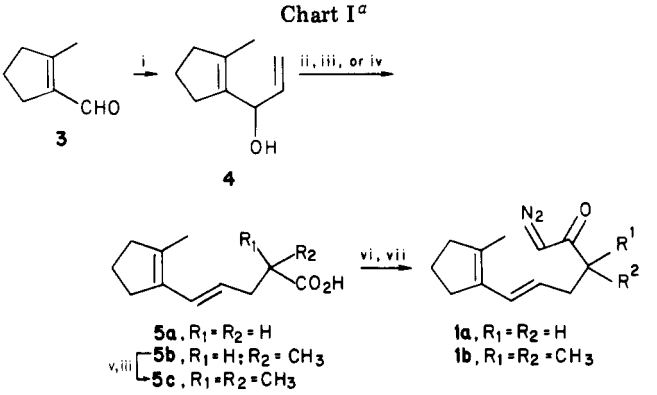
The linearly fused triquinane sesquiterpene hirsutene has been synthesized in our laboratory by the cyclopropanation and subsequent rearrangement of a dienic diazoketone using the [4 + 1] annulation strategy shown



(1) (a) Fellow of the Alfred P. Sloan Foundation, 1981-1985; Recepient of the Research Cancer Development Award, 1984-1989 (NIH-AI-00564). (b) Contribution from the Department of Chemistry, Illinois Institute of Technology, Chicago, IL 60616.
(2) Hudlicky, T.; Kutchan, T. M.; Wilson, S. R.; Mao, D. T. *J. Am. Chem. Soc.* **1980**, *102*, 6351.

Chart I[a]



[a] Reagents: (i) $CH_2CHMgBr/THF$; (ii) $RCH_2C(OEt)_3/H^+/\Delta$; (iii) KOH/H_2O; (iv) $(CH_3)_2CHCOCl/Et_3N$, then LDA/THF (-78 °C → 25 °C); (v) LDA, THF/MeI; (vi) $(COCl)_2$/benzene; (vii) CH_2N_2/Et_2O.

in eq 1.[2] We assumed that the reversal of the order of the ring-closing sequence of this methodology applied to the diazoketone **1** depicted in eq 2 would eventually lead to the tricyclic ketone **2** containing the necessary ring A oxygenation for eventual elaboration to coriolins.

During the past few years, we have developed a reliable method of intramolecular cyclopentene annulation via the cyclopropanation-cyclopentene rearrangement[3] or the acid-catalyzed decomposition[4] of dienic diazoketones. We were especially interested in testing the conditions of sequential radical release of dihalides such as **6** (Chart II) anticipating two consecutive carbon-carbon bond forming steps in direct parallel to the behavior of diazoketones under the conditions of acid catalysis. Since the literature contained examples of radical closures elicited by the interaction of olefins with halides using the $R_3SnH/AIBN$ system[5] or photolysis,[6] the extrapolation to a diene-geminal dihalide system seemed a logical one. The cyclopentene portion of diazoketone **1** and cyclopropane **7** contains unfavorable steric disposition, and since the rearrangements of *congested* vinylcyclopropanes to cyclopentenes tend to be sluggish,[8] we had hoped to test alternate methods of carbon-carbon bond formation on these substrates. In this paper we report on the parallel behavior of this diazoketone and its derivatives under a variety of conditions.

Diazoketones **1** were prepared as outlined in Chart I. The dimethylated dienic acid **5c** was prepared by the application of Claisen rearrangement of the enolate anion derived from the isobutyrate of alcohol **4** under conditions developed by Ireland[7] or by the methylation (LDA/MeI) of the ester of the monomethyl acid **5b** obtained by the rearrangement of **4** in refluxing triethyl orthopropionate

(3) For recent examples of this methodology, see: (a) Short, R. P.; Revol, J. M.; Ranu, B. C.; Hudlicky, T. *J. Org. Chem.* **1983**, *48*, 4453. (b) Govindan, S. V.; Hudlicky, T.; Koszyk, F. J. *J. Org. Chem.* **1983**, *48*, 3581. (c) Hudlicky, T.; Govindan, S. V.; Reddy, D. B.; Kulp, T.; Still, B.; Sheth, J. P. *J. Org. Chem.* **1983**, *48*, 3422. (d) Short, R. P.; Hudlicky, T. *J. Org. Chem.* **1982**, *47*, 1522. (e) Hudlicky, T.; Koszyk, F. J.; Dochwat, D.; Cantrell, G. L. *J. Org. Chem.* **1981**, *46*, 2911. (f) Hudlicky, T.; Kutchan, T. M.; Koszyk, F. J.; Sheth, J. P. *J. Org. Chem.* **1980**, *45*, 5020.
(4) For application of this methodology to total synthesis of filifolone, see: Hudlicky, T.; Kutchan, T. M. *Tetrahedron Lett.* **1980**, *21*, 691.
(5) Hart, D. J.; Tsai, Y. M. *J. Am. Chem. Soc.* **1982**, *104*, 1430. Curran, D. P.; Rakiewicz, D. M. 187th National Meeting of the American Chemical Society St. Louis, MO, April 1984; Abstract 30.
(6) Kropp, P. J.; Pienta, N. J. *J. Org. Chem.* **1983**, *48*, 2084.
(7) Ireland, R. E.; Mueller, R. H.; Willard, A. K. *J. Am. Chem. Soc.* **1976**, *98*, 2868.
(8) Ketley, A. D.; Berlin, A. J.; Fischer, L. P. *J. Org. Chem.* **1966**, *31*, 2648. Hudlicky, T.; Kutchan, T. M.; Naqvi, S. M. *Org. React. (N.Y.)* **1984**, *33*, 247.

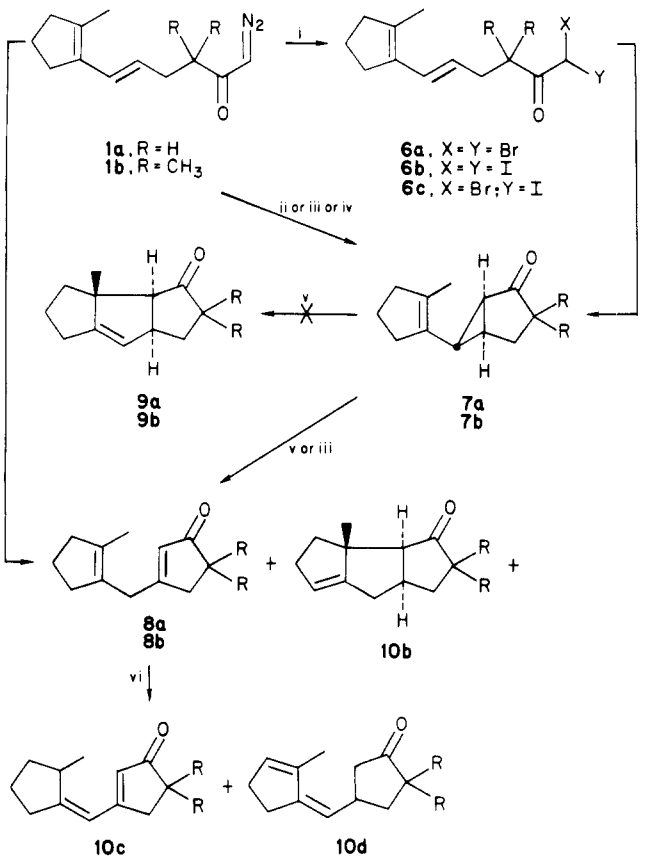
0022-3263/85/1950-0123$01.50/0

Table I. Product Distribution from Decompositions of Diazoketone 1b and Its Derivatives

starting material	conditions	products (% yield) 7b[a]	7b	9b	10b	10c	10d
1b	$CuSO_4$/benzene	96					
1b	BF_3·Et_2O	trace	trace				82
1b	$h\nu$, hexane	64					
1b	$TiCl_4$ or $SnCl_4$ in benzene		60				
6b	AIBN, Bu_3SnH/Δ[b]	20					
6c	AIBN, Bu_3SnH/Δ[b]	45					
7b	580 °C, $PbCO_3$, Vycor		72		5	10	
7b	$TiCl_4$ or $SnCl_4$ in benzene, 6 °C		68				
7b	$h\nu$, hexane	inert					
7b	AIBN, Bu_3SnH	inert					
8b	$h\nu$, hexane					60	

[a] Isolated yields. [b] These reactions were performed on the dihalides generated in situ from **1b** and not subjected to purification.

Chart II[a]

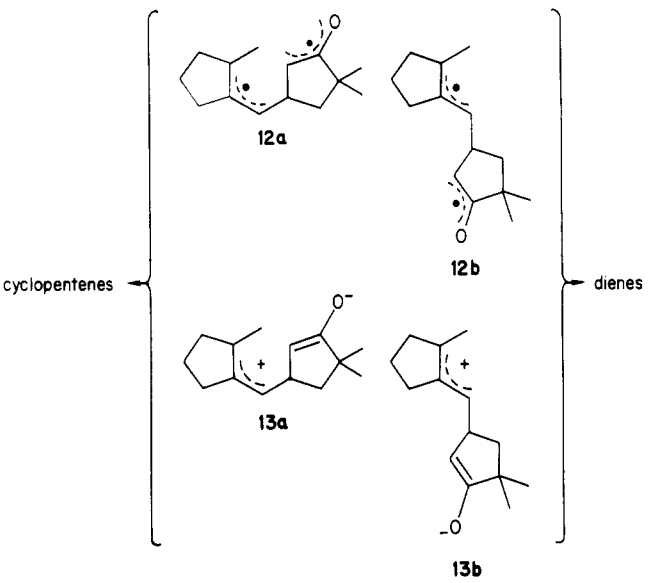


[a] Reagents: (i) XY in Et_2O; (ii) $CuSO_4$/benzene/Δ; (iii) BF_3·Et_2O/benzene/6 °C/10 s or $TiCl_4$/benzene; (iv) Bu_3SnH/AIBN/benzene or toluene/Δ; (v) 580 °C/$PbCO_3$/Vycor; (vi) $h\nu$/hexane/2 h.

followed by hydrolysis. The former method proved superior in yield (Chart I). The model diazoketone **1a** gave cyclopropane **7a** in high yield on exposure to $CuSO_4$ in refluxing benzene (Chart II). The pyrolysis of this substrate under the usual conditions[3] gave essentially a single product identified as enone **8a**. The expected tricyclic ketone **9a** was not isolated from the reaction mixture. The dimethylated diazoketone **1b** gave a high yield of vinylcyclopropane **7b** whose pyrolysis furnished ~70% yield of enone **8b**. From the small fraction of minor products, the tricyclic ketone **10b** was isolated in a yield of <5% in addition to dienes **10c** and **10d**. The yields of tricyclic materials, either **9** or **10**, did not improve when the temperature of pyrolyses was raised (a usual remedy in similar cases).[8]

We next turned our attention to acid-catalyzed rearrangements of **1b**. Expecting to obtain the tricyclic ketones

Scheme I

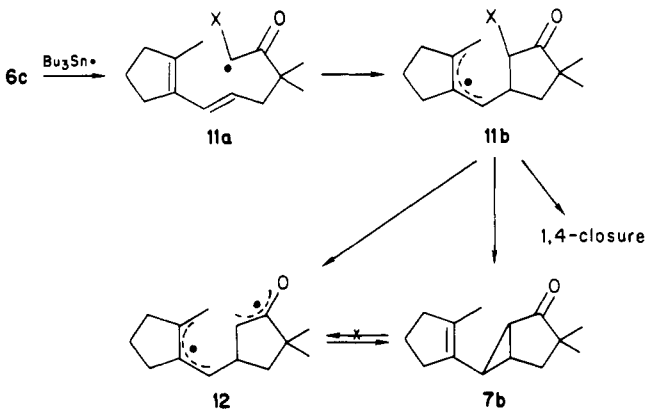


9 or **10** in analogy with our work on filifolone,[4] we were surprised to obtain a product crosssection essentially identical with that of pyrolyses. Several systems were used for this rearrangement: BF_3·$Et_2O(CH_2Cl_2)$, $CF_3CO_2H(CH_2Cl_2)$, $SnCl_4$(benzene), $TiCl_4$(benzene), *p*-TsOH(benzene), $HBF_4(CH_2Cl_2)/(CHCl_3)$, and others.[9] In all experiments the major product was the enone **8b** or its conjugated isomers **11**, **10c**, and **10d**. We list in Table I only those conditions which gave preparatively useful results.

To our further surprise, the same products were isolated when the vinylcyclopropane **7b** was exposed to identical reaction conditions. We interpreted these observations in the following way: The pyrolyses generate a biradical species (**12**) which can exist in either cisoid (**12a**) or transoid (**12b**) conformation (Scheme I). Similarly, the zwitterion **13** or, more likely, its protonated enol presumably generated from **1b** can assume cisoid or transoid conformations **13a** and **13b**, respectively. Of these, only the cisoid species can undergo carbon–carbon bond formation leading to cyclopentene. The presence of vinyl substituents retards the tendency to assume the cisoid conformation, thereby allowing the less hindered, transoid species to predominate and to furnish the competing dienic products which arise by normal hydrogen shift processes. Although these results were not encouraging in terms of the ultimate objective of producing tricyclic ketones **9** or **10**, they provided a hint that more sterically favorable

(9) See, for example: ref 4; Smith, A. B., III; Dieter, R. K. *J. Org. Chem.* **1977**, *42*, 396.

Scheme II



systems may indeed provide cyclopentenes through the agency of ionic or diradical processes that are milder than the pyrolytic conditions employed at present.

The diazoketone **1b** was next converted to the dihalides **6a–c** by titrating etheral solutions of **1b** with standard solutions of the appropriate halogen species in ether. Upon the exposure of **6a–c** to either Zn or AIBN/Bu_3SnH in refluxing DME or benzene, respectively, good yields of cyclopropane **7b** were obtained. Even though this is hardly surprising since dihalo ketones or dihalo esters are susceptible to Simmons–Smith reaction,[10] this experiment constituted to our knowledge the first example of intramolecular Simmons–Smith reaction. When mixed dihalide **6c** was decomposed under AIBN/Bu_3SnH conditions, a higher percentage of cyclopropane **7b** was obtained. To our surprise the enone **8** or dienes **10c** and **10d** were absent from the reaction mixtures. We interpreted this observation by invoking the mechanism in Scheme II. This mechanism parallels conceptually the ionic mechanism involved in the acid-catalyzed rearrangements with one important exception. The vinylcyclopropane **7b** which can be formed from *either cisoid* or *transoid* conformations of type **12** or **13** has been found *inert* to the conditions employing Bu_3SnH/AIBN. The cyclopropane is not inert under either thermal or acidic conditions where it readily cleaves to furnish the respective intermediates of type **12** or **13**. If the formation of radical **11a** constitutes a rational first step in this mechanism, then the second step should involve either the formation of a carbene or carbenoid from **11a** or the production of **11b** by internal alkylation. At present we tend to favor **11b** as the rational intermediate. This substance can form either cyclopropane **7b** or biradical **12** which can, in *either* of its conformations, lead to **7b**.[12] The formation of enone **8** in the pyrolyses may be controlled by the thermodynamics of biradical **12**, whereas cyclopropane **7b** may be the result of a kinetic closure of *either* **11b** or **12**. It seems likely that intermediates of type **11b** would undergo some 1,4-closure once the unfavorable steric interaction of the vinyl methyl is removed.[12] Finally, under photolytic conditions diazoketone **1b** gave the expected high yield of the corresponding Arndt–Eistert product when photolyzed in MeOH, whereas its photolysis in hexane gave a good yield of cyclopropane **7b**. Enone **8b** was not present in the reaction mixture and was not generated by the photolysis of cyclopropane **7b** under identical conditions. The results including yields of products are summarized in Table I.

In summary, the behavior of diazoketone **1b** under several distinctly different experimental conditions indicated to us that both radical and ionic species are subject to the same fate once they are formed. The specific fate is dictated only by the steric constraints of the particular system. While this particular project has come to a dead end in terms of the coriolin synthesis which has since been redesigned, the observations described in this report portend well for the institution of milder alternatives of cyclopentene annulation on sterically more favorably disposed substrates. The investigation of a more general utility of the decomposition of mixed halides of type **6** is now under way in our laboratories.

Experimental Section

Melting and boiling points are uncorrected. All nonhydrolytic reactions were carried out under an inert atmosphere (nitrogen or argon). All solvents were distilled prior to use. Ultradry solvents were produced accordingly (THF and DME from benzophenone and potassium, benzene from P_2O_5, Et_2O from $LiAlH_4$, CH_2Cl_2 from BaO). Infrared spectra were recorded on Perkin-Elmer 257 or Pye-Unicam 3-3300 spectrophotometers.[1] ^1H NMR spectra were obtained on Varian T-60, Varian EM 390, JEOL FX 200, IBM 270, and Nicolet 300 instruments while ^{13}C NMR spectra were recorded on JEOL FX 60Q, JEOL FX 200, Varian CFT-20, IBM NR-80, and IBM WP-270. In all instances tetramethylsilane was used as a reference.

Chromatography was performed on Brinkman (EM reagents) silica PF 254 (TLC) or Macherey Nagle and Co. (column). The purity of compounds was ascertained by chromatographic and spectral means (gas chromatography on OV-101/flame ionization, analytical TLC, and ^{13}C NMR spectra).

Mass spectral measurements were obtained on a DuPont 20-491 (low resolution) or DuPont 21-110C instrument (exact mass).

2-Methylcyclopentene-1-carboxaldehyde (3). This compound was prepared by a modification of the procedure of J. White et al.[11] Methylcyclohexene (29.1 g, 0.3 m), methanol (150 mL), and CH_2Cl_2 (75 mL) were ozonized at −78 °C until slight blue coloring of the solution persisted. The solution was degassed with nitrogen and slowly poured into 75 g of Me_2S containing *p*-toluenesulfonic acid (0.75 g). The mixture was stirred at room temperature for 3 h, diluted with CH_2Cl_2, and washed with 3 N HCl. The CH_2Cl_2 extracts were rinsed several times with water and brine and dried over Na_2SO_4. Evaporation gave oil which was distilled (Kugelrohr, 65–90 °C (0.025 mmHg)) to give 47.4 g (91%) of pure 1,1-dimethoxyheptan-6-one: IR (neat) 1710 cm^{-1}; ^1H NMR ($CDCl_3$), 1.2 (m, 6 H), 2.05 (s, 3 H), 2.4 (m, 2 H), 3.2 (s, 6 H), 4.2 (t, 1 H, J = 6 Hz); ^{13}C NMR ($CDCl_3$) δ 17.8 (t), 29.6 (t), 29.5 (q), 31.2 (t) (double intensity), 48.9 (q), 50.1 (q), 101.9 (d), 171.3 (s); mass spectrum (70 eV), m/e (relative intensity) 173 (M − 1) (5), 143 (30), 125 (20), 111 (60), 75 (B), 43 (70); calcd for $C_9H_{18}O_3$ 174.1256, found 174.1260.

The pure ketoacetal above (25 g, 0.142 m) was dissolved in 250 mL of THF cooled to 0 °C, 250 mL of 3% $HClO_4$ was added, and the mixture was stirred for 3 h at 0 °C and 3 h at room temperature, diluted with CH_2Cl_2, and washed with 5% $NaHCO_3$, dried, and evaporated to yield 15 g (81%) of pure 6-ketoheptanal which was immediately converted to its enamine in a procedure analogous to that used by J. White.[11] Any attempts at a more direct preparation of this substance by ozonolysis of methylcyclohexene failed to produce good yields or pure material. We found this two-step procedure convenient since the intermediate

(10) See, for example: Buchel, K. H.; Forte, F. *Z. Naturforsch. B* **1962**, *17*, 349. Simmons, H. E.; Cairns, T. L.; Vladuchik, S. A.; Hoines, C. M. *Org. React. (N.Y.)* **1973**, *20*, 1.

(11) White, J. D.; Ruppert, J. F.; Avery, M. A.; Torii, S.; Nokami, J. *J. Am. Chem. Soc.* **1981**, *103*, 1813.

(12) To test the mechanistic details of this reaction we will need to prepare the dihalide i and expose it to the AIBN/Bu_3SnH conditions. In this way **11b** will be generated and its fate tested on both substrates (R = H and CH_3). In the sterically less congested case we would expect some 1,4-closure.

i, R = H or CH_3

acetal was easily purified whereas 6-ketoheptanal could not be distilled from the crude ozonolysis mixture.

The enamine was cyclized by using Et_2O/HOAc at reflux to give **4** in 63% yield from 6-ketoheptanal. **4**: (bp 30–75 °C (0.05 mmHg), Kugelrohr); IR (neat) 1695, 1660 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.8 (t, 3 H, J = 7 Hz), 2.15 (s, 3 H), 2.6 (t, 6 H, J = 7 Hz), 10.0 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 13.4 (q), 20.5 (t), 29.8 (t), 40.2 (t), 137.4 (s), 161.8 (s), 187.2 (d); mass spectrum (70 eV) m/e (relative intensity) 110 (M^+) (60), 95 (60), 81 (90), 67 (B), 53 (65); calcd for $C_7H_{10}O$ 110.0732, found 110.0735.

1-(2-Methylcyclopent-1-enyl)-1-hydroxy-2-propene (4). Aldehyde **3** (5 g, 0.045 mol) in 10 mL of dry THF was added to freshly prepared solution of vinylmagnesium bromide (from vinyl bromide (6.4 g, 0.06 mol) and magnesium (1.44 g, 0.6 mol) in 45 mL of THF cooled to 0 °C. After dropwise addition was complete, the reaction mixture was stirred for 1 h at room temperature and allowed to stand overnight whereupon it was quenched with saturated NH_4Cl and extracted with ether (3 × 50 mL). The combined ether extracts were washed with brine, dried over Na_2SO_4, and evaporated to give an oil which was distilled (85–90 °C (0.1 mmHg), Kugelrohr) to afford 5.8 g (92%) of pure **4**: IR (neat) 3200, 1640 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.8 (s, 3 H), 1.9 (t, 3 H, J = 7 Hz), 2.3 (m, 4 H), 2.8 (br s, 1 H, D_2O-exchanged), 4.8 (m, 1 H), 5.0–6.0 (m, 3 H, vinyl); ^{13}C NMR ($CDCl_3$) δ 13.4 (q), 21.2 (t), 30.7 (t), 38.5 (t), 69.1 (d), 113.4 (t), 134.3 (s), 135.1 (s), 138.8 (d); mass spectrum (70 eV), m/e (relative intensity) 138 (M^+) (30), 123 (50), 109 (40), 95 (60), 81 (50), 67 (40), 55 (B); calcd for $C_9H_{14}O$ 138.1044, found 138.1049.

5-(2-Methylcyclopent-1-enyl)-2,2-dimethylpent-4-enoic Acid (5c). A. From the Ethyl Ester of 5b. The ethyl ester of **5b** (obtained from the ortho ester Claisen rearrangement of **4** in triethyl orthopropionate—see supplementary material section for details) (4.3 g, 0.02 mol) in 5 mL of THF was added to a solution of lithium diisopropylamide (from 3.0 g of diisopropylamine and 25 mL of a 1.6 M solution of n-BuLi in hexane) in 25 mL of THF at −78 °C. The solution was stirred for 15 min, methyl iodide (4.2 g, 0.03 mol) was added, and the reaction mixture was brought to room temperature over 1 h, whereupon it was quenched with brine (100 mL), acidified with 3 N HCl (50 mL), and extracted with ether (3 × 40 mL). The ether extracts were washed with 5% $NaHCO_3$, dried over Na_2SO_4, and evaporated to give 4.2 g (92%) of the ethyl ester of **5c** which was of suitable purity for the next step: ^1H NMR ($CDCl_3$) δ 1.1 (s, 6 H), 1.2 (t, 3 H, J = 7 Hz), 1.6–2.4 (m, 8 H), 4.15 (q, 2 H, J = 7 Hz), 5.3 (m, 1 H), 6.2 (d, 1 H, J = 14 Hz).

The ester (4.2 g, 0.017 mol) was refluxed in 100 mL of 20% ethanolic KOH for 5 h. The mixture was cooled, diluted with H_2O (100 mL), and extracted with ether (3 × 50 mL). The aqueous layer was acidified with 50% HCl and extracted with chloroform (4 × 50 mL). The chloroform extract was washed with brine, dried over Na_2SO_4, and evaporated to give 2.4 g (66%) of **5c**.

B. From Carbinol 4. To a solution of vinyl alcohol **4** (12 g, 0.086 mol) in 200 mL of CH_2Cl_2 and pyridine (7.4 g, 0.094 mol) cooled to 0 °C was added freshly distilled isobutyryl chloride (9.11 g, 0.086 mol). The reaction mixture was stirred for 30 min at 0 °C and then at room temperature for 1.5 h. The reaction mixture was then quenched with brine, washed successively with 3 N HCl, $NaHCO_3$, and brine, dried over Na_2SO_4, and evaporated to give 16.5 g (91%) of isobutyryl ester which was immediately used in the next step: IR (neat) 1820, 1740, 1640 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.2 (d, 6 H, J = 7 Hz), 1.8 (s, 3 H), 1.8–2.2 (m, 4 H), 2.3 (t, 2 H, J = 7 Hz), 2.6 (hp, 1 H, J = 7 Hz), 5.0–6.0 (m, 3 H, vinyl), 5.2 (d, 1 H, J = 8 Hz); ^{13}C NMR ($CDCl_3$) δ 14.0 (q), 18.4 (q) and 19.1 (q) (rotamers), 21.8 (t), 31.8 (t), 34.4 (d), 38.9 (t), 71.6 (d), 115.5 (t), 135.4 (d), 135.9 (s), 137.1 (s), 161.0 (s). The isobutyrate prepared above (16.5 g, 0.079 mol) was added over 5 min to 150 mL of a THF solution of lithium diisopropylamide (from 8.77 g of diisopropylamine and 61.3 mL of a hexane solution of n-BuLi) at −78 °C. After 5 min at −78 °C, the cooling bath was removed and the reaction mixture was brought to room temperature (1 h) and stirred for 20 min. The mixture was poured into 300 mL of 5% NaOH and extracted with ether to separate any neutral materials. The aqueous layer was acidified with 50% HCl and extracted with CH_2Cl_2 (4 × 75 mL), and combined extracts washed with brine, dried with Na_2SO_4, and evaporated to give 9.8 g (59.3%) of acid **5c** as a waxy solid (bp 100–110 °C (0.05 mmHg), Kugelrohr). This procedure proved superior to the former in terms of *overall* yield of acid **5c**: IR (neat) 3300–2800, 1705 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.2 (s, 6 H), 1.8 (m, 4 H), 2.3 (m, 4 H), 5.4 (m, 1 H), 6.3 (d, 1 H, J = 14 Hz); ^{13}C NMR ($CDCl_3$) δ 13.8 (q), 21.4 (t), 24.6 (q) (double intensity), 33.07 (t), 39.2 (s), 42.6 (t), 43.7 (t), 124.2 (d), 128.2 (d), 133.4 (s), 136.6 (s), 184.4 (s); mass spectrum (70 eV), m/e (relative intensity) 208 (M^+) (15), 121 (B), 93 (95), 79 (80), 55 (48), 43 (52); calcd for $C_{13}H_{20}O_2$ 208.1463, found 208.1467.

6-(2-Methylcyclopent-1-enyl)-1-diazo-3,3-dimethylhex-5-en-2-one (1b). Freshly distilled oxalyl chloride (952 mg, 7.5 mmol) was added in one portion to a solution of **5c** (1.04 g, 5 mmol) in 10 mL of benzene at 6 °C. After 2 h of stirring at room temperature, the solvent and excess oxalyl chloride were removed in vacuo to leave the acid chloride of **5c** as an oil (IR 1775 cm^{-1}). The acid chloride was taken up in ether (5 mL) and added to a cold (0 °C) etheral solution of diazomethane [prepared from (nitrosomethyl)urea][3] containing 0.5 mL of Et_3N. The mixture was stirred for 30 min, filtered through a fritted glass disk, and evaporated to afford an oil which was dissolved in hexane/ether (3:1) and filtered through a short column (5 cm) of basic alumina to give 775 mg (70%) of pure **1b** as a light yellow oil: IR (neat) 2100, 1635 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.12 (s, 6 H), 1.78 (br s, 3 H), 1.4–1.8 (m, 2 H), 2.3 (m, 6 H), 5.30 (m, 1 H), 5.35 (s, 1 H, diazo), 6.28 (d, 1 H, J = 14 Hz); ^{13}C NMR ($CDCl_3$) δ 13.7 (q), 21.2 (t), 24.5 (q) (double intensity), 32.8 (t), 38.9 (t), 43.8 (t), 46.0 (s), 52.2 (d), 127.8 (d), 128.4 (d), 133.1 (s), 136.4 (s), 200.2 (s); mass spectrum (70 eV) m/e (relative intensity) 204 (M^+ − 28) (5), 176 (10), 161 (15), 134 (80), 119 (85), 105 (70), 91 (80), 83 (40), 79 (75), 55 (B); calcd for $C_{14}H_{20}O$ [M − 28] 204.1514, found 204.1520.

6β-(2-Methylcyclopent-1-enyl)-3,3-dimethyl-1β-bicyclo[3.1.0]hexan-2-one (7b). To a stirred refluxing suspension of 100 mg of $Cu(acac)_2$ and 2 g of $CuSO_4$ in 50 mL of benzene was added diazoketone **1b** (1.0 g, 4.3 mmol) in 25 mL of benzene during 1 h. After an additional 1 h at reflux, the mixture was cooled and filtered [the solids were washed with ~20 mL of benzene] and evaporated to leave 845 mg (96%) of pure cyclopropane **7b**: bp 100 °C (0.005 mmHg), Kugelrohr; IR (neat) 1710 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.12 (s, 6 H), 1.7 (s, 3 H), 1.4–2.3 (m, 1 H); ^{13}C NMR ($CDCl_3$) δ 13.6 (q), 21.2 (t), 22.9 (d), 26.7 (d), 27.8 (q), 28.5 (q), 32.2 (t), 34.3 (d), 38.7 (t), 39.5 (t), 43.6 (s), 130.4 (s), 134.0 (s), 217.4 (s); mass spectrum (70 eV) m/e (relative intensity) 204 (M^+) (18), 189 (5), 176 (10), 161 (20), 134 (90), 119 (B), 105 (60), 91 (65), 79 (30) (This compound was extremely hygroscopic. Attempts at combustion analysis of its sample gave four sets of erroneous data on the same sample which proved extremely hygroscopic.); calcd for $C_{14}H_{20}O$ 204.1518, found 204.1520.

(2-Methylcyclopent-1-enyl)(4,4-dimethyl-3-oxocyclopent-1-enyl)methane (8b). A. From Pyrolysis of 7b. Vinylcyclopropane **7b** (1 g, 4.9 mmol) was evaporated through a $PbCO_3$-conditioned Vycor tube at 580 °C (0.05 mmHg).[3] The crude pyrolysate (890 mg), collected in a trap cooled with liquid nitrogen, was chromatographed on silica (hexane/methylene chloride, 1:1) to give 720 mg (72%) of enone **8b** and a small amount (<15%) of minor products which were rechromatographed to furnish small amounts of diene **10c** and 7 mg of **10b**: IR (neat) 1735, 1640 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.08 (s, 3 H), 1.09 (s, 3 H), 1.3 (s, 3 H), 1.2–1.7 (m, 6 H), 1.78 (t, 2 H, J = 7 Hz), 2.6 (m, 2 H), 6.6 (t, 1 H, J = 2 Hz).

B. From Acid-Catalyzed Rearrangement of 7b. Vinylcyclopropane **7b** (100 mg, 0.49 mmol) in 5 mL of CH_2Cl_2 was cooled to 0 °C and 0.1 mL of $TiCl_4$ was added. After 30 min at 0 °C the reaction was quenched with $NaHCO_3$ solution, extracted with CH_2Cl_2, dried with Na_2SO_4, and evaporated to give reddish oil which was chromatographed on silica (hexane/ether, 2:1) to give 68 mg (68%) of **8b**. Similar results were obtained with $SnCl_4$ in DME or benzene as solvents. **8b**: IR (neat) 1700, 1620 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.10 (s, 6 H), 1.6 (s, 3 H), 1.4–2.4 (m, 8 H), 3.1 (s, 2 H), 5.78 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 13.8 (q), 21.6 (t), 25.02 (q) (double intensity), 32.7 (t), 36.3 (t), 38.3 (t), 44.3 (s), 48.01 (t), 127.3 (d), 130.0 (s), 134.9 (s), 177.5 (s), 214.0 (s); mass spectrum (70 eV), m/e (relative intensity) 204 (M^+) (B), 189 (96), 161 (71), 147 (29), 134 (46), 133 (56), 120 (25), 119 (56), 105 (48), 91 (49), 81 (73), 79 (51), 77 (32). Anal. Calcd for $C_{14}H_{20}O$: C, 82.35; H, 9.80. Found: C, 82.36; H, 9.83.

Photolysis of Diazoketone 1b. A. Diazoketone **1b** (50 mg, 0.21 mmol) was irradiated in 50 mL of MeOH with a 100-W medium-pressure lamp (Rayonett reactor) through a Pyrex tube for 7 h. The solution was evaporated and filtered through a short column of silica gel to afford 44 mg (87%) of the Arndt–Eistert product methyl 6-(2-methylcyclopent-1-enyl)-3,3-dimethylhex-5-enoate: IR (neat) 1730 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.02 (s, 6 H), 1.8 (s, 3 H), 1.7–2.6 (m, 8 H), 2.2 (s, 2 H), 3.6 (s, 3 H), 5.4 (m, 1 H), 6.3 (d, 1 H, J = 14 Hz); ^{13}C NMR ($CDCl_3$) δ 13.9 (CH_3), 21.5 (CH_2), 27.2 (CH_3) (double intensity), 33.1 (CH_2), 34.0 (C), 39.3 (CH_2), 45.7 (CH_2), 46.1 (CH_2), 51.1 (CH_3), 125.5 (CH), 127.9 (CH), 133.6 (C), 136.4 (C), 172.9 (C).

B. An identical procedure was repeated for a solution of **1b** in hexane. After 6 h the solution was evaporated and filtered as above to give 28 mg (64%) of **7b** identical with a sample obtained from cyclopropanation of **1b**. The vinylcyclopropane was inert to the conditions of photolysis.

Acid-Catalyzed Rearrangement of Diazoketone 1b. A solution of boron trifluoride etherate (284 mg, 2 mmol) in 5 mL of benzene was cooled to 6 °C and diazoketone **1b** (232 mg, 1 mmol) in 2 mL of benzene was added during *30 s*. *Immediately* afterward the reaction mixture was quenched with $NaHCO_3$, and the organic phase was separated, washed with brine, dried over Na_2SO_4, and evaporated to yield a yellow oil which was chromatographed to furnish 145 mg (82%) of diene **10d**: IR (neat) 1732, 1665 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.07 (s, 3 H), 1.12 (s, 3 H), 1.7 (br s, 3 H), 1.4–3.2 (m, 9 H), 4.9–5.2 (m, 1 H), 5.7 (br s, 1 H); ^{13}C NMR ($CDCl_3$) δ 12.7 (q), 24.4 (q) (double intensity), 27.2 (t), 30.0 (t), 33.4 (d), 44.5 (t), 45.9 (t), 45.9 (s), 119.5 (d), 133.9 (d), 140.3 (s), 148.5 (s), 222.9 (s); mass spectrum (70 eV), m/e (relative intensity) 204 (M^+) (89), 189 (63), 174 (21), 161 (22), 147 (26), 133 (42), 120 (B), 105 (73), 91 (52).

Simmons-Smith and Bu_3SnH/AIBN Reactions of Dihalides 6a–c. To a stirred solution of diazoketone **1b** (232 mg, 1 mmol) in 10 mL of benzene at 6 °C was added a standard solution (previously titrated) of either Br_2, I_2, or IBr. The reaction mixture was stirred for 15 min at which time TLC analysis indicated complete disappearance of **1b** and formation of the corresponding dihalides **6a**, **6b**, or **6c**, respectively (NMR δ 5.6, 1 H). The dihalides were unstable to any attempts at purification and were therefore generated in situ. To the solution of appropriate dihalide was added either Zn dust or Bu_3SnH (436 mg, 1.5 mmol) and 25 mg of AIBN dropwise over 30 min. The reaction mixture was then refluxed for 30 min, filtered, washed with brine, dried over Na_2SO_4, and evaporated to give brown oils which were chromatographed to afford cyclopropanes **7b** in the yields of 20% from **6a**, **6b**, and 45% from **6c**, respectively. The cyclopropane isolated from these reactions was identical with a sample obtained by cyclopropanation of **1b**. The relatively poor yields reflect the purity of starting dihalides—a better method of their production must therefore be developed.

Photolysis of Enone 8b. Enone **8b** (204 mg, 1 mmol) was irradiated in *either* MeOH *or* hexane (100 mL) as described above. After 20 h, the solution was filtered and evaporated to give 202 mg (98%) of a yellow oil identified as diene **10c**: IR (neat) 1700, 1620, 1580 cm^{-1}; ^1H NMR ($CDCl_3$) 1.05 (d, 3 H, J = 7 Hz), 1.15 (s, 6 H), 1.4–2.7 (m, 8 H), 3.4 (m, 1 H), 5.95 (br s, 1 H), 6.2 (br s, 1 H); ^{13}C NMR ($CDCl_3$) δ 19.6 (q), 23.8 (q) (double intensity), 24.1 (t), 24.3 (t), 28.9 (t), 29.8 (d), 42.5 (t), 44.5 (s), 121.9 (d), 123.6 (s), 131.7 (s), 137.8 (s), 201 (s).

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Registry No. **1a**, 93453-83-9; **1b**, 93453-84-0; **3**, 81328-61-2; **4**, 93453-85-1; 4 isobutyrate, 93453-86-2; **5a**, 93453-87-3; **5a** ethyl ester, 93454-03-6; **5b** ethyl ester, 93453-88-4; **5c**, 93453-89-5; **5c** ethyl ester, 93454-01-4; **5c** acid chloride, 93454-02-5; **6a**, 93453-90-8; **6b**, 93453-91-9; **6c**, 93453-92-0; **7a**, 93453-93-1; **7b**, 93453-94-2; **8a**, 93453-95-3; **8b**, 93453-96-4; **9a**, 93453-97-5; **9b**, 93453-98-6; **10b**, 93454-04-7; **10c**, 93454-05-8; **10d**, 93473-49-5; CH_2=CHBr, 593-60-2; $(MeO)_2CH(CH_2)_4C(O)CH_3$, 36727-64-7; $CH_3C(O)(CH_2)_4CHO$, 19480-04-7; $(CH_3)_2CHC(O)Cl$, 79-30-1; $CH_3CH_2C(OEt)_3$, 115-80-0; methyl (*E*)-6(2-methylcyclopent-1-enyl)-3,3-dimethylhex-5-enoate, 93453-99-7; 5-(2-methylcyclopent-1-enyl)pent-4-enoyl chloride, 93454-00-3; 1-methylcyclohexene, 591-49-1.

Supplementary Material Available: Experimental and spectral data for compounds **1a**, **5a**, **5b**, **7a**, and **8a** (2 pages). Ordering information is given on any current masthead page.

Convenient Synthesis of (*S*)-Citronellol of High Optical Purity

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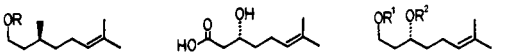
Optically active citronellol has recently attracted much attention as a useful chiral building block in synthetic studies of complex natural products.[1] However, natural citronellol, as well as citronellal and citronellic acid, is known ordinarily to be a mixture of *R* and *S* enantiomers with the optical purity less than 80%.[2] While several routes to citronellol of higher enantiomeric excess, both chemical transformations of other terpenes[2,3] and asymmetric syntheses,[4] have already been developed, there are only a few that can provide virtually enantiomerically pure citronellol in quantity.[3,4c] We now report a convenient chemomicrobiological synthesis applicable for a large-scale preparation of (*S*)-(−)-citronellol (**1**) of at least 96% ee using all commercially available materials and reagents.



1, R=H
2, R=COBu-*t*

3

4, R^1=R^2=H
5, R^1=COBu-*t*, R^2=H
6, R^1=COBu-*t*, R^2=Ts

Enantiomerically pure (*R*)-3-hydroxy-7-methyloct-6-enoic acid (**3**) was readily prepared in 67% crude yield by Baker's yeast reduction of the corresponding potassium β-keto carboxylate.[5,6] Without purification, the crude acid **3** was reduced by $LiAlH_4$ (2 molar equiv) in THF to give the chiral diol **4**, $[\alpha]^{18}_D$ +5.9° (*c* 2.0), in 74% yield. After **4** was selectively acylated to the pivaloyl ester **5** [*t*-BuCOCl (1.0 equiv)/pyridine/room temperature, $[\alpha]^{20}_D$ −2.8°/(*c* 2.0), 81%], **5** was treated with excess tosyl chloride and 1.3 equiv of NEt_3 in pyridine to give the tosylate **6** ($[\alpha]^{20}_D$ −8.9° (*c* 2.0), 82% yield). Substitution of the tosyloxy by

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