a VG Micromass 7070 F instrument operating at an ionizing potential of 70 eV. GLC was performed by using a steel column packed with Chromosorb PAW 80-100. Infrared spectra (IR) were recorded on a Perkin-Elmer 377 spectrophotometer.

General Procedure for Preparation of Chloro Lactones. To a suspension of 105 mmol of anhydrous chloramine T[9] in 80 mL of anhydrous benzene or chlorobenzene were added dropwise 100 mmol of unsaturated acid and 105 mmol of methanesulfonic acid simultaneously. The reaction was very exothermic, and the addition of reagents was adjusted to a rate so as to keep the temperature below 50 °C. At the end of the addition, the mixture was heated to 80 °C until the complete consumption of chloramine T (checked by iodometric analysis). After the mixture returned to room temperature and was filtrated, the solvent was removed by rotary evaporation. He chloro lactone was separated by direct distillation or purified by column chromatography on silica with methylene chloride as solvent and then distilled.

3: IR (neat ν_{max} 1775 (C=O) 1180 (CO) cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.83 (complex m, 1 H), 3.77 (d, 2 H), 2.51 (complex m, 4 H); ^{13}C NMR ($CDCl_3$) δ 24.86, 28.36, 46.69, 78.72, 177.10; mass spectrum, *m/e* (relative intensity) 136 ($^{37}ClM^+$, 0.8), 134 ($^{35}ClM^+$, 2.6), 85 ($M^+ - CH_2Cl$, base peak), 55 (16.7), 49 (11.4), 41 (13.5), 39 (17).

Anal. Calcd for $C_5H_7ClO_2$: C, 44.63; H, 5.24; Cl, 26.35. Found: C, 44.43; H, 5.17; Cl, 26.22.

5: IR (neat) ν_{max} 1740 (C=O) 1170 (CO) cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.50 (complex m, 1 H), 3.73 (d, 2 H), 2.40 (m, 4 H), 1.83 (m, 2 H); ^{13}C NMR ($CDCl_3$) δ 18.10, 25.21, 29.51, 46.41, 79.12, 171.25; mass spectrum, *m/e* (relative intensity) 150 ($^{37}ClM^+$, 0.6), 148 ($^{35}ClM^+$, 1.9), 99 ($M^+ - CH_2Cl$, 98.9), 71 (42), 55 (60.9) 42 (base peak), 41 (75.9), 39 (54.8).

Anal. Calcd for $C_6H_9ClO_2$: C, 48.50; H, 6.10; Cl, 23.86. Found: C, 48.74; H, 6.36; Cl, 23.56.

7: IR (KBr) ν_{max} 1787 (C=O) cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.77 (br t, 1 H), 4.33 (br t, 1 H), 2.80–1.77 (complex m, 7 H); ^{13}C NMR ($CDCl_3$) δ 22.40, 27.90, 31.91, 38.27, 53.57, 79.06, 177.84; mass spectrum, *m/e* (relative intensity) 162 ($^{37}ClM^+$, 2.4), 160 ($^{35}ClM^+$, 7.1), 124 ($M^+ - HCl$, 39.6), 120 (28.0), 118 (base peak), 97 (27.3), 83 (41.4), 81 (46.1), 80 (34.8), 42 (68.3), 41 (51.4).

Anal. Calcd for $C_7H_9ClO_2$: C, 52.35; H, 5.65; Cl, 22.10. Found: C, 52.24; H, 5.92; Cl, 22.12.

8: IR (KBr) ν_{max} 1775 (C=O) cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.85 (d, 1 H), 4.19–3.97 (complex m, 1 H), 2.75–1.55 (complex m, 7 H); ^{13}C NMR ($CDCl_3$) δ 26.41, 30.02, 37.13, 37.41, 57.12, 81.59, 177.67; mass spectrum, *m/e* (relative intensity) 162 ($^{37}ClM^+$, 1.5), 160 ($^{35}ClM^+$, 6.2), 124 (44.5), 120 (34.4), 118 (base peak), 97 (32), 83 (44.5), 81 (53.4), 80 (37.4), 70 (30.7), 42 (67.6), 41 (48).

Anal. Calcd for $C_7H_9ClO_2$: C, 52.35; H, 5.65; Cl, 22.10. Found: C, 52.30; H, 5.56; Cl, 22.18.

10: IR (KBr) ν_{max} 1788 (C=O) cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.53 (m, 1 H), 4.10 (m, 1 H), 2.53 (complex m, 3 H), 2.33–1.2 (complex m, 6 H); ^{13}C NMR ($CDCl_3$) δ 14.84, 19.36, 27.73, 30.94, 34.60, 35.92, 59.70, 83.71, 179.84; mass spectrum, *m/e* (relative intensity) 188 ($^{37}ClM^+$, 5.4), 186 ($^{35}ClM^+$, 13.9), 158 ($M^+ - CO$, 16.9), 151 ($M^+ - Cl$, 21.2), 150 (95.4), 131 (22.3), 123 (87.6), 122 (30.6), 107 (34.2), 95 (49.8), 91 (48.6), 80 (51.7), 79 (base peak), 78 (75.7), 77 (42), 70 (59.7), 67 (47.7), 65 (20.4), 41 (28.5).

Anal. Calcd for $C_9H_{11}ClO_2$: C, 57.61; H, 6.45, Cl, 18.89. Found: C, 57.23; H, 6.11; Cl, 18.77.

12: IR (neat) ν_{max} 1780 (C=O) cm^{-1}; ^1H NMR ($CDCl_3$) δ 5.50–4.60 (complex m, 2 H), 4.00–3.80 (complex m, 4 H), 3.20–1.30 (complex m, 4 H); ^{13}C NMR ($CDCl_3$) δ 35.52, 36.78, 44.40, 44.69, 45.03, 45.38, 52.42, 76.49, 76.89, 77.46, 77.80, 173.03; mass spectrum, *m/e* (relative intensity) 254 ($^{37}ClM^+$, 0.4), 252 ($^{35}ClM^+$, 0.6), 208 ($M^+ - CO_2$, 11.0), 205 ($M^+ - CH_2Cl$, 34.1), 203 (base peak) 161 (25.5), 159 (80.7), 137 (30.5), 97 (56.6), 67 (76.2), 65 (20), 43 (21.8), 41 (52.4).

Anal. Calcd for $C_9H_{10}Cl_2O_4$: C, 42.71; H, 3.98; Cl, 28.02. Found: C, 42.77; H, 3.98; Cl, 27.96.

Registry No. 1, 127-65-1; 2, 591-80-0; 3, 39928-72-8; 4, 1577-22-6; 5, 77944-06-0; 6, 4771-80-6; 7, 20893-19-0; 8, 77924-81-3; 9, 40610-12-6; 10, 77924-82-4; 11, 4372-31-0; 12, 77944-07-1.

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Acid-Catalyzed Annulation. Simple and Highly Stereospecific Synthesis of *cis*-5,10-Dimethyl-1(9)-octal-2-one

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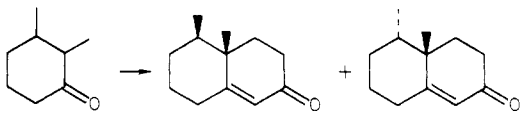
The problem of stereochemical control with respect to vicinally disposed *cis*-dimethyl groups of **1** which characterizes the eremophilane–valencane family of terpenes has been studied[1] by several groups of workers. Our interest in **1** resulted from a project directed toward the synthesis of certain eremophilane-type sesquiterpenoids. Direct Robinson annulation of 2,3-dimethylcyclohexanone with methyl vinyl ketone in the presence of base affords **1** and **2** in a nonstereospecific manner (3:2 trans/cis) and in poor



1 **2**

yield (15%).[2,3] Octalone **1** has also been obtained by dehydration of the purified aldol intermediate[4] resulting from ordinary annulation at −15 °C but in low yield.

A higher degree of stereospecifity (9:1, cis/trans) was observed in an alternative approach to (**1**) by reaction of the enolate of 2,3-dimethyl-6-[(*n*-butylthio)methylene]-cyclohexanone[2] and ethyl 3-bromopropionate, the corresponding keto esters being precursors to the *cis*- and *trans*-dimethyloctalones. A conjugate addition–annulation reaction[5] involving 1,4 conjugate addition to 2-methyl-2-cyclohexenone and alkylation of the resulting regiospecificly generated enolate with 3-(trimethylsilyl)-3-buten-2-one followed by subsequent cyclization has also been reported to afford **1** and **2** in high stereospecificity (97:3 cis/trans) as determined by VPC analysis.

These alternate syntheses of **1** involve multistep conversions of 2,3-dimethylcyclohexanone and 2-methyl-2-cyclohexenone followed by base-catalyzed cyclization to **1** and **2**. Although the overall yields of **1** are good (30–54%) and the realized stereospecificity is ≥90%, the overall pathways are six to seven steps in length and would require a substantial synthetic effort for the preparation of large quantities of **1**.

We report herein a simple and highly stereospecific synthesis of **1** which can be obtained via an acid-catalyzed[6,7] Robinson annulation reaction. When 2,3-dimethylcyclohexanone and methyl vinyl ketone in the presence of sulfuric acid in benzene were allowed to react

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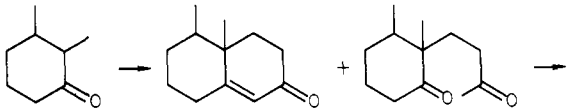
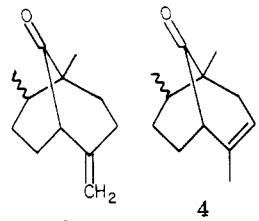
at 0–5 °C, a mixture of octalones and diketones (eq 1) was



1 + 2 (1)

isolated. The structure of the mixture was inferred from the singlet absorptions due to the vinyl proton (δ 5.75) and the methyl proton (δ 2.10) in the NMR spectrum as well as the characteristic carbonyl absorptions at 1675 and 1710 cm^{-1} in the IR spectrum. Base-catalyzed cyclization[8] of the mixture of octalones and diketones with sodium methoxide in methanol at 45–50 °C afforded a 33% yield of 1 and 2 in a ratio ≥9:1 as determined by ^{13}C NMR analysis.[9] A mixture (~5%) of the bicyclic ketones 3 and 4 were also isolated, after chromatography, in a 2:1 ratio as determined by ^{13}C NMR analysis.



3 4

When 2,3-dimethylcyclohexanone and methyl vinyl ketone were refluxed in the presence of sulfuric acid in benzene for 20 h, the octalones 1 and 2 (~25%) were obtained in a ratio of ≥9:1, and the bicyclo[3.3.1]nonenones 3 and 4 (5–7%) were also isolated as minor components of the reaction mixture.

Experimental Section

***cis*-5,10-Dimethyl-1(9)-octal-2-one (1).** A mixture of 2,3-dimethylcyclohexanone (19.0 g, 0.15 mol) and methyl vinyl ketone (10.5 g, 12.1 mL, 0.15 mol) in 100 mL of benzene was cooled to 0 °C (ice–salt bath). Concentrated sulfuric acid (3.0 mL) was added dropwise via a syringe, and the reaction mixture was stirred at 0 °C for 2 h. After 2 h, methyl vinyl ketone (6.1 mL, 0.075 mol) and 1.0 mL of concentrated sulfuric acid (dropwise addition) were added, and the reaction mixture was stirred at 0 °C for an additional 2.5 h. A final addition of methyl vinyl ketone (6.1 mL, 0.075 mol) was added, and the reaction mixture was stirred overnight at 0 °C.

The reaction mixture was poured into 400 mL of ether, and the polymeric residue was washed with two 200-mL portions of ether. The organic solutions were combined and washed with 200 mL of a 1 N sodium hydroxide solution and 400 mL of brine. The aqueous solution was rewashed with two 400-mL portions of ether; and the organic solutions were combined, dried ($MgSO_4$), and concentrated in vacuo to afford an oil. Distillation afforded 6.8 g (36%) of recovered 2,3-dimethylcyclohexanone [bp 60–65 °C (15 mm)] and 12.2 g of a mixture of octalones and diketones: bp 85–95 °C (0.03 mm); NMR (CCl_4) δ 5.75 (s), 1.15 (s), 2.10 (s); IR (neat) 1675, 1710 cm^{-1}. Cyclization of the mixture with sodium methoxide in methanol by following the procedure of Marshall and Schaeffer[8] and subsequent distillation and chromatography on silica gel (elution with hexanes and ether–hexane solutions) afforded 8.7 g (33%) of 1 and 2 in a ratio ≥9:1 as determined by ^{13}C NMR[9] analysis (the spectral properties of the mixture of 1 and 2 were identical with those reported[10] previously for 1 and 2) and approximately 5% of the bicyclo[3.3.1]nonenones 3 and 4 in a 2:1 ratio: ^{13}C NMR (90 M Hz, proton decoupled, $CDCl_3$) 217.82, 217.23, 217.03 and 216.37 (carbonyls), 134.16 and 133.78 (endocyclic quarternary carbon), 123.03 and 122.74 (endocyclic tertary carbon), 110.75 and 110.19 ppm (exocyclic methylene); IR (neat) 1720 cm^{-1}. Anal. Calcd for $C_{12}H_{18}O$: C, 80.84; H, 10.18. Found: C, 80.71; H, 10.20.

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Registry No. 1, 43209-93-4; 2, 43209-94-5; 3, 78019-73-5; 4, 78019-74-6; 2,3-dimethylcyclohexanone, 13395-76-1; methyl vinyl ketone, 78-94-4.

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α-Oxoketene Dithioacetal Chemistry. 2. Conjugate Reductions with Electrophilic Reducing Agents

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Regiospecific hydride reductions of α,β-unsaturated carbonyl compounds continue to play an important role in organic synthesis. In recent years an increased number of reports have appeared describing the regiospecific reduction of various β-heteroatom enones.[2] These reductions have increased in popularity by virtue of the ease of preparation of the β-heteroatom enones and their subsequent conversion to those functionalities routinely used by organic chemists in synthesis. As with the hydride reductions of simple unsaturated carbonyl systems, reductions of these functionalized enones are not always straightforward, and many times complex mixtures of reduction products arise. There are, however, a number of specific and synthetically useful β-heteroatom enone reductions that give either 1,2 hydride reduction and thus allylic alcohols (or the products of dehydration) as products[2a-c] or 1,4 hydride reduction and thus β-functionalized carbonyl compounds as products.[2c-f,h,i]

α-Oxoketene dithioacetals are highly functionalized three-carbon units whose utility in synthesis has steadily been increasing.[3] As part of a program to explore the chemistry of these compounds, we were intrigued with the possibility of selectively controlling, by hydride delivery, the various oxidation levels at each of the three carbon atoms in the α-oxoketene dithioacetal system. Our earliest

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