Syntheses of Methyl *dl*-Jasmonate and Methyl *dl*-2-Epijasmonate

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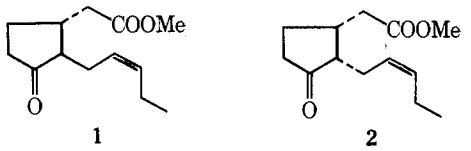
Syntheses of methyl *dl*-jasmonate (1) and methyl *dl*-2-epijasmonate (2) from 3a,7a-*cis*-3a,4,7,7a-tetrahydro-1-indanone (**3a**) are described. Efficient construction of the carbomethoxymethyl and *cis*-pentenyl moieties could be achieved by developing a successful method for a key step, the partial oxidation of aldehyde hemiacetal **6**, prepared from **3a**, to acid hemiacetal **7a**. The methyl ester of **7a** was converted to both **1** and **2** by different routes *via* the thioacetals **8b** and **11**, respectively.

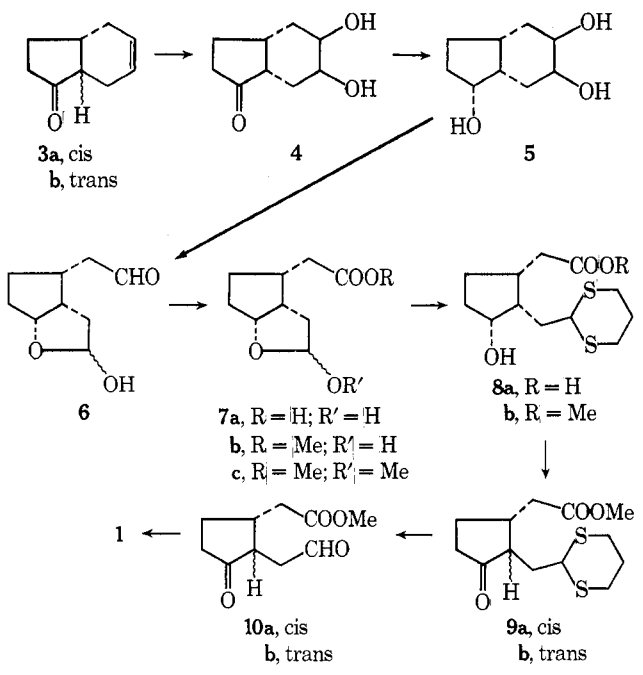
Methyl jasmonate[1] and related compounds[2] have been of interest as synthetic targets because of their use in the perfumery industry and as new members among the plant hormones. Indeed, much attention have been paid to the preparation of methyl *dl*-jasmonate (**1**) in recent years.[3] We now report syntheses of methyl *dl*-jasmonate (**1**) and methyl *dl*-2-epijasmonate (**2**), which involve efficient construction of the carbomethoxymethyl and *cis*-pentenyl moieties and include as a key step the partial oxidation of aldehyde hemiacetal **6**. In order to satisfy the stereochemical requirement for the formation of **6** we chose 1,7a-*cis*-3a,7a-*cis*-1,5,6-trihydroxyperhydroindan (**5**) as a starting material, which could be provided from 3a,7a-*cis*-3a,4,7,7a-tetrahydro-1-indanone (**3a**).[4]



1 **2**

The synthetic pathway leading to methyl *dl*-jasmonate is outlined in Scheme I. Interesting questions with regard to the scheme were whether oxidative fission of triol **5** would provide **6** and whether the formyl group of **6** could be oxidized selectively to the acid hemiacetal **7a**.

Scheme I



Oxidation of **3a** with $KMnO_4$–$MgSO_4$[5] in methanol at −40° afforded the diol **4** as white crystals in 69% yield. Stereoselective reduction of **4** was achieved by the treatment with sodium borohydride in ethanol to give **5** in good yield. The structure assignment could be established by conversion of **5** into the δ-lactone **11** and the γ-lactone **16**, respectively.

Treatment of **5** with sodium metaperiodate[6] at 2° gave the aldehyde **6** in 98% yield. The structure assignment of **6** was corroborated by the following spectral data.[7] The ir spectrum exhibited a broad band at 3320 (OH) and characteristic streching bands at 2723 (aldehyde, ν_{CH}) and 1724 cm^{-1} (C=O). The nmr spectrum in $CDCl_3$ showed δ 3.73 (1 H, OH), 4.82 (1 H, CHO), 5.51 (1 H, OCHO), and 9.75 (1 H, CHO).

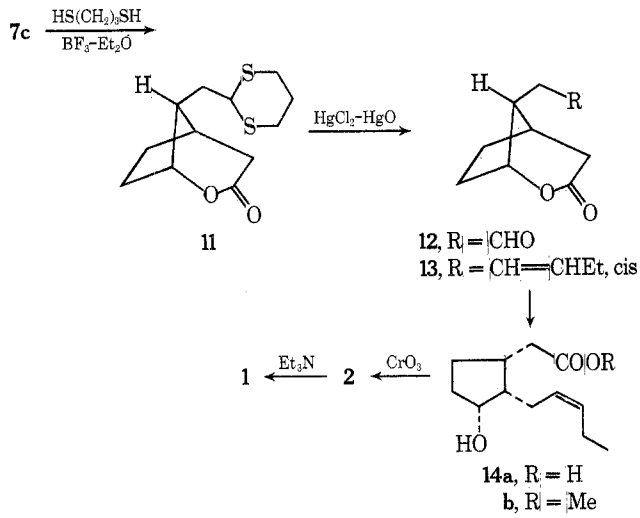
Under carefully controlled reaction conditions, oxidation of **6** with $KMnO_4$–$MgSO_4$ in aqueous acetone at 2° and subsequent esterification with diazomethane afforded the hemiacetal ester **7b** (60%) along with the dimer **17b** (10%)[8] and the lactone **16b** (10%). Without further purification the crude product was refluxed in dry methanol in the presence of a catalytic amount of *p*-toluenesulfonic acid. Separation of the product by column chromatography over silica gel gave **7c** (65% yield based on **6**) and **16b** (10%). The nmr spectrum of **7c** showed the presence of two singlets due to a methoxy group at δ 3.27 (acetal) and 3.64 (ester), respectively. The acetal ester **7c** was converted in two steps, by thioacetalization to **8b** and by a slight modification of the Corey's oxidation method,[9] to the keto ester **9a** in 64% yield. Epimerization of **9a** was carried out by heating in triethylamine in a sealed tube at 130° to give **9b** in quantitative yield. Hydrolysis of **9b** with $HgCl_2$–HgO in aqueous acetonitrile[10] gave **10b** in 90% yield. The Wittig reaction of **10b** with salt-free *n*-propylidenetriphenylphosphorane[11] afforded **1** in 88% yield.

In the course of the thioacetalization of **7c** the presence of a catalytic amount of water facilitated formation of the thioacetal δ-lactone **11** (80% yield) rather than **8**. Hydrolysis of **11** with aqueous methanolic potassium hydroxide and subsequent esterification with diazomethane yielded **8** in 85% yield.

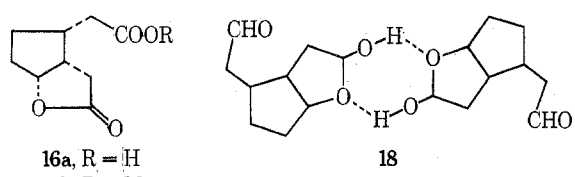
The second approach from **11** as shown in Scheme II also led to **1** *via* **2**. The conversion was accomplished as follows: hydrolysis of **11** to **12** and subsequent Wittig reaction afforded **13**, which on hydrolysis and esterification with diazomethane yielded **14b**.[12] Subsequent oxidation with chromic acid gave **2** in 61% overall yield. Epimerization of **2** to **1** proceeded smoothly on treatment with triethylamine in a sealed tube at 130°. Another route to methyl *dl*-2-epijasmonate (**2**) involved **10a**, prepared in 95% yield by hydrolysis of the thioacetal **9a** with $HgCl_2$–HgO in aqueous acetonitrile. Wittig reaction of **10a** with the salt-free phosphorane afforded **2** in good yield.

Normally one would expect that in the formation of **7a** from **6** the hemiacetal function should be protected from the action of oxidation reagents. Thus, oxidation of **6** with

Scheme II



chromic acid[13] followed by esterification gave the γ-lactone ester **16b** in quantitative yield. In contrast, runs using $KMnO_4$–$MgSO_4$ at 2° exhibit nearly exclusive selectivity for the oxidation of the formyl group. The reason for this behavior may be the presence of the dimeric form 18 and/



or hydrogen bonding to the acetone solvent *in situ*, which results in resistance to oxidation of the hemiacetal function.[14]

Experimental Section

Melting points and boiling points are uncorrected. Nmr spectra were determined with Hitachi R-24 and R-20 instruments. Ir spectra were recorded on a Hitachi EPI-S2, only major absorptions being cited. Mass spectral analyses were carried out on Hitachi RMS-4 and JEOL JMS-OISG mass spectrometers at 70 eV, with molecular and major fragment ions being cited: *m/e* (relative intensity). Column chromatography was carried out using Wako gel C-200 (silica gel) with benzene–AcOEt (20:1) as the developing solvent. Elemental analyses were performed by Mr. Tsutomu Okamoto of our laboratory. Anhydrous sodium sulfate was used for all drying operations.

3a,7a-*cis*-5,6-Dihydroxyperhydro-1-indanone (4). To a stirred EtOH solution (75 ml) of 3a,7a-*cis*-3a,4,7,7a-tetrahydro-1-indanone (**3a**)[4] (3.60 g, 26.5 mmol) a solution of $KMnO_4$ (3.98 g, 25.2 mmol) and $MgSO_4$ (2.98 g, 24.8 mmol) in water (95 ml) was added over 2 hr at −45 to −40°. After the addition was completed, the reaction mixture was stirred for 2 hr and for an additional 1 hr at room temperature and then filtered. The precipitate was washed several times with hot water. The combined filtrates were concentrated to *ca.* 10 ml using a rotary evaporator. The aqueous solution was extracted several times with AcOEt and the extracts were dried and concentrated. The residue was chromatographed (CH_2Cl_2–AcOEt, 1:1) to give 3.1 g (69%) of **4**: white crystals; mp 122–123°; ir (Nujol) 3375, 3280 (OH), and 1735 cm^{-1} (C=O); nmr ($CDCl_3$) δ 3.90 (m, 1 H, HCO), 3.45 (m, 1 H, HCO), 3.20 (s, 2 H, OH), and 3.00–1.50 (m, 10 H); mass spectrum 170 (M^+).

Anal. Calcd for $C_9H_{14}O_3$: C, 63.51; H, 8.29. Found: C, 63.57; H, 8.22.

3a,7a-*cis*-1,7a-*cis*-1,5,6-Trihydroxyperhydroindan (5). A mixture of **4** (2.00 g, 11.75 mmol) and $NaBH_4$ (1.05 g, 27.85 mmol) in EtOH (200 ml) was stirred for 12 hr at room temperature. The reaction mixture was cooled with an ice–water bath and 34 ml of AcOH was added. After stirring for additional 0.5 hr, the mixture was evaporated to dryness and the residue was extracted ten times with hot AcOEt. Evaporation of the solvent afforded a white solid, whose recrystallization from AcOEt gave 1.72 g (84.9%) of **5**: white crystals; mp 160.5–161.0°; ir (neat) 3300 cm^{-1} (OH).

Anal. Calcd for $C_9H_{16}O_3$: C, 62.77; H, 9.36. Found: C, 62.83; H, 9.57.

1,5-*cis*-5,6-*cis*-6-Formylmethyl-3-hydroxy-2-oxabicyclo-[3.3.0]octane (6). A solution of **5** (300 mg, 1.74 mmol) and sodium metaperiodate (375 mg, 1.75 mmol) in water (90 ml) was stirred for 7 hr at 2° under nitrogen. The aqueous solution was extracted with $CHCl_3$, washed with water, dried, and concentrated to give 295 mg of **6**: ir (neat) 3320 (OH), 2723 (CHO), and 1724 cm^{-1} (C=O); nmr ($CDCl_3$) δ 1.21–3.37 (10 H), 3.73 (br s, 1 H, OH), 4.82 (m, 1 H, CHO), 5.51 (d, J = 3.6 Hz, OCHO), and 9.75 (m, 1 H, CHO). The product **6** was homogeneous in tlc [Merck PF 254, R_f 0.32 (benzene–acetone–*n*-hexane, 2:1:1)]; however, **6** is hygroscopic and was used in the following experiment without further purification. To a stirred acetone (60 ml) solution of **6** (300 mg, 1.76 mmol) a solution of $KMnO_4$ (279 mg, 1.75 mmol) and $MgSO_4$ (209 mg, 1.73 mmol) in water (6 ml) was added dropwise for 1 hr at 2–3°. After addition was completed, the mixture was stirred for 9 hr at 2–3°, and then 2-propanol (30 ml) was added. The mixture was stirred for 10 hr at 2–3° and for additional 5 hr at room temperature. The mixture was filtered and the precipitate was washed with hot water (3 ml). The combined filtrate and washings were concentrated to 3 ml and washed with $CHCl_3$. The aqueous solution was acidified with diluted HCl and extracted with $CHCl_3$. The extracts were dried. Removal of the solvent under reduced pressure gave 265 mg of an oil. Without further purification, the crude oil was treated with diazomethane to give 280 mg of products. Preparative tlc analysis of the liquid products indicated the following compounds to be present [R_f values, AcOEt–benzene (1:3); yields based on **6**]: **7b** (0.15, *ca.* 60%), **16b** (0.47, *ca.* 10%), and **17b** (0.55, *ca.* 10%). The physical and spectral data together with elemental analyses are as follows.

Compound **7b:** bp 65–68° (0.03 mm); ir (neat) 3425 (OH) and 1738 cm^{-1} (C=O); nmr ($CDCl_3$) δ 1.27–3.22 (10 H), 3.49 (br, 1H, OH), 3.67 (s, 3 H, CH_3O), 4.71 (m, 1 H, CHO), and 5.55 (d, J = 4.5 Hz, 1 H, OCHO).

Anal. Calcd for $C_{10}H_{16}O_4$: C, 59.98; H, 8.05. Found: C, 60.28; H, 8.18.

Compound **16b:** bp 82–85° (0.02 mm); ir (neat) 1775 (lactone C=O) and 1735 cm^{-1} (C=O); nmr ($CDCl_3$) δ 1.60–3.20 (10 H), 3.69 (s, 3 H, CH_3O), and 5.05 (m, 1 H, CHO); mass spectrum 198 (M^+, 2), 180 (10), 166 (52), 152 (55), 149 (50), 138 (50), 125 (58), 96 (100), 81 (63), 74 (68), 67 (50), 55 (55), and 41 (63).

Anal. Calcd for $C_{10}H_{14}O_4$: C, 60.59; H, 7.12. Found: C, 60.80; H, 7.14.

Compound **17b:** mp 94.5–95.0°; ir (Nujol) 1739 cm^{-1} (C=O); nmr ($CDCl_3$) δ 1.13–3.20 (20 H), 3.67 (s, 6 H, CH_3O), 4.52 (m, 2 H, CHO), and 5.35 (d, J = 4.2 Hz, 2 H, OCHO); mass spectrum (15 eV) 199 [(M^+ + O)/2,2], 183 [(M^+ − O)/2, 99], 182 [(M^+ − O)/2 − H, 34], 151 (60), 150 (22), 139 (10), 123 (17), 122 (20), 109 (18), 108 (36), 95 (26), 94 (48), 82 (100), 81 (89), 68 (31), and 59 (25).

Anal. Calcd for $C_{20}H_{30}O_7$: C, 63.16; H, 8.10. Found: C, 63.42; H, 8.13.

1,5-*cis*-5,6-*cis*-6-Carbomethoxymethyl-3-methoxy-2-oxabicyclo[3.3.0]octane (7c). A solution of **7b** (170 mg, 0.85 mmol) and *p*-toluenesulfonic acid (3 mg) in MeOH (10 ml) was refluxed for 30 min. After distillation of most of the solvent fresh MeOH (30 ml) was added slowly during 2 hr under heating. When the addition was completed, the mixture was refluxed and then diluted cautiously with benzene (10 ml). The mixture was distilled slowly to a small volume (*ca.* 5–10 ml) under atomospheric pressure. The residue was taken up in ether (10 ml) and washed with aqueous $NaHCO_3$, dried, and concentrated. The residue was chromatographed to give 173 mg (95%) of **7c**: ir (neat) 1739 cm^{-1}; nmr ($CDCl_3$) δ 1.30–2.50 (10 H), 3.27 (s, 3 H, CH_3O), 3.64 (s, 3 H, CH_3O), 4.53 (m, 1 H, CHO), and 4.55 (d, J = 4.2 Hz, 1 H, OCHO); mass spectrum 199 (M^+ − Me, 5), 181 (M^+ − MeO, 18), 182 (M^+ − MeOH, 48), 151 (51), 139 (11), 122 (46), 108 (58), 94 (83), 82 (90), 81 (100), 71 (60), 68 (59), 59 (58), 53 (49), and 41 (58).

Anal. Calcd for $C_{11}H_{18}O_4$: C, 61.66; H, 8.47. Found: C, 61.62; H, 8.42.

In the similar manner, the acetalization of **17b** with MeOH gave **7c** in almost quantitative yield.

Preparation of Thioacetals (8b and 11). To a stirred dry $CHCl_3$ solution (2 ml) of boron trifluoride etherate (251 mg, 1.80 mmol) a solution of **7c** (180 mg, 0.84 mmol) and 1,3-propanedithiol (92 mg, 0.85 mmol) in dry $CHCl_3$ (1 ml) was added dropwise at 2°. After stirring for 12 hr at room temperature the mixture was poured into ice–water and extracted with $CHCl_3$. The extracts were washed with aqueous $NaHCO_3$ and with water, dried, and

concentrated. The residue was chromatographed to give 187 mg (80%) of **8b** together with 15 mg (7%) of **11**.

In this reaction, when an excess amount of boron trifluoride etherate and commercial $CHCl_3$ (without drying operation) were employed, **11** was obtained in 80% yield together with a trace of **8b**.

Compound **8b** boiled at 112–114° (0.01 mm): ir (neat) 3485 and 1725 cm^{-1}; nmr ($CDCl_3$) δ 1.40–2.33 (10 H), 2.17 (s, 1 H, OH), 2.45 (br s, 2 H, CH_2CO), 2.87 (m, 4 H, CH_2S), 3.64 (s, 3 H, CH_3O), 4.10 (t, J = 6.6 Hz, SCHS), and 4.27 (m, 1 H, CHO); mass spectrum 290 (M^+, 8), 272 (1), 258 (3), 230 (1), 225 (1), 198 (4), 183 (19), 171 (2), 165 (4), 151 (43), 139 (10), 132 (74), 119 (100), 108 (33), 94 (20), 81 (56), 74 (39), 68 (21), 59 (26), and 41 (85).

Anal. Calcd for $C_{13}H_{22}O_3S_2$: C, 53.78; H, 7.64. Found: C, 53.64; H, 7.60.

Compound **11** melted at 105.2–105.5°: ir (Nujol) 1723 cm^{-1} (C=O); nmr ($CDCl_3$) δ 1.53–2.73 (12 H), 2.81 (m, 4 H, CH_2S), 4.10 (t, J = 8.4 Hz, 1 H, SCHS), and 4,63 (m, 1 H, CHO); mass spectrum 258 (M^+, 26), 230 (8), 211 (3), 198 (3), 186 (4), 156 (11), 132 (100), 119 (96), 106 (34), 74 (26), 67 (17), 55 (14), and 41 (44).

Anal. Calcd for $C_{12}H_{18}O_2S_2$: C, 55.78; H, 7.02. Found: C, 55.80; H, 6.88.

2,3-*cis*-3-Carbomethoxymethyl-2-(1′,3′-dithianyl-2′)methylcyclopentan-1-one (9a). To a stirred solution of *N*-chlorosuccinimide (100 mg, 0.74 mmol) in toluene (5 ml) was added at 0° methyl sulfide (1 ml) under nitrogen. The mixture was cooled to −25° and a solution of **8b** (60 mg, 0.21 mmol) in toluene (1 ml) was added dropwise. Stirring was continued for 3 hr at −25°, and then triethylamine (78 mg, 0.77 mmol) was added. The cooling bath was removed and after 5 min, ether was added. The organic layer was washed with 5% HCl and with water, dried, and concentrated. The residue was chromatographed to give 45 mg (76%) of **9a**: bp 107–110° (0.01 mm) (bath temperature); ir (neat) 1741 (shoulder) and 1734 cm^{-1} (C=O); nmr ($CDCl_3$) δ 1.36–2.96 (16 H), 3.71 (s, 3 H, CH_3O), and 4.16 (t, J = 7.2 Hz, 1 H, SCHS); mass spectrum 288 (M^+, 9), 257 (4), 215 (1), 182 (1), 134 (38), 133 (62), 132 (100), 119 (58), 106 (10), 97 (15), 85 (11), 83 (21), and 41 (31).

Anal. Calcd for $C_{13}H_{20}O_3S_2$: C, 54.16; H, 6.99. Found: C, 54.12; H, 7.00.

Epimerization of 9a. A solution of **9a** (24 mg, 0.08 mmol) in triethylamine (1 ml) was heated for 20 hr at 135–140° in a sealed tube. After removal of the solvent, distillation of the residue gave 23 mg (96%) of **9b**: bp 115–120° (0.02 mm) (bath temperature); ir (neat) 1737 cm^{-1} (C=O); nmr ($CDCl_3$) δ 1.48–2.95 (16 H), 3.70 (s, 3 H, CH_3O), and 4.28 (t, J = 7.2 Hz, 1 H, SCHS); mass spectrum 288 (M^+, 10), 257 (4), 215 (2), 182 (2), 134 (44), 133 (66), 132 (100), 119 (61), 106 (10), 97 (15), 86 (50), 84 (60), and 41 (38).

Anal. Calcd for $C_{13}H_{20}O_3S_2$: C, 54.16; H, 6.99. Found: C, 54.05; H, 7.06.

2,3-*trans*-3-Carbomethoxymethyl-2-formylmethyl-1-cyclopentanone (10b). To a stirred suspension of $HgCl_2$ (43 mg, 0.16 mmol) and HgO (17 mg, 0.08 mmol) in aqueous 80% MeCN (2 ml) a solution of **9b** (21 mg, 0.07 mmol) in aqueous 80% MeCN (2 ml) was added under nitrogen. The mixture was refluxed for 4 hr with stirring. After cooling the mixture was filtered and the precipitate was washed with CH_2Cl_2–*n*-hexane (1:1). The combined filtrates were washed with aqueous $AcONH_4$ and water, dried, and concentrated. The residue was chromatographed to give 13 mg (90%) of **10b**: bp 64–67° (0.04 mm) (bath temperature); ir (neat) 2775 (CHO), 1745, 1730, and 1722 cm^{-1} (C=O); nmr ($CDCl_3$) δ 1.35–2.90 (10 H), 3.67 (s, 3 H, CH_3O), and 9.71 (s, 1 H, CHO).

Anal. Calcd for $C_{10}H_{14}O_4$: C, 60.59; H, 7.12. Found: C, 60.62; H, 7.08.

Methyl *dl*-Jasmonate (1). To a stirred solution of **10** (8 mg, 0.04 mmol) a salt-free benzene solution (2 ml) of *n*-propylidenetriphenylphosphorane prepared from *n*-propyltriphenylphosphonium bromide (100 mg, 0.25 mmol) by the reported method[11] was added. After stirring for 10 hr at room temperature the reaction mixture was evaporated to a small volume and the residue was extracted several times with *n*-hexane. The extracts were concentrated and the residue was chromatographed to give 8 mg (88%) of **1**: bp 120–125° (7 mm) [lit.[3a] bp 81–84° (0.001 mm)]; ir (neat) 3000 (HC=C), 1741 (C=O), and 1650 cm^{-1} (C=C); nmr ($CDCl_3$) δ 0.97 (t, J = 7.2 Hz, 3 H, CH_3C), 1.45–2.90 (12 H), 3.69 (s, 3 H, CH_3O), 5.27 (d, J = 6 Hz, 1 H, HC=C), and 5.45 (d, J = 6 Hz, HC=C). Ir, nmr, and mass spectral data were identical with those of methyl *dl*-jasmonate reported in the literature.[3a,b]

8-*syn*-Formylmethyl-2-oxabicyclo[3.2.1]octan-3-one (12). To a stirred suspension of $HgCl_2$ (238 mg, 0.88 mmol) and HgO (95 mg, 0.44 mmol) in aqueous 80% MeCN (2 ml) a solution of **11** (100 mg, 0.39 mmol) in aqueous 80% MeCN (4 ml) was added. The mixture was refluxed for 4 hr. After work-up in the usual manner, there was obtained 62 mg (96%) of **12**: bp 115–125° (0.03 mm) (bath temperature); ir (neat) 2725 (CHO), 1747, 1735, and 1715 cm^{-1} (C=O); nmr ($CDCl_3$) δ 1.60–3.06 (10 H), 4.68 (m, 1 H, CHO), and 9.88 (s, 1 H, CHO).

Anal. Calcd for $C_9H_{12}O_3$: C, 64.27; H, 7.19. Found: C, 64.20; H, 7.47.

8-*syn*-(2-*cis*-Pentenyl)-2-oxabicyclo[3.2.1]octan-3-one (13). To a stirred solution of **12** (45 mg, 0.27 mmol) in benzene (0.5 ml) a salt-free benzene solution (2 ml) of *n*-propylidenetriphenylphosphorane prepared from *n*-propyltriphenylphosphonium bromide (200 mg, 0.52 mmol) was added under nitrogen and the mixture was stirred for 12 hr at room temperature. After work-up in the usual manner, there was obtained 44 mg (85%) of **13**: ir (neat 3000 (HC=C), 1738 (C=O), and 1651 cm^{-1} (C=C); nmr ($CDCl_3$) δ 0.96 (t, J = 7.2 Hz, 3 H, CH_3C), 1.52–2.75 (12 H), 4.59 (m, 1 H, CHO), and 5.13–5.73 (m, 2 H, HC=C); mass spectrum (80 eV) 194 (M^+, 3), 176 (1), 162 (3), 151 (3), 134 (82), 125 (23), 119 (36), 105 (26), 93 (41), 81 (49), 79 (72), 68 (100), 67 (75), 55 (59), and 41 (89).

Anal. Calcd for $C_{12}H_{18}O_2$: C, 74.19; H, 9.34. Found: C, 74.38; H, 9.36.

1,2-*cis*-2,3-*cis*-3-Carbomethoxymethyl-2-(*cis*-2-pentenyl)-cyclopentan-1-ol (14b). A solution of **13** (45 mg, 0.27 mmol) and KOH (100 mg, 1.8 mmol) in MeOH (1 ml) containing a few drops of water was stirred for 12 hr at room temperature. The reaction solution was diluted with 3 ml of water and concentrated to a small volume with a rotary evaporator. The aqueous solution was acidified to pH 3–4 with diluted H_2SO_4, extracted with $CHCl_3$, washed with water, and dried. Evaporation of the solvent gave 34 mg of **14a**: ir (neat) 3700–2350 (COOH) and 1710 cm^{-1} (C=O); nmr ($CDCl_3$) δ 0.98 (t, J = 7.2 Hz, 3 H, CH_3C), 1.50–2.72 (12 H), 4.22 (m, 1 H, CHO), 5.11–5.68 (m, 2 H, HC=C), and 6.33 (br s, 2 H, OH). Without further purification, the crude carboxylic acid **14a** was treated with diazomethane followed by column chromatography to give 35 mg (92%) of **14b**: bp 75–80° (0.01 mm) (bath temperature); ir (neat) 3500 (OH), 3000 (HC=C), 1734 (C=O), and 1654 cm^{-1} (C=C); nmr ($CDCl_3$) δ 0.97 (t, J = 7.2 Hz, CH_3C), 1.49–2.57 (12 H), 1.60 (s, 1 H, OH), 3.65 (s, 3 H, CH_3O), 4.20 (m, 1 H, CHO), and 5.09–5.70 (m, 2 H, HC=C); mass spectrum 208 ($M^+ - H_2O$, 19), 193 (2), 176 (9), 165 (30), 152 (64), 148 (27), 139 (64), 134 (100), 119 (85), 107 (74), 105 (80), 95 (67), 93 (81), 91 (63), 83 (56), 81 (57), 79 (88), 67 (73), 55 (84), and 41 (85).

Anal. Calcd for $C_{13}H_{22}O_3$: C, 68.99; H, 9.80. Found: C, 68.97; H, 9.70.

Methyl *dl*-2-Epijasmonate (2). To a stirred CH_2Cl_2 solution (3 ml) of **14b** (12.5 mg, 0.59 mmol) Jones reagent (0.2 ml) prepared from $Na_2Cr_2O_7$ (40 mg) and concentrated H_2SO_4 (50 mg) was added under cooling with an ice bath. After stirring for 10 min the ice bath was removed and the mixture was stirred for 5 hr at room temperature. The organic phase was separated, washed with aqueous $NaHCO_3$ followed with brine, dried, and concentrated. The residue was chromatographed to give 10 mg (81%) of **2**: bp 120–125° (7 mm) (bath temperature); ir (neat) 3000 (HC=C), 1742 (C=O), and 1654 cm^{-1} (C=C); nmr ($CDCl_3$) δ 0.95 (t, J = 7.2 Hz, 3 H, CH_3C), 1.60–2.99 (12 H), 3.69 (s, 3 H, CH_3O), and 5.07–5.71 (m, 2 H, HC=C); mass spectrum (80 eV) 224 (M^+, 26), 206 (10), 193 (9), 177 (7), 167 (3), 165 (2), 156 (20), 151 (46), 133 (15), 121 (13), 109 (32), 95 (64), 83 (100), 67 (50), 55 (52), and 41 (75).

Anal. Calcd for $C_{13}H_{20}O_3$: C, 69.61; H, 8.99. Found: C, 69.53; H, 9.05.

Epimerization of 2. A solution of **2** (10 mg, 0.045 mmol) in triethylamine (0.5 ml) was heated in a sealed tube for 6 hr at 130°. Evaporation of the solvent followed by distillation gave 9.5 mg of **1** (95%). Ir and nmr spectral data were identical with those of an authentic sample. The compound **1** boiled at 57–59° (0.025 mm).

2,3-*cis*-3-Carbomethoxymethyl-2-formylmethyl-1-cyclopentanone (10a). To a stirred suspension of $HgCl_2$ (65 mg, 0.24 mmol) and HgO (28 mg, 0.13 mmol) in aqueous 80% MeCN (1 ml) a solution of **9a** (32 mg, 0.11 mmol) in aqueous 80% MeCN was added. After refluxing for 3.5 hr the mixture was worked up in the usual manner to give 21 mg of **10a**: bp 67–69° (0.04 mm); ir (neat) 2720 (CHO) and 1738 cm^{-1} (C=O); nmr ($CDCl_3$) δ 1.42–3.25 (10 H), 3.68 (s, 3 H, CH_3O), and 9.77 (m, 1 H, CHO).

Anal. Calcd for $C_9H_{14}O_4$: C, 60.59; H, 7.12. Found: C, 60.61; H, 7.03.

Wittig Reaction of 10a. To a stirred solution of **10a** (21 mg, 0.106 mmol) in benzene (0.5 ml) a benzene solution of salt-free *n*-propylidenetriphenylphosphorane prepared from *n*-propyltriphenylphosphonium bromide (200 mg, 0.52 mmol) was added under nitrogen and the mixture was stirred for 15 hr at room tem-

perature. The mixture was worked up in the usual manner to give 17 mg of **2** (72%), whose ir and nmr spectral data were identical with those of **2** obtained in the preceding experiment.

Hydrolysis of δ-Lactone 11. A solution of **11** (46 mg, 0.18 mmol) and KOH (100 mg) in MeOH (0.5 ml) containing a few drops of water was stirred for 6 hr at room temperature. The mixture was diluted with 5 ml of water and washed with $CHCl_3$. The aqueous solution was acidified with diluted HCl and extracted with $CHCl_3$. The extracts were washed with water and dried. Removal of the solvent gave 42 mg of **8a** as white crystals: mp 119.5–120.0°; ir (Nujol) 3525 (OH), 3350–2200 (COOH), and 1687 cm^{-1} (C=O).

Anal. Calcd for $C_{12}H_{20}O_3S_2$: C, 52.17; H, 7.30. Found: C, 52.31; H, 7.10.

Treatment of **8a** with diazomethane followed by distillation gave 44 mg of **8b** (85%): bp 116–119° (0.02 mm). Ir and nmr spectra of **8b** were identical with those of an authentic sample.

1,5-*cis*-5,6-*cis*-6-(2′,2′-Dimethoxyethyl)-3-methoxy-2-oxabicyclo[3.3.0]octane (15). A solution of **6** (382 mg, 2.24 mmol) and *p*-toluenesulfonic acid (10 mg) in MeOH (35 ml) was refluxed for 2 hr. After processing as described in the preparation of **7c**, the residue was taken up in $CHCl_3$ (30 ml), washed with aqueous $NaHCO_3$, and dried. Removal of the solvent gave 465 mg (90%) of **15**: bp 50–52° (0.03 mm); ir (neat) 1126 and 1096 cm^{-1}; nmr ($CDCl_3$) δ 1.20–2.20 (10 H), 3.31 (s, 9 H, CH_3O), 6.38 (t, J = 5.7 Hz, 1 H, CHO), 6.56 (m, 1 H, CHO), and 6.98 (d, J = 4.2 Hz, 1 H, CHO).

Anal. Calcd for $C_{12}H_{22}O_4$: C, 66.64; H, 9.15. Found: C, 66.98; H, 9.21.

1,5-*cis*-5,6-*cis*-6-Carbomethoxymethyl-3-oxo-2-oxabicyclo[3.3.0]octane (16b). To a stirred solution of **6** (205 mg, 1.20 mmol) in ether (10 ml) was added an aqueous solution of 4 *N* chromic acid (1.3 ml) at 10° and the mixture was stirred for 10 hr at room temperature. The ether layer was separated and the aqueous solution was extracted with ether. The combined extracts were washed with water and dried. Removal of the solvent gave 191 mg (84%) of **16a**: ir (Nujol) 1767 (lactone) and 1698 cm^{-1} (COOH).

Without further purification, the acid **16a** was converted into the lactone ester **16b** by the action of diazomethane in quantitative yield: bp 82–85° (0.02 mm); ir (neat) 1775 (lactone C=O) and 1735 cm^{-1} (ester C=O); nmr ($CDCl_3$) δ 1.60–3.20 (10 H), 3.69 (s, 3 H, CH_3O), and 5.05 (m, 1 H, CHO); mass spectrum 198 (M^+, 2), 180 (10), 166 (52), 152 (55), 149 (50), 138 (50), 125 (58), 96 (100), 81 (63), 74 (68), 67 (50), 55 (55), and 41 (63).

Anal. Calcd for $C_{10}H_{14}O_4$: C, 60.59; H, 7.12. Found: C, 60.80; H, 7.14.

Chromic Acid Oxidation of 7b. To a stirred solution of **7b** (30 mg, 0.15 mmol) in ether (5 ml) a solution of 4 *N* chromic acid (0.3 ml) was added dropwise at room temperature. After processing as described above 27 mg (90%) of **16b** was obtained, whose ir and nmr spectra were identical with those of an authentic sample.

Registry No.—**1**, 20073-13-6; **2**, 53369-26-9; **3a**, 53320-14-2; **4**, 53320-15-3; **5**, 53320-16-4; **6**, 53320-17-5; **7b**, 53320-18-6; **7c**, 53320-19-7; **8a**, 53320-20-0; **8b**, 53320-21-1; **9a**, 53320-22-2; **9b**, 53320-23-3; **10a**, 53320-24-4; **10b**, 53320-25-5; **11**, 53320-26-6; **12**, 53320-27-7; **13**, 53403-88-6; **14a**, 53369-27-0; **14b**, 53369-28-1; **15**, 53320-28-9; **16a**, 53320-29-9; **16b**, 53320-30-2; **17b**, 53403-89-7; 1,3-propanedithiol, 109-80-8; *n*-propylidenetriphenylphosphorane, 16666-78-7.

References and Notes

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(4) Fractional distillation of cycloaddition products **3a** and **3b** prepared from cyclopentenone with butadiene by a 75-cm spinning column gave 48% of a higher boiling fraction, bp 99.5–100.0° (15 mm), which contains 98% of the cis isomer monitered by glpc: H. O. House and G. H. Rasmusson, *J. Org. Chem.*, **28**, 31 (1963).

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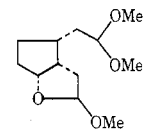
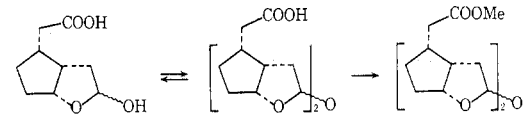
(7) Assignment of structure **6** was also based on its chemical nature, since conversion of **6** into the diacetal **15** was accomplished when it was refluxed in methanol in the presence of a catalytic amount of *p*-toluenesulfonic acid.



15

(8) Independent treatment of the acid hemiacetal **7a** with slightly acidic $CHCl_3$ and then standing for several days at room temperature afforded **17a** in good yield, which on treatment with diazomethane gave **17b**.



7a 17a 17b

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(15) Tlc analysis using Merck silica gel 60 PF-254 precoated plates after treatment with 5% silver nitrate in EtOH–MeCN (1:1) before use revealed that the cis olefin (R_f 0.48) was contaminated with *ca.* 5% of the trans olefin (R_f 0.56) using benzene–AcOEt (10:1) as a developer.