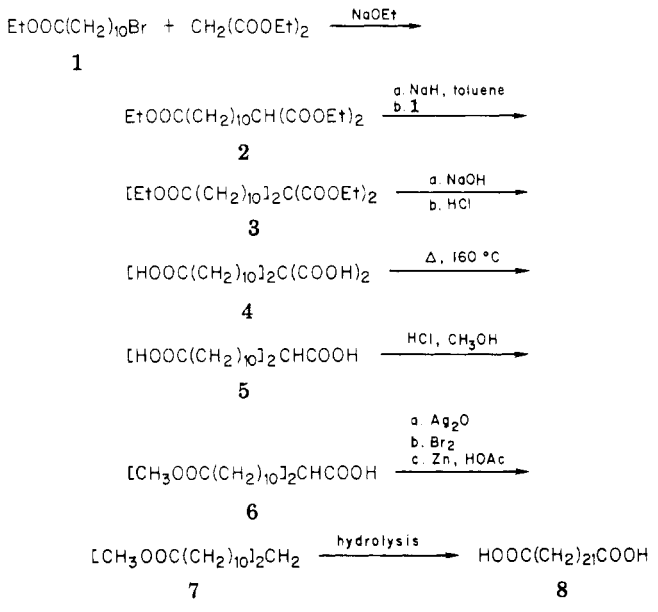
Scheme I



and cooled to -5 °C. The crystals which separated, mp 50–55 °C, 142 g (67%), were collected.[9] This acid was converted into the ethyl ester,[9] L, in 93% yield via the acid chloride prepared with thionyl chloride.

Dimethyl 11-Carboxy-1,21-heneicosanedioate, 6. To the solution prepared by reacting 9.0 g (0.39 mol) of sodium with 250 mL of absolute ethanol was added 80 mL (ca. 0.5 mol) of diethyl malonate and 115 g (0.39 mol) of **1**. After 6 h at reflux the alcohol was largely distilled and the residue was diluted with water and extracted with ether–benzene. After the solution was washed with saturated brine, the solvents were removed by heating and then about 20 mL of diethyl malonate was distilled at 75 °C (2.3 mm), leaving crude reaction product, mainly **2**. To a mixture prepared by reacting 7.3 g (0.30 mol) of sodium hydride in 300 mL of toluene with the above **2** for 0.5 h was added 97 g (0.33 mol) of **1**. The stirred mixture was held at reflux for 40 h (titration showed all base had been used up), cooled, and taken up in ether. After the solution was washed with water, dilute acetic acid, and brine, the solvents were removed and the residue, mainly **3**, was heated for 1 h at reflux with a solution of 10 g of NaOH in 250 mL of 95% ethanol and then with excess 6% NaOH while allowing most of the alcohol to distill. After 1 day at reflux the solution was treated with dilute HCl until the solid which formed just redissolved. After extraction with benzene the aqueous layer was added to excess aqueous HCl. The solid product was collected, washed with water and ether, and dried in a vacuum desiccator over concentrated H_2SO_4 for 12 h. The crude acid, **4**, mp 116–118 °C, was heated at 160 °C for 85 min to effect decarboxylation to yield 88 g (28% based on **1**) of heneicosane-1,11,21-tricarboxylic acid, **5**, mp 89.0–90.5 °C, neutralization equivalent 143.4 (theory 142.7). A solution of 21 g of **3** in 400 mL of dry methanol and 30 mL of 0.38 N HCl in methanol was held at room temperature for 1 h and then in the icebox for 15 h. By filtration there was obtained crude **6** and additional **6** on allowing the mother liquor to stand for 4 days in the icebox. Recrystallization afforded 14 g (69%) of pure **6**, mp 62.5–63.5 °C (corr). Anal.[10] Calcd for $C_{26}H_{48}O_6$: C, 68.4; H, 10.6. Found: C, 68.4; H, 10.3. Additional **6** was present in the mother liquor which was useful in recrystallizing material from another run. The remaining material in the mother liquor was mainly **5**.

1,21-Heneicosanedioic Acid, 8. A stirred mixture of 20 g of pure **6**, the silver oxide freshly prepared from 8 g of $AgNO_3$ and 2.5 g of NaOH in water, 100 mL of water, and 10 mL of ether was distilled. Addition of a little methanol caused the silver salt to coagulate and the brownish solid was collected, washed with methanol, and dried under vaccum at 60–70 °C. The silver salt, 24 g, was suspended in CCl_4 and treated with 5 mL of bromine.[11] After a few minutes the mixture was filtered and the filtrate was washed with cold aqueous K_2CO_3 and brine, and the CCl_4 was removed under vacuum to yield a soft waxy solid. This material was heated under reflux with stirring with 20 g of zinc dust and 150 mL of acetic acid for 2 h. The acetic acid was separated from the zinc dust and poured into ice water to yield 12 g (66% based on **6**, 13% based on **1**) of colorless dimethyl 1,21-heneicosanedioate, mp 73–74 °C (lit.[7] mp 70.8 °C). Alkaline saponification yielded pure **8**, mp 127–128 °C (lit.[7] mp 127.5 °C), in almost quantitative yield.

Registry No. 1, 6271-23-4; 2, 74965-67-6; 3, 74965-68-7; 4, 74965-69-8; 5, 74965-70-1; 6, 74965-71-2; 7, 42235-77-8; 8, 73292-43-0; $CH_2(COOEt)_2$, 105-53-3.

(10) Analysis by Mrs. E. H. Klotz.
(11) Cf.: Cristol, S. J.; Firth, W. C., Jr. *J. Org. Chem.* **1961** *26*, 280.

The Structure of Helminthogermacrene

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The coproduction of (-)-sativene (I) and (-)-longifolene (II) by *Helminthosporium* species[2] and the different stereospecificities of the crucial 1,3-hydride shifts occurring during biosynthesis of these compounds[3] have been interpreted in terms of a common precursor possessing a unique conformation (Scheme I).[4] According to this proposal cyclization of *cis,trans*-farnesyl PP[5] with the *re* face of the terminal double bond leads initially to medium-ring carbocycles containing one cis double bond[6] and conformationally well-suited for the hydrogen migrations.

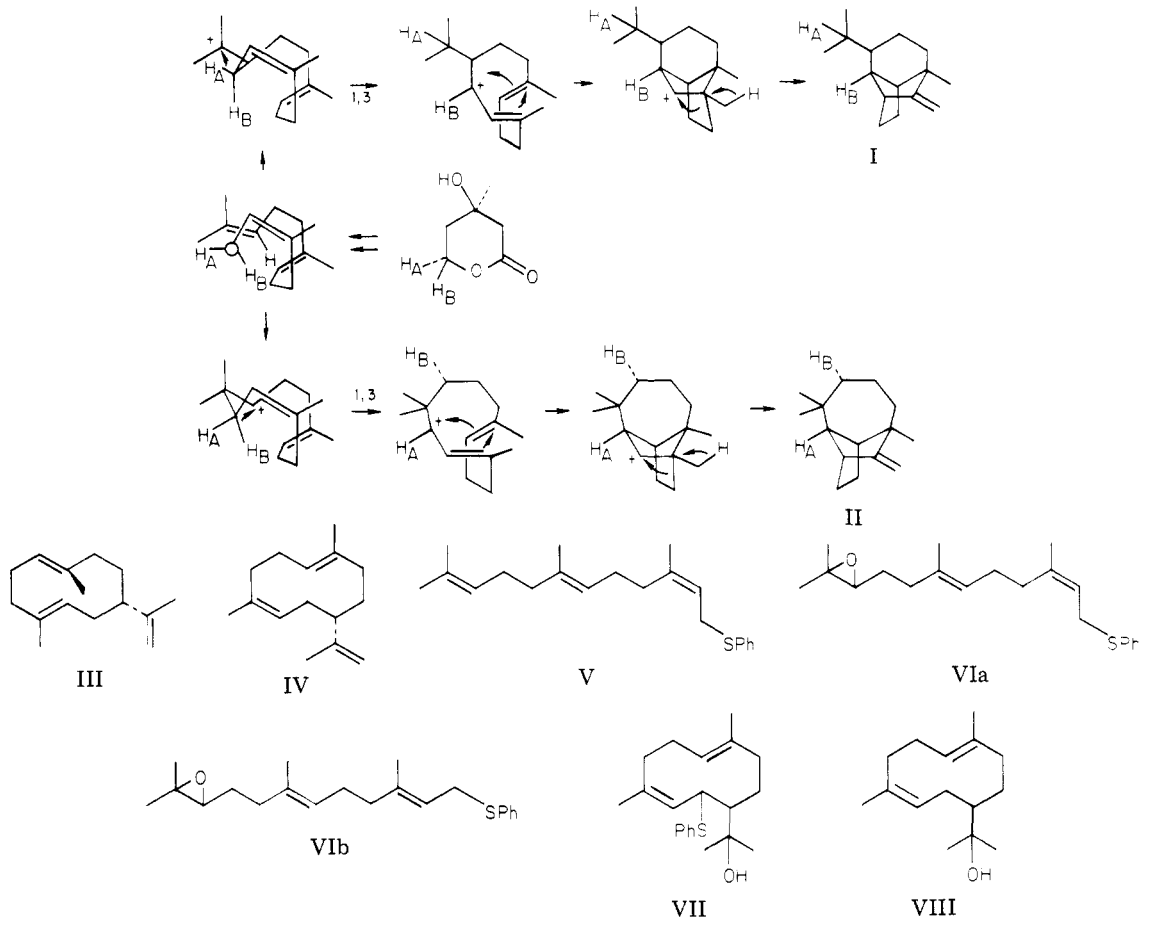
We report here the isolation and structure verification by synthesis of a new hydrocarbon from *Helminthosporium sativum*; the structure of this hydrocarbon corresponds to the ten-membered-ring intermediate required for sativene biosynthesis and thereby provides indirect evidence in support of the biosynthetic proposal.

Careful analysis of the hydrocarbon fractions obtained from mycellium of *H. sativum* has revealed the presence of components other than I and II.[7] Repeated chromatography gave a levorotatory $C_{15}H_{24}$ hydrocarbon which exhibited spectroscopic properties requiring three olefinic methyl groups [δ 1.70 (3 H) and 1.74 (6 H)] and four vinyl hydrogens, two of which compose a terminal methylene [δ 4.70 (2 H) and 5.1–5.5 (2 H) and $\bar{\nu}$ 3065, 3020, 1640, and 890 cm^{-1}]. The properties of this substance did not correspond with those of any known sesquiterpene hydrocarbon and in particular ruled out (-)-germacrene-A (III)[8] as a possible structure. This fact and the biogenetic arguments summarized above suggested that the new hy-

(1) Visiting Scholar at the Eidgenössische Technische Hochschule, 1975–76.
(2) Dorn, F.; Arigoni, D. *Experientia* **1974**, *30*, 851.
(3) Dorn, F.; Bernasconi, P.; Arigoni, D. *Chimia* **1975**, *29*, 24.
(4) Arigoni, D. *Pure Appl. Chem.* **1975**, *41*, 219.
(5) Or the conformationally equivalent form of nerolidyl PP (cf. ref 4, also recent reports by Cane, D. E.; Iyengar, R. *J. Am. Chem. Soc.* **1979**, *101*, 3386).
(6) Cf.: Hendrickson, J. B. *Tetrahedron* **1959**, *7*, 82.
(7) Dorn, F. *Diss. ETH* **1975**, 5554.
(8) Weinheimer, A. J.; Youngblood, W. W.; Washecheck, P. H.; Karns, T. K. B.; Cereszko, L. S. *Tetrahedron Lett.* **1970**, 497.

0022-3263/80/1945-4786$01.00/0

Scheme I



drocarbon be formulated as IV, a deduction which could be substantiated by total synthesis; accordingly, the name helminthogermacrene has been adopted for this new compound.

The synthetic approach was patterned after Itô's method for the construction of medium-size carbocycles,[9] beginning with the phenyl thioether V,[10] readily available from *cis,trans*-farnesol, and involving carbanionic cyclization of epoxide VIa obtained from V by terminal epoxidation.[11] Epoxide VIa exhibited chromatographic properties and an infrared spectrum virtually identical with those of the isomer VIb,[12] prepared from *trans,trans*-farnesol. Whereas only minor differences could be detected in the ^1H NMR spectra of VIa and VIb, ^{13}C NMR spectroscopy clearly differentiated between the two compounds and thereby provided evidence for their stereochemical integrity.

Cyclization of VIa was accomplished by treatment with butyllithium in the mixed solvent THF/HMPA, the only cyclic product obtained being the *cis,trans*-germacradiene VII.[13] Reduction of VII with lithium in liquid ammonia proceeded without detectable allylic rearrangement and furnished the alcohol VIII in high yield; the same compound has been reported by Itô.[12] Dehydration of VIII using thionyl chloride in pyridine gave a mixture of hydrocarbons from which the major component could be separated in pure form by chromatography over $AgNO_3$-impregnated silica gel. This compound exhibited ^1H NMR and IR spectra identical with those of natural helminthogermacrene.

While a number of germacrane derivatives possessing a 4,5-cis double bond have been characterized in recent years,[14] they probably arise from trans,trans intermediates which undergo subsequent trans-to-cis isomerization in the course of oxidative transformations. In contrast, the cooccurrence of helminthogermacrene (IV) and its isomers (-)-sativene (I) and (-)-longifolene (II) implies a more fundamental relationship among these hydrocarbons. Thus, IV can be taken to represent a product of deprotonation of the first cyclic cationic intermediate in sativene biosynthesis (cf. Scheme I). The yet unproven absolute configuration shown for helminthogermacrene in IV has been chosen in conformity with this scheme.

Experimental Section

Unless noted otherwise, the following general information applies. Infrared (IR) spectra were recorded on Perkin-Elmer spectrophotometers, Models 237 or 21; only the principal bands are listed. Proton magnetic resonance (NMR) spectra were recorded with a Varian A-100 spectrometer; chemical shifts are reported in parts per million (δ) relative to tetramethylsilane as an internal standard. Mass spectra were obtained by electron impact at 70 eV, using a Hitachi/Perkin-Elmer RMU 64 or AEI MS2/H; only the most characteristic and/or most intense fragment ions are tabulated. Thin-layer chromatographic analyses (TLC) were performed with Merck Fertigplatten with Kiesel-

(9) Kodama, M.; Matsuki, Y.; Itô, S. *Tetrahedron Lett.* **1975**, 3065.
(10) Bielman, J. F.; Ducep, J. B. *Tetrahedron* **1971**, *27*, 5861.
(11) vanTamelen, E. E.; Curphy, T. J. *Tetrahedron Lett.* **1962**, 121. vanTamelen, E. E.; Sharpless, K. B. *Ibid.* **1967**, 2655.
(12) Kodama, M.; Matsuki, Y.; Itô, S. *Tetrahedron Lett.* **1976**, 1121.
(13) Itô and co-workers reported[12] an apparent loss of stereointegrity during cyclization of VIb in the presence of DABCO and obtained VII as well as the expected trans,trans isomer. We have not detected significant crossover on cyclization of either VIa or VIb in the presence of HMPA.
(14) For examples, see: Watkins, S. F.; Fischer, N. H.; Bernal, I. *Proc. Natl. Acad. Sci. U.S.A.* **1973**, *70*, 2434; Takeda, K. *Tetrahedron* **1974**, *30*, 1525; McPhail, A. T.; Onan, K. D.; Lee, K.-H.; Ibuka, T.; Huang, H.-C. *Tetrahedron Lett.* **1974**, 3202 and references cited therein.

gel-254+355, developing solvent as indicated, and visualization by spraying with concentrated sulfuric acid and heating briefly. TLC mobilities (R_{st}) are reported relative to the starting material for the reaction under investigation. Merck Fertigplatten für Shicht Chromatographie were used for preparative thin-layer separations. Column chromatographic separations were achieved with Merck Kieselgel-60, Kieselgel DC for dry columns, or Merck Kieselgel *G* acc. Stahl for short columns with solvents as indicated. Gas chromatographic analyses were performed with a Carlo Erb Fractovap-2450 T equipped with a capillary column (Emulphor E, 20 m × 6.27 mm) and flame-ionization detector.

Microanalyses were performed by Mr. W. Manser (Zürich); all samples were chromatographically purified and distilled in a Kugelrohr apparatus at high vacuum.

Helminthogermacrene (IV) from *Helminthosporium sativum*. Repeated chromatography of the neutral extracts obtained from the mycellium of *H. sativum* over a 10–50-fold excess of silica gel furnished a hydrocarbon fraction free of (−)-sativene and (−)-longifolene. Helminthogermacrene (IV) was obtained therefrom as the slowest moving component on silver nitrate impregnated silica gel plates: $[\alpha]^{25}_D$ −28° (*c* 0.5, CCl_4); IR (CCl_4) 3065, 3020, 1640, 1375, 890 cm^{-1}; NMR ($CDCl_3$) 1.70 (m, 3 H), 1.74 (m, 6 H), 4.70 (m, 2 H), 5.1–5.5 (m, 2 H); mass spectrum, *m/e* 204 ($M^{+\cdot}$).

***cis,trans*-Farnesyl Phenyl Sulfide (V).** A mixture of 3.73 g of *cis,trans*-farnesol[15] (17 mmol), 2.70 g of triethylamine (2 mmol) and 3.23 g of 2,4-dinitrofluorobenzene (17 mmol) was warmed at 70 °C for about 0.5 h and then stood for an additional hour at room temperature. During this period the entire reaction mixture became a solid (crystalline) mass. Thereafter, additional triethylamine (2.0 mL, 14 mmol) and thiophenol (2.5 mL, 24 mmol) were added, and the reaction mixture was cooled briefly and then allowed to stand overnight at ambient temperature. The dark colored reaction mixture was poured into water and extracted with ether, and the organic layer was washed successively with 1 N sodium hydroxide, 5% aqueous hydrochloric acid, and saturated aqueous sodium bicarbonate. After the solution was dried over anhydrous sodium sulfate, the solvent was evaporated under reduced pressure, furnishing crude V (5.58 g) as a yellow orange oil. Purification was achieved by percolation through alumina (100 g, hexane); subsequent Kugelrohr distillation at 0.001 mm (air bath temperature 185 °C) furnished 4.80 g (91%) of V as a pale yellow oil: NMR ($CDCl_3$) 1.61 (s, 2 CH_3), 1.70 (s, 1 CH_3), 1.73 (d, J = 2 Hz, 1 CH_3), 2.40 (m, 4 CH_2), 3.45 (d, J = 8 Hz, CH_2S), 5.11 (br m, C=CH), 5.32 (td, J = 8, 1.5 Hz, 2 C=CH), 7.05–7.45 (m, aromatic CH);[10] IR (neat) 3080, 3065, 1590, 745, 695 cm^{-1}.[10]

10,11-Epoxy-*cis,trans*-farnesyl Sulfide (VIa). A solution of 1.74 g of *cis,trans*-farnesyl phenyl sulfide (5.5 mmol) in 40 mL of tetrahydrofuran and 15 mL of water was cooled in an ice bath, and 1.10 g of *N*-bromosuccinimide (6.2 mmol) was added portionwise during a period of about 1 h. An additional 5 mL of water was added in small portions to maintain cloudiness and cooling was continued throughout the addition period. After 2 h, brine was added, the layers were separated, the organic layer was washed with additional brine, and the aqueous layers were extracted with ether. The combined organic layers were dried over anhydrous sodium sulfate and the solvent was evaporated under reduced pressure, furnishing the crude bromohydrin (2.40 g, theoretical 2.28 g) as a slightly yellowish oil. TLC analysis (hexane/ethyl acetate, v/v, 6:1) indicated the major reaction product with R_{st} 0.45; separation was achieved by dry column chromatography over silica gel. Chromatographically, homogeneous bromohydrin (1.11 g, 49%) was obtained as a pale yellowish oil: NMR ($CDCl_3$) 1.33 (s, 2 CH_3), 1.62 (m, 1 CH_3), 1.74 (m, 1 CH_3), ca. 2.1 (m, 4 CH_2), 3.45 (d, J = 9 Hz, CH_2S), 3.97 (dd, J = 10, 3 Hz, CHBr), 5.20 (br m) and 5.34 (td, J = 8, 1.5 Hz, 2 C=CH), 7.0–7.5 (m, aromatic CH).

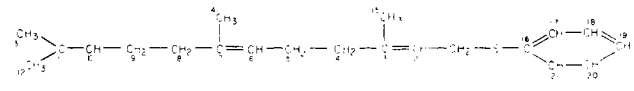
Conversion to epoxide VIa was accomplished by dissolution of the bromohydrin (1.11 g, 2.7 mmol) in 40 mL of anhydrous methanol and treatment with anhydrous potassium carbonate (2.10 g, 15 mmol) while the reaction mixture was cooled in an ice bath and an inert atmosphere was maintained. TLC analysis (hexane/ethyl acetate, v/v, 6:1) indicated the complete disappearance of starting material and the formation of a single reaction product, R_{st} 1.75, within 1 h. After 1 h, water was added and the product extracted with hexane; the hexane extracts were dried over sodium sulfate and the solvent was evaporated under reduced pressure. The residual slightly colored oil (0.90 g, 100%) was TLC homogeneous. An analytical sample was prepared by Kugelrohr distillation at 0.001 mm (air bath temperature 180 °C): NMR ($CDCl_3$) 1.26 (s, 1 CH_3), 1.30 (s, 1 CH_3), 1.64 (m, 1 CH_3), 1.74 (m, 1 CH_3), ca. 2.1 (m, 4 CH_2), 2.71 (t, J = 6 Hz, CH–O), 3.55 (d, J = 8 Hz, CH_2S), 5.2 (v br) and 5.38 (br t, J = 8 Hz, 2 C=CH), 7.0–7.3 (m, aromatic CH); IR (CCl_4) 3080, 3060, 1585, 690 cm^{-1}; mass spectrum, *m/e* (relative intensity) 330 (7), 221 (19), 220 (25), 203 (19), 149 (11), 147 (13), 135 (33), 134 (17), 133 (12), 127 (11), 123 (13), 121 (17), 119 (21), 110 (15), 109 (34), 107 (34), 105 (15), 94 (11), 93 (48), 91 (14), 83 (11), 82 (12), 81 (100), 80 (20), 79 (25), 77 (12), 71 (45), 69 (31), 68 (13), 67 (33), 65 (15), 55 (33), 53 (14), 43 (55), 41 (37), 39 (12), 29 (10). Anal. Calcd for $C_{21}H_{30}SO$: C, 76.31; H, 9.15; S, 9.70. Found: C, 76.14; H, 9.06;, S, 9.64.

^{13}C NMR data for VIa and its isomer VIb[12] are summarized in Table I.

Table I. ^{13}C NMR Spectral Data for VIa and VIb[a]

δ VIa	δ VIb	$\Delta\delta$ (VIa − VIb)	assignment[b]
139.497 (s)	139.695 (s)	−0.20	
136.717 (s)	136.915 (s)	−0.20	C_3, C_7, C_{16}
134.239 (s)	134.540 (s)	−0.30	
129.758 (d)	129.370 (d)	+0.39	C_2 or C_6
128.559 (d)	128.605 (d)	−0.05	
125.853 (d)	125.787 (d)	+0.07	$C_{17(21)}$, $C_{18(20)}$, C_{19}
124.306 (d)	124.244 (d)	+0.06	
119.326 (d)	119.868 (d)	−0.54	C_6 or C_2
64.027 (d)	63.994 (d)	+0.03	C_{10}
58.098 (s)	58.132 (s)	−0.03	C_{11}
36.273 (t)	36.281 (t)	−0.01	C_8
39.420 (t)	31.916 (t)	+7.50	C_4
32.135 (t)	31.771 (t)	+0.36	C_1
27.448 (t)	27.410 (t)	+0.04	C_5 or C_9
26.310 (t)	26.410 (t)	−0.01	C_9 or C_5
24.871 (q)	24.871 (q)	0.00	C_{14}
24.871 (q)	23.302 (q)	+1.57	C_{15}
18.727 (q)	18.723 (q)	0.00	C_{12} or C_{13}
15.989 (q)	16.014 (q)	−0.02	C_{13} or C_{12}

[a] Parts per million relative to Me_4Si, Varian XL-100 in $CDCl_3$ solution. [b] Numbering as indicated in the following formula for VIa and VIb:



Cyclization of 10,11-Epoxy-*cis,trans*-farnesyl Phenyl Sulfide. A solution of 0.477 g of 10,11-epoxy-*cis,trans*-farnesyl phenyl sulfide (VIa, 1.4 mmol) in 125 mL of tetrahydrofuran/hexamethylphosphoric acid triamide (v/v, 4:1), kept under argon and cooled in dry ice–2-propanol, was treated dropwise with 2 N butyllithium (in hexane). Initially, each drop produced a red-orange coloration which faded rapidly on stirring. After a lasting color was achieved, an additional 0.75 mL of butyllithium solution (1.5 mmol) was added at once, resulting in a deep red color. Thereafter, the cooling bath was removed and the reaction mixture allowed to warm to room temperature. During the latter part of the warming period a gradual fading of the intense red color was evident and at the end of the warmup period only a pale yellow orange color remained. TLC analysis (hexane/ethyl acetate, v/v, 6:1) of samples removed periodically from the reaction mixture revealed that new products were formed at or above ca. 0 °C; the major product was characterized by R_{st} 0.7 and by formation of a bright yellow color on treatment with concentrated sulfuric acid (cold). After 5–6 h the reaction mixture had reached ambient temperature and was worked up by the addition of brine and extraction with hexane. After evaporation of all volatile solvents, the residue was repartitioned between water and hexane and the hexane layer dried over anhydrous sodium sulfate. Evaporation of the solvent under reduced pressure furnished crude

(15) The isomeric farnesols (>95% pure) were obtained by repeated fractional ("spahltrohr") distillation of commercially available material (Fluka).

VII (0.475 g) as a viscous light yellow oil. Purification was achieved by short column chromatography (24 g, ca. 13 × 2.5 cm, hexane/ethyl acetate, v/v, 6:1), giving chromatographically homogeneous VII (0.204 g, 43%) as a thick (very viscous) colorless oil. An analytical sample was prepared by Kugelrohr distillation at 0.001 mm (air bath temperature ca. 150 °C): NMR ($CDCl_3$) 1.33 (s, 1 CH_3), 1.46 (s, 1 CH_3), 1.7 (m, 2 CH_3), 3.30 (d, J = 11.5 Hz, CHS), 5.21 (v br t, J = 7 Hz) and 5.65 (br d, J = 11.5 Hz, 2 CCH), 7.0–7.6 (m, aromatic CH); mass spectrum, m/e (relative intensity) 330 (2), 220 (7), 203 (25), 202 (34), 187 (32), 174 (13), 163 (70), 162 (51), 161 (11), 160 (11), 159 (59), 147 (51), 145 (12), 134 (14), 133 (12), 131 (10), 121 (10), 120 (12), 119 (23), 110 (100), 109 (25), 107 (27), 95 (17), 94 (21), 93 (17), 91 (25), 81 (36), 79 (19), 77 (22), 69 (13), 66 (30), 65 (15), 59 (75), 55 (15), 51 (11), 43 (25), 41 (24), 39 (14). Anal. Calcd for $C_{21}H_{30}SO$: C, 76.31; H, 9.15; S, 9.70. Found: C, 76.39; H, 9.19; S, 9.83.

Reduction of VII. A mixture of 0.110 g of VII (0.29 mmol) in ca. 1 mL of tetrahydrofuran and 20 mL of liquid ammonia, cooled in dry ice–2-propanol, was treated with 0.020 g of lithium wire (3 mmol), a deep blue color ensuing. The cooling bath was removed, and the reaction mixture maintained at under reflux for 0.5 h. Thereafter, ammonium chloride was added (discharging the blue color) and the condenser removed to allow evaporation of the ammonia. The residue was partioned between water and hexane, the organic extracts were dried over anhydrous sodium sulfate, and the solvent was removed in vacuo, giving 0.077 g of colorless oil (theoretical 0.074 g). TLC analysis (hexane/ethyl acetate, v/v, 4:1) indicated only one significant product, characterized by R_{st} 0.8. Preparative TLC furnished 0.0625 g of pure VIII (85%); an analytical sample was prepared by Kugelrohr distillation at 0.001 mm (air bath temperature ca. 110 °C): NMR ($CDCl_3$) 1.18 (s, 1 CH_3), 1.21 (s, 1 CH_3), 2.72 (br s, 2 CH_3), 5.32 (br t, J = 8 Hz, 2 C=CH); IR (CCl_4) 3615, 1665, 1155, 880, 860 cm^{-1}; mass spectrum, m/e (relative intensity) 222 (1), 204 (43), 189 (43), 164 (12), 162 (13), 161 (74), 149 (17), 147 (14), 135 (22), 133 (17), 123 (10), 122 (10), 121 (38), 109 (19), 108 (16), 107 (56), 105 (34), 95 (34), 94 (207), 93 (76), 91 (20), 82 (11), 81 (47), 80 (12), 77 (12), 71 (14), 69 (24), 68 (18), 67 (35), 59 (100), 55 (26), 53 (15), 44 (16), 43 (38), 41 (44), 39 (12), 29 (12), 18 (78), 17 (15). Anal. Calcd for $C_{15}H_{26}O$: C, 81.02; H, 11.785. Found: C, 80.88; H, 11.83.

Dehydration of VIII. A solution of 0.169 g of VIII (0.75 mmol) in 3.0 mL of pyridine cooled in an ice–water bath was treated with 0.22 g of thionyl chloride (1.85 mmol). The reaction mixture was stirred and cooling of the mixture was maintained for ca. 15 min. The reaction mixture was poured into chilled aqueous bicarbonate, extracted with hexane, washed with dilute hydrochloric acid and saturated bicarbonate, and dried over anhydrous sodium sulfate. Evaporation of the solvent under reduced pressure furnished a slightly cloudy oil, 0.097 g (theoretical 0.153 g). TLC analysis (hexane/ethyl acetate, v/v, 4:1) indicated the absence of VIII and products at R_{st} ca. 1.6 as well as significant material at the origin; GLC analysis (122 °C) indicated two major volatile components in a somewhat variable ratio, initially ca. 10:1 but only 4:1 for samples standing for sometime. On chromatography over silver nitrate impregnated silica gel (hexane/ethyl acetate, v/v, 1:1), the major component appeared as the slower moving. Preparative TLC over argenated silica gel furnished this component (0.044 g, ca. 20%) as homogeneous: NMR ($CDCl_3$) 1.68 (m, 1 CH_3), 1.71 (m, 2 CH_3), 4.68 (br s, 2 CCH), 5.27 (br, C=CH_2); IR (CCl_4) 3075, 3030, 1645, 890 cm^{-1}; mass spectrum, m/e (relative intensity) 204 (50), 189 (56), 162 (10), 161 (57), 148 (16), 147 (49), 135 (16), 134 (11), 133 (23), 122 (13), 121 (43), 120 (10), 119 (28), 109 (15), 108 (28), 107 (54), 106 (11), 105 (36), 95 (29), 94 (28), 93 (87), 92 (11), 91 (29), 81 (29), 81 (62), 80 (12), 79 (41), 77 (19), 69 (20), 68 (100), 67 (56), 65 (10), 55 (34), 53 (36), 43 (15), 41 (64), 40 (11), 39 (29), 29 (20), 27 (16), high-resolution mass spectrum, calcd for $C_{15}H_{24}$ 204.1878, found 204.1877.

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Registry No. IV, 75023-40-4; V, 28413-58-3; VIa, 74986-29-1; VIb, 60441-27-2; VII, 60441-28-3; VIII, 60479-01-8; *cis,trans*-farnesol, 61764-67-8; thiophenol, 108-98-5; 10-bromo-*cis,trans*-farnesyl sulfide, 74986-30-4; *cis,trans*-8-(1-methylethenyl)-18-dimethyl-1,5-cyclodecadiene, 69460-22-6.

Novel Cyclization Reaction of Methyl Styryl Sulfone with Ketone Enolates

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α,β-Unsaturated sulfur compounds have been used as important reagents in synthetic chemistry,[1] for example, vinyl sulfides as carbonyl synthons[2] and vinylsulfonium salts as precursors of cyclopropanes.[3] However, application of vinyl sulfones has been restricted since conversion of the sulfonyl group to another functional moiety is generally difficult. Posner demonstrated that the addition reaction of organocuprates to methyl vinyl sulfones was unsuccessful or gave low yields due to predominant proton abstraction from the methyl group.[4] In a previous communication, we reported the synthesis of 2-thiadecalin derivatives from cyclohexanone enolates and dimethylstyrylsulfoniuim salts.[5] If this annelation reaction was applicable to methyl styryl sulfone, it would be expected to introduce two alkyl groups into the carbonyl substrate by removal of the sulfonyl group from the resulting cyclic sulfones. We report herein the reaction of methyl styryl sulfone with lithium ketone enolates and desulfonylation of the products.

Methyl styryl sulfone (**1**) was allowed to react with lithium cyclohexanone enolate in THF–DMF (1:2) at 80 °C to give 8a-hydroxy-4-phenyl-2-thiadecalin 2,2-dioxide (**2**) in quantitative yield. A similar reaction between **1** and other lithium ketone enolates gave the corresponding cyclic sulfones in fairly good yields (Table I).[6]

The sulfone **2** was identified with an authentic sample prepared from 8a-hydroxy-4-phenyl-2-thiadecalin and *m*-chloroperbenzoic acid. Although **2** was proved to be single isomer by TLC and NMR, its stereochemistry could not be settled with certainty because five protons at C^1, C^3, and C^4 appeared as a multiplet at δ 3.10–3.20. Four protons at C^1 and C^3 were easily deuterated by treatment with sodium carbonate and deuterium oxide.[7] The NMR of the deuterated sulfone showed a doublet at δ 3.20, assignable to C^4 proton, and its coupling constant was 6.8 Hz, indicating an axial–axial relationship between the protons at C^4 and C^{4a}. This structural assignment is in agreement with the annelation reaction of butadienylsulfonium salts and cyclohexanone.[8] Structures of other cyclic sulfones were confirmed by NMR data, similar to that of **2**. In the reaction of 2-decalone and cycloheptanone, dehydrated products (**6**, **11**) were obtained in addition to β-hydroxy sulfones in 18 and 44% yields, respectively. Methyl vinyl sulfone (**1**) reacted with acetone enolate also to give cyclic sulfone **12** in a relatively low yield. On the basis of these results, it is clear that methyl vinyl sulfone (**1**) is predominantly transformed into cyclic sulfones by the addition of ketone enolates and subsequent

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