85849-94-1; **1e**, 51786-15-3; **1g**, 29210-09-1; **1h**, 85828-28-0; **1i**, 85828-29-1; **5a**, 85828-30-4; **5b**, 85828-31-5; **5c**, 85828-32-6; **5d**, 85828-33-7; **5e**, 85828-34-8; **5f**, 85828-35-9; **5g**, 85828-36-0; **5h**, 85828-37-1; **5i**, 85828-38-2; **5j**, 85282-39-3; **7c**, 85828-40-6; **12d**, 85828-41-7; **13d**·HCl, 85828-42-8; allyllithium, 3052-45-7; allylmagnesium bromide, 1730-25-2; methionine, 63-68-3; benzenesulfonyl chloride, 98-09-9; *n*-butyllithium, 109-72-8; vinylmagnesium bromide, 1826-67-1; *O*-benzyltyrosine, 16652-64-5; ethyl chloroformate, 541-41-3; lysine hydrochloride, 657-27-2; L-N^{ϵ}-(ethoxycarbonyl)lysine, 5701-16-6; serine, 56-45-1.

Polyene Pheromone Components from an Arctiid Moth (*Utetheisa ornatrix*): Characterization and Synthesis[1]

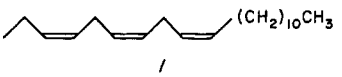
Subhash C. Jain,[2] David E. Dussourd, William E. Conner,[3] Thomas Eisner, Angel Guerrero,[4] and Jerrold Meinwald*

Department of Chemistry and Section of Neurobiology and Behavior, Cornell University, Ithaca, New York 14853

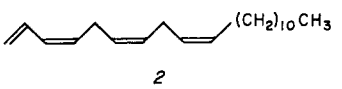
Received August 20, 1982

In our earlier study of the female sex attractant from an arctiid moth (*Utetheisa ornatrix*), the occurrence of an uncharacterized C-21 tetraene was noted along with (*Z,Z,Z*)-3,6,9-heneicosatriene, the major pheromone constituent. The sex attractant glands of females from other populations of this moth have now yielded this C-21 tetraene as a major component, accompanied by a new C-21 diene. Spectral and chemical studies of these two EAG-active compounds led to their characterization as (*Z,Z,Z*)-1,3,6,9-heneicosatetraene and (*Z,Z*)-6,9-heneicosadiene. These structures and configurations were confirmed by synthesis.

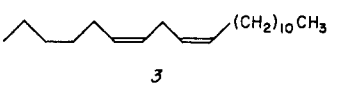
We previously reported the characterization and synthesis of (*Z,Z,Z*)-3,6,9-heneicosatriene (**1**), the principal



1



2



3

component of the sex attractant secretion of female *Utetheisa ornatrix*. This C-21 triene was shown to be biologically active in field and electroantennogram (EAG) bioassays.[1] We also noted an accompanying minor component, an EAG-active C-21 tetraene. In order to characterize the *U. ornatrix* pheromone more fully, we have examined new samples of this glandular product. We now report the full characterization and synthesis of the rather unstable tetraene [(*Z,Z,Z*)-1,3,6,9-heneicosatetraene (**2**)], as well as of an EAG-active diene [(*Z,Z*)-6,9-heneicosadiene, (**3**)] also found in the secretion.

Moths from five locations were used in our studies (Gainesville, FL; Lake Placid, FL; Poplarville, MS; Cameron, NC; Isabela, Puerto Rico). Composition of the secretion was found to vary geographically, within populations, and even from year to year. Details of variability, involving the nature, number, and ratio of gland components, will be published elsewhere. We here deal only with the chemistry of the diene and tetraene, two compounds not previously known from an insectan source.

Secretion was obtained by hexane extraction of glands freshly extricated with forceps from 318 live females (1–14 days old). These had been laboratory reared on a semisynthetic diet[5] supplemented with either *Crotalaria mucronata* beans (one of their natural food sources) or pinto beans; they represented first and third generation descendants stemming respectively from Gainesville and Poplarville field populations. The extract was concentrated, and a small portion was analyzed on GLC (10% XF-1150 at 150 °C). This analysis showed the presence of two components, designated as A and B. Neither of these corresponded to the previously reported triene **1**. However, A, now the major component, proved to be identical with the previously noted C-21 tetraene. Component B, also EAG active, had not been detected in our original samples of secretion (Lake Placid populations). These two compounds were separated and purified by preparative GLC and characterized as described below.

The mass spectrum of A showed a molecular ion at m/z 288.2818 (CI MS 289, MH^+) corresponding to the molecular formula $C_{21}H_{36}$ (calcd 288.2817). Microhydrogenation gave a product indistinguishable (GC/MS) from *n*-heneicosane ($C_{21}H_{44}$), indicating the presence of four centers of unsaturation in an unbranched chain of 21 carbon atoms. Microozonolysis, followed by reduction of the ozonide with triphenylphosphine, gave a material indistinguishable from *n*-dodecanal (GC/MS) as the only isolable product. The ultraviolet spectrum of A showed a strong absorption at 229 nm, indicating the presence of a conjugated diene chromophore. The 300-MHz ^1H NMR spectrum of A allows only a small number of possible structures. The presence of a total of nine protons in the olefinic region, along with the observation of only one terminal methyl group, requires one of the double bonds to occupy a terminal position (C-1). The ozonolysis experiment requires

(1) For the previous paper in this series, see: Conner, W. E.; Eisner, T.; Vander Meer, R. K.; Guerrero, A.; Ghiringhelli, D.; Meinwald, J. *Behav. Ecol. Sociobiol.* **1980**, *7*, 55.

(2) K. M. College, University of Delhi, Delhi-110007, India.

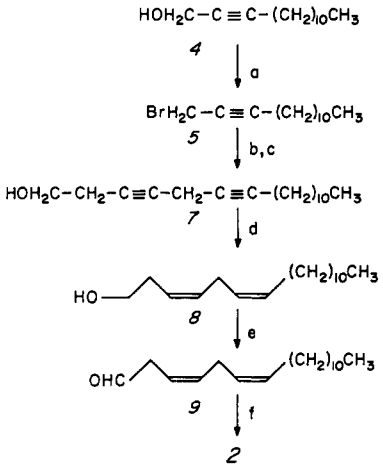
(3) Present address: Department of Zoology, Duke University, Durham, NC 27706.

(4) Instituto de Quimica Bio-Orgânica, Jorge Girona Salgado s/n. Barcelona-34, Spain.

(5) Miller, J. R.; Baker, T. C.; Cardé, R. T.; Roelofs, W. L. *Science (Washington, D.C.)* **1976**, *192*, 140.

0022-3263/83/1948-2266$01.50/0

Scheme I. Synthesis of (Z,Z,Z)-1,3,6,9-Heneicosatetraene[a]



[a] (a) PBr_3; (b) $HC{\equiv}CCH_2CH_2OTHP$; (c) CH_3OH, H^+; (d) P-2 Ni, H_2; (e) CrO_3, pyridine; (f) $Ph_3P{=}CHCH{=}CH_2$.

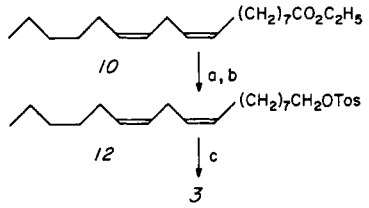
another double bond at C-9, with no additional unsaturation at higher numbered positions. The placement of the remaining two double bonds must be accomplished so as to create one diene chromophore and four doubly allylic protons. Of the several structures meeting these requirements, **2** seemed most likely because of its close relationship to the previously isolated pheromone **1**.[6] This assignment was confirmed by synthesis, as outlined in Scheme I.

1-Bromotetradec-2-yne (**5**) was conveniently prepared by treatment of tetradec-2-ynol (**4**) with phosphorus tribromide. The Grignard derivative of 1-(2-tetrahydropyranyloxy)but-3-yne (**6**) coupled with **5** to give octadeca-3,6-diynol (**7**) after a hydrolytic workup. Partial hydrogenation over P-2 nickel[7] gave the corresponding *Z,Z*-dienol (**8**).

Oxidation of this homoallylic alcohol with chromium trioxide–pyridine complex gave the labile, β,γ-unsaturated aldehyde **9**, which was subjected to immediate Wittig reaction with allyltriphenylphosphorane without prior purification. GLC and mass spectral analysis of the resulting hydrocarbon revealed the presence of the desired tetraene (**2**), along with a small amount of an isomeric hydrocarbon.[8] These products were separated on a 10% $AgNO_3$ impregnated silica gel column. The sample of **2** synthesized in this way was indistinguishable from the natural gland component A (GLC on two columns, GC/MS, ^1H NMR, and UV spectra). It must be noted, however, that admixture of *E,Z,Z* isomer with the desired *Z,Z,Z* isomer might well not be detected by these means.

The mass spectrum of B showed a molecular ion at m/z 292 (CI MS 293, MH^+) corresponding to the molecular formula $C_{21}H_{40}$, a heneicosadiene. Microozonolysis of B gave *n*-dodecanal and *n*-hexanal. These results unambiguously localize double bonds at C-6 and C-9, leading directly to structure **3** for B.[6] This structure is supported by the ^1H NMR spectral evidence, which confirms the presence of four olefinic protons, two doubly allylic protons, four allylic protons, and two terminal methyl groups. Finally, this structure, as well as the *Z,Z* stereochemistry,

Scheme II. Synthesis of (Z,Z)-6,9-Heneicosadiene[a]



[a] (a) $LiAlH_4$; (b) *p*-toluenesulfonyl chloride; (c) $(CH_3CH_2CH_2)_2CuLi$.

was firmly established by the very simple synthesis of **3** outlined in Scheme II.

Ethyl linoleate (**10**) was converted into tosylate **12** by reduction with lithium aluminum hydride (giving **11**) followed by treatment with *p*-toluenesulfonyl chloride in pyridine. Coupling of **12** with lithium di-*n*-propylcuprate gave the desired (*Z,Z*)-6,9-heneicosadiene (**3**), which proved active in EAG assays. Its GLC behavior (on two columns) and spectral data (EI MS, ^1H NMR, infrared) were indistinguishable from those of natural B.

Pheromones **1** and **3** have structures and configurations analogous to those of linolenic and linoleic acids, polyunsaturated C-18 compounds of wide distribution in nature. The possibility that these acids may serve as biosynthetic precursors for triene **1**[9] and for related insect pheromones[10] has been noted. In these cases, the biosynthesis would require simply a chain-lengthening process and/or concomitant adjustment of oxidation state. However, no fully analogous process would rationalize the biosynthesis of tetraene **2** or of the closely related C-19 geometrid pheromone (*Z,Z,Z*)-1,3,6,9-nonadecatetraene,[11] since the requisite C-18 tetraenic acid is unknown. Whether any or all of these C-21 polyenes are derived from C-18 acids and, if so, how the chains are extended remain open questions.

Experimental Section

Melting points were obtained in sealed capillary tubes by using a Thomas-Hoover melting point apparatus and are uncorrected. Infrared spectra were obtained on a Perkin-Elmer 299B spectrophotometer. Proton magnetic resonance spectra were recorded on Varian EM-390 (90 MHz) and Bruker WM-300 (300 MHz) spectrometers, with tetramethylsilane and chloroform, respectively, as references. Mass spectra were taken on an AEI MS 902/CIS-2 mass spectrometer, while GC/MS analyses (EI and CI) were carried out by using a Finnigan 3300 GC/MS instrument coupled to a System Industries "System 150" data system. Ultraviolet spectra were recorded on either Cary 14 or Hewlett-Packard 8450 A UV/vis spectrophotometers. GLC analyses were carried out by using a Varian Aerograph series 2100 instrument equipped with a Shimadzu C-RIA Chromatopac recorder. TLC separations were carried out by using Polygram SIL G/UV_{254} precoated plastic plates (40 × 80mm; 0.25-mm silica gel with fluorescent indicator). The components were located by spraying with 2% ethanolic phosphomolybdic acid solution and warming with a hot-air gun.

Isolation of Sex Attractants. Sex attractant glands from 318 female *U. ornatrix* were dissected and extracted with hexane. The extract was concentrated to a small volume (ca. 0.4 mL), and a sample was analyzed on GLC (10% XF-1150 on Chromosorb W-AW-DMCS, 80/100 mesh, 2.4 m × 2 mm i.d. column, 32 mL of N_2/min). This analysis showed the presence of two volatile components, A (t_r 11.9 min) and B (t_r 6.3 min). Neither of these was the previously characterized C-21 triene **1**. However, the major constituent, A, corresponded closely (GLC and GC/MS) to the

(6) The absence of infrared absorption in the 970-cm^{-1} region indicated that all double bonds were of the *Z* configuration.

(7) Brown, C. A.; Ahuja, V. K. *J. Org. Chem.* **1973**, *38*, 2226; *J. Chem. Soc., Chem. Commun.* **1973**, 553.

(8) The ultraviolet absorption spectrum of this isomer is characteristic of a conjugated triene chromophore. This product apparently arises by isomerization of **9** to the corresponding α,β-unsaturated aldehyde, which then gives a 1,3,5,9-heneicosatetraene as its Wittig product.

(9) Conner, W. E. Doctoral dissertation, submitted to Cornell University, 1979.

(10) Hill, A. S.; Kovalev, B. G.; Nikolaeva, L. N.; Roelofs, W. L. *J. Chem. Ecol.* **1982**, *8*, 383.

(11) Roelofs, W. L.; Hill, A. S.; Linn, C. E.; Meinwald, J.; Jain, S. C.; Herbert, H. J.; Smith, R. F. *Science (Washington D.C.)* **1982**, *217*, 657.

"minor", EAG-active, C-21 tetraene noted in our previous publication.[1] A and B were separated and purified by preparative GLC (10% XF-1150 column as described above, 25 mL of N_2/min, 145 °C). Both collected fractions gave single peaks on two analytical columns (3% OV-1 and 3% Carbowax 20M).

The electron-impact (EI) mass spectrum of A showed a molecular ion (M^+) at m/z 288, corresponding to the molecular formula $C_{21}H_{36}$. Other major ions were observed at m/z (relative intensity) 147 (8), 137 (8), 133 (17), 121 (9), 120 (12), 119 (30), 107 (10), 106 (33), 105 (28), 94 (17), 93 (34), 92 (46), 91 (92), 81 (12), 80 (88), 79 (100), 78 (43), 77 (28), 71 (9), 69 (10), 67 (45), 66 (19), 65 (10), 57 (22), 55 (32), 54 (8), 53 (9), 43 (16), and 41 (23). The chemical-ionization (CI) mass spectrum showed an intense MH^+ ion at m/z 289: UV (hexane) λ_{max} 229 nm; ^1H NMR (300 MHz, $CDCl_3$) δ 6.63 (1 H, m), 6.00 (1 H, t, J = 10.8 Hz), 5.36 (5 H, m), 5.19 (1 H, dd, J = 17.0 Hz), 5.10 (1 H, dd, J = 10.3 Hz), 2.95 (2 H, t, J = 6.1 Hz), 2.80 (2 H, t, J = 5.9 Hz), 2.03 (2 H, m), 1.24 (18 H, s), 0.86 (3 H, t, J = 6.6 Hz). Microhydrogenation over Adams catalyst (PtO_2) in methanol gave a product with a GLC retention time identical with that of n-heneicosane on a FFAP column. Microozonolysis in methylene chloride at -78 °C, followed by reduction of the ozonide with triphenylphosphine, gave a product indistinguishable from n-dodecanal on two GLC columns (3% OV-1, 70–270 °C, 8 °C/min, and 10% XF-1150 at 140 °C).

The EI MS of B showed a molecular ion (M^+) at m/z 292, corresponding to the molecular formula $C_{21}H_{40}$. It showed other ions at m/z (relative intensity) 208 (1), 137 (8), 124 (24), 123 (14), 111 (9), 110 (40), 109 (28), 97 (22), 96 (76), 95 (59), 85 (16), 83 (30), 82 (83), 81 (85), 80 (18), 79 (30), 71 (26), 69 (36), 68 (48), 67 (100), 66 (8), 57 (37), 55 (51), 54 (33), 43 (25), and 41 (26). The CI MS showed an intense MH^+ ion at m/z 293: ^1H NMR (300 MHz, $CDCl_3$) δ 5.33 (4 H, m), 2.76 (2 H, t, J = 5.9 Hz), 2.03 (4 H, m), 1.26 (24 H, s), 0.87 (6 H, m). Microozonolysis in methylene chloride at -78 °C, followed by reduction of the resulting ozonide with triphenylphosphine, gave two products which on two GLC columns were indistinguishable from n-hexanal (3% OV-1 at 70 °C and 10% XF-1150 at 60 °C) and n-dodecanal (3% OV-1, 70–270 °C, 8 °C/min, and 10% XF-1150 at 140 °C) by direct comparison with authentic samples of these aldehydes.

Tetradec-2-ynol (4).[12] Prop-2-ynol (11.42 g, 0.204 mol) in 40 mL of THF was added in 20 min at −70 °C to a previously prepared, well-stirred solution of $LiNH_2$ (from 2.82 g, 0.47 mol, of Li in 300 mL of liquid NH_3). The solution turned gray after the addition was over; the mixture was stirred for an additional 0.5 h in an acetone–dry ice bath. 1-Bromoundecane (28.2 g, 0.12 mol) in 60 mL of THF was then added to the reaction mixture over 15 min, and the mixture was allowed to reflux gently for 8 h in a CCl_4–dry ice bath. Excess NH_3 was removed, and the residue poured into an ice-cooled dilute HCl solution. The resulting mixture was extracted four times with ether, the combined ether extracts were washed with a saturated solution of NaCl, dried over $MgSO_4$, and evaporated, and the residue was crystallized from aqueous alcohol to give 4: 24.5 g (97%); mp 41 °C (lit.[12] bp 40–42 °C). The purity of 4 was confirmed by TLC in hexane/ether (9:1) and by GLC (3% OV-1, 170–270 °C, 12 °C/min): IR (CCl_4) ν_{max} 3620, 2925, 2850, 2284, 2220, 1710, 1468, 1380, 1270, 1138, 1020, 985, 720 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 4.22 (2 H, t, J = 2.2 Hz, CH_2OH), 2.19 (2 H, m, $CH_2C{\equiv}$), 1.51 (2 H, m, $CH_2CH_2C{\equiv}$), 1.24 (16 H, s, $(CH_2)_8$), 0.85 (3 H, t, J = 6.7 Hz, CH_3).

1-Bromotetradec-2-yne (5). Dry PBr_3 (10.83 g, 40 mmol) was added at −10 °C over 20 min to a solution of 22.47 g (107 mmol) of tetradec-2-ynol and 4.4 mL of pyridine in 300 mL of anhydrous ether. The reaction mixture was stirred at room temperature for 10 min and then gently refluxed for 3 h. After cooling, the reaction mixture was quenched with ice–water and extracted three times with ether. The combined ether extract was washed with dilute $NaHCO_3$ solution and then NaCl solution. It was dried over anhydrous $MgSO_4$ and evaporated; the residue was purified by column chromatography over silica gel with hexane as eluent to give 18.02 g (62%) of pure 1-bromotetradec-2-yne as a colorless oil: GLC (3% OV-1, 140–240 °C, 8 °C/min), single peak; IR (film) ν_{max} 2920, 2848, 2230, 1462, 1208, 665 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 3.91 (2 H, t, J = 2.3 Hz, CH_2Br), 2.21 (2 H, m, $CH_2C{\equiv}$), 1.47 (2 H, m, $CH_2CH_2C{\equiv}$), 1.24 (16 H, s, $(CH_2)_8$), 0.86 (3 H, t, J = 6.5 Hz, CH_3).

1-(2-Tetrahydropyranyloxy)but-3-yne (6). 2,3-Dihydropyran (15.48 g, 0.184 mol) was added over 25 min, with stirring, to 10.9 g (0.156 mol) of but-3-ynol containing 10 drops of concentrated hydrochloric acid. The reaction mixture was cooled in an ice bath during the addition. The reaction mixture was stirred for 2 h at room temperature and then washed with saturated Na_2CO_3 solution, followed by NaCl solution. It was dried over anhydrous $MgSO_4$. On distillation, 18.2 g (76%) of 6 was obtained as a colorless oil, bp 100–102 °C (20 mm). Its purity was checked by TLC in hexane/ether (5:1).

Octadeca-3,6-diynol (7). Ethylmagnesium bromide was prepared by stirring a mixture of 6.89 g (60.3 mmol) of dry ethyl bromide and magnesium (1.46 g, 60 molar equiv) in 20 mL of tetrahydrofuran under argon. A solution of 9.24 g (60 mmol) of 6 in 60 mL of THF was then added over 20 min to the clear solution of Grignard reagent, and the mixture was refluxed for 6 h. The reaction mixture was cooled to room temperature. Cuprous chloride (0.5 g) was added rapidly. The resulting mixture was stirred for 15 min. 1-Bromotetradec-2-yne (12.28 g, 45 mmol) in 75 mL of THF was then added to this mixture over 20 min. A yellow precipitate appeared, and the mixture was stirred overnight at room temperature. The reaction mixture was then gently refluxed for 9 h and the reaction monitored by TLC with 4:1 hexane/ether. No spot corresponding to 5 was seen while a new spot appeared at lower R_f. The coupling mixture (containing the yellow precipitate) was cooled and poured into ice–water almost saturated with ammonium chloride. It was then extracted four times with ether, and the combined extract was dried over anhydrous $MgSO_4$, concentrated on a rotary evaporator, and dried at 0.2 mm to yield 16.1 g of crude 1-(2-tetrahydropyranyloxy)-octadeca-3,6-diyne. This was hydrolyzed directly as described below.

The protected coupling product (16.1 g) was taken up in 200 mL of methanol and hydrolyzed by refluxing it with 0.4 g of p-toluenesulfonic acid for 2 h. The brown solution which resulted was cooled and the solvent evaporated. The residue was poured into an ice-cooled saturated $NaHCO_3$ solution slowly with stirring. The light yellow product which precipitated was taken up in ether, washed with NaCl solution, and dried over anhydrous $MgSO_4$. The solvent was then evaporated. The crude product was purified by column chromatography over silica gel. Elutions with 85:15 hexane/ether gave octadeca-3,6-diynol (7) as a white solid: 6.85 g (58% from 5); mp 44 °C. The purity of 7 was checked by TLC (hexane/ether, 6:4) and GLC (3% OV-1, 170–270 °C, 12 °C/min): IR (CCl_4) ν_{max} 2927, 2856, 1470, 1314, 1054 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 3.68 (2 H, t, J = 6.2 Hz, CH_2OH), 3.12 (2 H, m, $\equiv CCH_2C{\equiv}$), 2.43 (2 H, m, $\equiv CCH_2CH_2OH$), 2.13 (2 H, m, $CH_2C{\equiv}$), 1.46 (2 H, m, $CH_2CH_2C{\equiv}$), 1.24 (16 H, s, $(CH_2)_8$), 0.86 (3 H, t, J = 6.7 Hz, CH_3).

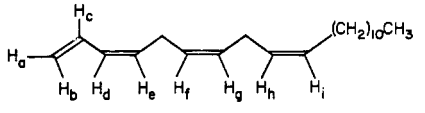
(Z,Z)-3,6-Octadecadienol (8). Nickel acetate tetrahydrate (3.78 g, 15 mmol) was dissolved in 200 mL of 95% ethanol. The flask was attached to a hydrogenator and the system flushed with hydrogen. Sodium borohydride solution (15.8 mL, 1.0 M) in ethanol was added with stirring to reduce the nickel acetate to P-2 nickel catalyst. When gas evolution ceased, the reactor was again purged with hydrogen. Ethylenediamine (3.6 g, 60 mmol) was then added, followed by 3.93 g (15 mmol) of octadeca-3,6-diynol in 25 mL of absolute ethanol. The hydrogen uptake was quantitative within 25 min and then ceased. The reaction mixture was examined by TLC (hexane/ether, 6:4) for the absence of 7 the hydrogenation was stopped; it was then filtered to remove catalyst, diluted with water, and extracted four times with ether. The combined extract was dried and solvent removed. The light brown oil which remained was purified by column chromatography over silica gel. Elution with hexane/ether (9:1) gave 3.67 g (92%) of (Z,Z)-3,6-octadecadienol (8) as a colorless oil. The purity of 8 was confirmed by TLC in hexane/ether (6:4) and by GLC with two columns (3% OV-1, 170–270 °C, 12 °C/min, and 10% XF-1150, 170 °C, isothermal): IR (film) ν_{max} 3310, 3000, 2910, 2840, 1463, 1042 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.52 (1 H, m) and 5.34 (3 H, m) (olefinic protons), 3.63 (2 H, t, J = 6.5 Hz, CH_2OH), 2.80 (2 H, t, J = 7.1 Hz, $=CHCH_2CH=$), 2.34 (2 H, m, $=CHCH_2CH_2OH$), 2.03 (2 H, m, $CH_2CH=$), 1.24 (16 H, s, $(CH_2)_8$), 0.86 (3 H, t, J = 6.7 Hz, CH_3). The EI MS showed a molecular

(12) Ames, D. E.; Corell, A. N.; Goodburn, T. G. J. Chem. Soc. 1963, 5889.

ion at m/z 266 (relative intensity) (0.3) corresponding to the molecular formula $C_{18}H_{34}O$. Other major ions appear at m/z (relative intensity) 121 (13), 111 (10), 109 (13), 107 (17), 98 (18), 97 (24), 96 (26), 95 (29), 94 (31), 93 (45), 91 (19), 84 (15), 83 (30), 82 (37), 81 (50), 80 (48), 79 (95), 77 (16), 71 (13), 70 (20), 69 (33), 68 (40), 67 (79), 66 (12), 57 (33), 56 (12), 55 (69), 54 (23), 53 (14), 43 (75), 41 (100), 39 (19).

(*Z*,*Z*)-3,6-Octadecadienal (9). Anhydrous CrO_3 (4.8 g, 48 mmol, dried in a vacuum desiccator) was quickly added to a stirred solution of 7.58 g (96 mmol) of dry pyridine in 75 mL of methylene chloride under argon. The reaction mixture was stirred for 5 min in an ice bath and then for 0.5 h at room temperature. A solution of 2.13 g (8 mmol) of (*Z*,*Z*)-3,6-octadecadienol in 15 mL of methylene chloride was added and the mixture stirred for another 2 h. The reaction mixture was periodically checked for completion of reaction by TLC with hexane/ether (6:4) as the solvent. Anhydrous ether (ca. 35 mL) was added and the stirring continued for an additional 10 min, followed by filtration of the reaction mixture through a thin layer of anhydrous $MgSO_4$. The precipitate was thoroughly washed with ether, and the washings were combined. The solvent was evaporated and dried at 0.2 mm to give 1.81 g (85%) of crude aldehyde **9**. This was immediately used in the next reaction. GLC (3% OV-1, 160–280 °C, 12 °C/min) showed the presence of one major peak: IR (film) ν_{max} 3006, 2920, 2850, 1735, 1432 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 9.7 (1 H, t, CHO), 5.45 (4 H, m, olefinic protons), 3.2 (2 H, m, $=CHCH_2CHO$), 2.8 (2 H, t, J = 7.0 Hz, $=CHCH_2CH=$), 2.08 (2 H, m, $CH_2CH=CH$), 1.28 (18 H, 5, $(CH_2)_9$), 0.9 (3 H, t, J = 6.7 Hz, CH_3).

(*Z*,*Z*,*Z*)-1,3,6,9-Heneicosatetraene (2). Allyltriphenylphosphonium bromide [1.915 g, 5.0 mmol; dried at 126 °C (0.6 mm) for 4 h] was stirred in 20 mL of THF under nitrogen for 10 min. The mixture was cooled in a dry ice–acetone bath, and 1.98 mL (5.0 mmol) of *n*-butyllithium in hexane (2.52 M) was added slowly. The solution acquired a permanent dark red color after the addition of the organometallic reagent was complete. The reaction mixture was stirred for 2 h. (*Z*,*Z*)-3,6-Octadecadienal (1.32 g, 5.0 mmol) in 12 mL of THF was then slowly added during a period of 20 min while the reaction mixture was cooled in a dry ice–acetone bath. The reaction mixture was stirred for 4 h, slowly brought to ambient temperature over a period of 1 h, and stirred for an additional hour. The reaction was monitored by GLC (3% OV-1, 100–200 °C, 10 °C/min). Excess pentane was added to precipitate the triphenylphosphonium oxide. Stirring was continued for another 15 min, the reaction mixture was filtered through a layer of anhydrous $MgSO_4$, and the solvent was evaporated. The resulting product was purified by column chromatogaphy over $AgNO_3$–silica gel (1:9) with hexane as the eluent to give 0.43 g (30%) of **2** as a colorless oil. GLC on two different columns (3% OV-17, 160–250 °C, 8 °C/min and 10% XF-1150, 145 °C, isothermal) indicated the product to be homogeneous: IR (film) ν_{max} 3016, 2930, 2856, 1470, 1002, 900 cm^{-1}; UV (hexane) λ_{max} 230 nm (ϵ 25 600); ^1H NMR (300 MHz, $CDCl_3$) δ 6.63 (1 H, m, H_c, 6.00 (1 H, t, J = 11.6 Hz, H_d), 5.37 (5 H, m,



H_e–H_i), 5.19 (1 H, dd, J = 16.9 Hz, H_b), 5.10 (1 H, dd, J = 10.1 Hz, H_a), 2.95 (2 H, t, J = 6.0 Hz, $=CHCH_2CH=CHCH=CH_2$), 2.80 (2 H, t, J = 5.9 Hz, $=CHCH_2CH=$), 2.03 (2 H, m, $CH_2CH=$), 1.24 (18 H, s, $(CH_2)_9$), 0.86 (3 H, t, J = 0.67 Hz, CH_3). The GC/MS (EI) was indistinguishable from that of natural A.

The $AgNO_3$–silica gel chromatography also yielded a small amount of an isomeric hydrocarbon (EI MS, m/z 288, M^+) with a conjugated triene chromophore: UV (hexane) λ_{max} 253, 263, 274 nm.

(*Z*,*Z*)-9,12-Octadecadienol (11). To a stirred solution of $LiAlH_4$ (0.148 g, 3.9 mmol) in 12 mL of anhydrous ether was added an ethereal solution of ethyl linoleate (**10**; 2.4 g, 7.79 mmol) under argon in such a way that the mixture refluxed gently. The flask contents were stirred and monitored by TLC with 1:1 hexane/ether as the solvent. After 4 h, when no more ester was seen, more anhydrous ether was added, followed by ethyl acetate (9 mL). The reaction mixture was stirred, and 0.1 mL of distilled water, 0.1 mL of 15% NaOH solution, and 0.3 mL of distilled water were added in succession. The resultant granular white precipitate was filtered, and the organic layer was washed with NaCl solution and dried. Evaporation of the solvent followed by chromatography of the residue on silica gel (eluted with 7:3 hexane/ether) gave pure (*Z*,*Z*)-9,12-octadecadienol (1.78 g, 86%) as a colorless oil. This material appeared as a single GLC peak (3% OV-1, 200 °C): IR (film) ν_{max} 3325, 3004, 2922, 2857, 1470, 1054 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$ δ 0.87 (3 H, t, J = 6.8 Hz, CH_3), 1.29 (16 H, s, $(CH_2)_8$), 1.54 (2 H, m, CH_2CH_2OH), 2.03 (4 H, m, $CH_2CH=CHCH_2CH=CHCH_2$), 2.75 (2 H, t, J = 5.8 Hz, $CH=CHCH_2CH=CH$), 3.62 (2 H, t, J = 6.6 Hz, CH_2 OH), 5.33 (4 H, m, $CH=CHCH_2CH=CH$). The EI MS showed a molecular ion at m/z 266 (16) corresponding to the molecular formula $C_{18}H_{34}O$. Other major ions appear at m/z (relative intensity) 135 (11), 124 (13), 123 (10), 121 (16), 110 (29), 109 (28), 107 (13), 98 (10), 97 (13), 96 (48), 95 (68), 94 (16), 93 (25), 91 (10), 83 (21), 82 (67), 81 (99), 80 (42), 79 (52), 77 (16), 69 (39), 68 (56), 67 (100), 66 (11), 57 (12), 55 (97), 54 (61), 53 (17), 43 (31), 41 (94), 39 (19).

(*Z*,*Z*)-9,12-Octadecadienol *p*-Toluenesulfonate (12). Dienol **11** (1.5 g, 5.64 mmol) in 12 mL of anhydrous pyridine was shaken with *p*-toluenesulfonyl chloride (1.08 g, 5.66 mmol), at 0 °C in an ice–salt bath until a clear solution was obtained. The reaction mixture was left at 0 °C for 24 h and quenched with ice–water containing hydrochloric acid. It was then extracted with ether, and the organic layer was washed with NaCl solution and dried. The solvent was removed and the crude product purified by column chromatography over silica gel. Elutions with 9:1 hexane/ether gave (*Z*,*Z*)-9,12-octadecadienol *p*-toluenesulfonate (2.27 g, 96%) as a pure colorless oil (showing a single spot on TLC in 1:1 hexane/ether and a single GLC peak on 3% OV-17, 250 °C): IR (film) ν_{max} 3006, 2923, 2858, 1600, 1470, 1365, 1190, 1180, 1098, 948, 832, 815, 665 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.77 (2 H, d, J = 8.3, 1.7 Hz, Ar H_a), 7.32 (2 H, d, J = 8.4, 1.6 Hz, Ar H_b), 5.33 (4 H, m, olefinic protons), 4.00 (2 H, t, J = 6.5 Hz, CH_2OSO_2), 2.75 (2 H, t, J = 5.9 Hz, $=CHCH_2CH=$), 2.43 (3 H, s, $C_6H_4(CH_3)$), 2.02 (4 H, m, $CH_2CH=CHCH_2CH=CHCH_2$), 1.61 (2 H, m, $CH_2CH_2OSO_2$), 1.30 (16 H, m, $(CH_2)_8$), 0.87 (3 H, t, J = 6.8 Hz, CH_3). The EI MS showed a molecular ion at m/z (relative intensity) 420 (21) corresponding to the molecular formula $C_{25}H_{40}SO_3$. Other major ions appear at m/z (relative intensity) 248 (13), 173 (11), 150 (13), 149 (10), 138 (12), 136 (12), 135 (18), 124 (20), 123 (11), 122 (15), 121 (23), 110 (30), 109 (21), 108 (12), 107 (15), 97 (17), 96 (49), 95 (47), 94 (24), 93 (30), 92 (10), 91 (67), 83 (22), 82 (58), 81 (77), 80 (58), 79 (56), 77 (13), 69 (36), 68 (38), 67 (100), 66 (10), 65 (16), 57 (15), 55 (74), 54 (39), 53 (11), 43 (14), 41 (59), and 39 (10).

(*Z*,*Z*)-6,9-Heneicosadiene (3). An ethereal solution of the above tosylate (1.82 g, 4.33 mmol, 50 mL) was slowly added to a solution of lithium di-*n*-propylcuprate (8.7 mmol, prepared from *n*-propyllithium[13]) in 20 mL of anhydrous ether at −30 °C. The reaction mixture was stirred under argon for 6 h and then quenched with a saturated aqueous ammonium chloride solution. The ether solution was separated, and the green aqueous solution was extracted twice with ether. The combined extract was washed with NaCl solution and dried over anhydrous $MgSO_4$. Evaporation of solvent and column chromatography of the resulting crude product over silica gel (eluted with hexane) gave pure (*Z*,*Z*)-6,9-heneicosadiene (1.25 g, 99%). The purity of **3** was checked on two GLC columns (3% OV-17, 100–250 °C, 8 °C/min, and 10% XF-1150, 145 °C isothermal): IR (film) ν_{max} 3008, 2956, 2914, 2852, 1468 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.33 (4 H, m, $CH=CHCH_2CH=CH$), 2.76 (2 H, t, J = 5.9 Hz, $=CHCH_2CH=$), 2.03 (4 H, m, $CH_2CH=CHCH_2CH=CHCH_2$), 1.26 (24 H, s, $(CH_2)_{12}$), 0.87 (6 H, m, $(CH_3)_2$). Its EI MS was superimposable on that of natural B.

Biological Assays. Standard electroantennograms,[14] as used previously with *Utetheisa* males for bioassay of the triene,[1] proved the diene and tetraene to be active as well. Each of six antennae (2-day-old Gainesville males) were presented with two successive randomized sequences of four stimuli: synthetic tetraene, triene, diene (10 μg each), and a hexane control. Activities ($\bar{x} \pm$ SEM)

(13) Johnson, C. R.; Dutra, G. A. *J. Am. Chem. Soc.* **1973**, *95*, 7777.
(14) Roelofs, W. L. In "Crop Protection Agents: Their Biological Evolution"; McFarlane, N. R., Ed.; Academic Press: New York, 1977; p 147.

of the alkenes, (tetraene, 2.47 ± 0.22 mV; triene, 1.52 ± 0.16 mV; diene, 1.34 ± 0.13 mV) were significantly ($p < 0.001$)[15] greater than that of the control (0.54 ± 0.07 mV). The higher activity of the tetraene relative to the other two alkenes is also significant ($p < 0.001$). An isomer of the natural diene, (*Z,Z*)-3,6-heneicosadiene,[16] assayed in similar tests (nine antennae from 4-day-old Gainesville and Poplarville males) proved significantly ($p < 0.001$) less active (0.42 ± 0.03 mV) than the natural diene (1.56 ± 0.11 mV) and only slightly more active ($p < 0.05$) than the control (0.33 ± 0.04 mV).

(15) Paired *t* tests were used in all statistical analyses of electroantennogram data.

(16) This diene was prepared by reaction of the Wittig reagent from (*Z*)-(3-hexenyl)triphenylphosphonium bromide with *n*-pentadecanal: ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.330 (4 H, m, olefinic protons), 2.76 (2 H, t, J = 6.4 Hz, $=CHCH_2CH=$), 2.06 (4 H, m, $CH_2CH=CHCH_2CH=CHCH_2$), 1.24 (24 H, s, $(CH_2)_{12}$), 0.95 (3 H, t, J = 7.3 Hz, $CH_3CH_2CH=$), 0.86 (3 H, t, J = 6.8 Hz, CH_3). The EI MS showed a molecular ion at m/z (relative intensity) 292 (0.8) corresponding to the molecular formula $C_{21}H_{40}$. Other major ions appear at m/z (relative intensity) 110 (15), 109 (23), 97 (15), 96 (58), 95 (51), 83 (21), 82 (100), 81 (60), 80 (12), 79 (21), 69 (19), 68 (37), 67 (84), 57 (12), 55 (33), 54 (16), 43 (22), and 41 (26).

Field tests, comparable to those carried out previously with the triene,[1] have been done only in areas of low *Utetheisa* density. The results, preliminary so far, show the tetraene (100 μg/moth trap) to be active.

Acknowledgment. We are grateful to the Indian Ministry of Education for the award of a National Scholarship to S.C.J. Additional support was provided by Research Grants AI-12020 and AI-02098 (NIH), Hatch Grant NYC-191406, and NIMH Training Grant T32 MH 15793. Special thanks to Audrey Balander, Karen Hicks, and Maura Malarcher for technical assistance and to Judy Gillmore, Dale H. Habeck, and Lena Brattsten for supplying some of the moths.

Registry No. **2**, 85612-05-1; **3**, 85613-23-6; **4**, 51309-22-9; **5**, 40924-12-7; **6**, 40365-61-5; **7**, 18202-26-1; 7 THP ether, 85613-24-7; **8**, 65050-40-0; **9**, 65050-43-3; **10**, 544-35-4; **11**, 506-43-4; **12**, 56401-30-0; $(CH_3CH_2CH_2)_2CuLi$, 43093-17-0; prop-2-yn-1-ol, 107-19-7; 1-bromoundecane, 693-67-4; but-3-yn-1-ol, 927-74-2; allyltriphenylphosphonium bromide, 1560-54-9.

Synthesis of Highly Unsaturated Insect Pheromones: (*Z,Z,Z*)-1,3,6,9-Heneicosatetraene and (*Z,Z,Z*)-1,3,6,9-Nonadecatetraene

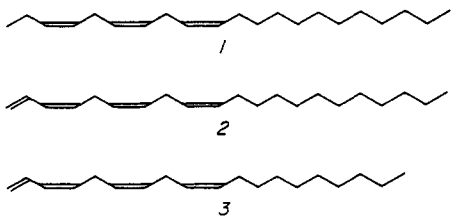
Wenkui Huang,[1] Steven P. Pulaski, and Jerrold Meinwald*

Department of Chemistry, Cornell University, Ithaca, New York 14853

Received July 20, 1982

Convenient syntheses of (*Z,Z,Z*)-1,3,6,9-heneicosatetraene (**2**) and (*Z,Z,Z*)-1,3,6,9-nonadecatetraene (**3**), female sex pheromones of an arctiid moth and of a geometrid moth, are reported. For each of these compounds, the key step is the partial hydrogenation of a crystalline triynol (**10**, **15**) by using Lindlar catalyst to give the corresponding (*Z,Z,Z*)-trienol (**11**, **16**).

Our recent studies of chemical communication in the arctiid moth *Utetheisa ornatrix* have led to the characterization of a C-21 triene, (*Z,Z,Z*)-3,6,9-heneicosatriene (**1**) as the major constituent of this insect's female pheromone.[2] Subsequent research has revealed that different populations of this moth have different female pheromone compositions and that a minor component in our original pheromone samples is a major component in the pheromone from other populations of the same species.[3] This new compound proved to be a C-21 tetraene, much more labile than **1**. We have shown this tetraene to be (*Z,Z,Z*)-1,3,6,9-heneicosatetraene (**2**) on the basis of chemical, spectral, and synthetic evidence.[3]



In an independent, parallel study, the first pheromone from a geometrid moth, *Operophtera brumata* (the winter moth), was isolated and found to be a straight-chain C-19 tetraene with a mass spectrum strikingly similar to that of **2**.[4] Additional degradative and synthetic evidence supported the hypothesis that the winter moth's female pheromone is (*Z,Z,Z*)-1,3,6,9-nonadecatetraene (**3**), a lower homologue of the C-21 arctiid tetraene.[5]

While the stereospecific synthesis of **1** can be achieved simply by a three-carbon extension of the triply unsaturated eighteen-carbon chain provided by linolenic acid,[2] syntheses of **2** and **3** are somewhat more of a challenge, since no correspondingly constituted, naturally occurring tetraenic acid appears to be known. We were interested in finding a good synthetic route to these two pheromones for several reasons. *U. ornatrix* females show the remarkable behavior of releasing their pheromonal signal in a pulsed fashion.[2] It would be very useful to have pure, synthetic samples of each of the pheromone components for this moth in order to try to unravel the biological significance of this pulsing behavior. In the C-19 case, the winter moth is an important forest pest in Europe, Canada, and the U.S.A.; a synthetic pheromone should be useful in monitoring populations of this pest and might even permit the disruption of its mating. Finally, with the discovery of these two closely related tetraenes among members of the arctiid and geometrid moths, it can be anticipated that these compounds or closely related ones will be found as pheromones in other lepidopteran species

(1) Dr. Huang Wenkui, of the Department of Chemistry, Lanzhou University, Lanzhou, Gansu, The People's Republic of China, died in a tragic plane accident in the PRC on Dec 25, 1982.

(2) Conner, W. E.; Eisner, T.; Vander Meer, R. K.; Guerrero, A.; Ghiringhelli, D.; Meinwald, J. *Behav. Ecol. Sociobiol.* **1980**, *7*, 55.

(3) Jain, S. C.; Dussourd, D.; Conner, W. E.; Eisner, T.; Guerrero, A.; Meinwald, J. *J. Org. Chem.*, preceding paper in this issue.

(4) Roelofs, W. L., private communication.

(5) Roelofs, W. L.; Hill, A. S.; Linn, C. E.; Meinwald, J.; Jain, S.C.; Herbert, H. J.; Smith, R. F. *Science (Washington, D.C.)* **1982**, *217*, 657.

0022-3263/83/1948-2270$01.50/0