

## A Rapid and Convenient Synthesis of the Sex Pheromone of the Douglas Fir Lepidoptera *Orgyia pseudotsugata*

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(Z)-Heneicos-6-en-11-one (5) has been synthesized in four steps from 2-hydroxytetrahydropyran, with an overall yield of 51%. The key step, a Wittig reaction, was found to be practically stereospecific (>98%).

THE structure of the sex pheromone of the Douglas fir Russock Moth *Orgyia pseudotsugata* was established in 1975.<sup>1</sup> In sharp contrast with other lepidopterous pheromones, which are unsaturated C<sub>12</sub>—C<sub>14</sub> primary

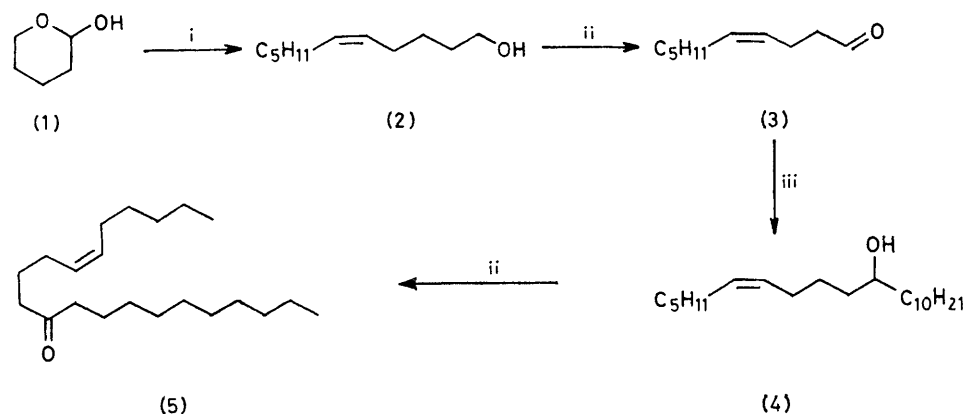
alcohols or esters (2),<sup>2</sup> this was found to be a C<sub>21</sub> ketone, (Z)-heneicos-6-en-11-one.

<sup>1</sup> R. G. Smith, G. E. Daterman, and G. D. Daves, *Science*, 1975, **188**, 63.

<sup>2</sup> K. Eiter, *Fortschr. Chem. org. Naturstoffe*, 1970, **28**, 204; M. Jacobson, 'Insect Sex Pheromones,' Academic Press, New York, N.Y., 1972; J. G. McConnel and R. M. Silverstein, *Angew. Chem. Internat. Edn.*, 1973, **12**, 644; D. A. Evans and C. L. Green, *Chem. Soc. Rev.*, 1973, **2**, 75.

Since this compound is a potent male attractant and might well be of practical interest, several syntheses have been carried out.<sup>3-5</sup> They all proceed *via* reduction of

The <sup>1</sup>H n.m.r. spectra were recorded on a Varian NV-14 (60 MHz) spectrometer, the compound being in solution in CDCl<sub>3</sub> or CCl<sub>4</sub>; the chemical shifts are expressed in p.p.m.



Reagents: i, C<sub>5</sub>H<sub>11</sub>CH=PPh<sub>3</sub>; ii, CrO<sub>3</sub>-pyridine; iii, C<sub>10</sub>H<sub>21</sub>MgBr.

an acetylenic intermediate. Our method based on a Wittig reaction has the advantage, apart from its high stereoselectivity, of using compounds available in large quantity. 2-Hydroxytetrahydropyran (1) was treated at -70 °C with the ylide C<sub>5</sub>H<sub>11</sub>CH=PPh<sub>3</sub><sup>6</sup> prepared from n-hexyltriphenylphosphonium bromide and potassium t-butyrate in tetrahydrofuran (THF). A 98 : 2 mixture of two isomeric alcohols was obtained. The major compound was the expected (*Z*)-undec-5-en-1-ol (2). Its structure was established as follows. (1) The Raman double-bond stretching vibration was observed at 1 652 cm<sup>-1</sup>; for *cis*-doubly substituted olefins the average value is 1 658 cm<sup>-1</sup> and is somewhat higher for the *trans*-isomer (1 674 cm<sup>-1</sup>).<sup>7</sup> (2) The chemical shifts observed in <sup>13</sup>C n.m.r. spectrum for the allylic carbon atoms (26.76 and 27.03 p.p.m.) are characteristic of *cis*-olefins; *trans*-olefins usually give rise to signals in the range of 33 p.p.m.<sup>8</sup> (3) *Z*- and *E*-Isomers were readily separated by h.p.l.c. In order to prove that the minor compound was indeed the *E*-isomer, the Wittig reaction was repeated under conditions which are known to be much less stereoselective (butyl-lithium as a base, room temperature instead of -70 °C). The amount of the minor compound increased moderately (20%). A new band appeared in the Raman spectrum (1 671 cm<sup>-1</sup>).

Oxidation of the alcohol (2) with CrO<sub>3</sub>-pyridine complex leads to (*Z*)-undec-5-en-1-al (3). A Grignard reaction with n-decylmagnesium bromide followed by oxidation (CrO<sub>3</sub>-pyridine complex) afforded (*Z*)-heneicos-6-en-11-one (5).

#### EXPERIMENTAL

The i.r. spectra were recorded with a Perkin-Elmer 577 instrument, and the values reported are expressed in cm<sup>-1</sup>.

<sup>3</sup> F. G. Smith, G. D. Daves, and G. E. Daterman, *J. Org. Chem.*, 1975, **40**, 1593.

<sup>4</sup> L. M. Stephenson, L. C. Falk, *J. Org. Chem.*, 1976, **41**, 2928.

<sup>5</sup> K. Mois, M. Uchida, and M. Matsin, *Tetrahedron*, 1977, **33**, 385.

<sup>6</sup> G. Forrest Woods, *Org. Synth.*, Coll. Vol. 1955, **3**, 470.

(reference SiMe<sub>4</sub>) and coupling constants in Hz. M.p.s were determined with a Reichert microscope, and are uncorrected. The Raman spectra were recorded with a Coderg Ph-O 800 mW argon laser instrument. The <sup>13</sup>C n.m.r. spectra were recorded on a Varian XI-100 spectrometer.

(*Z*)-Undec-5-en-1-ol (2).—Dry triphenylhexylphosphonium bromide (85.4 g, 0.2 mol) was added to a solution of potassium t-butoxide (21.8 g, 0.195 mol) in THF (350 ml; distilled from KOH) under a nitrogen atmosphere. The solution became bright orange and a precipitate formed. The suspension was cooled to -70 °C and freshly distilled hydroxypentanal (18.7 g, 0.183 mol) was added; the colour faded. After 0.5 h at -70 °C, 0.5 h at 0 °C, and 1 h at room temperature, the solvent was evaporated under reduced pressure; the residue was then exhaustively steam-distilled. The aqueous phase was extracted with ether and dried (Na<sub>2</sub>SO<sub>4</sub>). The solvent was evaporated under vacuum to give undec-5-en-1-ol (17.6 g, 60%), b.p. 63 °C at 0.01 Torr;  $\nu_{\max}(\text{CS}_2)$  3 630 (OH) and 3 010 cm<sup>-1</sup> (=CH-);  $\delta(\text{CDCl}_3)$  3.62 (t, 2 H, *J* 6 Hz), 5.35 (m, 2 H); Raman 1 652 cm<sup>-1</sup> (capillary);  $\delta_{\text{C}}$  13.9, 22.4, 25.7, 26.7, 27.0, 29.2, 31.3, 32.1, 62.1, 128.2, and 129.1; *m/e* 170 (4), 152 (16), 124 (16), 109 (18), 95 (56), 82 (79), 67 (100), 53 (88), 41 (97), and 31 (28), *M* 170 (Found: C, 77.35; H, 13.05. C<sub>11</sub>H<sub>22</sub>O requires C, 77.6; H, 13.0%); g.l.c. analysis, capillary column, packed with graphitized thermal carbon black sterling FTG modified with 0.4% poly(phenyl ether sulphone); h.p.l.c. analysis pyrocarbon on silica.

(*Z*)-Undec-5-en-1-al (3).—The pyridine-chromic anhydride complex was prepared at 0 °C, by adding CrO<sub>3</sub> (30 g, 0.3 mol) in small amounts to a solution of dry pyridine (47.45 g, 0.6 mol) and purified dichloromethane (650 ml). After 15 min of undec-5-en-1-ol (8.5 g, 0.05 mol) diluted in

<sup>7</sup> Marvin C. Tobin, 'Laser Raman Spectroscopy,' ed. P. J. Elving and I. M. Kolthoff, 1971, Sadtler Research Laboratory, Inc., 'The Sadtler Standard Spectra,' Raman Spectra N° 2790 R, 2798 R (1976), Forrest F. Cleveland, 'Determination of Organic Structures by Physical Methods,' eds. E. A. Brande and F. C. Nachod, 1955.

<sup>8</sup> S. Rang, E. Lippmaa, T. Pekk, and O. Eisen, *Festi N. S. V. Tead. Akad. Toim. Keem. Geol.*, 1968, **17**, 294; E. Lippmaa, S. Rang, O. Eisen, and T. Pekk, *Eesti N. S. V. Tead. Akad. Toim. Keem. Geol.*, 1967, **16**, 351.

the minimum amount of dichloromethane was added. The shaking was continued for 15 min at room temperature. After filtration on Florisil and evaporation of the solvent under vacuum (water-bath, 25–30 °C), the residue was extracted with ether, washed with dilute HCl to pH 2–3 and then with brine to pH 7. The extract was dried and the solvent evaporated under vacuum (water-bath, 30 °C) to give the oxidised compound (8.2 g, 90–95%);  $\nu_{\max}(\text{CS}_2)$  2 810, 2 710, 1 728 (CHO), and 3 010 (=CH-);  $\delta_{\text{H}}(\text{CDCl}_3)$  5.35 (m, 2 H) and 9.6 (s, 1 H); dinitrophenylhydrazone, m.p. 69–70 °C (95% EtOH);  $M$  348 (Found: C, 58.75; H, 69.2; O, 18.4; N, 16.15.  $\text{C}_{17}\text{H}_{24}\text{N}_4\text{O}_4$  requires C, 58.6; H, 6.95; O, 18.35; N, 16.1%).

(*Z*)-Heneicos-6-en-11-ol (4).—A solution of n-decylmagnesium bromide was prepared from magnesium turnings (0.06 g, 2.5 g-atom) and a solution of n-bromodecane (0.55 g, 2.5 mmol) diluted in dry ether (3 ml). To the magnetically stirred Grignard reagent was added dropwise a solution of undecen-5-al (0.336 g, 2.0 mmol) in dry ether (3 ml). After 3 h at room temperature the mixture was hydrolysed with an ammonium chloride solution, acidified with dilute HCl, and extracted with ether; after neutralisation, the ether extract was dried ( $\text{Na}_2\text{SO}_4$ ) and evaporated under vacuum; yield 0.448 g (100%);  $\nu_{\max}(\text{CCl}_4)$  3 630 (OH) and 3 010 (=CH-);  $\delta_{\text{H}}(\text{CDCl}_3)$  3.5 (m, 1 H) and 5.3 (m, 2 H); Raman 1 652  $\text{cm}^{-1}$  (capillary);  $m/e$  310 (2), 292 (18), and 124 (100);  $M$  310 (Found: C, 81.45; H, 13.6.  $\text{C}_{21}\text{H}_{42}\text{O}$  requires C, 81.2; H, 13.65%).

(*Z*)-Heneicos-6-en-11-one (5).—(*Z*)-Heneicos-6-en-11-ol (620 mg, 2 mmol) in  $\text{CH}_2\text{Cl}_2$  (1 ml) was added to a solution of pyridine– $\text{CrO}_3$  complex (from 1.5 g  $\text{CrO}_3$  and 2.3 g pyridine). After 15 min at room temperature, filtration on Florisil, and evaporation of the solvent under vacuum (water-bath 25–30 °C) the oily residue was dissolved in ether and washed with 0.1M-HCl and then with brine. The neutral solution was evaporated under vacuum. The residue was purified by chromatography; yield 560 mg (95%);

$\nu_{\max}(\text{CCl}_4)$  3 010 (=CH-) and 1 718 (C=O);  $\delta_{\text{H}}(\text{CDCl}_3)$  2.3 (t, 4 H,  $J$  6 Hz), 5.3 (m, 2 H, double bond); Raman 1 652  $\text{cm}^{-1}$  (capillary);  $m/e$  308 (12), 167 (34), and 124 (100);  $M$  308 (Found: C, 81.5; H, 13.1.  $\text{C}_{21}\text{H}_{40}\text{O}$  requires C, 81.75; H, 13.05%).

Mixture of (*Z*)- and (*E*)-Undec-5-en-1-ol.—A Wittig reaction was carried out with n-hexyltriphenylphosphonium bromide (17.08 g, 40 mmol), a 15% solution of commercially available n-butyl-lithium in hexane (17 ml, 40 mmol), and 2-hydroxytetrahydropyran (4.08 g) in THF. After hydrolysis, evaporation of the solvents, and exhaustive steam-distillation, a mixture of (*E*)- and (*Z*)-undec-5-en-1-ol (1.8 g, 27%) was obtained;  $\nu_{\max}(\text{neat})$  3 335 (OH) and 3 010  $\text{cm}^{-1}$  (=CH-); Raman 1 671 and 1 656  $\text{cm}^{-1}$  (capillary); g.l.c. analysis, capillary column packed with graphitized thermal carbon black Sterling FTG modified with 0.4% polyphenyl ether sulphone; h.p.l.c. analysis, pyrocarbon on silica.

Stereochemicals Analysis.—Samples of (*Z*)-undec-5-en-1-ol (2) and a mixture of (*Z*)- and (*E*)-(2) prepared as described above were examined. The stereoisomers were separated using a h.p.l.c. with a refractometer as detector (Waters); column, 50 cm  $\times$  4.6 mm; solvent, methanol; flow, 0.5  $\text{cm}^3 \text{min}^{-1}$ ; phase, pyrocarbon on silica (prepared by Chimie Analytique Physique–Ecole Polytechnique, Palaiseau, 91128 Cedex, France. Chromatograph, Trocar pump 995 with a Rheodyne sampling valve. Ambient temperature. The two isomers (*Z*) and (*E*) were eluted at 18.5 and 23 min respectively. Evaluation using peak height and width at half height show the (*Z*)-isomer (2) to be 98.0% pure; the mixture contained 80% of the (*Z*)-isomer.

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