4-Nitrobenzyl phenyl sulfide: mp 74.5–76.5 °C (EtOH) (lit.[11] mp 76–77 °C); NMR ($CDCl_3$) δ 4.21 (s, 2 H), 7.34 (s, 5 H), 7.45 (d, 2 H), 8.23 (d, 2 H).

2-Nitro-5-phenylbenzyl phenyl sulfide: oil; NMR ($CDCl_3$) δ 4.55 (s, 2 H), 7.2–7.7 (m, 12 H), 8.18 (d, 1 H). Anal. Calcd for $C_{19}H_{15}NO_2S$: C, 71.01; H, 4.70; N, 4.36. Found: C, 71.15; H, 4.68; N, 4.13.

(2-Nitro-5-phenylphenyl)bis(phenylthio)methane: oil; NMR ($CDCl_3$) δ 6.68 (s, 1 H), 7.2–7.7 (m, 16 H), 8.03 (d, 1 H), 8.18 (s, 1 H). Anal. Calcd for $C_{25}H_{19}NO_2S_2$: C, 69.90; H, 4.46; N, 3.26. Found: C, 69.31; H, 4.37; N, 3.13.

(2-Nitro-5-(phenylthio)benzyl) phenyl sulfide: oil; NMR ($CDCl_3$) δ 4.40 (s, 2 H), 7.03 (s, 1 H), 7.18 (d, 1 H), 7.33 (s, 5 H), 7.50 (s, 5 H), 8.01 (d, 1 H). Anal. Calcd for $C_{25}H_{19}N_2O_2S_2$: C, 64.56; H, 4.28; N, 3.96. Found: C, 64.77; H, 4.21; N, 3.75.

(2-Nitro-5-(phenylthio)phenyl)bis(phenylthio)methane: mp 135–136.5 °C (EtOH); NMR ($CDCl_3$) δ 6.63 (s, 1 H), 7.08 (d, 1 H), 7.35 (d, 10 H), 7.53 (s, 5 H), 7.69 (s, 1 H), 7.84 (d, 1 H). Anal. Calcd for $C_{25}H_{19}NO_2S_3$: C, 65.05; H, 4.15; N, 3.03. Found: C, 64.81; H, 3.95; N, 3.50.

(4-Nitrophenyl)(phenylthio)phenylmethane: oil; NMR ($CDCl_3$) δ 5.46 (s, 1 H), 7.1–7.3 (m, 10 H), 7.41 (d, 2 H), 7.98 (d, 2 H). Anal. Calcd for $C_{19}H_{15}NO_2S$: C, 71.01; H, 4.70; N, 4.36. Found: C, 70.83; H, 4.51; N, 4.34.

(4-Nitro-3-(phenylthio)phenyl)(phenylthio)phenylmethane: mp 86–87.5 °C (EtOH); NMR ($CDCl_3$) δ 5.19 (s, 1 H), 6.83 (s, 1 H), 7.1–7.4 (m, 16 H), 8.06 (d, 1 H). Anal. Calcd for $C_{25}H_{19}N_2O_2S_2$: C, 69.90; H, 4.46; N, 3.26. Found: C, 69.77; H, 4.31; N, 3.05.

Potassium *tert*-Butoxide/DMF System. General Procedure. A solution of 1.55 g (0.005 M) of **3** and 0.005 M nitrocompound in 10 mL of DMF was slowly added to stirred solution of 3.5 g of potassium *tert*-butoxide in 10 mL of DMF, which had been cooled to −10 °C. Stirring was continued for an additional 3 h at −10 °C. Workup and isolation of products proceed as in previous procedure.

(11) Jarvis, B. B.; Saukaitis, J. C. *J. Am. Chem. Soc.* **1973**, *95*, 7708.

2-Nitrobenzyl diethyldithiocarbamate: mp 28–29 °C (EtOH); NMR ($CDCl_3$) δ 1.28 (t, 6 H), 3.93 (m, 4 H), 5.08 (s, 2 H), 7.48–7.78 (m, 2 H), 7.98 8.19 (m, 2 H). Anal. Calcd for $C_{12}H_{16}N_2O_2S_2$: C, 50.68; H, 5.67; N, 9.85. Found: C, 50.07; H, 5.67; N, 9.82.

4-Nitrobenzyl diethyldithiocarbamate: mp 76–77 °C (EtOH) (lit.[12] 75–76 °C); NMR ($CDCl_3$) δ 1.30 (t, 6 H), 3.93 (m, 4 H), 4.75 (s, 2 H), 7.65 (d, 2 H), 8.25 (d, 2 H).

5-Chloro-2-nitrobenzyl diethyldithiocarbamate: mp 74–75.5 °C (EtOH); NMR ($CDCl_3$) δ 1.28 (t, 6 H), 3.98 (m, 4 H), 5.05 (s, 2 H), 7.48 (d, 1 H), 7.96 (s, 1 H), 8.08 (d, 1 H). Anal. Calcd for $C_{12}H_{15}N_2ClO_2S_2$: C, 45.20; H, 4.74; N, 8.79. Found: C, 45.28; H, 4.78; N, 8.86.

2-Nitro-5-phenylbenzyl diethyldithiocarbamate: mp 87–88 °C (EtOH); NMR ($CDCl_3$) δ 1.23 (t, 6 H), 3.93 (m, 4 H), 5.13 (s, 2 H), 7.4–7.8 (m, 6 H), 8.18 (d, 1 H), 8.23 (s, 1 H). Anal. Calcd for $C_{18}H_{20}N_2O_2S_2$: C, 59.97; H, 5.59; N, 7.78. Found: C, 59.77; H, 5.47; N, 7.65.

Registry No. **1**, 3561-67-9; **2**, 7695-69-4; **3**, 22656-77-5; nitrobenzene, 98-95-3; 4-phenyl-1-nitrobenzene, 92-93-3; 4-(phenylthio)-1-nitrobenzene, 952-97-6; 2-(phenylthio)-1-nitrobenzene, 4171-83-9; 4-chloro-1-nitrobenzene, 100-00-5; 2-nitrobenzyl phenyl sulfide, 91718-67-1; 4-nitrobenzyl phenyl sulfide, 7703-38-0; 2-nitro-5-phenylbenzyl phenyl sulfide, 93304-88-2; (2-nitro-5-phenylphenyl)bis(phenylthio)methane, 93304-89-3; 2-nitro-5-(phenylthio)benzyl phenyl sulfide, 93304-90-6; (2-nitro-5-(phenylthio)phenyl)bis(phenylthio)methane, 93304-91-7; (4-nitrophenyl)(phenylthio)phenylmethane, 93304-92-8; (4-nitro-3-(phenylthio)phenyl)(phenylthio)phenylmethane, 93304-93-9; 2-nitrobenzyl diethyldithiocarbamate, 93304-94-0; 4-nitrobenzyl diethyldithiocarbamate, 28371-57-5; 5-chloro-2-nitrobenzyl diethyldithiocarbamate, 93304-95-1; 2-nitro-5-phenylbenzyl diethyldithiocarbamate, 93304-96-2; (2-nitrophenyl)bis(phenylthio)methane, 93304-97-3.

(12) Ishii, T., Teiichiro, J. Japan Patent 70 34 804; *Chem. Abstr.* **1971**, *74*, 87665.

Communications

Ligand-Assisted Catalysis: New Active and Selective Nickel Modified Homogeneous Catalysts for Linear Dimerization of Butadiene

Summary: New aminophosphinite-modified Ni(0) catalysts have been found to be the most active ever described for linear dimerization of butadiene, affording almost exclusively 1,3,6- and 2,4,6-octatrienes, according to the reaction conditions.

Sir: Linear dimerization of butadiene into mixtures of octatrienes has been effected on Ni^0 catalysts, using nickel carbonyl phosphine or phosphite complexes in the presence of alcohols[1,2] or morpholine (morpholine/Ni = 50),[3] in which case the products are almost exclusively (*Z,E*)- and (*E,E*)-1,3,6-octatrienes. More recent results by Pittman have shown that upon reduction of $NiBr_2(PPh_3)_2$ by sodium borohydride in a mixture of THF and ethanol, the catalyst gave selectively the (*E,E*)-1,3,6-octatriene, with yields up to 95%.[4] We now report unprecedented results for linear dimerization of butadiene which occur at ambient temperature with nickel catalysts, and where a mixture of (*E,E*)- and (*Z,E*)-1,3,6-octatrienes is obtained selectively, before the occurrence of an isomerization process which gives essentially the (*E,E,E*)-2,4,6-octatriene. As a consequence of our recent studies in the field of synthesis of new aminophosphine–phosphinite ligands for asymmetric catalytic reactions,[5] we have synthesized a series of aminophosphinite compounds, which combine both characteristics desired for linear dimerization of butadiene on nickel systems: (i) a ligand containing at least one (–P–O–) moiety; (ii) a pendant N–H group at the other side of the chain, favoring a stereochemical approach of the proton in close proximity to the metal. These ligands

(1) Muller, H.; Wittenberg, D.; Seibst, H.; Scharf, E. *Angew. Chem., Int. Ed. Engl.* **1965**, *4*, 327.
(2) Beger, v. J.; Duschek, C.; Füllbier, H.; Gaube, W. *J. Prakt. Chem.* **1974**, *816*, 526.
(3) Heimbach, P. *Angew. Chem., Int. Ed. Engl.* **1973**, *12*, 975.
(4) Pittman, C. U., Jr.; Smith, L. R. *J. Am. Chem. Soc.* **1975**, *97*, 341.
(5) Petit, M.; Mortreux, A.; Petit, F.; Buono, G.; Peiffer, G. *Nouv. J. Chim.* **1983**, *7*, 593.

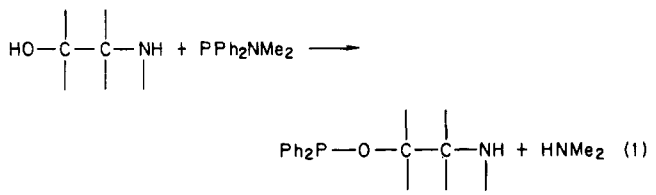
0022-3263/84/1949-5274$01.50/0

Table I. Linear Dimerization of Butadiene on $Ni(COD)_2$-Aminophosphinite Complexes[a]

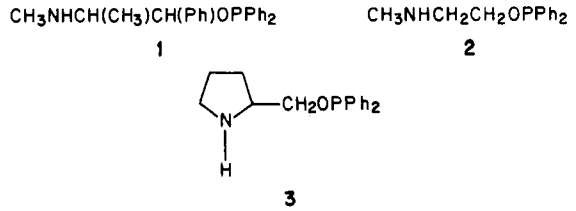
entry	aminophosphinite (mmol)	butadiene (mmol)	$Ni(COD)_2$ (mmol)	reaction time (min)	convn (%)	1,3,6-octatrienes (%)	2,4,6-octatrienes (%)	1,4-VCH[b] (%)	1,5-COD[b] (%)	MVCP[b] (%)	other isomers
1	1 (2.5)	125	2.5	10	90	94.5		3.2	1.0	1.3	
2	1 (2.5)	125	2.5	20	100		87.8	3.8	0.8		7.6
3	1 (0.037)	185	0.037	360[c]	60	92.8		2.7	2.5	2.0	
4	2 (2.5)	125	2.5	40	90	94.7		2.7	1.0	1.6	
5	3 (2.5)	125	2.5	10	90	98.4		0.6	0.6	0.4	

[a] Experimental conditions: solvent = toluene (10 mL); T = 40 °C; conversion and selectivities were determined by GPC, by using n-heptane as internal standard, on a Carbowax 20M capillary column. [b] 1,4-VCH = 1,4-vinylcyclohexene; 1,5-COD = 1,5-cyclooctadiene; MVCP = (2-methylenevinyl)cyclopentane. [c] T = 60 °C.

were merely prepared in one step from commercial aminoalcohols according to eq 1.



Such compounds **1–3**, whose structures are shown, were prepared from ephedrine, 2-(methylamino)ethanol, and prolinol.[6] Typical reactions were done with these ligands,



with dicyclooctadienenickel as the source of Ni^0. The results are summarized in Table I. They indicate that in each case a mixture of (*Z,E*)- and (*E,E*)-1,3,6-octatrienes was obtained: all the analyses performed on different capillary columns (Carbowax 20M, Squalane, PPG) did not allow any separation of these two isomers, but, in contrast, two chromatographic peaks were found by using the polar β,β'-oxydipropionitrile stationary phase, which was also used for preparative chromatography in order to isolate the major compound (*E,E*)-1,3,6-octatriene (60%).[7] The cis–trans isomer was isolated after reaction of the mixture with maleic anhydride.[8]

Interestingly, it has to be noticed that if the reaction is continued further after consumption of butadiene (entry 2), an isomerization process is observed, giving rise essentially to production of (*E,E,E*)-2,4,6-octatriene[9] together with a mixture of its stereochemical isomers (36%).

Similar results are obtained by using a direct reduction of a Ni^{II} salt by triethylaluminium or $LiAlH_4$ in situ, in the presence of butadiene, followed by addition of the ligand.

Experiments were also carried out with pure deuterated $PPh_2OCH_2CH_2ND(CH_3)$, obtained by deuterium exchange with D_2O on the N–H compound, and catalysis was stopped rapidly in order to analyze the butadiene dimers arising from the first rotations (TN < 10)[10] and look at the possibility of deuterium incorporation into the 1,3,6-octatrienes, which should occur according to the mechanism proposed by Heimbach.[3] Up to now, with this ligand, *no* deuterium incorporation was observed in the triene (NMR, IR),[11] so that the role of the N–H moiety is still an open question.[12]

The above results differ essentially from the previous work in this field by several interesting features:

(i) The proton donor reagent is used in equimolar amounts with the metal, whereas it is necessary to introduce this compound in large excess either when morpholine[3] or ethanol[4] are added as cocatalysts.

(ii) The observed activity of our system is much higher (TN > 5000) than those previously depicted: the reaction temperature can be lowered to ambient temperature or even lower with ligand **1**, so that the time required for a total conversion is considerably reduced (Table I).

(iii) A careful choice of the reaction time allows one to selectively produce different hydrocarbons: 1,3,6-octatrienes with up to 95% selectivity if the reaction is stopped just before total butadiene consumption or 2,4,6-octatrienes (>85%) if the reaction is continued, by further isomerization.

Further experiments are in progress to account for the mechanism and the role of the N–H bond during this specific reaction.

Acknowledgment. We thank Dr. B. Mouchel for skilful assistance in NMR spectroscopy. P. D. thanks the CNRS for financial support.

(6) Kosalopoff, G. M.; Maïer, L. *Org. Phosphorus Comp.* **1973**, *4*, 504. NMR for compounds **1**, **2**, and **3**: each ^1H NMR spectrum is consistent with the presence of a $NH-CH_3$ group. ^{31}P NMR: 112.3, 113.5 and 113.1/H_3PO_4, respectively.

(7) Separation of the *E,E* isomer of the 1,3,6-octatrienes mixture was performed at 20 °C on a $^3/_8$ in. β,β'-oxydipropionitrile column (3 m, 20% on Chromosorb 45/60 mesh): IR (neat) 3085 (m), 3021 (s), 2964 (m), 2936 (m), 2918 (m), 2885 (m), 1644 (m), 1593 (m), 1452 (m), 1063 (w), 997 (s), 966 (s), 905 (s), 788 (w); ^1H NMR ($CDCl_3$) in first approximation, the CH_3 signals appear as a first-order spectrum which consists in a doublet of triplets centered at 1.66 ppm whose coupling constants are assigned as follows: $-CH_2{}^5CH^6{=}CH^7CH_3{}^8$ $^3J_{6-7} \simeq 0$ (<0.3 Hz, as δ H^6 and H^7 are almost equivalents), $^4J_{6,8} \simeq 0$, $^3J_{7,8}$ = 4.7 Hz, $^5J_{5,8}$ = 1.4 Hz; the other signals appear at 2.76 (m, 2 H) and 4.9–6.7 ppm (7 H, olefinic protons). ^{13}C NMR ($CDCl_3$) δ 17.93 (C^8), 35.5 (C^5), 115.10 (C^1), 126.19 (C^7), 128.67 (C^6), 131.28 (C^4), 133.52 (C^3), 137.09 (C^2).

(8) Separation of the *Z,E* isomer was undertaken after reaction of the *E,E* isomer with maleic anhydride. The resultant mixture, free of the *E,E* isomer, was distilled in order to remove the *Z,E* isomer which was further purified by preparative chromatography on a 20% SE-30 column at 110 °C. This compound had the same IR spectrum as the *E,E* isomer; the ^1H spectrum differs essentially in the olefinic region, which is larger (4.90–7.05, 7 H, olefinic protons); ^{13}C NMR ($CDCl_3$) δ 17.87 (C^8), 30.9 (C^5), 117.22 (C^1), 125.76 (C^7), 128.79 (C^6), 129.46 (C^4), 130.43 (C^3), 132.06 (C^2); as a mixture, the *E,E* and *Z,E* isomers give rise to 14 signals in ^{13}C NMR spectroscopy, as the C^6 and C^8 atoms are not separated. In our hands, we have found that Pittman's catalytic system[3] gave the mixture of these two isomers.

(9) The analysis of the IR and ^1H NMR spectra of this (*E,E,E*)-2,4,6-octatriene fit well with the literature (see ref 2); ^{13}C NMR ($CDCl_3$) δ 18.17 (C^1 and C^8), 128.61 (C^2 and C^7), 130.55, and 131.8.

(10) Three similar catalytic reactions were done with the deuterated aminophosphine **2** under the following conditions: $Ni(COD)_2$, 4.9 g, 17.8 mmol); ligand **2** 6.04 g (23.5 mmol); butadiene 9 g (166 mmol) in toluene (20 mL); T = 20 °C. The reactions were stopped after 3 min in order to avoid the isomerization process into 2,4,6-octatrienes. Most of the organometallic compounds was precipited with sulfur, and the 1,3,6-octatrienes (98.5% purity) were isolated by preparative GPC after distillation on a Nester and Faust spinning band column.

(11) The infrared spectrum of the resulting 1,3,6-octatriene was undertaken in such a way that less than 1% of deuterium incorporation could be detected in the ν_{CD} region.

(12) The presence of a N–H group in the ligand is essential for linear dimerization, as experiments carried out with ligand **1′** ($(CH_3)_2NCH(CH_3)CH(Ph)OPPh_2$) derived from ephedrine has given only a mixture of 4-vinylcyclohexene and 1,5-cyclooctadiene, with a much lower activity.

Registry No. 1, 92490-07-8; 2, 92490-08-9; 3, 92490-09-0; $Ni(COD)_2$, 1295-35-8; butadiene, 106-99-0; (Z,E)-1,3,6-octatriene, 22038-68-2; (E,E)-1,3,6-octatriene, 22038-69-3.

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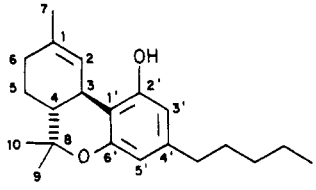
Received September 7, 1984

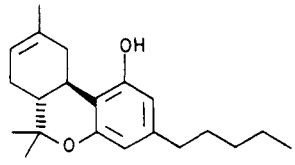
A Novel Approach to the Synthesis of the Cannabinoids

Summary: The primary cannabinoids have been prepared by a novel sequence of reactions from methyl methacrylate and methyl vinyl ketone.

Sir: Marijuana is a complex mixture of many compounds, but the psychotropic activity of this drug is derived principally from the presence of the tetrahydrocannabinols (THC's), *trans*-Δ^1-THC (**1**) and *trans*-Δ^6-THC (**2**).[1,2]



1

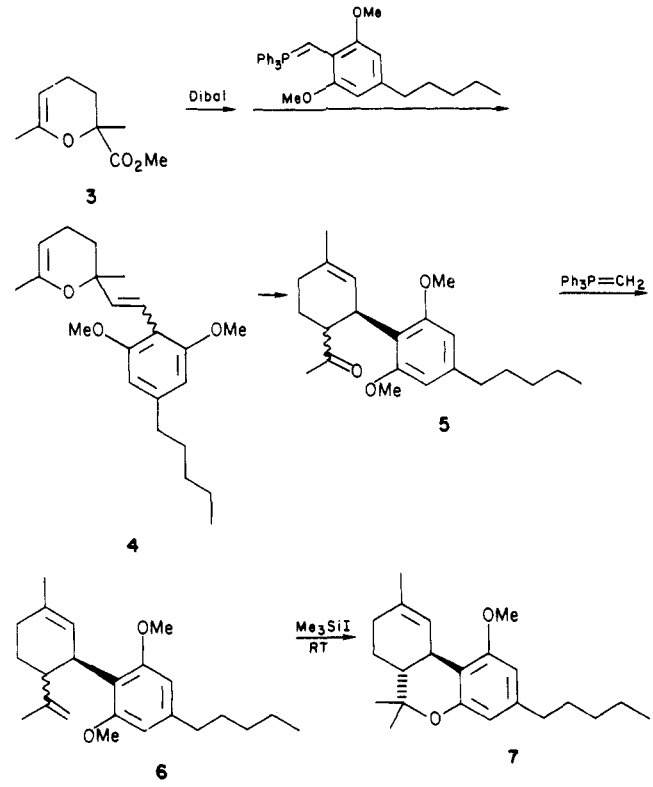


2

Other physiological activity has been attributed to marijuana,[1a] so that much effort has been expended on the synthesis of the THC's and numerous analogues.[1,3] A particularly effective synthesis of Δ^1-THC should avoid acid because of the facile conversion of Δ^1-THC to Δ^6-THC under acidic conditions.[1,4]

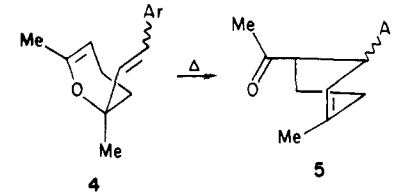
We report a new method for the preparation of *trans*-Δ^1-THC which should be adaptable to the synthesis of numerous analogues as well as large-scale syntheses (see Scheme I). Thus, the substituted dihydropyran **3**, available from methyl vinyl ketone and methyl methacrylate,[5] is converted into the diene **4**[6] in 67% yield by selective reduction with diisobutylaluminum hydride (Dibal)[8,9] followed by a Wittig reaction[7,9] with a suitable

Scheme I



ylide and chromatography on neutral alumina. This product was isolated as a 1:1 mixture of cis and trans isomers.[10]

The key step in the synthesis is a Claisen rearrangement.[11] This is an interesting reaction not only because of the synthetic conversion but also because the reaction must proceed through a boat conformation of the dihydropyran ring (eq 1).[7,9,12] Büchi[7] and Ireland[9] have



(1)

reported that such rearrangements do occur although the temperatures are high (190–400 °C).[7] Danishefsky[13] observed a related conversion of unsaturated lactone silyl ethers but at much lower temperatures (105 °C).

In view of these literature results, it is most striking that our rearrangement occurs at *room temperature*![14] Indeed, a 94% yield of the ketone **5** is isolated after chromatography on silica gel as a 1:1 mixture of cis and trans iso-

(1) For excellent reviews, see: (a) Razdan, R. K. "The Total Synthesis of Natural Products"; ApSimon, J., Ed.; Wiley: New York, 1981; Vol. 4, pp 185–262. (b) Mechoulam, R.; McCallum, N. K.; Burstein, S. *Chem. Rev.* **1976**, *76*, 1.

(2) The monoterpenoid numbering used in *Chemical Abstracts* is followed here.

(3) One of the more recent synthetic efforts is as follows: Richards, R. W.; Rönneberg, H. *J. Org. Chem.* **1984**, *49*, 572.

(4) (a) Taylor, E. C.; Lenard, K.; Shvo, Y. *J. Am. Chem. Soc.* **1966**, *88*, 367. (b) Gaoni, Y.; Mechoulam, R. *Ibid.* **1966**, *88*, 5673.

(5) This can be accomplished by a modification of the procedure of Mundy: Mundy, B. P.; Otzenberger, R. D.; De Bernardis, A. R. *J. Org. Chem.* **1971**, *36*, 2390.

(6) The ^1H NMR of diene mixture **4** shows an enol ether vinyl CH at 4.3 ppm and other vinyl CH at 5.4–6.0 ppm in agreement with the reported values for 2-methyl-2-vinyl-3,4-dihydro-2*H*-pyran and analogues prepared by Büchi and Powell.[7] GC/MS shows a parent ion of *m/e* 344 and a base peak of *m/e* 208.

(7) Büchi, G.; Powell, J. E., Jr. *J. Am. Chem. Soc.* **1976**, *92*, 3126.

(8) For example, see: Szantay, C.; Töke, L.; Kolonits, P. *J. Org. Chem.* **1966**, *31*, 1447. Corey, E. J.; Broger, E. A. *Tetrahedron Lett.* **1969**, 1779. Grieco, P. A.; Yokoyama, Y.; Withers, G. P.; Okuniewicz, F. J.; Wang, C.-L. J. *J. Org. Chem.* **1978**, *43*, 4178.

(9) Ireland, R. E.; Aristoff, P. A. *J. Org. Chem.* **1979**, *44*, 4323.

(10) This ratio was based on the integration of the styryl vinyl peaks in the ^1H NMR and the relative peak areas upon analysis by capillary GC.

(11) For general reviews of the Claisen rearrangement, see: Ziegler, F. E. *Acc. Chem. Res.* **1977**, *10*, 227. Rhoads, S. J.; Raulins, N. R. *Org. React. (N.Y.)* **1975**, *22*, 1. Bennett, G. B. *Synthesis* **1977**, 589.

(12) Lutz, R. P.; Roberts, J. D. *J. Am. Chem. Soc.* **1961**, *83*, 2198.

(13) Danishefsky, S.; Funk, R. L.; Kerwin, J. F., Jr. *J. Am. Chem. Soc.* **1980**, *102*, 6889.

(14) The reaction mixture was allowed to stir in dichloromethane for 48 h. The required time may be considerably less since the compound without a pentyl group rearranges completely in 2 h.

0022-3263/84/1949-5276$01.50/0