peting reactions or autocatalysis. The formation of a stable intermediate seems unlikely, based on the activation parameters, the ^{119}Sn NMR results, and on the DCD theoretical model.

Isomerization of **2** to **1** by $PdCl_2$ occurs at a slower rate than the $SnCl_2$ reaction but both reactions have nearly the same $\Delta G^{\ddagger}$ values. Thus $PdCl_2$ reaction rates are slower because of the zero-order dependence of the reaction at higher concentrations of quadricyclane. These results are compatable with the reversible formation of an intermediate species.

Experimental Section

All materials used were obtained from commercial sources and were not purified: deuterated methanol (Sigma), quadricyclane (Aldrich), stannous chloride (Fischer), palladium chloride (Alfa), *p*-dichlorbenzene (Fischer). ^1H NMR spectra were recorded at 60 MHz on a JEOL-FX60Q pulsed NMR spectrometer. A spectral with width of 600 Hz was used with a single 90° pulse and 8K bits of data collection. Probe temperatures were measured with a thermometer immersed in a sample tube placed in the NMR cavity before and after each run.

Kinetic Experiments. A solution consisting of 1.0 mL of CD_3OD, an accurately measured amount of quadricyclane, and 50 mg of *p*-dichlorobenzene (which was used as an internal standard for proton integration) was placed in the NMR instrument probe and the instrument was tuned to 0.15-Hz resolution. $SnCl_2$ (50 mg) or $PdCl_2$ (50 mg) was added all at once to the tube, the contents were shaken vigorously, and the sample was locked on the deuterium signal of the spectrometer.

Spectra were recorded and stored on tape at 2–5-min intervals for a period of 2–4 h. The amount of norboradiene produced was obtained from NMR integration of the four-proton alkene multiplet at 6.8 ppm and referenced to the four-proton singlet for *p*-dichlorobenzene at 7.1 ppm. The relative integrated area obtained for norbornadiene was used in a second-order plot of $(\ln 1/(a-b))(\ln (b(a-x)/a(b-x)))$ vs. time (s), where a and b are the initial molar concentrations of metal salt and quadricyclane, respectively, and x is the molar concentration of norbornadiene formed. First-order plots exhibited linearity in some cases, but second-order kinetics were consistently much better as determined from linear least-squares correlation coefficients of 0.98 or greater and standard deviation of less than 3%.

Acknowledgment. This research was supported by the donors of the Petroleum Research Fund, administered by the American Chemical Society.

Registry No. $SnCl_2$, 7772-99-8; $PdCl_2$, 7647-10-1; quadricyclane, 278-06-8; norbornadiene, 121-46-0.

Stereo- and Photochemistry of 1,2,3,4,5-Pentaphenyl-1,3,5-heptatriene

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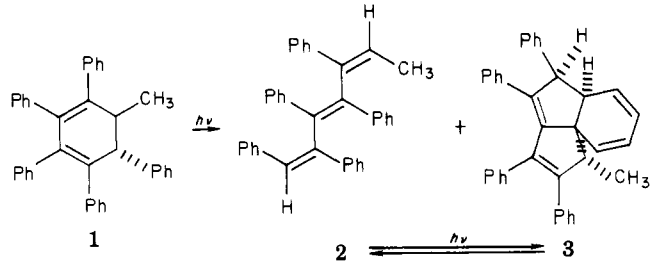
Received September 14, 1983

The stereochemistry of 1,2,3,4,5-pentaphenyl-1,3,5-heptatriene (**2**) previously isolated from the photolysis of *cis*-6-methyl-1,2,3,4,5-pentaphenyl-1,3-cyclohexadiene has been shown to be *Z,E,Z* on the basis of X-ray crystallographic analysis and chemical data. The stereo- and regiospecificity of the formation and further photolysis of **2** to a tricyclo photoproduct by an apparent [6 + 2] cycloaddition reaction are discussed.

Introduction

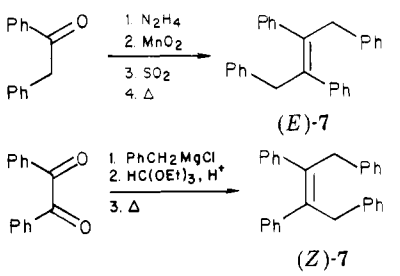
Irradiation of 6-methyl-1,2,3,4,5-pentaphenyl-1,3-cyclohexadiene (**1**) has been previously shown to generate the tricyclo[6.4.0.0^{4,8}]dodecatetraene **3** as well as an open chain triene **2** (reaction 1).[1] Evidence has also been presented



(1)

supporting the generation of **3** from **2** in the photolysis mixture.[1] On the basis of the unifying concept of cyclohexadiene–hexatriene photochemistry that the principle ground-state conformation of the polyene would determine the reaction path for the triene,[2-5] we contended that the lack of ground-state conformers allowing either vinylcyclobutene or bicyclo[3.1.0]hexene formation forced another reaction path on triene **2**, a [6 + 2] cycloaddition reaction to tricyclo **3**. In order to investigate this possiblity further, a determination of the stereochemistry and ultimately the conformation of the triene **2** was initiated, using chemical as well as crystallographic analysis. This report validates aspects of the contention mentioned above.

Scheme I



Results

Initially it was felt that the stereochemistry of triene **2** could be established by comparison to a series of models

(1) Woolsey, N. F.; Radonovich, L. J.; Saad, F. M.; Koch, F. J. *J. Org. Chem.* **1979**, *44*, 2483.

(2) Havinga, E.; De Kock, R. J.; Rappoldt, M. D. *Tetrahedron* **1960**, *11*, 276. Havinga, E.; Schlatmann, J. L. M. A. *Ibid.* **1961**, *16*, 146. Vroegop, P. J.; Lugtenburg, J.; Havinga, E. *Ibid.* **1973**, *29*, 1393.

(3) Dauben, W. G.; Kellogg, M. S.; Seeman, J. I.; Vietmeyer, N. D.; Wendschuh, P. H. *Pure Appl. Chem.* **1973**, *33*, 197.

(4) Padwa, A.; Brodsky, L.; Clough, S. *J. Am. Chem. Soc.* **1972**, *94*, 6767.

(5) Courtot, P.; Rumin, R.; Salaun, J. Y. *Pure Appl. Chem.* **1977**, *49*, 317.

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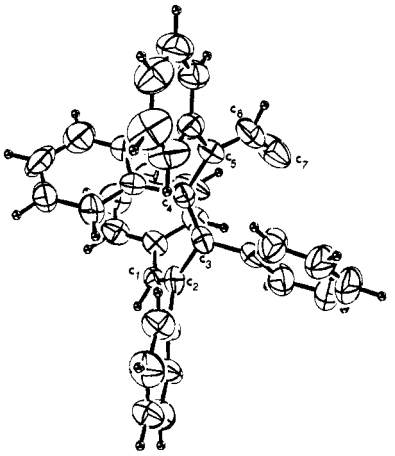
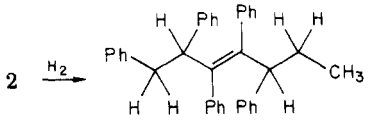


Figure 1. A computer drawing of $C_{37}H_{30}$ with anisotropic ellipsoids represented at 50% probability. Hydrogen atoms have been reduced in size for clarity.

for each of the double bonds. The models selected for the C_1–C_2 double bond were (*E,E*)-, (*E,Z*)-, and (*Z,Z*)-tetraphenylbutadiene (**4**), which are all known and characterized isomers.[6] For the C_5–C_6 double bond the stereoisomers of 3,4-diphenyl-2,4-hexadiene (**5**) were synthesized (see Experimental Section). The NMR data for the models were consistent with *Z* C_1–C_2 and *Z* C_5–C_6 stereochemistry in triene **2** but not unequivocal for this assignment.

Assignment of the C_3–C_4 double-bond stereochemistry was not possible in **2** itself. Catalytic hydrogenation of **2**, however, gave a complex mixture of polyhydro derivatives and diastereomers from which a tetrahydro diastereomer of **6** was isolated in 14% yield (reaction 2). The spectral



(2)

6

and analytical data (see Experimental Section) for **6** were consistent with this assignment. Stereomodels for **6** (the stereoisomers of 1,2,3,4-tetraphenyl-2-butene (**7**)) and their preparation, which required different reaction paths, are shown in Scheme I (see Experimental Section for details).

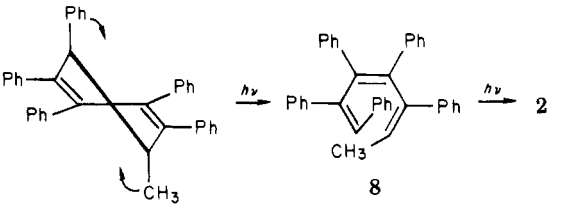
The lack of a definitive stereochemical assignment to the C_5–C_6 double bond and the fact that **6** constituted only 14% of the product on hydrogenation of **2** left some doubt concerning the stereochemistry assigned to **2**. Thus, a complete X-ray structural determination was carried out on crystals of **2**.

An ORTEP[7] drawing of one molecule of **2** is shown in Figure 1 with the atomic numbering scheme for the triene framework. Within this framework the average C–C double-bond distance (C_1–C_2, C_3–C_4, C_5–C_6) is 1.347 (7) Å, while the average single-bond value (C_2–C_3, C_4–C_5) is 1.494 (7) Å. The five C_{sp^2}–C_{phenyl} distances average 1.487 (8) Å, and the C_6–CH_3 distance is 1.511 (8) Å. Bond parameters of the phenyl rings are normal, within experimental error, and no unusual nonbonded interactions occur.

Discussion

The photochemistry of cyclohexadienes and hexatrienes has been extensively investigated by Havinga,[2] Dauben,[3] Padwa,[4] Courtot,[5] and their co-workers. As a result, many of the reactions in this series are fairly well-understood. Application of the evolving principles of cyclohexadiene–hexatriene photochemistry allows the photochemistry of **1** and **2** to be understood in the general context of this photochemical area. The major points to be discussed concern the stereochemistry of both **2** and **3** and the regiospecificity of the formation of **3**.

The terminal double-bond stereochemistry of **2** is undoubtedly controlled by the ground-state conformation of the cyclohexadiene **1** by the "accordant rule" as has been shown previously.[3,5] The 5-phenyl and 6-methyl groups in **1** are forced pseudoaxial by the 4- and 1-phenyl rings, respectively. From this conformation a conrotatory electrocyclic ring opening under orbital symmetry control[8] favors terminal *Z,Z* stereochemistry in the resulting heptatriene **8** and subsequently in **2**. The heptatriene **8** with



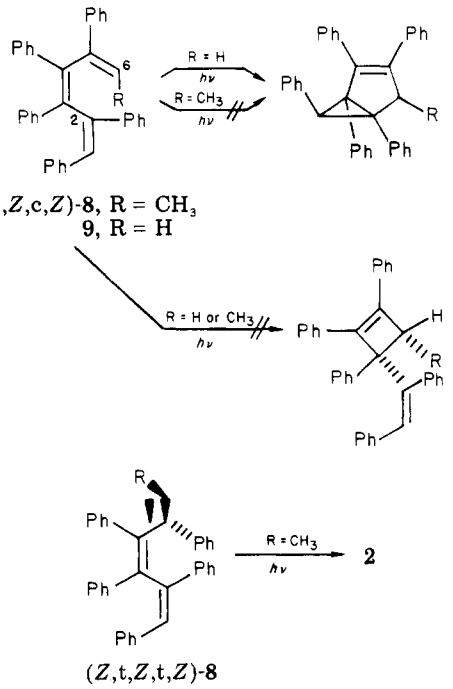
1 **8**

the *ZcZcZ* stereochemistry and conformation is exceedingly crowded if the heptatriene unit is planar. This effectively prevents photoreversion to **1**[5] and requires adoption of another conformation. Twisting the terminal double bonds 90° so that they are orthogonal to the C_3–C_4 double bond considerably alleviates the steric crowding as molecular models readily show. Models do not show the increase in energy due to loss of conjugation of the heptatriene unit, however, but do indicate that the *ZtZcZ* conformation appears to be the most nearly planar with the least steric crowding for the heptatriene chain. In this conformation the longest wavelength absorbing moiety would be the C_1–C_4 diphenylbutadiene unit, which would be expected to absorb near 310 nm in the UV spectrum.[9] Indeed the absorption in this region of the UV spectrum increases at short irradiation times of the starting cyclohexadiene **1**. As the irradiation proceeds, absorption in this region decreases somewhat. Isomerization of (*Z,Z,Z*)-**8** to (*Z,E,Z*)-**2** could be brought about by absorption of a second photon and be driven by the relative absorption at irradiation wavelengths. Selective isomerization at the central hexatriene double bond has been observed previously and appears to be wavelength and structure dependent.[5] The reason for this may be conformational in origin, but this apparently has not been settled yet.[5] Partial isomerization from a vibrationally activated ground state after initial ring opening or thermal isomerization to the more thermodynamically stable isomer, (*Z,E,Z*)-**2**, cannot be eliminated as a viable reaction path. This latter possibility is consistent with the ready thermal isomerization of the model alkene (*Z*)-**7** on recrystallization (see Experimental Section). The fact that both terminal double bonds have *Z* stereochemistry indicates that their stereochemistry does not change on C_3–C_4 double-bond isomerization.

Isomerization of (*Z,Z,Z*)-**8** rather than bicyclization to bicyclo[3.1.0]hexene is precedented in the work of Courtot

(6) Freedman, H. H.; Doorakian, G. A.; Sandel, V. R. *J. Am. Chem. Soc.* **1965**, *87*, 3019.
(7) Johnson, D. P. Report ORNL-3794, Oak Ridge National Laboratory, Oak Ridge, TN, 1965.
(8) Woodward, R. B.; Hoffmann, R. "The Conservation of Orbital Symmetry"; Academic Press: New York, 1970.
(9) Pinckard, J. H.; Wille, B.; Zechmeister, L. *J. Am. Chem. Soc.* **1948**, *70*, 1938.

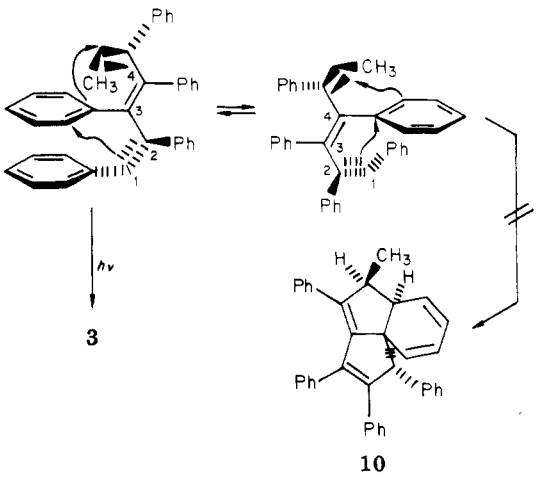
Scheme II



et al. with 1,6-diphenyl-1,3,5-heptatriene.[5] The fact that **9** does undergo [3.1.0]bicyclization whereas **8** results in cis–trans isomerization can be traced to the added 2,6-interaction in the required *ZcZtZ* conformation[3-5] of the intermediate, leading to bicyclization (see Scheme II). While it has not been possible to study the effect of alkene torsional angles on open-chain hexatrienes, it is evident from *o*-divinylbenzene photochemistry[10] (where central double-bond isomerization is not possible) that small changes in phenyl torsional angles can significantly affect photochemical [2 + 2] or [2 + 4] cycloaddition reaction paths. The same effect is apparently seen here with the hexatriene torsional angles. Even though the addition of a methyl group causes only moderately increased hindrance in an already highly hindered (*Z*,t,*Z*,c,*Z*)-**8**, this is apparently enough to prevent significant bicyclization as is seen when the methyl is not present.[11] The same hindrance prevents adoption of an appropriate conformation that would allow [2 + 2] cycloaddition or cyclobutene formation (see Scheme II).

No literature case provides precedent for the [6.4.0.0^{4,8}]tricyclization of **2** to **3**. If the tricyclization reaction is concerted, there are two allowed pathways for **3** formation: the [π6s + π2s] and the [π6a + π2a] processes.[8] Consideration of **3** stereochemistry indicates only the π6a + π2a process is observed despite the fact that the syn solid-state conformation (where both terminal double bonds are orthogonal and on the same side of the C_3–C_4 double-bond plane) can be oriented by a minor rotation about the C_4–C_5 bond to bring both C_1 and C_6 near the C_4-phenyl ring. The bonding distances in the excited state of this conformation are apparently just too great for significant interaction. In order for reaction to take place by an allowed [π6a + π2a] pathway, an anti conformation must be assumed. This can be done from the solid-state conformation by rotation of either the C_1–C_2 or the C_5–C_6 double bond into an anti orientation relative to the other terminal double bond (note from Figure 1 that these

Scheme III



double bonds are syn in the solid state). From this anti conformation two possible pathways exist. The observed pathway to **3** occurs by reaction with the C_3-phenyl ring as the π2a partner. A similar pathway to **10** exists where the π2a component involves the C_4-phenyl ring. The source of the regioselectivity whereby only **3** is formed probably resides in the (C_1-phenyl)–(C_4-phenyl) interaction in the anti conformation for reaction with the C_4-phenyl ring (see Scheme III). The corresponding interaction in the observed pathway is the lower energy (C_3-phenyl)–(C_6-methyl) interaction. In this conformation, leading to reaction and formation of **3**, the reacting C_3-phenyl ring becomes sandwiched between the C_1-phenyl and the C_6-methyl group. Maximum overlap appears to be possible when the C_1- and the C_3-phenyl rings are tipped about 45° relative to their double bonds. The methyl then fits beneath the C_3-phenyl ring, reinforcing the steric orientation.

It appears then that the regioselectivity for **3** formation has a steric origin. The stereoselectivity may also result from steric factors that do not necessarily determine the most favorable conformation from which reaction proceeds but do determine the most rapid photoreaction. This distinction has also been seen in the [3.1.0]bicyclization series.[5]

As noted above the stereochemistry of the **2** to **3** reaction is correct for a concerted [π2a + π6a] photoallowed process. However, it is not clear that this process occurs in a concerted fashion. The distorted nature of the heptatriene chain decreases overlap of the adjacent double bonds (as has been noted from the UV spectrum of **2**).[1] If the double bonds were not significantly overlapped, it seems reasonable that orbital restrictions may be somewhat relaxed. This has also been pointed out for [3.1.0]bicyclization via "sudden polarization" in the hexatriene series.[3,12] Thus, one bond may be substantially formed before the second has started to form. The observed stereospecificity in the reaction then could be a result more of steric than electronic factors. Our inability to prepare the corresponding *cis*-**1** isomer[1] and thus the (*E*,*E*,*Z*)-**2** isomers has prevented a test of this possibility as has been done for [3.1.0]bicyclization, where concerted as well as stepwise reaction has been observed, depending on starting triene.[2-5]

Experimental Section

General Procedures. Melting points were determined on a calibrated Fisher-Johns hot stage. Infrared (IR), ultraviolet (UV),

(10) For leading references, see: op den Brouw, P. M.; Laarhoven, W. H. *J. Chem. Soc., Perkin Trans. 2* **1983**, 1015.

(11) Evanega, G. R.; Bergmann, W.; English, J., Jr. *J. Org. Chem.* **1962**, *27*, 13.

(12) Bonacic-Koutecky, V. *J. Am. Chem. Soc.* **1978**, *100*, 396.

and proton NMR were recorded on a Beckman IR-12, a Cary 14, and a Varian A-60 instrument, respectively. NMR values are in ppm downfield from internal Me_4Si; coupling and assignments were verified by decoupling experiments. Mass spectra were recorded by Morgan-Schaffer, Inc., Montreal, Quebec.

3,4-Diphenyl-2,4-hexadiene (5). (*E,E*)-**5** was prepared by the literature procedure:[13] mp (lit.[13] mp 104–105 °C); UV max (EtOH) 215 nm (ϵ 23 600), 226 sh (20 200); NMR ($CDCl_3$) δ 7.3 (m, 10 H, aryl H), 5.25 (q, 2 H, J = 6.5 Hz, vinyl H), 1.43 (d, 6 H, J = 6.5 Hz, CH_3). The Diels–Alder adduct was prepared in refluxing benzene: mp 203–204 °C (lit.[13] mp 201–202 °C); NMR ($CDCl_3$) δ 7.3–6.7 (m, 10 H aryl H), 3.49 (d of d, 2 H, J_1 = 4 Hz, J_2 = 2 Hz, HCC=O), 3.2–2.8 (m, 2 H, $CHCH_3$), 1.25 (d, 6 H, J = 7 Hz, CH_3). The *E,Z* and *Z,Z* isomers were prepared by irradiation of the *E,E* isomer under sensitized conditions. The diene (5.0 g) and benzophenone (9.1 g) were dissolved in benzene (1 L), flushed with nitrogen, and then irradiated in a Rayonet apparatus using 3500-Å lamps for 4 h. One-half the solvent was removed, maleic anhydride (5.0 g) and hydroquinone (0.2 g) were added, and then the mixture was refluxed overnight. The benzene was removed under reduced pressure and the residue chromatographed on alumina. The material eluted with hexane was shown to contain ca. 8% benzophenone, 83% (*Z,E*)-**5**, and 9% (*Z,Z*)-**5** by NMR analysis. Rechromatography as before and preparative gas chromatography gave enough material for NMR spectra of both the (*Z,E*)- and (*Z,Z*)-**5** isomers. (*Z,E*)-**5** isomer: oil; NMR ($CDCl_3$) δ 7.4–7.1 (m, 10 H aryl H), 6.05 (q, 1 H, J_{ab} = 7.2 Hz, vinyl H_a), 5.76 (q, 1 H, J_{cd} = 7.2 Hz, vinyl H_c), 1.89 (d, 3 H, J_{cd} = 7.2 Hz, CH_3^d), 1.84 (d, 1 H, J_{ab} = 7.2 Hz, CH_3^b). (*Z,Z*)-**5** isomer: melting point on standing at 0 °C several days 36–38 °C; NMR ($CDCl_3$) δ 7.6–7.1 (m, 10 H, aryl H), 6.37 (q, 2 H, J = 7.2 Hz, vinyl H), 1.73 (d, 6 H, J = 7.2 Hz, CH_3). Since insufficient quantities were isolated for analysis, the 83:9 mixture (0.10 g) from above and benzophenone (0.18 g) in benzene (70 mL) were irradiated as before for 2 h. To the crude photolysate was added maleic anhydride (0.10 g), and the solution was refluxed overnight. Removal of the benzene and trituration with hexane gave the Diels–Alder adduct of the (*E,E*)-**5** isomer, mp 203–204 °C (mmp with the (*E,E*)-**5** isomer 203–204 °C). Thus, the (*Z,E*)- and (*Z,Z*)-**5** isomers had been converted back to the (*E,E*)-**5** isomer, indicating no gross structural change, other than stereochemical, during the irradiation.

Preparation of 1,2,3,4-Tetraphenyl-2-butene (7). (*E*)-7. A solution of deoxybenzoin hydrazone (5.00 g, mp 53–58 °C) in a benzene (125 mL)–hexane (200 mL) mixture was stirred with activated manganese oxide (20 g) at 0–40 °C for 6.5 h.[14] Celite was added and the mixture filtered twice through a Celite mat to remove suspended manganese oxides. IR monitoring after solid removal showed the presence of a strong diazo band at 2045 cm^{-1}. NMR δ 3.75 (s, CN_2CH_2). The filtrate, a clear red solution, was cooled below 10 °C and a stream of nitrogen and sulfur dioxide gas was bubbled through the solution.[15] The red color disappeared and a white precipitate formed. This suspension was heated to reflux on a steam bath for several hours. After the mixture stood overnight, the solvent was removed and the residue chromatographed on alumina. Elution with hexane gave 1.73 g (40%) of crude crystalline material, which on recrystallization from benzene–hexane and benzene–ethanol gave an analytical sample of (*E*)-**7**: mp 191.5–192.5 °C; NMR ($CDCl_3$) δ 7.3–6.8 (m, 20 H, aryl H), 3.58 (s, 4 H, CH_2). Anal. Calcd for $C_{28}H_{24}$: C, 93.29; H, 6.71. Found: C, 93.15; H, 6.93.

(*Z*)-7. The literature[16] Grignard reaction between benzil and benzylmagnesium chloride provided samples of both the high-melting [mp 215–218 °C (lit.[16] mp 211 °C); NMR ($CDCl_3$) δ 7.5–6.6 (m, 20 H, aryl H), 3.67 (d, 2 H, J = 14 Hz, CH_aH_b), 2.95 (d, 2 H, J = 14 Hz, CH_aH_b), 2.23 (s, 2 H, OH)] and the lower melting [mp 172–173 °C (lit.[10] mp 175 °C); NMR ($CDCl_3$) δ 7.25–6.8 (m, 20 H, aryl H), 3.46 (d, 2 H, J = 14 Hz, CH_aH_b), 3.01 (d, 2 H, J = 14 Hz, CH_aH_b), 2.78 (s, 2 H, OH)] diastereomers by fractional crystallization from methanol, methanol–benzene, and ethanol–benzene.

A mixture of the high-melting diastereomer (1.00 g, mp 215–218 °C) and ethyl orthoformate (0.45 g) was prepared.[17] After a preliminary heating with toluene for 24 h during which time no change occurred (TLC), the solvent was removed under reduced pressure and replaced with ethyl orthoformate (8 mL) and 1 drop of sulfuric acid. Refluxing overnight under nitrogen followed by removal of the volatiles to 140 °C under reduced pressure gave a pale yellow glass (1.18 g), which solidified on standing. NMR showed that mainly the cyclic ortho ester was present: NMR ($CDCl_3$) δ 7.5–6.8 (m, 20 H, aryl H), 6.42 (s, 1 H, $HC(OR)_3$), 3.92 (q, 2 H, J = 7 Hz, OCH_2), 3.72 (d, 2 H, J = 14 Hz, CH_aH_b), 3.58 (d, 2 H, J = 14 Hz, CH_aH_b), 1.35 (t, 3 H, J = 7 Hz, CH_3). The crude, neat material was heated to 180–200 °C for 1 h under nitrogen. NMR showed mainly the (*Z*)-**7** butene with no (*E*)-**7** isomer present. The residue was chromatographed on alumina, eluting with hexane. The first crystalline fractions on combination and attempted recrystallization turned yellow. The combined crystalline fractions were rechromatographed on alumina, eluting with hexane. Recrystallization of the first fraction from methanol gave crude (*Z*)-**7** (0.33 g), mp 76.5–78 °C. Heating or recrystallization of this material in the light seemed to isomerize to the less soluble, more stable (*E*)-**7** isomer, mp 183–184 °C. The filtrates from several recrystallization attempts were concentrated under reduced pressure. Methanol was added and the mixture heated rapidly to boiling. Cooling overnight in the dark gave an analytical sample: mp 76–77.5 °C (dried to constant weight at 50 °C (0.25 mm)); NMR ($CDCl_3$) δ 7.20 (s, 10 H, aryl H), 6.98 (s, 10 H, aryl H), 4.03 (s, 4 H, CH_2). Anal. Calcd for $C_{28}H_{24}$: C, 93.29; H, 6.71. Found: C, 93.03; H, 6.82. The relative stereochemistry of (*Z*)- and (*E*)-**7** was established by comparison of the NMR spectrum of **7** isomers to those of 2,3-diphenyl-2-butene.[18]

Reduction of 2 to 6. A solution of phototriene **2** (0.700 g) in chloroform (30 mL) with 10% palladium on charcoal (0.1 g) was kept under ca. 1 atm of hydrogen gas for 30 days. After filtration and removal of the solvent under reduced pressure, the residue, a pale yellow oil, was chromatographed on a 20% silver nitrate–silica gel (125 g in a 2.5 × 75 cm column). The fractions eluted with 7:2 *n*-hexane–benzene (500 mL) were combined and chromatographed successively on the following (column material, mass, column size, elution solvent, volume of eluent): silica gel, 125 g, 2.5 × 75 cm, 4:1 *n*-hexane–benzene, 1 L; alumina, 75 g, 2.5 × 50 cm, 4:1 *n*-hexane–benzene, 0.5 L; alumina, 125 g, 2.5 × 75 cm, 5:1 *n*-hexane–benzene, 0.3 L. The resulting colorless oil was crystallized from methanol–ethanol to give heptene **6** (100 mg, 14%): mp 114–116 °C; UV max (CH_3CN) 269 (ϵ 1040), 258 (1940), and shoulders at 262 (1640) and 253 nm (2200); NMR ($CDCl_3$) δ 7.5–6.5 (m, 25 H, aryl H), 4.0 (t, 1 H, J = 7 Hz, $PhCH_2CH$(Ph)CPh=), 3.5 (t, 1 H, J' = 7 Hz, CH_3CH_2CH(Ph)CPh=), 3.0 (d, 2 H, J = 7 Hz, $PhCH_2$), 1.84–1.30 (quintet, 2 H, J' = 7 Hz, CH_3CH_2), 1.30 (t, 3 H, J' = 7 Hz, CH_3). Recrystallization twice from methanol and drying (80 °C (0.3 mm)) for 48 h over silica gel–paraffin wax gave an analytical sample, mp 115–116 °C. Anal. Calcd for $C_{37}H_{34}$: C, 92.84; H, 7.16. Found: C, 92.72; H, 7.20. Molecular weight from mass spectroscopy 478.

X-ray Structure of 2. Colorless crystals of **2** were prepared from a hexane solution and mounted on glass fibers with silicone adhesive. A crystal of approximate dimensions 0.30 × 0.25 × 0.60 mm was used for the structure determination. The compound crystallizes in space group $P2_1/c$ with four molecules of $C_{37}H_{30}$ per unit cell volume and lattice constants of a = 10.207 (7), b = 29.86 (2), c = 9.347 (7) Å and β = 107.03 (2)°. The calculated density was 1.15 g/mL, while the observed density, by flotation in aqueous KI solution, was 1.14 g/mL.

Intensity data were collected as described previously,[1] using a scan width of 1.3° in 2θ. Some 2370 data having $F_o > 3\sigma_F$ were utilized in the determination. Standard deviation were calculated according to $\sigma_F = [C + k^2B + (0.01I)^2/4ILp^2]^{1/2}$, where C is the count of the scan, B is the background count, k is the ratio of scan to background counting time, I is the net intensity of the peak,

(13) Chardonnens, L.; Chardonnens, H. *Helv. Chim. Acta* **1966**, *49*, 1931.
(14) For example, see: Murry, R. W.; Trozzolo, A. M. *J. Org. Chem.* **1961**, *26*, 3109.
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(18) Umbreit, M. A.; White, E. H. *J. Org. Chem.* **1976**, *41*, 479.

and Lp is the Lorentz–polarization correction.

The structural problem was solved and the model was refined as described previously.[1] Final refinement, treating the 37 carbons anisotropically and the 27 non-methyl hydrogens as fixed contributors,[19] produced an R value of 10.7% and an R_w of 10.5%. A final difference synthesis revealed the largest residual electron density was 0.41 e/Å^3, confirming the correctness of the structure.

Acknowledgment. N.F.W. acknowledges the financial support of the Petroleum Research Foundation, administered by the American Chemical Society, and the University of North Dakota Faculty Research Committee. The contributions of Donella Donmine, Robert Klun, Walter O. Carlson, and Dr. George Vesely toward the preparation and separation of **5** isomers are gratefully acknowledged. L.J.R. acknowledges the University of North Dakota for the contributions of computer time.

Registry No. (*Z,E,Z*)-**2**, 89726-81-8; **3**, 70456-59-6; (*E,E*)-**5**, 24815-65-4; (*E,Z*)-**5**, 89726-82-9; (*Z,Z*)-**5**, 80242-32-6; **6**, 89746-16-7; (*E*)-**7**, 55255-19-1; (*Z*)-**7**, 55255-18-0; deoxybenzoin hydrazone, 5171-96-0.

Supplementary Material Available: Tables of atomic coordinates (Table I), thermal parameters (Table II), bond distances (Table III), angles (Table IV), and intensity data (Table V) for photoproduct **2** (21 pages). Ordering information is given on any current masthead page.

(19) Theoretical positions for the 25 phenyl hydrogens and two olefin hydrogens were calculated at distances of 0.95 and 1.05 Å, respectively.

Ethyl 13,14-Dihydro-13,14-methyleneretinoates: Analogues of *all-trans*- and 13-*cis*-Retinoic Acid

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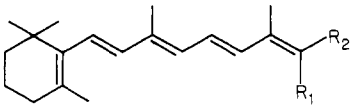
Received October 3, 1983

The synthesis of analogues of ethyl *all-trans*- and 13-*cis*-retinoates containing a 13,14-cyclopropyl moiety (**3** and **4**) as well as the identical analogues of ethyl 13-desmethyl-*all-trans*- and 13-*cis*-retinoates (**5** and **6**) is described. Wittig reaction between β-ionylideneethyltriphenylphosphonium bromide (**7**) and the appropriate formylcyclopropanecarboxylate afforded **3**/**4** and **5**/**6** in 79% yields as mixtures of their 11-*Z* and -*E* isomers. Purification of isomer mixtures by HPLC permitted stereochemical assignments after ^{1}H NMR analysis.

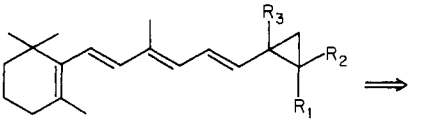
In 1967, 13-*cis*-retinoic acid (**1**) was identified in rat tissue extracts and was postulated to be a natural metabolite of *all-trans*-retinoic acid (**2**).[2] The isomer **1** has



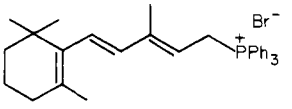
1, R_1 = COOH; R_2 = H
2, R_1 = H; R_2 = COOH

been found to be at least as effective as the parent compound **2** in promoting vitamin A dependent growth[3] as well as in controlling epithelial cell differentiation.[4] Recent work suggests that **1** is not solely produced as an artifact of isolation but that **2** is isomerized in mammals to some extent to **1**.[5] With a view toward studies of the significance of this reversible isomerization on biological activity, the rigid cyclopropyl analogues **3**–**6** have been prepared (Scheme I). The utility of **1** in treating dermatological conditions,[6] its tumor inhibitory properties,[7] and its reduced toxicity relative to the parent **2**[8] also supported the attractiveness of these cyclopropyl retinoids as synthetic candidates.

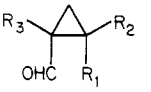
Scheme I



3, R_1 = CO_2Et; R_2 = H; R_3 = CH_3
4, R_1 = H; R_2 = CO_2Et; R_3 = CH_3
5, R_1 = CO_2Et; R_2 = H; R_3 = H
6, R_1 = H; R_2 = CO_2Et; R_3 = H



7



8, R_1 = CO_2Et; R_2 = H; R_3 = CH_3
9, R_1 = H; R_2 = CO_2Et; R_3 = CH_3
10, R_1 = CO_2Et; R_2 = H; R_3 = H
11, R_1 = H; R_2 = CO_2Et; R_3 = H

Retrosynthetic analysis (Scheme I) immediately suggested the classical "C_{15} + C_5" route to **3**–**6**.[9] This methodology had recently been successfully employed by Davalian and Heathcock for the preparation of the

(1) (a) National Cancer Institute Fellow, 1982–1984. (b) Program Project Grant No. AM-14881 of the National Institutes of Health.

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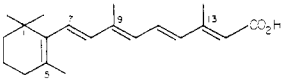

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