Synthesis of a New System Containing a Pyramidalized Double Bond: *cis*-3,8-Dicarbomethoxy-3,8-dihydroheptalene and Its Reaction with Benzyne

Abdullah Menzek,[†] Nurullah Saraçoğlu,[†] Mariusz Krawiec,[‡] William H. Watson,[‡,§] and Metin Balcı*,[†]

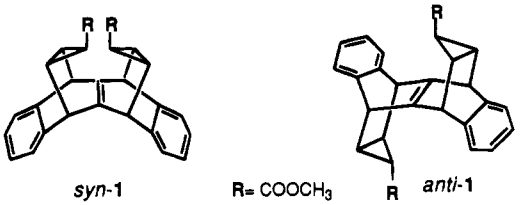
Department of Chemistry, Faculty of Art and Sciences, Atatürk University, 25240 Erzurum, Turkey, and Department of Chemistry, Texas Christian University, Fort Worth, Texas 76129

Received July 25, 1994[⊗]

The strained system *syn*-**1** was the object of synthetic and structural studies because of its double bond pyramidalization. The starting material, *cis*-3,8-dicarbomethoxy-3,8-dihydroheptalene, was synthesized by two different approaches. Addition of ethyl diazoacetate then gave *syn*-addition product **2**. Transesterification and NBS-bromination followed by Zn–AcOH elimination resulted in the formation of *cis*-dihydroheptalene **5**, which was also synthesized by silica gel catalyzed isomerization of the *trans*-**5** isomer. Addition of benzyne to *cis*-**5** gave the target compound *syn*-**1**, whose structure was investigated by X-ray diffraction. These data show its pyramidalization angle to be 16.8°.

Ab initio molecular orbital calculations indicate that a number of strained olefins prefer a nonplanar structure.[1] Theoretical work has shown that a trigonal center of a double bond pyramidalizes when located in an unsymmetrical environment.[2,3] When there is an unsymmetrical arrangement of allylic bonds with respect to an alkene, there is a driving force for pyramidalization in order to achieve partial staggering of the alkene with respect to the allylic bonds. Furthermore, Houk has postulated that the electron density of the alkenyl π bond influences the degree of pyramidalization. If the alkene bears donor substituents, which increase the electron density of the π-system, the alkene becomes more carbanion-like. The out-of-plane bending force constants are diminished and the degree of bending increases.[4,5] Schleyer and Pople performed computations on distorted ethylene moieties in which they constrained the HCC angles. They found that as the vicinal hydrogen atoms are moved toward each other, the molecule becomes nonplanar, even in the absence of any asymmetric torsional interaction.[1]

In 1980, *syn*- and *anti*-sesquinorbornene were synthesized independently by Bartlett[6] and Paquette.[7] X-ray studies[8] showed that the π-bonded carbons in the *syn* isomer are significantly pyramidalized, with folding angles ranging from 16° to 18°. Furthermore, Paquette has reported the synthesis of *syn*- and *anti*-sesquinorbornatriene[9] and their derivatives, in which structural analysis indicates a pyramidalization angle of $\phi = 32.4°$ in a sterically shielded derivative of the *syn* isomer.[10]



Recently, we reported the synthesis of *anti*-**1**.[11] Because the two faces of the double bond are equivalent in *anti*-**1** and the molecule possesses a C_2 axis of symmetry that lies along the C–C double bond, a planar equilibrium geometry at the doubly bonded carbons is at least a possibility. X-ray diffraction analysis indicates that the central double bond is, in fact, planar.

In contrast, the doubly bonded carbon in *syn*-**1** would not be expected to be planar. Therefore, the present study was undertaken in order to obtain structural information about this pyramidalized alkene. In this paper we wish to report the synthesis and X-ray structure of *syn*-**1**.

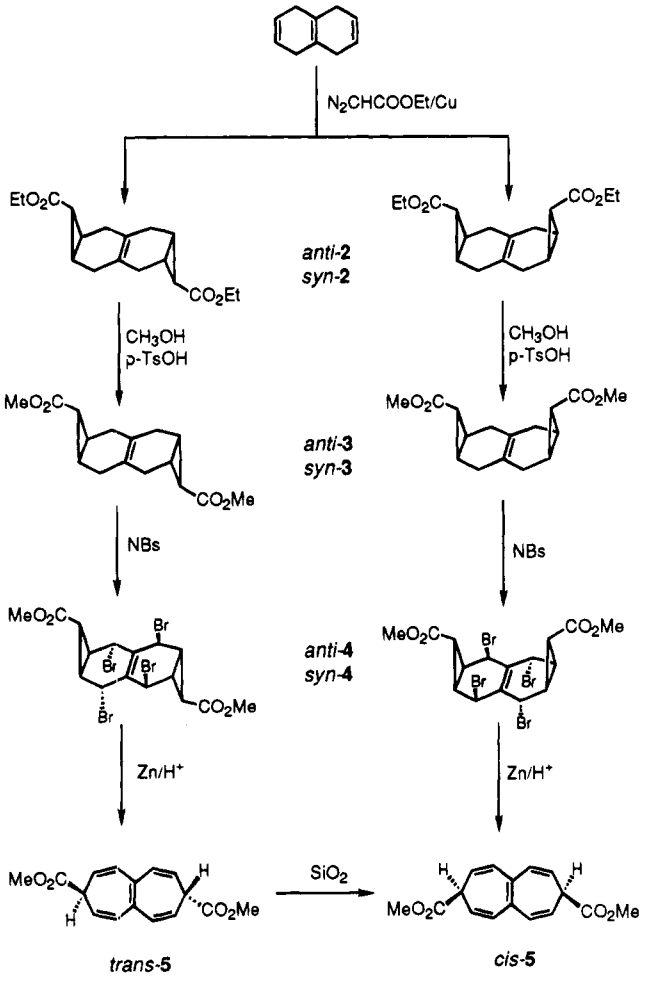
Our *anti*-**1**[11] synthesis entailed the addition of 2 mol of benzyne to the *trans*-dihydroheptalene derivative **5**[12] and took advantage of the cycloheptatriene–norcaradiene equilibrium.[13] For the preparation of the *syn*-**1**, we had

[†] Atatürk University.
[‡] Texas Christian University.
[§] Author to whom inquiries concerning the X-ray structure should be directed.
[⊗] Abstract published in *Advance ACS Abstracts,* December 1, 1994.

(1) Wagner, H. U.; Szeimis, G.; Chandrasekhar, J.; Schleyer, P. v. R.; Pople, J. A.; Binkley, J. S. *J. Am. Chem. Soc.* **1978**, *100*, 1210.
(2) (a) Wipf, G.; Morokuma, K. *Tetrahedron Lett.* **1980**, *21*, 4445. (b) Paddon-Row, M. N.; Randan, N. G.; Houk, K. N. *J. Am. Chem. Soc.* **1982**, *104*, 7162.
(3) Hake, H.; Landen, H.; Martin, H.-D.; Spellmeyer, D. C. *Tetrahedron Lett.* **1989**, *29*, 6601.
(4) Houk, N. Kendall. In *Stereochemistry and Reactivity of Systems Containing π Electrons*; Watson, W. H., Ed.; Verlag Chemie International: Deerfield Beach, FL, 1983.
(5) Rondan, N. G.; Paddon-Row, M. N.; Caramella, P.; Houk, K. N. *J. Am. Chem. Soc.* **1981**, *103*, 2436.
(6) Bartlett, P. D.; Blakeney, A. J.; Kimura, M.; Watson, W. H. *J. Am. Chem. Soc.* **1980**, *102*, 1383.
(7) Paquette, L. A.; Carr, R. V. C.; Böhm, M. C.; Gleiter, R. *J. Am. Chem. Soc.* **1980**, *102*, 1186, 7218.
(8) (a) Pinkerton, A. A.; Schwarzenbach, D.; Stibbard, J. H. A.; Carrupt, P.-A.; Vogel, P. *J. Am. Chem. Soc.* **1981**, *103*, 2095. (b) Paquette, L. A.; Schaefer, A. G.; Blount, J. F. *J. Am. Chem. Soc.* **1983**, *105*, 3642.
(9) (a) Paquette, L. A.; Künzer, H.; Green, K. E.; De Lucchi, O.; Licini, G.; Pasquato, L.; Valle, G. *J. Am. Chem. Soc.* **1986**, *108*, 3453. (b) Paquette, L. A.; Shen, C.-C.; Krause, J. A. *J. Am. Chem. Soc.* **1989**, *111*, 2351. (c) Paquette, L. A.; Shen, C.-C. *J. Am. Chem. Soc.* **1990**, *112*, 1159.
(10) For a review for pyramidalized double bonds, see: Borden, W. T. *Chem. Rev.* **1989**, *89*, 1095.
(11) Menzek, A.; Krawiec, M.; Watson, W. H.; Balcı, M. *J. Org. Chem.* **1991**, *56*, 6755.
(12) (a) Vogel, E.; Hogrefe, F. *Angew. Chem., Int. Ed. Engl.* **1974**, *13*, 735. (b) Hogrefe, F. Dissertation Thesis, University of Cologne, 1978. (c) For cycloaddition reactions to *trans*-**1**, see: Menzek, A.; Balcı, M. *Austr. J. Chem.* **1993**, *46*, 1613.
(13) Balcı, M. Doğa, *Turk. J. Chem.* **1992**, *16*, 42.

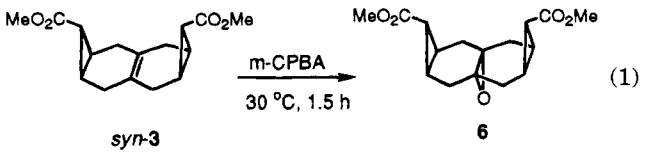
0022-3263/95/1960-0829$09.00/0 © 1995 American Chemical Society

Scheme 1



to synthesize the precursor **5** with the *cis*-configuration (Scheme 1). Vogel[12] reported that isotetraline reacts with excess ethyl diazoacetate to deliver bis-adduct *anti*-**2** in a yield of 18%. We examined the reaction mixture carefully and found that the *syn*-isomer **2** was also present, in a total yield of 28%. After repeated column chromatography, we isolated the desired pure *syn*-isomer **2**. The relative stereochemistries of the adducts could be clearly discerned from their ^1H and ^{13}C spectra.

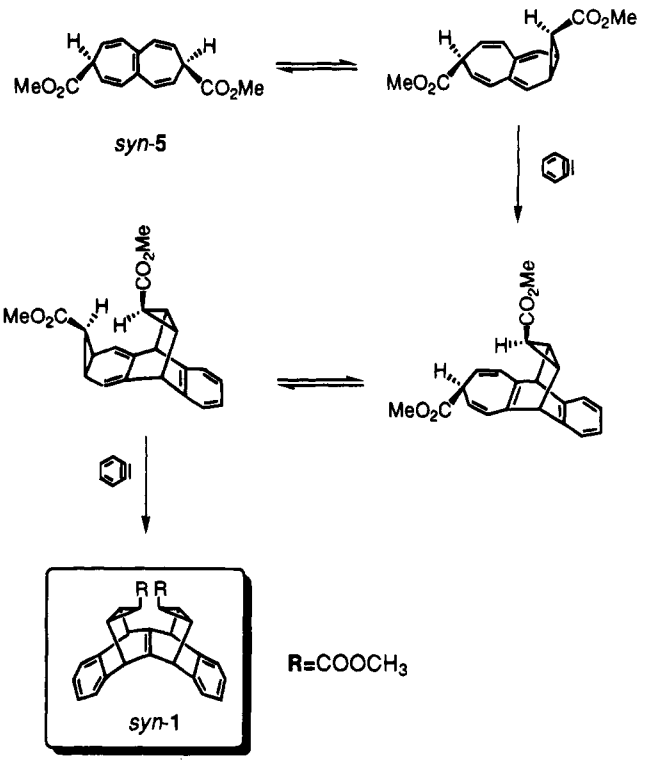
The presence of a symmetry element in both *syn*-**2** and *anti*-**2** was indicated by their seven-line ^{13}C NMR spectra. However, whereas the epoxidation of *syn*-**3** gave a single compound in which the plane of symmetry in the molecule was retained, epoxidation of *anti*-**3** gave a single epoxide in which the axis of symmetry in the molecule was lost.[12b] These results establish the stereochemistries of the proposed structures.



(1)

For transesterification of **2** to **3**, we refluxed the ethyl esters in methanol for 3 days in the presence of *p*-toluene sulfonic acid. From *syn*-**2**, *syn*-**3** was obtained in over 95% yield. *N*-Bromosuccinimide bromination of *syn*-**3** gave a single tetrabromide (**4**), whose configuration was established by NMR. Differential ^1H NMR–NOE measurements support this proposed structure. Then, *syn*-**4** reacted smoothly with Zn–AcOH to give *cis*-**5** in 95% yield.

Scheme 2



cis-3,8-Dicarbomethoxy-3,8-dihydroheptalene (*cis*-**5**) was also independently synthesized by isomerization of *trans*-**5**. Refluxing *trans*-**5** in $CHCl_3$ containing silica gel afforded *cis*-**5** in a yield of 61%. *cis*-Diester **5** (pale yellow crystals) was characterized by its 200 MHz ^1H NMR spectrum. Its six-line ^{13}C NMR spectrum is particularly informative.

Construction of the *syn*-**1** framework was dependent on successful reaction of benzyne with *cis*-**5** (Scheme 2). Benzyne, generated from benzenediazonium-2-carboxylate hydrochloride,[9c] reacted with *cis*-diester **5** to give *syn*-compound **1** in a yield of 37%. The structural assignment was made from the NMR data. The spectra of *syn*-**1** were very similar to those of *anti*-**1**, except that the two-proton triplet around δ 0.3 in the ^1H NMR spectrum of *anti*-**1** appears at δ 2.68 in the spectrum of *syn*-**1**. We attribute this extraordinary shift to steric compression between these two protons in *syn*-**1**, although pyramidalization of the double bond might also contribute. The benzene protons exhibit an AA'BB' pattern as expected from molecular symmetry. Bridgehead protons appear at 3.99 ppm as a quasi-triplet, while the other cyclopropane protons are located at 1.96 ppm. A nine-line ^{13}C spectrum is also consistent with the symmetry of the molecule *syn*-**1**.

The X-ray crystal structure of *syn*-**1** was determined,[14–18] and the molecule was found to have symmetry in the crystal (Figure 1). From the bond angles R–C–R and R–C–C about the double-bonded carbon, the pyrami-

(14) X-ray structural analysis of *syn*-**1**: a = 7.535 (4), b = 8.352, and c = 35.024 (3) Å, β = 94.28(2)°, V = 2198(1) Å^3, 298 K, monoclinic, space group $P2_1/c$ (no. 14), Z value = 4, D_{calc} = 1.283 g/cm^3, Cu (Kα) radiation, μ = 6.45 cm^{-1}, $2\theta_{max}$ = 157.9°, 4837 unique reflection.

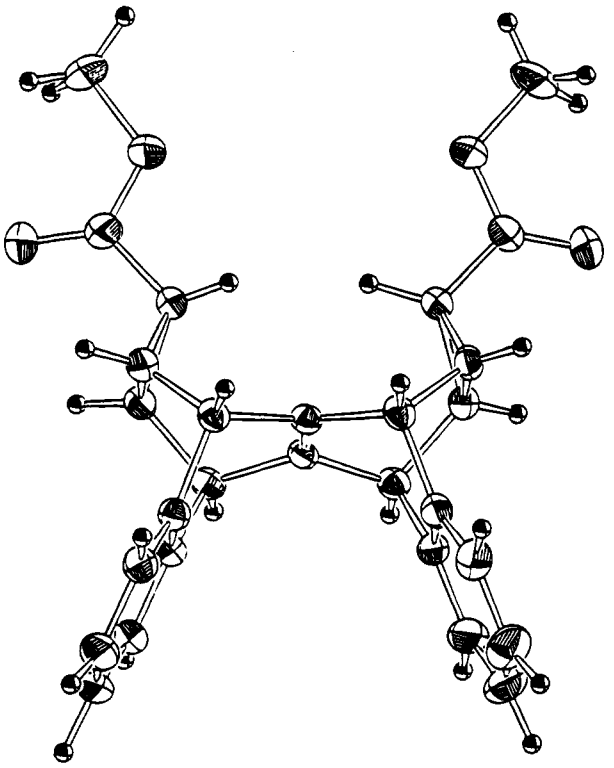


Figure 1. X-ray structure of *syn*-**1**.

dalization angle can be obtained from the formula[10,15]

$$\cos \phi = -\cos(\text{R-C-C})/\cos {}^1/_2(\text{R-C-R})$$

We obtained a pyramidalization angle $\phi = 16.8°$. Calculations indicate that pyramidalization has little effect on the energy of the HOMO, but that of the LUMO is lowered dramatically.[16,17] This should be reflected in the chemical reactivity of pyramidalized compounds. However, when epoxidation, bromination, and hydrogenation of compound *syn*-**1** were attempted, in all cases we isolated only unreacted starting material. This lack of reactivity can be rationalized in terms of steric shielding of the double bond by the adjacent cyclopropane and benzene rings.

Experimental Section

General Methods. Solvents were concentrated at reduced pressure. Infrared spectra were obtained from KBr pellets or from solution in 0.1 mm cells on a infrared recording spectrophotometer. ^{1}H NMR spectra were recorded on a 200 MHz spectrophotometer and are reported in δ units with TMS as the internal standard. All column chromatography was performed on silica gel (60-mesh, Merck).

Reaction of Isotetralin with Ethyl Diazoacetate. To a magnetically stirred suspension of isotetralin (44.4 g, 0.34 mol) and Cu powder (2.8 g) at 100 °C was added dropwise ethyl diazoacetate (112 g, 0.98 mol) during 48 h. After completion of the addition, the brown reaction mixture was cooled to room temperature and then 280 mL of ether was added. The ether solution was allowed to standard for 12 h at −20 °C. The formed precipitate, *anti*-bis-adduct **2** (13.4 *g*, 13%) and Cu powder, was removed by filtration, and the solvent was evaporated. Then 4.0 g of the residue (115.5 g) was submitted to silica gel (100 g) column chromatography, eluting with benzene/hexane (5:95). As the first fraction we isolated *syn*-bis-adduct **2** (28%, 894 mg), followed by anti-bis-adduct **2** (5.2%, 192 mg). The same chromatographic method was applied to the residue. The reaction products were crystallized from hexane.

***syn*-Diethyl tetracyclo[5.5.0.0^{3,5}.0^{9,11}]dodec-1(7)-ene-4,10-dicarboxylate (2)**: mp 79−80 °C; IR (CCl_4, cm^{-1}) 2980, 2895, 2825, 1720, 1440, 1370, 1345, 1290, 1175; ^{1}H NMR (200 MHz, $CDCl_3$) δ 4.10 (q, J = 7.13 Hz, 4H), 2.31 (d, J = 15.9 Hz, 4H), 2.02 (d, 4H), 1.71 (m, 4H), 1.42 (t, J = 4.05 Hz, 2H), 1.26 (t, J = 7.13 Hz, 6H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 175.10, 120.82, 60.74, 28.77, 23.14, 22.19, 14.17. Anal. Calcd for $C_{18}H_{24}O_4$: C, 71.02; H, 7.95. Found: C, 71.23; H, 7.75.

***syn*-Dimethyl tetracyclo[5.5.0.0^{3,5}.0^{9,11}]dodec-1(7)-ene-4,10-dicarboxylate (3).** A solution of *syn*-**2** (1.0 g, 3.29 mmol) and *p*-toluenesulfonic acid (280 mg, 0.92 mmol) in 70 mL of methanol was refluxed for 3 days. After evaporation of the solvent, 100 mL of $CHCl_3$ was added to the residue. The formed organic layer was separated, washed with water (4 × 50 mL), and dried over anhydrous $MgSO_4$, and the solvent was evaporated. The reaction product, *syn*-**3** (862.5 mg, 95%), was crystallized from hexane: mp 109-111 °C; IR (KBr, cm^{-1}) 3040, 2960, 2880, 2820, 1720, 1450, 1350, 1300, 1240, 1190, 1165, 950, 710; ^{1}H NMR (200 MHz, $CDCl_3$) δ 3.64 (s, 6H), 2.30 (bd, J = 15.9 Hz, 4H), 2.02 (bd, J = 15.9 Hz, 4H), 1.71 (m, 4H), 1.42 (t, J = 4.05 Hz, 2H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 175.49, 120.79, 52.00, 28.75, 22.97, 22.29. Anal. Calcd for $C_{16}H_{20}O_4$: C, 69.54; H, 7.30. Found: C, 68.96; H, 7.21.

Epoxidation of *syn*-3. *syn*-**3** (420 mg, 1.52 mmol) and *m*-chloroperbenzoic acid (574 mg, 3.33 mmol) were dissolved in 30 mL of $CHCl_3$. The formed solution was placed into a ultrasonic apparatus (Branson 3200) and reacted at room temperature for 1.5 h. The resulting reaction mixture was washed with Na_2CO_3 (20%, 3 × 20 mL) and water (20 mL) and dried over anhydrous $MgSO_4$, and the solvent was evaporated. The formed epoxide **6** (444 mg, 98%) was crystallized from CH_2Cl_2/hexane: mp 161−163 °C; IR (KBr, cm^{-1}) 3000, 2910, 2840, 1730, 1710, 1440, 1350, 1290, 1200, 1130, 1070, 840, 700; ^{1}H NMR (200 MHz, $CDCl_3$) δ 3.64 (s, 6H), 2.34 (bd, J = 16.1 Hz, 4H), 1.67 (bd, J = 16.1 Hz, 4H), 1.49 (m, 4H), 0,93 (t, J = 4.40 Hz, 2H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 174.57, 56.81, 52.21, 28.93 (2C) 19.01.

Tetrabromide *syn*-4. A solution of *syn*-**3** (1.0 g, 0.362 mmol), *N*-bromosuccinimide (2.9 g, 16.29 mmol), and α,α′-azobis(isobutyronitrile) (0.049 g) in 25 mL of CCl_4 was refluxed for 2 h. The reaction mixture was cooled to room temperature and the formed precipitate removed by filtration. The solvent was evaporated. The tetrabromide *syn*-**4** (1.14 g, 53%) was crystallized from $CHCl_3$/ether: mp 186−187 °C; IR (KBr, cm^{-1}) 2970, 1720, 1450, 1430, 1340, 1265, 1170, 1145; ^{1}H NMR (200 MHz, $CDCl_3$) δ 5.45 (m, 2H), 5.40 (m, 2H), 3.77 (s, 3H), 3.70 (s, 3H), 2.75 (m, 2H), 2.59 (m, 2H), 1.89 (t, J = 4.9 Hz, 1H), 1.63 (t, J = 4.0 Hz, 1H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 172.33, 170.93, 131.23, 53.09, 52.89, 47.53, 43.57, 35.17, 32.26, 27.19, 24.89.

***cis*-3,8-Dicarbomethoxy-3,8-dihydroheptalene (*cis*-5): Path A.** A mixture of *syn*-**4** (500 mg, 0.85 mmol), Zn (400 mg), and acetic acid (three drops) in 30 mL of absolute tetrahydrofuran (THF) was refluxed for 45 min. After the solution was cooled to room temperature, unreacted Zn was removed by filtration. The solvent was evaporated, and 50 mL of $CHCl_3$ was added to the residue. The organic layer was washed with water (3 × 50 mL) and dried over anhydrous $MgSO_4$, and the solvent was evaporated. *cis*-Dihydroheptalene **5** (218 mg, 95%) was crystallized from ether.

Path B. To a solution of *trans*-3,8-dicarbomethoxy-3,8-dihydroheptalene **5** (1088 mg, 4 mmol) in 70 mL of $CHCl_3$ was added 6.0 g of thin layer silica gel (741-Kieselgel 60 $HF_{254-366}$). The reaction mixture was refluxed for 4 days and cooled to room temperature. The reaction mixture was filtrated and washed with ethyl acetate. The combined organic solvents were evaporated, and the residue was purified by crystalliza-

(15) Volland, W. V.; Davidson, R. E.; Borden W. T. *J. Am. Chem. Soc.* **1979**, *101*, 533.
(16) Hrovat, D.; Borden W. T. *J. Am. Chem. Soc.* **1988**, *110*, 4710.
(17) This prediction has found experimental confirmation: Smith, J. M.; Hrovat, D. A.; Borden, W. T. *J. Am. Chem. Soc.* **1993**, *115*, 3816.
(18) The author has deposited atomic coordinates for this structure with the Cambridge Crystallographic Data Centre. The coordinates can be obtained, on request, from the Director, Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge, CB2 1EZ, UK.

tion from ether, giving *cis*-3,8-dihydroheptalene **5** (660 mg, 61%): pale yellow crystals, mp 114–116 °C; IR (KBr, cm^{-1}) 3000, 2950, 2820, 1735, 1615, 1433, 1300, 1205, 1170, 1040, 975, 915, 810, 720; ^1H NMR (200 MHz, $CDCl_3$) δ 6.32 (d, J = 9.9 Hz, 4H), 5.81 (dd, J = 9.9, 5.56 Hz, 4H), 3.80 (s, 6H), 2.53 (t, J = 5.6 Hz, 2H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 173.51, 139.97, 129.40, 124.40, 52.83, 44.55. Anal. Calcd for $C_{16}H_{16}O_4$: C, 70.57; H, 5.92. Found: C, 70.02; H. 5.81.

4,10-Dicarbomethoxy-*cis*,*cis*-2,6,8,12-dibenzohexacyclo-[5.5.0.0^{3,5}.0^{9,11}]dodec-1(7)-ene (*syn*-1). To a refluxing solution of *cis*-3,8-dicarbomethoxy-3,8-dihydroheptalene **5** (544 mg, 2 mmol) in 50 mL of 1,2-ethylene dichloride was added 2.6 g (14 mmol) of benzenediazonium-2-carboxylate hydrochloride under an N_2 atmosphere. The colorless mixture became dark. The reaction mixture was refluxed for 1 day and the solvent evaporated. Crystallization of the residue from $CHCl_3$/ether afforded the *syn*-bis-adduct **1** (314 mg, 37%) as colorless crystals: mp 274–275 °C; IR (KBr, cm^{-1}) 3010, 2980, 1725, 1460, 1440, 1400, 1300, 1210, 1150, 765; ^1H NMR (200 MHz, $CDCl_3$) δ 6.87–6.65 (AA'BB' system, 8H), 3.99 (m, 4H), 3.68 (s, 6H), 2.68 (t, J = 2.95 Hz, 2H), 1.96 (m, 4H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 172.69, 146.99, 146.81, 124.79, 122.95, 52.28, 45.05, 30.10, 29.36. Anal. Calcd for $C_{28}H_{24}O_4$: C, 79.22; H, 5.70. Found: C, 78.85; H, 5.57.

Acknowledgment. The authors are indebted to the Department of Chemistry (Atatürk University) and the Robert A. Welch Foundation (P-074) for financial support of this work and the State Planning Organization of Turkey (DPT) for purchasing a 200 MHz NMR spectrometer and Prof. Dr. Emanuel Vogel for the generous gift of isotetralin.

Supplementary Material Available: Copies of ^1H NMR spectra of *syn*-**4**, *cis*- and *trans*-**5**, and *syn*- and *anti*-**1**, a copy of the ^{13}C NMR spectrum of *syn*-**4**, and an Ortep of *syn*-**1** (4 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

JO9412746