

4-aminoanthranilic acid (8)²⁴ condensing with a third erythrose-4-phosphate with loss of the carboxyl group of 8. This new quinoline-generating pathway would be directly analogous to tryptophan biosynthesis (Scheme I) and is supported by the apparent excess enrichment of C-8, C-6', and C-9', each of which is apparently derived from C-1 of 4. The previously observed²⁷ equilibrium between (glucose derived) fructose diphosphate and the triose phosphates would be expected to generate a subpopulation of labeled erythrose in which the aldehyde carbon is no longer coupled to its neighbor.

Although the identity of the precursors to streptonigrin will have to be confirmed by specific feeding experiments, the study reported here clearly demonstrates the value of [U-¹³C₆]glucose in elucidating complex biosynthetic pathways.

Acknowledgment. This work was supported by grants from the NIH, CA 27339 (S.J.G.) and GM 22172 (D.E.C.). Initial ¹³C NMR spectra were obtained by Peter Demou on a Bruker HX 270 spectrometer at the Northeast Regional NSF-NMR Facility, Yale University, partially supported by the National Science Foundation, Grant CHE 79-16210. The Bruker WM 250 spectrometer at Brown University was purchased with funds provided by the NSF and the Montedison Company. We thank Tzzy-Chyau Liang, Brown University, for carrying out the ¹³C-¹³C decoupling experiments. Strains of *S. flocculus* were a gift of Dr. John DeZeeuw of Chas. Pfizer, Inc.

Registry No. 1a, 80206-29-7; 2, 80206-30-0; 3a, 80206-31-1; 4, 80206-32-2; 5, 80206-33-3; 6, 80206-34-4; 7, 80206-35-5.

Supplementary Material Available: Additional ¹³C NMR spectra of 1a, including expansions of significant regions and additional ¹³C-¹³C decoupling experiments (5 pages). Ordering information is given on any current masthead page.

(24) The same C₆N₂ unit may also be involved in the formation of the structurally related metabolites, lavendamycin²⁵ and nybomycin.²⁶

(25) Doyle, T. W.; Balitz, D. M.; Gurlich, R. E.; Nettleton, D. E.; Gould, S. J.; Tann, C.-H.; Moews, A. E., submitted for publication.

(26) Nadzan, A. M.; Rinehart, K. L., Jr. *J. Am. Chem. Soc.* **1976**, *98*, 5012.

(27) Ugurbil, K.; Brown, T. R.; den Hollander, J. A.; Glynn, P.; Shulman, R. G. *Proc. Natl. Acad. Sci. U.S.A.* **1978**, *75*, 3742. den Hollander, J. A.; Brown, T. R.; Ugurbil, K.; Shulman, R. G. *Ibid.* **1979**, *76*, 6096.

Synthesis of a Helical Ferrocene

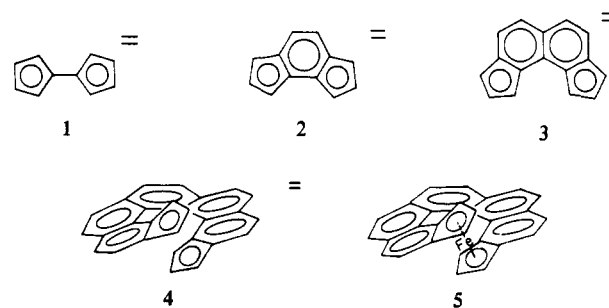
Thomas J. Katz* and Jaan Pesti

Department of Chemistry, Columbia University
New York, New York 10027

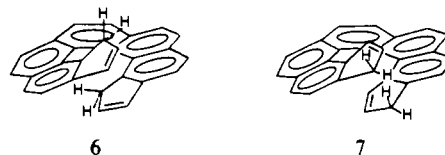
Received August 24, 1981

Hydrocarbon dianions comprised of a pair of conjugated cyclopentadienyl anions, such as 1,¹ 2,² or 3,³ as well as other examples,^{3,4} react with transition-metal halides to yield dimeric sandwich molecules. However, were many more angularly fused rings than in 2 or 3 to separate the terminal rings, the hydrocarbon

would be helical⁵ and incapable of giving the analogous dimer,³ and were the fused ring system to contain five benzene rings, a unique opportunity would arise.⁶ The cyclopentadienyl rings would almost superimpose (structure 4), and if a metal cation, say ferrous, were to unite them as in 5, the product would be an unprecedented metallocene with unbroken conjugation between its planes.⁷ We are reporting here the synthesis of the first example of such a structure.



The initial stage involved synthesizing the [7]-helicene analogue 6 and was carried out as outlined in Scheme I. Notable features



are the use of the abundant 2,7-dihydroxynaphthalene,⁸ the vinyl ketone cyclization as a means for fusing an unsubstituted cyclopentenone to the 1,2-positions of a naphthalene,^{9,10} the photocyclization uniting only the α carbons of the naphthalenes to give the helical structure despite the congesting saturated rings,^{11,12} and the confirmation of the structure of hydrocarbon 6¹³ by X-ray diffraction.¹⁶

(5) Martin, R. H. *Angew. Chem., Int. Ed. Engl.* **1974**, *13*, 649.

(6) Ślusarek, W. Dissertation, Columbia University, New York, 1977.

(7) There are related molecules with alternating single and double bonds but adjacent double bonds are not constrained parallel: (a) Kasahara, A.; Izumi, T.; Shimizu, I. *Chem. Lett.* **1979**, 1119. (b) Tanner, D.; Wennerström, O. *Acta Chem. Scand., Ser. B* **1980**, *B34*, 529.

(8) Porzi, G.; Concilio, C. *J. Organomet. Chem.* **1977**, *128*, 95. See also: Schaefer, J. P. et al. "Organic Syntheses"; Wiley: New York, 1973; Collect. Vol. V, p 142. *J. Org. Chem.* **1967**, *32*, 1607.

(9) This has been done before only with 2-naphthyl vinyl ketones that are substituted on the double bond.^{10a-c} Unsubstituted 1-naphthyl vinyl ketone has been cyclized as well.^{10d}

(10) (a) Baddeley, G.; Holt, G.; Makar, S. M.; Iverson, M. G. *J. Chem. Soc.* **1952**, 3605. (b) Nazarov, I. N.; Nagibina, T. D. *Zh. Obshch. Khim.* **1953**, *23*, 801. (c) Shotter, R. G.; Johnston, K. M.; Williams, H. J. *Tetrahedron* **1973**, *29*, 2163. (d) Burkhalter, J. H.; Fuson, R. C. *J. Am. Chem. Soc.* **1948**, *70*, 4184.

(11) (a) Scholz, M.; Mühlstädt, M.; Dietz, F. *Tetrahedron Lett.* **1967**, 665. (b) Scholz, M.; Dietz, F.; Mühlstädt, M. *Z. Chem.* **1967**, *7*, 329. (c) Laarhoven, W. H.; Cuppen, T. J. H. M.; Nivard, R. J. F. *Recl. Trav. Chim. Pays-Bas* **1968**, *87*, 687. (d) Laarhoven, W. H.; Cuppen, T. J. H. M.; Nivard, R. J. F. *Tetrahedron* **1970**, *26*, 4865.

(12) (a) Wisnonski-Knittel, T.; Fischer, E. *J. Chem. Soc., Perkin Trans. 2* **1979**, 449. (b) Muszkat, K. A.; Sharafi-Ozeri, S.; Seger, G.; Pakkanen, T. A. *Ibid.* **1975**, 1515 and references cited therein.

(13) The ¹H NMR spectrum [(300 MHz, C₆D₆) δ 7.80 (d, J = 8.6 Hz), 7.78 (d, J = 8.2 Hz), 7.75 (s), 7.62 (d, J = 8.6 Hz), 7.62 (d, J = 8.6 Hz), 7.41 (d, J = 8.6 Hz) [total aromatic integration = 10.71 H], 6.42 (d of t, 1.52, J = 5.6 Hz, J' = 1.7 Hz), 5.72 (d of t, 1.61, J = 5.6 Hz, J' = 1.7 Hz), 2.35 d of t, 2.08, J = 24.1 Hz, J' = 1.9 Hz), 2.02 (d of br t, 2.08, J = 23.6 Hz, J' ~ 1.4 Hz)¹⁴] supports the structure inasmuch as the olefinic signals are shifted upfield from their positions in simpler indenenes³ (in CDCl₃, by 0.5 and 0.8 ppm, respectively) by the shielding effect of the opposing rings^{15a} and inasmuch as there are two different allylic proton resonances.

(14) The pattern of the aromatic resonances resembles that due to the corresponding protons in [7]helicene.¹⁵

(15) (a) Martin, R. H.; Defay, N.; Figeys, H. P.; Flammang-Barbieux, M.; Cosyn, J. P.; Gelbeke, M.; Schurter, J. J. *Tetrahedron* **1969**, *25*, 4985. (b) Defay, N. *Org. Mag. Reson.* **1974**, *6*, 221.

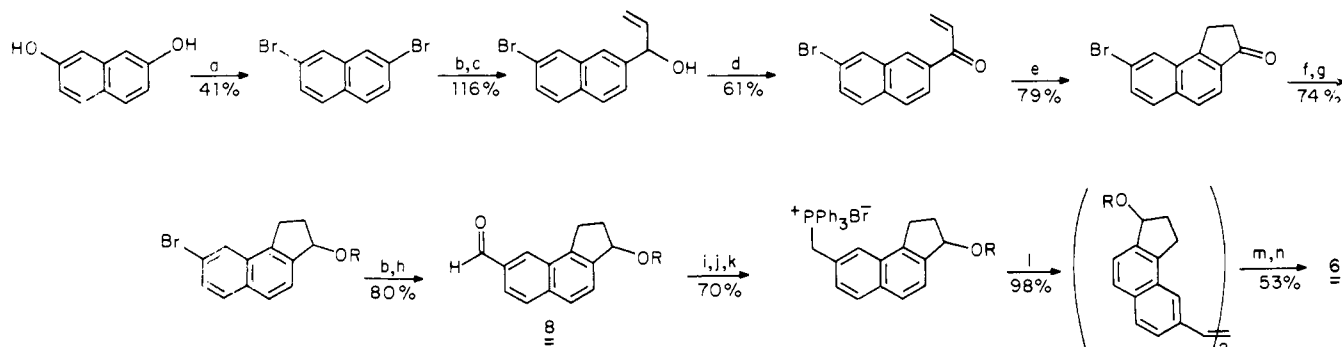
(16) Dewan, J. *Acta Crystallogr., Sect. B* **1981**, *37*, 1421.

(1) (a) LeVanda, C.; Bechgaard, K.; Cowan, D. O.; Mueller-Westerhoff, U. T.; Eilbracht, P.; Candela, G. A.; Collins, R. L. *J. Am. Chem. Soc.* **1976**, *98*, 3181. (b) Davison, A.; Smart, J. C. *J. Organomet. Chem.* **1973**, *49*, C43. (c) Smart, J. C.; Pinsky, B. L. *J. Am. Chem. Soc.* **1977**, *99*, 956. (d) Smart, J. C.; Curtis, C. J. *Inorg. Chem.* **1977**, *16*, 1788. (e) Smart, J. C.; Curtis, C. J. *J. Am. Chem. Soc.* **1977**, *99*, 3518. (f) Smart, J. C.; Pinsky, B. L. *Ibid.* **1980**, *102*, 1009. (g) McKinney, R. J. *J. Chem. Soc., Chem. Commun.* **1980**, 603.

(2) (a) Katz, T. J.; Schulman, J. *J. Am. Chem. Soc.* **1964**, *86*, 3169. (b) Katz, T. J.; Balogh, V.; Schulman, J. *Ibid.* **1968**, *90*, 734.

(3) Katz, T. J.; Ślusarek, W. *J. Am. Chem. Soc.* **1979**, *101*, 4259.

(4) (a) Katz, T. J.; Acton, N. J. *J. Am. Chem. Soc.* **1972**, *94*, 3281. (b) Katz, T. J.; Acton, N.; McGinnis, J. *Ibid.* **1972**, *94*, 6205. (c) Katz, T. J.; Ślusarek, W. *Ibid.* **1980**, *102*, 1058. (d) Schneider, R. S. *J. Polym. Sci., Part C* **1970**, *27*.

Scheme 1^a

^a (a) $\text{Ph}_3\text{P}\cdot\text{Br}_2$, 320 °C; (b) *n*-BuLi/THF, -55 °C; (c) acrolein/THF; (d) $\text{MnO}_2/\text{CH}_2\text{Cl}_2$; (e) concentrated H_2SO_4 ; (f) $\text{LiEt}_3\text{BH}/\text{THF}$; (g) (*t*-Bu) Me_2SiCl , imidazole/DMF; (h) DMF/THF, -70 °C; (i) DIBAL-H/hexane; (j) (*n*- C_8H_{17}) $_3\text{P}$, CBr_4 /ether; (k) $\text{Ph}_3\text{P}/\text{C}_6\text{H}_6$, 80 °C; (l) 8, LiOEt/EtOH ; (m) *h\nu*, catalytic $\text{I}_2/\text{C}_6\text{H}_6$; (n) *p*-TsOH· $\text{H}_2\text{O}/\text{C}_6\text{H}_6$, 60 °C. R = (*t*-Bu) Me_2Si .

The methylene hydrogens about carbons within the helix, splaying the structure considerably. The angle between the outer rings is 69.1°, much greater than in other helicenes.¹⁷ The removal of the methylene hydrogens by base should thereby be facilitated, but in fact the reaction seems difficult to effect. Thus *n*-butyllithium in tetrahydrofuran (THF), which easily deprotonates simpler indenenes (including the precursors of **2**² and **3**³), seems to work only poorly with **6**,¹⁹ but *tert*-butyllithium in THF works well, giving **4** and after quenching with aqueous acetic acid **7**.²⁰ The implication may be that Coulombic repulsions prevent the splayed structure in **6** from relaxing in **4**, an effect that may account for the course of the reactions discussed below.

When solutions of **4** as its lithium salt in THF are combined at -65 °C with very pure FeCl_2 ,²¹ they give as the only product soluble in CS_2 a very dark red crystalline solid²² in yields of 60%, which mass spectrometry,²³ ¹H NMR spectroscopy,²⁴ and X-ray diffraction analysis²⁵ identify as **5**. The metal atom presumably bonds to the inside faces of the cyclopentadienyl rings in **4** because the helical structure is splayed, additional evidence for which is the observation that deuterated acids attack almost as often from

the inside as from the outside.²⁶ Drawn by the concentrated negative charge the metal cation moves to a position between the rings, which then clamp at 19.4°, almost parallel,²⁷ as characteristic of the ferrocenes.²⁵

Acknowledgment. We are grateful for the support of the National Science Foundation (CHE 75-20621) and the National Institutes of Health (GM-19173). We thank Dr. John Dewan for the X-ray diffraction analyses.

(26) In the ¹H NMR spectrum (300 MHz, CDCl_3) of the deuterated product **7** the ratio of the intensities of the exo and endo protons (at δ 3.21 and 3.07) is 0.52. This requires that approximately every third deuterium approach endo to the ring. The possibility was considered that deuterons attach only exo and methylene protons transfer intramolecularly, but the observed couplings exclude this mechanism.

(27) The torsional angles around the inner core of benzenoid C-C bonds are, from terminus to terminus, 15, 20, 27, 17, and 16°.

Catalytic Hydrolysis of Esters of *p*-Nitrophenol Bound by Amylose in the $\text{Me}_2\text{SO}-\text{H}_2\text{O}$ Mixed-Solvent System¹

Yongzheng Hui,* Shujing Wang, and Xikui Jiang

Shanghai Institute of Organic Chemistry
Academia Sinica, Shanghai 200032, China

Received July 31, 1981

Our recent investigations have established that the formation of helical supramolecular complexes of amylose **1** or its derivatives with long-chain substrates in both aqueous and $\text{Me}_2\text{SO}-\text{H}_2\text{O}$ mixed-solvent systems is accompanied by conformational changes of the macromolecules.² In comparison with the well-studied cyclodextrin and functionalized polymer systems, two merits of our new systems are apparent: (1) binding sites are similar to that of the cyclodextrins and are thus well-defined; (2) the process of substrate binding can be accomplished only by conformational changes which may serve as a mimicry for the "induced fit" of enzymatic processes. Noteworthy rate accelerations with enzymelike kinetics have already been achieved with the hydrolysis of some esters in aqueous phase with sodium carboxymethyl-amylose (Na-CMA).^{2a} The present communication reports similar results from an investigation of the hydrolysis of five esters of *p*-nitrophenol (**2-6**), which have been used in several other investigations,³ in the $\text{Me}_2\text{SO}-\text{H}_2\text{O}$ mixed-solvent system (cf. ref

(17) The corresponding angle in the benzene analogue of **5**, [7]helicene, is 32.4°.¹⁸

(18) (a) Beurskens, P. T.; Beurskens, G.; van der Hark, Th. E. M. *Cryst. Struct. Commun.* **1976**, *5*, 241, 247. (b) Joly, M. et al. *Helv. Chim. Acta* **1977**, *60*, 537.

(19) Experiments in which **6** was combined with 6 equiv of *n*-BuLi in THF (-78 → 0 °C, 1 h) and then quenched (D_2O) gave impure **7**. The ¹H NMR's of some of these impurities fall at 3.0 ppm, obscuring the integration of **7**'s allylic proton resonances. Variations using HMPA and TMEDA as solvents or cosolvents gave **7** or mixtures of **6** and **7**, but impurities blocked our ability to use the integrals of the allylic and olefinic ¹H NMR's as measures of the extent of deuteration.

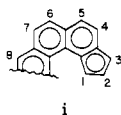
(20) When **6** was combined with 17 equiv of *t*-BuLi in THF (-65 → -20 °C, 45 min; -20 °C, 2.5 h) and quenched with $\text{D}_2\text{O}/\text{CH}_3\text{CO}_2\text{D}$, **7-d**₂ was produced. The ratio of the allylic and olefin protons, measured by ¹H NMR spectroscopy, was 0.51. The mass spectrum indicated it to be 79.5 ± 2% dideuterated and 11.1 ± 1% monodeuterated (CI, methane).

(21) Commercial FeCl_2 gave no metallocene. We used the THF adduct,^{1a} which is easy to purify and stable to oxidation.

(22) UV-visible, nm (log ϵ) in tetrahydrofuran: 261 (4.46), 284 (4.33), 329 (3.85), 391 (3.38), 417 (3.18), 456 (2.69), all shoulders, but with 284 distinct, 261 and 329 less so, and the others less yet.

(23) The mass spectrum (CI, methane) is dominated by the parent peaks (base peak *m/e* 409), and except for a peak attributable to residual **6** (at *m/e* 355, 17%), none are as much as 10% the size of the base peak.

(24) ¹H NMR (250 MHz, C_6D_6 , see structure i) δ 7.67 (d, *J* = 7.9 Hz, H_7), 7.55 (s, H_8), 7.54 (d, *J* = 8.1 Hz, H_6), integral 5.68; 7.27 (d, *J* = 9.0 Hz, H_2), 7.12 (d of d, *J* = 8.9, 0.8 Hz, H_4), integral 6.16 (augmented by C_6D_6 and minor impurities); 4.39 (d of d, *J* = 2.6, 1.1 Hz, H_3), integral 1.97; 3.88 (t, *J* = 2.5 Hz, H_2), integral 2.45; 3.68 (d of d of d, *J* = 2.6, 1.1, 0.8 Hz, H_1), integral 1.89.¹⁴



(25) Dewan, J., to be published.

(1) The Microenvironmental Effects of the Helical Conformations of Amylose and Its Derivatives. 5.

(2) (a) Hui, Yongzheng; Gu, Jianhua *Hua Hsueh Hsueh Pao* **1981**, *39*, 309-318. (b) Hui, Yongzheng; Gu, Jianhua; Jiang, Xikui *Ibid.* **1981**, *39*, 376-381. (c) Hui, Yongzheng; Cheng, Xianen; Gu, Jianhua; Jiang, Xikui *Scientia Sinica*, submitted for publication.