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Total Synthesis of a Monosubstituted Dodecahedrane. The Methyl Derivative

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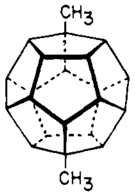
Abstract: Sequential photocyclization, dehydration, and diimide reduction of keto ester **5b** yielded the trisecododecahedryl ester **14**. This key intermediate was reduced in two steps to the aldehyde whose controlled irradiation at −78 °C led to installation of another framework carbon–carbon bond and formation of alcohol **17**. Oxidation of **17** gave ketone **18**, which underwent efficient excited-state homo-Norrish cyclization. With arrival at the monoseco alcohol **19**, dehydration to **20** was next effected. Attempts at direct acid-catalyzed cyclization of this olefin led predominantly to the "isododecahedrane" **21** whose structure was established by X-ray analysis. To bypass this complication, **20** was subjected to diimide reduction and resulting hydrocarbon **23** was dehydrogenated with a modified Pd–C catalyst. The structure of methyldodecahedrane (**6**) obtained in this manner was also confirmed by X-ray analysis. The aesthetically pleasing symmetry of the dodecahedral framework was clearly apparent. Since this present approach has the potential of serving as a general route to dodecahedranes, there is included a description of the manner in which Pōlya's theorem can be applied to the enumeration of substituted dodecahedrane isomers.

Two limitations make it impractical to exploit the availability of 1,16-dimethyldodecahedrane (**1**)[2] as a precursor to the monomethyl derivative or the parent $C_{20}H_{20}$ polyhedrane. Methyl group hydrogenolysis over nickel–alumina catalysts, a most useful and convenient technique developed by Schleyer and co-workers for the dealkylation of alkyladamantanes, diamantanes, and triamatanes,[3] has not proven feasible because of the quite low volatility of **1**. This property of the disubstituted dodecahedrane requires that significantly reduced pressures be applied to the flow apparatus in order to promote passage of the hydrocarbon into the hydrogen carrier gas, a condition that results in efficient catalyst deactivation.[4] The less direct approach involving oxidation of the methyl groups and ultimate decarbonylation or decarboxylation has not been considered seriously because of the presently unknown relative reactivity differences between the primary and two different tertiary carbon–hydrogen bonds in **1**. Additionally, our past difficulties in accomplishing the conversion of **2a** to **3** and failure in achieving the decarboxylation of **2b**[5] did not augur well. Furthermore, the entire synthetic sequence would be protracted by the inclusion of these proposed transformations.



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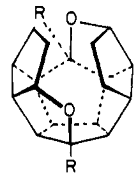
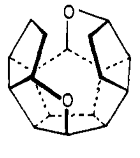


2a, R = CHO
b, R = COOOC(CH$_3$)$_3$



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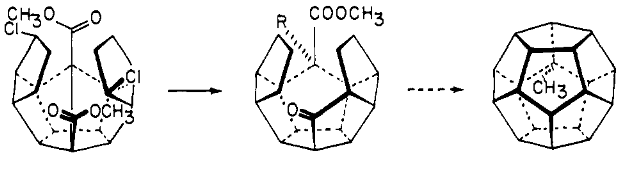
As a direct consequence of the preceding considerations and our continued determination to maintain the total number of requisite laboratory steps to a number not exceeding twenty (equivalent to the framework carbon atom count), we chose to modify the earlier serial synthesis that successfully delivered **1**. In an antecedent paper,[6] a critically important step involving the conversion of dichloro diester **4** into the monoalkylated keto ester **5a** was reported. Herein, we detail the preparation of methyldodecahedrane (**6**) from **5b**, an intermediate available in as few as ten steps from cyclopentadienide anion.[2,7]



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5a, R = CH$_2$CH$_2$Br
b, R = CH$_3$

6

Three structural features of **5b** are directly pertinent to our objectives. Firstly, its two functional groups differ suitably in their chemical reactivity. Secondly, the photochemically active ketone carbonyl, properly positioned with respect to geometry and distance relative to the transannular C–H bond,[8] was expected to undergo homo-Norrish cyclization without difficulty. Also, the endo stereochemistry of the carbomethoxy group should allow suitable incorporation of this carbon atom into the structural matrix, subsequent to proper adjustment of its oxidation level.

Reduction of **4** with 6 equiv of lithium metal in liquid ammonia at −78 °C followed by the addition of 1 equiv of methyl iodide immediately following fading of the blue color gave **5b** in 46% yield. Since the major accompanying product proved to be **7**, the question of possibly reversing this transannular process was briefly addressed. Attempts to trap the reverse aldol product by reaction with sodium hydride and methyl iodide led repeatedly to the O-alkylated derivative **8**. More satisfactorily, **7** underwent smooth reduction to diol **9a** upon treatment with Dibal-H and the primary hydroxyl function in this substance could be selectively monotosylated. Grob fragmentation of **9b** with potassium *tert*-butoxide provided the enone **10**, which was characterized by a typical exocyclic methylene pattern in the ^{1}H NMR spectrum and an infrared carbonyl stretch at 1730 cm^{-1}. Following cleavage of the transannular bond, the response of the carbonyl group in **10** returns to normal, its photoexcitation leading efficiently to the trisecododecahedryl alcohol **11**. Additional studies involving **11** are currently pending.

Upon irradiation of deoxygenated benzene–*tert*-butyl alcohol (4:1) solutions of **5b** with a 450-W Hanovia lamp, ring closure occurred smoothly to deliver **12** in essentially quantitative yield.

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[1] (a) The Ohio State University Fellow, 1977–1978. (b) Presidential Fellow, The Ohio State University, 1979–1980. (c) Individual responsible for the section dealing with Pōlya's theorem.

[2] (a) Paquette, L. A.; Balogh, D. W.; Usha, R.; Kountz, D.; Christoph, G. G. *Science* **1981**, *211*, 575. (b) Paquette, L. A.; Balogh, D. W. *J. Am. Chem. Soc.* **1982**, *104*, 774. (c) Christoph, G. G.; Engel, P.; Usha, R.; Balogh, D. W.; Paquette, L. A. *Ibid.* **1982**, *104*, 784. (d) Paquette, L. A.; Balogh, D. W. *Ibid.* **1981**, *103*, 228.

[3] (a) Grubmüller, P.; Schleyer, P. v. R.; McKervey, M. A. *Tetrahedron Lett.* **1979**, *181*. (b) Grubmüller, P.; Maier, W. F.; Schleyer, P. v. R.; McKervey, M. A.; Rooney, J. J. *Chem. Ber.* **1980**, *113*, 1989.

[4] Balogh, D. W., unpublished observations.

[5] Paquette, L. A.; Begley, W. J.; Balogh, D.; Wyvratt, M. J.; Bremner, D. *J. Org. Chem.* **1979**, *44*, 3630.

[6] Paquette, L. A.; Balogh; D. W.; Ternansky, R. J.; Begley, W. J.; Banwell, M. G. *J. Org. Chem.*, in press.

[7] Paquette, L. A. In "Organic Synthesis Today and Tomorrow"; Trost, B. M., Hutchinson, C. R., Eds.; Pergamon Press: New York, 1981; 335.

[8] Scheffer, J. R.; Dzakpasu, A. A. *J. Am. Chem. Soc.* **1978**, *100*, 2163.

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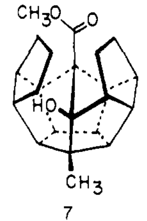

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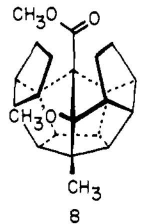

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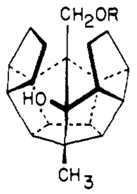
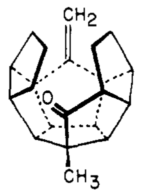


9a, R = H
b, R = Ts



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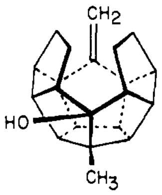

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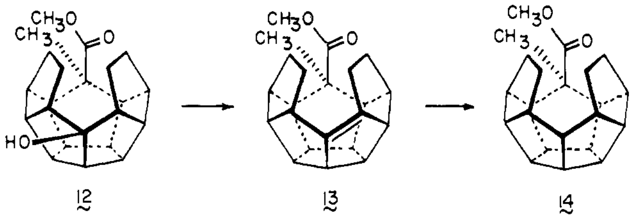
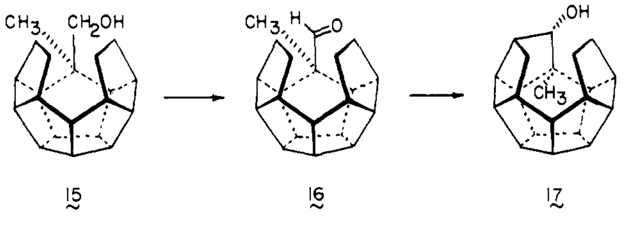
In practice, **12** was directly dehydrated with *p*-toluenesulfonic acid in refluxing benzene. As a consequence of the C_s symmetry of **12**, the only olefin produced was **13** (92% overall). Our past experience with molecules containing somewhat twisted double bonds of this type has shown that simple catalytic hydrogenation in a Paar apparatus is not an effective method of reduction.[2] Consequently, **13** was treated with diimide, as generated from hydrazine and hydrogen peroxide, and thereby converted to **14** with high efficiency. As expected from its symmetric nature, **14** is characterized by a simplified ^{13}C NMR spectrum consisting of only 14 lines.

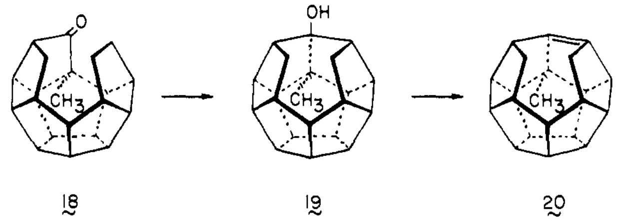


With arrival at **14**, construction of the front portion of the developing sphere (as drawn) is completed, and the carbomethoxy group remains as the lone oxygenated functionality. Its chemical manipulation posed no difficulties, despite its highly congested environment. Thus, reduction with diisobutylaluminum hydride in benzene gave rise to primary carbinol **15**, oxidation of which with pyridinium chlorochromate furnished **16**. Both steps were highly efficient.



It is now appropriate to point out that **16** is an aldehyde whose α position is fully substituted. Accordingly, this substance was expected on the basis of literature precedent to be subject to facile decarbonylation. In actuality, this untoward excited-state property proved rather difficult to surmount. After much trial experimentation, partial success was achieved by performing the irradiation of **16** in a 9:1 toluene–ethanol solvent system at −78 °C. Under these conditions, a single epimeric alcohol (**17**) was produced in 25% yield. Although the major byproduct proved to be the decarbonylated hydrocarbon, some photoreduction to **15** was also noted.

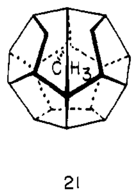
Indication that the photocyclization of **16** had proceeded to furnish the cyclopentanol **17** was gained by oxidation of **17** to ketone **18**. The intense 1710-cm^{-1} infrared band of this product conformed closely to our expectations for a cyclopentanone absorption. These gratifying results provided the opportunity to implement a third homo-Norrish carbon–carbon bond-forming step. It proved an easy matter to bring about clean-cut and complete transformation in the desired direction of **19**. The return to a molecule having a plane of symmetry was again accompanied by suitable simplification of its ^{13}C NMR spectrum. Removal of the tertiary hydroxyl group in **19** was achieved by acid-catalyzed dehydration as before. With the acquisition of **20**, we were now very close to our objective. It remained only to effect suitable isomerization of this olefin with installation of the final framework bond.



In this circumstance, it was natural to apply to **20** the same strongly acidic conditions that had previously resulted in the successful isomerization of a dimethyl derivative of the identical seco olefin ring system to 1,16-dimethyldodecahedrane (**1**).[2] Although the timing of the methyl migration relative to closure of the final framework bond in this prototypical example remains unknown, the complexity of the multistep process was fully appreciated. In the event, treatment of **20** with trifluoromethanesulfonic acid in dichloromethane as before resulted in rearrangement to a complex mixture of hydrocarbons in which **6** was clearly not dominant (capillary VPC analysis). By careful repeated recrystallization, the major constituent (55–60% of the volatile components) was obtained in a pure state and identified as the "isododecahedrane" **21** by ^1H NMR and X-ray crystal structure analysis.[9] A new C–C bond had indeed been formed, but perpendicular to that direction that would have given a dodecahedrane! Hydrocarbon **21** was found to consist of one external methyl group and 20 carbon atoms arranged in a cage framework of multiply fused five-membered rings.

Evidently, the very severe nonbonded interactions prevailing within **20** and the carbocations derived therefrom provide adequate steric driving force for transannular electrophiic attack at the unactivated methine carbon with *apparent* inversion of configuration. Carbonium ion **22** represents the shortest pathway to product.[10] However, this reaction course need not be favored relative to a multistep process, and the possible operation of any of a number of cationic rearrangement reactions has not been ruled out.

To eliminate this unwanted reaction channel and simultaneously realize a more generally applicable and universal approach to dodecahedrane ring construction, the fully saturated seco hydrocarbon **23** was prepared by diimide reduction of **20**. The removal of a molecule of hydrogen from the two opposed methylene groups in **23** should be highly favorable in an energetic sense, since a great deal of steric strain would be relieved. The use of catalytic dehydrogenation for the formation of carbon–carbon



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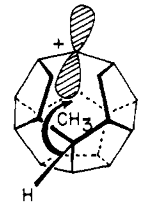

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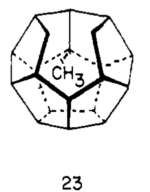

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[9] Kuhler, K. M.; Kountz, D. J.; Gallucci, J.; Christoph, G. G., manuscript in process.

[10] Kirchen, R. P.; Ranganayakulu, K.; Raouk, A.; Singh, B. P.; Sorensen, T. S. *J. Am. Chem. Soc.* **1981**, *103*, 588 and references cited therein.

bonds is a well-established process.[11] Although generally used for the formation of olefins, some examples of the use of this protocol in σ-bond-forming reactions are known.[11-13] It was our hope that this process could be applied to the task at hand.

When an intimate mixture of **23** and 10% palladium on carbon was heated in a sealed stainless steel reactor at 250 °C for 30 min, reaction occurred as judged by capillary gas chromatographic analysis. Among the products formed were several compounds that appeared to contain sites of unsaturation. Presumably, dehydrogenation had materialized by removal of hydrogen from the methine units. Repetition of the process under an atmosphere of argon did not alter the results.

It occurred to us at this point that it might be possible to suppress (or reverse) the olefin-forming process by performing the dehydrogenation under a hydrogen atmosphere. Indeed, success was realized upon heating (250 °C) an intimate mixture of **23** with 50 times its weight of 10% palladium on carbon, previously exposed to 50 psi of hydrogen, for 7 h in a sealed stainless steel chamber as before. Although capillary gas chromatography indicated that a variety of products had formed, the olefinic components earlier in evidence were now insignificant. From ^{1}H NMR analysis of the mixture, monomethyldodecahedrane (**6**) was determined to be present to the extent of 35–40%. By recrystallization of the reaction mixture from benzene, a 28% yield of **6** was realized.

Preliminary structural assignment to **6** was made on the basis of its high-resolution mass spectrum and ultrasimple ^{1}H NMR spectrum.[14] Additionally, the characteristic reluctance toward melting observed for **1** was witnessed with **6**. Ultimate confirmation was realized through X-ray crystal-structure analysis.[9] The topological features of methyldodecahedrane, though artistically delightful, are reassuringly unremarkable in their regularity and self-consistency; within experimental error, the molecule possesses C_{3v} point group symmetry in the crystal.

With the successful development of this synthetic protocol, additional derivatives are certain to be forthcoming, and the number of possible structural and optical isomers of substituted dodecahedranes will therefore soon be of interest to organic chemists. Because dodecahedrane possesses the highest possible point group symmetry, I_h, with 120 symmetry operations, the enumeration of isomers for its derivatives would be prohibitively difficult without resort to Pôlya's counting theorem,[15] which is based on the theory of permutation groups. Even these calculations are tedious, and it would be inefficient and unrealistic to expect individual organic chemists to repeat them. For these reasons, we present here the group theoretical derivation and the numbers of structural and optical isomers for substituted dodecahedranes containing up to four different functional groups as calculated from Pôlya's theorem:

Consider a set of n points and a group G, of order g, of permutations of these points. Let $g(i) = g(i_1,i_2,....,i_n)$ be the number of permutations of G that have the *cycle structure* $(i) = (1^{i_1}2^{i_2}...n^{i_n})$, i.e., may be represented as a product of disjoint cycles of which i_1 are of length 1, i_2 are of length 2, etc. The *cycle index* of G is

$$Z(G) = (1/g)\sum_{(i)} g(i) f_1^{i_1} f_2^{i_2} ... f_n^{i_n} \qquad (1)$$

where $f_1,f_2,....,f_n$ are functions to be specified; the sum in eq 1 extends over all values of i_1, i_2, ..., i_n for which $i_1 + 2i_2 + ... + ni_n = n$.

Table I. Numbers of Isomers for Substituted Dodecahedranes

molecular formula	number of isomers[a] N_{as}	N_{cs}	$N_S = N_{as} + N_{cs}$	$N_P = N_{as} + 2N_{cs}$
$C_{20}H_{20}$	1	0	1	1
$C_{20}H_{19}X_1$	1	0	1	1
$C_{20}H_{18}(X_1)_2$	4	1	5	6
$C_{20}H_{18}X_1X_2$	3	2	5	7
$C_{20}H_{17}(X_1)_3$	9	6	15	21
$C_{20}H_{17}(X_1)_2X_2$	11	23	34	57
$C_{20}H_{17}X_1X_2X_3$	6	54	60	114
$C_{20}H_{16}(X_1)_4$	20	38	58	96
$C_{20}H_{16}(X_1)_3X_2$	25	151	176	327
$C_{20}H_{16}(X_1)_2(X_2)_2$	41	233	274	507
$C_{20}H_{16}(X_1)_2X_2X_3$	27	471	498	969
$C_{20}H_{16}X_1X_2X_3X_4$	6	966	972	1938

[a] See the text for definitions of the symbols.

In the present application, the $n = 20$ points are the vertices of a regular dodecahedron representing the rigid carbon framework of $C_{20}H_{20}$, and G is a group of permutations of these vertices induced by operations of either of two point groups: the icosahedral group (I_h) of order 120 or the subgroup (I) of order 60 consisting of all proper rotations in I_h. The cycle indices for these two cases are[16]

$$Z(I_h) = (1/120)(f_1^{20} + 15f_1^4f_2^8 + 20f_1^2f_3^6 + 16f_2^{10} + 20f_2^1f_6^3 + 24f_5^4 + 24f_{10}^2) \qquad (2)$$

$$Z(I) = (1/60)(f_1^{20} + 20f_1^2f_3^6 + 15f_2^{10} + 24f_5^4) \qquad (3)$$

We now state Pôlya's theorem in a form sufficiently general for the present application. Substitution in the cycle index of eq 1 of

$$f_l = 1 + X_1^l + X_2^l + ... + X_{n-1}^l \quad (l = 1, 2, ..., n) \qquad (4)$$

yields a *generating function*, $C(G;X_1,X_2,....)$ which has the property (after expansion of C in powers of X_1, X_2, ...) that the *coefficient* $A_{k_1k_2...}$ of $X_1^{k_1}X_2^{k_2}...$ represents the number of configurations containing k_1 substituents X_1, k_2 substituents X_2, etc., no two of which can be superimposed by any of the permutations in G (and which thus represent inequivalent isomers under G).

Substitution of eq 4 into eq 2 yields the numbers, N_s, of *structural* isomers for substituted dodecahedranes, since optical isomers are superimposable by the improper operations contained in I_h and each *pair of enantiomers* is counted as a *single* structural isomer. On the other hand, optical isomers are *not* superimposable by any of the operations of the pure rotation group I, so that the generating function obtained by substitution of eq 4 into eq 3 counts each pair of enantiomers as *two* inequivalent isomers and yields the *total* number, N_p, of *positional* (i.e., structural *and* optical) isomers.[17]

It is then trivial to calculate, for each type of substitution, the number, $N_{cs} = N_p - N_s$, of *chiral* structural isomers (which is also the number of *enantiomeric pairs* of isomers) and the number,

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[11] Rylander, P. N. "Organic Synthesis with Noble Metal Catalysis"; Academic Press: New York, 1973; 28.

[12] Kazanskii, B. A.; Balenkova, E. S.; Khromov, S. I. *Russ. Chem. Rev.* (*Engl. Transl.*) **1967**, *36*, 866 and references cited therein.

[13] (a) Burns, W.; McKervey, M. A.; Mitchell, T. R. B.; Rooney, J. J. *J. Am. Chem. Soc.* **1978**, *100*, 906. (b) Crawford, M.; Supanekar, V. R. *J. Chem. Soc.* **1964**, 2380.

[14] Inadequate quantities of **6** were prepared to allow for ^{13}C NMR analysis.

[15] Reviews: (a) Harary, F.; Palmer, E. M.; Robinson, R. W.; Read, R. C. In "Chemical Applications of Graph Theory"; Balaban, A. T., Ed.; Academic Press: New York, 1976; pp 11–24. (b) de Boer, J.; Uhlenbeck, G. E. "Studies in Statistical Mechanics"; North-Holland: Amsterdam, 1962; Vol. 1, pp 167–181, 198–199.

[16] Schulman, J. M.; Venanzi, T.; Disch, R. L. *J. Am. Chem. Soc.* **1975**, *97*, 5335. Although these authors obtained eq 2 and 3, they give only a few illustrative isomer counts. Obtaining the cycle index is relatively simple when G is isomorphic with a point group, as the quantities $g(i)$ in eq 1 are then the orders (or sums of orders) of *classes* of the point group, which may be read from the character table of the point group. The coefficients of the terms within the parentheses on the right-hand side of eq 2 are the orders (or sums of orders) of the following classes of I_h: E, σ, C_3, $C_2 + i$, S_6, $C_5 + C_5^2$, and $S_{10} + S_{10}^3$, respectively. Similarly, the classes of I that contribute to the coefficients in eq 3 are E, C_3, C_2, and $C_5 + C_5^2$, respectively. The cycle structures of the permutations of G corresponding to operations in these classes are indicated by the exponents in eq 2 and 3, in accord with the discussion of eq 1.

[17] A systematic procedure for the separate enumeration of structural, optical, and geometrical isomers by means of Pôlya's theorem was first given by: Taylor, W. J. *J. Chem. Phys.* **1943**, *11*, 532.

$N_{as} = N_s - N_{cs}$, of *achiral* structural isomers. The isomer counts for substituted dodecahedranes obtained in this way are given in Table I. It can be seen that the number of chiral structural isomers is very large for tetrasubstituted dodecahedranes. However, an important theoretical application of Pôlya's theorem justifies carrying all such calculations through tetrasubstitution. The integrals required for ab initio molecular orbital calculations on dodecahedrane contain atomic orbitals (and for nuclear attraction integrals an operator) associated with a *maximum of four nuclei*. The number of distinct integrals of each kind (kinetic energy, nuclear attraction, and electron repulsion), involving given atomic orbitals and a given number of nuclei, are expressible in terms of the numbers of structural isomers for up to four different substituents.[18]

Experimental Section

Proton magnetic resonance spectra were obtained with Varian T-60, Varian EM-390, and Bruker WP-200 spectrometers except where indicated; apparent splittings are given in all cases. ^{13}C NMR spectra were recorded on Bruker WP-80, HX-90, and WM-300 spectrometers. Infrared spectra were recorded on a Perkin-Elmer Model 467 instrument. Mass spectra were determined on an AEI-MS9 spectrometer at an ionization potential of 70 eV. Elemental analyses were performed by the Scandinavian Microanalytical Laboratory, Herlev, Denmark.

Reductive Cyclization–Methylation of 4 with Lithium in Liquid Ammonia. To 60 mL of liquid ammonia (freshly distilled from sodium) cooled to −78 °C was added 40 mg (5.7 mmol) of lithium wire. After the lithium had dissolved, a solution of **4** (390 mg, 0.92 mmol) in anhydrous tetrahydrofuran (5 mL) was added dropwise until approximately 95% of the diester had been added. After 0.5 h at −78 °C, the remainder of **4** was added dropwise (the final addition should be discontinued at that point where the deep color begins to dissipate). A solution of methyl iodide (131 mg, 0.92 mmol) in 2 mL of dry tetrahydrofuran was immediately added in one portion. After 15 min, solid ammonium chloride (ca. 500 mg) was introduced, and the ammonia was evaporated under a stream of argon. The residue was added to dichloromethane (250 mL) and washed with water and brine. Concentration of the dried organic phase left a clear oil that was subjected to preparative TLC on silica gel (10% CH_2Cl_2–15% ether–75% hexane elution). Three bands were observed.

(a) $R_f = 0.6$—there was isolated 75 mg (24%) of **7**: mp 108–109 °C (from ethyl acetate); IR (KBr, cm^{-1}) 3480, 2950, 1700, 1190, and 1115; ^1H NMR ($CDCl_3$) δ 5.25 (s, 1 H), 3.60 (s, 3 H), 3.2–0.8 (series of m, 21 H), 1.15 (s, 3 H); ^{13}C NMR (ppm, $CDCl_3$) 178.71, 82.29, 60.88, 60.44, 59.52, 58.94, 58.36, 57.68, 57.04, 56.32, 51.46, 50.88, 49.47, 48.31, (2 C), 47.77, 32.77, 26.85, 26.02, 25.54, 24.22, 19.47; *m/e* calcd (M^+) 340.2038, obsd 340.2046.

Anal. Calcd for $C_{22}H_{28}O_3$: C, 77.61; H, 8.29. Found: C, 77.51; H, 8.30.

(b) $R_f = 0.3$—there was obtained 144 mg (46%) of **5b**: mp 141–142 °C (from ethyl acetate); IR (KBr, cm^{-1}) 2938, 1725, 1265, 1138, 1099; ^1H NMR ($CDCl_3$) δ 4.0–0.8 (series of m, 22 H), 3.60 (s, 3 H), 1.38 (s, 3 H); ^{13}C NMR (ppm, $CDCl_3$) 227.26, 176.83, 65.17, 59.29 (2 C), 59.16, 57.34, 56.37, 54.67, 54.01, 53.10, 52.73, 50.91, 50.67 (2 C), 38.89, 35.19, 30.94 (2 C), 30.34, 27.73 (22nd signal not observed and may overlap); *m/e* calcd (M^+) 340.2038, obsd 340.2047.

Anal. Calcd for $C_2H_{28}O_3$: C, 77.61; H, 8.29. Found: C, 77.40; H, 8.30.

(c) The material having an $R_f = 0.1$ (4.5 mg) was not identified.

Methyl Hexadecahydro-9-methoxy-8-methyl-1,4,8-metheno-dipentaleno[1,2,3-*cd*:1′,2′3′-*gh*]pentalene-4(1*H*)-carboxylate (8). Hydroxy ester **7** (50 mg, 0.154 mmol) was dissolved in 5 mL of dry benzene. Sodium hydride (10 mg oil free) was added along with 1 mL of methyl iodide. The mixture was heated at the reflux temperature for 24 h, cooled, quenched with water, and extracted with ether. Preparative TLC on silica gel (5% ether–hexane) separated **8** ($R_f = 0.25$) from unreacted **7** ($R_f = 0.2$). There was obtained 30 mg (56%, 90% on the basis of recovered **7**) of product: mp 178–180 °C (from ethyl acetate); IR (KBr, cm^{-1}) 2940, 1730, 1180, 1130, 1076; ^1H NMR ($CDCl_3$) δ 3.65–1.0 (m, 21 H), 3.60 (s, 3 H), 3.45 (s, 3 H), 1.16 (s, 3 H); ^{13}C NMR (ppm, $CDCl_3$) 175.21, 87.00, 62.00, 61.46 (2 C), 59.38, 58.55 (2 C), 57.58, 52.48, 50.93 (2 C), 50.05, 48.65, 48.40 (2 C), 32.77, 26.75 (2 C), 26.26, 25.83, 20.20 (23rd signal not observed and may overlap); *m/e* calcd (M^+) 354.2195, obsd 354.2203.

Anal. Calcd for $C_{23}H_{30}O_3$: C, 77.93; H, 8.53. Found: C, 77.84; H, 8.49.

Hexadecahydro-9-hydroxy-8-methyl-1,4,8-methenodipentaleno[1,2,3-*cd*:1′,2′,3′-*gh*]pentalene-4(1*H*)-methanol (9a). Hydroxy ester **7** (500 mg, 1.47 mmol) was dissolved in 20 mL of toluene and cooled to −78 °C. Diisobutylaluminum hydride (1 M in hexane, 3.7 mL, 3.7 mmol) was added and the mixture was warmed gradually to 25 °C. $LiAlH_4$ (50 mg) and $AlCl_3$ (60 mg) were added along with 10 mL of ether and the mixture was stirred for 60 h. The reaction mixture was quenched with water and extracted with dichloromethane. The combined organic extracts were washed with dilute hydrochloric acid, water, and brine and then dried. Upon removal of solvent, diol **9a** crystallized on standing. Recrystallization from ethyl acetate–ether gave a colorless solid: mp 133–135 °C; IR (KBr, cm^{-1}) 3400, 2900, 1383, 1122, 1038; ^1H NMR ($CDCl_3$) δ 4.14 ($^1/_2$ AB q, $J = 11$ Hz, 1 H), 3.78 ($^1/_2$ AB q, $J = 11$ Hz, 1 H), 2.9–0.9 (m, 23 H), 1.12 (s, 3 H); ^{13}C NMR (ppm, $CDCl_3$) 83.60, 62.97, 59.43, 58.72, 56.61, 56.17 (2 C), 56.00, 54.96, 54.59, 51.32, 50.22, 47.94, 47.87, 47.16, 28.33, 27.67, 27.31, 26.17, 25.39, 19.27; *m/e* calcd ($M^+ - H_2O$) 294.1985, obsd 294.1991.

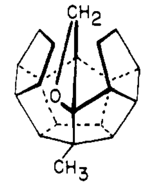
Anal. Calcd for $C_{21}H_{28}O_2$: C, 83.73; H, 9.03. Found: C, 80.84; H, 9.02.

Hexadecahydro-9-hydroxy-8-methyl-1,4,8-methenodipentaleno[1,2,3-*cd*:1′,2′,3′-*gh*]pentalene-4(1*H*)-methanol 4-(4-Methylbenzenesulfonate) (9b). Diol **9a** (500 mg, 1.6 mmol) was dissolved in pyridine (20 mL) and cooled to 0 °C. To this solution was added *p*-toluenesulfonyl chloride (610 mg, 3.2 mmol) and 4-(dimethylamino)pyridine (50 mg, 0.40 mmol). The mixture was allowed to stand at 0 °C for 3 days. Ice chips were added and the mixture was added to dichloromethane and washed with water (2x) and brine prior to drying. Solvent evaporation gave a clear oil that crystallized on standing. Filtration and drying afforded 702 mg (94%) of the purified tosylate: IR (KBr, cm^{-1}) 3538, 1355, 1173, 845, 665; ^1H NMR (C_5D_5N) δ 7.94 ($^1/_2$ AB q, $J_{AB} = 8$ Hz, 2 H), 7.26 ($^1/_2$ AB q, $J_{AB} = 8$ Hz, 2 H), 5.91 (s, 1 H), 4.78 ($^1/_2$ AB q, $J_{AB} = 10.5$ Hz, 1 H), 4.71 ($^1/_2$ AB q, $J_{AB} = 10.5$ Hz, 1 H), 3.2–0.7 (m, 21 H), 2.18 (s, 3 H), 1.18 (s, 3 H); *m/e* 294 (M^+ − TsOH).

Octadecahydro-3a-methyl-7-methylene-3*H*-cyclopenta[3,4]pentaleno-[2,1,6-*gha*]pentaleno[1,2,3-*cd*]pentalen-3-one (10). Hydroxy tosylate **9b** (300 mg, 0.67 mmol) was dissolved in 10 mL of *tert*-butyl alcohol and 2 mL of tetrahydrofuran with stirring under a nitrogen atmosphere. A 200-mg sample of potassium *tert*-butoxide was added and stirring was continued for 24 h. A fresh 100 mg of the alkoxide was introduced and after 5 h, the mixture was added to water (50 mL), and the products were extracted into ether (3 × 75 mL). The combined ether extracts were washed twice with water, dried, and concentrated to leave a clear oil. Preparative TLC purification on silica gel (elution with 10% ether–10% dichloromethane–80% hexane) gave two components.

(a) $R_f = 0.35$—85 mg (43%) of **10** as a colorless solid: IR (KBr, cm^{-1}) 1730, 1635, 887, 880; ^1H NMR ($CDCl_3$) δ 5.08 (br s, 1 H), 4.78 (br s, 1 H), 3.6–0.8 (series of m, 21 H), and 1.4 (s, 3 H); *m/e* calcd (M^+) 294.1983, obsd 294.1975.

(b) $R_f = 0.30$—66 mg (34%) of oxetane A was obtained: IR (KBr, cm^{-1}) 2930, 1450, 890, 880; ^1H NMR ($CDCl_3$) δ 4.80 ($^1/_2$AB q, $J = 6.0$ Hz, 1 H), 4.10 ($^1/_2$AB q, $J = 6.0$ Hz, 1 H), 3.2–0.8 (m, 21 H), 1.04 (s, 3 H); *m/e* calcd (M^+) 294.1984, obsd 294.1975.



A

Photocyclization of 10. A solution of **10** (200 mg, 0.68 mmol) in 10 mL of benzene–*tert*-butyl alcohol (4:1) was irradiated for 16 h through Pyrex with a 450-W Hanovia lamp at 10 °C. The evaporated reaction mixture was chromatographed on a silica gel plate (elution with 10% ether–10% dichloromethane–80% hexane). There was isolated a single major band at $R_f = 0.2$ identified as **11** (145 mg, 73%). The colorless oil crystallized on standing but was not further purified: ^1H NMR ($CDCl_3$) δ 4.84 (s, 2 H), 3.9–0.8 (series of m, 21 H), and 1.14 (s, 3 H); ^{13}C NMR (ppm, $CDCl_3$) 158.12, 110.35, 99.37, 67.96, 63.45, 61.85, 60.15, 56.07, 51.89, 29.71, 29.51, 26.70.

Methyl Octadecahydro-3b-hydroxy-7-methyl-1,6-methanocyclopenta-[3,4]pentaleno[2,1,6-*cde*]pentaleno[2,1,6-*gha*]pentalene-7-carboxylate (12). A solution of **5b**[5] (100 mg, 0.29 mmol) in 10 mL of a dry deoxygenated benzene–*tert*-butyl alcohol solvent system (4:1) was irradiated with a 450-W Hanovia lamp through Pyrex for 16 h under a nitrogen atmosphere. The resulting pale yellow solution was concentrated in vacuo to leave 100 mg of **12**, which although not further purified proved to be quite free of contaminats (TLC analysis); IR (KBr, cm^{-1}) 3512, 2940,

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(18) Taylor, W. J., unpublished work.

1715, 1263, 1132; *m/e* calcd (M^+) 340.2038, obsd 340.2046.

Methyl 1,1a,1b,2,2,3a,4,5,5a,6,6a,6b,6c,6d,6e,6f-Hexadecahydro-7-methyl-1,6-methanocyclopenta[3,4]pentaleno[2,1,6-*cde*]pentaleno[2,1,6-*gha*]pentalene-7-carboxylate (13). A solution of **12** (100 mg, 0.29 mmol) and *p*-toluenesulfonic acid (10 mg) in 15 mL of dry benzene was heated at the reflux temperature with continuous removal of water for 6 h. The benzene was evaporated in vacuo to leave a yellow oil that crystallized on standing. Preparative TLC purification on silica gel (elution with 15% ether in hexane) of this material afforded 86 mg (92%) of **13**: mp 133–135 °C (from hexane); IR (KBr, cm^{-1}) 2940, 2875, 1728, 1254, 1128; ^1H NMR ($CDCl_3$) δ 4.1–0.8 (series of m, 20 H), 3.68 (s, 3 H), 1.40 (s, 3 H); ^{13}C NMR ($CDCl_3$, ppm) 177.30, 140.30, 136.95, 72.38, 69.61, 63.45, 63.11, 62.72, 59.47, 58.74, 57.38, 52.52, 50.87, 48.93, 48.50, 46.89, 41.07, 30.29, 28.59, 28.10, 24.22; *m/e* calcd (M^+) 322.1933, obsd 322.1941.

Methyl Octadecahydro-7-methyl-1,6-methanocyclopenta[3,4]pentaleno[2,1,6-*cde*]pentaleno[2,1,6-*gha*]pentalene-7-carboxylate (14). To a cold (0 °C) solution of **13** (100 mg, 0.31 mmol) in 10 mL of an ethanol–tetrahydrofuran mixture (5:1) was added anhydrous hydrazine (97%, 600 μL). Hydrogen peroxide (30%, 2.14 mL) was introduced dropwise to the cooled reaction mixture over a period of 45 min with stirring. After 2 h at 0 °C and 12 h at 25 °C, the solution was poured into dichloromethane and was washed with water (2x) and brine. Drying of the organic phase and solvent evaporation afforded 100 mg of a semicrystalline solid which was purified by TLC on silica gel (10% dichloromethane–20% ether–70% hexane elution). Pure **14** was obtained as a colorless solid: mp 155–156.5 °C (from ethyl acetate); IR (KBr, cm^{-1}) 2925, 1730, 1261, 1106; ^1H NMR ($CDCl_3$) δ 4.2–0.8 (series of m, 22 H), 3.68 (s, 3 H), 1.34 (s, 3 H); ^{13}C NMR ($CDCl_3$, ppm) 177.39, 70.39, 66.51, 64.27, 59.66, 58.25, 57.19, 52.91, 50.92, 50.73, 49.66, 39.17, 31.07, 30.44; *m/e* calcd (M^+) 324,2089, obsd 324.2097.

Anal. Calcd for $C_{22}H_{28}O_2$: C, 81.44; H, 8.70. Found: C, 81.50; H, 8.67.

Octadecahydro-7-methyl-1,6-methanocyclopenta[3,4]pentaleno[2,1,6-*cde*]pentaleno[2,1,6-*gha*]pentalene-7-methanol (15). A solution of **14** (180 mg, 0.56 mmol) in anhydrous benzene (10 mL) was stirred at room temperature while diisobutylaluminum hydride (2 mL of 1 M in hexane, 2.0 mmol) was introduced. The reaction mixture was stirred at 25 °C for 13 h under argon, treated dropwise with methanol to destroy excess hydride, and poured into dichloromethane (50 mL). The organic layer was washed with dilute hydrochloric acid, saturated sodium bicarbonate solution, water, and brine prior to drying.

Octadecahydro-7-methyl-1,6-methanocyclopenta[3,4]pentaleno[2,1,6-*cde*]pentaleno[2,1,6-*gha*]pentalene-7-carboxaldehyde (16). A solution of **15** (160 mg, 0.54 mmol) in 1 mL of dichloromethane was added to a suspension of pyridinium chlorochromate (200 mg, 0.93 mmol) in 5 mL of the same solvent with stirring under argon. After 1.5 h, ether was added and the organic layer was decanted. The residual salts were washed with ether (2x) and the combined organic solutions were washed with dilute hydrochloric acid, saturated sodium bicarbonate solution, water, and brine. Following drying and solvent evaporation, there was obtained 160 mg (100%) of **16** as a clear oil that crystallized on standing. Recrystallization from ethyl acetate at −10 °C gave pure **16** as white crystals: mp 173–176 °C; IR (KBr, cm^{-1}) 2920, 1710, 1445; ^1H NMR ($CDCl_3$) δ 9.92 (s, 1 H), 4.0–0.6 (series of m, 20 H), 1.16 (s, 3 H); ^{13}C NMR ($CDCl_3$, ppm) 204.33, 70.21, 66.94, 64.75, 59.17, 57.59, 57.17, 52.61, 50.31, 49.88, 34.77, 31.50, 30.52; *m/e* calcd (M^+) 294.1984, obsd 294.1991.

Octadecahydro-7f-methyl-1,6,7-metheno-2*H*-cyclopenta[3,4]pentaleno[2,1,6-*gha*]pentaleno[1,2,3-*cd*]pentalen-2-one (18). A cold (−78 °C) solution of **16** (150 mg, 10.51 mmol) in 10 mL of a deoxygenated 9:1 toluene–ethanol solvent system was irradiated under nitrogen with a 450-W Hanovia lamp through Pyrex. After a 4-h reaction period, the solution was allowed to warm to 25 °C, and the solvent was removed under reduced pressure. Preparative TLC on silica gel (elution with 10% dichloromethane–15% ether–75% hexane) gave three bands. The major band (R_f = 0.8) was a mixture of decarbonylated materials (60 mg) which were not characterized. The R_f = 0.4 band comprised alcohol **17** (38 mg, 25%), a colorless crystalline solid: IR (KBr, cm^{-1}) 3425 and 2920; ^1H NMR ($CDCl_3$) δ 4.11 (d, *J* = 6.2 Hz, 1 H), 4.0–0.8 (series of m, 22 H), 1.21 (s, 3 H); *m/e* calcd (M^+) 294.1984, obsd 294.1991. The R_f = 0.3 band proved to be alcohol **15** (30 mg, 22%).

The alcohol **17** (38 mg, 0.12 mmol) dissolved in dichloromethane (1 mL) was added under argon to a stirred suspension of pyridinium chlorochromate (35 mg, 0.16 mmol) in 5 mL of the same solvent. After 2.5 h, ether (15 mL) was added and the organic phase was decanted. The residual brown salts were triturated with ether (2x) and the combined solutions were washed with dilute hydrochloric acid, saturated sodium bicarbonate solution, water, and brine prior to drying and solvent evaporation. There was obtained 37 mg (98%) of **18** as a pale yellow oil. The pure sample was obtained by preparative TLC on silica gel (elution with 10% ether in hexane) and sublimation at 125 °C and 0.1 mm. The colorless crystals gradually decomposed when heated above 180 °C with softening occurring at ~255 °C; IR (KBr, cm^{-1}) 2920, 1710, 1445; ^1H NMR ($CDCl_3$) δ 4.1–1.0 (series of m, 21 H), 1.21 (s, 3 H); ^{13}C NMR ($CDCl_3$, ppm) 229.76, 69.36, 68.15, 67.97, 67.72, 67.12, 65.66, 65.12, 62.93, 61.60, 59.35, 58.74, 53.34, 52.01, 51.83, 51.10, 49.94, 36.72, 34.10, 30.65, 27.92; *m/e* calcd (M^+) 292.1827, obsd 292.1809.

1,1a,1b,2,3,3a,4,5,5a,6,6a,6b,6c,6d,6e,6f-Hexadecahydro-7-methyl-1,6,2,5-ethanediylidenecyclopenta[3,4]pentalen[2,1,6-*cde*]pentaleno[2,1,6-*gha*]pentalene (20). A solution of **18** (37 mg, 0.13 mmol) in 3 mL of a benzene–*tert*-butyl alcohol solvent system (4:1) was irradiated with a 450-W Hanovia lamp for 16 h through Pyrex under a nitrogen atmosphere. The solvent was removed in vacuo to give **19** as a pale yellow oil (37 mg) which was crystallized on standing. This material was taken up in benzene (5 mL), a crystal of *p*-toluenesulfonic acid was added, and the mixture was heated at the reflux temperature for 3 h. The cooled solution was evaporated and the residue was subjected to TLC purification on silica gel (elution with 5% dichloromethane in hexane). There was isolated 30 mg (84%) of **20** which could be recrystallized from hexane. The colorless crystals did not give evidence of melting, but gradually decomposed between 270–350 °C (accompanied by some sublimation): IR (KBr, cm^{-1}) 3011, 2920, 2841; ^1H NMR ($CDCl_3$) δ 3.9–0.9 (series of m, 19 H), 1.24 (s, 3H); ^{13}C NMR ($CDCl_3$, ppm) 145.94, 140.02, 78.16, 67.43, 66.95, 66.61, 65.83, 65.69, 63.99, 63.79, 61.85, 60.54, 59.33, 52.72, 52.04, 51.02, 47.00, 33.16, 30.34, 25.56, 15.29; *m/e* calcd (M^+) 274.1721, obsd 274.1730.

Hexadecahydro-6d-methyl-1*H*-1,6,2,3b,5-[1]ethanyliden[2]ylidynecyclopenta[3,4]pentaleno[2,1,6-*cde*]pentaleno[2,1,6-*gha*]pentalene (21). To a stirred solution of **20** (20 mg, 0.07 mmol) in dichloromethane (5 mL) was added 5 drops of trifluoromethanesulfonic acid. This mixture was stirred at 25 °C under nitrogen for 30 min, treated with water (1 mL), and extracted with dichloromethane. The organic phase was washed with water, saturated sodium bicarbonate solution, and brine prior to drying and concentration. Sublimation of the semicrystalline residue at 200 °C (1 mm) followed by preparative VPC (5% SE-30, 250 °C) afforded two fractions. The more volatile fraction proved to be **21** (57% of the volatile components), which was recrystallized from hexane. The colorless crystals did not give evidence of melting (capillary sealed under vacuum), but gradually decomposed between 290–360 °C accompanied by sublimation: IR (KBr, cm^{-1}) 2970, 2930, 2850; ^1H NMR ($CDCl_3$) δ 3.23 (m, 2 H), 2.78 (m, 5 H), 2.42 (m, 4 H)8 2.13 (m, 4 H), 1.78 (t, *J* = 1.75 Hz, 1 H), 1.73 (t, *J* = 1.75 Hz, 1 H), 1.25 (t, *J* = 1.75 Hz, 1 H), 1.19 (t, *J* = 1.75 Hz, 1 H), 1.07 (s, 3 H); ^{13}C NMR ($CDCl_3$, ppm) 67.87, 65.50, 63.27, 62.15, 58.56, 51.04, 48.76, 45.59, 34.48, 25.06 (3 signals not observed); *m/e* calcd (M^+) 274.1721, obsd 274.1730.

Octadecahydro-7-methyl-1,6,2,5-ethanediylidenecyclopenta[3,4]pentaleno[2,1,6-*cde*]pentaleno[2,1,6-*gha*]pentalene (23). To a cold (0 °C) solution of **20** (10 mg, 0.04 mmol) in 5 mL of an ethanol–tetrahydrofuran mixture (5:1) was added anhydrous hydrazine (95%, 195 μL). Hydrogen peroxide (30%, 660 μL) was introduced dropwise to the cooled reaction mixture over a period of 30 min with stirring. Following the addition, the reaction mixture was allowed to warm to 25 °C and stirring was maintained overnight. The reaction mixture was diluted with dichloromethane and washed with water (2x) and brine. Drying of the organic phase and solvent evaporation followed by filtration through silica gel (hexane elution) afforded 10 mg (100%) of **23** as a crystalline solid. Recrystallization from hexane gave pure product: mp (sealed, evacuated capillary) no melting—slight decomposition 241–243.5 °C accompanied by sublimation; IR (CCl_4, cm^{-1}) 3020, 2930, 2850; ^1H NMR ($CDCl_3$) δ 3.47–2.92 (series of m, 16 H), 2.70–2.48 (m, 3 H), 1.58–1.46 (m, 2 H), 1.16 (s, 3 H); ^{13}C NMR ($CDCl_3$, ppm) 69.96, 69.23, 68.21, 66.12, 65.98, 62.14, 58.94, 52.87, 52.38, 50.05, 33.74, 32.33 (1 signal not observed); *m/e* calcd (M^+) 276.1878, obsd 276.1886.

Methyldodecahedrane (6). An intimate mixture of **23** (2 mg, 0.007 mmol) and 10% palladium on carbon (ca. 100 mg) was placed in a stainless steel reactor and flushed with argon. The catalyst bed was then saturated with hydrogen gas (50 psi) and the reactor sealed. The reaction vessel was lowered into a molten salt bath maintained at 250 °C. After 7 h, the reactor was removed and allowed to cool. The reaction mixture was removed and placed on a short silica gel column. Elution with hexane gave the product mixture (2 mg) that contained 35–40% of **6** (^1H NMR analysis). A total of 4.5 mg of **23** was treated in this way. From the combined reaction mixtures, 1.2 mg of **6** (28%) was obtained by crystallization from benzene: mp >450 °C (sealed, evacuated capillary; darkening occurs above 210 °C with some sublimation); IR (KBr, cm^{-1}) 2940, 1295, 735; ^1H NMR ($CDCl_3$) δ 3.38 (br s, 16 H), 2.92 (narrow m, 3 H), 1.14 (s, 3 H); *m/e* calcd (M^+) 274.1721, obsd 274.1730.

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Registry No. **4**, 71342-50-2; **5b**, 82390-84-9; **6**, 86289-31-8; **7**, 80317-84-6; **8**, 86289-32-9; **9a**, 86289-33-0; **9b**, 86289-34-1; **10**, 86289-35-2; **11**, 86307-78-0; **12**, 82390-85-0; **13**, 86289-36-3; **14**, 82390-86-1; **15**, 86289-37-4; **16**, 82390-87-2; **17**, 86289-38-5; **18**, 82390-88-3; **19**, 86289-39-6; **20**, 82390-89-4; **21**, 82390-90-7; **23**, 82390-91-8; A, 86307-79-1.

Total Synthesis of Dodecahedrane

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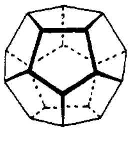
Abstract: The chemical transliteration of Plato's universe—the dodecahedrane—has been synthesized in 23 steps. The key stages of the sequence starting from dichloro diester **2** involve the following: (a) reduction–monoalkylation of **2** using chloromethyl phenyl ether to give **7**; (b) photocyclization of aldehyde **12** without interference from the geminal side chain; (c) retro-aldol cleavage of keto aldehyde **15**; and (d) catalytic dehydrogenation of **19**. The single-peak nature of the ^{1}H and ^{13}C NMR spectra of **1** conforms to its ultrahigh (I_h) symmetry. The spherical hydrocarbon exhibits three infrared-active and eight Raman-active bands. The unique physical behavior of **1** upon heating to temperatures above 400 °C is detailed.

For centuries, the dodecahedron has been esteemed as the most complex and aesthetically pleasing of the perfect solids of antiquity. In more recent times, scientists have come to regard its molecular transliteration, dodecahedrane ($C_{20}H_{20}$, **1**), as the "Mount Everest of Alicyclic Chemistry".[3] Thus, history did early place before any interested organic chemist the formidable challenge of synthesizing a uniquely symmetric (I_h) hydrocarbon composed exclusively of (12) five-membered rings whose construction could hardly fail to excite interest and curiosity. The problem of defining suitable synthetic protocols for arrival at **1**, which was first given attention 20 years ago in Woodward's laboratory,[4,5] has only recently been successfully resolved at Ohio State.[6,7] Herein, we provide details of the manner in which this achievement was realized.



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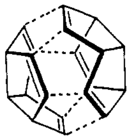
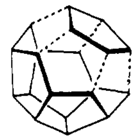
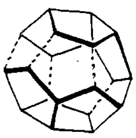
From the first, we looked upon any *convergent* approach to dodecahedrane as plagued with the onerous burden of properly aligning the pair of structural components involved. This complication is most acute when two unconnected segments must be properly conjoined as in the dimerization of triquinacene (A)[4] or the "capping" of peristylane (B).[8] However, highly disadvantageous steric and entropic factors persist subsequent to installation of an interconnective C–C bond as in C.[9,10] Thus, *x*-ray analysis has clearly revealed the two triquinane rings in *dl*- and *meso*-bivalvane to be as mutually distal as possible.[11]



A



B



C

Consequently, our design was to employ a *serial* synthesis that, however, would be significantly abbreviated by taking advantage of the enormous symmetry of the target molecule. Indeed, it was our original intent to arrive at **1** by deploying individual laboratory steps fewer than or equal to the number of constituent carbon atoms. Relevantly, certain restrictions exist on the symmetry level of the intermediates. While planar symmetric (i.e., C_s) and twofold axially symmetric (i.e., C_2) molecules were considered quite serviceable,[12] adherence to threefold axial symmetry must deliver a C_{19} precursor and ultimately require introduction of a discrete "CH" unit.[13] Consequently, we opted for the direct construction of C_{20} precursors to **1** that fulfill the first set of criteria.

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(10) For other examples of this line of reasoning, consult: (a) Repic, O. Ph.D. Dissertation, Harvard University, 1976. (b) Deslongchamps, P.; Soucy, P. *Tetrahedron* **1981**, *37*, 4385. (c) Roberts, W. P.; Shoham, G. *Tetrahedron Lett.* **1981**, 4895. (d) McKervey, M. A.; Vibuljan, P.; Ferguson, G.; Siew, P. Y. *J. Chem. Soc., Chem. Commun.* **1981**, 912.

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(12) Along this line of reasoning, C_{2v} structures would also be admissible to a point. Once a reasonably advanced stage of framework construction had been maintained, one would be forced to lower the symmetry level in order to arrive ultimately at the I_h species in question.

(13) A molecule that could be adapted to this protocol is C_{16}-hexaquinacene [Paquette, L. A.; Snow, R. A.; Muthard, J. L.; Cynkowski, T. *J. Am. Chem. Soc.* **1978**, *100*, 1600; **1979**, *101*, 6991]. However, various schemes to rapidly lessen the symmetry level of certain derived intermediates have also been given attention [Osborn, M. E.; Kuroda, S.; Muthard, J. L.; Kramer, J. D.; Engel, P.; Paquette, L. A. *J. Org. Chem.* **1981**, *46*, 3379]. Also, Professor Jack Baldwin (Oxford University) has recently informed us of an approach being developed in his laboratory to access **1** via intermediates having threefold axial symmetry.