Oxidative Elimination of 2-(2-Pyridylseleno)heptan-1-al. General Procedure for Oxidation by Sodium Metaperiodate. To a solution of 2-(2-pyridylseleno)heptan-1-al (0.27 g, 1.0 mmol) in methanol (12 mL) was added a solution of sodium metaperiodate (0.43 g, 2.0 mmol) in water (2 mL) at room temperature. The resulting white turbid mixture was stirred for 1 h. After the addition of saturated aqueous $NaHCO_3$ (30 mL), the products were extracted with $CHCl_3$ (20 mL × 3). GLC analysis of the organic layer using *p*-methylanisole as an internal standard showed the presence of *trans*-2-hepten-1-al; 0.90 mmol, 90%.

Oxidative elimination of 2-(2-pyridylseleno)-3-methylbutanal was carried out in the same way at 40 °C.

All of the enones thus prepared are either commercially available or reported compounds.[11]

Acknowledgment. This work was supported in part by the Grant-in-Aid for Special Project Research by the Ministry of Education, Japan.

Registry No. **1**, 82998-12-7; (*cis*)-**2**, 91491-57-5; (*trans*)-**2**, 91491-58-6; **3**, 91491-59-7; **4**, 6610-21-5; **5**, 1121-18-2; selenium, 7782-49-2; 2-bromopyridine, 109-04-6; 2,2′-dipyridyl diselenide, 59957-75-4; 2-pyridylselenenyl bromide, 91491-61-1; 2-pyridylselenenyl chloride, 82998-10-5; cyclooctanone, 502-49-8; 2-(2-pyridylseleno)cyclooctanone, 82998-14-9; cyclododecanone, 830-13-7; 2-(2-pyridylseleno)cyclododecanone, 91491-56-4; cycloheptanone, 502-42-1; 2-(2-pyridylseleno)cycloheptanone, 82998-13-8; 2-(2-pyridylseleno)cyclopentanone, 82998-11-6; cyclopentanone, 120-92-3; cyclohexanone, 108-94-1; 2-(2-pyridylseleno)propiophenone, 82998-15-0; propiophenone, 93-55-0; 2-methylcyclohexanone, 583-60-8; 2-(2-pyridylseleno)heptan-1-al, 82998-17-2; heptan-1-al, 111-71-7; 3-phenyl-2-(2-pyridylseleno)propan-1-al, 82998-16-1; 3-phenylpropan-1-al, 104-53-0; 3-methyl-2-(2-pyridylseleno)butan-1-al, 91491-60-0; 3-methylbutan-1-al, 590-86-3; 2-cyclooctenone, 1728-25-2; *trans*-2-hepten-1-al, 18829-55-5; 2-cyclopentenone, 930-30-3; 2-cyclohexenone, 930-68-7; 2-cycloheptenone, 1121-66-0; 2-cyclododecenone, 42858-38-8; 1-phenyl-2-propen-1-one, 768-03-6; *trans*-3-phenyl-2-propen-1-al, 14371-10-9; 3-methyl-2-buten-1-al, 107-86-8.

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[11] Cyclopentenone, cyclohexenone, *trans*-2-hepten-1-al, *trans*-3-phenyl-2-propen-1-al, and 3-methyl-2-buten-1-al are commercially available. References for spectral data and/or preparation procedure of reported compounds are as follows: 2-cycloheptenone, 2-cyclooctenone, *trans*-2-cyclododecenone, 1-phenyl-2-propen-1-one, and 6-methyl-2-cyclohexenone, ref 8; 2-methyl-2-cyclohexenone, Warnhoff, E. W.; Martin, D. G.; Johnson, W. S. "Organic Syntheses"; Wiley: New York, 1963; Collect. Vol. IV, pp 162–166; 2-methylenecyclohexanone, Ksander, G. M.; McMurry, J. E.; Johnson, M. *J. Org. Chem.* **1977**, *42*, 1180–1185.

Conformational Analysis of Tricyclo[7.3.1.0^{5,13}]tridecane (Perhydrophenalene) by Molecular Mechanics

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Molecular mechanics were used to calculate the steric energy of the stable conformations of *trans,trans,trans-*, *cis,cis,trans-*, *cis,trans,trans-*, and *cis,cis,cis*-tricyclo[7.3.1.0^{5,13}]tridecane (perhydrophenalene). The pseudorotation of the flexible forms is studied with idealized models and compared with the results from the force field calculations.

Fused ring systems are of considerable interest to organic chemists because of their widespread occurrence in saturated products and as models for conformational studies. Conformational analysis of a variety of bicyclic systems has been examined in detail, but related studies upon fused tricarbocyclic systems have hitherto concentrated upon perhydrophenanthrene[1] and perhydroanthracene.[2-4]

The tricyclo[7.3.1.0^{5,13}]tridecanes (perhydrophenalenes) have attracted little attention and the available information about the stability of the different forms is scarce. In an early study by Schneider et al.,[5] aluminum halide catalyzed isomerization of perhydrofluorene at 0 °C gives one compound, perhydrophenalene, with all trans ring fusions. Equilibrium constants and compositions of perhydroanthracene and the most stable methylperhydrophenalenes were estimated.[6]

Reaction of the cis,cis isomer of perhydro-13-boraphenalene with potassium cyanide and then trifluoroacetic anhydride, followed by oxidation gives *trans,trans,trans*-perhydrophenalen-13-ol,[7] whereas carbonylation–oxidation yields the all cis isomer.[8]

Starting from spiro[cyclohexanone-2,4′-cyclohex-2′-en]-1′-one, Seshu Sekhara Rao et al.[9] synthesized perhydrophenalene-2,6-dione, which they assumed to be in the all trans configuration.

The steric energy of the four possible isomers of 13-methylperhydrophenalene were calculated by Gund and Gund[10] by using Boyd's program.[11] Assuming a printing error for the cis,cis,trans form,[12] the energy sequence is trans,trans,trans < cis,cis,trans < cis,cis,cis = cis,trans,-trans.

Interest in the conformations of perhydrophenalene arises out of work carried out in this laboratory[13] on syn-

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[1] Allinger, N. L.; Gordon, B. J.; Tyminsky, I. J.; Wuesthoff, M. T. *J. Org. Chem.* **1971**, *36*, 739.

[2] Allinger, N. L.; Wuesthoff, M. T. *J. Org. Chem.* **1971**, *36*, 2051.

[3] Vanhee, P.; van de Graaf, B.; Baas, J. M. A.; Tavernier, D. *Tetrahedron Lett.* **1982**, *23*, 3837.

[4] Vanhee, P.; van de Graaf, B.; Tavernier, D.; Baas, J. M. A. *J. Org. Chem.* **1983**, *48*, 648.

[5] Schneider, A.; Warren, R. W.; Janoski, E. J. *J. Am. Chem. Soc.* **1964**, *86*, 5365.

[6] Schneider, A.; Warren, R. W.; Janoski, E. J. *J. Org. Chem.* **1966**, *31*, 1617.

[7] Pelter, A.; Maddocks, P. J.; Smith, K. *J. Chem. Soc., Chem. Commun.* **1978**, 805.

[8] Brown, H. C.; Dickason, W. C. *J. Am. Chem. Soc.* **1969**, *91*, 1226.

[9] Seshu Sekhara Rao, C.; Rajagopalan, K.; Swaminathau, S. *Tetrahedron* **1982**, *38*, 2195.

[10] Gund, P.; Gund, T. M. *J. Am. Chem. Soc.* **1981**, *103*, 4458.

[11] Boyd, R. H.; Breitling, S. M.; Mansfield, M. *AIChE J.* **1973**, *19*, 1016.

[12] The energy for this form is probably 20.9 kcal/mol rather than 30.9.

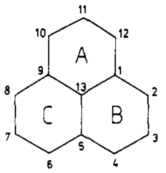

Figure 1. Numbering of atoms and specification of the rings in perhydrophenalene.

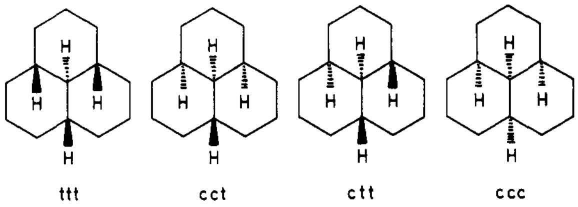

Figure 2. Schematic view on the four configurations of perhydrophenalene: trans,trans,trans, cis,cis,trans, cis,trans,trans, and cis,cis,cis.

thetic routes to perhydrobenzo[4.5.6]cholest-4-enes, in which rings A, B, and E constitute a perhydrophenalene moiety. In order to understand the conformational behavior of these steroids, a molecular mechanics study on the conformations of the perhydrophenalene skeleton was performed.

Specification of Conformations. Interring relationships are specified by the positions of the hydrogen atoms attached to the carbon atoms, and are denoted cis or trans according to the usual conventions. With the numbering of atoms given in Figure 1, ring junctions are denoted clockwise starting from bond C(9)–C(13). Four distinct configurations of perhydrophenalene are thus possible (Figure 2), referred to in this paper as trans,trans,trans (ttt), cis,cis,trans (cct), cis,trans,trans (ctt), and cis,cis,cis (ccc).

It is well-known that two separate conformations are possible for a single six-membered ring: the rigid chair (C) and the flexible boat manifold (B).

For perhydrophenalene, the conformations of the individual rings are denoted in the sequence A–B–C (see Figure 1). Thus (*ctt*)-BCB-perhydrophenalene is the cis,trans,trans form with rings A, B, and C in a boat, chair, and boat conformation, respectively.

Geometrical Considerations. Before the presentation of the calculated results from molecular mechanics, it is worthwhile to consider the conformations of perhydrophenalene on the basis of idealized framework models with undeformable bond lengths and valence angles.

From this idealized model, it is intuitively seen that the lowest energy form of each configuration will have as many rings as possible in a chair conformation. At least one ring must attain a boat-like conformation in the cis,trans,trans and all cis forms (see Figure 3).

It is also seen that the flexibility of the ring system increases with the number of cis ring junctions, if more than one ring is in a boat conformation. Maximum flexibility is thus achieved in the all boat ccc form, and decreases in the corresponding cct, ctt, and ttt forms. Only the former can undergo complete pseudorotation without deformation of the individual rings. From the model, it is seen that this pseudorotation consists of a simultaneous movement of the three rings and that the system has only one degree of freedom. A relationship between the pseudorotation phases of the individual rings can easily be derived.

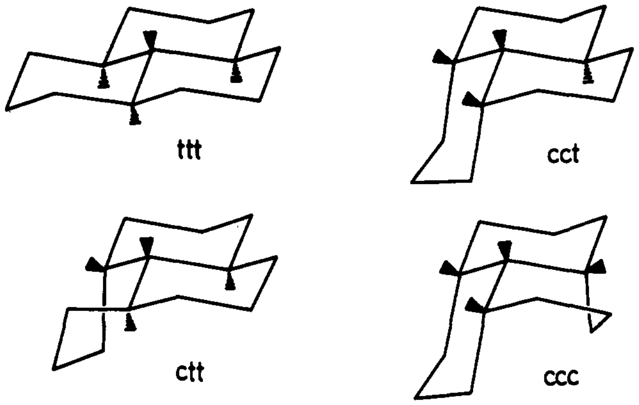

Figure 3. The lowest energy conformation for each configuration.

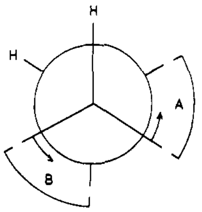

Figure 4. Projection of a central bond with a cis ring coupling.

From Figure 4, it is seen that it is possible to write for a cis ring coupling that $\omega_i(\mathrm{A}) = \omega_j(\mathrm{B})$, where i and j are the numbers of the torsion angles ω_i and ω_j in rings A and B, respectively. Three of these equations can be written for perhydrophenalene.

The empirical formula found by Buys and Geise[14] gives a relationship between the torsion angles (ω_k) and the pseudorotation phase (ϕ) of boatlike conformations of a six-membered ring. Substituting this information in the three mentioned equations, it is easily found that the total pseudorotation of the ccc form is described by

$$\psi = \phi_{\mathrm{A}} = \phi_{\mathrm{B}} + 2\pi/3 = \phi_{\mathrm{C}} + 4\pi/3 \tag{1}$$

Equation 1 uniquely describes the relationship between the pseudorotation of the three rings. It is seen that the rings pseudorotate with the same "frequency" but with a different starting phase. ϕ can have all values between 0 and 2π.

Things become more complicated, if one of the rings is in a chair conformation, or if a trans ring junction is present in the system. For two cis coupled rings in a boat conformation, it is possible to write with the above strategy, that

$$\phi_{\mathrm{A}} = \pm\phi_{\mathrm{B}} + \xi \tag{2}$$

where ξ is a constant, depending on the nature of the ring junctions with ring C and on the conformation of this ring. In general, the range of the pseudorotation phase will be limited. In the BB form of *cis*-decalin, where both rings are equivalent and no third ring exists, eq 2 reduces to $\phi_{\mathrm{A}} = \pm\phi_{\mathrm{B}}$, a result derived by Baas et al.,[15] starting from different considerations.

Computational Results and Discussion. All calculations are performed with Allinger's MM2 force field[16] and the program devised by the same author.[17] The puckering, Q, and the pseudorotation phase of the six-membered rings are calculated as defined by Cremer and Pople.[18] The

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(13) Bull, J. R.; Steer, L. M.; van Rooyen, P. H. *J. Chem. Soc., Perkin Trans. 1*, submitted for publication.

(14) Buys, H. R.; Geise, H. J. *Tetrahedron Lett.* **1968**, *54*, 5619.

(15) Baas, J. M. A.; van de Graaf, B.; Tavernier, D.; Vanhee, P. *J. Am. Chem. Soc.* **1981**, *103*, 5014.

(16) Allinger, N. L. *J. Am. Chem. Soc.* **1977**, *99*, 8127.

(17) Allinger, N. L.; Yuh, Y. H. *QCPE* **1981**, *8*, 317.

Table I. Calculated Sterical Energies,[a] Ring Puckering, and Pseudorotation Phase ϕ^b (in Parentheses) of the Perhydrophenalene Ring System

conformation[c]	E^d	ΔE^e	ring A	ring B	ring C
(*ttt*)-CCC	15.5		0.582	0.582	0.582
BCC	22.7	7.2	0.739 (181.6)	0.581	0.585
BBC	28.8	13.3	0.738 (203.0)	0.787 (200.9)	0.580
BBB	33.4	17.9	0.772 (207.8)	0.772 (207.9)	0.772 (207.9)
(*cct*)-CCC	19.2 (3.7)		0.567	0.566	0.566
CBC	24.9	5.6	0.554	0.754 (161.7)	0.544
BCC	27.8	8.6	0.701 (22.5)	0.548	0.585
BBC	28.3	9.1	0.724 (40.3)	0.736 (139.9)	0.559
CBB	30.1	10.9	0.551	0.709 (194.0)	0.791 (207.4)
BBB	30.8	11.6	0.717 (83.1)	0.754 (97.1)	0.786 (212.3)
(*ctt*)-BCC	25.6 (10.1)		0.796 (91.6)	0.631	0.538
BCB	26.0	0.4	0.737 (121.3)	0.586	0.741 (242.6)
BBB	31.0	5.4	0.783 (334.7)	0.755 (83.3)	0.776 (321.3)
BBC	31.6	6.1	0.779 (87.7)	0.792 (197.6)	0.548
(*ccc*)-CCB	30.1 (14.6)		0.538	0.522	0.764 (87.3)
CBB1	31.2	1.1	0.547	0.720 (265.0)	0.698 (149.8)
BBBr	33.4	3.3	0.716 (86.4)	0.717 (86.4)	0.718 (86.3)
CBB2	34.0	3.9	0.533	0.665 (48.2)	0.691 (289.3)
BBB2	36.9	6.8	0.727 (204.4)	0.666 (76.7)	0.686 (317.3)
BBB1	39.5	9.4	0.638 (0.5)	0.686 (248.4)	0.696 (124.0)

[a] In kcal/mol. [b] Puckering in Å, phase in degrees. ϕ is not defined for a chair form. [c] See text for nomenclature. [d] Difference relative to (*ttt*)-CCC is parentheses. [e] Relative to the most table conformation in the group.

phase, ϕ, is however dependent upon the choice of a reference point. In perhydrophenalene, the central atom C(13) is chosen as the reference point for the three rings, the other atoms are taken in a clockwise sequence.

The absolute and relative sterical energies of the studied systems, and the ring puckring and pseudorotation phases are summarized in Table I.

trans**,*****trans*****,*****trans*****-Perhydrophenalene.** Four nonequivalent conformations are possible for the ttt configuration, viz., CCC, CBC, CBB, and BBB.

As expected, the all chair form (CCC) is the most stable conformation. The ring puckering of the individual rings is similar to that found for cyclohexane, using the same force field. The C–C bond length between two tertiary C atoms equals the value found for neopentane[16] and decreases toward the normal value for the bond between secondary atoms.

The BCC form is 7.2 kcal/mol higher in energy than the all chair conformation, which is 0.7 kcal/mol more than one would expect from the difference between the boat and chair forms of cyclohexane.[19] This is mainly due to extra bending energy and van der Waals interactions.

Part of the energy increase of the BBC form is relieved because both boat rings are deformed toward a twist conformation. This effect is more pronounced in the all boat form (BBB), where the energy is increased by only 4.6 kcal/mol relative to the BBC conformation, because the three rings can now assume a twist conformation. The pseudorotation phase for the rings is $\phi = 208°$, whereas an ideal twist-boat is found at $\phi = 210°$. The rings are deformed however, because the individual bonds are not sterically equivalent.

The symmetrical (C_v) all boat conformation is 4.0 kcal/mol higher in energy than the nonsymmetrical form. Since conversion paths were not investigated, it is not clear if this conformation is the top of the potential barrier, which separates both enantiomorphic forms.

cis**,*****cis*****,*****trans*****-Perhydrophenalene.** The cct system has a bigger spread in conformational possibilities, owing to the presence of the nonequivalent ring coupling. Unique conformations are the CCC, BCC, CBC, CBB, BBC, and BBB forms.

The all chair form has the lowest energy, but is 3.7 kcal/mol higher than that of the all chair ttt form. This value is comparable with the energy difference between the ttt and cct forms of 13-methylperhydrophenalene given by Gund and Gund,[10] if one keeps in mind that for these compounds the ttt form has two more gauche butane interactions than the cct form.

The distribution of C–C bond lengths is identical with that of the ttt configuration, although small individual differences exist. From Table I, it is seen that the rings are somewhat flatter than in the ttt form.

The CBC conformation raises the energy by 5.6 kcal/mol. Ring B assumes a slightly distorted boat conformation. In the BCC form however, ring A is much more deformed because of the short distance between the axial hydrogen atoms on C(11) and C(5). This is reflected in the value of $\phi = 22.5°$ and in the increase in energy of 8.6 kcal/mol relative to the all chair form.

In the BBC form, rings A and B form a subsystem similar to the BB conformation of *cis*-decalin, thus offering the possibility of partial pseudorotation with $\phi_A = \pm\phi_B + \xi$, as described earlier. The chair conformation of the ring C, and the trans junction between rings B and C limit the flexibility to $\phi_A = -\phi_B + \pi$, with restricted possible values of the phases. The minimum energy conformation on the potential curve has $\phi_A = 40.3°$ and $\phi_B = 139.9°$, in excellent agreement with the ideal values. The energy is only 0.5 kcal/mol higher than that of the BCC form.

An additional 1.8 kcal/mol is added to the energy of the CBB system, where the boat conformations are deformed toward a twist. This form does not show the flexibility of the former and is separate from its enantiomorph by a barrier of 1.3 kcal/mol.

There is no simple linear relationship that describes the complex flexibility of the all boat conformation. Using different starting models, the most stable form was found to have an energy of 11.6 kcal/mol above the all chair conformation. The three rings are in a distorted twist conformation.

cis**,*****trans*****,*****trans*****-Perhydrophenalene.** Physical possible conformations of ctt-perhydrophenalene are the BCC, BCB, BBC, and BBB forms. There is no all chair form.

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(18) (a) Cremer, D.; Pople, J. A. *J. Am. Chem. Soc.* **1975**, *97*, 1358. (b) Cremer, D. *QCPE* **1975**, *2*, 288.

(19) According to the MM2 force field, the twist-boat and boat conformations are situated respectively 5.5 and 6.5 kcal/mol above the chair form (ref 16).

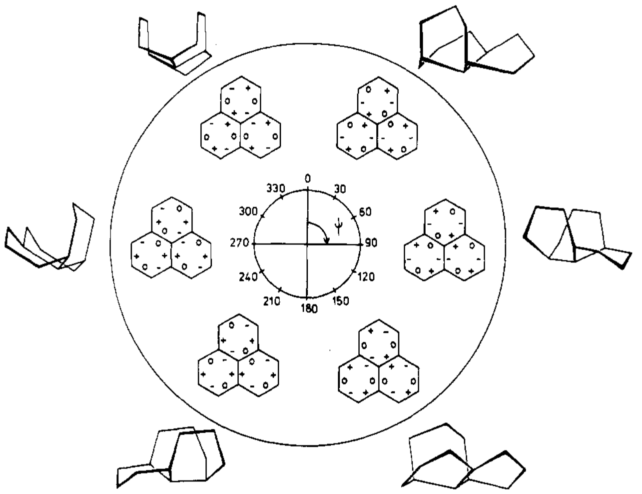

Figure 5. The pseudorototational path of the all boat conformation in the ccc form with a perspective view on the symmetrical molecules.

The two trans ring junctions restrict the maximum flexibility to some wagging around a higher symmetrical form.

The A ring of the BCC form is frozen in a twist conformation. It is the most stable conformation in this group, although 10.1 kcal/mol higher in energy than the all chair ttt configuration.

The BCB, BBB, and BBC forms are situated respectively 0.4, 5.4, and 6.1 kcal/mol higher in energy. The boat rings are all deformed twist conformations.

***cis,cis,cis*-Perhydrophenalene.** As above, no all chair conformation is possible. The CCB form is built up from two flattened chair conformations and a distorted twist. It is 14.6 kcal/mol higher in energy than the ttt-CCC form.

Two symmetrical forms of the CBB type may be distinguished, resulting from a flipping of ring A in the all boat form to a chair conformation at $\psi = 150°$ and $\psi = 330°$ (see Figure 5). They are denoted CBB1 and CBB2, respectively. Equivalent forms of CBB1 are generated at $\psi = (4n + 1)\pi/6$ and at $\psi = (4n - 1)\pi/6$, ($n = 0, 1, 2...$) for CBB2. Symmetry is lost during energy minimization however, in order to relieve the strain resulting from very short H···H distances. Stable conformations are found with energies of 31.2 (CBB1) and 34.0 (CBB2) kcal/mol.

As explained earlier, the all boat form has only one degree of freedom, and a complete potential function can be calculated by driving only one torsion angle. In practice however, it is necessary to switch to other angles during this process, owing to the ambiguous relationship between torsion angles and pseudorotation.

Owing to extremely short H···H distances, some rings in perhydrophenalene will flip from a boat to a chair conformation, rather than surmount the high potential barrier. A potential function may be calculated by imposing more constraints on the molecule, but this would lead to unrealistic results.[20] Therefore, only optimized BBB1 and BBB2 conformations are given here. The energies are 39.5 and 36.9 kcal/mol, respectively, and the boat conformations are in fact distorted twist forms.

It is seen from table I, that for both conformations, the pseudorotational phases agree very well with the values predicted from the geometrical model since $\phi_B \simeq \phi_C + 2\pi/3 \simeq \phi_A + 4\pi/3$, which is equivalent to eq 1 derived earlier.

An interesting conformation is a combination of three symmetrical twist boat rings, resulting in a *rigid* molecule with C_3 symmetry, and denoted BBBr. This form is 3.3 kcal/mol higher in energy than the CBB conformation and lies on a transition path between the CBB and all boat forms.

Conclusions

In this paper, the stable conformations of the four possible configurations of perhydrophenalene are studied.

With idealized models, the reasonable conformations are deducted, and a simple model for the "in between" conformations is derived.

As one could intuitively expect, the all chair form has the lowest energy in the ttt and cct configurations. In both the ctt and ccc forms, at least one ring must be in a boatlike conformation. In these two configurations, the difference in sterical energy between the two most stable conformations is relatively small, and it is thus uncertain that the same conformational preference will be found in the related steroids.

A molecular mechanics study of the conformations of the perhydrobenzo[4.5.6]androstanes and crystal structure elucidations of related compounds is in progress and will be reported elsewhere.

Registry No. (*ttt*)-Perhydrophenalene, 40250-64-4; (*cct*)-perhydrophenalene, 86118-18-5; (*ctt*)-perhydrophenalene, 91465-59-7; (*ccc*)-perhydrophenalene, 91465-60-0.

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(20) See White and Bovill (White, D. N. J.; Bovill, M. J. *J. Chem. Soc., Perkin Trans. 2* 1977, 1610) for an example of completely different results using other contraints.

A New Approach to Morphinans: Total Synthesis of *O*-Methylpallidinine[1]

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We have devised a general method for the synthesis of 4a-aryloctahydroisoquinolines related to morphine and have shown how these compounds may be used in a route to morphinan alkaloids. The key step in this route involves the addition of diazomethane to a 4a-aryloctahydroisoquinolinium salt, followed by spontaneous cyclization to the morphinan. Studies of this step indicate that it is not compatible with the presence of an alkoxyl group at C4 of the aryl ring. The value of this method has been demonstrated in the context of stereospecific total synthesis of *O*-methylpallidinine.

The morphine alkaloids[2] are a large class of natural products that have, over the year, provoked an extraordinary amount of activity by synthetic organic chemists. Total syntheses of morphine have been achieved by several