C, 71.39; H, 9.59. Found: C, 71.32; H, 9.49.

4-Hydroxy-2,2,6,6-tetramethylcyclohexanone (33). A modification of the method of Leuenberger et al.[21] was used. A solution of 250 mg (1.49 mmol) of diketone **29** in 3 mL of MeOH was hydrogenated (1 atm) at 25 °C over 300 mg of Raney Ni.[33] After 30 min, the solution was decanted and the nickel residue was washed with MeOH. The MeOH was removed and the residue was dissolved in 10 mL of ether, dried ($MgSO_4$), and concentrated to afford 252 mg of alcohol **33** as white needles. Recrystallization from hexane afforded 242 mg (95%) of **33**: mp 61–61.7 °C; NMR δ 1.15 (s, 6), 1.23 (s, 6), 1.54–2.18 (complex m, 4), 1.76 (br s, 1), 4.32 (m, 1); IR (CCl_4) 3616, 3508, 1705 cm^{-1}. Anal. Calcd for $C_{10}H_{18}O_2$: C, 70.55; H, 10.66. Found: C, 70.33; H, 10.66.

4-Hydroxy-3,3,5,5-tetramethylcyclohexanone (31) and *cis*- and *trans*-2,2,6,6-Tetramethyl-1,4-cyclohexanediol (32). In general, mixtures of **31**, **32**, and **33** were obtained when diketone **29** was reduced with either sodium borohydride in MeOH or isopropyl alcohol, lithium tri-*sec*-butylborohydride (L-Selectride) in ether (gave essentially only **33**) or diisobutylaluminum hydride (Dibal-H) in benzene (see text). The following procedure is representative. To a stirred solution of 45 mg (0.27 mmol) of **29** in 3.0 mL of MeOH at 0 °C was added 2.5 mg (0.07 mmol) of solid sodium borohydride. After 30 min the solution was diluted with water and extracted with ether. The residue obtained from the extract was fractionated by preparative TLC (Whatman PK6F plates, 1/1 ethyl acetate/hexane) to give two major bands: 14 mg (31%) of **31**, mp 89.5–90 °C (hexane), R_f 0.65, NMR spectrum identical with that reported for **31**;[34] 4 mg (9%) of **33**, R_f 0.52 (see above). When a 5-fold molar excess of sodium borohydride was used, there was obtained **32** (35%, isomer a) and **32** (45%, isomer b). Isomer a: mp 145–145.3 °C (CCl_4); R_f 0.47; NMR δ 0.99 (s, 6), 1.04 (s, 6), 1.22 (t, 2), 1.43 (br s, 2), 1.84 (dd, 2), 3.04 (s, 1), 3.93 (m, 1); IR ($CHCl_3$), 3609, 3540–3340 cm^{-1}; mass spectrum, *m/e* 172.147 (calcd for $C_{10}H_{20}O_2$, 172.146). Isomer b: mp 145.8–146.1 °C (hexane); R_f 0.35; NMR δ 1.07 (s, 6), 1.10 (s, 6), 1.45–1.58 (m, 4), 1.48 (br s, 2), 2.96 (s, 1), 3.97 (m, 1); IR ($CHCl_3$) 3639, 3610, 3530–3380 cm^{-1}. Anal. Calcd for $C_{10}H_{20}O_2$: C, 69.72; H, 11.70. Found: C, 69.70; H, 11.60.

3,5-Dibromo-2,2,6,6-tetramethyl-1,4-cyclohexanedione (35). To a solution of 1.0 g of diketone **29** (5.9 mmol) in 10 mL of glacial acetic acid was added 0.60 mL (11.9 mmol) of bromine dropwise over a period of 12 min with stirring. The solution was then poured into water and extracted with CH_2Cl_2. The usual workup gave 2.03 g of a yellow solid. This was shown by NMR to be largely (>90%) the desired 3,5-dibromide **35** (45/55 mixture of cis, trans isomers), which was used in the next step without further purification.

The cis isomer can be separated from the crude dibromide by two recrystallizations from CH_2Cl_2: white needles, mp 182–186 °C; NMR δ 1.31 (s, 6), 1.45 (s, 6), 4.89 (s, 2); IR ($CHCl_3$) 1702, 1752 cm^{-1}. Anal. Calcd for $C_{10}H_{14}Br_2O_2$: C, 36.84; H, 4.33. Found: C, 36.89; H, 4.12. NMR of the trans isomer: δ 1.32 (s, 6), 1.41 (s, 6), 5.13 (s, 2).

4-Oxo-3,3,5,5-tetramethyl-1-cyclopentene-1-carboxamide (38). To a solution of 1.0 g of crude dibromide **35** in 55 mL of CH_2Cl_2 was bubbled ammonia gas over a period of 1 h while stirring. The mixture was filtered and the filtrate was washed with water, dried ($MgSO_4$), and concentrated to afford a solid. This was twice recrystallized from benzene to give 445 mg (82% based on **29**) of **38** as white needles: mp 156–158 °C; NMR δ 1.21 (s, 6), 1.36 (s, 6), 5.73 (br s, 2), 6.51 (s, 1); IR ($CHCl_3$) 3532, 3412, 1750, 1674, 1616, 1582 cm^{-1}. Anal. Calcd for $C_{10}H_{15}NO_2$: C, 66.27; H, 8.34; N, 7.73. Found: C, 66.34; H, 8.24; N, 7.55.

4-Oxo-3,3,5,5-tetramethyl-1-cyclopentene-1-carboxylic Acid (39). To a stirred solution of 150 mg (0.83 mmol) of the amide **38** in 5 mL of MeOH was added 5 mL of 10% aqueous sodium hydroxide. The solution was heated at reflux for 48 h. The cooled solution was acidified with 2 N HCl and extracted with ether. The usual workup gave a residue which was twice recrystallized from benzene to give 136 mg (90%) of **39** as white plates: mp 174–175 °C; NMR δ 1.23 (s, 6), 1.35 (s, 6), 7.13 (s, 1), 10.14 (br s, 1); IR ($CHCl_3$) 1750, 1691, 1618 cm^{-1}. Anal. Calcd for $C_{10}H_{14}O_3$: C, 65.92; H, 7.74. Found: C, 65.74; H, 7.37.

Methyl 4-Oxo-3,3,5,5-tetramethyl-1-cyclopentene-1-carboxylate (40). To a solution of 500 mg of crude dibromide **35** in 6 mL of CH_2Cl_2 was added 6 mL of 1 M sodium methoxide in MeOH. After a 15-min stir at 25 °C, the solution was neutralized with 1 N H_2SO_4 and extracted with CH_2Cl_2. Distillation afforded 255 mg of (87% based on **29**) ester **40** as a viscous oil that subsequently solidified: bp 76 °C (2.5 mm); mp 49–50 °C; NMR δ 1.19 (s, 6), 1.31 (s, 6), 3.80 (s, 3), 6.96 (s, 1); IR ($CHCl_3$) 1751, 1713 cm^{-1}. Anal. Calcd for $C_{11}H_{16}O_3$: C, 67.32; H, 8.22. Found: C, 67.31; H, 8.16.

Acknowledgment. This research was supported by Public Health Service Research Grants GM 24951 and GM 27137 from the National Institute of General Medical Sciences.

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[33] Raney Ni was generated from nickel–aluminum alloy (Grace, No. 2813) by following the procedure of R. Mozingo, "Organic Syntheses", Collect. Vol. 3, Wiley, New York, 1955, pp 181–183. However, instead of washing the nickel to the neutral point, the washing was continued until the pH of the washings was about 9. The nickel was then washed with absolute MeOH twice and stored under MeOH.

[34] M. M. Green and C. Djerassi, *J. Am. Chem. Soc.*, 89, 5190–5198 (1967).

Notes

An Application of Molecular Mechanics to Structure Determination

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Received July 13, 1981

Recently, we have had occasion to react 1-acetoxybutadiene (**4**) with 2-(3,4-dichlorophenyl)-*N*-methylmaleimide (**3**) and have observed the formation of a single Diels–Alder product **5**. In principle, there are four possible regio- and stereoisomeric products, and distinguishing among them is not simple. Hückel calculations show that the LUMO of phenylmaleimide is nonbonding, implying high reactivity with electron-rich dienes. The LUMO, at least at the level of simple Hückel theory, has equal coefficients at the two olefinic carbons, and one can not predict by frontier molecular orbital theory the orientation of cycloaddition. The diene **4** is a mixture of geometric isomers[1] which further complicates the assignment of structure to the adduct **5**.

The NMR data demonstrate that the cyclohexene ring

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[1] (a) Wichterle, O.; Hudlicky, M. *Collect. Czech. Chem. Commun.* **1947**, *12*, 564. (b) We find the commerical material to be a 2:1 mixture of *E* and *Z* isomers.

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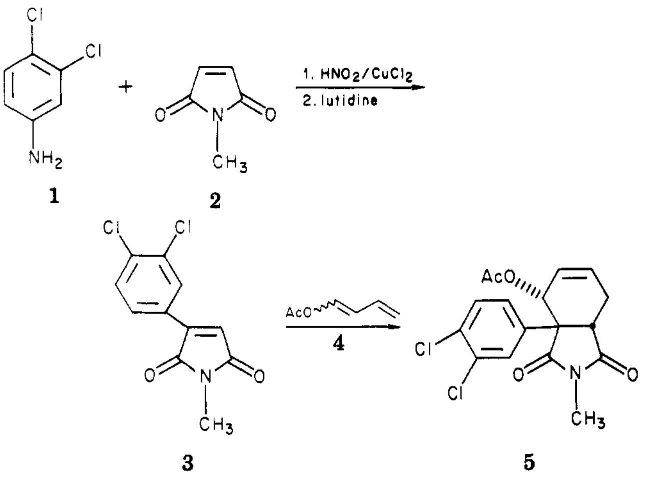

of the adduct is not in a normal chair or boat conformation in solution. With Garbisch's[2] equation, the dihedral angle between the carbinyl proton, H-12 (see figure 1), and the adjacent olefinic proton, H-11,[3] was found to be 30° from the ^{1}H NMR coupling constant. This dihedral angle would be 15° in a twist-boat and 45° in a half-chair. Possible dihedral angles involving the bridgehead protion, H-7, where obtained from a self-consistent solution of the Karplus[4] equation and the ^{1}H NMR coupling of this atom. We suspected that the acetate group was located on a carbon atom adjacent to the phenyl; however to establish rigorously the structure and conformation of the adduct, we calculated the dihedral angles of all four diastereomers by molecular mechanics and compared them to those determined by NMR. Dreiding models were not adequate for this purpose because of the flexible conformation of the cyclohexene ring.

Each diastereomer possesses at least four conformational minima corresponding to different forms of the pyrrolidine and cyclohexene rings as well as a trio of minima related to rotation of the phenyl group. The phenyl rotation was ignored, but the dihedral angles of the remaining conformations of each diastereomer were found. The calculated dihedral angles of one of the conformers fit the observed ^{1}H NMR data within 19° (see Table I). The other structures had dihedral angles differing by 50° or more from the observed values. The correct calculated conformation was a distorted boat with the acetate trans to the phenyl ring and in a prow (axial) position. We used the program BIGSTRN[5] with locally modified potential functions for heteroatoms. Due to the large number of functional groups, relative strain energies may not have been calculated correctly. Thus it was necessary to examine all the conformations of a particular diastereomer not merely the lowest energy one.

Because of the uncertainity introduced by the problems with the energies, we felt it prudent to confirm the conformational assignment by single-crystal X-ray analysis. The X-ray structure is shown in Figure 1. The X-ray result agrees in both configuration and conformation with the structure found by the combination of NMR and calculation. The only difference is the twisting of the methylene carbon, C-12, away from the acetate, causing a flattening of the cyclohexene ring. There is always a question of whether a molecule has the same conformation in solution as it does in the crystal. Molecular mechanics calculation coupled with NMR do give an accurate picture of the conformation in solution as well as answer structural questions.

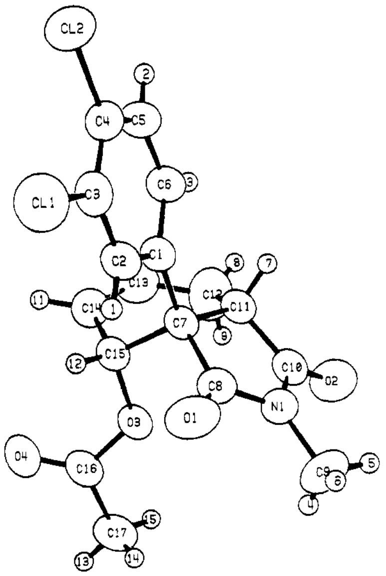

Figure 1. ORTEP drawing of **5**.

Table I. Dihedral Angles (deg) of 5

bond	gas phase (calcd)	liquid phase (^{1}H NMR)	solid phase (X-ray)
H-11,H-12	43	32	14
H-7,H-8	29	10	19
H-7,H-9	148	130	131
C-12-C-11 C-7-C-15	6		25

Since the observed regioselectivity can not be explained by frontier orbitals, one must look for other factors such as secondary orbital interactions between the acetate and the aromatic ring, or some steric effect. Examination of the HOMO of butadiene 4 shows the largest coefficient to be on carbon atom 4. One might expect in the asymmetric transition state, this carbon would bond to the least hindered side of the dieneophile, frontier orbital factors being equal. This effect would explain the empirical rule[6] that 1-substituted dienes lead to ortho products even when orbital effects do not predict this. The stereochemistry of the adduct **5** would follow from endo addition to the *E* isomer of the diene **4**.

Experimental Section

***N*-Methyl-2-(3,4-dichlorophenyl)maleimide (3)** was prepared from 3,4-dichloroaniline and *N*-methylmaleimide by our published[7] procedure. The yield on a 1-mol scale was 45% after recrystallization from acetonitrile: mp 158–160 °C; ^{1}H NMR (CCl_3D) δ 8.14 (d, $J = 2$ Hz, 1 H, H-2′), 7.36–7.96 (m, 2 H, H-5′, H-6′), 6.99 (s, 1 H, H-3), 3.08 (s, 3 H, NCH_3); IR (KBr) 1767 (m), 1695 cm^{-1} (s, CO); mass spectrum, m/e 255 (76%, M$^+$), 220 (15, M–Cl), 170 (100, M–$OCNCH_3CO$).

Anal. Calcd for $C_{11}H_7Cl_2NO_2$: C, 51.59; H, 2.76; Cl, 27.69; N, 5.47. Found: C, 51.42; H, 2.69; Cl, 27.71; N, 5.61.

1,2-[(Carbonylamino)carbonyl]-1β-(3,4-dichlorophenyl)-6α-hydroxy-*N*-methyl-4-cyclohexenyl Acetate (5). A stirred mixture of 11.5 g (44.9 mmol) of maleimide **3**, 10.0 g

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(2) Garbisch, E. W. *J. Am. Chem. Soc.* **1965**, *86*, 5561.

(3) The numbering system is taken from the ORTEP drawing in Figure 1. Systematic nomenclature is used in the experimental section.

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(5) Andose, J. D.; Engler, E. M.; Collins, J. B.; Hummel, J. P.; Mislow, K.; Schleyer, P. v. R. *QCEP* **1978**, *10*, 348.

(6) March, J. "Advanced Organic Chemistry", 2nd ed.; McGraw-Hill: New York, 1977; p 765.

(7) Epstein, J. W.; McKenzie, T. C.; Lovell, M. F.; Perkinson, N. A. *J. Chem. Soc., Chem. Commun.* **1980**, 314.

Table II. Coordinates of the Heavier Atoms of 5

atom	*x*	*y*	*z*
Cl1	0.21926 (6)	0.01325 (8)	0.04100 (4)
Cl2	0.04780 (6)	0.29197 (8)	0.06547 (3)
O1	0.2496 (1)	−0.0939 (2)	−0.23057 (10)
O2	0.0756 (2)	0.1700 (2)	−0.44231 (9)
O3	0.0096 (1)	−0.2083 (2)	−0.32703 (8)
O4	−0.489 (2)	−0.4403 (2)	−0.28476 (10)
N1	0.1863 (2)	0.0433 (2)	−0.3412 (1)
C1	0.0565 (2)	0.0974 (2)	−0.1734 (1)
C2	0.1287 (2)	0.0349 (2)	−0.1094 (1)
C3	0.1267 (2)	0.0939 (3)	−0.0363 (1)
C4	0.0515 (2)	0.2149 (3)	−0.0255 (1)
C5	−0.0219 (2)	0.2751 (3)	−0.0876 (1)
C6	−0.0196 (2)	0.2179 (3)	−0.1610 (1)
C7	0.0549 (2)	0.0272 (2)	−0.2536 (1)
C8	0.1761 (2)	−0.0158 (3)	−0.2703 (1)
C9	0.2865 (2)	0.0111 (4)	−0.3779 (2)
C10	0.0890 (2)	0.1221 (3)	−0.3770 (1)
C11	0.0068 (2)	0.1398 (2)	−0.3202 (1)
C12	−0.1215 (2)	0.1184 (4)	−0.3561 (2)
C13	−0.1879 (2)	0.0179 (3)	−0.3100 (2)
C14	−0.1415 (2)	−0.0958 (3)	−0.2645 (1)
C15	−0.0149 (2)	−0.1289 (2)	−0.2578 (1)
C16	−0.0098 (2)	−0.3656 (2)	−0.3328 (1)
C17	0.0246 (2)	−0.4282 (3)	−0.4046 (1)

(89 mmol) of 1-acetoxybutadiene (Aldrich), 0.5 g of hydroquinone, and 200 mL of chloroform was heated under reflux for 2 days. An additional 5 g of diene was added and reflux was continued for an additional day. The volatiles were removed at reduced pressure to give a tacky, brown solid. Recrystallization from 2-propanol gave 12.3 g (74.4% yield) of straw-colored crystals: mp 146–148 °C; ^{1}H NMR δ 7.36–7.80 (m, 3 H, aromatic), 5.73–6.08 (m, 2 H, vinyl), 5.39 (d, J = 5.5Hz, 1 H, HCOAc), 3.27 (d of d, J = 9.9, 4.5 Hz, 1 H, H-2), 3.00 (s, 3H, NCH_3), 1.90 (s, 3 H, Ac); IR (KBr), 1778 (m), 1731 (s, ester), 1699 cm^{-1} (s, imide); mass spectrum, m/e 367 (9%, M$^+$), 325 (24, $M-CH_2CO$), 256 (83, $C_{11}H_7Cl_2NO_2$ + H$^+$), 112 (88, $M-C_{11}H_7Cl_2NO_2$), 70 (100, 112 - CH_2O).

Anal. Calcd for $C_{17}H_{15}Cl_2NO_4$: C, 55.45; H, 4.11; Cl. 19.26; N, 3.80. Found: C, 55.67; H, 4.17; Cl, 19.37; N, 3.81.

X-ray Crystal Structure of 5. The crystals were monoclinic, space group $P2_1/n$ (centrosymmetric). The cell dimensions, based on measurements for 24 strong reflections, are as follows: a = 11.694 (1) Å, b = 8.408 (1) Å, c = 17.566 (2) Å, β = 99.58 (1)°. The calculated density is 1.44 g cm^{-3} for one molecule in the asymmetric unit. Three-dimensional data collection on a CAD4 diffractometer with graphite monochromatized Cu Kα radiation gave 3510 independent reflections to a maximum 2θ of 150.0°. Of these 2574 were classified as observed by the criterion $I(h) > 3.0\sigma I(h)$.

The structure was solved by direct methods with the set of normalized structure factors $E(h) > 1.9$. An E map gave the positions of 18 atoms. The remaining atoms, including the hydrogens, were located in succeeding difference Fourier synthesis.

The structure was refined by the full-matrix least-squares method with isotropic hydrogen atoms. The final discrepancy factor was R = 0.041. The atomic parameters are listed in Tables II, III, and IV (Tables III and IV, supplementary material). The bond distances and angles are given in Table V (supplementary material).

Acknowledgment. The spectral data were obtained by Dr. W. E. Gore and staff. The elemental analyses were performed by Mr. L. M. Brancone and staff. The X-ray determination was carried out by the Molecular Structure Corp., College Station, TX. We thank Dr. Allan Wissner of Lederle Laboratories for adapting the Hückel program to run on the American Cyanamid DEC-10 computer.

Registry No. 1, 95-76-1; 2, 930-88-1; 3, 79722-40-0; 4, 1515-76-0; 5, 79735-26-5.

Supplementary Material Available: Table III containing anisotropic temperature factors, Table IV containing hydrogen coordinates and isotropic temperature factors, and Table V containing bond distances and angles (4 pages). Ordering information is given on any current masthead page.

Spectroscopic and Photochemical Properties of Diastereoisomeric α,α′-Disubstituted Bis[(9-anthryl)methyl] Ethers

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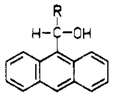
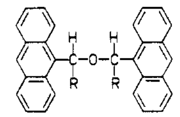
Received July 22, 1981

During their attempts to prepare 9-vinylanthracene from methyl(9-anthryl)carbinol (1), both Fieser and Hartwell



1: R=CH_3

2: R=C_6H_5



3: R=CH_3 a: meso-form

4: R=C_6H_5 b: dl-form

and subsequently Hawkins noted the formation of a dimeric product which, on the basis of elemental analysis and infrared data, was presumed to be bis[α-(9-anthryl)ethyl] ether (3).[1,2] Most recently, bis[α-(9-anthryl)benzyl] ether (4) was reported to be formed, among other products, from (9-anthryl)benzyl hexachloroantimonate by treatment with potassium *tert*-butoxide.[3] Remarkably, in none of these reports has the problem of stereoisomerism of α,α′-disubstituted bis[(9-anthryl)methyl] ethers been mentioned. Bis[(9-anthryl)methyl] ethers 3 and 4 are characterized by having two like asymmetric carbon atoms and could, therefore, have been obtained as a mixture of isomers, namely, the *dl* form and the meso compound.

Inspection of Dreiding molecular models of α,α′-disubstituted bis[(9-anthryl)methyl] ethers suggests the molecular geometry of the meso form to be very much different from that of the *dl* form because the sterically demanding α-substituents always should be aligned more favorably out of the plane of the anthracene. The conformational consequences with respect to the mutual orientation of the two molecular halves could be dramatic. In the sterically possible conformation of the meso form, electronic interactions between the two anthracene moieties may be formidable, as fully overlapping alignment of the aromatic π systems (see Figure 1a) is possible in conjunction with rotation about the 9-anthryl–alkyl–ether bonds. By contrast, the molecular geometry of the *dl* form may be far less conducive to intramolecular π-orbital interaction. Model considerations lead to the conclusion that a conformational arrangement of perfectly overlapping anthracene moieties is not possible for steric reasons (see Figure 1b).

We have now found that α,α′-disubstituted bis[(9-anthryl)methyl] ethers can be prepared conveniently by reaction of the corresponding secondary 9-anthrylcarbinols with potassium hydrogen sulfate and that they indeed exist in diastereoisomeric meso and *dl* forms. For example, keeping methyl(9-anthryl)carbinol (1, 1.78 g) in the presence of $KHSO_4$ (35 mg) at 140 °C for 5 min gives a mixture (approximate ratio 1:1) of diastereoisomeric bis[α-(9-anthryl)ethyl] ethers (3) in 84% yield. Separation into the meso form **3a** and the *dl* racemate **3b** was accomplished

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[2] Hawkins, E. G. E. *J. Chem. Soc.* **1957**, 3858.

[3] Takagi, M.; Ogata, F.; Nojima, M.; Kusabayashi, S. *J. Chem. Soc., Perkin Trans. 1* **1979**, 2948.