left in the refrigerator for 2 days. It was then poured into concentrated HCl and ice, extracted into ether, washed with saturated $NaHCO_3$ and water, and dried over anhydrous Na_2SO_4. After removal of the solvent, ditosylate (XIX) was obtained (540.6 mg, 96.2%). It was recrystallized from ether: mp 184–185 °C; NMR ($CDCl_3$) 7.74 (d, 4 Hz, 4 H), 7.32 (d, 4 Hz, 4 H), 3.60 (s, 4 H), 2.44 (s, 6 H), 1.34 (s, 12 H); IR ($CDCl_3$) 2980, 2900, 1200, 1190; MS 18 ev ($C_{24}H_{30}O_6S_2$) calcd, 478.1484; obsd, 478.1448.

Bicyclo[2.2.2]octane-1,4-dimethanol *p*-Toluenesulfonate (XXII). III (150 mg, 0.498 mmol) was placed in a 25-mL, two-neck flask equipped with a drying tube. Then 1.4 mL of dry pyridine was added followed by *p*-toluenesulfonyl chloride (94.9 mg, 0.498 mmol) in 0.7 mL of pyridine. After 2 days in the refrigerator the reaction was poured into concentrated HCl and ice, extracted with ether, washed with saturated $NaHCO_3$ and water, and dried over anhydrous Na_2SO_4. After removal of the solvent, the crude product was chromatographed on silica gel. Elution with benzene/acetone (10:1) yielded a small amount of ditosylate (XIX). Elution with benzene/acetone (5:1) gave the product (XXII) (115 mg, 74.2%). Elution with acetone gave a small amount of diol (III). The product (XXII) was recrystallized from benzene: mp 122–123 °C (lit.[4b] 128–129 °C); NMR ($CDCl_3$) 7.76 (d, 4 Hz, 2 H), 7.34 (d, 4 Hz, 2 H), 3.64 (s, 2 H), 3.26 (s, 2 H), 2.44 (s, 3 H), 1.38 (s, 12 H); IR ($CDCl_3$) 3660, 2970, 2900, 1200, 1190.

C. Attempted S_N2 Reactions on Mono- and Ditosylates. (a) $(CH_3)_2NH$ with XIX. Ditosylate (XIX) (50 mg) was mixed with 40% aqueous $(CH_3)_2NH$ (30 mL) and dioxane (20 mL) in a 100-mL flask. This reaction was heated at 60–65 °C for 3 days under a reflux condenser. After cooling to room temperature, it was extracted with $CHCl_3$, dried over $MgSO_4$, and concentrated by vacuum. NMR analysis showed the mixture of products and unreacted starting material indicated above.

Modification of the above procedure by the use of a 20-mL stainless steel bomb was effected with 30 mg of XIX in 4.5 mL of aqueous dimethylamine and 2.5 mL of dioxane. Heating at 150 °C for 3 h, followed by cooling and workup as above, gave a sample of XVII which was at least 80% pure by NMR and showed no unreacted tosylate.

(b) $(CH_3)_2NLi$ with XIX. A 50-mL, three-neck flask was fitted with two septa, a dry ice condenser, a magnetic stirring bar, and a nitrogen inlet. Gaseous $(CH_3)_2NH$ (1 mL) was condensed into the flask and dry THF (5 mL) was added followed by *n*-BuLi (0.83 mL, 2.4 M in hexane). This mixture was stirred for 15 min at −63 °C and then warmed to room temperature for another 15 min. After cooling to −40 °C, a solution of XIX (200 mg) in 5 mL of dry THF was added. The reaction was warmed to room temperature and stirred for 2 h. The reaction was poured into water and extracted with $CHCl_3$. After passage through a short silica gel column, the $CHCl_3$ solution was concentrated and analyzed by NMR. This analysis showed <10% unreacted tosylate with the remainder of the product being diol (III).

(c) $LiAlH_4$ with XIX. A 100-mL, 3-neck flask was equipped with a magnetic stirring bar, a reflux condenser, and a nitrogen inlet. The flask was charged with a slurry of LAH (400 mg, 10.5 mmol) in dry THF (30 mL). A solution of XIX (30 mg, 0.06 mmol) in a minimal amount of dry THF was added and the reaction was allowed to reflux for 20–21 h. Workup with water, aqueous NaOH, and saturated aqueous NaCl was followed by drying with solid anhydrous Na_2SO_4. The solvent was removed by vacuum and the product was analyzed by both gas chromatography (15% SE-30; 140–180 °C) and by NMR for the ratio of diol (III) to alcohol (XX). Two independent analyses of each of two runs showed 60% ± 3% III and 40% ± 3% XX. XX: NMR ($CDCl_3$) 0.78 (s, 3 H), 1.38 (s, 12 H), 1.50 (br s, 1 H), 3.26 (s, 2 H); IR ($CHCl_3$) 3660, 3510, 1045, 920.

(d) $LiAlH_4$ with XXII. In an attempt to repeat the results of Stock et al.[4b] the procedure described above for the reaction of LAH with XIX was used with monotosylate XXII (30 mg, 0.09 mmol). Using the same workup and analysis as above, the product mixture again showed a 60:40 mixture of III:XX.[13]

Acknowledgment. Financial support from NIH (GM-27355) is gratefully acknowledged.

Registry No. I, 843-59-4; I (bis(dithiane) ketal), 41034-55-3; I (bis(dithiolane) ketal), 1686-98-2; II, 1659-75-2; III, 826-45-9; IV, 28673-85-0; V, 84774-84-5; VI, 88393-16-2; VII, 88393-17-3; VIII, 88393-18-4; IX, 88393-19-5; X, 88393-20-8; XI, 88393-21-9; XII, 88393-22-0; XIII, 88393-23-1; XIV, 88393-24-2; XV, 88393-25-3; XVI, 88393-26-4; XVII, 34131-02-7; XVIIIa, 88393-27-5; XVIIIb, 88393-29-7; XIX, 88412-20-8; XX, 28305-83-1; XXI, 88393-31-1; XXII, 898-81-7; $(CH_3)_2NH$, 124-40-3; CH_3Ph_3PI, 2065-66-9; $CH_3OCH_2Ph_3PCl$, 4009-98-7; diethyl 2,5-dioxocyclohexane-1,4-dicarboxylate, 787-07-5; 1,2-dibromoethane, 106-93-4; 1,3-propanedithiol, 109-80-8; 1,2-ethanedithiol, 540-63-6; acetone, 67-64-1.

Synthesis of Methyl- and Nitro-Substituted Pentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecane-8,11-diones

Alan P. Marchand* and Suresh Chander Suri

Department of Chemistry, North Texas State University, Denton, Texas 76203

Arthur D. Earlywine, Douglas R. Powell, and Dick van der Helm

Department of Chemistry, University of Oklahoma, Norman, Oklahoma 73019

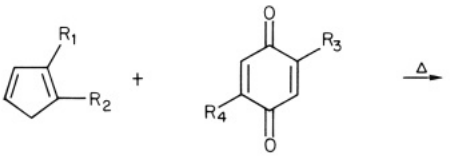
Received September 7, 1983

Diels–Alder cycloaddition of an appropriately substituted cyclopentadiene to an appropriately substituted *p*-benzoquinone (**1a–c**) followed by photocyclization of the resulting endo cycloadduct **2a–d** was employed to synthesize the following monomethylated pentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecane-8,11-diones: 1-methyl (**3a**), 2-methyl (**3b**), and 3-methyl (**3c**). Single-crystal X-ray structural analysis was performed on **3c**. 2-Nitrobenzoquinone, generated via silver(I) oxide promoted oxidation of 2-nitrohydroquinone, was trapped in situ by cyclopentadiene, affording four products: 4a-nitro-1,4,4a,8a-tetrahydro-*endo*-1,4-methanonaphthalene-5,8-dione (**4**, 40%), 4a-nitro-1,4,4a,8a-tetrahydro-*exo*-1,4-methanonaphthalene-5,8-dione (**5**, 7%), and two 2:1 diene:dienophile cycloadducts [**6** (2%, from further reaction of **4** with cyclopentadiene) and **7** (4%, from further reaction of **5** with cyclopentadiene)]. The assignment of endo configuration for **4** was confirmed via its facile intramolecular photocyclization to 9-nitropentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecane-8,11-dione (**8**). Attempted column chromatographic purification of **4** on either alumina or silica gel resulted in the formation of 1,4-dihydro-1,4-methano-5,8-naphthoquinone (**10**) via elmination of nitrous acid from **4**. Reduction of **4** with methanolic sodium borohydride in the presence of cerous chloride afforded 4a-nitro-1,4,4a,8a-tetrahydro-*endo*-1,4-methanonaphthalene-5,8-diol (**9**) in 75% yield.

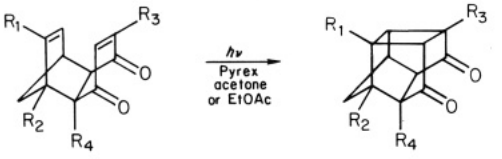
As part of a continuing study of the synthesis[1] and chemistry[2–6] of substituted pentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]-undecanes, we have undertaken the synthesis and characterization of 1-methyl-, 2-methyl-, 3-methyl-, and 9-

0022-3263/84/1949-0670$01.50/0 © 1984 American Chemical Society

nitropentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecane-8,11-diones (compounds **3a–c** and **8**, respectively). In all cases, the



1a, $R_3 = R_4 = H$
b, $R_3 = CH_3$; $R_4 = H$
c, $R_3 = H$; $R_4 = NO_2$



2a, $R_3 = CH_3$; $R_1 = R_2 = R_4 = H$
b, $R_1 = CH_3$; $R_2 = R_3 = R_4 = H$
c, $R_2 = CH_3$; $R_1 = R_3 = R_4 = H$
4, $R_4 = NO_2$; $R_1 = R_2 = R_3 = H$

3a, $R_3 = CH_3$; $R_1 = R_2 = R_4 = H$
b, $R_1 = CH_3$; $R_2 = R_3 = R_4 = H$
c, $R_2 = CH_3$; $R_1 = R_3 = R_4 = H$
8, $R_4 = NO_2$; $R_1 = R_2 = R_3 = H$

basic synthetic approach involves Diels–Alder cycloaddition of an appropriately substituted cyclopentadiene to an appropriately substituted *p*-benzoquinone (**1a–c**) followed by intramolecular [2 + 2] photocyclization of the resulting endo cycloadduct (**2a–d**).[1]

The 1-methyl isomer **2a** obtained via Diels–Alder addition of cyclopentadiene to toluquinone (**1a**)[7] is a single, isomerically pure substance. The fact that this Diels–Alder reaction proceeds with endo regiospecificity is verified by the facile intramolecular photocyclization of **2a** to **3a**. Interestingly, compound **2a** could not be induced to undergo further Diels–Alder addition to cyclopentadiene even when **2a** was refluxed overnight with excess cyclopentadiene in benzene solution.

The remaining two monomethylpentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecane-8,11-diones (**3b** and **3c**) were prepared via a similar sequence starting with the Diels–Alder cycloaddition of methylcyclopentadiene to *p*-benzoquinone (**1a**). Thermal cracking of the methylcyclopentadiene dimer[8] affords a mixture of 1-methyl- and 2-methylcyclopentadienes.[9] Diels–Alder cycloaddition of the diene mixture to **1a** afforded a mixture of adducts, **2b** and **2c** (product ratio ca. 45:55). The mixture of isomeric adducts **2b** and **2c** could be separated conveniently via fractional recrystallization from methanol. That each of these isomeric adducts possesses the endo configuration was shown by their respective facile intramolecular photochemical cyclizations to **3b** and **3c**.

As part of this study, we have performed single-crystal X-ray structural analysis on **3c**. A perspective view of **3c** is shown in Figure 1. Much of the strain inherent in this ring system is accommodated by a lengthening of the C(2)–C(7) and C(4)–C(5) bonds, [both 1.589 (2) Å]. The

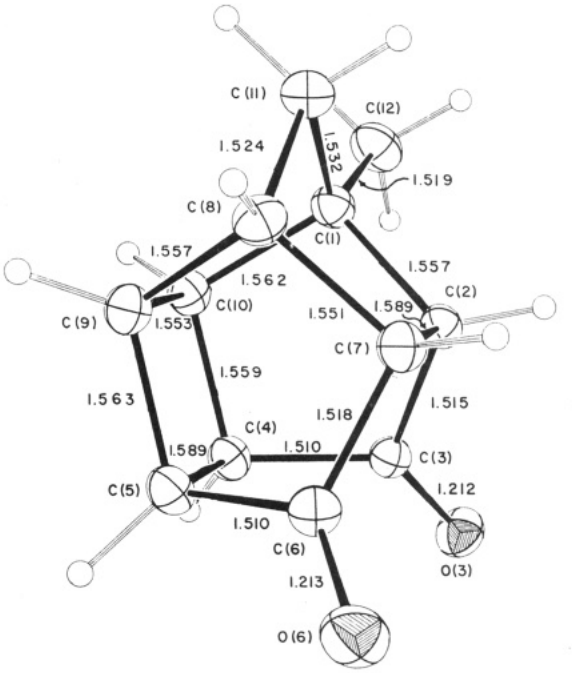


Figure 1. Perspective view of **1**. Carbon and oxygen atoms are shown as 50% probability ellipsoids (oxygens are shaded). Hydrogens are displayed as arbitrary spheres.[26] Estimated standard deviations of bond lengths are ±0.002 Å.

corresponding carbon–carbon bonds in a closely related polycyclic system studied by Mehta and co-workers[10] have an average length of 1.590 Å.

With the exception of the exocyclic atoms on C(1) and C(8), the compound would have a mirror plane passing through C(11) and bisecting the C(2)–C(7), C(4)–C(5), and C(9)–C(10) bonds. This mirror is approximately present in the solid state. Bonds equivalent by mirror symmetry show a maximum variation in length of 4σ for bonds involving C(1) or C(8). However, mirror equivalent bonds between atoms not bonded to C(1) or C(8) have differences less than σ. Bond angles show a similar mirror equivalence, with angles between atoms furthest from C(1) and C(8) having the smallest differences.

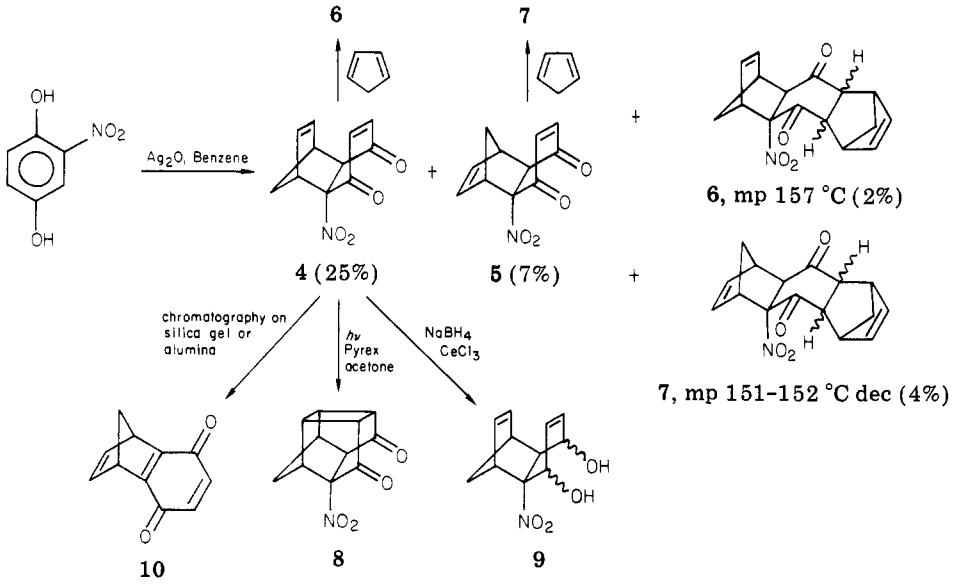
The two five-membered rings that contain C(11) have a nearly ideal envelope conformation as shown by the values of the asymmetry parameters[11] $\Delta C_s(2\text{–}7) = 0.90°$, $\Delta C_s(9\text{–}10) = 0.96°$. In contrast, the conformation of the five-membered rings with carbonyl groups is highly distorted [$\Delta C_s(4\text{–}10) = 11.2°$, $\Delta C_2(2\text{–}3) = 18.9°$, and $\Delta C_s(5\text{–}9) = 12.9°$, $\Delta C_2(6\text{–}7) = 28.0°$]. The four-membered ring is planar with a maximum atomic displacement of 0.0011 (12) Å.

The C(1)–C(12) bond [1.519 (2) Å] is considerably shorter than the normal 1.54 Å. This shortening can be explained in terms of a hybridization effect at C(1). The strained ring system increases the C(12)–C(1)–C(i) bond angles beyond the normal 109.5° [i = 2, 114.06 (11)°; i = 10, 115.58 (10)°; i = 11, 118.34 (11)°]. This suggests an increase in the p character of the molecular orbitals directed toward the ring system and an increase in the s character of the orbital directed toward C(12).

There are three short intermolecular contacts: O(3)···H(10) ($^1/_2 + x$, $^1/_2 - y$, $z - ^1/_2$) 2.48 (2) Å, O(3)···H(5) ($-x$, $-y$, $-z$) 2.55 (2) Å, and O(6)···H(4) ($-x$, $-y$, $-z$) 2.59 (2) Å.

(1) Marchand, A. P.; Allen, R. W. *J. Org. Chem.* **1974**, *39*, 1596.
(2) Marchand, A. P.; Chou, T.-C. *J. Chem. Soc., Perkin Trans. 1* **1973**, 1948.
(3) Marchand, A. P.; Chou, T.-C. *Tetrahedron* **1975**, *31*, 2655.
(4) Marchand, A. P.; Chou, T.-C. *Tetrahedron Lett.* **1975**, 3359.
(5) Marchand, A. P.; Chou, T.-C.; Ekstrand, J. D.; van der Helm, D. *J. Org. Chem.* **1976**, *41*, 1438.
(6) Marchand, A. P.; Kaya, R. *J. Org. Chem.* **1983**, *48*, 5392.
(7) Alder, K; Flock, F. H.; Beumling, H. *Chem. Ber.* **1960**, *93*, 1896.
(8) Available from Exxon Corporation; we gratefully acknowledge the gift of a generous sample of methylcyclopentadiene dimer, which was provided by Exxon.
(9) Csicsery, S. M. *J. Org. Chem.* **1960**, *25*, 518.
(10) Mehta, G.; Singh, V.; Srikrishna, A.; Cameron, T. S.; Chan, C. *Tetrahedron Lett.* **1979**, 4595.
(11) Duax, W. L.; Norton, D. A. "Atlas of Steroid Structure"; Plenum: New York, 1975; Vol. 1, pp 16–22.

Scheme I



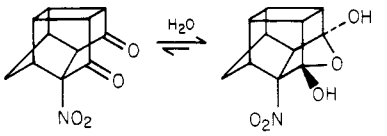
We were also interested in synthesizing nitro-substituted pentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecane-8,11-diones as part of this study. Synthetic entry into these systems conceivably could be gained via Diels–Alder additions of nitrocyclopentadienes to nitrobenzoquinones. However, both nitrocyclopentadienes[12] and nitrobenzoquinones[13] are known generally to be quite unstable.

Recently, Kraus and Taschner[14] have reported that unstable benzoquinones can be generated via Ag_2O-promoted oxidation of the corresponding substituted hydroquinone. In practice, these unstable oxidation products were not isolated but instead could be trapped in situ by acyclic 1,3-dienes.[14] This procedure was applied to the oxidation of 2-nitrohydroquinone using cyclopentadiene to trap in situ the 2-nitrobenzoquinone thereby generated. A total of four cycloadducts were isolated from this reaction: two 1:1 adducts (**4** and **5**) and two 2:1 diene:dienophile adducts (**6** and **7**, see Scheme I). The major reaction product was shown to be the endo 1:1 adduct **4**; this material underwent facile intramolecular photocyclization to 9-nitropentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecane-8,11-dione (**8**, vide infra). The corresponding exo 1:1 adduct **5** could be recovered unchanged upon attempted photolysis under comparable conditions. Interestingly, column chromatography on either silica gel or neutral alumina proved to be unsuitable as a method for purifying **4**. Under these conditions, **4** suffered elimination of nitrous acid to afford the corresponding strained triene **10**.[15]

Attempted reduction of the carbonyl groups in **4** with sodium borohydride afforded an intractible mixture of alcohols.[16] However, we found that sodium borohydride reduction of **4**, when carried out in the presence of cerium(III) chloride in methanol solution,[17] afforded a single diol, **9**, as the sole reaction product. The stereochemistry of the C–OH bonds in **9** will be determined in a future study.

It is likely that the two 2:1 diene:dienophile cycloadducts **6** and **7** are formed via further reaction of **4** and **5** with cyclopentadiene in situ. This conclusion is supported by the following observations. Pure **4**, when reacted thermally with excess cyclopentadiene, afforded a single cycloadduct, which proved to be identical with **6**, the 2:1 adduct, mp 157 °C, which was isolated from the reaction indicated in Scheme I. Similarly, pure **5** reacted with excess cyclopentadiene to afford a single product, mp 151–152 °C dec, which was identical in all respects with compound **7**.

Purification and characterization of compound **8** was



8 **11**

hindered by the apparent strong tendency of this diketone to form a hydrate whose probable structure is **11**. When we attempted to free **8** from the hydrate via vacuum sublimation, a light blue solid deposited on the cold finger of the sublimation apparatus. This blue solid is unstable and difficult to purify; additional efforts to purify and characterize this material are underway.

Experimental Section

Melting points and boiling points are uncorrected. Proton NMR spectra (60 MHz) were obtained on Varian EM-360, Varian T-60, and Hitachi-Perkin Elmer Model R-24B NMR spectrometers. ^{13}C NMR spectra were recorded on a JEOL FX-90Q NMR spectrometer. In all cases, signals are reported in parts per million (δ) downfield from internal tetramethylsilane. Infrared spectra were obtained on Perkin-Elmer Model 1330 and Beckman Model 4250 infrared spectrophotometers. Mass spectra were obtained on a Hewlett-Packard Model 5985B mass spectrometer (70 eV). High-resolution mass spectra were obtained on an AEI MS-9 double focussing high-resolution mass spectrometer. Elemental microanalyses were performed by Midwest Microlab, Ltd., Indianapolis, IN, and by Galbraith Laboratories, Inc., Knoxville, TN.

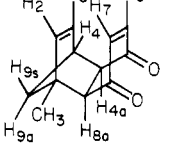
1-Methylpentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecane-8,11-dione (3a). A solution of 6-methyl-1,4,4a,8a-tetrahydro-*endo*-1,4-

(12) Kerber, R. C.; Chick, M. J. *J. Org. Chem.* **1967**, *32*, 1329.
(13) Cason, J. *Org. React.* **1948**, *4*, 305.
(14) Kraus, G. A.; Taschner, M. J. *J. Org. Chem.* **1980**, *45*, 1174.
(15) Relatively facile elimination of nitrous acid from compounds that contain (i) an angular nitro group and (ii) an electron-withdrawing substituent situated β to the NO_2 group has been reported, see: Ono, N.; Miyake, H.; Tanikaga, R.; Kaji, A. *J. Org. Chem.* **1982**, *47*, 5017.
(16) Reduction of pentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecane-8,11-dione (**3**, $R_1 = R_2 = R_3 = R_4 = H$) with sodium borohydride in ethanol has been reported similarly to afford a mixture of isomeric alcohols, see: Sasaki, T.; Eguchi, S.; Kiriyama, T.; Hiroaki, O. *Tetrahedron* **1974**, *30*, 2707 and references cited therein.
(17) (a) Luche, J.-L.; Rodriguez-Hahn, L; Crabbé, P. *J. Chem. Soc., Chem. Commun.* **1978**, 601. (b) Luche, J.-L. *J. Am. Chem. Soc.* **1978**, *100*, 2226.

methanonaphthalene (**2a**)[18] (7.5 g, 40 mmol) in ethyl acetate (500 mL) was irradiated for 16 h under N_2 with a Hanovia medium-pressure Hg lamp (Pyrex filter). The solution was concentrated, whereupon **3a** crystallized as a colorless, microcrystalline solid: 6.3 g, 84%; mp 64–65 °C; ^{1}H NMR ($CDCl_3$) δ 1.13 (s, 3 H), AB pattern centered at δ 1.95 (J_{AB} = 10.5 Hz, 2 H), 2.22–3.42 (br m, 7 H); ^{13}C NMR ($CDCl_3$) δ 212.5 (s), 211.8 (s), 54.3 (d), 54.2 (d), 50.0 (d), 48.0 (s), 44.6 (d), 43.9 (d), 43.2 (d), 40.4 (t), 35.8 (d), 15.3 (q) IR (KBr) 2980 (s), 2970 (s), 2936 (s), 2872 (m), 2872 (m), 1746 (vs), 1730 (sh, vs), 1443 (m), 1286 (m), 1227 (m), 1195 (m), 1181 (m), 1111 (m), 1081 (s), 1060 (s), 912 (m), 876 cm^{-1} (m); mass spectrum (70 eV), *m/e* (relative intensity) 188.1 (molecular ion, 100.0), 173.0 (6.2), 161.1 (6.4), 160.1 (39.4), 159.1 (17.5), 146.0 (6.2), 145.0 (44.4), 133.0 (6.6), 132.1 (34.2), 131.0 (25.8), 129.0 (6.5), 118.1 (10.6), 117.1 (81.4), 116.1 (10.5), 115.1 (27.9), 105.1 (10.5), 94.1 (22.2), 92.1 (6.7), 91.1 (36.9), 79.1 (7.8), 78.1 (7.8), 77.1 (15.5), 66.1 (34.6), 65.1 (18.5), 51.1 (5.7).

Anal. Calcd for $C_{12}H_{12}O_2$: C, 76.57; H, 6.43. Found: C, 76.68; H, 6.38.

Diels–Alder Addition of Methylcyclopentadienes to *p*-Benzoquinone. To a solution of *p*-benzoquinone (116 g, 1.07 mol) in methanol (200 mL) at −70 °C was added a solution of freshly cracked methylcyclopentadiene (mixture of 1-methyl- and 2-methylcyclopentadienes,[9] 86.5 g, 1.08 mol) in cold methanol (50 mL). The solution was allowed to warm slowly to room temperature, and the product was collected by suction filtration. Yellow brown crystals (**2b** + **2c**, 176.9 g, 94%) were obtained. Integration of the proton NMR spectrum of the crude product mixture revealed that **2b** and **2c** were formed in the ratio of ca. 45:55. This mixture of isomeric adducts was separated by careful fractional crystallization from absolute methanol. The isomer that was less soluble in methanol was isolated first by this procedure. After several recrystallizations, an analytical sample of 1-methyl-1,4,4a,8a-tetrahydro-*endo*-1,4-methanonaphthalene-5,8-dione (**2c**) was isolated as a pale yellow microcrystalline solid:

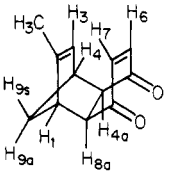


2c

mp 116–117 °C; ^{1}H NMR ($CDCl_3$) δ 1.40 (br s, 2 H, H_{9a} and H_{9s}), 1.55 (s, 3 H, CH_3), 2.73–3.07 (m, 1 H, H_4), 3.20–3.58 (m, 2 H, H_{4a} and H_{8a}), AB pattern centered at 5.98 (J_{AB} = 6 Hz, 2 H, H_2 and H_3), 6.53 (s, 2 H, H_6 and H_7) (the lowfield half of the AB pattern is doubled due to coupling J_{34} = 2 Hz, thereby indicating that H_3 absorbs at lower field than does H_2); ^{13}C NMR ($CDCl_3$) δ 199.3 (s), 198.6 (s), 141.9 (d), 141.4 (d), 138.8 (d), 134.7 (d), 57.4 (s), 55.0 (t), 52.3 (d), 50.5 (d), 48.8 (d), 17.1 (q); IR (CCl_4) 3062 (w), 3000 (w), 2970 (m), 2936 (m), 2872 (w), 1678 (vs), 1450 (w), 1381 (w), 1342 (w), 1297 (m), 1274 (m), 1143 (w), 1117 (w), 1079 (m), 1036 (w), 858 cm^{-1} (w); mass spectrum (70 eV), *m/e* (relative intensity) 189.1 (M + 1, 6.6), 188.1 (molecular ion, 44.4), 160.1 (6.9), 145.1 (5.9), 117.1 (6.1), 115.1 (5.7), 91.1 (12.8), 82.1 (5.1), 80.2 (100.0), 79.1 (51.6), 78.1 (5.5), 77.1 (18.6), 65.1 (4.7), 54.1 (5.2).

Anal. Calcd for $C_{12}H_{12}O_2$: C, 76.57; H, 6.43. Found: C, 76.87; H, 6.67.

Continued fractional recrystallization using 1:1 methanol–hexane of the mother liquor from the above reaction afforded 2-methyl-1,4,4a,8a-tetrahydro-*endo*-1,4-methanonaphthalene-5,8-dione (**2b**) as a pale yellow microcrystalline solid: mp 101.0–101.5 °C; ^{1}H NMR ($CDCl_3$) AB pattern centered at δ 1.51 (J_{AB} = 9 Hz, 2 H, H_{9a} and H_{9s}), 1.60 (d, J = 1–2 Hz, 3 H, CH_3 coupled to H_3), 3.07–3.60 (br s, 4 H, H_1, H_4, H_{4a}; and H_{8a}), 5.62 (br s, 1 H, H_3), 6.57 (s, 2 H, H_6 and H_7); ^{13}C NMR ($CDCl_3$) δ 199.3 (s), 199.0 (s), 145.4 (s), 141.7 (d), 141.4 (d), 127.5 (d), 53.4 (d), 49.3 (d), 49.0 (d), 48.6 (t), 48.1 (d), 16.2 (q); IR (CCl_4) 3058 (w), 2990



2b

(m), 2970 (m), 2940 (m), 2915 (m), 2870 (m), 1678 (vs), 1605 (m), 1442 (m), 1375 (m), 1321 (w), 1296 (s), 1274 (s), 1135 (m), 1115 (m), 899 (w), 858 cm^{-1} (s); mass spectrum (70 eV), *m/e* (relative intensity) 188.1 (molecular ion, 39.4), 145.0 (6.3), 115.1 (5.4),91.1 (14.4), 80.1 (100.0), 79.1 (52.8), 78.1 (7.2), 77.1 (20.1), 65.1 (7.8), 54.1 (8.5), 53.1 (4.8), 51.2 (6.2).

Anal. Calcd for $C_{12}H_{12}O_2$: C, 76.57; H, 6.43. Found: C, 76.35; H, 6.41.

2-Methylpentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecane-8,11-dione (3b). Intramolecular photochemical cyclization of **2b** to **3b** was performed by using the method described above for the photolytic conversion of **2a** to **3a**. Compound **3b** prepared via this procedure was obtained as a colorless microcrystalline solid (88%): mp 181–182 °C; ^{1}H NMR ($CDCl_3$) δ 1.32 (s, 3 H), 1.95 (br s, 2 H), 2.17–3.17 (m, 7 H); ^{13}C NMR ($CDCl_3$) δ 211.7 (s), 210.4 (s), 55.6 (d), 53.0 (d), 50.2 (d), 48.3 (d), 45.9 (s), 44.6 (d), 44.0 (d), 40.2 (d), 37.7 (t), 20.6 (q); IR (KBr) 2978 (sh, s), 2961 (s), 2950 (sh, s), 2918 (m), 2870 (sh, m), 2860 (m), 1750 (vs), 1730 (sh, vs), 1710 (sh, s), 1451 (m), 1368 (w), 1320 (m), 1284 (m), 1272 (m), 1239 (m), 1217 (m), 1191 (m), 1180 (m), 1137 (m), 1121 (m), 1058 (sh, m), 1040 (s), 969 (m), 949 (m), 893 (m), 855 (w), 842 (w), 835 (sh, w), 776 (w), 762 (w), 751 cm^{-1} (w); mass spectrum (70 eV), *m/e* (relative intensity) 189.4 (M + 1, 13.6), 188.4 (molecular ion, 89.7), 173.3 (10.8), 160.4 (20.2), 159.3 (13.2), 145.3 (44.8), 132.3 (20.1), 131.3 (24.4), 118.4 (10.7), 117.3 (83.1), 116.3 (12.6), 115.3 (45.3), 105.3 (11.9), 103.3 (10.2), 94.3 (10.1), 92.3 (10.6), 91.3 (51.1), 81.2 (12.1), 80.3 (100.0), 79.2 (27.5), 78.2 (11.8), 77.2 (25.8), 66.2 (21.0), 65.2 (25.5), 51.2 (10.3).

Anal. Calcd for $C_{12}H_{12}O_2$: C, 76.57; H, 6.43. Found: C, 76.42; H, 6.47.

3-Methylpentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecane-8,11-dione (3c). Intramolecular photochemical cyclization of **2c** to **3c** was performed by using the method described above for the photolytic conversion of **2a** to **3a**. Compound **3c** prepared via this procedure was obtained as a colorless microcrystalline solid (85%): mp 175 °C; ^{1}H NMR ($CDCl_3$) δ 1.20 (s, 3 H), AB pattern centered at 1.92 (J_{AB} = 11 Hz, 2 H), 2.23–3.55 (m, 7 H); ^{13}C NMR ($CDCl_3$) δ 211.9 (s), 211.3 (s), 60.0 (d), 55.4 (d), 55.4 (d), 52.3 (s), 45.8 (t), 44.4 (d), 44.2 (d), 42.9 (d), 39.6 (d), 15.6 (q); IR (KBr) 2982 (s), 2962 (s), 2940 (s), 2918 (s), 2860 (s), 2820 (w), 1750 (vs), 1720 (vs), 1700 (sh, vs), 1447 (s), 1373 (m), 1313 (m), 1273 (s), 1240 (s), 1181 (s), 1118 (m), 1092 (m), 1057 (vs), 971 (m), 912 (m), 860 (m), 814 (w), 774 (w), 750 cm^{-1} (w); mass spectrum (70 eV), *m/e* (relative intensity) 189.1 (M + 1, 13.5), 188.1 (molecular ion, 100.0), 173.0 (8.6), 160.1 (15.5), 159.1 (11.2), 145.1 (32.8), 132.1 (27.9), 131.1 (25.3), 117.1 (91.7), 115.1 (29.4), 91.1 (26.1), 81.0 (6.5), 80.1 (36.1), 79.1 (14.4), 77.0 (15.9), 65.1 (7.8).

Anal. Calcd for $C_{12}H_{12}O_2$: C, 76.57; H, 6.43. Found: C, 76.84; H, 6.48.

In Situ Generation of 2-Nitrobenzoquinone and Diels–Alder Trapping with Cyclopentadiene. To a cooled (ice bath) suspension of dry silver(I) oxide[13] (11.94 g, 51.5 mmol) in benzene (50 mL) was added 2-nitrohydroquinone[19] (4.0 g, 25.8 mmol) followed by freshly cracked cyclopentadiene (1.70 g, 25.8 mmol). The ice bath was then removed, and the reaction mixture was stirred for 8 h after attaining room temperature. The reaction mixture was then filtered, and the residue was washed with ether. The combined filtrates were concentrated in vacuo. The resulting oil was then adsorbed on silica gel (100 g) and quickly extracted with 5% ethyl acetate–hexane solution (600 mL).[20] The extract was concentrated in vacuo, affording a mixture of two 1:1 Diels–Alder cycloadducts (2.25 g, 40%). Repeated fractional

(18) Compound **2a** was synthesized via Diels–Alder addition of cyclopentadiene to toluquinone.[7] The material thereby synthesized was recrystallized from methanol to afford a pale yellow microcrystalline solid, mp 61–63 °C (lit.[7] mp 62 °C).

(19) Baker, W.; Lothian, O. M. *J. Chem. Soc.* **1936**, *139*, 274.

(20) This procedure was necessitated by the instability of the Diels–Alder adducts toward silica gel (see text).

crystallization of the crude product from 20% ethyl acetate–hexane afforded pure **4** (1.41 g, 25%) as a pale yellow microcrystalline solid: mp 134–135 °C; ^{1}H NMR ($CDCl_3$) δ 6.80 (s, 2 H), 6.28 (dd, J = 2.5, 5.7 Hz, 1 H), 6.03 (dd, J = 2.5, 5.7 Hz, 1 H), 4.04 (m, 1 H), 3.62 (m, 2 H), 1.85 (m, 2 H); ^{13}C NMR ($CDCl_3$) δ 194.2 (s), 184.6 (s), 142.2 (d), 140.3 (d), 140.0 (d), 133.4 (d), 96.4 (s), 56.3 (d), 52.3 (d), 47.7 (t), 47.4 (d); IR (KBr) 3005 (w), 2990 (w), 1675 (s), 1660 (s), 1600 (w), 1540 (s), 1360 (m), 1280 (m), 1080 (m), 750 cm^{-1} (s); mass spectrum (70 eV), m/e (relative intensity) 219.8 (molecular ion, 0.8), 174.1 (10.2), 173.0 (83.2), 145.0 (27.0), 127.1 (30.0), 119.1 (9.1), 118.1 (12.0), 117.1 (100.0), 116.2 (22.1), 115.1 (95.8), 107.1 (40.3), 92.1 (10.8), 91.1 (94.8), 90.0 (15.3), 89.1 (32.4), 82.0 (16.2), 79.1 (24.2), 77.0 (15.9), 66.1 (66.3), 65.1 (80.5), 64.2 (12.8), 63.1 (36.5), 62.1 (13.6), 55.1 (15.9), 54.1 (41.1), 53.1 (35.3), 52.2 (7.4), 51.2 (26.1), 50.1 (14.6).

Anal. Calcd for $C_{11}H_9NO_4$: C, 60.28; H, 4.14. Found: C, 60.36; H, 4.19.

Repeated fractional crystallization of the mother liquor from 5% ethyl acetate–hexane afforded pure **5** (0.4 g, 7%) as a pale yellow microcrystalline solid: mp 107 °C; ^{1}H NMR ($CDCl_3$) δ 6.90 (s, 2 H), 6.50 (dd, J = 2.7, 5.7 Hz, 1 H), 6.20 (dd, J = 2.7, 5.7 Hz, 1 H), 3.70 (m, 1 H), 3.29 (m, 1 H), 3.06 (m, 1 H), 1.3–1.7 (m, 2 H); ^{13}C NMR ($CDCl_3$) δ 193.8 (s), 186.6 (s), 142.4 (d), 140.0 (d), 139.3 (d), 135.6 (d), 99.0 (s), 55.1 (d), 52.3 (d), 49.1 (d), 45.6 (t); IR (KBr) 2990 (w), 2960 (w), 1670 (s), 1610 (w), 1540 (s), 1345 (m), 1275 (m), 1110 (m), 1080 (m), 730 cm^{-1} (s); mass spectrum (70 eV), m/e (relative intensity) 219.1 (molecular ion, 1.0), 211.0 (5.6), 173.0 (7.0), 117.1 (8.8), 115.1 (14.4), 91.1 (25.0), 89.1 (6.4), 81.0 (8.0), 79.1 (5.9), 77.1 (6.8), 67.1 (6.9), 66.1 (100.0), 65.1 (25.5), 53.1 (5.6).

Anal. Calcd for $C_{11}H_9NO_4$: C, 60.28; H, 4.14. Found: C, 60.29; H, 4.16.

Further extraction of the products that remained adsorbed on silica gel using 20% ethyl acetate–hexane afforded a mixture of two 2:1 (diene:dienophile) Diels–Alder cycloadducts. This mixture was separated via column chromatography (silica gel adsorbent, 10% ethyl acetate–hexane eluent). The first material thereby collected was a colorless microcrystalline solid, mp 157 °C (**6**, 0.22 g, 2%). Compound **6** could also be obtained via Diels–Alder addition of **4** to cyclopentadiene: ^{1}H NMR ($CDCl_3$) δ 6.53 (dd, J = 2, 5 Hz, 1 H), 6.0–6.3 (m, 3 H), 3.9 (m, 1 H), 3.4 (m, 4 H), 3.0 (m, 2 H), 1.3–2.0 (m, 4 H); ^{13}C NMR ($CDCl_3$) δ 206.4 (s), 200.8 (s), 140.0 (d), 137.0 (d), 136.7 (d), 132.8 (d), 102.6 (s), 60.1 (d), 54.4 (d), 52.9 (d), 52.7 (d), 51.1 (t), 48.7 (d), 47.2 (t), 46.6 (d), 46.2 (d); IR (KBr) 2990 (m), 1690 (s), 1550 (s), 1365 (w), 1195 (m), 1060 (m), 705 cm^{-1} (s); mass spectrum (70 eV), m/e (relative intensity) 240.0 (10.6), 239.0 (94.7), 238.0 (14.4), 237.0 (100.0), 211.0 (16.9), 208.9 (18.6), 159.0 (14.7), 158.0 (31.0), 157.0 (24.2), 141.0 (18.6), 131.0 (9.4), 130.0 (59.5), 129.0 (81.4), 128.1 (21.9), 127.1 (10.0), 116.2 (10.6), 115.1 (46.9), 78.1 (22.2), 77.1 (18.6), 66.1 (23.4), 65.1 (12.1).

Anal. Calcd for $C_{16}H_{15}NO_4$: C, 67.36; H, 5.30. Found: C, 67.14; H, 5.36.

Continued extraction of the silica gel column with 15% ethyl acetate–hexane afforded the second 2:1 cycloadduct as a colorless microcrystalline solid (**7**, 0.4 g, 4%), mp 151–152 °C dec. Compound **7** could also be obtained via Diels–Alder addition of **5** to cyclopentadiene: ^{1}H NMR ($CDCl_3$) δ 5.9–6.6 (m, 4 H), 3.7 (br s, 1 H), 3.48 (s, 4 H), 3.3 (br s, 1 H), 2.9 (d, J = 2.5 Hz, 1 H), 1.2–2.4 (m, 4 H); ^{13}C NMR ($CDCl_3$) δ 205.7 (s), 199.6 (s), 140.3 (d), 137.1 (d), 136.9 (d), 136.4 (d), 104.5 (s), 59.2 (d), 53.6 (d), 52.6 (d), 52.5 (d), 50.5 (d), 47.5 (t), 46.9 (d), 46.4 (d), 45.2 (t); IR (KBr) 2990 (w), 1690 (s), 1535 (s), 1350 (m), 1240 (m), 1170 (m), 705 cm^{-1} (s); mass spectrum (70 eV), m/e (relative intensity) 285.3 (molecular ion, 0.1), 189.0 (48.4), 161.1 (28.5), 133.0 (80.5), 119.1 (16.9), 115.1 (28.8), 105.1 (100.0), 103.1 (22.4), 91.1 (19.9), 79.2 (25.8), 78.1 (13.0), 77.1 (26.4), 65.1 (7.7), 55.2 (15.0), 51.2 (8.3).

Anal. Calcd for $C_{16}H_{15}NO_4$: C, 67.36; H, 5.30. Found: C, 67.57; H, 5.35.

9-Nitropentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecane-8,11-dione (8). A solution of **4** (0.05 g, 0.2 mmol) in acetone was purged with nitrogen and irradiated with a sunlamp (1 h). Solvent was then removed from the reaction mixture in vacuo, and the residue was washed with dry ether, affording a colorless microcrystalline solid, mp 110 °C dec. This material was found to be a mixture of **8** and its corresponding hydrate: ^{1}H NMR ($CDCl_3$) δ 2.6–4.2 (m, 10 H), 1.65 (s, 2 H); IR (KBr) 3420 (m), 2990 (w), 1720 (s), 1680 (s), 1540 (s), 1370 (s), 740 cm^{-1} (s); high-resolution mass spectrum calcd for $C_{11}H_9NO_4$ molecular ion m/e 219.0532, found 219.0524; calcd for $C_{11}H_9NO_4 \cdot H_2O$, molecular ion m/e 237.0638, found 237.0634.

Table I. Crystallographic Data

a. Preliminary Information

formula	$C_{12}H_{12}O_2$	
M_r	188.23	
ρ_c, g cm^{-3}	1.382	
ρ_m	1.37	
space group	$P2_1/n$	
temperature, K	294 (2)	138 (2)
a, Å	9.933 (2)	9.8547 (7)
b, Å	11.576 (2)	11.4664 (9)
c, Å	7.865 (2)	7.8100 (6)
β, deg	90.00 (2)	90.231 (7)
V, Å^3	904.4	882.5
radiation	Mo Kα_1	Cu Kα_1

b. Intensity Data and Results

radiation	Cu K$\bar{\alpha}$ (λ = 1.5418)
data limit	$2\theta < 150°$
scan method	$\omega/2\theta$
temperature	138 (2) K
unique data	1813
R	0.044
R_w	0.062
maximum on final difference electron density map	0.29

4a-Nitro-1,4,4a,8a-tetrahydro-*endo*-1,4-methanonaphthalene-5,8-diol (9). To a 0.4 M solution of cerous chloride in methanol (4.5 mL, 1.8 mmol) at room temperature was added **4** (0.2 g, 0.9 mmol). Sodium borohydride (0.070 g, 1.8 mmol) was then added portionwise with stirring to the reaction mixture. After the addition of sodium borohydride had been completed, the reaction mixture was stirred for an additional 5 min, and then it was quenched with water (20 mL). The resulting mixture was extracted with ether (50 mL). The combined ethereal extracts were dried (anhydrous Na_2SO_4) and filtered, and the filtrate was concentrated in vacuo. An analytical sample of **9** was prepared via repeated recrystallization of the residue thereby obtained from chloroform–ether mixed solvent. Pure **9** was obtained as a colorless microcrystalline solid: 0.15 g, 75%; mp 145–146 °C; ^{1}H NMR ($CDCl_3$) δ 6.01 (dd, J_1 = 3 Hz, J_2 = 5 Hz, 1 H), 5.8 (dd, J_1 = 3 Hz, J_2 = 5 Hz, 1 H), 5.42 (d, J = 1 Hz, 2 H), 4.4–4.75 (m, 2 H), 3.6–3.8 (m, 2 H), 3.0–3.2 (m, one exchangeable proton, 2 H), 2.11 (br s, exchangeable proton, 1 H), 1.5 (m, 2 H); ^{13}C NMR (acetone-d_6) δ 141.0 (d), 133.7 (d), 131.6 (d), 131.2 (d), 104.3 (s), 72.4 (d), 66.1 (d), 50.9 (d), 48.1 (d), 48.1 (t), 45.0 (d); IR (KBr) 3380 (s), 1525 (s), 1345 (s), 705 cm^{-1} (s).

Anal. Calcd for $C_{11}H_{13}NO_4$: C, 59.19; H, 5.87. Found: C, 59.16; H, 5.77.

1,4-Dihydro-1,4-methano-5,8-naphthoquinone (10). A small alumina column was charged with **4** (0.050 g, 0.23 mmol) and eluted with 10% ethyl acetate–hexane. The eluate was concentrated in vacuo, affording a yellow microcrystalline solid: 40 mg, 100%; mp 68–69 °C (lit.[21] mp 70 °C); ^{1}H NMR ($CDCl_3$) δ 6.8 (m, 2 H), 6.6 (s, 2 H), 4.1 (m, 2 H), 2.3 (m, 2 H); ^{13}C NMR ($CDCl_3$) δ 183.5 (s), 160.3 (s), 142.3 (d), 135.5 (d), 73.5 (t), 48.1 (d); IR (film) 1635 (s), 1577 (m), 1552 (w), 1230 (m), 832 (m), 730 cm^{-1} (m).

Single-Crystal X-ray Structural Analysis of 3c. A summary of the crystallographic data is listed in Table I. The unit cell parameters were determined from a least-squares fit of the $\pm 2\theta$ values of 40 reflections distributed throughout reciprocal space. The measurement of the density by floatation in aqueous KI was hampered by the apparent reaction of the material with water. Lattice constants and intensity data were measured on a Enraf-Nonius CAD-4 diffractometer. Three intensity monitors, remeasured after every 2 h of X-ray exposure, showed an overall change of 4.8%. Of the 1813 unique data, 147 had measured intensities with $I < 2\sigma(I)$. These weak data were assigned $I = \sigma(I)$.

(21) Diels, O.; Alder, K. *Chem. Ber.* **1929**, *62*, 2354.

All non-hydrogen atoms were located on an E map based upon 256 data with the largest E values.[22] The structure was refined by using SHELX[23] with weights of $w = \sigma^{-2}(F)$. Hydrogen atoms were located on a difference electron density map. An analysis of the variance after refinement of the data revealed no systematic variation of $\sum w(|F_o| - |F_c|)^{11}$ with either sin θ or F. The scattering factors for C and O were from Cromer and Mann[24] and the scattering factors for H were from Stewart, Davidson, and Simpson.[25] Atomic parameters, bond angles, and observed and calculated structure factors are included in the supplementary material.

Acknowledgment. We thank Dr. P. R. Pednekar (University of Alberta) for kindly obtaining the high-resolution mass spectrum of 8. Financial support of our study by the United States Army Armament Research and Development Command, the Naval Air Systems Command, The Robert A. Welch Foundation (Grant B-963), and the North Texas State University Faculty Research Committee is gratefully acknowledged. The X-ray crystallographic structure determination of **3c** was supported in part by a grant from the DHHS, National Cancer Institute, CA17562 (to D.v.d.H.); we also thank the University of Oklahoma Computing Center for providing computing facilities and service in this connection.

Supplementary Material Available: A list of atomic parameters, bond angles, and observed and calculated structure factors for **3c** (11 pages). Ordering information is given on any current masthead page.

(22) Main, P.; Fiske, S. J.; Hull, S. E.; Lessinger, L.; Germain, G.; Declercq, J.-P.; Woolfson, M. M. "MULTAN 80, A System of Computer Programs for the Automatic Solution of Crystal Structures from X-ray Diffraction Data"; Universities of York, England, and Louvain-la-Neuve, Belgium, 1980.
(23) Sheldrick, G. M. "SHELX 76. Program for Crystal Structure Determination"; University Chemical Laboratory: Cambridge, England, 1976.
(24) Cromer, D. T.; Mann, J. B. *Acta Crystallogr., Sect. A* **1968**, *A24*, 321-324.
(25) Stewart, R. F.; Davidson, E. R.; Simpson, W. T. *J. Chem. Phys.* **1965**, *42*, 3175-3187.
(26) Johnson, C. K. "ORTEP"; Report ORNL-3794 revised; Oak Ridge National Laboratory: Oak Ridge, TN, 1971.

Enantioselective Ester Hydrolyses Employing *Rhizopus nigricans*. A Method of Preparing and Assigning the Absolute Stereochemistry of Cyclic Alcohols

Masaji Kasai,[1a] Ken-ichi Kawai,[1b] Mitsuru Imuta,[1c] and Herman Ziffer*

Laboratory of Chemical Physics, Department of Health and Human Services, Public Health Service, Bethesda, Maryland 20205

Received July 15, 1983

The mold *Rhizopus nigricans* has been used to hydrolyze enantioselectively the acetates of several series of benzocycloalken-3-ols and 2-substituted cycloalkanols to yield chiral alcohols. The configurations of the alcohols formed were established. The absolute stereochemistries of 25 of the 26 alcohols obtained were found to conform to a generalization based on the effective sizes of substituents on the carbinol carbon. The relative sizes of substituents required for agreement were identical with those employed in Horeau's method of establishing the absolute stereochemistry of the same compounds. The use of these microbially mediated hydrolyses to assign the absolute stereochemistry of cyclic secondary alcohols is compared to Horeau's method and to the use of empirical relations between the absolute stereochemistry of an enantiomer and the order, relative to its antipode, in which it is eluted from a chiral (Pirkle) column.

Recently we have shown[2,3] that the mold *Rhizopus nigricans* could be used to hydrolyze a series of racemic 1-arylalkyl acetates to yield alcohols enriched in one enantiomer, while the recovered acetate is enriched in the antipode. The absolute stereochemistry of the alcohol formed could be predicted by using a rule which states that the enantiomer shown in Figure 1, where R_1 is larger than R_2, is the one more rapidly hydrolyzed. In the acyclic series the aromatic ring (carbocyclic or heterocyclic) is always R_1 and an alkyl group (including tert-butyl) R_2. In addition to providing a new method for assigning the configurations of 1-arylalkanols, these hydrolyses can also be used in the preparation of synthetically useful amounts of chiral alcohols. These findings prompted us to examine the ability of *R. nigricans* to hydrolyze acetates of cyclic carbinols and to determine whether the rule accounts for the absolute stereochemistry of the alcohols formed. Since we wanted to examine as many compounds as possible and since it was important to compare our results with published information, substrates were chosen which satisfy the following criteria: (1) the absolute stereochemistry of the alcohol should be known; (2) it should be possible to compare the relative sizes of the same substituents in two series of esters in order to determine whether the relative sizes established in one series could be used in another one; (3) some of the alcohols should have been studied previously by Horeau's method[4] to provide an independent estimate of the relative sizes of substituents on the carbinol carbon; (4) in order to establish the general utility of the method some of the substrates studied should be alicyclic acetates.

Results

In probing the ability of *R. nigricans* to hydrolyze acetates of cyclic alcohols to yield chiral carbinols of a pre-

(1) (a) On leave from Kyowa Hakko Kogyo Co., Ltd., Tokyo Research Laboratory, 3-6-6 Asahi-machi, Machidashi, Tokyo, 194 Japan. (b) Hoshi College of Pharmacy, 2-4-41, Ebara, Shinagawa-Ku, Tokyo, 142 Japan. (c) Shionogi Research Laboratory, Shionogi and Co., Ltd., Fukushima-Ku, Osaka, 553 Japan.
(2) Ziffer, H.; Kawai, K.; Kasai, M.; Imuta, M.; Froussios, C. *J. Org. Chem.* **1983**, *26*, 3017.
(3) Kawai, K.; Imuta, M.; Ziffer, H. *Tetrahedron Lett* **1981**, *22*, 2527.
(4) Horeau, A. "Stereochemistry Fundamentals and Methods"; George Thieme Verlag: Stuttgart, 1977; Vol. 3, pp 51-94.

This article not subject to U.S. Copyright. Published 1984 by the American Chemical Society