The Octant Rule. 15.[1] Antioctant Effects: Synthesis and Circular Dichroism of 2-*exo*- and 2-*endo*-Alkylbicyclo[2.2.1]heptan-7-ones and -bicyclo[3.2.1]octan-8-ones

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Circular dichroism spectra of the n → π* transition of alkylbicyclo[2.2.1]heptan-7-ones and alkylbicyclo-[3.2.1]octan-8-ones have helped to define the boundary separating front and back octants in the ketone octant rule. Series of (1*S*,4*R*)-*exo*-2(*R*)-alkylbicyclo[2.2.1]heptan-7-ones and (1*S*,4*R*)-*endo*-2(*S*)-alkylbicyclo[2.2.1]-heptan-7-ones were prepared and their circular dichroism (CD) spectra measured and compared with (1*S*,3*R*)-4(*S*)(a)- and -4(*R*)(e)-methyladamantan-2-ones. The alkyl groups include methyl, ethyl, and *n*-hexyl. Similarly, (1*R*,5*S*)-*exo*-6(*R*)- and -*endo*-6(*S*)-methylbicyclo[3.2.1]octan-8-ones were synthesized and their CD spectra determined. The CD Cotton effects for the n → π* transitions of these ketones aid in defining the third nodal surface of the octant rule as convex, bending outward from behind the carbonyl carbon toward oxygen. The ring skeletal symmetry was examined by molecular mechanics (MM2) calculations, which located the coordinates (positions) of lone dissymmetric methyl groups relative to the carbonyl group. ^{13}C NMR spectroscopy confirmed the methyl group locations and provided additional new examples of the γ-gauche effect.

The octant rule[2,3] has long been recognized as a powerful chirality rule for predicting (1) the absolute configuration of ketones, given a knowledge of conformation, or (2) the conformation, given the absolute configurations. It has been successfully applied to saturated alkyl ketones with (often many) perturbers in back octants, and there have been relatively few anomalies, the most notable of which include twistanone, 3-oxo-5β-steroids and, especially, 3-(a)-methylcyclohexanone (as seen in 4(a)-methyladamantan-2-one).[4] The orginally formulated octant rule[2] stated that the space surrounding the carbonyl chromophore of an optically active ketone is divided into eight regions (octants) by (i) the two symmetry planes (*XZ* and *YZ*, Figure 1) of the isolated (C_{2v}) chromophore, and (ii) by a third plane (*A*, Figure 1) perpendicular to and bisecting the C=O bond. If these three planes are taken to define a Cartesian coordinate system, then the sign of the contribution made by an alkyl substitutent to the observed n → π* CE is determined by the sign of the product $X \cdot Y \cdot Z$ of the atomic coordinates. Atoms lying on symmetry planes make no contribution, and atoms having counterparts symmetrically disposed across the carbonyl symmetry planes will exert no effect on the circular dichroism (CD) due to cancellation.

The adamantanone system possesses an especially attractive molecular framework for chirality rule studies. It is rigid, with a well-defined chair cyclohexanone moiety, and it is also symmetric and therefore provides an excellent model for isolating and examining individual effects in detail. Thus, Snatzke et al.[5] were able to confirm with a wide variety of substituents that β-equatorially substituted adamantanones made the expected, normal octant contributions (consignate[6]) but that β-axially substituted adamantanones did not (dissignate[6]) when the substituents were Cl, Br, I, N_3, or CH_3. The methyl group, however, was a dissignate perturber in polar solvents and a consignate perturber in hydrocarbon solvents. We recently reexamined the β-methyladamantanones and showed that at low temperatures the β-axial methyl group makes a strong dissignate contribution, independent of solvent.[7] The extreme sensitivity of the β-axial methyl group is also observed in thioadamantanone and is explained in both cases by restricted rotation and vibronic effects of the β-axial methyl group, which is located very close to, or possibly in front of an octant nodal surface.[8]

In order to explore further the peculiar "antioctant" (or dissignate) effects of the β-methyl group in a stereochemically well-defined environment, we prepared and examined the epimeric 2-methylbicyclo[2.2.1]heptan-7-ones (**1** and **2**). Here, as in the adamantanones, the bicyclo-[2.2.1]heptan-7-one framework is symmetric. It is also fairly rigid and therefore serves as a useful system for isolating and studying the properties of individual perturbers. Interestingly, the relative displacements of carbonyl and β-methyl groups are very similar in the two systems, a fact that made the bicyclic model an especially attractive one to us. In our preliminary work, we showed that, as anticipated, the 2-*endo*-CH_3 makes a consignate octant contribution, paralleling the behavior of β(equatorial)-CH_3 of adamantanone or cyclohexanone.[4] However, at room temperature the 2-*exo*-CH_3 makes a moderately strong dissignate or "antioctant" contribution in polar and nonpolar solvents. This behavior was especially intriguing because the *exo*-CH_3 and β(axial)-CH_3 are very similarly located relative to their respective carbonyl groups. In the current work we have extended our investigations in the bicyclo[2.2.1]heptan-7-one system to 2-ethyl (**3** and **4**) and *n*-hexyl perturbers (**5** and **6**), which may stretch farther into octant space. And in order to probe the nature of the third nodal octant surface by further varying the location of a methyl perturber, we synthesized the epimeric 6-methylbicyclo[3.2.1]octant-8-ones (**11** and **12**),[9] in which the *exo*-CH_3 perturber lies farther behind the carbonyl

(1) For Part 14, see: Crist, B. V.; Lightner, D. A. *Tetrahedron*, in press.
(2) Moffitt, W.; Woodward, R. B.; Moscowitz, A.; Klyne, W.; Djerassi, C. *J. Am. Chem. Soc.* **1961**, *83*, 4013–4018.
(3) Bouman, T. D.; Lightner, D. A. *J. Am. Chem. Soc.* **1976**, *98*, 3145–3154.
(4) For leading references, see: Lightner, D. A.; Jackman, D. E. *J. Am. Chem. Soc.* **1974**, *96*, 1938–1939.
(5) (a) Snatzke, G.; Eckhardt, G. *Tetrahedron* **1968**, *24*, 4543–4558. (b) Snatzke, G.; Ehrig, B.; Klein, H. *Tetrahedron* **1969**, *25*, 5601–5609.
(6) (a) Klyne, W.; Kirk, D. N. *Tetrahedron Lett.* **1973**, 1483–1486. (b) Kirk, D. N.; Klyne, W. *J. Chem. Soc. Perkin Trans 1* **1974**, 1076–1103.
(7) Lightner, D. A.; Wijekoon, W. M. D. *J. Org. Chem.* **1982**, *47*, 306–310.
(8) Lightner, D. A.; Bouman, T. D.; Wijekoon, W. M. D.; Hansen, Aa, E. *J. Am. Chem. Soc.* **1984**, *106*, 934–944.
(9) Rodgers, S. L.; Kalyanam, N.; Lightner, D. A. *J. Chem. Soc., Chem. Commun.* **1982**, 1040–1042.

0022-3263/85/1950-3867$01.50/0

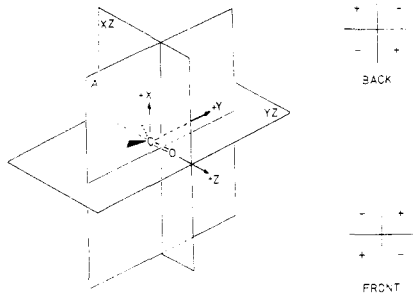
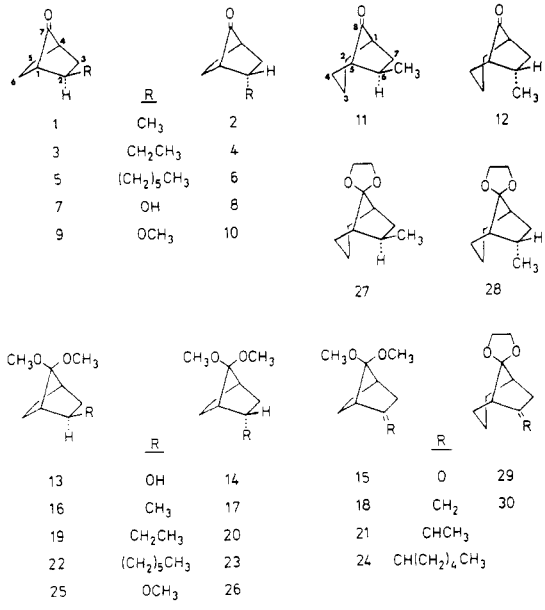


Figure 1. Classical octant diagram for the n → π* transition of the ketone carbonyl chromophore. With an origin at the C=O carbon, all space is divided into quadrants by the local C_{2v} symmetry derived planes *XZ* and *YZ*, and then divided again into octants by a surface (*A*) which was approximated as a plane intersecting the C=O bond (see footnotes 4 and 17 of ref 2). Atoms lying in the octants make contributions to the n → π* Cotton effect whose signs are given by the product *X*·*Y*·*Z* of the coordinates, as shown to the right of the Figure, for back octants (behind *A*) and front octants (in front of *A*).

Chart I

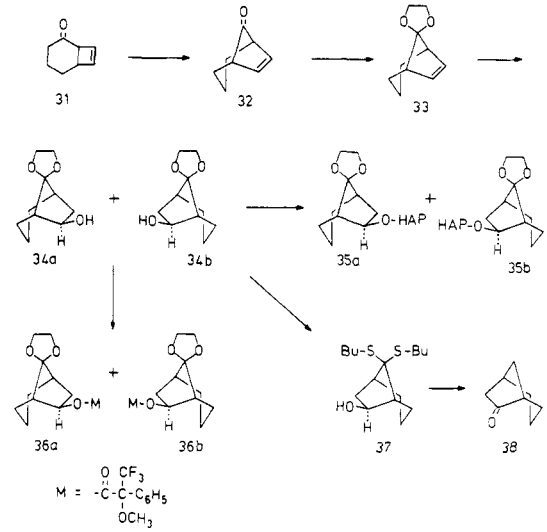


carbon than in either the bicyclo[2.2.1]heptan-7-one analogue or β(axial)-methyladamantanone. This collection of compounds provides new evidence that the third nodal surface lies behind the carbonyl carbon (as viewed from oxygen toward carbon) and that the so-named "antioctant" contributions of these perturbers are in fact octant consignate for ordinary front octant perturbers.

Results and Discussion

Synthesis and Stereochemistry. Optically active 2-methyl-, 2-ethyl-, and 2-*n*-hexylbicyclo[2.2.1]heptan-7-ones (**1–6**) were prepared from optically active 7,7-dimethoxybicyclo[2.2.1]heptan-2-one (**15**) of known absolute configuration.[10] Reaction of **15** with the appropriate triphenylphosphonium alkylide afforded the alkylidene derivatives **18**, **21** and **24**, which were reduced catalytically to give the corresponding mixtures of *exo*- and *endo*-alkyl-7,7-dimethoxybicyclo[2.2.1]heptanes (**16** + **17**, **19** + **20**, **22** + **23**). The major epimer was always the exo, and the exo/endo ratio varied from 10:1 to 3:1 depending on the alkylidene group as well as choice of catalyst and solvent

Scheme I



(see, e.g., Table V of the Experimental Section). In each case the mixture of epimers could be separated by preparative gas chromatography at the ketal stage (**16** + **17**, **19** + **20**, **22** + **23**) or at the ketone stage (**1** + **2**, **3** + **4**, **5** + **6**) following deketalization in aqueous acetic acid–concentrated HCl.

Our efforts to prepare bicyclo[2.2.1]heptan-2-ones with 2-hydroxy and 2-methoxy perturbers were not entirely successful, owing at least in part to the sensitivity of these substances to acid-catalyzed rearrangement during deketalization. The *exo*-hydroxy ketone (**7**) could be obtained by careful deketalization of the dimethoxy ketal (**13**),[10] and the *exo*-methoxy ketone (**9**) could be obtained similarly from its precursor ketal (**25**), which was prepared from by reaction of the alkoxide of **13** with CH_3I. Although we could prepare the *endo*-hydroxy ketal (**14**) in high yield via Meerwein–Ponndorf–Verley reduction of ketone **15**, and could prepare its methyl ether derivative (**26**), attempts to deketalize proved unrewarding. Deketalization of the endo epimers appears to be inherently slower than with the exo epimers,[11] and the more forcing conditions used to effect their deketalization lead to rapid destruction of the derived ketones. The success in deketalizing the exo epimers under mild conditions appears to reflect[9] steric acceleration[11] that alleviates a 1,3-diaxial-like interaction of the 2-exo group with the *syn*-OCH_3 at C-7.

The less common bicyclo[3.2.1]octan-8-one system proved to be a more difficult synthetic objective. Our target molecule was the ketal (**33**) of bicyclo[3.2.1]oct-6-en-8-one (**32**), which was unknown at the time we started this work, as was a facile synthesis of the parent ketone. Cargill and Crawford had reported on the acid-catalyzed thermal rearrangement of *cis*-bicyclo[4.2.0]oct-7-en-2-one (**31**) to **32** by passing small quantities of gaseous **31** through a column of acid-washed alumina at 200 °C,[12] and it seemed likely that a preparative scale acid-catalyzed rearrangement of **31** in solution might be found. We modified to large scale the previously reported preparation of ketone **31** which involved synthesis of 2-cyclohexenone[13] and photochemical cycloaddition[14] with *trans*-1,2-di-

(10) Lightner, D. A.; Gawroński, J. K.; Bouman, T. D. *J. Am. Chem. Soc.* **1980**, *102*, 1983–1990.

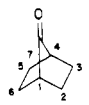
(11) Bicyclo[2.2.1]heptan-7-one ketals are very resistant to acid-catalyzed deketalization, presumably because of increased strain associated with rehybridization at C-7; However 2-*exo*-methyl substituents have been reported to accelerate the deketalization rate. Jung, M. L.; Radcliffe, C. D. *Tetrahedron Lett.* **1980**, *21*, 4397–4400.

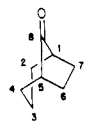
(12) Cargill, R. L.; Crawford, J. W. *J. Org. Chem.* **1970**, *35*, 356–359.

(13) Garbisch, E. W., Jr. *J. Org. Chem.* **1965**, *30*, 2109–2120.

(14) House, H. O.; Cronin, T. H. *J. Org. Chem.* **1965**, *30*, 1061–1070.

Table I. Comparison of Selected Internal and Torsion Angles Calculated of Bicyclo[2.2.1]heptan-7-ones, Bicyclo[3.2.1]octan-8-ones and Chair Cyclohexanone from MM2[a] Molecular Mechanics Calculations

	torsion angle, deg								internal angle, deg
							β		
	φ(3,4) (1-2-3-4)	(x-2-3-x)[b]	(n-2-3-n)[b]	φ(5,6) (1-6-5-4)	(x-6-5-x)[b]	(n-6-5-n)[b]	(O-7-1-H_1)	(O-7-1-H_4)	(1-7-4)
	0.000	0.000	0.000	0.000	0.000	0.000	−0.142	0.127	97.13
2-*exo*-CH_3	2.259	5.361	5.658	1.770	2.147	2.357	−0.238	0.298	97.17
2-*endo*-CH_3	−2.708	−8.125	−7.207	2.353	3.239	4.137	−0.069	0.062	97.16

	torsion angle, deg										
	φ(6,7) (1-6-7-5)	(x-7-6-x)[b]	(n-6-7-n)[b]	φ(1,8) (2-1-8-5)	φ(5,8) (1-8-5-4)	φ(2,3) (1-2-3-4)	φ(3,4) (2-3-4-5)	(H_5-5-8-O)	(H_1-1-8-O	(1-8-5)	(2-3-4)
	0.023	0.024	0.024	−73.32	72.32	−44.61	44.62	13.89	−13.89	104.1	112.2
2-*exo*-CH_3	0.905	4.066	4.635	−72.38	72.46	−44.22	44.56	13.23	−13.79	104.2	112.2
2-*endo*-CH_3	−9.609	−16.39	−15.91	−74.77	72.06	−43.11	41.19	12.72	−15.83	104.1	112.8

	torsion angle, deg							
	(3-2-1-6)	(2-1-6-5)	(2-3-4-5)	(3-4-5-6)	(H_{6e}-2-1-0)	(H_{2e}-2-1-0)	(2-1-6)	(3-4-5)
	−51.51	51.51	−57.51	57.51	8.889	−8.892	115.4	110.9

[a] See ref 17. Limited certainty in the values begin with the fourth significant figure. [b] An exo group is abbreviated x; an endo group is abbreviated n.

chloroethylene, ketalization of the bicyclic adduct with ethylene glycol followed by Na/liquid NH_3 dechlorination, and ketalization. Because our objective was to prepare the ketal (**33**), we first explored ketal to ketal rearrangement conditions starting from the ketal of **31**. Although many different reagents and conditions were tried, inter alia $SnCl_4/CCl_4$, $BF_3{\cdot}Et_2O/CCl_4$, *p*-toluenesulfonic acid/benzene, all led to rearrangement products other than the desired ketal (**33**). Consequently, we focussed on the ketone (**31**) to ketone (**32**) rearrangement. After considerable experimentation, successful conversion was achieved with a catalytic amount (5 mol %) of freshly distilled $BF_3{\cdot}Et_2O$ in refluxing dry benzene. The sensitive ketone product (**32**) could be converted to its ethylene ketal (**33**) with ethylene glycol and *p*-toluenesulfonic acid catalyst in hot benzene, but a more efficient synthesis was developed for converting **31** to **33** via **32** in one reaction pot by first allowing the **31** to **32** rearrangement to proceed in cold benzene with excess $BF_3{\cdot}Et_2O$, followed by addition of ethylene glycol to the reaction.

The conversion of **33** to methylketones **11** and **12** parallels the conversion of 7,7-dimethoxybicyclo[2.2.1]heptene to **1** and **2**. Introduction of an *exo*-hydroxyl group was accomplished stereospecifically as before[10] by oxymercuration of **33**. The resulting racemic hydroxy ketal (**34**) was converted to its half-acid phthalate (**35**) and resolved as the salt with (+)-α-(1-naphthyl)ethylamine. The enantiomeric excess of the resolved hydroxy ketal was accomplished by derivatization as the Mosher ester (**36**) with the acid chloride of (+)-(*R*)-α-methoxy-α-(trifluoromethyl)acetic acid followed by integration of the separated diastereotopic CF_3 by ^{19}F NMR resonances.[10,15] The (−)-alcohol was assigned absolute configuration **34a** in LIS NMR experiments on **36**, where the ^{19}F signal of the predominant enantiomer (**36a**) was faster moving upon addition of $Eu(fod)_3$.[15] Confirmation of this assignment was made by converting (+)-alcohol (**34b**) to bicyclo[3.2.1]octan-6-one (**38**) of known absolute configuration[16] by a sequence of reactions[10] involving transthioketalization (**34b** → **37**) followed by Ni(R) desulfurization and Jones oxidation.

Oxidation of optically active ketal **34a** afforded the corresponding ketone **29**, which was converted to the methylene ketal (**30**) as previously for **15** → **18**. Catalytic hydrogenation of **30** in pentane with Pd(C) gave a ~2:1 endo:exo ratio of methyl ketals **27** and **28**. These were smoothly deketalized to give a mixture of the desired ketones (**11** + **12**), which were separated by preparative gas chromatography.

Molecular Geometry. Because analysis of spectral data, especially circular dichroism and ^{13}C NMR, is assisted by a clear picture of molecular structure, we investigated the molecular structures of the methyl ketones (**1**, **2**, **11**, and **12**) with molecular mechanics (MM2)[17] calculations. Our primary interest was to learn (1) whether the ring skeletons were seriously desymmetrized by introduction of a methyl group and (2) the exact locations of the methyl groups relative to a carbonyl carbon origin. Thus, as seen in the internal torsion angles, φ(3,4) and φ(5,6) (Table I), MM2 calculations show that very little ring distortion (relative to the parent unsubstituted, symmetric ketone) is realized when either an *exo*- or *endo*-CH_3 is introduced at C-2 in bicyclo[2.2.1]heptan-7-one. Introduction of a CH_3 leads to a $CH_3|H$ eclipsing interaction with an H at C_3, and this interaction is minimized by small torsion angle deformations about the C_2–C_3 bond. The *exo*-CH_3 is tilted slightly toward the carbonyl group, whereas the *endo*-CH_3 is tilted slightly away from C-6. The eclipsing interaction is somewhat alleviated by increasing

(15) For leading references see: Kalyanam, N.; Lightner, D. A. *Tetrahedron Lett.* **1979**, 415–418.

(16) Numata, A.; Suzuki, T.; Ohno, K.; Uyeo, S. *Yakugaku Zasshi* **1968**, *88*, 1298–1305.

(17) Allinger, N. L.; Yuh, Y. Y. *QCPE* 423 (adapted for CDC by S. Profeta), Quantum Chemistry Program Exchange, Indiana University, Bloomington, IN.

the *syn*-CH_3–C_2–C_3–H torsion angles by 5–8° and the internal torsion angles $\phi(2,3)$ and $\phi(5,6)$ by an even smaller (~2°) quantity. These small deformations from the symmetry of the parent ketone are the result of only very minor changes in ring carbon and hydrogen positions, and they are not viewed as being important in octant rule considerations.

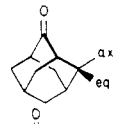
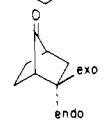
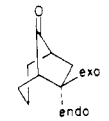
Bicyclo[3.2.1]octan-8-one presents a potentially more flexible ring system. Its cyclohexanone ring is pinched together at the α-carbons resulting in an ~11° smaller carbonyl internal angle (C_1–C_8–C_5) than that of cyclohexanone, but it is also more relaxed (by ~7°) than the carbonyl internal angle (C_1–C_7–C_4) of bicyclo[2.2.1]heptan-7-one (Table I). Compression of the carbonyl internal angle (relative to cyclohexanone) does not, however, result in a major opening of the opposing internal angle, cf. C_2–C_3–C_4. As expected, the cyclohexanone ring of the bicyclo[3.2.1]octan-8-one system experiences a major ring puckering (relative to cyclohexanone) in the vicinity of its carbonyl group, cf. $\phi(1,8)$ or $\phi(5,8)$, vs. the corresponding torsion angles of cyclohexanone 3–2–1–6 and 2–1–6–5. And it experiences a major flattening across the ring from the carbonyl, cf. $\phi(2,3)$ or $\phi(3,4)$—the antireflex effect[18] previously described for bicyclo[3.2.1]octan-3-one.[19] Addition of an *exo*-CH_3 to C-6 produces only a very minor change in the symmetry of the parent carbocyclic ring system as can be seen in the internal torsion angle $\phi(6,7)$, where deformities should be most easily detected. This behavior parallels that observed in the bicyclo[2.2.1]heptan-7-one system, and both results are important because the *exo*-CH_3 is expected to lie very close to the octant third nodal surface and make only a small contribution to the Cotton effect.

Unlike the bicyclo[2.2.1]heptan-7-one system, however, when an *endo*-CH_3 is introduced at C_6 in bicyclo[3.2.1]-octan-8-one, much larger ring distortion is observed for groups about C_6–C_7. The *endo*-CH_3 tilts sharply away from C_4 across the ring, and the internal torsion angle $\phi(6,7)$ accomodates the tilting by moving ~10° out of planarity. This may be contrasted with much smaller (~3°) distortion from planarity about the equivalent torsion angle, $\phi(3,4)$, in 2-*endo*-methylbicyclo[2.2.1]heptan-7-one. These findings suggest that where symmetry considerations are important, as in the interpretation of circular dichroism spectra, ring distortion in the bicyclo-[3.2.1]octan-8-one system should be taken into account.

The coordinates of the methyl carbons of **1**, **2**, **11**, and **12** may be obtained from the MM2 energy-minimized molecular geometries and compared with those similarly obtained for 4-methyladamantan-2-ones (Table II). Interestingly, the locations of the *exo*- and β(axial)-methyl groups are nearly invariant in the *X* and *Y* directions, in agreement with estimation that the *exo*-CH_3 is a good model for β-axial. The major differences lies in the *Z* direction (along the C=O axis): the *Z* coordinates reveal that the *exo*-CH_3 group of **1** lies ~0.3 Å farther behind the C=O carbon than the β(axial)-CH_3 group, and the *exo*-CH_3 group of **11** lies ~0.6 Å farther behind. These data suggest that if a β(axial)-CH_3 group on adamantanone lies just in front of an octant nodal surface,[3,7,8] the *exo*-CH_3 groups of **1** and **11** might lie behind it.

In contrast with the above, the location of the equatorial CH_3 of 4(e)-methyladamantanone relative to the C=O is poorly modeled by the *endo*-CH_3 of **2** and **12**. The *endo*-CH_3 groups lie in nearly equivalent locations, but they are also nearly 1 Å closer to the *Y* axis and ~0.7 Å farther from the *Z* axis than the β(equatorial)-CH_3. All these CH_3 groups, however, lie well behind the C=O carbon and thus firmly in a back octant.

Table II. Coordinates[a] of Methyl Carbons in 4-Methyladamantan-2-ones, 2-Methylbicyclo[2.2.1]heptan-7-ones (1 and 2), and 6-Methylbicyclo[3.2.1]octan-8-ones (11 and 12) from MM2[b] Molecular Mechanics Calculations

structure			coordinates, Å		
			X	*Y*	*Z*
		ax-CH_3	2.54334	1.46656	-0.90471
		eq-CH_3	1.50531	2.56932	-2.46963
		ax-OH	2.38999	1.25403	-0.96663
	1	*exo*-CH_3	2.52717	1.39751	-1.24920
	2	*endo*-CH_3	1.42168	1.42317	-3.16147
	7	*exo*-OH	2.38753	1.22755	-1.18431
	11	*exo*-CH_3	2.46223	1.37941	-1.55847
	12	*endo*-CH_3	1.22628	1.52497	-3.20389

[a] Values in Angstroms. [b] MM2 energy-minimized geometry (ref 17) with the carbonyl carbon at the origin and oxygen in the +*Z* direction. Limited certainty in the values begins with the fourth significant figure.

^{13}C NMR. The ^{13}C NMR assignments for bicyclic ketones **1**–**4**, **11**, and **12** are given in Table III along with the parent ketones. The more compressed carbonyl internal angle (C_1–C_7–C_4, Table I) of bicyclo[2.2.1]heptan-7-one leads to an ~6 ppm more shielded carbonyl carbon resonance than in the bicyclo[3.2.1]octan-8-ones. In both systems, introduction of the alkyl group leads to a small deshielding of the carbonyl resonance relative to the parent, unsubstituted ketone, and endo substitution generates a slightly larger (~0.4 ppm) deshielding than exo.

As has been noted previously with *exo*- and *endo*-2-methyl- and 2-ethylbicyclo[2.2.1]heptane, the endo carbons are more deshielded than the exo by 4–5 ppm.[20] The same relative deshielding is evident for the CH_3 groups of ketones **1** and **2** and the ethyl CH_2 of ketones **3** and **4**, where a 4–5 ppm deshielding of the endo carbon is seen relative to the exo (Table III). A much smaller deshielding ($\Delta\delta$ ~0.7) attends the *endo*-ethyl or CH_3 resonance relative to exo in **3** and **4** (Table III) and in the parent hydrocarbon.[20] In the bicyclo[3.2.1]octan-8-ones, a much larger ($\Delta\delta$ ~9) relative deshielding of the *endo*-CH_3 is found. The origin of this larger effect is unclear, but it is interesting to note that the *exo*-CH_3 resonance of **11** is farther upfield ($\Delta\delta$ ~2.5) than that of **1**, and the *endo*-CH_3 resonance of **12** is farther downfield (~2 ppm) than that of **2**. The endo carbon deshieldings (relative to exo) are all larger than the deshielding of β-axial relative to β-equatorial ($\Delta\delta$ ~2); the CH_3 ^{13}C resonance of 4(a)-methyladamantan-2-one lies at δ 18.50 and that for 4(e)-methyladamantan-2-one at δ 16.80.

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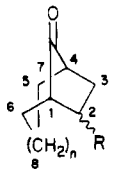
(20) Lippmaa, E.; Pehk, T.; Belikova, N. A.; Bobyleva, A. A.; Kalinichekko, A. N.; Ordubadi, M. D.; Plate, A. F. *Org. Magn. Reson.* **1976**, *8*, 74–78.

Table III. Carbon-13 NMR Chemical Shift[a] Assignments of Bicyclic Ketones[b]



C	n = 0, R = H	n = 0, R = *exo*-$^9CH_3$	n = 0, R = *endo*-$^9CH_3$	n = 1, R = H	n = 1, R = *exo*-$^9CH_3$	n = 1, R = *endo*-$^9CH_3$	n = 0, R = *exo*-$^9CH_2{}^{10}CH_3$	n = 0, R = *endo*-$^9CH_2{}^{10}CH_3$
1	37.81 (d)	44.93 (d)	43.53 (d)	44.81 (d)	53.47 (d)	49.38 (d)	42.77 (d)	41.65 (d)
2	24.12 (t)	31.94 (d)	27.31 (d)	22.72 (t)	32.82 (d)	28.49 (d)	38.32 (d)	34.58 (d)
3	24.12 (t)	34.03 (t)	33.90 (t)	22.72 (t)	30.77 (t)	30.95 (t)	32.00 (t)	32.29 (t)
4	37.81 (d)	38.78 (d)	40.24 (d)	44.81 (d)	46.16 (d)	45.98 (d)	39.26 (d)	39.55 (d)
5	24.12 (t)	23.38 (t)	24.97 (t)	37.03 (t)	36.79 (t)	36.81 (t)	23.34 (t)	25.04 (t)
6	24.12 (t)	23.38 (t)	16.16 (t)	37.03 (t)	36.56 (t)	31.74 (t)	23.34 (t)	16.15 (t)
7	216.20 (s)	216.40 (s)	216.84 (s)	222.04 (s)	222.29 (s)	222.62 (s)	215.75 (s)	216.17 (s)
8					17.90 (t)	17.73 (t)		
9		21.61 (q)	17.05 (q)		23.46 (q)	14.63 (q)	28.61 (t)	24.86 (t)
10							11.12 (q)	11.82 (q)

[a] Determined in $CDCl_3$ at 25.1 MHz and expressed in ppm downfield from $(CH_3)_4Si$. The multiplicities are given in parentheses. [b] Numbering system chosen to facilitate comparison of resonances for carbons at equivalent sites.

These data clearly show that assignments of exo/endo epimers can be made, and they are backed up with the observation that the resonance of the ring carbon (C_2, Table III) to which the substituent is attached is also sensitive to the exo/endo orientation of the substituent: exo substitution produces a relatively greater ($\Delta\delta$ 3–4) shift than endo substitution, cf. C_2 Table III. This is larger than that ($\Delta\delta \sim 2$) observed for the parent hydrocarbons of 1–4,[20] and it is also opposite to that observed for C_4 of 4(a)-methyladamantan-2-one ($\delta \sim 43.07$) and 4(e)-methyladamantan-2-one ($\delta \sim 39.91$).[8]

The γ-gauche effect of an endo substituent on the carbon directly across the ring (C_6, Table III) explains the large shielding relative to the parent ketone, $\Delta\delta \sim 8$ for **2** and **4**, and compares favorably with that observed[20] for the parent hydrocarbons ($\Delta\delta \sim 8$). The smaller γ-gauche effect ($\Delta\delta \sim 5$) found in **12** suggests a relatively greater distance between C_6 and C_9, but this is not found in MM2 calculations: the C(2)–C(9) nonbonded distances are 3.097 Å in **12** and 3.104 Å in **2**. The relative angular orientations of the methyl substituent with the γ-gauche carbon (C_6, Table III) do differ, however. MM2 calculations give a C_6–C_1–C_2–CH_3 torsion angle of 58.12° in **2**, one not very different from that of the CH_3–C_2–C_3–CH_3 dihedral angle of gauche butane. In contrast, **12** exhibits a much smaller angle, 49.07°. The magnitude of the γ-gauche effect is clearly sensitive to the size of the relevant dihedral angle.

Circular Dichroism. The circular dichroism (CD) spectra of ketones **1–6** are given in Figure 2 and clearly show that the exo (**1**, **3**, **5**) and endo (**2**, **4**, **6**) series have oppositely signed Cotton effects (CEs). The endo substituents lie well behind the carbonyl group (octant nodal surface) in an upper right or lower left octant and, as expected, all exhibit strong consignate[6] behavior. As the size (and extension) of the alkyl group increases, the magnitude of its contribution to the octant rule also increases. And the reduced rotatory strengths are fairly insensitive to temperature variation, e.g., for **4** $[R]^{25°}$ −5.67, $[R]^{-120°}$ −4.36, and $[R]^{-167°}$ −5.19 in methylcyclohexane–isopentane 4:1 (v/v) (see also Table IV). The *endo*-CH_3 of **2** gives essentially the same CE contributions as the β(equatorial)-CH_3 of 4(e)-methyladamantan-2-one (Table IV) despite the fact that they lie in different back octant locations (Table II). However, the *endo*-CH_3 of **12**, which lies in nearly the same back octant location as the *endo*-CH_3 of **2**, appears to make an unusually large octant contribution (Figure 3). The origin of this large difference is not entirely clear, but ring dissymmetry of **12** (Table I), with ring atoms now making octant contributions, may play a role.[9]

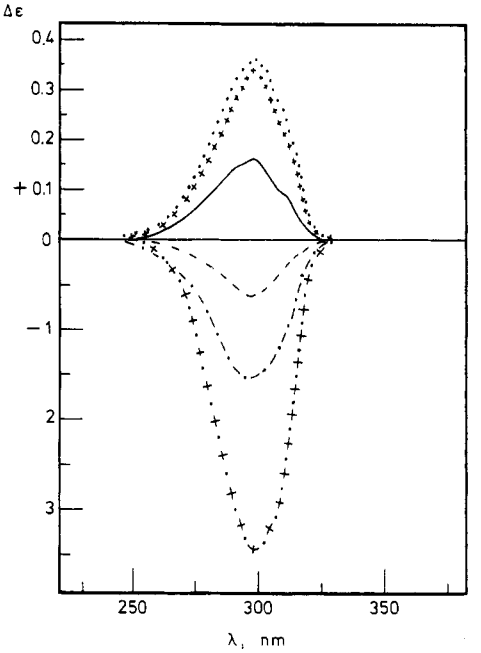


Figure 2. Circular dichroism (CD) spectra of (1*S*,4*R*)-*exo*-2-(*R*)-alkylbicyclo[2.2.1]heptan-7-ones: methyl (**1**) (—), ethyl (**3**) (···), and *n*-hexyl (**5**) (+ +), all showing positive Cotton effects (CEs), and (1*S*,4*R*)-*endo*-2(*S*)-alkylbicyclo[2.2.1]heptan-7-ones, methyl (**2**) (– –), ethyl (**4**) (– ·), and *n*-hexyl (**6**) (+ ·) in methylcyclohexane–isopentane (4:1, v/v) at 25 °C. Sample concentrations were 0.01–0.001 M and the data are corrected to 100% ee.

The behavior of the corresponding *exo*-alkyl substituents (of **1**, **3**, and **5**, Figure 2) which also lie behind the carbonyl carbon in upper right or lower left octants of the classical octant rule is in marked contrast to that of the endo: all exhibit dissignate or apparently antioctant behavior. However unlike the endo substituents, the exo exhibit much weaker contributions to the CE. The dissignate or antioctant contributions of the exo substituents parallel the behavior of β(axial)-alkyladamantanones, e.g., 4(a)-methyladamantanone, except the former exhibit dissignate behavior in both hydrocarbon and polar solvents. The

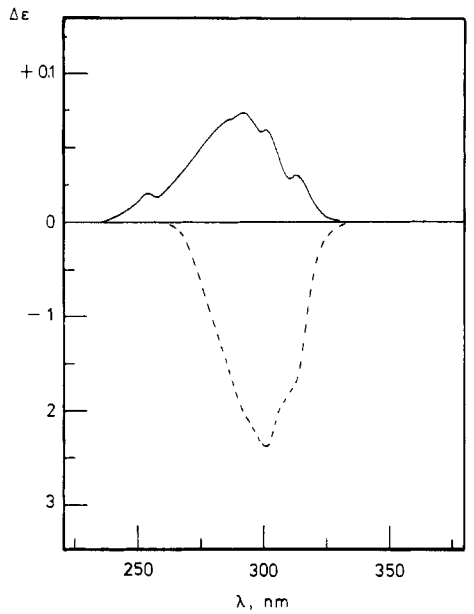
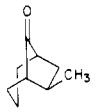
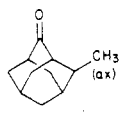
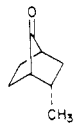
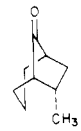
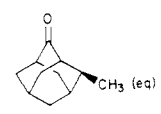


Figure 3. Circular dichroism (CD) spectra of (1*S*,4*R*)-*exo*-2-(*R*)-methylbicyclo[3.2.1]octan-8-one (**11**) (—) and (1*R*,6*R*)-*endo*-6(*R*)-methylbicyclo[3.2.1]octan-8-one (**2**) (- -) in pentane at 20 °C. Sample concentrations were ~0.01 M and the data are corrected to 100% ee.

Table IV. Reduced Rotatory Strengths[a] for the n → π* Transition of β-Methyl Bicyclic Ketones and Comparison with β-Methyladamantanones in Methylcyclohexane–Isopentane 4:1 (v/v)

no.		$[R]^{25\pm2}$	$[R]^{-100\pm2}$	$[R]^{-175\pm2}$
1		+0.379	+0.500	+0.580
11		+0.229[b]	+0.462[b,c]	
		−0.078	+0.436	+0.758
2		−1.95	−1.82	−1.88
12		−6.32[b]	−6.13[b,c]	
		−1.54	−1.83	−1.85

[a] Reduced rotatory strength, [*R*] = rotatory strength (cgs) × 1.08 × 10^{40}; superscript temperatures in °C. [b] In pentane solvent. [c] −112 °C.

origin of the dissignate effects associated with the exo alkyl substituents can be explained in terms of the location of the octant rule "third nodal surface", i.e., that surface (*A*, Figure 1) which divides the C=O local symmetry-derived (planes *XZ* and *YZ* Figure 1) quadrant space into octants. Recently, the shape and location of the third nodal surface was revised on the basis of extensive CNDO/S calculations[3] to a convex surface bending outward toward the +*Z* direction, as shown by *A* in Figure 4. In this revised octant rule, the third nodal surface cuts just behind the exo positions of **1**, **3**, **5**, and **11** as well as the β-axial position of 3-methylcyclohexanone and 4(a)-methyladamantan-2-one.[3] Consequently, groups at exo and β-axial positions lie in front of the third nodal surface and are actually front octant rather than back (anti-) octant perturbers.

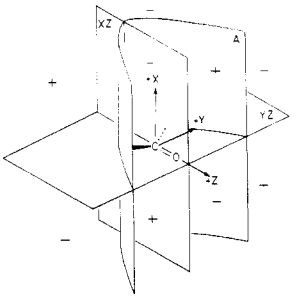


Figure 4. Revised octant diagram for the n → π* transition of the ketone carbonyl chromophore. The revision defines the third nodal surface (*A*, of Figure 1) as a convex surface bending outward in the +*Z* direction (ref 3). The signs of the CE contributions of atoms lying in the octants are shown on the diagram and correspond to those in Figure 1 for, mutatis mutandis, front and back octant regions as defined by surface *A*.

To probe the location of the third nodal surface (*A*, Figure 4) we compare the CD data for **1** and **11** with 4-(a)-methyladamantanone[7] (Table IV). By expanding the carbon chain connecting C_1 and C_4 of the bicyclo[2.2.1]-heptan-7-one system from two carbons to three, the C_2–C_1–C_7 angle opens from 100.6° to 101.2°, and the C_7–C_1–C_2–CH_3 dihedral angle opens from −88.87° to −94.96°. These have the effect of moving the CH_3 perturber of **11** toward a back octant (Table II). Despite the changes in molecular geometry that might be seen to move the CH_3 of **11** into a back octant region, it remains an obvious front octant perturber (Figure 3), albeit one with a smaller magnitude than that of **1**.

The moderately strong front octant contributions of the *exo*-CH_3 groups of **1** and **11** at room temperature contrast strongly with the variable, weak contributions of a β(axial)-CH_3 group of adamantanone[7] (Table IV). Apparently solvational, restricted rotation, and vibronic effects[8] play a much more important role in determining the sign and magnitude of the β(axial)-methyl contribution than for *exo*-CH_3 despite the fact that they lie in very similar geometries relative to the C=O group (Table II). The weak, variable CEs of the β(axial)-CH_3 become uniformly strongly positive at low temperatures,[7] where both *exo*- and β(axial)-methyl groups make substantial front octant contributions to the n → π* CE (Table IV).[21] These data may be compared with those of the *exo*-ethyl group of **3**, which extends farther into a lower left or upper right front octant and makes an even stronger, fairly temperature insensitive front octant contribution: $[R]^{25°}$ +1.11, $[R]^{-112°}$ +1.21, $[R]^{-180°}$ +1.36. The data of Tables II and IV reinforce the suggestion that the third nodal surface (*A*, Figure 4) intersects the *YZ* plane approximately along the line $Y = Z + 2$.[3]

The front octant behavior of the *exo*-alkyl groups of **1**, **3**, **5**, and **11**, and that of the β(axial)-methyl- or halo-adamantanones is not observed for the *exo*-OH and OCH_3

(21) Moderately strong, similarly temperature-invariant front octant contributions have also been recorded in more polar solvents: **1** in EPA (ether–isopentane–ethano, 5:5:2, v/v/v) shows $[R]^{25°}$ +0.441, $[R]^{-100°}$ +0.545, $[R]^{-130°}$ +0.672. The reduced rotatory strengths for (+)-(1*S*,3*R*)-4*S*(a)-methyladamantan-2-one are $[R]^{25°}$ +0.100, $[R]^{-100°}$ +0.492, $[R]^{-175°}$ +0.916 in EPA (ref 7).

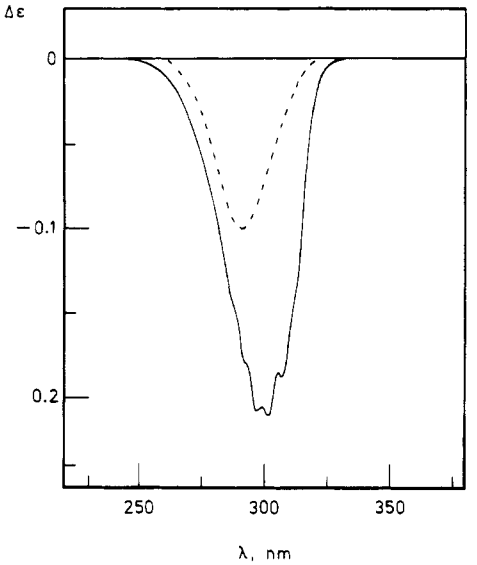


Figure 5. Circular dichroism (CD) spectra of (1*S*,4*R*)-*exo*-2-(*R*)-methoxybicyclo[2.2.1]heptan-7-one (**9**) (—) and (1*S*,4*R*)-*exo*-2(*R*)-hydroxybicyclo[2.2.1]heptan-7-one (**7**) in isopentane at 20 °C. Sample concentrations were ~0.01 M and the data are corrected to 100% ee. Methoxy ketone **9** also has a (–), essentially temperature invariant CE in EPA.

groups of bicyclo[2.2.1]heptan-7-one (Figure 5), whose perturbers exhibit octant consignate behavior. The origin of this effect is not entirely clear. When a substituent lies near a nodal surface, its attached hydrogens also make contributions, and the numbers and locations of them clearly differ in OH vs. CH_3 and OCH_3 vs. CH_2CH_3. It is important to note, however, that the shape and location of the third nodal octant surface will differ somewhat from substituent to substituent[3] and that unlike the situation for carbon substituents it may well cut in front of the substituent oxygen rather than behind.

Conclusions

We have shown experimentally that for a series of *exo*-2-alkylbicyclo[2.2.1]heptan-7-ones (**1**, **3**, and **5**) and for the analogous *exo*-2-methylbicyclo[3.2.1]octan-8-one (**11**) the lone dissymmetric alkyl perturber lies in a front octant; whereas, the corresponding *endo*-alkyl ketones have their perturbers in a back octant. Using MM2 molecular mechanics calculations to detect skeletal deformations and locate the position of methyl perturbers, the location of the third nodal surface (Figure 4) has become better defined as intersecting the *YZ* plane (*B*, Figure 4) approximately along the line $Y = Z + 2$.

Experimental Section

General Methods. Circular dichroism (CD) spectra were recorded on a JASCO J-40 instrument equipped with a photoelastic modulator and a J-DPY data processor. Variable temperature CD measurements were performed with a cryoscopic Dewar. Ultraviolet spectra were recorded on a Cary 219 or Beckman 25 spectrophotometer, and sodium D line rotations were determined in dichloromethane, unless otherwise indicated, on a Perkin-Elmer Model 141 polarimeter. All nuclear magnetic resonance (NMR) spectra were determined in $CDCl_3$ and reported in ppm downfield from tetramethylsilane unless otherwise indicated on a Perkin-Elmer R-24B (^1H) or JEOL FX-100 (^1H, ^{13}C, and ^{19}F) instrument. Mass spectra (MS) were recorded at 70, 20, or 14 eV ionizing voltage on a JEOL-JMS-07 or AEI MS-9 mass spectrometer. Infrared (IR) spectra were measured on a Perkin-Elmer Model 599 or 457 instrument. All melting points are uncorrected and were determined on a Thomas-Hoover or Mel-Temp capillary apparatus. Combustion analysis were performed by Micro-Analytical Lab, Mountain View, CA. Analytical gas chromatography (GC) was performed on a Varian-Aerograph Model 1200 or 2400 F/I instrument on 6 ft × $^1/_8$ in. diameter columns with the stationary phases noted and adsorbed on 80/100 Chromosorb W-AW-DMCS: column A (5% FFAP), column B (5% Carbowax 750), column C (7% Carbowax 20M) and column D (5% SE-30). Preparative gas chromatography (GC) was performed on 6 ft × $^3/_8$ in. diameter columns (unless noted otherwise): column E (10% Carbowax 750 on 60/80 Chromosorb W, 20 ft), column F (12% of QF-1 on 60/80 chromosorb W AW-DMCS), or column G (3% Carbowax 20 M on Chromosorb W, 1/4 in. diameter) with a Varian-Aerograph Model 1720 T/C instrument.

Spectral data were obtained by using spectral grade solvents (MCB). Low temperature CD measurements were run in methylcyclohexane–isopentane (4:1, v/v) (MI) and ether–isopentane–ethyl alcohol (5:5:2, v/v/v) (EPA). Other solvents were distilled and dried before use: benzene, petroleum ether (30/60), pentane, chloroform, and dichloromethane all from P_2O_5, acetone from $KMnO_4$, and diethyl ether and tetrahydrofuran from $LiAlH_4$ under N_2; the solvents used were freshly distilled or stored over 4A molecular sieves (Linde). Pyridine was distilled from BaO and stored over KOH or 3A molecular sieves; dioxane and dimethyl sulfoxide (Me_2SO) were distilled from CaH_2 and stored over 4A molecular sieves. Column chromatography was accomplished on 0.05–0.20 mm particle size Florisil (Floridin Co.) (0.05–0.20 mm) or on neutral alumina (Merck or MCB).

(–)-(1*S*,4*R*)-2-Methylene-7,7-dimethoxybicyclo[2.2.1]heptane (18). Sodium hydride (57%), 274 mg (6.5 mmol) was washed free of mineral oil with petroleum ether (30–60 °C), then heated, and stirred with 6 mL of Me_2SO at 65–80 °C for 1 h under nitrogen. The temperature was lowered to 52 °C and then 3.0 g (7.5 mmol) of triphenylmethylphosphonium iodide[22] (dissolved in a minimum amount of Me_2SO) was added. After 10 min, ketone **15**[10] (850 mg, 5 mmol), $[\alpha]^{22}_D$ +17.7°, 30% e.e., was added to the red ylid solution. The solution was stirred at 60 °C for 16 h. The reaction was quenched by pouring into 200 mL of ice water followed by extraction with petroleum ether (30–60 °C). The combined organic layers were washed well with water, dried ($MgSO_4$), and concentrated to a volume of about 20 mL. On cooling and scratching, triphenylphosphine oxide crystallized and was removed by filtration and discarded. The solution was then passed through a column of 10 g of activity III neutral alumina. Distillation of olefin-containing fractions gave 700 mg (83%) of product with bp 70–74 °C (13 mm) [lit.[23] bp 76–80 °C (15 mm) for racemic material]. It was >99% pure by GC on column A: $[\alpha]^{25}_D$ −11.7° (*c* 1.7, pentane); IR (neat) ν 3070, 2970, 2940, 2830, 1655, 1320, 1070, 875 cm^{-1}; ^1H NMR δ 1.07–2.77 (m, 8 H), 3.22 (s, 6 H, 2 × OCH_3), 4.6 (br s, 1 H, =CH), 4.8 (br s, 1 H, =CH); ^{13}C NMR δ 47.08 (d, C_1), 151.81 (s, C_2), 35.69 (t, C_3), 38.43 (d, C_4), 26.39 (t, C_5 or C_6), 27.03 (t, C_6 or C_5), 112.73 (s, C_7), 103.61 (t, $=CH_2$), 49.43 and 50.02 (q, OCH_3).

***exo*- and *endo*-(1*S*,4*R*)-2-Methyl-7,7-dimethoxybicyclo[2.2.1]heptane (16 + 17).** The ratio of epimers (**16** and **17**) formed

Table V. Influence of Solvent and Catalyst on the Catalytic Hydrogenation of 2-Methylene-7,7-dimethoxybicyclo[2.2.1]heptane (18) to *exo*- and *endo*-2-Methyl-7,7-dimethoxybicyclo[2.2.1]heptane (16 + 17)

catalyst	solvent	exo:endo[a]
5% Pd/C	hexane	80:20
5% Pd/C	CH_3COCH_3	85:15
PtO_2	CH_3OH	92:8
$(Ph_3P)_3RhCl$	benzene	78:22
Raney Ni[b]	CH_3OH	66:34
Raney Ni[b]	pentane	74:26
N_2H_4, Cu^{2+}, H_2O_2	CH_3OH	*c*

[a] Ratios were determined by peak areas on GC column A (80 °C). [b] Raney Ni was prepared according to the procedure described in ref 24. [c] No reduction occurred, as judged by GC (column A) after 24 h.

(22) Prepared by mixing triphenylphosphine and alkyl iodide (40% excess) in benzene, filtration of the salt, and drying under vacuum at 80 °C for 4 h.

(23) Ashby, E. C.; Noding, S. A. *J. Org. Chem.* **1977**, *42*, 264–270.

during various methods of reduction has been reviewed in the text and in Table V. When more of the endo isomer **17** is desired, we recommend using Ni(R)[24]/CH_3OH. Olefin **18** prepared above (200 mg, 1.2 mmol, 30% e.e.) was hydrogenated in cyclohexane at atmospheric pressure in the presence of 10 mg of 5% Pd/C. Filtration and evaporation gave 200 mg of a 4:1 mixture of epimers (**16**:**17**) which was separated by preparative GC on column E by using 50-μL injections. The major epimer (exo) (**16**) had the shorter retention time and exhibited IR (neat) ν 1195, 1095, 1065, and 995 cm^{-1} and ^1H NMR ν 1.05 (d, 3 H, J = 6 Hz), 1.15–2.05 (m, 9 H), 3.24 (s, 6 H, 2 × OCH_3). The endo epimer (**17**) had IR (neat) ν 1455, 1325, 1200, 1140, 1095 cm^{-1} and ^1H NMR ν 0.93 (d, 3 H, J = 6 Hz), 1.05–2.05 (m, 9 H), 3.30 (s, 6 H, 2 × OCH_3).

Anal. Calcd for $C_{10}H_{18}O_2$ (170): C, 70.58; H, 10.59. Found: C, 70.37; H, 10.49.

(−)-(1*S*,4*R*)-*exo*-2(*R*)-Methylbicyclo[2.2.1]heptan-2-one (1). Ketal **16** (150 mg 0.88 mmol) was placed in a deketalizing mixture of ca. 7 mL of 75% acetic acid–water and 5 drops of concentrated HCl. The solution was purged with nitrogen, sealed in a glass tube and heated at 80 °C for 24 h. It was cooled, poured into cold 10% aqueous K_2CO_3, and extracted with CH_2Cl_2. The CH_2Cl_2 solution was dried ($MgSO_4$) and evaporated to afford 100 mg (92%) of **1**, which was >99% pure according to GC on column A or column B: UV (isooctane) ϵ^{max}_{290} 16.5; CD (MI) ϵ^{max}_{294} +0.16, corr to 100% e.e. [lit.[4] $\Delta\epsilon^{max}_{294}$ −0.15, $\Delta\epsilon^{max}_{187}$ +2.8 for the enantiomer in isopentane]; $[\alpha]^{22}_D$ −7.9° (*c* 1.0), 30% e.e.; IR (neat) ν 1845, 1770 cm^{-1}; ^1H NMR δ 0.93 (d, 3 H, J = 6 Hz), 1.04–2.02 (m, 9 H); ^{13}C NMR in Table III [lit.[23] ^1H NMR δ 0.96 ppm for racemic ketone]; MS, m/z (relative intensity) 124.0883 [M^+, calcd for $C_8H_{12}O$ 124.0881] (40) 95.0881 [C_7H_{11}] (17), 93.0706 [C_7H_9] (10), 81.0705 [C_6H_9] (92), 79.0548 [C_6H_7] (12), 69.0706 [C_5H_9] (8), 68.0621 [C_5H_8] (30), 67.0530 [C_5H_7] (39), 57.0704 [C_4H_9] (11).

(+)-(1*S*,4*R*)-*endo*-2(*S*)-Methylbicyclo[2.2.1]heptan-2-one (2). Ketal **17** (30 mg, 0.18 mmol) was treated as above in 2.5 mL of the deketalization mixture to give 20 mg (95%) of **2**, which was >99% pure by GC on column A or column B: UV (MI) ϵ^{max}_{301} 17; CD (MI) $\Delta\epsilon^{max}_{305}$ −0.68, corr. to 100% e.e. [lit.[4] $\Delta\epsilon^{max}_{305}$ +0.6, $\Delta\epsilon^{max}_{189}$ −1.2 for the enantiomer in isopentane]; $[\alpha]^{22}_D$ +4.5° (*c* 1.0), 30% e.e.; IR (neat) ν 1840, 1765 cm^{-1}; ^1H NMR 1.09 (d, 3 H, J = 6 Hz), 1.16–2.30 (m, 9 H); ^{13}C NMR in Table III; MS, m/z (relative intensity) 124.0894 [M^+, calcd for $C_8H_{12}O$ 124.0881] (41), 95.0857 [C_7H_{11}] (35), 93.0700 [C_7H_9] (18), 81.0703 [C_6H_9] (78), 79.0550 [C_6H_7] (16), 69.0706 [C_5H_9] (21), 68.0622 [C_5H_8] (27), 67.0549 [C_5H_7] (42), 57.0703 [C_4H_9] (20), 55.0547 (C_4H_7) (100).

An NMR shift reagent experiment was done on ketones **1** and **2** by adding Eu(thd) (Resolve-Al, Aldrich) in increments and noting the chemical shift of the methyl doublet. When [Eu(thd)]/[substrate] = 0.8, the exo ketone (**1**) had $\Delta\delta$ 91 Hz. A straight line could be drawn through the points when plotting $\Delta\delta$ vs. [Eu(thd)]/[substrate]. The slope for **1** is 1.12 and the slope for **2** is 0.75.

(−)-(1*S*,4*R*)-2-Ethylidene-7,7-dimethoxybicyclo[2.2.1]heptane (21). Sodium hydride (460 mg, from 821 mg of a suspension of NaH (56%) in mineral oil) was kept under a free flow of dry N_2 for ca. 10–15 min. and 8 mL of Me_2SO (distilled twice from CaH_2) was added. The resulting solution was heated at 75–80 °C until hydrogen evolution completely subsided. The solution was cooled (ice–water bath), ethyltriphenylphosphonium iodide[22] (7.87 g, 18.8 mmol) in 4–5 mL of warm Me_2SO was added, and the resultant red ylid solution was stirred at room temperature for 10 min. Then 7,7-dimethoxynorbornanone (**15**) (1.98 g, 11.5 mmol), $[\alpha]^{22}_D$ +17.7°, 30% e.e., in 5 mL of Me_2SO was added and the resultant mixture was stirred at 55–60 °C for 2 days. The reaction mixture was quenched with cold water, extracted with pentane, dried ($MgSO_4$), and concentrated. GC on column A indicated the presence of olefin, some starting ketone, and another small side product of the olefin which was separated on Activity III neutral alumina with pentane eluent and concentrated. Olefin (**21**) (1.48 g, 70%) was obtained as a mixture of *E* and *Z* isomers by distillation, bp 55–60 °C (1 mm), and was >99% pure by GC on column A: $[\alpha]^{22}_D$ −14.4° (*c* 0.7); IR (neat) ν 3050, 2978, 2836, 1690, 1462, 1442, 1323, 1128, 1100, 1070, 998, 829, 801 cm^{-1}; ^1H NMR δ 1.12–2.88 (m, 11 H), 3.18 (s, 3 H, OCH_3), 3.22 (s, 3 H, OCH_3), 4.82–5.32 (m, 1 H, =CH); ^{13}C NMR δ 46.74 and 41.60 (d, C_1), 143.10 and 142.16 (s, C_2), 33.29 and 36.04 (t, C_3), 38.14 and 37.97 (d, C_4), 27.26, 26.68 and 26.33 (t, C_5 and C_6), 113.26 (s, C_7), 113.73 and 112.91 (d, =CH—), 13.87 and 13.65 (q, $=CCH_3$), 50.31 and 49.67 (q, OCH_3).

Anal. Calcd for $C_{11}H_{18}O_2$ (182): C, 72.48; H, 9.95. Found: C, 72.60; H, 10.15.

(1*S*,4*R*)-2-Ethyl-7,7-dimethoxybicyclo[2.2.1]heptane (19 + 20). To a well-stirred solution of sodium hydroxide (49 g in 190 mL of distilled water) was added Raney nickel alloy (Sargent-Welch) powder (35 g) with a spatula. The solution was maintained at 75 °C with a cooling water bath. After the addition, the catalyst solution was stirred for additional 30–40 min, the supernatant liquid was decanted, and the catalyst was transferred to a tall graduated cylinder placed in the sink. A glass tube reaching to the bottom of the cylinder was attached to the distilled water tap and the water flow was adjusted so that the catalyst rises freely but was not washed out of the cylinder. After a neutral pH was indicated (by pH paper), the aqueous layer was removed, and the catalyst was washed with CH_3OH thoroughly. Then CH_3OH was finally replaced with enough pentane to cover up the entire catalyst. Ethylidene ketal **21** from above (1.48 g, 0.813 mmol) was added, and the reduction was monitored by GC (Column A). After reduction was complete, the catalyst was thoroughly extracted with pentane several times, total 500 mL. The pentane was removed by distillation to yield pure ketal (1.14 g, 75%) as a mixture of exo and endo isomers (**19** and **20**) in the ratio ca. 4:1, respectively. Reduction of **21** with 5% Pd(C) in cyclohexane at 50 psi gave a 3:1 mixture of **19** and **20**, respectively. The mixture was not separated but was taken directly to the deketalization step. It was >99% pure by GC on column A and had IR (neat) ν 2960, 2880, 2820, 1468, 1458, 1380, 1340, 1228, 1198, 1098, 1065, 1000 cm^{-1}.

Anal. Calcd for $C_{11}H_{20}O_2$ (184): C, 71.70; H, 10.94. Found: C, 71.75; H, 10.97.

(−)-(1*S*,4*R*)-*exo*-2(*R*)-Ethylbicyclo[2.2.1]heptan-7-one (3). The above ketal mixture (**19** + **20**) (2.2 g, 5.8 mmol) was added to a hydrolysis mixture of 7.5 mL of acetic acid, 2.5 mL of water, and 2 mL of concentrated HCl. The resulting solution was stirred vigorously for two days at room temperature. The mixture was then quenched with 15% aqueous NaOH—enough to bring the pH to ca. 10. The mixture was extracted with ether (3 × 30 mL), and the aqueous layer was saturated with NaCl and then extracted again with ether (30 mL). The combined organic extracts were dried (Na_2SO_4) and the ether solvent was removed by distillation to give a mixture of ketones **3** and **4**, 0.7 g, 85%. Separation was accomplished by preparative GC on column F, with **3** moving faster than **4**. The exo ketone (**3**) with the shorter retention time was collected and was >99% pure as determined by GC on column A (110 °C): UV (MI) ϵ^{max}_{290} 18; CD (MI) $\Delta\epsilon^{max}_{298}$ +0.36, $\Delta\epsilon^{max}_{185}$ −0.41, corr to 100% e.e.; $[\alpha]^{25}_D$ −11.4° (*c* 0.5), 30% e.e.; IR (neat) ν 2955, 2870, 1635, 1770, (s), 1745, 1455, 1378, 1138, 1095, 755 cm^{-1}; ^1H NMR δ 0.87 (t, 3 H, J = 7, CH_3), (q, 2 H, J = 7, CH_2), 1.0–2.0 (m, 9 H); ^{13}C NMR in Table III.

Anal. Calcd for $C_9H_{14}O$ (138): C, 78.21; H, 10.21. found: C, 78.27; H, 10.22.

(+)-(1*S*,4*R*)-*endo*-2(*S*)-Ethylbicyclo[2.2.1]heptan-7-one (4). The *endo*-ethyl ketone (**4**) was isolated as the minor isomer from the above mixture of **3** and **4** with preparative GC on column F: UV (MI) ϵ^{max}_{292} 17; CD (MI) $\Delta\epsilon^{max}_{297}$ −1.61, $\Delta\epsilon^{max}_{187}$ +0.43) corr to 100% e.e., $[\alpha]_D$ +3.23° (*c* 0.5), 30% e.e.; IR ($CHCl_3$) ν 2955, 2870, 1768, 1701, 1455, 1145, 1075, 855, 795 cm^{-1}; ^1H NMR δ 0.88 (t, 3 H, J = 7, CH_3), 1.87 (q, 2 H, J = 7, CH_2), 1.2–2.2 (m, 9 H); ^{13}C NMR in Table III.

Anal. Calcd for $C_9H_{14}O$ (138): C, 80.41, H, 11.34. Found: C, 80.41; H, 11.45.

(1*S*,4*R*)-*exo*-2(*R*)-*n*-Hexylbicyclo[2.2.1]heptan-2-one (5) and (1*S*,4*R*)-*endo*-2(*S*)-*n*-Hexylbicyclo[2.2.1]heptan-2-one (6). One gram (5.9 mmol) of ketone **15**, $[\alpha]^{22}_D$ +16.3, 28% e.e., was treated as above, except *n*-hexyltriphenylphosphonium iodide and KH were used to yield 0.5 g (36%) of a mixture of *E* and *Z* *n*-hexylidene derivatives (**24**), bp 130–132 °C (0.5 mm). This material was hydrogenated directly at 50 psi in cyclohexane with 30 mg of 5% Pd(C) for 3 days, at which point no vinyl hydrogens were observed by NMR. Analytical GC on column C showed two peaks (10:1) with retention times of 8.5 and 10 min, corresponding

(24) Prepared as described: Fieser, L. F.; Fieser, M. "Reagents for Organic Synthesis"; Wiley and Sons: New York; 1967; vol 1, p 729.

to **22** and **23**, respectively. The catalyst was removed by filtration, the solvent was evaporated, and the mixture was deketalized in acetic acid water–concentrated HCl (75:25:0.5 v/v/v) by first heating on a steam bath for 30 min then allowing to stand overnight at room temperature. Workup as with **1** and **2** by using K_2CO_3 and ether gave an oily mixture (10:1) of **5** and **6** which was separated by preparative GC on column G to give the exo ketone (**5**) as the major faster moving isomer and the endo ketone (**6**) as the minor isomer. Ketone **5**: UV (*n*-heptane) ϵ^{max}_{292} 21; CD (*n*-heptane) $\Delta\epsilon^{max}_{295}$ +0.34 (corr to 100% e.e.); MS, *m/z* (relative intensity) 194.1671 [M^+, $C_{13}H_{22}O$ 194.1671]. Ketone **6**: UV (*n*-heptane) ϵ^{max}_{290} 18; CD (*n*-heptane) $\Delta\epsilon^{max}_{298}$ −3.43; MS, *m/z* (relative intensity) 194.1670 [M^+, $C_{13}H_{22}O$ 194.1671].

Anal. Calcd for $C_{13}H_{22}O$ (194): C, 80.41; H, 11.34. Found: C, 80.37; H, 11.48.

(−)-(1*S*,4*R*)-*exo*-2-Hydroxybicyclo[2.2.1]heptan-7-one (7).[25] Hydroxy ketal **13** (0.3 gm, 1.9 mmol), $[\alpha]^{25}_D$ −7.1° (*c* 0.5), 14% e.e., was deketalized in 2 mL of water containing 2 drops of concentrated H_2SO_4, room temperature, 12 h. The mixture was extracted with ether and the ether was washed with bicarbonate and dried ($NaSO_4$) to give 120 mg of oil (**7**), which was purified by preparative GC on column E. It gave a crystalline tosylate, mp 89–91 °C, $[\alpha]^{25}_D$ +0.6° (*c* 1.0) [lit.[25] mp 72.4–73.0 °C, racemate]. Ketol **7** had CD (dioxane) $\Delta\epsilon^{max}_{295}$ −0.12 (corr to 100% e.e.).

(+)-(1*S*,4*R*)-*exo*-2,7,7-Trimethoxybicyclo[2.2.1]heptane (25). Method I. *exo*-7,7-Dimethoxybicyclo[2.2.1]heptan-2-ol (**13**) (400 mg, 2.32 mmol), $[\alpha]^{22}_D$ −14.4°, 30% e.e., was heated at reflux with NaH (500 mg, 20.8 mmol) in dry THF for 17 h. The reaction mixture was cooled to room temperature, CH_3I (2.6 g, 18.3 mmol) was added, and the mixture stored at room temperature for an additional 18 h. Water was added carefully, and the reaction mixture was extracted with ether, dried (Na_2SO_4), and concentrated. The resulting oil was distilled (60 °C (1 mm)), to yield **25**, 340 mg (1.83 mmol, 79%) of product.

Method II. To NaH (18 mg, 0.78 mmol) under a flow of N_2 was added 0.5 mL of Me_2SO and the mixture was heated to 70 °C for 1 h. To the resulting solution was added 120 mg (0.7 mmol) of the alcohol **13** (30% e.e.) at room temperature. Methyl iodide (106.5 mg, 0.75 mmol) was added. The cloudy solution immediately cleared up and was stirred for 10 h. It was then decomposed with water and extracted with pentane. The pentane extracts were passed through a short column of Activity III neutral Al_2O_3, concentrated, and distilled as above to yield pure ether, 80% yield. The product from either method was >99% pure by GC on column A: $[\alpha]^{24}_D$ +32.7° (*c* 0.98, pentane); IR (neat) ν 2980, 2850, 2836, 1465, 1450, 1370, 1340, 1305, 1262, 1228, 1202, 1176, 1145, 1120, 1090, 1072, 1050 cm^{-1}; ^1H NMR δ 0.83–2.32 (br m, 8 H), 2.88–3.40 (m, 1 H, CHO, 3.18 (s, 3 H, OCH_3), 3.22 (s, 3 H, OCH_3), 3.25 (s, 3 H, OCH_3); ^{13}C NMR δ 39.96 (d, C_1), 82.96 (d, C_2), 36.45 (t, C_3), 36.62 (d, C_4), 24.92 (t, C_5) 23.52 (t, C_6), 112.68 (s, C_7), 55.64 (q, C_2OCH_3), 48.91 and 49.67 (q, 7, 7-OCH_3).

Anal. Calcd for $C_{10}H_{18}O_3$ (186): C, 64.49; H, 9.74. Found: C, 64.44; H, 9.74.

(−)-(1*S*,4*R*)-*exo*-2(*R*)-Methoxybicyclo[2.2.1]heptan-7-one (9). Ketal **25** (300 mg, 1.16 mmol, 30% e.e.) was mixed with 1 mL of glacial acetic acid and kept in a sealed tube at 110 °C for 18 h. The reaction mixture was quenched carefully with cold 35% aqueous NaOH, extracted with ether (4 × 20 mL), and dried (Na_2SO_4). The ether was removed by distillation to give a colorless oil (160 mg, 1.13 mmol, 70%), which was distilled to give methoxy ketone **9**, bp 60–65 °C (1 mm), in 35% yield. It was >99% pure by GC on column A: UV (isooctane) ϵ^{max}_{287} 17; CD (isooctane) $\Delta\epsilon^{max}_{301}$ −0.21 (corr to 100% e.e.); $[\alpha]^{25}_D$ −3.6° (*c* 1.0, EPA), 30% e.e.; IR (neat) ν 2940, 2880, 2824, 1845, 1776, 1468, 1455, 1360, 1214, 1135, 1115, 1092, 1050 cm^{-1}; ^1H NMR δ 1.0–2.25 (br m, 8 H), 3.23 (s, 3 H, OCH_3), 3.33–3.67 (m, 1 H; ^{13}C NMR δ 42.30 (d, C_1), 78.76 (d, C_2), 35.16 (t, C_3), 37.73 (d, C_4), 23.23 (t, C_5), 18.60 (t, C_6), 214.76 (s, C_7), 56.10 (q, OCH_3).

Anal. Calcd for $C_8H_{12}O_2$ (140): C, 68.54; H, 8.63. Found: C, 68.45; H, 8.63.

(+)-(1*S*,4*R*)-*endo*-7,7-Dimethoxybicyclo[2.2.1]heptan-2-ol (14). A three-neck flask was equipped with rubber septum, addition funnel, and a vigreux column (over which was mounted a distillation assembly consisting of a distillation, head, condenser, and receiver flask). The reaction flask was charged with freshly distilled aluminum isopropoxide (2.8 g in 50 mL of isopropyl alcohol) and heated to gentle reflux by means of an oil bath. Ketone **15** (1.75 g, 10.42 mmol, $[\alpha]^{24}_D$ +17.7°, 30% e.e.) in 15 mL of isopropyl alcohol was added dropwise through the addition funnel. The oil bath temperature was raised sufficiently (120 °C range) to ensure rapid distillation of acetone–isopropyl alcohol. Fresh isopropyl alcohol was added periodically through the addition funnel to replace that removed by distillation. The reaction was terminated after 5 h by distilling away the remaining isopropyl alcohol. The residue was dissolved in 6% aqueous NaOH (170 mL), extracted with ether (5 × 50 mL), and dried (Na_2SO_4). Ether was distilled, and the remaining oil was distilled with a short path apparatus to afford 1.6 g of product (90%), bp 90 °C (1–2 mm) [lit.[25] bp 77 °C (0.28 mm)], contaminated with 5% of the exo alcohol (**13**) according to GC on column A (140 °C): $[\alpha]^{24}_D$ +0.4° (*c* 1.5); IR (neat) ν 3680–3100 (broad), 2960, 2824, 1465, 1445, 1322, 1195, 1140, 1114, 1105, 1060, 1030, 988, 934 cm^{-1}; ^1H NMR δ 1.00–2.42 (br m, 8 H), 2.78–3.25 (br 1 H, OH), 3.15 (s, 3 H, OCH_3), 3.18 (s, 3 H, OCH_3), 4.08–4.48 (m, 1 H, CHO); ^{13}C NMR δ 43.35 (d, C_1), 69.03 (d, C_2), 37.56 (t, C_3), 38.03 (d, C_4), 27.03 (t, C_5), 17.20 (t, C_6), 113.73 (s, C_7), 49.79 and 49.32 (q, OCH_3).

(−)-(1*S*,4*R*)-*endo*-2,7,7-Trimethoxybicyclo[2.2.1]heptane (26). Sodium hydride suspension in mineral oil (1.6 g, 56% NaH) was washed thoroughly with pentane to remove the mineral oil, and the NaH powder was dried under N_2 for 10 min. Ten milliliters of THF (distilled from $LiAlH_4$) was added, followed by addition of endo alcohol **14** (692 mg, 4.07 mmol, 30% e.e.) as a solution in THF (4 mL). The mixture was stirred and heated at reflux for 24 h. Then 3 mL of CH_3I was added, at which point the hitherto lightly colored solution become white, and the reaction mixture was stirred for 12 h at room temperature. Distilled water (2 mL) was then carefully added, and the mixture extracted with ether (4 × 20 mL), dried (Na_2SO_4), concentrated, and distilled to give 690 mg (92%) of **26**, bp 60–63 °C. The distilled product was chromatographed on neutral alumina (MCB) with pentane as eluent. This treatment removed traces of polar material, and the resulting liquid was distilled again to yield an analytical sample of the desired ether (**26**) which was >99% pure by GC on column A: $[\alpha]^{24}_D$ −8.4° (*c* 1.05); IR (neat) ν 2870, 2800, 2738, 1468, 1448, 1360, 1328, 1270, 1200, 1120, 1100, 1070, 1010, 986 cm^{-1}; ^1H NMR δ 0.85–2.48 (br, m, 8 H), 3.17, 3.18 (s, 9 H, 3 × OCH_3), 3.65–4.08 (m, 1 H); ^{13}C NMR δ 40.95 (d, C_1), 79.45 (d, C_2), 35.92 (t, C_3), 38.14 (d, C_4), 27.73 (t, C_5), 17.78 (t, C_6), 114.14 (s, C_7), 50.25 and 49.84 (q, OCH_3).

Anal. Calcd for $C_{10}H_{18}O_3$ (186): C, 64.49; H, 9.74. Found: C, 64.50; H, 9.75.

***cis*-Bicyclo[4.2.0]oct-7-en-2-one (31).**[12] A large scale preparation of the ketone **31** is described in the following from cyclohexenone and 1,2-dichloroethylene.

1,1-(Ethylenedioxy)-2-bromocyclohexane.[13] In a 3-neck, 2-L round-bottom flask fitted with a mechanical stirrer, addition funnel, and gas trap were placed 294 g (3 mol) of cyclohexanone (Aldrich) and 700 mL of ethylene glycol (Eastman). A portion of 160 mL (3.1 mol) of bromine (Baker) was added to start the reaction, and the rest of the bromine was added at such a rate as to maintain a faint bromine coloration. The addition took ca. 6 h at which time 200 g of anhydrous Na_2CO_3 were added very cautiously to the reaction mixture. Then 800 mL of pentane and 800 mL of water were added, the mixture was extracted, and the pentane was separated and dried (Na_2SO_4). Concentration of the solvent gave 627 g (2.84 mol, 95% crude yield) which upon distillation (60–70 °C (0.45 mm)) afforded 508.45 g (73%) of a clear liquid: ^1H NMR (CCl_4) δ 1.3–2.4 (m, 8 H) and 4.0 (m, 5 H, OCH_2CH_2O, CHBr).

1,1-(Ethylenedioxy)-2-cyclohexene.[13] A solution of 508.45 g (2.3 mol) of bromo ketal from above, 370 g (9.25 mol) of NaOH, and 2 L of absolute methanol was heated at reflux for 40 h, at which time at least 1 L of absolute methanol was distilled out of the reaction mixture. Enough water was added to dissolve all the precipitate, and the resulting solution was extracted (2×) with 500 mL of pentane. The combined pentane layers were washed with saturated brine solution and dried ($MgSO_4$). Concentration at atmospheric pressure gave 274.5 g (1.96 mol 85% crude yield)

(25) For racemic hydroxy ketone see: Gassman, P. G.; Marshall, J. L. *J. Am. Chem. Soc.* **1966**, *88*, 2822–2830.

of a clear, cloudy oil which was not purified further: ^{1}H NMR (CCl_4) δ 1.8 (m, 6 H), 3.8 (s, 4 H, OCH_2CH_2O), 5.35 (dt, H, α=CH), 5.73 (dt, 1 H, β=CH).

2-Cyclohexenone.[13] A solution of 274.5 g (1.96 mol) of the above ketal and 400 mL of 5% aqueous H_2SO_4 was stirred for 30 min at room temperature. The reaction mixture was extracted with 400 mL of ether, and the ether layers were washed with saturated aqueous $NaHCO_3$ and dried ($MgSO_4$). Concentration at atmospheric pressure gave 154 g (1.60 mol, 82% crude yield) of an oil which upon distillation (68–72 °C (23 mm)) afforded 103 g (55%) of a clear liquid: IR (neat) ν 1690 cm^{-1}; ^{1}H NMR (CCl_4) δ 2.2 (m, 6 H), 5.8 (d, 1 H, α=CH), 6.85 (m, 1 H, β=CH).

2,2-(Ethylenedioxy)-7,8-dichloro-*cis*-bicyclo[4.2.0]octane.[14] A solution of 50 g (0.52 mol) of 2-cyclohexenone, 235 g (2.45 mol) of *trans*-1,2-dichloroethylene (Eastman), and 750 mL of pentane was irradiated at room temperature with a Hanovia 450-W high-pressure Hg lamp. The progress of the reaction was followed by IR by observance of the disappearance of the carbonyl peak at 1690 cm^{-1}. After 44 h, the reaction appeared complete and the solution was concentrated under vacuum to give 126.3 g of a brown oil. To this oil were added 38 g of ethylene glycol (Eastman), a few milligrams of *p*-toluenesulfonic acid (MCB), and 300 mL of benzene. The flask was fitted with a Dean–Stark trap and heated at reflux for ca. 16 h. The solution was concentrated under vacuum, with the final volatile components being removed at 25 °C (0.5 mm) to give 107.7 g (0.45 mol, 87% crude yield) of a brown oil which was taken directly to the next step.

2,2-(Ethylenedioxy)-*cis*-bicyclo[4.2.0]oct-7-ene.[14] To a solution of 117.8 g (0.495 mol) of the above dichloro bicyclo ketal in 250 mL of anhydrous ether and ca. 700 mL of anhydrous liquid NH_3 at −76 °C was added 43 g (1.87 mol) of Na metal in small pieces. After the reaction had stirred for 2 h, solid NH_4Cl was added to dispel the blue color of the reaction mixture. The NH_3 was then allowed to evaporate overnight. Water was then added to dissolve the solids, and the resulting solution was extracted (2×) with 500 mL of ether. The extracts were washed with brine and dried ($MgSO_4$). Concentration gave 74.3 g (90% crude yield) of a yellow oil which upon distillation (54–64 °C (0.5 mm)) afforded 44.85 g (0.27 mol, 55%) of a clear liquid: ^{1}H NMR (CCl_4) δ 1.63 (m, 6 H), 2.77 (d, 1 H), 3.05 (m, 1 H), 3.8 (s, 4 H, OCH_2CH_2O), 6.08 (dd, 2 H, CH=CH).

***cis*-Bicyclo[4.2.0]oct-7-en-2-one (31).**[12] A solution of 35 g (210 mmol) of bicyclooctene ketal above, 75 mL of 10% aqueous HCl, and 175 mL of ether was stirred vigorously for 4.5 h. The aqueous layer was separated and extracted with ether. The combined ether layers were then washed with water, saturated aqueous $NaHCO_3$, and saturated brine solution and dried ($MgSO_4$). Concentration of the solvent gave 25.55 g (99% crude yield) of a cloudy oil. Distillation (30–40 °C (0.29–0.34 mm)) gave 20.05 g (78.5%) of a clear liquid: IR (neat) ν 1695, 775, 695 cm^{-1}; ^{1}H NMR (CCl_4) δ 1.5–2.4 (m, 6 H), 3.4 (m, 2 H), 6.0 (dd, 2 H, CH=CH).

8,8-(Ethylenedioxy)bicyclo[3.2.1]oct-6-ene (33). A solution of 15 g (123 mmol) of bicyclo[4.2.0]oct-7-en-2-one (**31**) in 125 mL of dry benzene (stored over sodium ribbon) was cooled to 0 °C. A solution of 7.89 mL (62.5 mmol) of BF_3·Et_2O in ca. 15 mL of dry benzene was cooled to 0 °C and then added to the ketone solution under nitrogen during 3 min. The solution was stirred for 30 min at 0 °C, and then ca. 9 mL of a 16.74-mL (ca. 300 mmol) aliquot of ethylene glycol was added dropwise over a 10-min period. GC analysis on column D indicated that after 5.5 h of stirring, the reaction was not complete, and the remainder of the ethylene glycol was added. After 25 additional h of stirring, the benzene, and the combined benzene layers were dried over first anhydrous Na_2SO_4 and then anhydrous $MgSO_4$. Concentration of the solvent gave 21.22 g of a brown oil. An additional 3.3 g from a previous run was added to the mixture for distillation. The fraction collected at 48–50 °C (0.65 mm) gave 9.86 g (40%) of a clear sweet-smelling oil: ^{1}H NMR (CCl_4) δ 1.0–2.0 (m, 6 H), 2.2 (br s, 2 H), 3.8 (t, 4 H, OCH_2CH_2O) and 5.7 (t, 2 H, CH=CH); MS, m/z (relative intensity) 166 [M$^+$·] (55), 151 (7), 138 (46), 99 (100).

Anal. Calcd for $C_{10}H_{14}O$ (166): C, 72.29; H, 8.43. Found: C, 72.05; H, 8.39.

(+)-(1*S*,5*R*)-*exo*-6(*R*)-Hydroxy-8,8-(ethylenedioxy)bicyclo[3.2.1]octane (34a + 34b). To a solution of 5 g (30 mmol) of the above ketal in 40 mL of THF was added all at once a solution of 10.8 g (33.96 mmol) of mercuric acetate dissolved in 40 mL of distilled water. The bright orange-yellow solution was stirred for 2 h at room temperature, after which time 34 mL (102 mmol) of 3 M NaOH was added. The solution, which remained yellow, was stirred for 15 min. Then a solution of 0.74 g (20 mmol) of $NaBH_4$ in 34 mL of 3 M NaOH was added cautiously, and the solution was stirred for an additional 45 min. The now pale yellow solution contained mercury at the bottom of the flask. Brine was added, and the reaction mixture was extracted twice with ether. The ether portions were dried ($MgSO_4$) before concentration of the solvent gave 5.35 g of a clear oil. Distillation gave the following 2 fractions: I, 2.24 g, 48 °C (0.43 mm), starting material; II, 2.80 g, 75 °C (0.37 mm), product. Based on recovered starting material, the product was obtained in about 92% yield: IR (neat) ν 3560, 3450, (br sh), 2940, 2865, 1145, 1125, 1105, 1055, 1030, 1020 cm^{-1}; ^{1}H NMR δ 1.2–2.2 (br m, 10 H), 2.75 (br, s, 1 H, OH), 3.9 (s, 5 H, CHO, OCH_2CH_2O); MS, m/z (relative intensity) 184 [M$^+$·] (25), 167 (36), 155 (7), 141 (35), 139 (14), 130 (20), 127 (35), 125 (64), 124 (34), 99 (100).

***exo*-8,8-(Ethylenedioxy)bicyclo[3.2.1]oct-6-yl Half-Acid Phthalate (35a + 35b).** A solution of 6.359 g (34.5 mmol) of hydroxy ketal (**34a + 34b**), 5.7 g (38.5 mmol) of pure phthalic anhydride, and 20 mL of anhydrous pyridine was removed under vacuum. The residue was dissolved in $CHCl_3$ and extracted with saturated aqueous $NaHCO_3$ (2 × 25 mL). The ice-cold combined aqueous layers were acidified carefully and then extracted with $CHCl_3$ (3 × 100 mL). The organic layers were dried (Na_2SO_4 + $MgSO_4$) and concentrated to give a thick, pale yellow oil containing some crystals. Trituration with pentane gave 8.65 g (76%) of a white solid with mp 148.5–150.5 °C: ^{1}H NMR δ 1–2.3 (m, 10 H, 3.9 (m, 4 H, OCH_2CH_2O), 5.15 (m, 1 H), 7.5 (m, 4 H, ArH), 11.5 (s, 1 H, CO_2H).

Anal. Calcd for $C_{18}H_{20}O_6$ (332): C, 65.06; H, 6.02. Found: C, 65.02; H, 6.06.

Resolution of Half-Acid Phthalates 35a and 35b. Formation of the Salt. To a warm solution of racemic half-acid phthalate (**35a + 35b**) (50 mg, 0.15 mmol in 0.5 mL of acetone) was added 25 mg (0.15 mmol) of *d*-α-(1-naphthyl)ethylamine (Aldrich). The resulting solution was warmed, and within 2 min crystals began to appear. The acetone solvent was removed by continuous warming, and the resulting solid was dried in a stream of N_2. The solid (A) was well-mixed, ground, and weighed (72 mg). It had $[\alpha]^{24}_D$ +1.6° (*c* 0.92, CH_3OH) and $[\alpha]_D$ +0.84° (*c* 0.24, CH_3OH).

Resolution of the Salt. To a hot solution of 2.25 g (6.8 mmol) of racemic half-acid phthalate (**35a + 35b**) in 20 mL of acetone was added a solution of 1.16 g (6.7 mmol of *d*-α-(1-naphthyl)-ethylamine (Aldrich) in 10 mL of acetone. The solution was boiled for 10 min and cooled at room temperature for 0.5 h and at −22 °C for 0.5 h. Most of the solid salt formed during cooling to room temperature. The crystals (B) were collected by filtration, air-dried, and successively recrystallized from CH_3OH to constant rotation: B 1.9 g, $[\alpha]^{24}_D$ −1.6° (*c* 0.6, CH_3OH); C 720 mg, $[\alpha]^{24}_D$ −5.4° (*c* 0.25, CH_3OH); D 400 mg, $[\alpha]^{24}_D$ −7.5 (*c* 0.20, CH_3OH). The mother liquor from D had $[\alpha]^{24}_D$ −4.6° (*c* 0.3, CH_3OH).

Hydrolysis of the Salt. Salt D (400 mg, 0.80 mmol) was suspended in 30 mL of ether. To the suspension was added 10 mL of 10% aqueous HCl, and the mixture was shaken vigorously in a separatory funnel. The organic layer was washed with saturated aqueous $NaHCO_3$ (3 × 10 mL) and dried ($MgSO_4$). The ether was evaporated to recover amine resolving agent. The bicarbonate washings were combined, 2 g of KOH were added to the combined wAshings, the solution was stirred for 1 h at room temperature, and then it was extracted with ether (3 × 30 mL). The combined ether layers were dried ($MgSO_4$) and concentrated to afford 118 mg of colorless, oily alcohol. An additional 10 mg of alcohol, obtained by ether extraction of the bicarbonate–KOH phase after standing at room temperature for 24 h, was isolated and combined with the major part to give a total of 128 mg (87%) of material with $[\alpha]^{24}_D$ −12.7° (*c* 0.36, CH_3OH) and $[\alpha]^{24}_D$ −2.6° (*c* 0.63, $CHCl_3$). In another solution, salt with $[\alpha]^{24}_D$ −4.7° (*c* 0.32, CH_3OH) gave alcohol with $[\alpha]^{24}_D$ −8.2° (*c* 0.41, CH_3OH) and salt mother liquor with $[\alpha]^{24}_D$ +8.3° (*c* 0.56, CH_3OH) gave alcohol with $[\alpha]^{24}_D$ +10.2° (*c* 0.5, CH_3OH).

***exo*-8,8-(Ethylenedioxy)bicyclo[3.2.1]oct-6-yl (+)-(*R*)-α-Methoxy-α-(trifluoromethyl)phenylacetate (36a + 36b). General Method.** An oven-dried 10 × 75 mm test tube was fitted with a rubber septum and 300 mL of pyridine, 26 mL of the acid chloride of (+)-(*R*)-α-methoxy-α-(trifluoromethyl)phenylacetic acid [(+)-(*R*)-MTPA-Cl], and 300 mL of CCl_4 (distilled over P_2O_5 and stored over 3A molecular sieves) were injected successively. To this mixture the substrate alcohol (10 mmol) was injected and the reaction mixture set aside for 48–60 h. Then 24 mL of 3-(diethylamino)-1-propylamine was added and the reaction mixture was shaken well. It was then diluted with ether, washed successively with dilute aqueous HCl (2×), saturated aqueous Na_2CO_3 (once), and saturated aqueous NaCl, and then dried ($MgSO_4$). The solvents were removed to yield the Mosher ester[26] usually in 90–95% yield. The mixture of **36a + 36b** was prepared in 90% yield (33 mg from 19 mg of starting alcohol, **34a + 34b**): ^1H NMR (100 MHz) δ 1.0–2.22 (m, 10 H), 3.59 (m, 3 H, OCH_3), 3.62–4.04 (m, 4 H, OCH_2CH_2O), 5.04 (t, 1 H, CHOR), 7.23–7.80 (m, 5 H, ArH); ^{19}F NMR δ 18.99. Upon addition of Eu(fod)$_3$ to the NMR solutions, the OCH_3 and CF_3 signals each split into 2 lines with $[LIS]_{OCH_3}$ = 1.3 and $[LIS]_{CF_3}$ = 1.2.[15]

Determination of Absolute Configuration and Enantiomeric Excess (34a and 34b). The enantiomeric excess (e.e.) of (−)-alcohol from above was determined by LIS-NMR[15] of its Mosher ester[26] (prepared as in **3la + 36b**). Thus, the Mosher ester of alcohol with $[\alpha]^{24}_D$ −8.2° (*c* 0.41, CH_3OH) had its ^{19}F NMR resonance at δ −18.98 (vs. $CFCl_3$) in $CDCl_3$. That signal became split upon addition of Eu(fod)$_3$, showing the diastereomeric CF_3 signals at δ −17.69 and −18.54 vs. $CFCl_3$ in the ratio 3.031:1 respectively. Accordingly, alcohol with $[\alpha]^{24}_D$ −8.2° (*c* 0.41, CH_3OH) corresponds to 50.4% e.e. The absolute configuration of the predominant enantiomer is assigned 1*R*,5*S*, corresponding to **34a** because the more intense ^{19}F signal of the pair of diastereomeric CF_3 groups was faster moving upon addition of Eu(fod)$_3$, as noted earlier.[15] Similarly, alcohol with $[\alpha]^{24}_D$ −12.7° (*c* 0.36, CH_3OH) showed a split ^{19}F NMR signal at δ −17.69 and −18.72 (vs. $CFCl_3$) upon addition of Eu(fod)$_3$. Once again, the more intense signal moved faster, hence the major enantiomer (**34a**) has the 1*R*,5*S* absolute configuration and is present here in 81% e.e. The ^{19}F NMR data are consistent with ^1H NMR measurements of the OCH_3 groups with the LIS technique.[15] Therefore, the rotation of optically pure **34a** is extrapolated to $[\alpha]^{24}_D$ −16.0° ± 0.3° (CH_3OH).

The absolute configuration of (+)-alcohol was confirmed as 1*S*,5*R* corresponding to **34b** by its conversion to ketone **38** of known absolute configuration[16] as follows. (+)-Alcohol (**34b**) (290 mg, 1.58 mmol), $[\alpha]^{24}_D$ +10.2° (*c* 0.5, CH_3OH), was heated at reflux with 5 mL of freshly distilled *n*-butanethiol and 10 drops of BF_3 etherate under N_2 for 18 h. The mixture was cooled, excess *n*-BuSH flash evaporated, and the residue passed through a column (20 in. × 1 in.) of neutral Al_2O_3 (MCB) with petroleum ether and then CH_2Cl_2 as eluents. The petroleum ether fractions (containing **37**) were combined and desulfurized with Ni(R)[24] in refluxing ethanol for 2 h. Separation of the Ni and evaporation of ethanol gave an oil with an odor similar to that of *exo*-norborneol. Jones oxidation afforded a ketone similar to that reported,[16] and with a (−) n → π* Cotton effect corresponding to the 1*R*,5*S* configuration (**38**).

(1*R*,5*S*)-8,8-(Ethylenedioxy)bicyclo[3.2.1]octan-6-one (29). (−)-Alcohol **34a** (180 mg, 0.98 mmol)e, $[\alpha]^{24}_D$ −8.2°, 50.4; e.e., was added to a magnetically stirred suspension of freshly prepared pyridinium chlorochromate[27] (425 mg, 197 mmol) in dry CH_2Cl_2 at room temperature. The reaction was complete in ca. 1.5 h, as determined by GC on columns A and D. Anhydrous ether was added to the reaction mixture, the total mixture was filtered through Florisil, and the eluent solvent evaporated to give 175 mg (98%) of oily **29**. Added sodium acetate does not affect the course of reaction, but the reaction time is critically dependent on stirring efficiency. The product had IR (neat) ν 1741 cm^{-1}; ^1H NMR δ 0.60–2.80 (br m, 10 H), 3.92 (s, 4 H, OCH_2CH_2O); MS, *m/z* (relative intensity) 182 [$M^{+\cdot}$] (20), 154 (15), 99 (100), 55 (35).

Anal. Calcd for $C_{10}H_{14}O_3$ (182): C, 65.91; H, 7.74. Found: C, 65.73; H, 7.43.

(+)-(1*R*,5*S*)-6-Methylene-8,8-(ethylenedioxy)bicyclo[3.2.1]octane (30). A 10-mL round-bottom flask with side arm was charged with NaH (NaH–mineral oil mixture, 55% NaH, 78 mg of the mixture corresponds to 43 mg of NaH, 1.8 mmol) and washed thoroughly with dry pentane. Then it was fitted with a reflux condenser and the whole system was filled with N_2 and evacuated alternately. The NaH was slowly heated to ca. 85 °C, then dry Me_2SO (1.5 mL, freshly distilled) was added, and the resulting mixture was maintained at 85 °C for 45 min. To the clear solution was injected 720 mg (1.78 mmol) of methyl triphenylphosphonium iodide[22] in 2 mL of warm Me_2SO, and the resulting red solution was stirred at room temperature for 10–15 min. The keto ketal **29** (147 mg, 0.81 mmol from above in 1 mL of Me_2SO) was injected into the red ylid solution, and the resulting solution was stirred for 48 h at 80 °C (oil bath). At the end of this period, the solution was poured into 10 mL of cold water and extracted with pentane (4 × 25 mL). The combined pentane extracts were dried (Na_2SO_4), concentrated to ca. 20 mL, and then passed through a short column of neutral alumina (2 g of 80–200 mesh, MCB). The pentane eluent (ca. 100 mL of pentane used) was evaporated to afford olefin **30**: 112 mg (77%); >99% pure by GC on column D (110 °C); $[\alpha]^{24}_D$ +7.8° (*c* 1.2, pentane); IR (neat) ν 3076, 1662, 880 cm^{-1}; ^1H NMR δ 0.71–2.82 (br m, 10 H), 3.88 (s, 4 H, OCH_2CH_2O), 4.85 (br s, 2 H, $=CH_2$).

Anal. Calcd for $C_{11}H_{10}O_2$ (180): C, 73.30; H, 8.96. Found: C, 73.21; H, 8.76.

(1*R*,5*S*)-*endo*- and -*exo*-6-Methyl-8,8-(ethylenedioxy)bicyclo[3.2.1]octane (27 + 28). Olefin **30**, (90 mg, 0.5 mmol, $[\alpha]^{24}_D$ +9.1° (*c* 1.2, pentane), 59% e.e.) in 5 mL of pentane was hydrogenated at atmospheric pressure with 5% Pd(C) catalyst. After termination of H_2 uptake (1 h), filtration, and solvent evaporation, 75 mg (82%) of the epimeric mixture of **27** and **28** was obtained. It contained <0.5% starting olefin as determined by GC on column A (110°) and showed an endo:exo ratio of 1.9:1. The mixture was carried on directly to the deketalization step.

(1*R*,5*S*)-*exo*-6(*R*)-Methylbicyclo[3.2.1]octan-8-one (11). The above mixture of epimeric methyl ketals (**27 + 28**) (70 mg, 0.38 mmol) was mixed with 2 mL of 18% aqueous HCl and 0.7 mL of glacial acetic acid. The resulting solution was stirred magnetically for 48 h at room temperature in a closed round-bottom flask. It was then neutralized with $NaHCO_3$ and NaOH (the resulting solution had pH ~9) and extracted with ether (50 mL, 5 × 10 mL). The ether was removed with a vigreux column to yield 37 mg of a mixture of epimeric methyl ketones (**11 + 12**). Separation of the mixture was achieved by preparative GC on column F. The faster moving exo isomer: UV (pentane) ϵ^{max}_{295} 16; CD (pentane) $\Delta\epsilon^{max}_{291}$ +0.07, corr to 100% e.e.; IR (neat) ν 1750 cm^{-1}; ^1H NMR δ 1.05 (d, 3 H, *J* = 6 Hz), 0.73–2.50 (br m, 11 H); ^{13}C NMR (Table III); MS, *m/z* 138.1040 [$M^{+\cdot}$, $C_9H_{14}O$ 138.1045].

Anal. Calcd for $C_9H_{14}O$ (138): C, 78.21; H, 10.21. Found: C, 78.01; H, 10.02.

(1*R*,5*S*)-*endo*-6(*S*)-Methylbicyclo[3.2.1]octan-8-one (12). The major isomer (endo) in the mixture of epimeric methyl ketones above had a longer retention time and was isolated by preparative GC on column F: UV (pentane) ϵ^{max}_{290} 32; CD (pentane) $\Delta\epsilon^{max}_{301}$ −2.4, corr to 100% e.e.; IR (neat) ν 1750 cm^{-1}; ^1H NMR δ 1.23 (d, 3 H, *J* = 6 Hz), 0.7–2.6 (br m, 11 H); ^{13}C NMR (Table III); MS, *m/z* 138.1042 [$M^{+\cdot}$, $C_9H_{14}O$: 138.1045].

Anal. Calcd for $C_9H_{14}O$ (138): C, 78.21; H, 10.21. Found: C, 78.01; H, 10.02.

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97858-80-5; **7**, 97858-70-3; **9**, 97858-82-7; **11**, 97858-71-4; **12**, 97858-72-5; **13**, 70981-37-2; **13** (tosylate), 97764-92-6; **14**, 97858-83-8; **15**, 83829-13-4; **16**, 97858-74-7; **17**, 97858-75-8; **18**, 97858-73-6; **19**, 97858-77-0; **20**, 97764-88-0; (*E*)-**21**, 97764-87-9; (*Z*)-**21**, 97858-76-9; **22**, 97764-90-4; **23**, 97858-79-2; (*E*)-**24**, 97764-89-1; (*Z*)-**24**, 97858-78-1; **25**, 97858-81-6; **26**, 97858-84-9; **27**, 97764-99-3; **28**, 97858-90-7; **29**, 97764-98-2; **30**, 97782-01-9; (±)-**31**, 97764-93-7; (±)-**31** (ketal), 97764-95-9; (±)-**33**, 97764-96-0; (±)-**34**, 97858-85-0; **34a**, 70981-38-3; **34b**, 70919-54-9; (±)-**35**, 97764-97-1; **35a**, 97858-87-2; **35b**, 97858-89-4; **36a**, 70919-50-5; **36b**, 70981-32-7; **37**, 97782-00-8; **38**, 21592-98-3; (+)-(*S*)-MTPA-Cl, 20445-33-4; $(C_6H_5)_3PCH_3^+I^-$, 2065-66-9; $(C_6H_5)_3PCH_2CH_3^+I^-$, 4736-60-1; $(C_6H_5)_3P(CH_2)_5CH_3^+I^-$, 60106-53-8; $HO(CH_2)_2OH$, 107-21-1; Br_2, 7726-95-6; *trans*-ClCH=CHCl, 156-60-5; *n*-BuSH, 109-79-5; cyclohexanone, 108-94-1; (±)-1,1-(ethylenedioxy)-2-bromocyclohexane, 97764-94-8; 1,1-(ethylenedioxy)-2-cyclohexene, 1004-58-6; 2-cyclohexenone, 930-68-7; 2,2-(ethylenedioxy)-7,8-dichlorobicyclo[4.2.0]octane, 2018-82-8; phthalic anhydride, 85-44-9; *d*-α-(1-naphthyl)ethylamine, 3886-70-2; 4(a)-methyl-2-adamantanone, 88494-22-8; 4(e)-methyl-2-adamantanone, 19301-60-1; 4(a)-hydroxy-2-adamantanone, 27863-77-0; bicyclo[3.2.1]octan-8-one, 55679-31-7.

Reaction of Nucleophiles with 1,1-Dinitro-2,2-diphenylethylene[1]

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Products of the reaction of a variety of nucleophiles with $Ph_2C{=}C(NO_2)_2$ are reported. Michael-type adducts have been isolated: $(Ph_2C(N)CH(NO_2)_2)$ for N^- = $(RO)_2PO^-$, $(RO)_2PS^-$, $RCOCH_2^-$. With the nucleophiles MeO^- or $Me_2C{=}NO_2^-$ in Me_2SO the adducts are formed but are hydrolyzed upon workup with 5% aqueous HCl at 25 °C to yield benzophenone. Benzophenone is also the major product from reaction with the nucleophiles NO_2^-, AcO^-, $MeC(=S)O^-$, EtO^-, and Me_3CO^- in Me_2SO. With N^- = Me_3CS^-, ArS^-, PhO^-, or $PhSe^-$ in Me_2SO, vinylic substitution occurs to yield $Ph_2C{=}C(N)NO_2$. With $ArSO_2^-$ in DMF nucleophilic aromatic substitution occurs to yield *p*-$ArSO_2C_6H_4COPh$.

We have found that 1,1-dinitro-2,2-diphenylethylene (**1**) undergoes a variety of reactions with nucleophiles. We originally thought that **1** might undergo vinylic substitution by an electron-transfer process[2,3] similar to the $S_{RN}1$ reaction which occurs for 2,2-dinitropropane[4,5] and other 2-substituted 2-nitro alkanes.[6,7] Depending upon the nucleophile and solvent, we have observed either the formation of an isolable Michael-type adduct (**2**), benzophenone, the vinyl substitution product (**3**), or the aromatic substitution product (**4**). Yields of these products are summarized in Table I. We believe these products are all formed from the initial Michael-type anion $\mathbf{2}^-$ (Scheme I). The reactions leading to the substitution products **3** or **4** were uneffected by light or free-radical inhibitors such as $(t\text{-Bu})_2NO\cdot$, and appear to be ionic rather than electron-transfer processes.

The hydrolysis of **1** to $Ph_2C{=}O$ in the presence of base is a well-studied process involving $\mathbf{2}^-$ (N = OH) as an intermediate.[8] We have utilized a hydrolytic workup procedure involving treatment of the reaction mixture with brine followed by ether extraction wherein the hydrolysis of **1** was negligible and recovered yields of **1** of 97–98% could be isolated in the absence of added nucleophiles with Me_2SO, DMF, THF, MeOH or EtOH as solvents or with "nonreacting" nucleophiles such as NO_3^-, N_3^-, or SCN^- in Me_2SO or $(EtO_2C)_2CR^-$ in THF (Table I).

The Michael-type adducts (**2**) with N = $(MeO)_2P(=O)$, $(EtO)_2P(=O)$, $(MeO)_2P(=S)$, $(EtO)_2P(=S)$, $MeSO_2CH_2$, or $MeSOCH_2$ were isolated from Me_2SO solution while the adducts **2** with N = $MeCOCH_2$, Me_3CCOCH_2, or $PhCOCH_2$ were prepared from lithium enolates in THF. The adducts with N = CN or MeO were prepared in EtOH and MeOH, respectively. Evidence for the adduct with N = $Me_2C{=}N(O)O$ is indirect and is based upon the fact that hydrolysis of the reaction product in Me_2SO with 5% aqueous HCl yielded benzophenone, whereas workup with a brine solution yielded recovered **1**. The adduct **2l** or the anion $\mathbf{2l}^-$ apparently reverts to **1** upon hydrolysis with the brine solution but can be converted by mineral acids to $Ph_2C(OH)CH(NO_2)_2$ which decomposes to yield $Ph_2C{=}O$. Other "nonreacting" anions such as $(EtO_2C)_2CMe^-$, $(MeO_2C)_2CH^-$, or $(i\text{-Pr})_2N^-$ may also form reversibly the anion $\mathbf{2}^-$ which upon hydrolysis reverts to **1** with protonation of N^- rather than $\mathbf{2}^-$.

Hydrolysis of **2** to yield benzophenone also occurs with **2j** (N = MeO). Treatment of the reaction product of **1** and excess MeO^- in MeOH with 5% aqueous HCl at 25 °C yielded only a mixture of $Ph_2C{=}O$ (14%) and $Ph_2C(OMe)_2$ (61%). However, acidification in a dry ice–acetone bath followed by extraction yielded 42% of **2j**[9] and 26% of $Ph_2C{=}O$. Treatment of the reaction product of **1** with 1 equiv of MeO^- with a brine workup also yielded mainly $Ph_2C{=}O$ (73%) but in this case a low yield of the substitution product, **3j** (7%), was also detected.

Benzophenone was the major product with oxygen nu-

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