Organic and Biological Chemistry

Dissymmetric Homoconjugated Chromophores. Circular Dichroism of Cyclopropyl Ketones[1]

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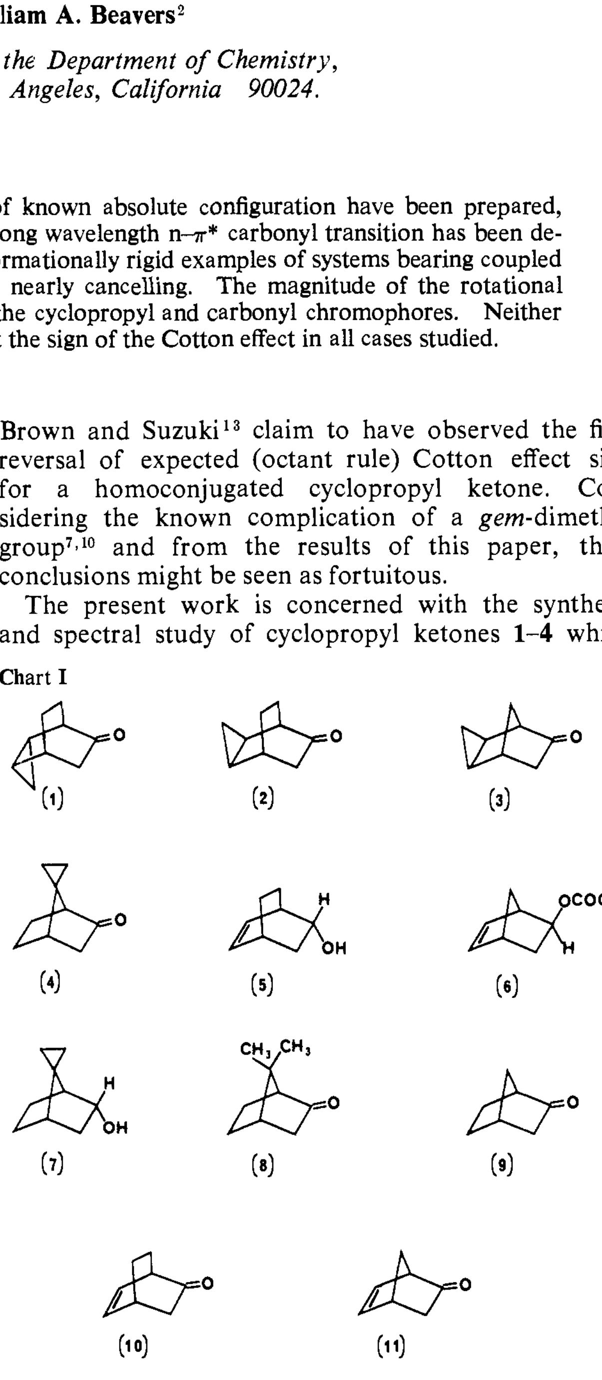
Abstract: Optically active β,γ-cyclopropyl ketones **1–4** of known absolute configuration have been prepared, and their circular dichroism behavior in the region of the long wavelength $n-\pi^*$ carbonyl transition has been determined. These compounds are structurally simple, conformationally rigid examples of systems bearing coupled chromophores in which the normal octant perturbers are nearly cancelling. The magnitude of the rotational strengths depends critically on the relative orientation of the cyclopropyl and carbonyl chromophores. Neither the octant rule nor "reversed" octant rules correctly predict the sign of the Cotton effect in all cases studied.

It was first noted by Djerassi, Riniker, and Riniker[3] that the optical rotatory dispersion (ORD) behavior of ketones is strongly affected by conjugated (α,β) cyclopropane rings. Later, Norin[4] observed that application of the octant rule[5,6] failed to assign correctly the cyclopropyl configuration in the thujane group. This discovery led to the further detailed investigation of the ORD and circular dichroism (CD) characteristics of cyclopropyl and epoxy derivatives of α,β-unsaturated ketones.[7–12] Djerassi and coworkers[7] and Schaffner and Snatzke[8] interpreted the ORD data of a large number of cyclopropyl ketones in terms of the octant rule[5,6] and concluded that cyclopropyl rings adjacent to the carbonyl group make contributions to the Cotton effect *opposite* to those made by ordinary alkyl perturbers. However, a few exceptions to the so-named "inverse" or "reversed" octant rule for cyclopropyl ketones have been noted: the rule fails when applied to (+)-carone, which has *gem*-dimethyl substitution on the cyclopropane ring,[7,10] but is obeyed by bicyclo[4.1.0]heptan-2-one which has no *gem*-dimethyl grouping.[10] Morever, $3\alpha,5\alpha$-cyclosteroid 6-ketones are claimed to follow the conventional octant rule.[12] In spite of these few counterexamples, the "reversed" octant rule for cyclopropyl ketones has enjoyed a large measure of success and has even been extended to conformational studies of β,γ-cyclopropyl ketones. Thus, for 4-isocaranone and 4-caranone, Brown and Suzuki[13] claim to have observed the first reversal of expected (octant rule) Cotton effect sign for a homoconjugated cyclopropyl ketone. Considering the known complication of a *gem*-dimethyl group[7,10] and from the results of this paper, their conclusions might be seen as fortuitous.

The present work is concerned with the synthesis and spectral study of cyclopropyl ketones **1–4** which contain the cyclopropyl and carbonyl chromophores in a rigidly fixed structural skeleton. In each instance the cyclopropyl ring bears a β,γ-relationship to the carbonyl group but is located in different orientations. Such examples probe the spatial requirements[14–16] for

Chart I



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(1) Financial support by the National Science Foundation (Grant No. GP-9533) is gratefully acknowledged.

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the "homoconjugation" of the cyclopropane ring relative to the carbonyl group.

Synthesis and Stereochemistry

Optically active cyclopropyl ketones **1**–**3** were generated from optically active precursors of known absolute configuration. Thus, entry into the bicyclo[2.2.2]octane series was achieved *via* partially resolved *endo*-bicyclo[2.2.2]oct-5-en-2-ol (**5**).[17] Treatment of the resolved *endo*-alcohol (**5**) with methylene iodide–zinc–copper couple[18,19] (Simmons–Smith reagent) gave only the *syn*-cyclopropyl *endo*-alcohol which was oxidized with "*active*" manganese dioxide[20] in methylene chloride to give (−)-*endo*-tricyclo[3.2.2.0^{2,4}]nonan-6-one (**1**). Simmons–Smith or diethylzinc catalyzed reactions[18,19] on allylic[21,22] or homoallylic[22] alcohols in five- or six-membered rings are highly stereoselectively controlled by the hydroxyl group and lead to the syn orientation of the product cyclopropyl alcohol. The epimeric *exo*-cyclopropyl ketone (**2**) was prepared from the acetate of **5** by a Simmons–Smith reaction carried out at high pressure.[23] It was reasoned that the steric crowding on the endo face of the acetate of **5** would provide sufficient distinction to promote formation largely of the *anti*-cyclopropyl *endo*-acetate. Both the *syn*- and *anti*-cyclopropyl *endo*-acetates were formed (ratio 5:2) and were converted to their corresponding ketones. The syn isomer gave a ketone identical with that above (**1**); the anti isomer gave the new epimeric ketone (**2**). In the Simmons–Smith reaction of the *endo*-acetate, it would appear that the acetate group does serve to direct syn formation of the cyclopropane ring to some extent and does not merely offer a steric bulk compelling anti formation.

The structurally related cyclopropylnorbornanones were synthesized in a similar manner from (+)-*exo*-norbornenol prepared by the asymmetric hydroboration of norbornadiene.[17] A high-pressure Simmons–Smith reaction[23] on (+)-*exo*-norbornenyl acetate (**6**) gave exclusively the *anti*-cyclopropyl epimer which was hydrolyzed and oxidized to the enantiomer of recently reported[24] (+)-*exo*-tricyclo[3.2.1.0^{2,4}]octan-6-one (**3**). All attempts to prepare the *pure syn*-cyclopropyl epimer were unsuccessful, although it was obtained as a mixture with the anti epimer by reaction of (−)-*endo*-bicyclo[2.2.1]hept-5-en-2-ol with diethylzinc and methylene iodide.[23] The preference for the formation of *exo*-cyclopropane in the norbornane skeleton has been demonstrated repeatedly in various carbene reactions on norbornene and substituted norbornenes.[25–27] Apparently, even the directing influence of the *endo*-alcohol is insufficient to alter this preference decidedly. Attempted separation of the two epimers by gas chromatography or *via* their *p*-nitrobenzoate esters failed.

Spirocyclopropyl ketone (**4**) was prepared by "active" manganese dioxide oxidation[20] in methylene chloride of the (−)-*endo*-alcohol (**7**) which had been partially resolved as the acid phthalate half-ester with brucine. The racemate of **7** was obtained by hydrolysis of the catalytically hydrogenated Diels–Alder condensation product[28] of spiro[2.4]hepta-4,6-diene and vinyl acetate. In order to determine the absolute configuration, the cyclopropane ring of spiro ketone **4** was opened by catalytic hydrogenation[29] to a *gem*-dimethyl group, thereby converting **4** to (−)-*endo*-7,7-dimethylbicyclo[2.2.1]heptan-2-ol, which was oxidized to the known[30] (−)-α-fenchocamphorone (**8**).

Discussion

Symmetric and Dissymmetric Chromophores. In treating ORD and CD behavior of chromophores in relation to molecular geometry, Moffitt and Moscowitz[31] and later Djerassi, Mislow, Moscowitz, and coworkers[32–36] found it useful to classify optically active chromophores in terms of two limiting types: (i) the inherently symmetric, but dissymmetrically perturbed, and (ii) the inherently dissymmetric chromophore. The inherently symmetric chromophore is one where the symmetry of the isolated chromophore is sufficiently high to preclude optical activity. As such, the signed magnitudes of the associated rotational strength [R] (weighted area under the CD curve) provide information as to the chemical nature of the molecular environment and its disposition relative to the symmetry planes of the chromophore (*e.g.*, the octant rule for the carbonyl group of saturated hydrocarbon ketones). On the other hand, the inherently dissymmetric chromophore is one where the geometry of the chromophoric group lacks an S_n alternating axis, so that even in isolation its transitions will manifest optical activity (*e.g.*, β,γ-unsaturated ketones). In terms of [R] values as observed in the visible and near ultraviolet, inherently dissymmetric chromophores are recognized by rotational strengths that can be of the order of 10^{-38} cgs, whereas inherently symmetric chromophores exhibit rotational strengths that are generally significantly less in magnitude. Thus, if the cyclopropyl ketones under study show rotational strengths of the order of magnitude of the structurally related saturated ketones α-fenchocamphorone (**8**) or bicyclo[2.2.1]heptan-2-one (**9**), they fall more nearly into the inherently symmetric classification and the octant rule is applicable. However, if the rotational strengths are of the order of magnitude of the unsaturated ketones

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(34) C. Djerassi, R. Records, E. Bunnenberg, K. Mislow, and A. Moscowitz, *ibid.*, 84, 570 (1962).

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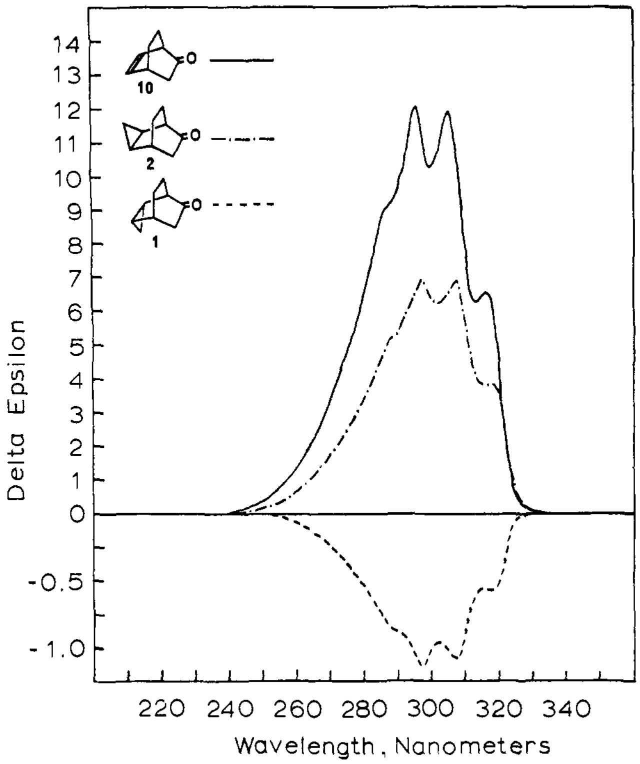

Figure 1. Circular dichroism spectra of bicyclo[2.2.2]oct-5-en-2-one (**10**) (——), *exo*-tricyclo[3.2.2.$0^{2,4}$]nonan-6-one (**2**) (–·–·–), and *endo*-tricyclo[3.3.2.$0^{2,4}$]nonan-6-one (**1**)- - - - -.

bicyclo[2.2.2]oct-5-en-2-one (**10**) or bicyclo[2.2.1]hept-5-en-2-one (**11**), they fall into the inherently dissymmetric classification and the octant rule is not strictly valid. Even when situated in dissymmetric molecular surroundings, the contributions to the signed magnitude of the large [*R*] values of inherently dissymmetric chromophores are determined primarily by the chirality of the chromophore itself. As such, qualitative stereochemical questions whose answers derive from the chiral nature of the chromophoric geometry can be posed and answered without recourse to considerations of dissymmetric vicinal action.

Circular Dichroism and the Sign of the Rotational Strength. The CD curves for the erstwhile n–π* transition of the epimeric cyclopropyl ketones **1** and **2** (Chart I) in the more highly symmetrical bicyclo[2.2.2]octane skeleton are shown in Figure 1. The signed Cotton effects may be compared to that of bicyclo-[2.2.2]oct-5-en-2-one (**10**) whose ORD behavior has been interpreted by Mislow and Berger[17] and Moscowitz[36] and Hansen[37] in terms of an inherently dissymmetric chromophore. On the basis of the magnitudes of the rotational strengths (see Table I) the chromophore of the exo epimer (**2**) might be classified as inherently dissymmetric [*cf.* bicyclooctenone (**5**)]. The classification of the endo epimer (**1**) is somewhat more difficult to define unless a knowledge of the contributions by static dissymmetric perturbers can be ascertained from the octant rule, for the magnitude of the rotational strength of the endo epimer (**1**) is closer to that of bicyclo[2.2.1]heptan-2-one (**9**) than to that of the β,γ-unsaturated ketone (**10**). The octant projection diagrams[38] of both **1** and **2** in Figure 2 indicate that at best only a very weak contribution (*positive*) to the Cotton effect might be attributed to static dissymmetric perturbers (octant rule). Consequently, the observed moderate-to-strong rotational strengths of both **1** and **2** can be associated mainly with the chirality of the inherently dissymmetric chromophore, and the chirality determines the sign of the Cotton effect.

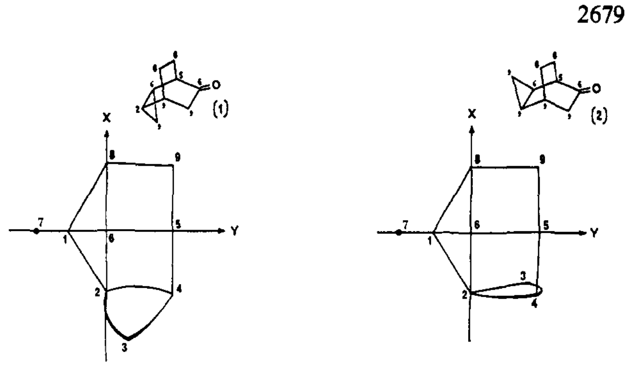

Figure 2. Octant projections of *endo*-tricyclo[3.2.2.$0^{2,4}$]nonan-6-one (**1**) and *exo*-bicyclo[3.2.2.$0^{2,4}$]nonan-6-one (**2**).

Table I. Rotational Strengths of β,γ-Cyclopropyl and Related Ketones

Compd no.	Absolute configuration	Rotational strength, cgs $\times 10^{40}$	Octant rule, predicted Cotton effect
1	1*R*,5*S*	−3.1	Weakly +
2	1*R*,5*R*	+20.2	Weakly +
3	1*R*,5*R*	+18.9	Weakly +
	1*R*,5*S*	Negative	Weakly +
4	2*S*	−9.0	−
8	1*S*	−5.9	−
9	1*S*	−1.2	Weakly −
10	1*R*	+29.0	
11	1*R*	+51.1	

A further consistent example of this type of behavior may be found in Figure 3 wherein the CD spectrum of *exo*-tricyclo[3.2.1.$0^{2,4}$]octan-6-one (**3**) exhibits a rotational strength more nearly characteristic of the inherently dissymmetric β,γ-unsaturated ketone (**11**) than the saturated ketone (**9**) (Table I). On the other hand, from the very similar rotational strengths (Table I) of spirocyclopropyl ketone **4** (Figure 4) and α-fenchocamphorone (**8**) we conclude that the former constitutes an example of a cyclopropyl ketone in which the normal octant perturbers dominate the contributions due to the chirality of the dissymmetric chromophore. The negative Cotton effect of **4** might therefore be correctly predicted by the Octant rule. In fact, the octant diagrams (Figure 5) predict a *negative* Cotton effect for both spirocyclopropyl ketone **4** and α-fenchocamphorone (**8**) (*cf.* Table I). However, although the octant diagrams (Figure 6) of **3** and its endo epimer suggest that these cyclopropyl ketones should both have a *weakly positive* Cotton effect, **3** is observed to have a *strongly positive* Cotton effect and the endo epimer, which we could not obtain pure, has a *negative* Cotton effect. The cyclopropyl ketone data point to the fact that neither the ordinary octant rule nor a "reversed"

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(37) Aa. E. Hansen, Licentiate Thesis, H. C. Oersted Institute, Copenhagen, 1964.

(38) C. Djerassi, "Optical Rotatory Dispersion," McGraw-Hill, New York, N. Y., 1960.

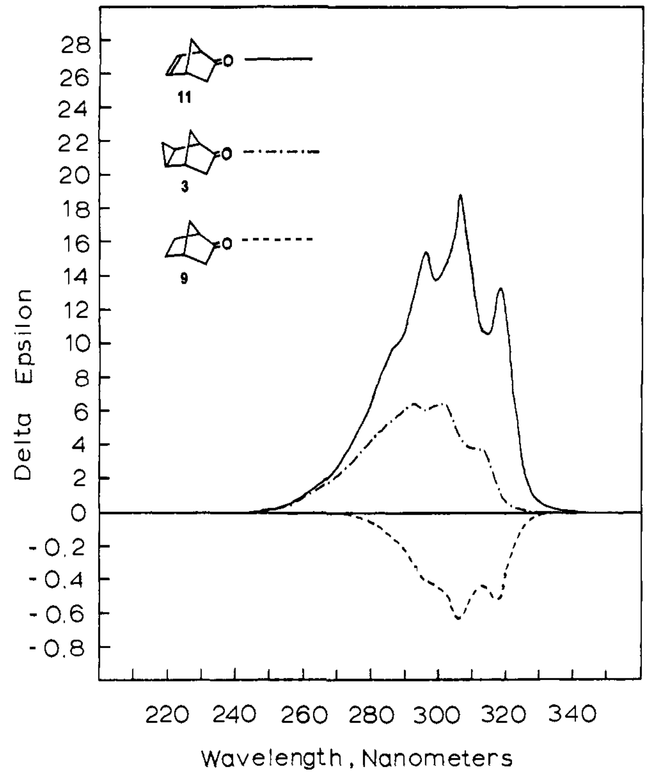

Figure 3. Circular dichroism spectra of bicyclo[2.2.1]hept-5-en-2-one (**11**) (——), *exo*-tricyclo[3.2.1.$0^{2,4}$]octan-6-one (**3**) (–·–·–), and bicyclo[2.2.1]heptan-2-one (**9**) (– – – – –).

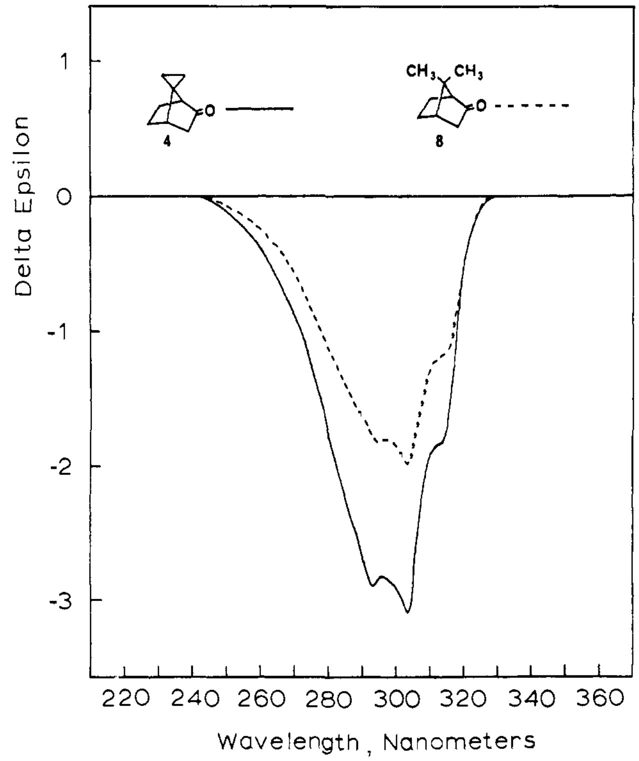

Figure 4. Circular dichroism spectra of spiro(cyclopropane-1,7′-norbornanone) (**4**) (——) and α-fenchocamphorone (**8**) (– – – – –).

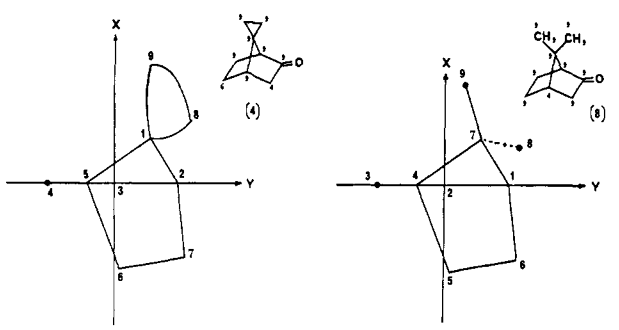

Figure 5. Octant projections for spiro(cyclopropane-1,7′-norbornanone) (**4**) and α-fenchocamphorone (**8**).

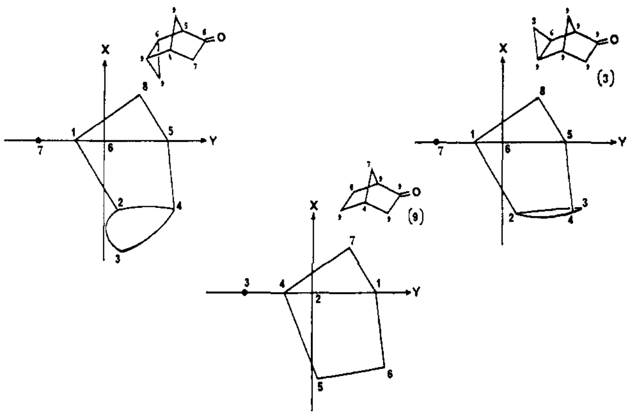

Figure 6. Octant projections for *endo*-tricyclo[3.2.1.$0^{2,4}$]octan-6-one, *exo*-tricyclo[3.2.1.$0^{2,4}$]octan-6-one (**3**), and bicyclo[2.2.1]heptan-2-one (**9**).

octant rule consistently predicts the observed Cotton effect sign.

Not unexpectedly therefore, the relative orientation of cyclopropane ring and the carbonyl group plays a crucial role in determining whether a cyclopropyl ketone falls firmly into the inherently dissymmetric classification, in which case the octant rule does not apply, or into the inherently symmetric classification for which the octant rule may be applied successfully. Any generalized rule[7–12] for predicting the Cotton effect sign of cyclopropyl ketones must take into account the relative orientation of the two chromophores and recognize the geometries in which they are weakly or strongly interacting.

Geometric and Theoretical Considerations. The importance of the relative orientation of the cyclopropane and the carbonyl chromophores has been discussed briefly[7] in terms of maximum overlap of the delocalized cyclopropane orbitals[39] and the nonbonding (n) orbitals of the carbonyl oxygen. Thus, the symmetry-forbidden carbonyl n–π* transition (electric dipole, μ_e, forbidden) takes on aspects of an allowed π–π* transition by mixing in delocalized cyclopropane excited states into the carbonyl n–π* state[40] (see Figure 7). The sign and magnitude of the mixing coefficient are determined by the energy difference between the cyclopropyl excited states and the carbonyl n–π* state and relative orientation of the two chromophores. Using these considerations to understand the magnitudes of the observed Cotton effects, it is to be expected that the mixing will be greater and lead to larger rotational strengths (*cf.* the *exo*-cyclopropyl epimers **2** and **3**)

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[39] A. D. Walsh, *Trans. Faraday Soc.*, **45**, 179 (1949); C. A. Coulson and W. E. Moffitt, *Phil. Mag.*, **40**, 1 (1949).

[40] The orbital description of this phenomenon is presented adequately in ref 7 and references therein.

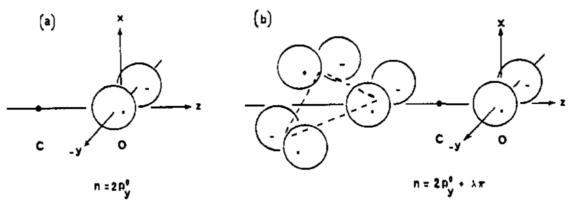

Figure 7. Schematic representation of n orbitals involved in the n–π* transition of (a) the isolated chromophore and (b) cyclopropyl ketones.

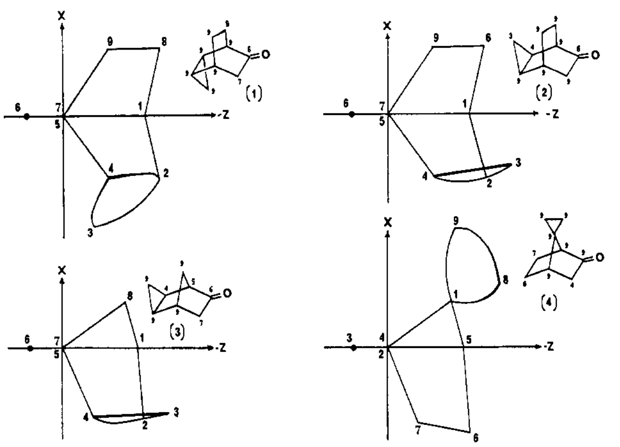

Figure 8. Projections in the *XZ* plane for *endo*-tricyclo[3.2.2.0^{2,4}]-nonan-6-one (**1**), *exo*-tricyclo[3.2.2.0^{2,4}]nonan-6-one (**2**), *exo*-tricyclo[3.2.1.0^{2,4}]octan-6-one (**3**), and spiro(cyclopropane-1,7′-norbornanone) (**4**).

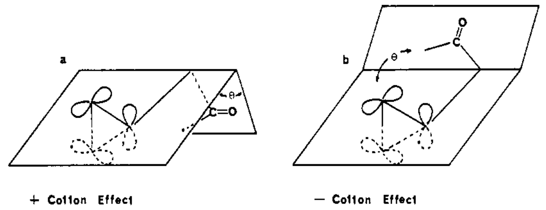

Figure 9. Enantiomeric chromophores associated with β,γ-cyclopropyl ketones.

when the plane of the carbonyl n system lies parallel with the cyclopropane ring (in which the cyclopropane delocalized orbitals lie). However, when the cyclopropane ring and carbonyl n system approach orthogonality, the independent chromophores are expected to exhibit less mixing as manifested by much lower rotational strengths, perhaps marginal for an inherently dissymmetric chromophore [*cf. endo*-cyclopropyl epimer **1** and the spirocyclopropyl compound (**4**)].

Some of the geometric considerations of the foregoing are found in Figure 8, which depicts the projections of **1**–**4** in the *XZ* plane (the carbonyl π orbitals lie in the *XZ* plane). Thus, for *exo*-cyclopropyl ketones **2** and **3** the plane of the cyclopropane ring (and the delocalized cyclopropane orbitals) is nearly parallel with the plane of the carbonyl n system, and the rotational strengths (Table I) are large. On the other hand, for cyclopropyl ketones **1** and **4**, the plane of the cyclopropane ring is nearly orthogonal to the carbonyl n system, and the small rotational strengths obtain (Table I).

In order to generate the *sign* of the Cotton effect from the relative orientation of the pertinent chromophores, we attempt to determine the "chirality" of the extended n system (Figure 7) from the skew angle (θ) determined by the intersection of (1) a plane orthogonal to the in-plane p orbital[39] of the cyclopropyl carbon β to the carbonyl carbon and (2) the plane of the oxygen n orbital ($2p_y^0$ of Figure 7). Qualitatively, θ is found to be (arbitrarily) positive (Figure 9a) for the *exo*-cyclopropyl ketones (**2** and **3**) and negative (Figure 9b) for the *endo*-cyclopropyl ketones (**2** and **3**) and negative (Figure 9b) for the *endo*-cyclopropyl ketone (**1**) and the spirocyclopropyl ketone (**4**). These observations correlate with the experimentally determined Cotton effect signs (Table I). Admittedly, this correlation lacks sufficient theoretical justification and is based merely on an extension of the β,γ-unsaturated ketone approach.[6,17] Such a simplified treatment neglects the multiplicity of low-lying cyclopropane electronic transitions[41] involving both π–σ* and π–π* states and gives special emphasis to only one of them. However, a correlation is found even though there are as yet too few examples to determine its general applicability. This approach also does not answer the problem posed by α,β-cyclopropyl ketones,[7] whose chromophores are potentially more strongly coupled (except in unfavorable spatial orientations) than those of β,γ-cyclopropyl ketones.

A more detailed theoretical treatment of the model compounds was attempted[42] in which the allowed cyclopropane transitions[43] were mixed with the carbonyl n–π* transition to give the excited-state wave function

$$\psi_{ex} = (n-\pi^*) + \sum_i \lambda_i(\pi-\sigma^*) + \sum_j \lambda_j(\pi-\pi^*)$$

Thus, in order to obtain qualitative predictions, a perturbation treatment based on point dipole (cyclopropane)–quadrupole (carbonyl) interactions as well as more extensive dipole–quadrupole interactions was carried out. However, it failed to predict correctly the observed Cotton effect signs. The possibility that the lowest energy cyclopropane transition is a Rydberg transition[41] and the general difficulty in assigning the lowest lying cyclopropane transitions complicate the theoretical treatment, and as yet no satisfactory results have been obtained.

Experimental Section[44]

Bicyclo[2.2.2]oct-5-en-2-yl Acetate. In a typical run 340 g (3.96 mol) of vinyl acetate (undistilled, Matheson Coleman and Bell) and 487 g of 65% 1,3-cyclohexadiene[45] were placed in a glass-lined 1-l. Parr bomb. The apparatus was swept with nitrogen and sealed. After 6 days of heating at 150°, the desired product was recovered

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(41) H. Basch, M. B. Robin, N. A. Kuebler, C. Baker, and D. W. Turner, *J. Chem. Phys.*, **51**, 52 (1969).

(42) C. W. Deutsche, UCLA Chemistry Department, unpublished results.

(43) J. W. Raymonda and W. T. Simpson, *J. Chem. Phys.*, 47, 430 (1967).

(44) All preparative gas chromatography was performed on an F & M Model 700 instrument equipped with the various columns noted in the Experimental Section. ORD and CD spectra were measured on a Cary 60 polarimeter equipped with a circular dichroism attachment. Nmr spectra were determined on a Varian A-60 instrument. All mass spectra were determined on an AEI MS-9 mass spectrometer. Microanalyses were performed by Miss Heather King of the UCLA chemistry department microanalytical laboratory. All melting points are uncorrected and were determined on a Mel-Temp heating block.

(45) J. Hine, J. A. Brown, L. H. Zalkow, W. E. Gardner, and M. Hine, *J. Amer. Chem. Soc.*, 77, 597 (1955).

by fractional distillation of the resulting crude yellow liquid. The fraction (261 g) distilling at 124–130° (45 Torr) was determined by glpc to contain 60% of the desired product and 40% of cyclohexadiene dimer. This mixture was used directly in the next reaction.

Bicyclo[2.2.2]oct-5-en-2-ol (5). A solution of 250 ml of 20% methanolic hydroxide was placed in a 1-l. round-bottomed flask equipped with a reflux condenser. To this solution was added 261 g of the crude bicyclo[2.2.2]oct-5-en-2-yl acetate from the Diels–Alder reaction above, and the mixture was heated at reflux for 24 hr. The methanol was removed at reduced pressure using a 2-ft. Vigreux column, and the residue was filtered to remove precipitated sodium acetate. This filtrate was dissolved in 500 ml of pentane, and the pentane was allowed to evaporate slowly at room temperature. The product crystallized from the solution and was purified by two recrystallizations from the original pentane solution by adding 200 ml of pentane and cooling in an acetone–Dry Ice bath. The total yield amounted to 61.9 g; mp 167–168° (lit.[17] mp 167.5–169°); nmr ($CDCl_3$) symmetrical sextet at δ 6.25 (2 H, J = 7.5 cps), 3.85 (1 H), 2.6 (2 H), multiplet at 2.2–1.4 (3 H, J = 2, J = 8 cps), and 1.3 (4 H).

Anal. Calcd for $C_8H_{12}O$: C, 77.37; H, 9.74. Found: C, 77.44; H, 9.74.

Bicyclo[2.2.2]oct-5-en-2-yl Phthalate. This general procedure was used for the preparation of all half-acid phthalates. To a 500-ml round-bottomed flask equipped with a drying tube was added 25 g (0.202 mol) of bicyclo[2.2.2]oct-5-en-2-ol, 50 ml of anhydrous pyridine, and 33 g (0.223 mol) of phthalic anhydride. The mixture was heated at 90° for 3.5 hr during the course of which the solution became homogeneous. The product was worked up by pouring the solution into 300 ml of chilled, dilute hydrochloric acid and extracting the resulting precipitate with three 100-ml portions of chloroform. The chloroform solution was extracted with three 100-ml portions of 5% sodium bicarbonate solution which was in turn washed with several portions of fresh chloroform. The aqueous layer was carefully acidified, and the purified product was extracted with three 100-ml portions of chloroform. The chloroform was removed on a rotory evaporator to yield 51 g of product (93% theory), mp 163–165° (lit.[17] mp 168–168.5°).

Anal. Calcd for $C_{16}H_{16}O_4$: C, 70.57; H, 5.93. Found: C, 70.59; H, 5.69.

Resolution of Bicyclo[2.2.2]oct-5-en-2-ol. The resolution is essentially that used by Mislow and Berger.[17] Starting with 67.3 g (0.247·mol) of bicyclo[2.2.2]oct-5-en-2-yl phthalate and 46.7 g (0.283 mol) of *l*-ephedrine there was obtained 16.6 g of the partially resolved salt after 19 recrystallizations from absolute ethanol, $[\alpha]^{26}\mathrm{D}$ +20.6°. For each recrystallization, 5–10 ml of ethanol/g of the salt was used with a recovery of 90–95% of material.

endo-Bicyclo[2.2.2]oct-5-en-2-yl phthalate was liberated from the salt by extracting a chloroform solution of the salt with three 100-ml portions of 2% aqueous potassium hydroxide, washing the combined aqueous phases with 50 ml of fresh chloroform, and carefully acidifying the aqueous phase with dilute hydrochloric acid. The product was collected on a Buchner funnel and air dried to yield 10 g of pale yellow solid, mp 156–159°, $[\alpha]^{27}\mathrm{D}$ +45.8°.

endo-Bicyclo[2.2.2]oct-5-en-2-ol was recovered from its half-phthalate by mixing 10 g (37 mol) of phthalate with 3.0 g of sodium hydroxide and allowing the solution to stand at room temperature for 3 hr. Initially, the mixture required brief heating to effect complete solution of the phthalate. This solution was then rapidly steam distilled until 100 ml of distillate had been collected. Then 20 g of sodium hydroxide in 20 ml water was added to the steam distillation residue, and steam distillation was continued until an additional 125 ml of distillate had been collected. The product was collected by saturating the aqueous distillates with sodium chloride and extracting with three 25-ml portions of dichloromethane. The solvent was carefully removed using a tantalum wire fractionating column (1 m) and the pot residue was sublimed to yield 4.2 g of a waxy solid, mp 156–167°, $[\alpha]^{27}\mathrm{D}$ +61.2° (*c* 1.0, chloroform). This represented an optical purity of 83.2% based on values reported by Goering and Towns.[46]

***endo*-Tricyclo[3.2.2.0^{2,4}]nonan-6-ol.** *endo*-Bicyclo[2.2.2]oct-5-en-2-ol (500 mg, 4.1 mmol), $[\alpha]^{27}\mathrm{D}$ +61.2°, was mixed with 2.17 g (8.1 mmol) of methylene iodide and 3 ml of absolute ether to aid dissolution. This solution was slowly added to 700 mg of 30 mesh zinc–copper couple[18,19] in 25 ml of refluxing absolute ether to which a few drops of methylene iodide had been added. The mixture was stirred and heated at reflux for 24 hr during which time the couple partially dissolved and the liquid phase acquired a darker coloration due to the finely divided copper suspension. The product was recovered by filtering the unreacted couple and washing the filtrate with two 25-ml portions of saturated aqueous ammonium chloride, saturated aqueous sodium bicarbonate, and water in that order. The organic phase was dried over anhydrous magnesium sulfate and filtered, and the ether was removed carefully using a tantalum wire fractionating column (1 m). The residue from the distillation was chromatographed on 40 g of silica gel (Merck) in a refrigerated room (5°) using gradient elution (0–30% ether in pentane). The final purification was achieved by sublimation to yield 185 mg of waxy-white solid; $[\alpha]^{25}\mathrm{D}$ +0.4° (*c* 1.8, dichloromethane); nmr δ 3.8, 2.0 (2 H), 1.7 (1 H), 1.5 (5 H), 0.9 (3 H), 0.3 (1 H, *exo*-H on cyclopropane ring); mass spectrum, *m/e* 138 (M^+), 79 (100%).

Anal. Calcd for $C_9H_{14}O$: C, 78.21; H, 10.21. Found: C, 78.42; H, 10.13.

(−)-*endo*-Tricyclo[3.2.2.0^{2,4}]nonan-6-one (1). *endo*-Tricyclo[3.2.2.0^{2,4}]nonan-6-ol (180 mg, 1.3 mmol), $[\alpha]^{25}\mathrm{D}$ +0.4°, was treated with 1.2 g of "active" manganese[20] dioxide at room temperature in 10 ml of methylene chloride for 2 days. The product was worked up by filtering the oxidant using a Hirsch funnel and washing the residue well with fresh methylene chloride. The solvent was carefully removed by fractional distillation, and the residue was further purified by preparative thin layer chromatography and sublimation: mp 118–121°; $[\alpha]^{26}\mathrm{D}$ −32.4° (*c* 0.3, isooctane); nmr, broad multiplet at δ 2.55 (1 H, tertiary bridgehead H adjacent to C=O), broad multiplet at 2.60 (1 H, tertiary bridgehead H), doublet at 1.95 (2 H, δ = 3 cps, $-CH_2-$ adjacent to C=O coupled with one tertiary H), multiplet at 1.8 (4 H, $-CH_2CH_2-$), multiplet at 1.2 (2 H, tertiary H on cyclopropyl ring), at least a sextet at 0.4 (2 H, J = 6–8 cps, due to $-CH_2-$ on cyclopropane ring); uv λ_{max} 297 nm (ϵ 27). A solution of 10.3 mg in 10.0 ml of isooctane was used for determination of the circular dichroism spectrum.

Anal. Calcd for $C_9H_{12}O$: C, 79.37; H, 8.88. Found: C, 79.52; H, 8.80.

***endo*-Bicyclo[2.2.2]oct-5-en-2-yl Acetate.** Exactly 3 g (24.2 mmol) of *endo*-bicyclo[2.2.2]oct-5-en-2-ol was dissolved in 9 ml of anhydrous pyridine, and 9 g of acetic anhydride was slowly added to the well-stirred solution. After complete addition of the acetic anhydride, the mixture was allowed to stand overnight at room temperature. The pyridine and acetic acid were removed by fractional distillation at reduced pressure, and the crude acetate remaining as a pot residue was transferred to a Hickmann short-path distillation apparatus.

Final distillation from the Hickmann tube was accomplished at 55° (1 Torr) to yield 3.92 g of product which was at least 99% pure by glpc (15% SE 30 on Chromosorb W). The acetate had $[\alpha]^{27}\mathrm{D}$ +44.7° (neat).

(+)-*exo*-Tricyclo[3.2.2.0^{2,4}]nonan-6-one (2). To a 165-ml capacity Parr bomb was added 2.00 g (12.1 mmol) of *endo*-bicyclo[2.2.2]oct-5-en-2-yl acetate, $[\alpha]^{27}\mathrm{D}$ +44.7°, 32.3 g (0.121 mmol) of methylene iodide, and 100 ml of anhydrous ether. The solution was blanketed with nitrogen, 10 g of 30 mesh zinc–copper couple was added, and the bomb sealed. The reaction was accomplished by heating the bomb to 105° for 4 hr with vigorous shaking. The bomb was allowed to cool to room temperature and unsealed, and the liquid phase decanted from the unreacted couple. This residue was washed thoroughly with ether. The combined organic phases had a deep purple coloration due to suspended copper metal. The metal was removed by centrifugation to yield a clear yellow solution. The solution was extracted with two 25-ml portions each of saturated ammonium chloride solution, saturated sodium bicarbonate solution, and water. The organic phase was filtered through anhydrous sodium sulfate to remove residual water and the solvent removed by careful fractional distillation. The residue was transferred to a Hickmann flask and distilled at reduced pressure to yield 1.5 g of crude product.

This clear, colorless liquid was added to a solution of 600 mg of potassium hydroxide in 5 ml of absolute methanol, and the mixture was allowed to stand overnight at room temperature. The reaction product was recovered by steam distillation and extracted into methylene chloride after saturating the distillate with sodium chloride. The solvent was removed by careful fractional distillation and the pot residue analyzed by glpc. Two different columns showed this residue to contain 65% starting material and 35% tricyclo[3.2.2.0^{2,4}]nonan-6-ol: 15% SE 30 on Chromosorb W at 180°, retention times 1.4 min (63%) and 2.9 min (37%); and on 20% Carbowax 1500 on Chromosorb W at 180°, retention times

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[46] H. L. Goering and D. L. Towns, *J. Amer. Chem. Soc.*, 85, 2295 (1963).

5.7 min (67%) and 12.8 min (33%). The predominant cyclopropyl alcohol had retention times identical with the authentic *syn-endo*-alcohol.

The crude mixture was sublimed and then oxidized directly without further attempts at purification. A 1-g sample of the crude sublimate was dissolved in 50 ml of methylene chloride and 20 g of "active" manganese dioxide was added. After a 2-day reaction period at room temperature, the oxidant was filtered off and the solvent removed by fractional distillation. The residue was purified by preparative gas chromatography (20% Carbowax 1500 on Chromosorb W) to yield (−)-*endo*-tricyclo[3.2.2.0^{2,4}]nonan-6-one, retention time 6.3 min (identical with authentic sample), and (+)-*exo*-tricyclo[3.2.2.0^{2,4}]nonan-6-one, retention time 7.3 min, in a ratio of 4:1.

Anal. Calcd for $C_9H_{12}O$: C, 79.37; H, 8.88. Found: C, 79.52; H, 8.80; and C, 79.22; H, 8.93.

The circular dichroism spectrum of the *exo*-cyclopropyl ketone was run in isooctane using a concentration of 7.1 mg in 10.0 ml. The material had $[\alpha]^{27}\mathrm{D}$ +280° and was presumably 83 ± 2% optically pure.

Spiro(cyclopropane-1,7′-*endo*-norbornen-6-yl Acetate). This compound was synthesized according to the method of Alder, Ache, and Flock.[28] Runs were made in sealed glass tubes using typically 15 g (0.16 mol) of spiro[2.4]-4,6-heptadiene and 18.5 g of vinyl acetate (Matheson Coleman and Bell), and allowing the tubes to stand at 175° for 24 hr. The yield was 18.3 g (63%) of product which had bp 114° (26 Torr) (lit.[28] bp 94° (11 torr)); nmr, symmetrical octet at δ 6.2 (2 H, J = 3, J = 6 cps), multiplet at 5.3, quartet at 2.3 (1 H, bridgehead H coupled to 3 H with identical J values, J = 3.4 cps), singlet at 2.1 (1 H, H on $-CH_2-$ adjacent to $-CHOAc-$), sharp singlet at 1.9 (3 H, acetate), pair of doublets centered at 1.0 (1 H, J = 2.8 cps, J = 13.9 cps, due to $-CH_2H$ (endo) adjacent to $-CHOAc-$); sharp singlet at δ 0.4 (4 H, cyclopropyl hydrogens); mass spectrum, m/e 152 (M^+), 66 or 43 (100%). Reactions run at 155° resulted in a much lower yield of the desired product due to formation of significant amounts of the dimer of spiro[2.4]-4,6-heptadiene. Interestingly, attempts to carry out the reaction at 175° using the glass sleeve in a 1-l. Parr bomb resulted in formation of decomposition products only.

Spiro(cyclopropane-1,7′-*endo*-norborneol Acetate). Spiro(cyclopropane-1,7′-*endo*-norbornenyl acetate) (15.3 g, 0.086 mol) was hydrogenated over 10% Pd–C in pentane at atmospheric pressure. The mixture was stirred vigorously with a magnetic stirring bar while being chilled in an ice bath. Over the course of several hours, 2114 ml of hydrogen was consumed (100% theory). The solvent was removed by fractional distillation and the product fractionally distilled to yield 14.3 g of product, bp 103.8–104.0° (14 Torr) (lit.[28] bp 99° (13 Torr).

Spiro(cyclopropane-1,7′-*endo*-norborneol). Spiro(cyclopropane-1,7′-*endo*-norbornyl acetate) (11.5 g, 0.064 mol) was hydrolyzed using 35 ml of 20% methanolic potassium hydroxide. After reacting at room temperature for 18 hr, the solution was steam distilled until approximately 500 ml of distillate had been collected. The distillate was saturated with sodium chloride and extracted with three 40-ml portions of ether. Removal of the ether gave 8.1 g (92%) of a waxy white solid: mp 109–110° (lit.[28] mp 112°); nmr δ 1.9–1.1 (8 H), 0.4 (4 H, cyclopropyl). Glpc analysis (20% Carbowax 1500 on Chromosorb W) indicated this alcohol to consist of 10% of the exo isomer, and 90% of the endo isomer.

Spiro(cyclopropane-1,7′-norbornyl phthalate). This compound was prepared in the same manner as was bicyclo[2.2.2]oct-5-en-2-yl phthalate. Spiro(cyclopropane-1,7′-norborneol) (35 g, 0.254 mol) was reacted with 41.5 g (0.280 mol) of phthalic anhydride in 60 ml of anhydrous pyridine at 80° for 4 hr. The product was purified by extracting the chloroform solution of the phthalate with 5% aqueous sodium bicarbonate and carefully reprecipitating it with dilute hydrochloric acid. The yield of air dried product was 67.3 g (93%), mp 148–150°.

Anal. Calcd for $C_{17}H_{18}O_4$: C, 71.31; H, 6.34. Found: C, 71.48; H, 6.18.

(−)-*endo*-Spiro(cyclopropane-1,7′-norborneol) (7). To 350 ml of absolute ethanol was added 67.3 g (0.235 mol) of spiro(cyclopropane-1,7′-norbornyl phthalate) and 108.4 g (0.235 mol) of brucine alkaloid which contained 14.5% water. The mixture was heated to dissolve all solids and filtered, and the filtrate allowed to remain at room temperature for several hours. The salt came out of solution as large transparent crystals which were collected on a Buchner funnel. The salt was recrystallized from ethanol six additional times using approximately 3 ml of solvent for each gram of salt (80–90% material was recovered at each stage of the recrystallizations). The total recovery of material amounted to 50 g.

The salt was dissolved in 300 ml of methylene chloride and extracted with three 100-ml portions of 5% aqueous sodium hydroxide. After washing the combined aqueous extracts with fresh methylene chloride, the partially resolved phthalate was precipitated with dilute hydrochloric acid. The yield was 20 g of material, $[\alpha]^{27}\mathrm{D}$ −4.7°.

A 20-g sample (0.070 mol) of the partially resolved half-acid phthalate in 75 ml of 20% aqueous sodium hydroxide was hydrolyzed by a rapid steam distillation. The distillation was continued until approximately 250 ml of distillate had been collected. The distillate was saturated with sodium chloride and extracted with three 50-ml portions of methylene chloride. The solvent was removed through a fractionating column and the residue was sublimed to yield 9.0 g of optically active alcohol, mp 111.2–112.9°, $[\alpha]^{27}\mathrm{D}$ −7.6° (*c* 1.0, methylene chloride). Glpc analysis (20% Carbowax 1500 on Chromosorb W) indicated a minimum purity of 99.5% for *endo*-spiro(cyclopropane-1,7′-norborneol).

Anal. Calcd for $C_9H_{14}O$: C, 78.21; H, 10.21. Found: C, 78.24; H, 10.18.

An attempted resolution using dehydroabietylamine and the half-acid phthalate produced, after eight recrystallizations from acetone–methanol (25:75), a 2% yield of salt with mp 203–205°. The desired alcohol was recovered from the salt in the usual way to yield a partially resolved product with $[\alpha]^{26}\mathrm{D}$ +10.7°. Glpc analysis using the same conditions as above indicated that this material contained 70% *exo*-spiro(cyclopropane-1,7′-norborneol) and 30% of the endo-alcohol.

(−)-Spiro(cyclopropane-1,7′-norbornanone) (4). Exactly 1 g (7.2 mmol) of (−)-*endo*-spiro(cyclopropane-1,7′-norbornenol) was oxidized using 17 g of "active" manganese dioxide[20] in 25 ml of methylene chloride. The mixture was stirred at room temperature for 2 days, and then the oxidant was removed by filtration and washed well with fresh methylene chloride. The solvent was removed through a fractionating column and the residue sublimed to give 400 mg of product: mp 70–73.5°; $[\alpha]^{26}\mathrm{D}$ −37.7° (*c* 1.0, methylene chloride); uv λ_{max} 294 nm (ϵ 51); nmr triplet at δ 2.5 (1 H, tertiary H on carbon α to C═O), multiplet at 2.4 (1 H, remaining tertiary H), multiplet at 1.9 (2 H, on α-carbon), multiplet at 1.7 (4 H, $-CH_2CH_2-$), multiplet at 0.4 (2 H, cyclopropyl H anti to C═O), multiplet at 0.25 (2 H, cyclopropyl H syn toC═O).

Anal. Calcd for $C_9H_{12}O$: C, 79.37; H, 8.88. Found: C, 79.33; H, 8.70.

A solution of 10.2 mg of (−)-spiro(cyclopropane-1,7′-norbornanone) in 10.0 ml of isooctane was used for the determination of the circular dichroism spectrum.

(−)-*endo*-Bicyclo[2.2.1]-7,7-dimethyl-2-heptanol. (−)-*endo*-Spiro(cyclopropane-1,7′-norbornanone) (1 g, 7.2 mol), $[\alpha]^{27}\mathrm{D}$ −7.6°, was dissolved in 20 ml of glacial acetic acid and transferred to a small Parr bomb. The solution was blanketed with nitrogen, 100 ml of platinum oxide catalyst was added, and the bomb was sealed. Cleavage of the cyclopropane ring[29] was accomplished by heating the bomb to 50°, maintaining the hydrogen pressure at 40 psi, and vigorously shaking the apparatus for 1.5 hr. After cooling, the bomb was unsealed and the catalyst removed by filtration. The solvent was removed by fractional distillation at reduced pressure, and the residue was sublimed to yield 850 mg of product, mp 126–128°, $[\alpha]^{26}\mathrm{D}$ −5.0°.

(−)-α-Fenchocamphorone (8). (−)-*endo*-Bicyclo[2.2.1]-7,7-dimethyl-5-heptanol (300 mg, 2.1 mmol), $[\alpha]^{26}\mathrm{D}$ −5.0°, was oxidized using 7 g of "active" manganese dioxide[20] in the usual way to yield 115 mg of product after sublimation, mp 109–111°, $[\alpha]^{26}\mathrm{D}$ −39.7° (*c* 1.2, dichloromethane).

Anal. Calcd for $C_9H_{14}O$: C, 78.21; H, 10.21. Found: C, 78.10, H, 10.18.

The circular dichroism spectrum was determined using 10.7 mg of (−)-α-fenchocamphorone in 10.0 ml of isooctane. Comparison of this spectrum with that of Coulombeau and Rassat[30] led to an assignment of 46% optical purity for this compound. Thus, the optical purity for all resolved precursor spiro compounds is assumed to be 46%.

Bicyclo[2.2.1]hept-5-en-2-yl Acetate. According to the method of Winstein and Trifan,[47] 100 g (1.52 mol) of freshly distilled cyclopentadiene was mixed with 150 g (1.74 mol) of vinyl acetate (Matheson Coleman and Bell) in a glass-lined 1-l. capacity Parr bomb. The bomb was sealed and heated to 174° for 20 hr. The resulting light yellow solution was fractionally distilled to give 91.8 g of

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(47) S. Winstein and D. Trifan, *J. Amer. Chem. Soc.*, 74, 1147 (1952).

water-white product, bp 77–80° (13 Torr) (lit.[47] bp 77–80° (13 Torr)). Other runs using freshly distilled vinyl acetate resulted in lower conversions of starting materials.

Bicyclo[2.2.1]hept-5-en-2-ol. Bicyclo[2.2.1]hept-5-en-2-yl acetate (30 g, 0.197 mol) was mixed with 60 ml of methanolic potassium hydroxide. After standing overnight, the product was worked up using a steam distillation to yield 20.1 g of product (92%). Analysis by glpc (20% Carbowax 1500 on Chromosorb W) indicated the product to be 75% endo, retention time 4.3 min, and 25% exo, retention time 5.2 min.

Bicyclo[2.2.1]hept-5-en-2-yl Phthalate. This compound was prepared according to the general procedure used for half-acid phthalates. Bicyclo[2.2.1]hept-5-en-2-ol (20 g, 0.182 mol) and 29.6 g (0.200 mol) of phthalic anhydride in 40 ml of anhydrous pyridine gave, after 3.5-hr heating period at 105° and the usual work-up and purification, 45.0 of white solid (96%), mp 90–93°.

Anal. Calcd for $C_{15}H_{14}O_4$: C, 69.76; H, 5.46. Found: C, 69.96; H, 5.59.

(−)-*endo*-**Bicyclo[2.2.1]hept-5-en-2-ol.** Bicyclo[2.2.1]hept-5-en-2-yl phthalate (40 g, 0.155 mol) and 61 g of brucine alkaloid (14.5% water) were dissolved in 150 ml of absolute methanol by gentle heating. The solution was filtered and placed in a refrigerator (5°) for 2 days until crystallization was nearly complete. The salt was collected by suction filtration and recrystallized five more times using 1–2 ml of methanol per gram of salt and recovering 75–85% of the material at each stage of the recrystallizations. The final crop of crystals weighed 33 g. The partially resolved half-acid phthalate was separated from the salt in the usual way to yield 13 g of material, $[\alpha]^{26}D$ +31.7° (*c* 1.5, chloroform).

The phthalate was hydrolyzed by the steam distillation technique to yield 5.0 g of waxy solid (95%): mp 103–107°, $[\alpha]^{27}D$ −11.3° (*c* 1.5, chloroform). Glpc analysis showed this substance to be 92% of the endo product and 8% of the exo product (20% Carbowax 1500 on Chromosorb W, retention times 4.3 and 5.2 min, respectively).

Anal. Calcd for $C_7H_{10}O$: C, 76.32; H, 9.15. Found: C, 75.92; H, 9.17.

(+)-*exo*-**Bicyclo[2.2.1]hept-5-en-2-ol.** This compound was prepared by an asymmetric hydroboration using 2.0 mol of norbornadiene and diisopinocampheylborane generated *in situ* according to the procedure outlined by Mislow and Berger.[17] The yield was 11 g of optically active (+)-*exo*-bicyclo[2.2.1]hept-5-en-2-ol, mp 87–90°, $[\alpha]^{26}D$ +4.3° (*c* 1.0, chloroform).

(−)-*exo*-**Bicyclo[2.2.1]hept-5-en-2-yl Acetate (6).** A mixture of 22 g of acetic anhydride and 25 ml of anhydrous pyridine was used to acetylate 4.78 g (0.043 mol) of (+)-*exo*-bicyclo[2.2.1]hept-5-en-2-ol, $[\alpha]^{26}D$ +4.3°. After standing at room temperature overnight, the solvent was removed at reduced pressure through a fractionating column. The desired product was fractionally distilled to yield 4 g of water-white liquid, bp 77° (14 Torr) (lit.[17] bp 75° (14 Torr)), $[\alpha]^{26}D$ +15.45° (neat). Based on the values reported by Mislow and Berger,[17] the compound has an optical purity of 32%.

(−)-*anti*-*exo*-**Tricyclo[3.2.1.0^{2,4}]octan-6-yl Acetate.** (−)-*exo*-Bicyclo[2.2.1]hept-5-en-2-yl acetate (1 g, 6.6 mol), $[\alpha]^{26}D$ +15.5°, was subjected to the high-temperature Simmons–Smith reaction outlined previously. Methylene iodide (17.6 g) and 6 g of 30 mesh zinc–copper couple in 25 ml anhydrous ether were heated to 110° in a small Parr bomb with vigorous shaking for 3 hr. The product was worked up in the usual way to yield 690 mg of water-white liquid, bp 102–105° (14 Torr), $[\alpha]^{26}D$ +3.8° (*c* 35.0, methanol). The optical purity of this compound is also assumed to be 32%, the same as the starting material.

Anal. Calcd for $C_{10}H_{14}O$: C, 72.26; H, 8.49. Found: C, 72.47; H, 8.52.

(−)-*anti*-*exo*-**Tricyclo[3.2.1.0^{2,4}]octan-6-ol** from (−)-*anti*-*exo*-tricyclo[3.2.1.0^{2,4}]octan-6-yl acetate (690 mg); $[\alpha]^{27}D$ +2.4° (*c* 11.0, methylene chloride).

Anal. Calcd for $C_8H_{12}O$: C, 77.37; H, 9.74. Found: C, 77.46; H, 9.49.

This compound was homogeneous on at least three different glpc columns (Varian Aerograph 1200 instrument with flame ionization detector): 20% Carbowax 1500 on Chromosorb W, 15% SE 30 on Chromosorb W, and 20% TCEP on Chromosorb P.

(−)-*exo*-**Tricyclo[3.2.1.0^{2,4}]octan-6-one (3).** (+)-*anti*-*exo*-Tricyclo[3.2.1.0^{2,4}]-6-octanol (400 mg, 3.22 mol), $[\alpha]^{26}D$ +2.4°, was oxidized using 6 g of "active" manganese dioxide[20] in 10 ml of methylene chloride for 2 days at room temperature. Work-up as before plus a final purification by preparative glpc (20% Carbowax 1500) yielded 150 g of product, $[\alpha]^{27}D$ +120° (*c* 0.13, isooctane); uv λ_{max} 292 nm (ϵ 70); nmr multiplet at δ 2.5 (2 H, tertiary H at bridgehead), multiplet at 1.9 (2 H, α to C═O), multiplet at 1.2 (2 H, cyclopropyl tertiary H), quartet at 0.9 (1 H, cyclopropyl H anti to C═O), multiplet at 0.9 (2 H, on carbon bridge), quartet at 0.4 (1 H, cyclopropyl H syn to C═O). The circular dichroism spectrum was determined using 12.9 mg of ketone in 10.00 ml of isooctane.

Anal. Calcd for $C_8H_{10}O$: C, 78.65; H, 8.25. Found: C, 78.38; H, 8.31.

(−)-*endo*-**Tricyclo[3.2.1.0^{2,4}]octan-6-one.** (−)-*endo*-Bicyclo-[2.2.1]hept-5-en-2-ol (1100 mg, 10 mmol), $[\alpha]^{27}D$ −11.3°, was added slowly to a solution of 2 ml of diethylzinc on 50 ml of anhydrous ether which was blanketed with nitrogen. After the initial reaction had subsided, 5.40 g (20 mol) of methylene iodide was added and the solution heated at reflux overnight. The product was worked up by extracting the ethereal solution with two 10-ml portions of 5% hydrochloric acid, 10% sodium bicarbonate solution, and then water. The product was concentrated by removal of the ether through a fractionating column and was analyzed by glpc (20% Carbowax 1500) to show a yield in excess of 35%.

Without further attempt at purification, the crude product was dissolved in methylene chloride and oxidized with "active" manganese dioxide.[20] The product was worked up as usual and purified *via* preparative glpc to yield 35 mg of product which was homogeneous by several glpc columns, but had a behavior identical with *exo*-tricyclo[3.2.1.0^{2,4}]octan-6-one on all columns. That this was not a single compound was discerned from the circular dichroism spectrum which indicated the presence at least two compounds displaying oppositely signed Cotton effects.

Further attempts to purify the *exo*-tricyclo[3.2.1.0^{2,4}]octan-6-ol *via* the *p*-nitrobenzoate derivative were unsuccessful.

Preparation[17] of the Bicyclic Ketones. (+)-Bicyclo[2.2.2]oct-5-en-2-one (10), (+)-Bicyclo[2.2.1]hept-5-en-2-one (11), (+)-Norbornanone (9). All ketones were synthesized from the corresponding alcohols *via* oxidations with "active" manganese dioxide[20] followed by the standard work-up procedures of the foregoing. (+)-Norborneol was prepared from (+)-bicyclo[2.2.1]hept-5-en-2-ol by hydrogenation over 5% palladium on charcoal in pentane (93% yield).

The optical purities of these ketones were taken from that of the corresponding alcohols, or, where such was not known, by comparison of their optical rotatory dispersion curves with published spectra.[17]

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