# Rearrangement of a Bicyclic [2.2.2] System to a Bicyclic [3.2.1] System. Nonclassical Ions[1]

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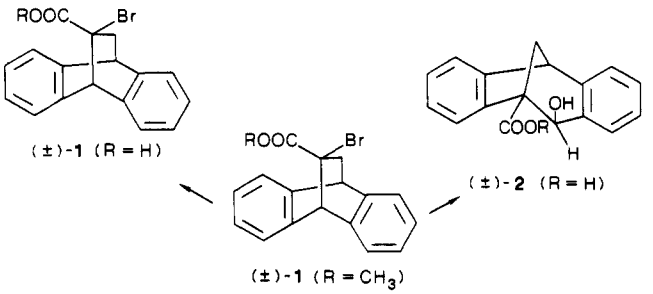
*Received August 30, 1988*

The syntheses and the establishment of the absolute configurations of chiral (*S*)-(+)-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxylic acid (**1**) and (1*S*,2*S*,5*S*)-(−)-*exo*-2-methoxydibenzobicyclo[3.2.1]octadiene-1-carboxylic acid (**2**) and their derivatives are described. The rearrangement of **1** to **2** is discussed in terms of a nonclassical ion intermediate in light of the observed stereochemistry.

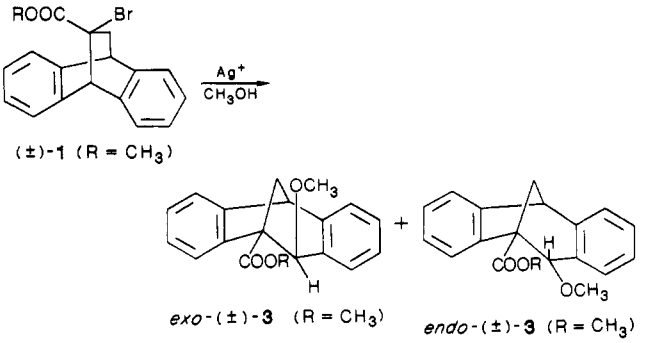
## Introduction

In an ancillary study we had the need to prepare optically active 2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxylic acid (**1**, R = H). The precursor racemic methyl ester **1** (R = $CH_3$) was readily prepared by the Diels–Alder condensation of anthracene with methyl $\alpha$-bromoacrylate. To our surprise the saponification of the ester with lithium hydroxide, following a procedure by Helmchen,[3] did not yield **1** (R = H), but instead we isolated the rearranged acid, 2-hydroxydibenzobicyclo[3.2.1]octadiene-1-carboxylic acid (**2**, R = H). The nature of this rearrangement is the subject of this paper.

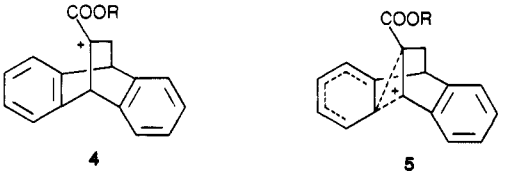



## Results

The saponification of **1** (R = $CH_3$) at room temperature was slow, as expected, due to steric hindrance. Attempts to increase the rate by increasing the temperature resulted in a reduced yield due to decomposition. Aqueous solutions of LiOH, NaOH, and KOH all led to the rearrangement of **1** (R = $CH_3$) to **2** (R = H). Saponification of **1** (R = $CH_3$) to **1** (R = H) was achieved by using tetraethyl or tetrabutylammonium hydroxide in absolute methanol or potassium trimethylsilanolate[4] in anhydrous ether. It became apparent that, under aqueous conditions and with an alkali metal gegenion present, solvolysis of the bromide competed with the saponification. Therefore it was decided to enhance this rearrangement by the use of silver perchlorate in methanol, conditions conducive to methanolysis. When **1** (R = $CH_3$) was treated with silver perchlorate in methanol, at 70 °C, rapid methanolysis occurred to give, in high yield, a mixture[6] of methyl *exo*- and *endo*-2-methoxydibenzobicyclo[3.2.1]octadiene-1-carboxylate (**3**) in the ratio 1.73:1.




A question arises as to the stereochemistry of this rearrangement. Does the reaction involve the removal of the bromide to yield a classical cationic intermediate such as **4** or is their $\sigma$ or $\pi$ bond participation to yield a nonclassical cation such as **5**? This can only be answered by establishing the stereochemistry of the rearrangement. Starting with chiral **1** (R = $CH_3$), if **4** is the intermediate, then the rearranged products *exo*- and *endo*-**3** (R = $CH_3$) will be racemic. However, if **5** is the intermediate then the products will not only maintain chirality but will be of inverted configuration. To this end the synthesis of chiral **1** and the determination of the absolute configurations of **1** and **3** were undertaken.




**Relative and Absolute Configurations.** The resolution of (±)-**1** (R = H) was accomplished by crystallization of the diastereomeric salts formed from (±)-**1** (R = H) and 0.5 equiv of (*R*)-(−)-2-amino-1-butanol. The initial crystals were hydrolyzed, and the acid isolated was recrystallized once to give (−)-**1** (R = H). The acid was shown by $^1H$ NMR spectroscopy of the (*S*)-(−)-$\alpha$-methylbenzylamine salt to be 82% optically pure (see the Experimental Section). The absolute configuration of (−)-**1** (R = H) was established by X-ray analysis of the amide formed from (−)-**1** (R = H) with (*S*)-(−)-$\alpha$-methylbenzylamine via the acid chloride formed from (−)-**1** (R = H). The analysis showed that (−)-**1** (R = H) has the *R* configuration (Figure 1).

The resolution of (±)-**2** (R = H) was achieved by forming the diastereomeric salt using 0.5 equiv of (*S*)-(−)-$\alpha$-methylbenzylamine. The pure diastereomeric salt, mp 211–212 °C, $[\alpha]^{20}_{Hg}$ −157.9 ± 0.2° (*c* 0.5, ethanol), was hydrolyzed to give pure acid, mp 203–204 °C and $[\alpha]^{20}_{Hg}$ −210.6 ± 0.3° (*c* 0.4, ethanol). The acid *exo*-(+)-**2** (R = H)

(1) Support of this work by the National Science Foundation is gratefully acknowledged.

(2) Visiting Professor from the Institute of Organic Chemistry, Technical University, Gdansk, Poland.

(3) Helmchen, G.; Ihring, K.; Schindler, H. *Tetrahedron Lett.* **1987**, *28*, 183.

(4) Laganis, E. D.; Chenard, B. L. *Tetrahedron Lett.* **1984**, *25*, 5831.

(5) Baird, M. S.; Reese, C. B. *Tetrahedron Lett.* **1971**, 4637.

(6) It has been established that protons $\alpha$ to an hydroxyl group when located in an endo position will resonate at higher field than the corresponding exo proton. See: Jackman, L. M.; Sternhell, S. *Application of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry*; Pergammon Press: New York, 1969. Ceccarelli, G.; Macchia, B.; Macchia, F.; Monti, L. *Org. Magn. Reson.* **1975**, *7*, 548. This observation was used to establish configuration (see, Experimental Section). X-ray analysis of *exo*-**3** confirmed the NMR assignment.

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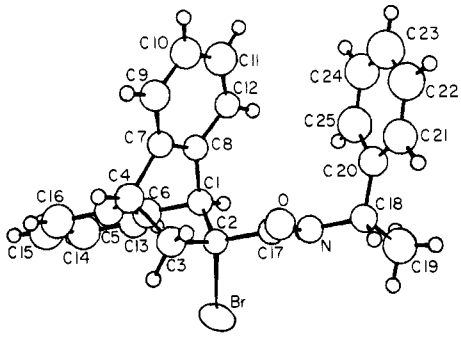



**Figure 1.** ORTEP plot of (*R*)-(−)-*N*-[(*S*)-1-phenylethyl]-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxamide.

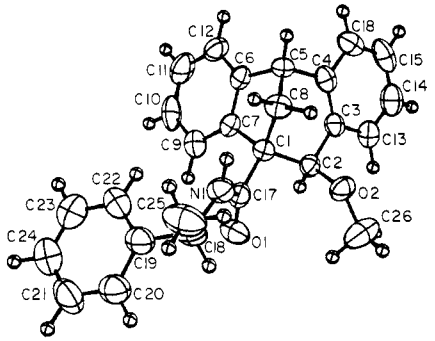
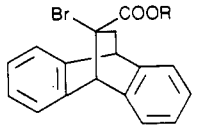
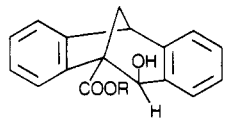



**Figure 2.** ORTEP plot of (1*R*,2*R*,5*R*)-(+)-*N*-[(*S*)-1-phenylethyl]-*exo*-2-methoxydibenzobicyclo[3.2.1]octadiene-1-carboxamide.

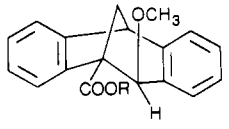
was converted to *exo*-(+)-**3** (R = $CH_3$) in 61% yield by treatment of *exo*-(+)-**2** (R = H) at room temperature, with KOH, methyl iodide, and few drops of Triton B. Saponification with potassium trimethylsilanolate gave the desired acid *exo*-(+)-**3** (R = H), $[\alpha]^{20}_{Hg}$ +163.4 ± 0.3° (*c* 0.5, ethanol), which was converted, via its acid chloride, to the amide, (+)-*N*-[(*S*)-1-phenylethyl]-*exo*-2-methoxydibenzobicyclo[3.2.1]octadiene-1-carboxamide, by reaction with (*S*)-(−)-α-methylbenzylamine. X-ray analysis showed that *exo*-(+)-**3** (R = H) had the 1*R*,2*R*,5*R* configuration (Figure 2). The configurations of (−)-**1**, *exo*-(+)-**2**, and *exo*-(+)-**3** are depicted below.




(*R*)-(−)-**1**




(1*R*, 2*R*, 5*R*)-(+)-*exo*-**2**

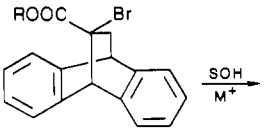



(1*R*, 2*R*, 5*R*)-(+)-*exo*-**3**

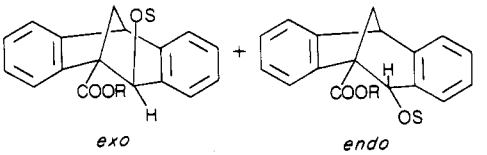
**Rearrangement Reactions.** Table I summarizes the reactions of (±)-**1**, which lead to the rearranged products *exo*- and *endo*-(±)-**2** and *exo*- and *endo*-(±)-**3**. As can be seen in reactions 1 and 2, the treatment of the acid with aqueous KOH resulted in a single rearranged product, exo, as did treatment of this acid with an excess sodium methoxide in methanol. In reaction 3 one notes that the reaction is no longer stereospecific and that one begins to form some endo product, which becomes even more pronounced in reactions 4–6.

In order to gain some insight as to the thermodynamic stability of the rearranged products, pure *exo*-(±)-**2** (R = H) was dissolved in trifluoroacetic acid and kept at 20 °C for 24 h. Analyses of the products before and after saponification showed an exo:endo ratio of 1.8:1. The product ratio did not change on allowing the reaction mixture to remain for a period longer than 24 h. Under identical conditions the *exo*-(±)-**2** (R = $CH_3$) gave an exo:endo ratio of 3.5:1. Noteworthy is the fact that no reverse rearrangement to the [2.2.2] system was observed even when more "severe conditions" were employed[16] such as acetic acid–perchloric acid. Again, only epimerization occurred and an exo:endo ratio of 1.9:1 was obtained.

**Table I. Rearrangement of (±)-2-Bromodibenzobicyclo[2.2.2]octadiene-2-carboxylic Acid and Derivatives**




(±)-**1**




*exo* *endo*

| reaction | (±)-1 (R) | SOH | $M^+$ | exo:endo ratio |
|---|---|---|---|---|
| 1 | K | H | K | only exo |
| 2 | Na | $CH_3$ | Na | only exo |
| 3 | $CH_3$ | H | Ag | 21:1 |
| 4 | $CH_3$ | $CH_3$ | Ag | 1.7:1 |
| 5 | $C_2H_5$ | $CH_3$ | Ag | 1.9:1 |
| 6 | H | H | Ag | 1.3:1 |

## Discussion

The observation that the [2.2.2] system undergoes a Wagner–Meerwein rearrangement to a [3.2.1] system is not surprising and has long been known.[7,8] Although the saturated bicyclo[2.2.2]octyl system has been shown to be in equilibrium with the rearranged [3.2.1] system,[9-12] the bicyclo[2.2.2]octenyl[13] and the bicyclo[2.2.2]octadienyl system[13-15] (**1**) are completely converted to the stable [3.2.1] system **6** under ordinary conditions.[16] This is not unex-

(7) Doering, W. E.; Farber, M. *J. Am. Chem. Soc.* **1949**, *71*, 1514.
(8) Newman, M. S.; Yu, Y. T. *J. Am. Chem. Soc.* **1952**, *74*, 507.
(9) Walborsky, H. M.; Baum, M. E.; Youssef, A. A. *J. Am. Chem. Soc.* **1961**, *83*, 988.
(10) Goering, H. L.; Sloan, M. F. *J. Am. Chem. Soc.* **1961**, *83*, 1397.
(11) Berson, J. A.; Reynolds-Warnhoff, P. *J. Am. Chem. Soc.* **1964**, *86*, 595.
(12) For a review, see: Bartlett, P. D. *Nonclassical Ions*; W. A. Benjamin, Inc.: New York, 1965.
(13) Goering, H. L.; Towns, D. L. *J. Am. Chem. Soc.* **1963**, *85*, 2295. Grunewald, G. L.; Ye, Q. *J. Org. Chem.* **1988**, *53*, 4021–4026. Grunewald, G. L.; Walters, D. E.; Kroboth, T. R. *J. Org. Chem.* **1978**, *43*, 3478. Smith, W. B. *J. Org. Chem.* **1985**, *50*, 5731. Smith, W. B.; Stock, L.; Cornforth, J. *Tetrahedron* **1983**, *39*, 1379. Hart, H.; Tagagi, K. *J. Org. Chem.* **1980**, *45*, 34. Gray, A. C.; Hart, H. *J. Am. Chem. Soc.* **1968**, *90*, 2569. Paquette, L. A.; Volz, W. E. *J. Am. Chem. Soc.* **1976**, *98*, 2910. Hales, N. J.; Heaney, H.; Ley, S. V. *J. Chem. Soc., Perkin Trans. 1*, **1974**, 2702. Nylund, T.; Morrison, H. *J. Am. Chem. Soc.* **1978**, *100*, 7364.
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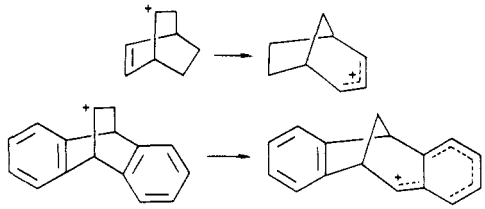
(15) (a) Cristol, S. J.; Bly, R. K. *J. Am. Chem. Soc.* **1960**, *82*, 6155. (b) Cristol, S. J.; Arganbright, R. P.; Tanner, D. D. *J. Org. Chem.* **1963**, *28*, 1374. (c) Cristol, S. J.; Tanner, D. D. *J. Am. Chem. Soc.* **1964**, *86*, 3122. (d) Cristol, S. J.; Parungo, F. P.; Plorde, D. E. *J. Am. Chem. Soc.* **1965**, *87*, 2870. (e) Cristol, S. J.; Parungo, F. P.; Plorde, D. E.; Schwarzenbach, K. *J. Am. Chem. Soc.* **1965**, *87*, 2879. (f) Cristol, S. J.; Kochansky, M. C. *J. Org. Chem.* **1975**, *40*, 2171.
(16) It has been reported under "severe conditions" the bicyclo-[3.2.1]octadienyl system may revert back to the bicyclo[2.2.2]octadienyl system, see ref 15e. However, using the identical conditions reported we were unabled to detect any conversion to the [2.2.2] in our system.

pected since the latter two systems give rise to an allylic and a benzylic cation, respectively.



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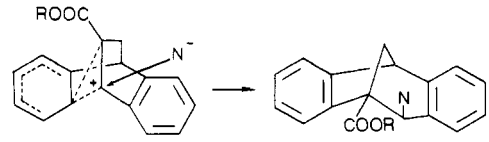
Although it was suggested[13,14] that phenyl participation[17] occurred in the rearrangement of **1** to **2** there was no evidence provided to support this speculation. We will now provide direct evidence that this is indeed the case.

As one can see from Table I, rearrangement (±)-**1**, [2.2.2], to *exo*-(±)-**2** (R = H) [3.2.1] occurs with the alkali metal cation sodium in anhydrous methanol or with potassium in aqueous solution. However, the silver cation is the most effective, causing complete rearrangement of (±)-**1** (R = $CH_3$) in 0.5–1 h whereas with the alkali metal cations the reaction took over 24 h. Since $Ag^+$ is the better cation for assisting the ionization of halogens, it became the ion of choice for the study of the rearrangement.

Stereochemistry provides the best evidence to establish whether or not there is participation of a neighboring group in a rearrangement reaction involving that group. This tool was used to show that in the acetolysis of (+)-(*S*)-bicyclo[2.2.2]oct-2-yl-*p*-bromobenzenesulfonate a partial rearrangement to (−)-(1*R*,2*R*,5*R*)-*exo*-bicyclo[3.2.1]oct-2-ylacetate was obtained.[9] This observation provided the evidence that σ-participation to give a dissymmetric nonclassical ion was involved in the rearrangement since a symmetrical classical ion would have resulted in complete racemization.

In order to ascertain whether the rearrangement of **1** (R = H, $CH_3$) to **2** (R = H, $CH_3$) involved a classical cationic intermediate **4** or a nonclassical cation **5**, optically active (−)-(*R*)-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxylic acid was subjected to solvolysis in aqueous solution with over 2 equiv of potassium hydroxide (basic conditions). A single product (−)-(1*S*,2*S*,5*S*)-*exo*-2-hydroxydibenzobicyclo[3.2.1]octadiene-1-carboxylic acid with complete retention of optical activity and overall inversion of configuration was obtained in 93% yield. This result provides the necessary evidence to exclude the symmetrical classical cation as an intermediate. Furthermore, the inversion of configuration in going from (−)-(*R*)-**1** (R = H) to (−)-(1*S*,2*S*,5*S*)-*exo*-**2** (R = H) shows that the phenyl group that migrates is the one that is trans to the leaving bromide, a predictable result based on the formation of a nonclassical ion intermediate. Whether one should view this participation as a phenonium ion or σ-participation cannot readily be decided since both the π and σ bonds are sterically available for delocalization. However, even if the σ bond is initially involved, once the nonclassical ion is formed the charge would be expected to become delocalized into the migrating phenyl ring. At this point, with the isolation of a single exo product from the rearrangement, it is tempting to conclude that the nonclassical ion was the sole intermediate in this reaction.




The results from the rearrangement of (−)-(*R*)-**1** (R = H) with silver acetate in a mixture of acetone and water are also consistent with the incursion of a nonclassical ion. In this case, under mild acidic conditions, a mixture of *exo*- and *endo*-**2** (R = H) was obtained. The mixture was esterified with diazomethane, and the resultant mixture of methyl esters was subjected to Swern oxidation[18] to yield a single product, methyl (+)-(1*S*,5*S*)-2-oxodibenzobicyclo[3.2.1]octadiene-1-carboxylate, which was 95% optically pure (based on optical purity of starting material) and of inverted configuration. This result is in further support of the stereospecific nature of the rearrangement.

However, since a mixture of exo and endo product was obtained and, as we have shown earlier, trifluoroacetic acid caused epimerization but did not cause rearrangement back to the [2.2.2] system, one must conclude, as did Cristol,[15e] that more than one intermediate is involved in the rearrangement. We believe that the two intermediates are the nonclassical intermediate **5** and the classical cation **6**.

Another question that has to be answered here is the nature of the rearranged intermediate, which is a classical benzylic cation having an adjacent neighboring carboxyl group in the form of an ester, acid, or carboxylate anion. As shown in Table I, the exo:endo product ratio is dependent on the type of carboxyl group. When the group present is a carboxylate anion and under aqueous conditions one obtains exclusively *exo*-**2** (R = H) or if methanol is the solvent, then only *exo*-**3** (R = H) is formed. However, the methyl or ethyl esters whether in aqueous or methanolic solution give rise to a mixture of exo and endo products as does the free carboxylic acid. These results qualitatively reflect the ability of the carboxyl derivatives to behave as a neighboring group[19] so that $COO^- \gg COOR > COOH$. The exo:endo ratio found under aqueous conditions is as follows: $COO^-$ give exclusively exo, $COOCH_3$ 21:1, and the free COOH gives 1.3:1 ratio. The thermodynamic ratios as judged by epimerization studies on *exo*-**2** (R = H) is 1.31 and *exo*-**2** (R = $CH_3$) is 3.5:1, showing that the carboxylic acid group does not behave as an effective neighboring group. Scheme I depicts a mechanistic scheme, which accounts for our observations on this rearrangement.

## Experimental Section

All melting points and boiling points are uncorrected. $^1H$ NMR spectra were recorded at 200 or 270 MHz with $CDCl_3$ as solvent unless noted otherwise, with $Me_4Si$ and $CHCl_3$ (7.26 ppm) as internal standards.

Optical rotations were measured at the 546.1-nm mercury line on a Bendix-Ericson Model 987 ETL/NPL polarimeter equipped with a Bendix Model DR-1 digital display. The cell length was 0.4 dm, and the accuracy was ±0.002°. Ultraviolet (UV) spectra was recorded with a Cary 219 spectrophotometer.

Column chromatography was carried out by using either silica gel (70–230 mesh) (Merck) or activated alumina F-20 (80–200 mesh). Radial chromatography separations were performed with

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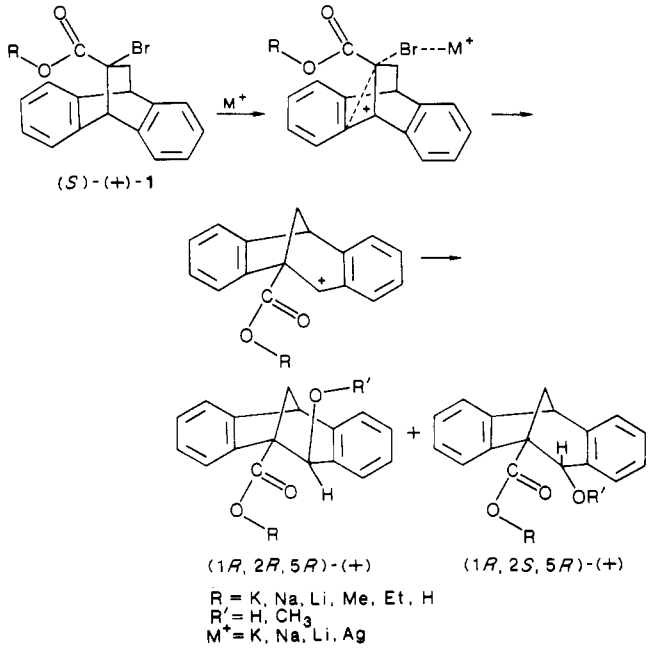
(19) March, J. *Advanced Organic Chemistry*, 3rd ed.; Wiley-Interscience: New York, 1985; p 270.

**Scheme I. Mechanism for Rearrangement of 2-Bromodibenzobicyclo[2.2.2]octadiene-2-carboxy Derivatives to *exo*- and *endo*-2-Hydroxydibenzobicyclo[3.2.1]octadiene-1-carboxy Derivatives**




Merck silica gel 60 $PF_{254}$. High-pressure liquid chromatography (HPLC) was performed on (4.6 mm × 25 cm) Ultrasphere-Si and Pirkle covalent phenylglycine columns using 2-propanol–heptane solvent mixtures with a flow rate of 1 mL/min and a variable wavelength detector.

All bulk solvents were distilled before use. Diethyl ether, dimethoxyethane, and THF were dried by refluxing and distilling from sodium benzophenone dianion.

**Methyl α-Bromoacrylate.** To a solution of 44.8 mL (0.5 mol) of methyl acrylate in 200 mL of chloroform was slowly added 25.7 mL (0.5 mol) of bromine. The reaction mixture was stirred for 3 h at 20 °C and then the solvent was removed under reduced pressure. The crude methyl 2,3-dibromopropionate was dissolved in a mixture of 300 mL of ether and 300 mL of pentane to which was added 69.5 mL of triethylamine. The reaction mixture was stirred for 3 h at room temperature. The precipitate was filtered, washed with pentane, and the combined organic solution was washed with water and dried over $MgSO_4$. The solvent was removed, and the residue distilled in vacuo to yield 70.5 g (85%) of pure product, bp 65 °C (50 mmHg).

**Methyl (±)-2-Bromodibenzobicyclo[2.2.2]octadiene-2-carboxylate.** To a mixture of 29.0 g (0.18mol) of $AlCl_3$ in 250 mL of methylene chloride at −30 °C was added 29.5 g (0.18 mol) of methyl α-bromoacrylate in 50 mL of methylene chloride. The reaction mixture was stirred for 5 min, and 32.08 g (0.18mol) of anthracene was added. The reaction mixture was allowed to come to ambient temperature and stirred over night. The mixture was washed with water and sodium bicarbonate and dried over anhydrous magnesium sulfate. The methylene chloride was removed under reduced pressure, and the residue was recrystallized from methanol to yield 59.7 g (97%) of methyl (±)-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxylate, mp 90–91 °C: IR ($CDCl_3$) 3070, 3020, 2940, 1715, 1470, 1451, 1450, 1275 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 2.32 (dd, $J_1$ = 14.4 Hz, $J_2$ = 2.9 Hz, 1 H), 3.13 (dd, $J_1$ = 14.4 Hz, $J_2$ = 2.4 Hz, 1 H), 3.65 (s, 3 H), 4.29 (dd, $J_1$ = 2.4 Hz, $J_2$ = 2.9 Hz, 1 H), 4.96 (s, 1 H), 6.90–7.50 (m, 8 H); MS (EI) 342 (M). Anal. Calcd for $C_{18}H_{15}O_2Br$: C, 62.99; H, 4.41. Found: C, 63.07; H, 4.45.

**(±)-2-Bromodibenzobicyclo[2.2.2]octadiene-2-carboxylic Acid.** Methyl (±)-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxylate (17.15 g, 0.05 mol) and 12.54 g (0.06 mol) of tetraethylammonium bromide were dissolved in 100 mL of anhydrous THF and 50 mL of absolute methanol, and 2.8 g (0.05 mol) of KOH was added. The reaction mixture was stirred for 48 h at room temperature, and the solvent was removed under reduced pressure. The residue was dissolved in 200 mL of cold water and extracted with ether (3 × 50 mL). The aqueous solution was acidified with 6 N hydrochloric acid and extracted with ether. The ether extract was dried over anhydrous magnesium sulfate, the solvent was removed in vacuo, and the residue was recrystallized from chloroform/hexane to yield 11.35 g (69%) of (±)-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxylic acid: mp 196–198 °C dec; IR ($CHCl_3$) 3580, 3060, 3000, 1710, 1600, 1340, 1105 $cm^{-1}$; NMR ($CDCl_3$) δ 2.33 (dd, $J_1$ = 14.4 Hz, $J_2$ = 2.6 Hz, 1 H), 3.05 (dd, $J_1$ = 14.4 Hz, $J_2$ = 2.7 Hz, 1 H), 4.30 (dd, $J_1$ = 2.6 Hz, $J_2$ = 2.7 Hz, 1 H), 4.92 (s, 1 H), 6.92–7.52 (m, 8 H), 8.14 (br s, 1 H). Anal. Calcd for $C_{17}H_{13}O_2Br$: C, 62.02; H, 3.98. Found: C, 62.01; H, 4.15.

**(±)-2-Hydroxydibenzobicyclo[3.2.1]octadiene-1-carboxylic Acid.** To 39.3 g (0.1 mol) of methyl (±)-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxylate dissolved in 150 mL of tetrahydrofuran was added 8.5 g (0.2 mol) of hydrated lithium hydroxide dissolved in 120 mL of water, and the reaction mixture was stirred at ambient temperature for 48 h. The solvent was stripped under reduced pressure, and the residue was dissolved in 200 mL of water. The aqueous solution was extracted with ether (3 × 50 mL), acidified with 6 N HCl, and then extracted with ether (4 × 50 mL). The ether extract was washed with saturated sodium chloride and dried over anhydrous magnesium sulfate, and the solvent was removed in vacuo to yield 29.2 g (91%) of (±)-2-hydroxydibenzobicyclo[3.2.1]octane-1-carboxylic acid: mp 203–209 °C (from AcOEt–hexane); IR ($CHCl_3$) 3550, 2400, 1710, 1600, 1490, 1480, 1460, 1280, 1000 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 2.63 (d, $J$ = 11.2 Hz, 1 H), 2.91 (dd, $J_1$ = 11.2 Hz, $J_2$ = 4.3 Hz, 1 H), 4.05 (d, $J$ = 4.3 Hz, 1 H), 5.01 (s, 1 H), 7.05–7.61 (m, 8 H). Anal. Calcd for $C_{17}H_{14}O_3$: C, 76.67; H, 5.30. Found: C, 76.46; H, 5.44.

**Chiral (*R*)-(−)-2-Bromodibenzobicyclo[2.2.2]octadiene-2-carboxylic Acid.** To 24.7 g (0.075 mol) of (±)-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxylic acid dissolved in 200 mL of ethyl acetate at 60 °C was added 3.54 mL (0.038 mol) of (*R*)-(−)-2-amino-1-butanol, and the reaction was allowed to slowly come to room temperature. The mother liquor was decanted from the crystals, and the crystals were washed with ethyl acetate, filtered, and dried to yield 9.45 g (60%), $[\alpha]^{20}_{Hg}$ −69.8 ±3° (*c* 0.6, ethanol), of salt.

A slurry of the salt in 200 mL of ether was shaken with 75 mL of 6 N HCl, and the organic layer was washed with water and saturated sodium chloride and dried over anhydrous magnesium sulfate. The ether was evaporated, and the residue was recrystallized from chloroform–hexane to yield 7.2 g (58%) of the acid, mp 148–152 °C, $[\alpha]^{20}_{Hg}$ −83.5 ± 0.3° (*c* 0.75, ethanol). The 270-MHz $^1H$ NMR spectrum ($CDCl_3$) of the salt, prepared by mixing an equimolar quantity of (*S*)-(−)-α-methylbenzylamine and the acid, revealed two singlets for the $C_1H$ (bridgehead) absorption at δ 4.85 and 4.64 ppm in an integrated ratio of 9.5:1, which indicates that the acid is 82% optically pure, and the optically pure acid should have $[\alpha]^{20}_{Hg}$ −101.8°.

**(±)-2-Bromodibenzobicyclo[2.2.2]octadiene-2-carboxylic Acid.** Methyl (±)-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxylate (6.86 g, 0.02 mol) was added in one portion to a stirred slurry of potassium trimethylsilanolate (2.6 g, 0.02 mol) in anhydrous ether, under nitrogen, and at ambient temperature. After being stirred for 12 h, the reaction mixture was acidified by addition of 200 mL of 6 N HCl, and the ether layer was separated, washed with water and saturated sodium chloride solution, and dried over anhydrous magnesium sulfate. The solvent was removed in vacuo, and the residue was recrystalized from chloroform–hexane to yield 6.05 g (92%) of acid, mp 196–198 °C dec; IR ($CHCl_3$) 3580, 3060, 3000, 1710, 1600, 1340, 1105 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 2.33 (dd, $J_1$ = 14.4 Hz, $J_2$ = 2.6 Hz, 1 H), 3.05 (dd, $J_1$ = 14.4 Hz, $J_2$ = 2.7 Hz, 1 H), 4.92 (s, 1 H), 6.92–7.52 (m, 8 H), 8.14 (br s, 1 H). Anal. Calcd for $C_{17}H_{13}O_2Br$: C, 62.02; H, 3.98. Found: C, 62.01; H, 4.15.

**(+)- and (−)-2-Hydroxydibenzobicyclo[3.2.1]octadiene-1-carboxylic Acid.** To solution of 3.2 g (0.012 mol) of acid dissolved in 70 mL of ethyl acetate, heated to 60 °C, was added 0.77 g (0.006 mol) of (*S*)-(−)-α-methylbenzylamine. The solution was seeded with a previously prepared crystal from (−)-acid and (*S*)-(−)-α-methylbenzylamine. (The seed was obtained by mixing 1 equiv

of (±)-acid with 0.5 equiv of (*R*)- or (*S*)-α-methylbenzylamine in ethyl acetate and allowing the crystal to form slowly at ambient temperature. This time-consuming procedure yields diastereomerically pure crystals, which are suitable as seeds.) The resulting solid was filtered, washed with ethyl acetate, and dried to yield 1.4 g (60%) of pure diastereomeric salt, mp 211–212 °C $[\alpha]^{20}_{Hg}$ −157.9 ± 0.2° (*c* 0.5, ethanol). A slurry of the salt in 75 mL of ether was shaken with 50 mL of 6 N HCl, and the ether layer was separated, washed with water and saturated sodium chloride, and dried over anhydrous magnesium sulfate. The ether was removed in vacuo, and the residue was recrystallized from ethyl acetate–hexane to yield 0.81 g (51%) of pure acid, mp 202–203 °C, $[\alpha]^{20}_{Hg}$ −214.6 ± 0.3° (*c* 0.4, ethanol).

The (+)-acid was prepared in an identical manner using a seed (see above) obtained from (*R*)-(+)-α-methylbenzylamine and (+)-acid. The acid had mp 203–204 °C and $[\alpha]^{20}_{Hg}$ 210.6 ± 0.3° (*c* 0.4, ethanol).

**(−)-*N*-[(1*R*)-1-Ethyl-2-hydroxyethyl]-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxamide.** To a solution consisting of 1.17 mL (0.015) of DMF in 50 mL of methylene dichloride at −10 °C was added 0.61 mL (0.015 mol) of oxalyl chloride. The reaction mixture was stirred for 30 min and cooled to −20 °C, a solution of 1.65 g (0.005 mol) of (−)-2-bromodibenzobicyclo-[2.2.2]octadiene-2-carboxylic acid, $[\alpha]^{20}_{Hg}$ −104.0 ± 0.3° (*c* 0.5, ethanol) in 10 ml of methylene chloride was added, and stirring was continued for an additional hour. (*R*)-(−)-Amino-1-butanol (1.9 mL, 0.02 mol) was added, and the solution was allowed to come to room temperature with stirring continued for 10 more hours. The reaction mixture was washed successively with water, 2 N HCl, sodium bicarbonate, and saturated sodium chloride, and dried over anhydrous magnesium sulfate. The solvent was removed in vacuo to yield, after recrystallization (benzene), 1.64 g (83%) of amide: mp 181–182 °C; $[\alpha]^{20}_{Hg}$ −65.9 ± 0.2° (*c* 1.2, chloroform); IR ($CHCl_3$) 3380, 2920, 2866, 1660, 1500, 1460, 1300, 1100, 980, 900 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 0.96 (t, *J* = 7.5 Hz, 3 H), 1.45–1.70 (m, 2 H), 2.00 (br s, 1 H), 2.32 (dd, $J_1$ = 2.5 Hz, $J_2$ = 14 Hz, 1 H), 3.59 (br s, 2 H), 3.60–3.80 (m, 1 H), 4.33 (dd, $J_1$ = 2.5 Hz, $J_2$ = 2.7 Hz, 1 H), 4.76 (s, 1 H), 6.32 (br s, 1 H), 7.00–7.50 (m, 8 H) ppm. Anal. Calcd for $C_{21}H_{22}NO_2Br$: C, 63.00; H, 5.54. Found: C, 62.89; H, 5.57.

**Methyl (+)-(1*R*,2*R*,5*R*)-2-Methoxydibenzobicyclo[3.2.1]-octadiene-1-carboxylate.** The mixture of 2.66 g (0.01 mol) of (+)-(1*R*,2*R*,5*R*)-2-hydroxydibenzobicyclo[3.2.1]octadiene-1-carboxylic acid ($[\alpha]^{20}_{Hg}$ +210.6 ± 0.3°), 7.09 g, (0.05 mol) of iodomethane, 70 mL of methylene chloride, 30 mL of 50% KOH, and a few drops of Triton B (40% in methanol) was stirred at ambient temperature for 24 h. The methylene chloride layer was separated, washed with 1 N HCl, water, and aqueous sodium carbonate, and dried over anhydrous magnesium sulfate. The methylene chloride was removed in vacuo, and the residue was purified by radial chromatography (hexane–ether, 1:1) to yield 1.79 g (61%) of product: mp 148 °C; $[\alpha]^{20}_{Hg}$ +168.0 ± 0.3° (*c* 0.5, ethanol); IR ($CHCl_3$) 3090, 3010, 3000, 2960, 2840, 1730, 1600, 1440, and 1090 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 2.70 (d, *J* = 11.2 Hz, 1 H), 2.86 (dd, $J_1$ = 4.6 Hz, $J_2$ = 11.2 Hz, 1 H), 3.69 (s, 3 H), 3.90 (s, 3 H), 4.00 (d, *J* = 4.6 Hz, 1 H), 4.57 (s, 1 H), 7.00–7.50 (m, 8 H). Anal. Calcd for $C_{19}H_{18}O_3$: C, 77.53; H, 6.16. Found: C, 77.46; H, 6.25.

**(+)-(1*R*,2*R*,5*R*)-2-Methoxydibenzobicyclo[3.2.1]octadiene-1-carboxylic Acid.** The methyl ester (2.94 g, 0.01mol) was added in one portion to a stirred slurry of potassium trimethylsilanolate (1.54 g, 0.012 mol) in 100 mL of anhydrous ether, and the mixture was kept at ambient temperature, under nitrogen, for 24 h. The reaction mixture was hydrolyzed with water, and the aqueous solution was extracted with ether, acidified with 6 N HCl, and extracted with ethyl acetate (3 × 50 mL). The extract was dried over anhydrous magnesium sulfate, and the solvent was removed in vacuo to yield, after recrystallization (ethyl acetate–hexane), 2.44 g (87%) of acid: mp 240–243 °C dec; $[\alpha]^{20}_{Hg}$ +163.4 ± 0.3° (*c* 0.5, ethanol); IR ($CHCl_3$) 3500–2400, 1720, 1600, 1420, 1280, 1090 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 2.75 (d, *J* = 11.2 Hz, 1 H), 2.89 (dd, $J_1$ = 4.3 Hz, $J_2$ = 11.2 Hz, 1 H), 3.68 (s, 3 H), 4.05 (d, *J* = 4.3 Hz, 1 H), 4.61 (s, 1 H), 7.00–7.60 (m, 8 H). Anal. Calcd for $C_{18}H_{16}O_3$: C, 77.12; H, 5.75. Found: C, 77.10; H, 5.88.

**(+)-(1*R*,2*R*,5*R*)-*N*-[(*S*)-1-Phenylethyl]-2-methoxydibenzobicyclo[3.2.1]octadiene-1-carboxamide.** To a solution consisting of 1.17 mL (0.015 mol) of DMF in 50 mL of methylene chloride cooled to −10 °C was added 0.61 mL (0.007 mol) of oxalyl chloride. The reaction mixture was stirred for 30 min and cooled to −20 °C, and a solution of 1.18 g (0.004 mol) of (+)-(1*R*,2*R*,5*R*)-2-methoxydibenzobicyclo[3.2.1]octane-1-carboxylic acid ($[\alpha]^{20}_{Hg}$ +163.4 ± 0.3°) in 10 mL of methylene dichloride was added, stirring was continued for an additional hour. (*S*)-(−)-α-Methylbenzylamine (2.6 mL, 0.02 mol) was added, the solution was allowed to reach ambient temperature, and stirring was continued for 10 more hours. The reaction mixture was washed successively with water, 2 N HCl, and sodium bicarbonate and dried over anhydrous magnesium sulfate. The solvent was removed in vacuo to yield, after recrystallization (ether–cyclohexane) 1.15 g (75%) of amide: mp 143–144 °C; $[\alpha]^{20}_{Hg}$ +126.4 ± 0.2° (*c* 0.52, ethanol); IR ($CHCl_3$) 3450, 3080, 3040, 3000, 2940, 2840, 1660, 1520, 1450, 1220, 1090 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 1.61 (d, *J* = 6.9 Hz, 3 H), 2.58 dd, $J_1$ = 4.5 Hz, $J_2$ = 9.7 Hz, 1 H), 2.70 (d, *J* = 9.7 Hz, 1 H), 3.65 (s, 3 H), 4.01 (d, *J* = 4.5 Hz, 1 H), 4.65 (s, 1 H), 5.21–5.35 (m, 1 h), 6.10 (br d, 1 H), 7.00–7.75 (m, 13 H). Anal. Calcd for $C_{26}H_{25}NO_2$: C, 81.43; H, 6.57. Found: C, 81.30; H, 6.63.

**(−)-(*R*)-*N*-[(*R*)-1-Phenylethyl]-2-bromodibenzobicyclo-[2.2.2]octadiene-2-carboxamide.** To a solution consisting 1.17 mL (0.015 mol) of DMF in 50 mL of methylene dichloride at −10 °C was added 0.88 mL (0.01 mol) of oxalyl chloride. The reaction mixture was stirred for 30 min and cooled to −20 °C, the solution of 1.65 g (0.005 mol) of (*R*)-(−)-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxylic acid, $[\alpha]_{Hg}$ −102.3 ± 0.3° (*c* 0.5 in ethanol), in 10 mL of methylene dichloride was added, and stirring was continued for an additional hour. (*R*)-(+)-α-Methylbenzylamine (2.58 mL, 0.02 mol) was added, and the solution was allowed to come to room temperature with stirring continued for 10 more hours. The reaction mixture was washed successively with water, 2 N HCl, sodium bicarbonate, and saturated sodium chloride and dried over $MgSO_4$. The solvent was removed in vacuo to yield after recrystallization from benzene 2.05 g (95%) of amide: mp 212 °C; $[\alpha]_{Hg}$ −71.2 ± 0.3° (*c* 0.5, chloroform); IR ($CHCl_3$) 3420, 3080, 3020, 2980, 2920, 1680, 1510, 1240 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 1.49 (d, *J* = 6.9 Hz, 3 H), 2.26 (dd, $J_1$ = 2.6 Hz, $J_2$ = 13.9 Hz, 1 H), 3.28 (dd, *J* = 2.6 Hz, $J_2$ = 13.9 Hz, 1 H), 4.33 (t, *J* = 2.6 Hz, 1 H), 4.73 (s, 1 H), 5.00–4.85 (m, 1 H), 6.35 (br d, *J* = 7.0 Hz, 1 H), 7.05–7.50 (m, 13 H). Anal. Calcd for $C_{25}H_{22}NOBr$: C, 69.45; H, 5.13. Found: C, 69.43; H, 5.12.

**(−)-(*R*)-*N*-[(*S*)-1-Phenylethyl]-2-bromodibenzobicyclo-[2.2.2]octadiene-2-carboxamide.** To a solution consising 1.17 mL (0.015 mol) of DMF in 50 mL of methylene dichloride at −10 °C was added 0.88 mL (0.01 mol) of oxalyl chloride. The reaction mixture was stirred for 30 min and cooled to −20 °C, the solution of 1.65 g (0.005 mol) of (*R*)-(−)-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxylic acid, $[\alpha]_{Hg}$ −102.3° (*c* 0.5 in ethanol), in 10 mL of methylene dichloride was added, and stirring ws continued for an additional hour. (*S*)-(−)-α-Methylbenzylamine (2.58 mL, 0.02 mol) was added, and the solution allowed to come to room tempterature with stirring continued for 10 more hours. The reaction mixture was washed successively with water, 2 N HCl, sodium bicarbonate, and saturated sodium chloride and dried over $MgSO_4$. The solvent was removed in vacuo to yield after recrystallization from benzene 1.99 g (92%) of amide: mp 185–186 °C; $[\alpha]_{Hg}$ −119.4 ± 0.3° (*c* 0.4, chloroform); IR ($CHCl_3$) 3420, 3080, 3020, 2980, 2920, 1680, 1510, 1240 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 1.47 (d, *J* = 6.9 Hz, 3 H), 2.88 (dd, $J_1$ = 2.7 Hz, $J_2$ = 14.0 Hz, 1 H), 3.27 (dd, $J_1$ = 2.7 Hz, $J_2$ = 14.0 Hz, 1 H), 4.31 (t, *J* = 2.7 Hz, 1 H), 4.61 (s, 1 H), 5.0–4.89 (m, 1 H), 6.32 (br d, *J* = 7.0 Hz, 1 H), 6.8–7.5 (m, 13 H).

**Rearrangement of (−)-(*R*)-2-Bromodibenzobicyclo-[2.2.2]octadiene-2-carboxylic Acid to (−)-(1*S*,2*S*,5*S*)-*exo*-2-Hydroxydibenzobicyclo[3.2.1]octadiene-2-carboxylic Acid.** To 1.6 g (0.005 mol) of (−)-(*R*)-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxylic acid ($[\alpha]^{20}_{Hg}$ −102.9 ± 0.4°, op 100%) was added, at 0 °C, 50 mL of an aqueous solution of 0.7 g (0.0125 mol) of KOH, and the reaction mixture was stirred for 6 h at 0 °C and then for 24 h at ambient temperature. The reaction was acidified with 3 N HCl at 0 °C and extracted with ethyl acetate (3 × 50 ml). The extract was dried over anhydrous magnesium sulfate, and the solvent was removed in vacuo. The residue was purified by radial chromatography (hexane–ether, 1:1) to yield 1.24 g (93%) of (−)-(1*S*,2*S*,5*S*)-*exo*-2-hydroxydibenzobicyclo[3.2.1]octadiene-

1-carboxylic acid, mp 202–203 °C; $[\alpha]^{20}_{Hg}$ –209.6 ± 0.4° (*c* 0.33, ethanol).

**Methyl (–)-(1*S*,2*S*,5*S*)-*exo*-2-Hydroxydibenzobicyclo[3.2.1]octadiene-1-carboxylate.** Esterification of the corresponding acid with diazomethane yielded the ester: mp 161–162 °C; $[\alpha]^{20}_{Hg}$ –211.9 ± 0.4° (*c* 0.56, ethanol); IR ($CHCl_3$) 3580, 3000, 2950, 1720, 1600, 1480, 1470, 1450, 1440, 1320, 1270, 1050, 1010 $cm^{-1}$; $^1H$ NMR ($CDCl_3/D_2O$) δ 2.63 (d, *J* = 11.1 Hz, 1 H), 2.93 (dd, $J_1$ = 11.1 Hz, $J_2$ = 4.3 Hz, 1 H), 3.90 (s, 3 H), 4.06 (d, *J* = 4.3 Hz, 1 H), 4.99 (s, 1 H), 7.00–7.45 (m, 8 H). Anal. Calcd for $C_{18}H_{16}O_3$: C, 77.12; H, 5.75. Found: C, 77.30; H, 5.66.

**Methyl (+)-(1*S*,5*S*)-2-Oxodibenzobicyclo[3.2.1]octadiene-1-carboxylate.** To a stirred solution of 0.5 mL (0.0055 mol) of oxalyl chloride in 10 mL of methylene chloride, at –78 °C, was added 0.85 mL (0.011 mol) of DMSO dissolved in 5 mL of methylene chloride. After the mixture was stirred for 10 min 1.4 g (0.005 mol) of methyl (–)-(1*S*,2*S*,5*S*)-2-hydroxydibenzobicyclo[3.2.1]octadiene-1-carboxylate ($[\alpha]^{20}_{Hg}$ –211.9 ● 0.4°) dissolved in 10 mL of methylene chloride was added, and the reaction mixture was stirred for 30 min. Finally, 3.5 mL of triethylamine was added, and the solution was allowed to come to room temperature. The reaction mixture was washed with water, 1 N HCl, and aqueous sodium bicarbonate and dried over anhydrous magnesium sulfate. The solvent was removed in vacuo to yield after recrystallization (ethyl acetate–hexane) 1.32 g (95%) of product: mp 177 °C; $[\alpha]^{20}_{Hg}$ +239 ± 0.4° (*c* 0.215, ethanol); IR ($CHCl_3$) 3080, 3040, 2980, 1740, 1690, 1600, 1450, 1440, 1320, 1290, 1260, 1220, 1150, 1130 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 3.09 (dd, $J_1$ = 4.5 Hz, $J_2$ = 11.2 Hz, 1 H), 3.18 (d, *J* = 11.2 Hz, 1 H), 3.90 (s, 3 H), 4.22 (d, *J* = 4.5 Hz, 1 H), 7.00–8.00 (m, 8 H). Anal. Calcd for $C_{18}H_{14}O_3$: C, 77.68; H, 5.07. Found: C, 77.64; H, 5.28.

**Rearrangement of (–)-(*R*)-2-Bromodibenzobicyclo[2.2.2]octadiene-2-carboxylic Acid by Silver Acetate.** A mixture of 3.2 g (0.01 mol) of (–)-(*R*)-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxylic acid ($[\alpha]^{20}_{Hg}$ –83.5 ± 0.4°, op ~82%), 3.34 g (0.02 mol) of silver acetate dissolved in 100 mL of acetone, and 50 mL of water was stirred for 24 h at ambient temperature. The silver salts were filtered, and the filtrate was evaporated to dryness. The residue was dissolved in 75 mL of ethyl acetate, washed with water and saturated sodium chloride and dried over anhydrous magnesium sulfate. The solvent was removed in vacuo to yield a mixture of *exo*- and *endo*-2-hydroxydibenzobicyclo[3.2.1]octadiene-1-carboxylic acids. $^1H$ NMR spectrum ($CDCl_3$) of the mixture revealed two singlets for C-2 H absorption δ 5.47 and 5.01 ppm in an integrated ratio of 0.8:1. The mixture of acids was esterified with diazomethane, and the resultant mixture of esters was oxidized as described above (Swern oxidation) to yield 2.17 g (78%) of methyl (+)-(1*S*,5*S*)-2-oxodibenzobicyclo[3.2.1]-octadiene-1-carboxylate, mp 175–177 °C, $[\alpha]^{20}_{Hg}$ +186.6 ● 0.4° (*c* 0.2, ethanol), op 78%.

**Rearrangement of Methyl (±)-2-Bromobicyclo[2.2.2]octadiene-2-carboxylate in the Presence of Silver Perchlorate in Methanol.** A mixture of 1.715 g (0.005 mol) of ester and 3.12 g (0.015 mol) of silver perchlorate in 100 mL of absolute methanol was stirred for 3 h at ambient temperature. The silver salts were filtered, and the solvent was evaporated. The residue was dissolved in ethyl acetate (75 mL), washed with water and saturated sodium chloride, and dried over anhydrous magnesium sulfate. The solvent was removed in vacuo to yield a mixture of methyl *exo*- and *endo*-2-methoxydibenzobicyclo[3.2.1]octadiene-1-carboxylates (1.4 g, 95%). The 270-MHz $^1H$ NMR sectrum ($CDCl_3$) of the mixture showed two singlets for $C_2$-H absorption at δ 4.57 and 5.25 ppm in an integrated ratio of 1.73:1.

**Exo Isomer.** Recrystallization of the mixture from absolute methanol gave 0.59 g (67%) of methyl *exo*-2-methoxydibenzobicyclo[3.2.1]octadiene-1-carboxylate: mp 130–133 °C; IR ($CHCl_3$) 3090, 3020, 2980, 1730, 1600, 1440, 1270, 1090 $cm^{-1}$; $^1H$ NMR ($CHCl_3$) δ 2.70 (d, *J* = 11.2 Hz, 1 H), 2.86 (dd, $J_1$ = 4.6 Hz, $J_2$ = 11.2 Hz, 1 H), 3.69 (s, 3 H), 3.90 (s, 3 H), 4.00 (d, *J* = 4.6 Hz, 1 H), 4.57 (s, 1 H), 7.00–7.50 (m, 8 H). Anal. Calcd for $C_{19}H_{18}O_3$: C, 77.53; H, 6.16. Found: C, 77.46; H, 6.25.

**Endo Isomer.** The mother liquors from the above crystallization was saponified with KOH to yield a mixture of exo and endo acids, which upon recrystallization from ether gave the endo isomer (0.32 g, 65%). Esterification with diazomethane yielded the desired ester, methyl *endo*-2-methoxydibenzobicyclo[3.2.1]-octadiene-1-carboxylate (oil): IR (film) 3080, 3090, 2980, 1730, 1600, 1490, 1440, 1250, 1100 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 2.51 (d, *J* = 10.9 Hz, 1 H), 2.72 (dd, $J_1$ = 10.9 Hz, $J_2$ = 4.7 Hz, 1 H), 3.69 (s, 3 H), 3.86 (s, 3 H), 3.92 (d, *J* = 4.7 Hz, 1 H), 5.25 (s, 1 H), 7.00–7.60 (m, 8 H).

**Rearrangement of (±)-2-Bromodibenzobicyclo[2.2.2]octadiene-2-carboxylic Acid in the Presence of Sodium Methoxide in Methanol.** Into a solution of sodium methoxide in absolute methanol (prepared from 0.28 g sodium (0.012 mol) and 100 mL of methanol) was added 1.65 g (0.005 mol) of (±)-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxylic acid. The reaction mixture was refluxed for 12 h and then stirred for 24 h at 20 °C. The solvent was evaporated, and the residue was dissolved in 100 mL of water, washed with 50 mL of ether, acidified with 3 N HCl, and extracted with ethyl acetate (3 × 50 mL). The combined extracts were washed with water and saturated sodium chloride, dried over $MgSO_4$, and evaporated in vacuo to yield after recrystallization (ethyl acetate–hexane) 1.72 g (83%) of (±)-*exo*-2-methoxydibenzobicyclo[3.2.1]octadiene-1-carboxylic acid: mp 202–204 °C; IR and $^1H$ NMR ($CDCl_3$) were identical with an authentic sample of (1*R*,2*R*,5*R*)-2-methoxydibenzobicyclo[3.2.1]octadiene-1-carboxylic acid.

**Rearrangement of Methyl (±)-2-Bromodibenzobicyclo[2.2.2]octadiene-2-carboxylate in the Presence of Silver Perchlorate in Acetone/Water Solution.** Into a solution of 2.4. g (0.012 mol) of silver perchlorate in 75 mL of acetone and 50 mL of water was added 1.72 g (0.005 mol) of methyl (±)-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxylate. The reaction mixture was stirred 0.5 h. The silver salt was filtered, and the solution was evaporated in vacuo. The residue was dissolved in 70 mL of ethyl acetate, washed with water, saturated NaCl, and $NaHCO_3$, and dried over anhydrous magnesium sulfate, and the solvent was removed in vacuo. The 270-MHz $^1H$ NMR ($CDCl_3$) spectrum of the crude product showed two singlets for $C_2$-H absorption at δ 4.99 ppm (exo isomer) and 5.43 ppm (endo-isomer) in an integrated ratio of 21:1. The recrystallization of the crude product from ethyl acetate–hexane yielded 1.28 g (91%) of methyl (±)-*exo*-2-hydroxydibenzobicyclo[3.2.1]octadiene-1-carboxylate: mp 176–178 °C; IR ($CDCl_3$) 3580, 3000, 2950, 1720, 1600, 1480, 1470, 1450, 1440, 1320, 1270, 1050, 1010 $cm^{-1}$; $^1H$ NMR ($CDCl_3/D_2O$) δ 2.63 (d, *J* = 11.1 Hz, 1 H), 2.93 (dd, $J_1$ = 11.1 Hz, $J_2$ = 4.3 Hz, 1 H), 3.90 (s, 3 H), 4.06 (d, *J* = 4.3 Hz, 1 H), 4.99 (s, 1 H), 7.00–7.45 (m, 8 H).

**Epimerization of (±)-*exo*-2-Hydroxydibenzobicyclo[3.2.1]octadiene-1-carboxylic Acid in Trifluoroacetic Acid.** Into 100 mL of trifluoroacetic acid was added 1.33 g (0.005 mol) of (±)-*exo*-2-hydroxydibenzobicyclo[3.2.1]octadiene-1-carboxylic acid. The reaction mixture was kept for 24 h at 20 °C, and the trifluoroacetic acid was evaporated in vacuo to yield a mixture of *exo*- and *endo*-(±)-2-*O*-trifluoroacetyldibenzobicyclo[3.2.1]-octadiene-1-carboxylic acid: IR ($CHCl_3$) 3500, 3300–2500, 1790, 1710, 1600, 1460, 1420, 1370, 1230, 1180, 1160 $cm^{-1}$. The 270-MHz $^1H$ NMR ($CDCl_3$) spectrum of the mixture showed two singlets for $C_2$-H absorption at 6.54 ppm (exo isomer) 6.93 ppm (endo isomer) in an integrated ratio of 1.8:1. The mixture of *exo*- and *endo*-*O*-trifluroacetylates was hydrolyzed with 0.7 g (0.0125 mol) of KOH to yield a mixture of *exo*- and *endo*-(±)-2-hydroxydibenzobicyclo[3.2.1]octadienecarboxylic acid (1.27 g, 95%): IR ($CHCl_3$) 3500–2200, 1710, 1600, 1460, 1420, 1280, 1210, 1050, 1040, 1000 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) of the mixture showed two singlets for $C_2$-H absorption at 5.02 ppm (exo isomer) and 5.48 ppm (endo isomer) in an integrated ratio of 1.8:1.

**Epimerization of Methyl (±)-*exo*-2-Hydroxydibenzobicyclo[3.2.1]octadiene-1-carboxylate in Trifluoroacetic Acid.** Into 100 mL of trifluoroacetic acid was added 1.4 g (0.005 mol) of methyl (±)-*exo*-2-hydroxydibenzobicyclo[3.2.1]octadiene-1-carboxylate. The reaction mixture was kept for 24 h at +20 °C, and the trifluoroacetic acid was evaporated in vacuo to yield a mixture of methyl *exo*- and *endo*-(±)-2-*O*-trifluoroacetyldibenzobicyclo[3.2.1]octadiene-1-carboxylate: IR ($CHCl_3$) 3080, 3020, 2960, 1790, 1740, 1600, 1440, 1230, 1160 $cm^{-1}$. The 270-MHz $^1H$ NMR ($CDCl_3$) spectrum of the mixture showed two singlets for $C_2$-H absorption at 6.5 ppm (exo isomer) and 6.9 ppm (endo isomer) in an integrated ratio of 2.3:1. MS high resolution for $C_{20}H_{15}O_4F_3$ calcd mass 376.0922, measured mass 376.0912. The mixture of *exo*- and *endo*-*O*-trifluoroacetylates was hydrolyzed

with 0.31 g (0.0055 mol) of KOH in methnol–water solution to yield a mixture of methyl *exo*- and *endo*-(±)-2-hydroxydibenzobicyclo[3.2.1]octadiene-1-carboxylate, 1.35 g (96%): IR ($CHCl_3$) 3580, 3000, 2950, 1720, 1600, 1480, 1470, 1450, 1440, 1320, 1270, 1050, 1010 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) of the mixture showed two singlets for $C_2$-H absorption at 4.98 ppm (exo isomer) and 5.43 ppm (endo isomer) in an integrated ratio of 3.5:1.

**Epimerization of Methyl (±)-*exo*-2-Hydroxydibenzobicyclo[3.2.1]octadiene-1-carboxylate in Perchloric Acid–Acetic Acid.** The *exo*-hydroxy ester (0.5 g) was dissolved in 50 mL of anhydrous 1 M perchloric acid in acetic acid and stirred at ambient temperature for 1 h. The reaction mixture was diluted with cold water and extracted with ether (3 × 100 mL). The ethereal solution was washed with water and sodium carbonate solution and dried over anhydrous sodium sulfate. Removal of solvent gave a quantitative yield of acetate product: IR (neat) 3070, 3030, 2960, 1736 (br), 1600, 1450(m), 1375, 1240, 1030–750 $cm^{-1}$; $^1H$ NMR of the mixture showed two singlets for $C_2$-H absorption at 6.41 ppm (exo isomer) and 6.75ppm (endo isomer) in an integrated ratio of 1.9:1. Stirring the reaction mixture for 24 h did not change the ratio.

**Ethyl (±)-2-Bromodibenzobicyclo[2.2.2]octadiene-2-carboxylate.** This compound was prepared, in 95% yield, according to the procedure used for the preparation of methyl (±)-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxylate, vide supra, mp 70–72 °C: IR ($CHCl_3$) 3070, 3020, 2940, 1715, 1600, 1470, 1460, 1275 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 1.24 (t, $J$ = 7.0 Hz, 3 H), 2.32 (dd, $J_1$ = 14.4 Hz, $J_2$ = 2.7 Hz, 1 H), 3.15 (dd, $J_1$ = 14.4 Hz, $J_2$ = 2.7 Hz, 1 H), 4.10 (q, $J$ = 7.0 Hz, 2 H), 4.29 (t, $J$ = 2.7 Hz, 1 H), 4.96 (s, 1 H), 7.00–7.50 (m, 8 H). Anal. Calcd for $C_{19}H_{17}O_2Br$: C, 63.88; H, 4.80. Found: C, 63.78; H, 4.79.

**Rearrangement of Ethyl (±)-2-Bromodibenzobicyclo-[2.2.2]octadiene-2-carboxylate in the Presence of Silver Perchlorate in Methanol.** Into a solution of 2.49 g (0.012 mol) of silver perchlorate in 75 mL of methanol was added 1.78 g (0.005 mol) of ethyl (±)-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxylate. The reaction mixture was stirred for 0.5 h. The silver salt was filtered, and the solution was evaporated in vacuo. The residue was dissolved in 70 mL of ethyl acetate, washed with water, saturated NaCl, and $NaHCO_3$, dried over $MgSO_4$, and evaporated in vacuo to yield a mixture of ethyl *exo*- and *endo*-2-methoxydibenzobicyclo[3.2.1]octane-1-carboxylate (98%). The 270-MHz $^1H$ NMR ($CDCl_3$) spectrum of the mixture showed two singlets for $C_2$-H absorption at 4.57 ppm (exo isomer) and 5.24 ppm (endo isomer) in an integrated ratio 1.85:1. The radial chromatography (hexane–ether, 10:1) gave two fractions, A and B. Fraction A: 0.81 g (53%) of ethyl (±)-*exo*-2-methoxydibenzobicyclo[3.2.1]-octane-1-carboxylate; mp 122–124 °C; IR ($CHCl_3$) 3040, 3010, 3000, 2980, 1750, 1600, 1450, 1270, 1200, 1080, 1060 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 1.40 (t, $J$ = 7.1 Hz, 3 H), 2.69 (d, $J$ = 10.7 Hz, 1 H), 2.86 (dd, $J_1$ = 10.7 Hz, $J_1$ = 4.9 Hz, 1 H), 3.62 (s, 3 H), 4.00 (d, $J$ = 4.9 Hz, 1 H), 4.75 (q, $J$ = 7.1 Hz, 2 H), 4.57 (s, 1 H), 7.00–7.50 (m, 8 H); MS high resolution for $C_{20}H_{20}O_3$ calcd mass 308.1412, measured mass 308.1418. Fraction B (mixture of epimers) was hydrolyzed with KOH to yield after the crystallization from ether 0.35 g of (±)-*endo*-2-methoxydibenzobicyclo[3.2.1]octadiene-1-carboxylic acid: mp 214–215 °C dec; IR ($CHCl_3$) 3500–2400, 1720, 1600, 1420, 1280, 1090 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) $\delta$ 2.56 (d, $J$ = 10.8 Hz, 1 H), 2.84 (dd, $J_1$ = 4.6 Hz, $J_2$ = 10.8 Hz, 1 H), 3.74 (s, 3 H), 3.96 (d, $J$ = 4.6 Hz, 1 H), 5.29 (s, 1 H), 7.00–7.60 (m, 8 H). Anal. Calcd for $C_{18}H_{16}O_3$: C, 77.12; H, 5.75. Found: C, 77.14; H, 5.78.

**Methyl (*R*)-(−)-2-Bromodibenzobicyclo[2.2.2]octadiene-2-carboxylate.** The esterification of (*R*)-(−)-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxylic acid, $[\alpha]_{Hg}$ −83.5 ± 0.3° (*c* 0.75, ethanol op 82%), with diazomethane yielded methyl (*R*)-(−)-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxylate, $[\alpha]_{Hg}$ −84.2 ± 0.3° (*c* 0.5 in methanol, op 82%). IR and $^1H$ NMR spectra were identical with an authentic sample of methyl (±)-2-bromodibenzobicyclo[2.2.2]octadiene-2-carboxylate. MS high resolution for $C_{18}H_{15}O_2Br$ calcd mass 342.0255, measured mass 342.0247.

**Details of X-ray Data Collection, Solution, and Refinement: $C_{25}H_{22}NOBr$.** Single crystals of $C_{25}H_{22}NOBr$ were grown by slow evaporation from a methanol solution. A fragment, 0.3 × 0.3 × 0.3 mm was cut from a much larger crystal. The crystals were monoclinic, space group $P2_12_12_1$, with $a$ = 9.579 (2), $b$ =19.985 (7), and $c$ = 21.727 (7) Å; $d_{calcd}$ = 1.38 g $cm^{-3}$; $d_{meas}$ = 1.36 g $cm^{-3}$ for $Z$ = 8 ($M_r$ = 432.4). The intensity data were measured on a CAD4 Enraf Nonius Diffractometer (Mo radiation, monochromated, $\theta$ scans). No absorption correction was made ($\mu$ = 19.7) in view of the uniform shape of the crystal. A total of 4125 reflections were measured for $\theta \leq 50$, of which 1950 were considered to be observed [$I \geq 2\sigma(I)$]. The structure was solved by Patterson and difference Fourier least squares techniques and refined by full-matrix least-squares methods. Because of the poorly diffracting nature of the crystal and the relatively small amount of observable data, only the bromine atoms were refined anisotropically. Methyl hydrogen atoms were located from a difference Fourier map; the remaining hydrogen atom parameters were calculated by assuming idealized geometry. Hydrogen atoms contributions were included in the structure factor calculations, but their parameters were not refined. The final discrepancy indices were $R$ = 7.4 and $R_w$ = 8.4 for the 1950 observed reflections. The final difference Fourier map was essentially featureless with no peaks greater than 0.3 e $Å^{-3}$.

**$C_{26}H_{25}NO_2$.** Single crystals of $C_{26}H_{25}NO_2$ were grown by slow evaporation of an ethyl acetate solution of the compound. The crystals were monoclinic, spacegroup $P2_1$, with $a$ = 5.748 (4), $b$ = 22.169 (5), and $c$ = 8.659 (5) Å; $\beta$ = 105.05 (5); and $d_{calcd}$ = 1.195 g $cm^{-3}$ for $Z$ = 2 ($M_r$ = 383.5). The intensity data were measured on a CAD4 Enraf Nonius Diffractometer (Mo radiation, monochromated, $\theta - 2\theta$ scans). The size of the crystal used for collection was approximately 0.3 × 0.3 × 0.3 $mm^3$. No absorption correction was necessary ($\mu$ = 0.70). A total of 2136 reflections were measured for $\theta \leq 50$, of which 1814 were considered to be observed [$I \geq 2\sigma(I)$]. The structure was solved by direct methods using MULTAN 78[20] and refined by full-matrix least-squares methods. In the final refinement, anisotropic thermal parameters were used for non-hydrogen atoms. Methyl hydrogen atoms were located from a difference Fourier map; the remaining hydrogen atom parameters were calculated, assuming idealized geometry. Hydrogen atom contributions were included in the structure factor calculations, but their parameters were not refined. The final discrepancy indices were $R$ = 0.064 and $R_w$ = 7.5 for the 1814 observed reflections. The final difference Fourier map was essentially featureless with no peaks greater than 0.3 e $Å^{-3}$.

**Acknowledgment.** We wish to thank Dr. S. Madhava Reddy for conducting the acetic acid–perchloric acid epimerization experiment.

**Supplementary Material Available:** Crystal data and tables of interatomic distances, selected bond angles, selected torsional angles, positional and thermal parameters, and their estimated standard for $C_{26}H_{25}NO_2$ and $C_{25}H_{22}NOBr$ (18 pages). Ordering information is given on any current masthead page.

(20) Main, P. *MULTAN 78. A System of Computer Programs for the Automatic Solution of Crystal Structures from X-ray Diffraction Data*; Department of Physics, University of New York: York, England. All computations were performed on a PDP 11/34 computer with the aid of the Structure Determination crystallographic program library obtained with the purchase of the X-ray equipment.