$k_{f,h}$ at this potential was measured for each bromide and divided by $k_{f,h}$ for isobutyl bromide to obtain relative electron-transfer rates. The data are displayed in Table III. The high relative rate of cleavage of the carbon–bromine bond of *tert*-butyl bromide is probably associated with the stability of the resulting tertiary radical manifesting itself in the transition state for electron transfer.[10b] It is possible that reduction of bromobenzene involves initial electron injection into the π system of the aromatic ring,[4,5] rather than direct bond breakage in the electron-transfer step, but as one of us has argued previously,[4] we regard this as unlikely because of the very negative potential necessary to reduce benzene directly.

Conclusions

The changes in half-wave potential of alkyl halides as the supporting electrolyte is varied could in principle be taken advantage of in a variety of ways, both synthetic and analytical, because they offer a way to improve the resolution of closely spaced voltammetric waves. The caution must be repeated here again that when dealing with highly irreversible systems it is not necessarily true that the supporting electrolyte with the most negative reduction potential ought to be selected; on the contrary, the converse may be true.

Acknowledgment. Financial support was provided by the National Science Foundation. Professors Sease and Wiberg kindly provided the sample of 1-bromonorbornane.

Registry No.—TMAHP, 558-32-7; TEAB, 71-91-0; TPAFB, 15553-52-3; TBAP, 1923-70-2; THpAI, 3535-83-9; pivalaldehyde, 630-19-3.

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Response of Homo- and Benzhomobarrelenes to Uniparticulate Electrophilic Attack. Effect of a Lateral Cyclopropane Ring on the Direction and Stereochemistry of Chlorosulfonyl Isocyanate Addition[1]

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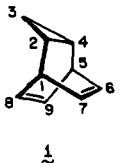
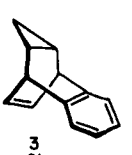
On reaction with chlorosulfonyl isocyanate, homobarrelene (1) afforded two isolable β-lactams, a γ-lactam, and a γ-lactone. All arise by electrophilic attack at the anti double bond with strong preference for endo approach. The site exclusivity was confirmed by ^{1}H NMR studies with unlabeled and 6,7-dideuterio-1. By way of contrast, the lone double bond in *syn*-benzohomobarrelene (2) experienced addition preferentially from the exo direction; two β-lactams and a γ-lactam were isolated in this instance. *anti*-Benzohomobarrelene (3) proved unreactive to chlorosulfonyl isocyanate under conditions where 1 and 2 reacted readily. Product structural assignments were made chiefly on the basis of spectral data, with extensive utilization of europium pseudocontact shifting. The mechanistic implications of these findings are discussed.

The rigid geometry and special three-dimensional π-electron character of barrelene has prompted experimental scrutiny of its capability to enter into molecular rearrangements.[2,3] High levels of interaction between the adjacent olefinic bridges are seen, but the symmetry properties of barrelene are such that stereochemical tests cannot be applied. To gain such information, some structural perturbation becomes necessary. In this paper, we report the first examples of electrophilic addition to homobarrelene (tricyclo[3.2.2.0^{2,4}]nona-6,8-diene, 1) and its isomeric benzo derivatives 2 and 3. Molecules other than 1 can in principle be



1

2



3

selected to address the stereochemical issue, but none of these share with homobarrelene the unique features imparted by the cyclopropane ring. Brown's examination of the steric effect caused by 7,7-dimethyl substitution at the

bridge carbon in norbornene has revealed a reversal in the customary exo direction of reaction in some, but not all, cases.[4] A comparable assessment of the influence of a cyclopropane ring laterally fused to a (necessarily homologous) bicyclo[2.2.2]octatriene frame has not been made. In addition to the purely steric factor, preferential interaction of the internal cyclopropane σ orbital with the C_6–C_7 π bond can gain importance. The possibility of selective stabilization of this type gains support from the photoelectron spectral behavior of 1.[5] In benzologues **2** and **3**, the available site for reaction is predetermined on structural grounds and only in one of these (**2**) is possible σ–π interaction attainable. The prevailing steric situations in **2** and **3** are also obviously quite different.

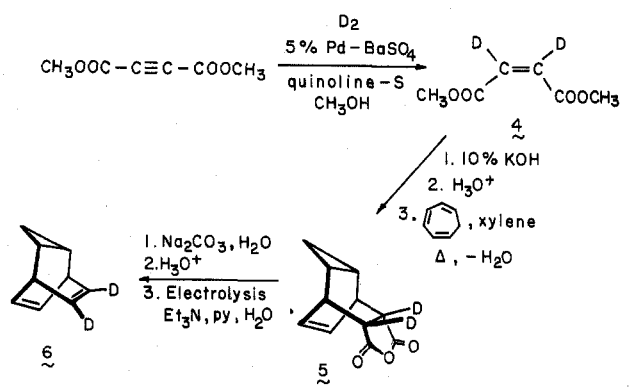
For these reasons, we have undertaken to study the comparative behavior of **1**–**3** toward chlorosulfonyl isocyanate (CSI). Use of this reagent was predicated on its recognized high reactivity, uniparticulate electrophilic character,[6] stereospecificity,[7] and appreciable steric requirements.[8] Furthermore, the *N*-chlorosulfonyl β-lactams which are formed initially under conditions of kinetic control are frequently rearrangement prone and sometimes experience ring opening–isomerization processes of mechanistic importance.

Results

Homobarrelene (1). The preparation of **1** was achieved by electrolytic decarboxylation[9] of the diacid obtained by aqueous hydrolysis of the cycloheptatriene–maleic anhydride adduct.[10] In agreement with earlier reports,[11,12] **1** was found to exhibit a ^{1}H NMR spectrum showing nearly degenerate secondary cyclopropyl protons (δ 0.60, m, 2), tertiary protons of the cyclopropane (1.10, m, 2) and bridgehead variety (3.60, m, 2), and two distinctive sets of olefinic proton pairs (5.90 and 6.45, q, 2 each). When **1** was treated with an equimolar quantity of CSI in purified deuteriochloroform solution and the progress of reaction monitored by NMR spectroscopy at ordinary probe temperatures, reduction of the intensity of the δ 6.45 signal to nil was noted during 15 min. The second olefinic quartet was somewhat reduced in area and some minor alteration in chemical shift was apparent as reaction progressed. A companion infrared study revealed the rapid appearance of a carbonyl band at 1825 cm^{-1} indicative of *N*-(chlorosulfonyl) β-lactam formation. With the passage of time, this peak was gradually (although never completely) supplanted by an absorption at 1790 cm^{-1}.

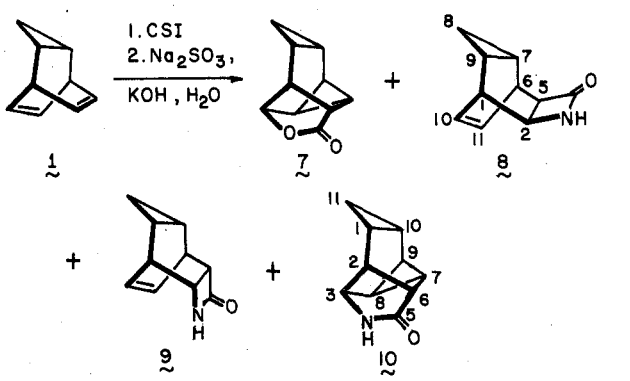
Using diamagnetic anisotropy arguments,[13] Rhodes and his co-workers[12] attributed the high-field olefinic quartet of **1** to H_8, H_9. Although support for the assumed selective shielding was gained by direct spectral comparisons with *syn*- and *anti*-tricyclo[3.2.2.0^{2,4}]non-6-ene, the difficulties sometimes encountered in determining the magnitude of long-range cyclopropane shielding effects[14] and possible anisotropic contributions of one double bond upon the other prompted us to establish the accuracy of these assignments in completely unequivocal fashion. To this end, the synthesis of homobarrelene specifically labeled with deuterium atoms at positions 6 and 7 was accomplished (Scheme I). Modified Lindlar reduction[15] of dimethyl acetylenedicarboxylate with deuterium gas gave dimethyl maleate-2,3-d_2 (**4**), the ^{1}H NMR spectrum of which consists of a sharp singlet at δ 3.75.[16] This diester was saponified and the resulting dideuteriomaleic acid was condensed directly with cycloheptatriene in refluxing xylene from which water was azeotropically removed. Subsequent hydrolysis and electrolytic decarboxylation of resulting anhydride **5** afforded **6** in low yield. The ^{1}H NMR and mass spectra of this hydrocarbon confirmed greater than 90% incorporation of two deuterium atoms. More specifically, the labeled diene almost completely lacked the downfield quartet centered at δ 6.45. With the knowledge that cycloheptatriene enters into Diels–Alder cycloadditions to give adducts having an anti cyclopropane orientation relative to the entering dienophile,[17] **6** is necessarily the 6,7-d_2 derivative and Rhodes' original assignments are fully confirmed.

Scheme I



These preliminary findings suggested that electrophilic attack on **1** occurs with total or near exclusivity at the anti double bond. Because the NMR spectra of the unpurified reaction mixtures were complex (several adducts were clearly in hand), product characterization was necessarily preceded by reductive dechlorosulfonylation and column chromatography. The latter separation was unavoidably deleterious to the resulting lactone and lactams with the result that high overall yields of pure materials were not realizable. Conversions to unpurified product mixtures were invariably quantitative. The addition proceeds to give four adducts (Scheme II), the relative proportions of which change with the duration of the experiment (Table I).

Scheme II



The availability of both β-lactam isomers facilitated the stereochemical assignments. The less dominant of these products [**8**, ν_{max} ($CHCl_3$) 1747 cm^{-1}] was shown by ^{1}H NMR analysis to have retained the high-field olefinic multiplet and to be of unrearranged structure (see Experimental Section). Appropriate Eu(dpm)$_3$-induced chemical shift studies established the proximal orientation of the amide functionality to the tertiary cyclopropyl hydrogens. For example, the relevant ΔEu values[18] for H_7 and H_9, determined to be −11.8 and −3.7, respectively, reveal the carbonyl oxygen to be the preferred site of lanthanide complexation. It follows that H_5 (−15.6) and H_6 (−9.5) should be affected to a greater extent than H_2 (−6.5) and H_1 (−2.8), and that the remaining olefinic protons should also be minimally but differently perturbed (H_{10}, −2.7; H_{11}, −3.8). In contrast, the tertiary cyclopropyl hydrogens in **9** (ν_{max} 1754 cm^{-1}) are characterized by small ΔEu shifts (H_7, H_9, −1.8).

Table I
Product Distribution after Chromatographic Separation of the CSI-Homobarrelene Adducts Formed at Various Reaction Times in Dichloromethane Solution (25°)

Reaction time, hr	Yield, %			
	7	8	9	10
0.5	1.5	1.5	9.1	1.0
5	2.3	3.2	8.3	2.6
24	*a*	*a*	9.0	28.0

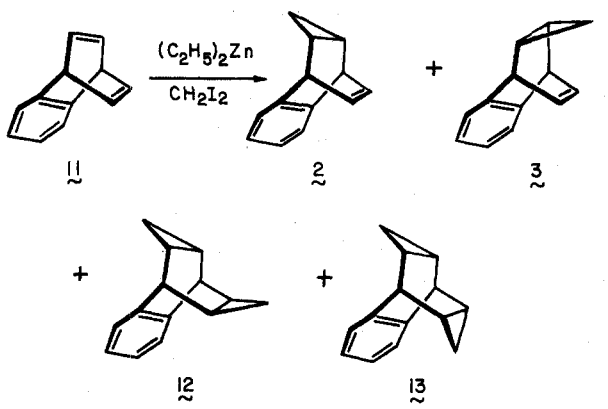
a Percent yield not determined.

That **10** is a γ-lactam follows from its intense carbonyl stretching frequency of 1700 cm^{-1}. The ^1H NMR spectrum is characterized by the absence of olefinic signals and the appearance of three new cyclopropyl protons. The presence of a total of seven such hydrogens is revealed by the array of multiplets appearing at 1.45–1.83 (1 H), 1.18–1.43 (2 H), 0.42–1.18 (2 H), 0.02–0.38 (1 H), and −0.08 to −0.37 ppm (1 H). The relative orientation of the lactam and cyclopropane groups was established by lanthanide shifting. The effect of added $Eu(fod)_3$ was most pronounced at H_6 (−10.8), H_7 (−5.1), and H_2 (−4.7) as well as at the >NH site (−11.1).

The most rapidly eluted adduct (**7**) was a γ-lactone (ν_{max} 1775 cm^{-1}), the ^1H NMR spectrum of which was very similar to that of **10** (see Experimental Section). As the direct result of lactam supplantation by lactone, downfield shifting of the three low-field multiplets [4.55–4.75 (1 H), 2.85–2.98 (1 H), and 2.52–2.79 ppm (1 H)] is observed. Both the basic structure and stereochemical disposition of the lactone unit were clear from this spectrum.

Benzohomobarrelenes 2 and 3. Reaction of benzobarrelene (**11**) with the Simmons–Smith reagent[19,20] gave a four-component mixture consisting of pairs of mono and bis adducts (Scheme III). Increased reliability and somewhat improved yields resulted from the use of diethylzinc[21] and this method was therefore preferred. Chromatography on silica gel–silver nitrate permitted isolation of the individual hydrocarbons in pure form. A distinction between syn and anti isomers in the monocyclopropanated products is reliably founded on ^1H NMR spectral data. The through-space shielding effect of the three-membered ring in **3** results in appearance of its olefinic protons at substantially higher field (δ 5.97–6.30) than those for **2** (6.68–6.90). Also, the secondary cyclopropyl protons in **2** (0.18–0.58; −0.26 to −0.53) appear upfield relative to those in **3** (1.03–1.40; 0.38–0.95) as a consequence of the diamagnetic anisotropy of the proximal benzene ring in the syn isomer. As concerns the bis adducts, the symmetry in **13** follows convincingly from the pairing of its proton signals. Definitive evidence for its syn,syn stereochemistry includes aromatic shielding of the individually resolvable secondary cyclopropyl protons (0.13 and −0.77). The aryl hydrogens of **13** are at approximately the same chemical shift as those of **12** but are split into a well-resolved AA'BB' multiplet.[22] The aryl protons of **12** appear as a narrow, unresolved multiplet. Hydrocarbon **12** lacks symmetry and is therefore uniquely reconcilable with prevailing syn,anti stereochemistry because of the four different secondary cyclopropyl resonances.

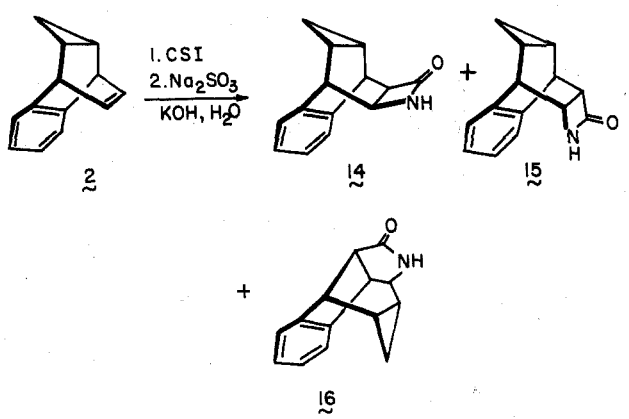
Scheme III



11 **2** **3** **12** **13**

Chlorosulfonyl isocyanate reacted with **2** at room temperature to give three lactams (Scheme IV) which could again be separated by silica gel chromatography, but with appreciable loss of product. The major component to be isolated from this mixture was β-lactam **14** (16%), the exo configuration of which was deduced by pseudocontact shifting of its ^1H NMR spectrum with $Eu(fod)_3$ (see Experimental Section). Its carbonyl stretching frequency in chloroform solution (1748 cm^{-1}) differed insignificantly from that of endo isomer **15** (1752 cm^{-1}) which was next eluted (4.0% isolated). The major distinguishing characteristic of these [2 + 2] adducts is the chemical shift difference of tertiary cyclopropyl protons H_7 and H_9, which appear more upfield in **15** (δ 1.00–1.37) than in **14** (1.67–1.83). The ΔEu values of these protons in **14** (−6.6, −2.4) conform expectedly to their closer proximity to the lactam functionality than is possible in **15** (−2.5, −1.9).

Scheme IV



2 **14** **15** **16**

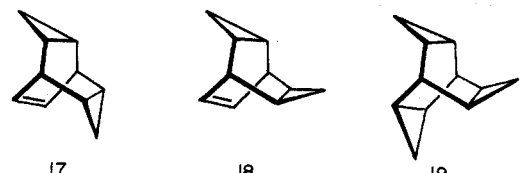
The minor (1.3%) product which accompanies the two β-lactams is assigned structure **16** on the basis of its intense absorption at 1700 cm^{-1} and key ^1H NMR signals at δ 4.15–4.33 (2 H) due to the protons flanking the amide group, 3.55–3.93 (2 H) arising from the benzylic bridgehead protons, and −0.1 to 0.9 (series of four one-proton multiplets) attributable to the individually distinctive cyclopropyl hydrogens. The precise alignment of the amide unit relative to the remainder of the molecular framework cannot be conclusively established from these data because the two adjoining methine protons (4.15–4.33) appear at chemical shifts sufficiently similar to preclude revealing double resonance studies; rather, this detail follows from mechanistic reasoning (vide infra).

Attempts to add chlorosulfonyl isocyanate to **3** under conditions where other analogous compounds reacted quite rapidly proved uniformly unsuccessful.

Discussion

Fusion of a cyclopropane ring to barrelene obviously exerts large effects upon the direction and stereochemistry of chlorosulfonyl isocyanate addition. The presence of the bulky three-membered ring modifies the steric environment such that electrophilic attack at the syn double bond lacks kinetic importance. The present results reveal further that a directive effect operates at the anti olefinic site, dif-

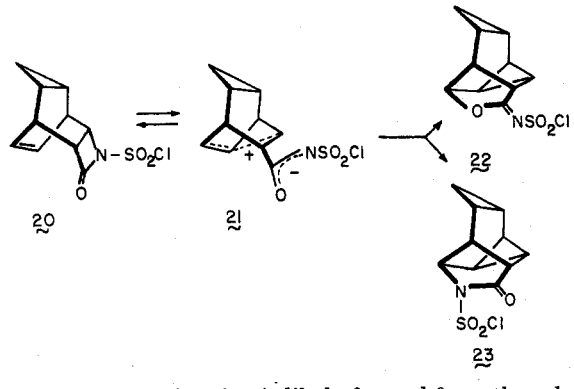
ferentiation arising in favor of endo attack, i.e., preferred addition from that direction proximal to the second double bond. This preference is not maintained during cuprous chloride promoted diazomethane addition to 1 where 17, 18, and 19 are reported to be formed in yields of 46, 25, and



17 18 19

27%, respectively.[23] It is our thesis that the smaller steric requirements of the latter reagent, coupled with its probable impingement upon the center rather than termini of the π bond, may allow for a lesser degree of selectivity. However, owing to the low material balance in the CSI reaction with 1, full assessment of the stereospecificity of electrophilic attack is beclouded.

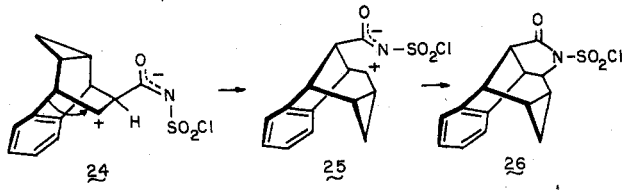
Once *N*-(chlorosulfonyl) β-lactam formation occurs from the endo direction the [2 + 2] adduct arising from endo capture (20) can experience ring opening with formation of zwitterion 21. Alternatively, if bonding occurs in stepwise fashion, 21 would be formed initially. This centrally important dipolar species can, of course, cyclize to 20; with involvement of the neighboring double bond, the possibility for more remote C–N and C–O closure with formation of 22 and 23 is also possible and does operate.[24]



20 21 22 23

An analogous zwitterion is likely formed from the related exo [2 + 2] adduct since double bond participation in this instance should be more facile. However, its further rearrangement (e.g., 1,2-vinyl shift) might be unfavorable, thus leading to 8 as the unique end product of this reaction pathway. Alternatively, the possibility that an isomerized lactam does result and is subsequently decomposed or consumed by further reaction with CSI cannot be dismissed.

The presence of the added benzene ring in 2 does not lend itself to comparably facile delocalization. However, isolation of 16 points up the real possibility for 1,2-phenyl migration in 24 with transient intervention of 25.



24 25 26

Replacement of the 8,9 double bond in 1 by a benzene ring can be expected to increase the level of steric interaction on the endo surface. The predominance of β-lactam 14 in the product mixture supports this contention, although the isolation of 15 reveals that chlorosulfonyl isocyanate bonding to 2 from the endo direction is not completely impeded. The total lack of reactivity of 3 under comparable conditions serves to emphasize the adverse effects engendered by the combination of the fused benzo substituent and a syn-oriented cyclopropane ring.

In conclusion, cycloaddition to homobarrelene and its syn benzologue via a process which may involve a cyclic $[_\pi 2_a + _\pi 2_s]$ four-membered transition state[7,8] is seen to proceed chiefly from the anti-endo and anti-exo directions, respectively. The effect of the cyclopropane ring is to deter attack at the syn double bond in 1 and the remaining double bond in 3. It would appear therefore that such rigid bicyclic systems as 1–3 may prove to be sensitive mechanistic probes of cyclic and noncyclic addition processes.

Experimental Section

Proton magnetic resonance spectra were obtained on Varian A-60A, Varian HA-100, and Jeolco MH-100 spectrometers; apparent splittings are given in all cases. Infrared spectra were determined on Perkin-Elmer Model 137 and 467 instruments. Mass spectra were recorded on an AEI-MS9 spectrometer at an ionizing potential of 70 eV. Elemental analyses were performed by the Scandinavian Microanalytical Laboratory, Herlev, Denmark.

Maleic Acid-*2,3-d*$_2$. The sulfur–quinoline poison was prepared by heating 1.0 g of sulfur in 6.0 g of pure synthetic quinoline at the reflux temperature for 5 hr, dilution with 50 ml of xylene, and filtration to remove insolubles. A mixture of 4.00 g (28.2 mmol) of dimethyl acetylenedicarboxylate, 100 ml of absolute methanol, and 0.40 g of 5% palladium on barium sulfate was treated with 8 drops of the poison and subjected to an atmosphere of deuterium gas at atmospheric pressure. After 4.5 hr of vigorous magnetic stirring, the mixture was rid of catalyst by filtration and the filtrate was evaporated under reduced pressure. The resulting yellow oil was dissolved in diethyl ether and remaining coagulated material was separated by filtration. The organic phase was extracted with 5% hydrochloric acid solution until yellow color was no longer removed and dried. Vacuum distillation gave 2.70 g of colorless liquid, bp 85–95° (2.5 mm), the ^{1}H NMR spectrum of which showed the material to consist of maleate (65%) and succinate (35%). This ratio was confirmed by VPC methods and comparison with undeuterated authentic samples.

A 2.38-g sample of this mixture was heated at reflux with 40 ml of 10% aqueous potassium hydroxide for 4 hr. The pH of the cooled solution was adjusted to 5 with concentrated hydrochloric acid. Continuous ether extraction (14 hr) furnished 30 mg of succinic acid, mp 182–186°. The pH was now adjusted to 3 and continuous ether extraction was resumed (2 days). From the dried organic extracts, there was obtained 800 mg of pale yellow solid, mp 120–180°. Adjustment to pH 1 and final extraction afforded 1.0 g (80% based upon estimate of 4 originally present) of maleic acid-*2,3-d*$_2$, mp 132–134.5°. Recrystallization from ether with charcoal decolorization gave pure product, mp 137–138°.

Tricyclo[3.2.2.0^{2,4}]nona-6,8-diene-*6,7-d*$_2$ (6). A mixture of maleic acid-*2,3-d*$_2$ (640 mg, 5.42 mmol), 10.0 g (0.108 mol) of distilled cycloheptatriene, and 10 ml of xylene was carefully heated to reflux (foaming!) in a 100-ml round-bottomed flask fitted with a Dean-Stark trap. After 1 day at 120°, the solvent was evaporated under reduced pressure. The residual anhydride (5) and 2.0 g of sodium carbonate in 50 ml of water were heated to reflux for 1 hr, cooled, adjusted to pH 6, and evaporated in vacuo. Of the 4.57 g of residue obtained in this manner, 4.2 g was dissolved in a small amount of hydrochloric acid (pH 1) and the volume reduced under reduced pressure until crystals began to form. The entire mixture was then extracted with ether (2 × 200 ml) to give 560 mg (49%) of crude diacid, mp 159–167° (with gas evolution).

This diacid (560 mg, 2.66 mmol) was dissolved in 100 ml of 10% aqueous pyridine containing 1.25 ml of triethylamine and the solution was electrolyzed at 100 V and 7–19° for 3 hr. The resulting brown solution was poured into 200 ml of water and extracted with pentane (5 × 100 ml). The combined pentane extracts were washed with 5% hydrochloric acid (4 × 50 ml) and saturated sodium carbonate solution (100 ml), dried, and reduced in volume to 2 ml by careful fractional distillation. The hydrocarbon product was isolated by preparative VPC on a 6 ft × 0.25 in. 10% FFAP column (105°). There was obtained 30 mg (9.4%) of 6: δ_{Me_4Si} (CCl_4) 6.50–6.67 (m, 0.10 H, residual H_6, H_7), 5.82–6.12 (m, 2, H_8, H_9), 3.45–3.75 (m, 2, H_1, H_5), 0.98–1.32 (m, 2, H_2, H_4), and 0.28–0.78 (m, 2, H_3); MS *m/e* 121 (3.8), 120 (41.8), 119 (100.0), 118 (34.3), and 117 (19.7).

Addition of Chlorosulfonyl Isocyanate to 1 with Stirring for 5 Hr. A SOLUTION OF 45] MG (3.81 mmol) of 1 in 10 ml of dry dichloromethane was stirred at 20° under nitrogen while 5.40 mg (3.81 mmol) of freshly distilled chlorosulfonyl isocyanate in 1 ml of the same solvent was introduced via syringe. After 5 hr, 50 ml of anhydrous ether was added and the solution maintained at 5° while 10 ml of 25% aqueous sodium sulfite and 1 ml of 10% potassium hydroxide solution were slowly added. After 1 hr at room temperature, the organic phase was separated and combined with an ether extract of the residual aqueous solution. After being washed successively with water (50 ml), 2% hydrochloric acid (50 ml), saturated sodium bicarbonate solution (50 ml), brine (50 ml), and water, the organic layer was dried and evaporated to leave 160 mg of pale yellow oil. Chromatographic separation was achieved on silica gel (Baker) using incrementally higher percentages of ethyl acetate in hexane as eluent.

The first substance to elute proved to be lactone **7** (14 mg, 2.3%), which was obtained as white crystals, mp 88.5–89.5°, after sublimation (50°, 0.02 mm) and recrystallization from ether–pentane: ν_{max} ($CHCl_3$) 1775 cm^{-1}; δ_{Me_4Si} ($CDCl_3$) 4.55–4.75 (m, 1, >CHO–), 2.85–2.98 (m, 1, >CHCO–), 2.52–2.79 (m, 1, bridgehead), 1.60–2.20 (m, 3, tertiary cyclopropyls), 0.77–1.52 (m, 2, tertiary cyclopropyls), 0.46–0.72 (m, 1, anti secondary cyclopropyl), and 0.12 to −0.17 (m, 1, syn secondary cyclopropyl).

Anal. Calcd for $C_{10}H_{10}O_2$: C, 74.06; H, 6.22. Found: C, 73.88; H, 6.23.

The second substance isolated was β-lactam **8** (20 mg, 3.2%), white crystals, mp 150–151°, after sublimation (80°, 0.02 mm) and recrystallization from ether: ν_{max} ($CHCl_3$) 3250 and 1747 cm^{-1}; δ_{Me_4Si} ($CDCl_3$) 6.33 (br s, 1, >NH), 5.77–6.05 (m, 2, olefinic), 3.44–3.68 (m, 1, >CHN<), 2.85–3.23 (m, 3, >CHCO– and bridgeheads), 0.77–1.42 (m, 2, tertiary cyclopropyls), and 0.02–0.33 (m, 2, secondary cyclopropyls); *m/e* (calcd) 161.0841, (obsd) 161.0843.

The ΔEu values as determined with $Eu(dpm)_3$ in $CDCl_3$ solution follow: H_1 (−2.8), H_2, (−6.5), H_3 (−11.7), H_5 (−15.6), H_6 (−9.5), H_7 (−11.8), H_{8a} (−2.7), H_{8b} (−1.4), H_9 (−3.7), H_{10} (−2.7), and H_{11} (−3.8).

Anal. Calcd for $C_{10}H_{11}NO$: C, 74.51; H, 6.88. Found: C, 74.44; H, 6.89.

The third component was identified as β-lactam **9** (51 mg, 8.3%), white crystals, mp 111.5–112.5°, from ether–pentane: ν_{max} ($CHCl_3$) 1745 cm^{-1}; δ_{Me_4Si} ($CDCl_3$) 6.45 (br s, 1, >NH), 5.62 (m, 2, olefinic), 3.40–365 (m, 1, >CHN<), 3.12–3.33 (m, 1, >CHCO–), 2.73–3.10 (m, 2, bridgehead), 0.60–1.00 (m, 2, tertiary cyclopropyl), and 0.05–0.33 (m, 2, secondary cyclopropyl).

The ΔEu values as determined with $Eu(fod)_3$ in $CDCl_3$ solution follow: H_1 (−1.5), H_2 (−2.7), H_3 (−6.4), H_5 (−7.7), H_6 (−5.2), $H_{7,9}$ (−1.8), H_{8a}, H_{8b} (−1.3), H_{10} (−1.4), and H_{11} (−3.2).

Anal. Calcd for $C_{10}H_{11}NO$: C, 74.51; H, 6.88; N, 8.69. Found: C, 74.70; H, 6.85; N, 8.53.

The last product eluted was characterized as γ-lactam **10** (16 mg, 2.6%), colorless crystals, mp 134–135°, from ether: ν_{max} ($CHCl_3$) 1700 cm^{-1}; δ_{Me_4Si} ($CDCl_3$) 7.00 (br s, 1, >NH), 3.28 (br s, 1, >CHN<), 2.40 (br s, 1, >CHCO–), 2.13 (m, 1, bridgehead), 1.45–1.83 (m, 1, tertiary cyclopropyl), 1.18–1.43 (m, 2, tertiary cyclopropyl), 0.42–1.18 (m, 2, tertiary cyclopropyl), 0.02–0.38 (m, 1, secondary cyclopropyl), and −0.08 to −0.37 (m, 1, secondary cyclopropyl).

The ΔEu values as determined with $Eu(fod)_3$ in $CDCl_3$ solution follow: H_1, H_{10} (−2.1), H_2 (−4.7), H_3 (−3.0), H_4 (−11.1), H_6 (−10.8), H_7 (−5.1), H_8, H_9 (−1.9), H_{11anti} (−1.3), and H_{11syn} (−1.6).

Anal. Calcd for $C_{10}H_{11}NO$: C, 74.51; H, 6.88; N, 8.69. Found: C, 74.53; H, 6.85; N, 8.69.

Cyclopropanation of Benzobarrelene (11). A solution of benzobarrelene (**11**, 3.47 g, 22.5 mmol)[25] in 50 ml of anhydrous ether containing 7.0 ml (70 mmol) of diethylzinc was stirred mechanically under a dry nitrogen atmosphere at room temperature while 6.20 g (25.0 mmol) of diiodomethane in 10 ml of dry benzene was introduced dropwise. Upon completion of the addition, the mixture was heated at reflux for 10 hr. An additional 4.0 g (15.0 mmol) of diiodomethane in 5 ml of benzene was again added and heating was continued for 24 hr. Hydrochloric acid (5%, 50 ml) was slowly introduced with ice cooling and the hydrolyzed reaction mixture was poured into 300 ml of ether. The organic phase was washed with 5% hydrochloric acid and these washings were extracted with ether. The combined organic layers were shaken with saturated sodium carbonate (300 ml) and sodium chloride solutions (300 ml), dried, and evaporated to leave 4.15 g of yellow oil.

This oil was chromatographed on silica gel–silver nitrate (10%); elution was performed with increasing amounts of ether in hexane. The first component to elute was identified as *syn,syn*-9,10-benzoquadricyclo[3.3.2.$0^{2,4}$.$0^{6,8}$]dec-9-ene (**13**, 130 mg, 3.2%). Sublimation (70°, 50 mm) afforded colorless needles: mp 129–130°; ν_{max} (CCl_4) 3020, 3005, and 2938 cm^{-1}; δ_{Me_4Si} ($CDCl_3$) 6.75–7.25 (AA'BB', 4, aromatic), 3.47 (five-line m, 2, bridgehead), 1.08–1.53 (m, 4, tertiary cyclopropyl), 0.13 (d of t, J_{gem} = 5.6 Hz, J_{cis} = 7.4 Hz, 2, anti secondary cyclopropyl), and −0.77 (d of t, J_{trans} = 3.8 Hz, 2, syn secondary cyclopropyl); *m/e* (calcd) 182.1095, (obsd) 182.1098.

Anal. Calcd for $C_{14}H_{14}$: C, 92.26; H, 7.74. Found: C, 92.02; H, 7.81.

The next hydrocarbon proved to be bis adduct **12**, rhombic crystals (from hexane) which were isolated in 6.1% yield (250 mg). Sublimation (70°, 50 mm) gave material of mp 91–92°; ν_{max} (CCl_4) 3075, 3010, and 2930 cm^{-1}; δ_{Me_4Si} ($CDCl_3$) 7.04 (narrow m, 4, aromatic), 3.37 (five-line m, 2, bridgehead, 1.79) (six-line m, 1, secondary cyclopropyl), 0.53–1.27 (m, 5, one secondary and four tertiary cyclopropyl), −0.27 (d of t, J_{gem} = 5.5, J_{cis} = 7.2 Hz, 1, secondary cyclopropyl), and −1.05 (d of t, J_{trans} = 3.8 Hz, 1, secondary cyclopropyl); *m/e* (calcd) 182.1095, (obsd) 182.1098.

Anal. Calcd for $C_{14}H_{14}$: C, 92.26; H, 7.74. Found: C, 92.23; H, 7.76.

The third component was a colorless oil (1.12 g, 29.6%) identified as *anti*-6,7-benzotricyclo[3.2.2.$0^{2,4}$]nona-6,8-diene (**3**): δ_{Me_4Si} ($CDCl_3$) 6.87–7.38 (m, 4, aromatic), 5.97–6.30 (m, 2, olefinic), 3.80–4.12 (m, 2, bridgehead), 1.03–1.40 (m, 2, tertiary cyclopropyl), and 0.38–0.95 (m, 2, secondary cyclopropyl).

Anal. Calcd for $C_{13}H_{12}$: C, 92.81; H, 7.19. Found: C, 92.45; H, 7.20.

The last product was the corresponding syn isomer (270 mg, 7.1%) which likewise was a colorless oil: δ_{Me_4Si} ($CDCl_3$) 6.92–7.08 (narrow m, 4, aromatic), 6.68–6.90 (m, 2, olefinic), 3.82–4.20 (m, 2, bridgehead), 1.23–1.60 (m, 2, tertiary cyclopropyl), 0.18–0.58 (m, J_{cis} = 7 Hz, 1, secondary cyclopropyl), and −0.26 to −0.53 (d of t, J_{gem} = 5.8, J_{trans} = 3.8 Hz, 1, secondary cyclopropyl).

Anal. Calcd for $C_{13}H_{12}$: C, 92.81; H, 7.19. Found: C, 93.06; H, 7.21.

Finally, 1.45 g (41.8%) of benzobarrelene was recovered unchanged.

Addition of Chlorosulfonyl Isocyanate to 2. To a solution of **2** (300 mg, 1.78 mmol) in 6.0 ml of dry dichloromethane was added with stirring under nitrogen 257 mg (1.82 mmol) of freshly distilled chlorosulfonyl isocyanate via syringe. The mixture was maintained at 25° for 72 hr before dilution with ether (20 ml) and introduction at 0° of 25% sodium sulfite solution (5 ml) and 10% potassium hydroxide (0.5 ml) followed by 10 ml of water. After 30 min at room temperature, the contents were poured into ether (100 ml) and the organic phase was washed with 5% hydrochloric acid (25 ml), saturated sodium carbonate (50 ml), and saturated brine solutions (50 ml). The organic layer was dried and evaporated to leave a yellow oil (409 mg) which was chromatographed on silica gel (elution with increasing amounts of ether in hexane).

Initially, there was recovered 60 mg (20%) of **2**. This was followed by β-lactam **14** (60 mg, 16.0%) which was obtained as small white needles: mp 238–239° (from ether–hexane); ν_{max} ($CHCl_3$) 1748 cm^{-1}; δ_{Me_4Si} ($CDCl_3$) 6.87–7.30 (m, 4, aromatic), 6.37 (br s, 1, >NH), 3.37–3.90 (m, 3, >CHN< and bridgeheads), 2.98–3.28 (m, 1, >CHCO–), 1.67–1.83 (m, 2, tertiary cyclopropyl), −0.12 to 0.28 (m, 1, secondary cyclopropyl), and −0.68 to −0.93 (m, 1, secondary cyclopropyl).

The ΔEu values as determined with $Eu(fod)_3$ in $CDCl_3$ solution follow: H_1, −2.0; H_2, −4.0; >NH, −8.0; H_5, −9.9; H_6, −6.2; H_7, −6.6; H_{8a}, −0.9; H_{8b}, −0.2; H_9, −2.4; H_{12}, −2.2; and H_{13-15}, −1.5.

Anal. Calcd for $C_{14}H_{13}NO$: C, 79.59; H, 6.20; N, 6.63. Found: C, 79.22; H, 6.37; N, 6.71.

The second product to elute was found to be β-lactam **15** (15 mg, 4.0%), off-white crystals: mp 164.5–166° (from ether); ν_{max} ($CHCl_3$) 1752 cm^{-1}; δ_{Me_4Si} ($CDCl_3$) 6.80–7.38 (m, 4, aromatic), 5.43 (br s, 1, >NH), 3.77–4.06 (m, 1, >CHN<), 3.38–3.72 (m, 3, >CHCO– and bridgeheads), 1.00–1.37 (m, 2, tertiary cyclopropyl), 0.07–0.47 (m, 1, secondary cyclopropyl), and −0.45 to −0.70 (m, 1, secondary cyclopropyl); *m/e* (calcd) 211.0997, (obsd) 211.1000.

The ΔEu values as determined with $Eu(fod)_3$ in $CDCl_3$ solution follow: H_1, −1.9; H_2, −2.5; >NH, −6.0; H_5, −7.5; H_6, −5.3; H_7; −2.5; H_{8a}, −1.4; H_{8b}, −1.9; H_9, −1.9; H_{12}, −3.5; and H_{13-15}, −1.3.

Lastly, there was isolated 5 mg (1.3%) of **16** as white needle clusters: mp 170.5–171° (from ether); ν_{max} ($CHCl_3$) 1700 cm^{-1}; δ_{Me_4Si} ($CDCl_3$) 6.80–7.32 (m, 4, aromatic), 6.22 (br, s, 1, >NH), 4.15–4.33 (m, 2, >CHCO– and >CHN<), 3.55–3.93 (m, 2, bridgehead), 0.8–0.9 (m, 1, tertiary cyclopropyl), 0.4–0.7 (m, 1, tertiary cyclopropyl),

−0.1 to 0.1 (m, 1, secondary cyclopropyl), and −0.5 to −0.7 (m, 1, secondary cyclopropyl); *m/e* (calcd) 211.0997, (obsd) 211.1000.

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Registry No.—**1**, 7092-05-9; **2**, 56960-48-6; **3**, 57029-75-1; **4**, 41411-75-0; **6**, 57029-76-2; **7**, 56960-49-7; **8**, 56960-50-0; **9**, 57029-77-3; **10**, 56960-51-1; **11**, 7322-47-6; **12**, 56960-52-2; **13**, 57029-78-4; **14**, 56960-53-3; **15**, 57029-79-5; **16**, 56960-54-4; maleic acid-2,3-d_2, 24461-33-4; dimethyl acetylenedicarboxylate, 762-42-5; succinic acid, 110-15-6; cycloheptatriene, 544-25-2; diacid, mp 159–167°, 57029-80-8; chlorosulfonyl isocyanate, 1189-71-5; diiodomethane, 75-11-6.

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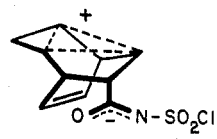

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Direct Determinations of *R/S* Enantiomer Ratios of Citronellic Acid and Related Substances by Nuclear Magnetic Resonance Spectroscopy and High Pressure Liquid Chromatography

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Two methods are described for direct determination of the enantiomer ratios of optically active 3,7-dimethyl-6-octenoic acid (citronellic acid), 3,7-dimethyloctanoic acid, and the homologous 3,7,11-trimethyldodecanoic acid. The first method is based on analysis of the C_3 methyl signal in the NMR spectra of methyl esters obtained in CS_2 in the presence of a chiral europium shift reagent. The second method is based on analytical separations by high pressure liquid chromatography of diastereomeric amides obtained by reaction of (*R*)-(+)-α-methyl-*p*-nitrobenzylamine with, e.g., citronellic acid. Both methods give directly *R/S* enantiomer ratios on samples of citronellic acid and epimer ratios on 3,7,11-trimethyldodecanoic acid. Using these methods citronellic acid samples from natural citronellal and (+)-pulegone have been shown to be respectively 80 and 96–98% excesses of the (3*R*)-(+) enantiomer.

Citronellal is a relatively inexpensive chiral substance which is found in over 50 essential oils,[1] typically as a mixture of *R* and *S* enantiomers with one predominating. Citronellal obtained from its most important source, Java citronella oil,[2] has been assigned the (3*R*)-(+)-1 configuration[3] but is known to be only about 75% optically pure.[4,5] This paper describes two convenient methods for direct determination of the enantiomeric composition of citronellic acid (**2**) which is readily derived from citronellal. One method involves analysis of NMR spectra of **3** obtained in the presence of the chiral shift reagent Eu(dcm)$_3$, **4**.[6] The other involves analytical separation by high pressure liquid chromatography of diastereomeric amides **6** obtained from reaction of **5** with excess (*R*)-(+)-α-methyl-*p*-nitrobenzylamine.[7]

Both methods have been used to determine the enantiomeric compositions of samples of **2** and **7** obtained from racemic citronellol, from natural citronellal having $[\alpha]^{25}D$