absorption at 227 nm had disappeared. Filtration and evaporation gave 203 mg (100% yield) of a white crystalline solid that proved to be identical with guanidine hydrochloride by TLC and ^{13}C NMR (δ 157.8).

When the hydrogenation was conducted in 1 N HCl no reaction was observed after shaking for 21 h at room temperature. The reaction mixture was then heated at 60 °C for 43 h at which point the UV absorption had disappeared. Filtration and evaporation of the solvent gave only guanidine hydrochloride. A duplicate reaction using 0.1 N HCl gave similar results.

Hydrogenation of Creatinine Hydrochloride (3) in D_2O. [4,5-$^2H_4$]-2-Imino-1-methyl-imidazolidine Hydrochloride (23). Creatinine hydrochloride (**3**, 373 mg, 2.5 mmol) was placed in an hydrogenation bottle and exchanged four times with D_2O by dissolution and evaporation. To this was then added PtO_2 (342 mg, 1.25 mmol) and D_2O (50 mL, 99.8% d), and the resultant mixture was hydrogenated as before for 26 h. After filtration and evaporation, 319 mg (89%) of a white crystalline solid was obtained: ^1H NMR δ 2.95 (s). The product was exchanged several times with water as before: MS *m/e* 104 (M^+ − HCl). A picrate was prepared in the same manner as for the nondeuterated compound **4** and showed the same melting point at 195–196 °C.

Hydrogenation of Pyrrolidinone (20). Pyrrolidinone (**20**, 213 mg, 2.5 mmol) and PtO_2 (342 mg, 1.25 mmol) were hydrogenated as before in 1 N HCl (50 mL). No reaction was apparent by ^1H NMR after 47 h at room temperature. The reaction was then heated at 60°C as described above for 88 h, after which time ^1H NMR and ^{13}C NMR (see below) showed the starting pyrrolidinone to be gone, and in its place a new product which, after filtration and evaporation, appeared as a crystalline solid: mp 133–135 °C; ^1H NMR pyrrolidinone δ 3.5 (5, t H), 2.2 (m, 4 H); hydrogenation product δ 3.0 (t, 2 H), 2.5 (t, 2 H), 2.0 (q, 2 H); ^{13}C NMR hydrogenation product δ 177.6 (s), 38.8 (t), 31.2 (t), 22.2 (t).

By comparison of melting points and NMR with that of an authentic sample, the product recovered from the hydrogenation reaction was established as γ-aminobutyric acid hydrochloride (**21**).

Registry No.—**3**, 19230-81-0; **4**, 67316-70-5; DL-**5a**, 302-72-7; L-**5a**, 56-41-7; **5b**, 63-91-2; DL-**6a**, 67337-40-0; L-**6a**, 1758-74-3; **6b**, 13551-04-7; **7a**, 67316-71-6; **7b**, 67316-72-7; **8a**, 67316-73-8; **9**, 15231-28-4; **10**, 26893-39-0; **18**, 5699-40-1; **18** HCl, 39270-72-9; **20**, 616-45-5; **23** HCl, 67316-74-9; **23** picrate, 67316-76-1; *S*-methylisothiourea sulfate, 867-44-7; β-alanine, 107-95-9.

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Synthesis of 1-Substituted Tricyclo[3.3.1.0^{2,7}]nonanes

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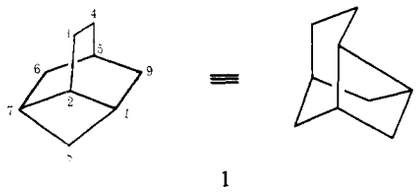
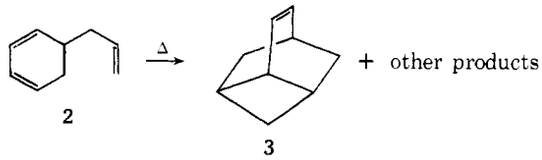
1-Acetyltricyclo[3.3.1.0^{2,7}]non-3-ene (**15**) has been prepared by a five-step reaction sequence from 3-*endo*-carboxybicyclo[3.3.1]non-6-ene. The skeletal framework of **15** follows from its conversion to the parent hydrocarbon, tricyclo[3.3.1.0^{2,7}]nonane. Alternative conditions for the epimerization of 3-*endo*-acetylbicyclo[3.3.1]non-6-ene have been determined.

Although the synthesis of tricyclo[3.3.1.0^{2,7}]nonane (**1**) has not been reported previously, two independent routes leading to compounds which contain this carbon skeleton are

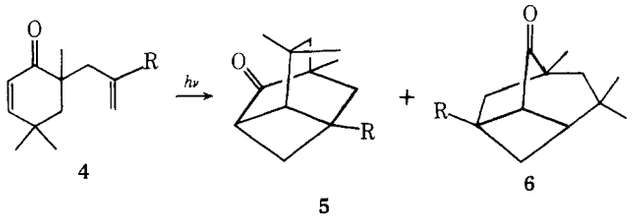


1

known. In 1967 Krantz noted that pyrolysis of 5-allylcyclohexa-1,3-diene (**2**) at 225 °C gives tricyclo[3.3.1.0^{2,7}]non-3-ene (**3**) as well as 1-allylcyclohexa-1,3-diene, 2-allylcyclohexa-1,3-diene, benzene, and recovered starting material.[2] Through labeling studies it was established that **3** is formed from **2** at 184 °C by a [4 + 2] cycloaddition mechanism.[3] At higher temperatures at least one other mechanistic pathway becomes competitive.[3] More recently, Fröstl and Margaretha have found that irradiation of various 6-allyl-4,4,6-trimethyl-2-cyclohexenones (**4**) gives mixtures of the isomeric tricyclononanones **5** and **6**.[4] The product ratio depends on the substituent R of the allylic side chain and is somewhat influenced by the solvent.[4] We now wish to report an alternative synthesis of the tricyclo[3.3.1.0^{2,7}]nonane skeleton which permits the



2 **3**



4 **5** **6**

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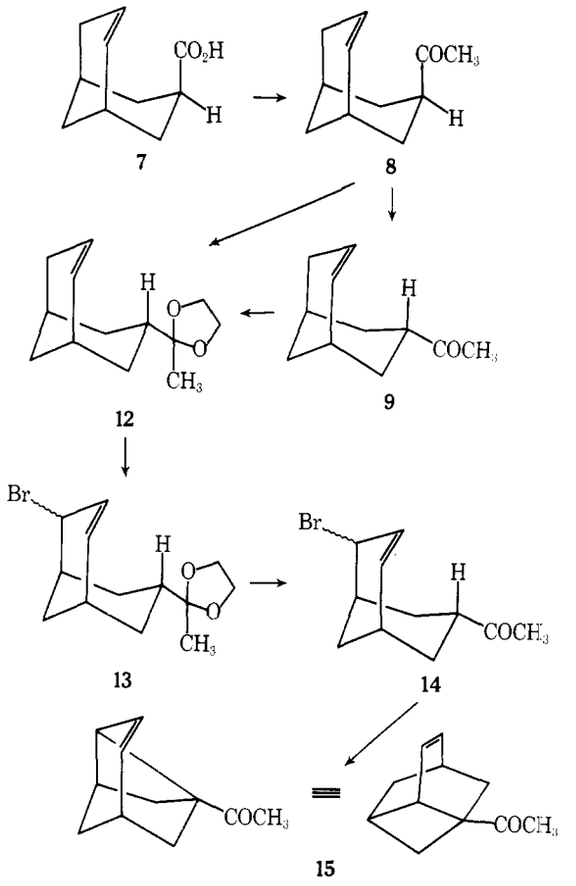
Scheme I

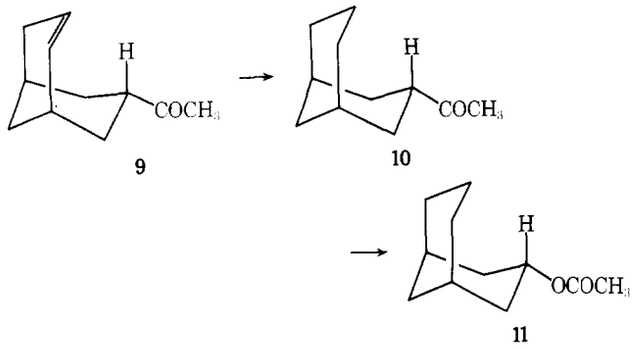


introduction of a variety of substituent groups at C-1. In the course of this study, we have also prepared the parent hydrocarbon 1.

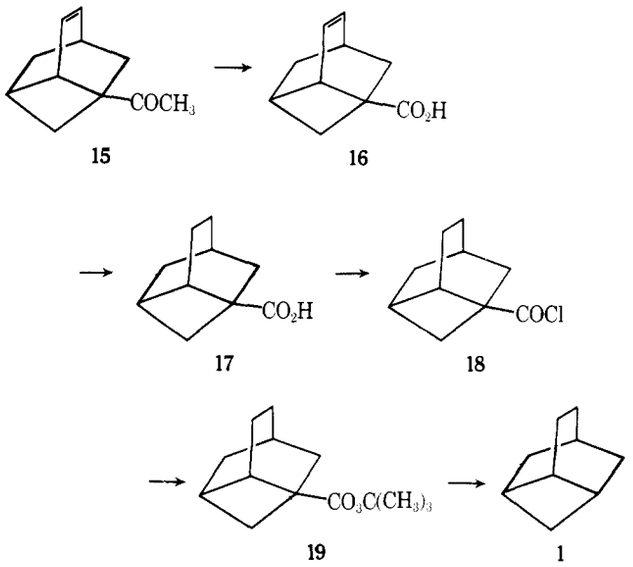
Results and Discussion

By inspection, it is apparent that 1 can be viewed as a "dehydro"bicyclo[3.3.1]nonane. Consequently, 3-*endo*-carboxybicyclo[3.3.1]non-6-ene (7), an acid which can readily be prepared from commercially available 2-adamantanone,[5] was selected as starting material. The sequence of reactions leading from 7 to 1-acetyltricyclo[3.3.1.0^{2,7}]non-3-ene (15) is summarized in Scheme I.[6]

Treatment of 7 with methyllithium provides 3-*endo*-acetylbicyclo[3.3.1]non-6-ene (8). Epimerization of 8 to ketone 9 can be accomplished under a variety of conditions: by refluxing 8 with a trace of *p*-toluenesulfonic acid in benzene, by treating 8 with potassium *tert*-butoxide in *tert*-butyl alcohol, or by heating 8 at 200–205 °C in a sealed ampule. As might be expected, the spectral properties of 8 and 9 are strikingly similar. However, they are readily differentiated as the olefinic protons of 9 are shifted downfield ca. 0.3 ppm relative to the olefinic protons of 8. The skeletal framework of 9 and the



Scheme II



skeletal position and stereochemistry of the acetyl group in 9 were firmly established by its conversion to the previously reported 3-*exo*-acetoxybicyclo[3.3.1]nonane[7] (11). Catalytic hydrogenation of 9 gives 3-*exo*-acetylbicyclo[3.3.1]nonane[8] (10) and Baeyer–Villiger oxidation of 10 with *m*-chloroperbenzoic acid provides 11.

In order to carry out bond formation between C-3 and C-8 in 9, it was necessary to introduce an appropriate leaving group at C-8. Since attempts to affect direct allylic bromination of 9 only led to complex reaction mixtures, the ketone was first converted to the corresponding ethylene ketal 12.[9] Reaction of 12 with *N*-bromosuccinimide under free-radical conditions provides bromo ketal 13 in quantitative yield and treatment of this ketal with dilute acid in acetone gives the desired 7-*exo*-acetyl-4-bromobicyclo[3.3.1]non-2-ene (14). Reaction of 14 with potassium *tert*-butoxide in *tert*-butyl alcohol proceeds smoothly to provide 15 as the only volatile product. By this sequence of reactions, 15 was obtained from acid 7 in an overall isolated yield of 28%.

In order to firmly establish the carbon skeleton of 15, it was converted to the parent hydrocarbon, tricyclo[3.3.1.0^{2,7}]-nonane (1), by the sequence of reactions summarized in Scheme II. Oxidation of methyl ketone 15 with sodium hypobromite gives 1-carboxytricyclo[3.3.1.0^{2,7}]non-3-ene (16) in quantitative yield. The infrared spectrum of 16 shows a broad absorption from 3500 to 2750 cm^{-1} and a carbonyl absorption at 1695 cm^{-1}. The ^{13}C NMR spectrum of 16 contains ten carbon resonances and features singlets at δ 181.9 and 46.1 which are assigned to the carboxylate carbon and the quaternary carbon at C-1, respectively. Catalytic hydrogenation of 16 affords the corresponding saturated acid 17 in 95% yield. Treatment of the sodium salt of 17 with oxalyl chloride provides 18. The acid chloride was not purified but rather was reacted immediately with *tert*-butyl hydroperoxide to give *tert*-butyl perester 19. Subsequent pyrolysis of the perester at 155 °C by the method of Langhals and Ruechardt[10] gives 1 in an overall isolated yield of 16% from acid 17. Consistent with the presence of a plane of symmetry in 1, the ^{13}C NMR spectrum of 1 contains only seven signals. Moreover, one of the four signals for methylene carbons is twice as intense as the others and one of the three signals for methine carbons is twice as intense as the others.

In view of the numerous reported transformations of 1-carboxyadamantane,[11] it is apparent that acids 16 and 17 offer convenient entry points for the preparation of a variety of bridgehead substituted tricyclo[3.3.1.0^{2,7}]nonanes.

Experimental Section

Melting points were obtained in sealed capillary tubes using a Thomas-Hoover melting point apparatus and are uncorrected. Infrared spectra were obtained on Perkin-Elmer 180 or 337 spectrophotometers. Proton magnetic resonance spectra were recorded with Varian A-60A or Perkin-Elmer R-12B 60 MHz spectrometers and are referenced to an internal standard of tetramethylsilane. Apparent splittings are reported in all cases. Carbon magnetic resonance spectra were taken at an operating frequency of 22.63 MHz on a Brüker HFX-90 spectrometer equipped for Fourier transform pulsed NMR with a Nicolet 1085 data acquisition system and are referenced to an internal standard of tetramethylsilane. Elemental analyses were performed by Microanalysis, Inc., Wilmington, Del.

3-*endo*-Acetylbicyclo[3.3.1]non-6-ene (8). An ethereal solution of methyllithium (80 mL of a 1.65 M solution, ca. 132 mmol) was added dropwise to a vigorously stirred solution of 3-*endo*-carboxybicyclo[3.3.1]non-6-ene[5] (9.8 g, 59 mmol) in anhydrous ether at 0 °C at such a rate that the temperature of the reaction mixture did not exceed 5 °C. Following this addition, the reaction was stirred at 0 °C for 30 min and at room temperature for 4 h. The reaction was quenched by slowly pouring the reaction mixture into a saturated solution of ammonium chloride. The aqueous layer was separated and extracted with ether (4 × 50 mL). The combined ether layers were washed with 5% aqueous sodium bicarbonate (4 × 50 mL; acidification of the combined basic washes afforded a 300 mg recovery of unreacted starting material) and water (2 × 50 mL) and then dried over anhydrous magnesium sulfate. Evaporation of the solvent at reduced pressure provided a yellow liquid. Vacuum distillation of this material gave 7.9 g (84% yield) of ketone 8 as a colorless liquid: bp 70–73 °C (0.5 mm); ^{1}H NMR ($CDCl_3$) δ 5.71–5.18 (br m, 2 H, –CH=CH–) and 2.68–1.28 (br m, 14 H, containing an acetyl methyl singlet at δ 2.05); ^{13}C NMR ($CDCl_3$) δ 211.1 (C=O), 131.4 (C-6 or C-7), 131.2 (C-6 or C-7), 46.3 (C-3), 33.1 (t), 32.9 (t), 31.7 (t), 31.1 (t), 29.8 (C-1 or C-5), 28.7 (CH_3), and 27.5 (C-1 or C-5); ν (CCl_4) 3020, 2925, 2905, 2855, 1704, 1430, 1350, 1210, 1190, 1170, and 1105 cm^{-1}.

The semicarbazone derivative of 8 was prepared according to the procedure outlined by Fieser,[12] mp 209–210 °C.

Anal. Calcd for $C_{12}H_{19}N_3O$: C, 65.13; H, 8.65; N, 18.99. Found: C, 64.89; H, 8.87; N, 18.87.

3-*exo*-Acetylbicyclo[3.3.1]non-6-ene (9). A. A stirred solution of 8 (2.0 g, 6.1 mmol) and *p*-toluenesulfonic acid monohydrate (150 mg) in benzene (200 mL) was heated at reflux for 48 h. The reaction mixture was then cooled to room temperature and diluted with ether (100 mL). The resulting soltuion was washed successively with 5% aqueous sodium bicarbonate (4 × 25 mL), water (2 × 25 mL), and saturated aqueous sodium chloride (25 mL) and then dried over anhydrous magnesium sulfate. Evaporation of the solvent at reduced pressure afforded a viscous yellow liquid which was purified by vacuum distillation to give 9 (1.34 g, 67% yield) as a colorless liquid. Further purification of 9 by GLC (5 ft × 0.25 in. Carbowax column, 225 °C) provided an analytical sample: ^{1}H NMR ($CDCl_3$) δ 6.10–5.57 (br m, 2 H, –CH=CH–) and 3.19–1.00 (br m, 14 H, containing an acetyl methyl singlet at δ 2.10); ^{13}C NMR δ ($CDCl_3$) 213.7 (C=O), 131.7 (C-6 or C-7), 130.8 (C-6 or C-7), 45.1 (C-3), 36.8 (t), 33.6 (t), 32.9 (C-1 or C-5), 32.2 (t), 30.3 (C-1 or C-5), 29.2 (CH_3), and 28.0 (t); ν (CCl_4) 3025, 2930, 2905, 2855, 2835, 1710, 1455, 1435, 1350, 1285, 1240, 1235, and 1170 cm^{-1}.

Anal. Calcd for $C_{11}H_{16}O$: C, 80.44; H, 9.82. Found: C, 80.58; H, 9.64.

Ketone 9 was recovered unchanged when it was submitted to the identical reaction conditions previously employed for 8 → 9.

B. A neat sample of 8 (175 mg, 1.1 mmol) was heated at 200–205 °C in a sealed ampule for 24 h. The infrared and ^{1}H NMR spectra of the crude product were identical with those previously obtained for 9 which had been generated by the acid-catalyzed epimerization of ketone 8. Particularly diagnostic for 8 vs. 9 is the chemical shift of the olefinic protons in the ^{1}H NMR spectra of these ketones which appear at δ 5.71–5.18 in 8 and at δ 6.10–5.57 in 9. Ketone 8 was recovered unchanged when it was heated at 100 °C for 24 h. On the other hand, ^{1}H NMR analysis of the crude reaction product obtained from heating 8 at 125 °C for 36 h indicated a ca. 1:1 ratio of 8 and 9.

C. A solution of 8 (200 mg, 1.2 mmol) in anhydrous *tert*-butyl alcohol (10 mL) was added dropwise to a freshly prepared solution of potassium (75 mg, 1.92 mmol) in anhydrous *tert*-butyl alcohol (75 mL). The resulting solution was stirred at room temperature for 12 h. The reaction mixture was then poured into a slurry of ice and water (500 mL) and extracted with pentane (4 × 100 mL). The combined pentane extracts were dried over anhydrous magnesium sulfate. Evaporation of the solvent at reduced pressure provided a pale yellow liquid (90 mg). Examination of both the ^{1}H NMR and IR spectra of the crude product indicated that complete epimerization had occurred to give 9.

3-*exo*-Acetylbicyclo[3.3.1]nonane (10). A. A mixture of 9 (250 mg, 1.5 mmol), 10% palladium on charcoal (25 mg), and ethanol (10 mL) was stirred under an atmosphere of hydrogen at room temperature for 25 h. At this point the catalyst was removed by suction filtration through Celite. Evaporation of the solvent from the filtrate at reduced pressure gave crude 10 (242 mg, 96% yield) as a colorless liquid. GLC analysis (10 ft × 0.25 in. SE-30 column, 175 °C) indicated the presence of a single component. Purification by GLC (above conditions) afforded an analytical sample of 10: ^{1}H NMR ($CDCl_3$) δ 3.42–2.70 (br m, 1 H, CHCOCH$_3$) and 2.16–1.35 (br m, 17 H, which contains an acetyl methyl singlet at δ 2.08); ν (CCl_4) 2930, 2860, 1710, 1465, 1440, 1350, 1295, 1245, 1235, and 1165 cm^{-1}.

Anal. Calcd for $C_{11}H_{18}O$: C, 79.46; H, 10.91. Found: C, 79.42; H, 11.01.

B. A neat sample of 20 (100 mg, 0.6 mmol) was heated at 200–205 °C in a sealed ampule for 24 h. Vacuum distillation of the crude product with a molecular still provided 10 (65 mg, 65% yield) as a colorless oil. The IR spectrum of this material was identical with that of 10 obtained by procedure A.

3-*exo*-Acetoxybicyclo[3.3.1]nonane (11). A solution of ketone 10 (100 mg, 0.6 mmol) in chloroform (3 mL) was added to a stirred solution of 85% *m*-chloroperbenzoic acid (500 mg, ca. 2.4 mmol) in chloroform (20 mL) and the reaction mixture was stirred at room temperature for 24 h. At this point the excess peracid present was destroyed by the addition of 10% aqueous sodium sulfite solution until a negative starch–iodide test was obtained. The reaction mixture was then diluted with ether (100 mL) and washed with 5% aqueous sodium bicarbonate (4 × 25 mL) and water (2 × 10 mL). The organic layer was dried over anhydrous magnesium sulfate and the solvent was evaporated at reduced pressure to give 108 mg (100% yield) of crude 11. Purification by GLC (10 ft × 0.25 in. SE-30 column, 200 °C) afforded pure acetate 11 as a colorless liquid. The IR and ^{1}H NMR spectra of this material were identical with those previously reported for 11.[7]

3-*exo*-Acetylbicyclo[3.3.1]non-6-ene Ethylene Ketal (12). A mixture of 8 (8.28 g, 50.4 mmol), ethylene glycol (3.76 g, 60.5 mmol), *p*-toluenesulfonic acid monohydrate (400 mg), and anhydrous benzene (180 mL) was stirred at reflux under a nitrogen atmosphere for 36 h. During this time, the water generated by the reaction was collected in a Dean-Stark trap. The reaction was cooled to room temperature and washed with 10% aqueous sodium hydroxide (3 × 50 mL), water (4 × 25 mL), and saturated sodium chloride (25 mL). After the organic layer had been dried over anhydrous magnesium sulfate, the solvent was evaporated at reduced pressure to give the crude ketal as a viscous, yellow liquid. Purification by vacuum distillation provided pure 12 as a colorless liquid (8.33 g, 79% yield): bp 75–78 °C (0.1 mm); ^{1}H NMR (CCl_4) δ 5.93–5.73 (m, 2 H, –CH=CH–), 3.87 (br s, 4 H, –OCH$_2$CH$_2$O–), and 2.67–0.98 (br m, 14 H, containing a methyl singlet at δ 1.15); ν (CCl_4) 3020, 2980, 2925, 2830, 1440, 1380, 1240, 1220, 1110, and 1055 cm^{-1}.

7-*exo*-Acetyl-4-bromobicyclo[3.3.1]non-2-ene Ethylene Ketal (13). A vigorously stirred mixture of 12 (5.24 g, 25.1 mmol), purified *N*-bromosuccinimide (4.5 g, 25.3 mmol), benzoyl peroxide (50 mg), and carbon tetrachloride (300 mL) was heated for 2 h under a nitrogen atmosphere. The reaction mixture was cooled to room temperature and the succinimide present was removed by suction filtration. The filtrate was evaporated at reduced pressure to afford crude bromo ketal 13 as a colorless liquid (7.12 g, ca. 99% yield): ^{1}H NMR (CCl_4) δ 6.30–5.67 (br m, 2 H, –CH=CH–), 4.65 (br d, J = 4 Hz, 1 H, CHBr), 3.88 (br s, 4 H, –OCH$_2$CH$_2$O–), and 2.71–0.97 (br m, 12 H, containing a methyl singlet at δ 1.14); ν (CCl_4) 3035, 2980, 2935, 2880, 1460, 1445, 1375, 1240, 1220, 1165, 1140, 1055, and 1040 cm^{-1}.

Due to the unstable nature of 13, no attempt was made at further purification and the crude material was immediately converted to 14.

7-*exo*-Acetyl-4-bromobicyclo[3.3.1]non-2-ene (14). A stirred solution of 13 (7.12 g, 24.8 mmol) and *p*-toluenesulfonic acid monohydrate (100 mg) in anhydrous acetone (175 mL) was heated at reflux for 24 h. The reaction mixture was then cooled to room temperature and the acetone was evaporated at reduced pressure. The residue was dissolved in ether (200 mL) and washed consecutively with 5% aqueous sodium bicarbonate (3 × 25 mL) and water (2 × 25 mL). The organic layer was then dried over anhydrous magnesium sulfate and treated with activated carbon. Evaporation of the ether at reduced pressure gave a dark brown liquid (6.10 g). Analysis of the crude product by ^{1}H NMR indicated the presence of 5.83 g of bromo ketone 14. This represents an overall yield of 95% from ketal 12 to 14. The crude bromo ketone was vacuum distilled through a 8 cm Vigreux

column to provide **14** as a pale yellow liquid (5.39 g, 89% yield): bp 100–105 °C (0.1 mm); ^{1}H NMR (CCl_4) δ 6.35–5.72 (br m, 2 H, –CH=CH–), 4.68 (br d, J = 4 Hz, 1 H, CHBr), and 2.90–1.29 (br m, 12 H, containing an acetyl methyl singlet at δ 2.05); ν (CCl_4) 3035, 2930, 2860, 1712, 1455, 1440, 1350, 1175, and 1160 cm^{-1}.

1-Acetyltricyclo[3.3.1.0^{2,7}]non-3-ene (15). A solution of **14** (1.6 g, 6.6 mmol) in dry *tert*-butyl alcohol (5 mL) was added dropwise to a stirred solution of potassium (270 mg, 6.9 mmol) in dry *tert*-butyl alcohol (50 mL, freshly distilled from sodium) which was maintained under a nitrogen atmosphere. An immediate pale yellow precipitate resulted. The reaction was stirred at reflux for 17 h, cooled to room temperature, and poured into a slurry of ice and water (250 mL). The aqueous phase was extracted with pentane (4 × 100 mL) and the combined organic extracts were dried over anhydrous magnesium sulfate. Evaporation of the solvent at reduced pressure afforded a pale yellow liquid (940 mg). Purification of this material by vacuum distillation provided pure **15** (510 mg, 48% yield) as a colorless liquid: bp 73–76 °C (0.03 mm); ^{1}H NMR ($CDCl_3$) δ 6.97–6.62 and 6.37–6.03 (each complex t, J = 7.5 Hz, each 1 H, –CH=CH–) and 3.32–0.86 (br m, 12 H, containing an acetyl methyl at δ 1.86); ν (CCl_4) 3050, 2945, 2865, 1701, 1445, 1360, 1285, 1270, 1235, 1225, 1100, and 1090 cm^{-1}.

The semicarbazone derivative of **15** was prepared according to the procedure outlined by Fieser,[12] mp 198–200 °C.

Anal. Calcd for $C_{12}H_{17}N_3O$: C, 65.73; H, 7.81; N, 19.16. Found: C, 65.46; H, 7.90; N, 19.19.

1-Carboxytricyclo[3.3.1.0^{2,7}]non-3-ene (16). A freshly prepared solution of sodium hypobromite (formed by the addition of 3.4 g of bromine to a solution of 3.3 g of sodium hydroxide in 30 mL of dioxane and 19 mL of water at 0 °C) was added rapidly to a vigorously stirred ice-cold solution of **15** (850 mg, 5.2 mmol) in dioxane (50 mL) and water (17.5 mL). As the reaction was stirred at 0 °C for 3 h, the color of the reaction mixture gradually changed from pale yellow to colorless. The reaction was quenched by the addition of a solution of sodium sulfite (1.2 g) in water (10 mL). The reaction mixture was then diluted with 10% aqueous sodium hydroxide (60 mL) and the aqueous phase was separated and washed with ether (2 × 50 mL). The aqueous layer was subsequently acidified with hydrochloric acid and the resulting precipitates were extracted into ethyl acetate (4 × 25 mL). The ethyl acetate extracts were combined and dried over anhydrous magnesium sulfate. Evaporation of the solvent at reduced pressure provided **16** (849 mg, 99% yield) as a waxy white solid which proved to be homogeneous by GLC analysis (10 ft × 0.25 in. SE-30 column, 175 °C; 10 ft × 0.25 in. DC-550 column, 175 °C). Acid **16** showed: ^{1}H NMR ($CDCl_3$) δ 11.53 (br s, 1 H, CO_2H), 7.00–6.60 and 6.36–5.96 (each complex t, J = 7 Hz, each 1 H, –CH=CH–), and 3.58–0.85 (br m, 9 H); ^{13}C NMR ($CDCl_3$) tentative assignments δ 181.9 (C=O), 140.6 (C-3 or C-4), 126.4 (C-3 or C-4), 46.1 (C-1), 40.4 (C-2), 39.7 (t), 35.1 (t), 31.9 (t), 31.5 (d), and 29.6 (d); ν (CCl_4) 3500–2750 (br), 3050, 2945, 2860, 1695, 1445, 1420, 1295, 1245, 1230, 1205, and 1120 cm^{-1}.

Acid **16** proved to be thermally labile under GLC conditions. Catalytic hydrogenation of **16** afforded **17** which could be completely characterized.

1-Carboxytricyclo[3.3.1.0^{2,7}]nonane (17). A mixture of **16** (100 mg, 0.6 mmol), 10% palladium on charcoal (20 mg), and ethanol (5 mL) was stirred under an atmosphere of hydrogen at room temperature for 15 h. The reaction mixture was then filtered to remove the catalyst and the ethanol was evaporated at reduced pressure to give a yellow liquid (97 mg, 95% yield) which by GLC analysis (10 ft × 0.25 in. DC-550 column, 200 °C) contained a single component. Isolation by GLC (above conditions) provided **17** as a colorless liquid: ^{1}H NMR ($CDCl_3$) δ 11.40 (br s, 1 H, CO_2H) and 2.67–1.20 (br m, 13 H); ν (CCl_4) 3400–2750 (br), 2935, 2860, 1696, 1460, 1420, 1335, 1290, 1130, and 1085 cm^{-1}.

Anal. Calcd for $C_{10}H_{14}O_2$: C, 72.26; H, 8.49. Found: C, 71.99; H, 8.46.

Tricyclo[3.3.1.0^{2,7}]nonane (1). A stirred mixture of acid **17** (3.2 g, 19.3 mmol) in 50% aqueous methanol (300 mL) was titrated to a phenolphtalein end point with 10% aqueous sodium hydroxide. After stirring the reaction mixture at room temperature for 3 h, the solvent was evaporated at reduced pressure and the residue was heated at 70 °C (0.01 mm) for 8 h. The resulting dry sodium salt of **17** was suspended in a mixture of anhydrous benzene (200 mL) and anhydrous pyridine (2.9 g), cooled to 0 °C, and stirred as oxalyl chloride (8 mL, 96 mmol) was added dropwise. After addition was complete, the reaction mixture was stirred at 0 °C for 15 min and at room temperature for 15 min. The resulting precipitates were filtered and washed with anhydrous benzene (2 × 50 mL). The filtrate and washings were combined and the solvent was evaporated at reduced pressure to provide **1-tricyclo[3.3.1.0^{2,7}]nonanoyl chloride** (18) as an oil: ν (neat) 1790 cm^{-1}.

A solution of the crude acid chloride in methylene chloride (70 mL) was then added to an ice-cooled stirred mixture of *tert*-butyl hydroperoxide (2.75 g, ca. 30 mmol) and anhydrous pyridine (2.3 g, 29 mmol) in methylene chloride (180 mL). The dropwise addition required 1 h. The reaction mixture was stored at 0 °C for 9 h. At this point the reaction mixture was washed successively with water (2 × 50 mL), 10% aqueous sulfuric acid (2 × 50 mL), 5% aqueous sodium bicarbonate (2 × 50 mL), and water (50 mL) and dried over anhydrous sodium sulfate. Evaporation of the solvent at room temperature under reduced pressure provided *tert*-butyl perester **19** as a pale yellow oil (2.25 g): ν (neat) 1745 cm^{-1}.

A solution of crude **19** in ethyl phenylacetate (30 mL) was heated at 155 °C for 2 h according to the method of Langhals and Ruechardt.[10] Methanol (10 ml) and 45% aqueous sodium hydroxide (80 g of sodium hydroxide dissolved in 100 mL of water) were added to the cooled reaction mixture and it was refluxed for 4 h under a nitrogen atmosphere. At this point the reaction mixture was cooled to room temperature and diluted with water (200 mL). The mixture was extracted with pentane (4 × 100 mL) and the combined organic extracts were dried over anhydrous magnesium sulfate. Removal of the solvent by atmospheric distillation afforded the crude hydrocarbon as a viscous yellow oil (380 mg, 16% yield) which by GLC analysis (10 ft × 0.25 in. SE-30 column, 140 °C) was homogeneous and contained no unreacted starting material. The hydrocarbon was purified by repeated sublimation at room temperature using a water aspirator to give pure **1** as a waxy, white solid: mp 131–133 °C; ^{1}H NMR ($CDCl_3$) δ 2.45–1.05 (complex m); ^{13}C NMR ($CDCl_3$) δ 38.5 (t), 35.1 (C-1 and C-7), 35.0 (C-6 and C-9), 33.3 (d), 29.5 (t), 26.4 (d), 19.6 (t); ν ($CDCl_3$) 2925, 2860, 1450, 1340, 1310, 1270, 1230, 1205, and 1140 cm^{-1}.

Anal. Calcd for C_9H_{14}: C, 88.45; H, 11.55. Found: C, 88.41; H, 11.58.

3-*endo*-Acetylbicyclo[3.3.1]nonane (20). An ethereal solution of methyllithium (4.5 mL of a 1.65 M solution, ca. 7.4 mmol) was added dropwise to a vigorously stirred solution of 3-carboxybicyclo[3.3.1]nonane[13] (**22**) (495 mg, 3 mmol) in anhydrous ether at 0 °C at such a rate that the temperature of the reaction mixture did not exceed 5 °C. Workup of the reaction mixture followed the procedure described for **7** → **8**. Evaporation of the solvent at reduced pressure afforded 460 mg (92% yield) of crude **20** as a pale yellow liquid. Analysis of the crude reaction mixture by GLC (10 ft × 0.25 in. SE-30 column, 210 °C) showed the presence of a single component. Purification of this material by GLC (above conditions) provided **20** as a colorless oil: ^{1}H NMR ($CDCl_3$) δ 2.76–0.90 (br m, containing an acetyl methyl singlet at δ 2.12); ν (CCl_4) 2930, 2850, 1710, 1460, 1440, 1350, 1250, and 1170 cm^{-1}.

Anal. Calcd for $C_{11}H_{18}O$: C, 79.47; H, 10.91. Found: C, 79.69; H, 10.62.

Oxidation of **20** (355 mg, 2.2 mmol) with sodium hypobromite by the procedure described for **15** → **16** gave acid **22** (200 mg, 55% yield). The infrared and ^{1}H NMR spectra of this material were identical with those of **22** obtained from the catalytic hydrogenation of **7**.

3-*endo*-Acetoxybicyclo[3.3.1]nonane (21). A solution of **20** (100 mg, 0.6 mmol) in chloroform (3 mL) was added to a stirred solution of 85% *m*-chloroperoxybenzoic acid (500 mg, ca. 2.4 mmol) in chloroform (20 mL) and the reaction mixture was stirred at room temperature for 48 h. Workup of the reaction mixture followed the procedure described for **10** → **11**. Evaporation of the solvent at reduced pressure provided 95 mg (95% yield) of crude **21**. Purification by GLC (10 ft × 0.25 in. SE-30 column, 200 °C) afforded pure acetate **21** as a colorless liquid. The IR and ^{1}H NMR spectra of this material were identical with those previously reported for **21**.[7]

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Registry No.—**1**, 766-67-6; **7**, 21932-98-9; **8**, 66483-55-4; **8** semicarbazone, 66483-56-5; **9**, 67226-63-5; **10**, 67226-64-6; **11**, 23825-38-9; **12**, 67226-65-7; **13**, 67226-66-8; **14**, 67226-67-9; **15**, 67226-68-0; **15** semicarbazone, 67226-69-1; **16**, 67226-70-4; **17**, 67226-71-5; **17** Na salt, 67226-72-6; **18**, 67226-73-7; **19**, 67226-74-8; **20**, 19489-20-4; **21**, 19490-34-7; **22**, 19489-18-0; ethylene glycol, 107-21-1.

References and Notes

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(3) A. Krantz, *J. Am. Chem. Soc.*, **94**, 4020 (1972).
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(6) No information concerning the conformational preferences of compounds **7–14** is meant to be implied by the indicated structures.
(7) M. Fisch, S. Smallcombe, J. C. Gramain, M. A. McKervey, and J. E. Anderson, *J. Org. Chem.*, **35**, 1886 (1970).
(8) Ketone **10** also can be obtained by heating 3-*endo*-acetylbicyclo[3.3.1]-nonane (**20**) in a sealed ampule at 200–205 °C. Ketone **20** is readily prepared from acid **7**. Catalytic hydrogenation of **7** gives 3-carboxybicyclo[3.3.1]nonane[13] which undergoes reaction with methyllithium to provide **20**. The skeletal framework of **20** and the skeletal position and stereochemistry of the acetyl group in **20** were firmly established by its oxidation with *m*-chloroperbenzoic acid to give the previously reported 3-*endo*-acetoxybicyclo[3.3.1]nonane[7] (**21**).
(9) Since **8** → **9** is acid-catalyzed, ketone **8** can be converted "directly" to epimerized ketal **12** by reaction of **8** with ethylene glycol containing a trace of *p*-toluenesulfonic acid.
(10) H. Langhals and C. Ruechardt, *Chem. Ber.*, **108**, 2156 (1975).
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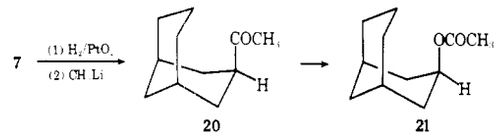

20 21

syn- and *anti*-Tricyclo[4.1.0.0^{2,4}]heptan-5-one

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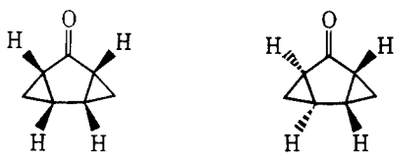
The synthesis, isolation, and spectroscopic characterization of the epimeric ketones *syn*- and *anti*-tricyclo[4.1.0.0^{2,4}]heptan-5-one (**1** and **2**) are described. Two synthetic schemes lead to a nearly equimolar mixture of **1** and **2**, while a third yields **2** almost exclusively. The syn isomer **1** proved much more labile compared to the anti isomer **2**. Complete assignments of protons in the NMR spectra were made possible by a study of lanthanide-induced chemical shift modifications.

The epimeric ketones *syn*- and *anti*-tricyclo[4.1.0.0^{2,4}]-heptan-5-ones (**1** and **2**) are of interest as precursors of the



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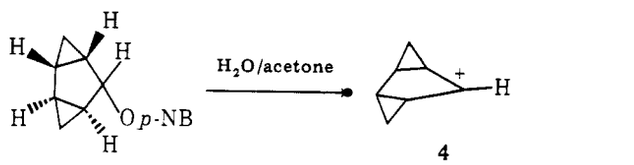
epimeric carbene species *syn*- and *anti*-tricyclo[4.1.0.0^{2,4}]-heptan-5-ylidenes[2] and as precursors of the carbonium ion species *syn*- and *anti*-tricyclo[4.1.0.0^{2,4}]hept-5-yl cations. The anti ketone **2** had earlier been synthesized by Gajewski and Shih and was utilized in an investigation of the properties of anti cation **4** as generated by the solvolysis of **3**.[3] **3** was found



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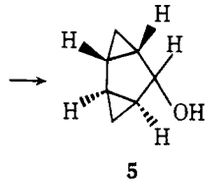

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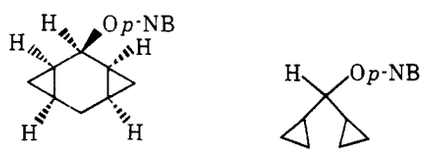
to be significantly less reactive than the model compounds **6** and **7**. We wish to report the details of the synthesis of the syn ketone **1** along with the total spectroscopic characterization



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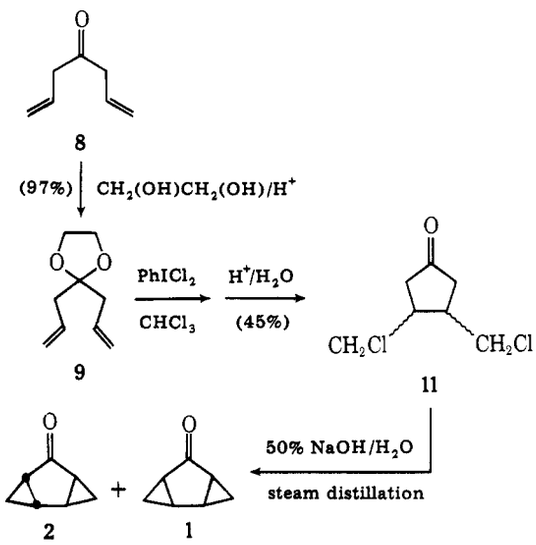
Scheme I



of both the syn and anti isomers and a discussion of their relative chemical properties.

Synthetic Methods. Three synthetic schemes were developed and successfully pursued for the preparation of **1** and **2**. Scheme I began with the known diallyl ketone **8**.[4] Ketalization and treatment of the ketal **9** with iodobenzene dichloride[5] led, after hydrolysis, to a mixture of *cis*- and *trans*-3,4-bis(chloromethyl)cyclopentanones (**11**). Treatment of **11** with 50% aqueous NaOH followed by steam distillation resulted in a mixture of products which proved to be 52 and 48% *syn*- and *anti*-tricyclo[4.1.0.0^{2,4}]heptan-5-one, respectively. Gajewski's synthesis of **2** also involved a cyclization process such as that used to convert **11**.[3] In their final step they converted a pure trans ditosylate into **2**.

Scheme II employed a sequence which appeared to be somewhat more convenient. Drawing on the analogues provided by Doering[6] and Gutsche[7] in performing intramolecular trapping of keto carbenoids by a remote double bond, a se-

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