# Proximity Effects. XLIII. The Solvolysis of 4-Cyclooctene-1-methyl Brosylate[1,2]

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The acetolysis of 4-cyclooctene-1-methyl brosylate led exclusively to bicyclic products endo-bicyclo[3.3.1]-no,1-2-yl acetate (75%), bicyclo[3.3.1]non-2-ene (14%), exo-bicyclo[3.3.1]non-2-yl acetate (3%), and a fourth compound tentatively identified as bicyclo[4.2.1]non-2-yl acetate (7%). A synthetic route to bicyclo[3.3.1]-nonan-2-ol has been developed.

The acetolyses of 4-cycloheptene-1-methyl brosylate (**1**)[5] and of *endo*-bicyclo[3.2.1]oct-2-yl tosylate (**2**)[6] have been reported to produce almost exclusively *endo*-bicyclo[3.2.1]oct-2-yl acetate (greater than 90% of the isolated product in both cases) *via* the symmetrical bridged ion **4**.[5-7] Other examples of the formation
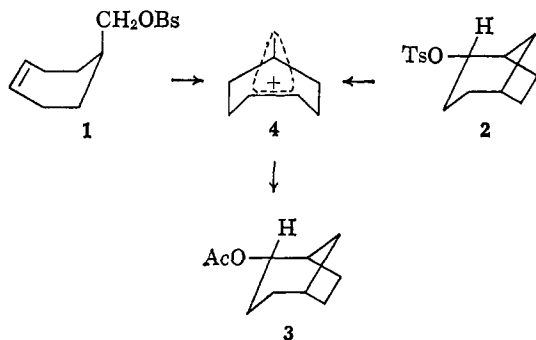
of bicyclic products from the solvolyses of cycloalkenyl-alkyl arenesulfonates have been noted.[7,8] The extension of these studies to a homolog of **1**, 4-cyclooctene-1-methyl brosylate (**5**), is reported in this paper. Two points of interest arise in comparison of the solvolyses of **1** and **5**. First, **1** gives rise to a symmetrical ion **4**, while the analogous bridged ion from **5** is unsymmetrical and could lead to derivatives of either bicyclo[3.3.1]-nonane or bicyclo[4.2.1]nonane. Second, markedly different behavior of homologous cyclooctene and cycloheptene derivatives was found in the solvolyses of 4-cycloocten-1-yl brosylate[9] and 4-cyclohepten-1-yl brosylate.[10] Participation of the double bond led to bicyclic products in the former case, but no such products were observed in the latter.

(1) Supported in part by a research grant (NSF·GP·1587) from the National Science Foundation.
(2) Paper XLII: A. C. Cope and J. K. Heeren, *J. Am. Chem. Soc.*, 87, 3125 (1965).
(3) National Science Foundation Postdoctoral Fellow, 1963–1964.
(4) National Institutes of Health Postdoctoral Fellow, 1961–1962.
(5) G. LeNy, *Compt. rend.*, 251, 1526 (1960); additional work on the solvolysis of this compound will be reported in a forthcoming paper by H. L. Goering and G. N. Fickes.
(6) H. L. Goering and M. F. Sloan, *J. Am. Chem. Soc.*, 83, 1397 (1961).
(7) S. Winstein and P. Carter, *ibid.*, 83, 4485 (1961).
(8) (a) R. G. Lawton, *ibid.*, 83, 2399 (1961); (b) P. D. Bartlett and S. Bank, *ibid.*, 83, 2591 (1961).
(9) (a) A. C. Cope and P. E. Peterson, *ibid.*, 81, 1643 (1959); (b) A. C. Cope, J. M. Grisar, and P. E. Peterson, *ibid.*, 82, 4299 (1960).
(10) A. C. Cope, C. H. Park, and P. Scheiner, *ibid.*, 84, 4862 (1962).

4-Cyclooctene-1-methyl brosylate (**5**) was solvolyzed in buffered acetic acid at 80° for 5 hr. Analysis of the crude product by gas chromatography indicated the presence of a single olefin and two saturated acetates in addition to several minor products (<1%). None of the major or minor products corresponded to the *unrearranged* acetate **6**. Gas chromatographic analysis of the product mixture after treatment with lithium aluminum hydride indicated the presence of an olefin (14%) and three alcohols, 3, 75, and 7% of the mixture, respectively, suggesting that two of the corresponding acetates were not resolved on the columns used. This was later confirmed.

The olefin product was shown to be bicyclo[3.3.1]-non-2-ene (**7**) by catalytic hydrogenation to a saturated hydrocarbon which was identical with authentic bicyclo[3.3.1]nonane (**8**) prepared by two methods from bicyclo[3.3.1]nonan-9-one.[11] For comparison purposes, bicyclo[4.2.1]nonane (**9**), m.p. 102–103°, was prepared from the corresponding 9-ketone[12] and was found to be easily distinguishable from **8**. In both cases reduction of the corresponding tosylhydrazones with sodium borohydride[13] was found to be a very convenient procedure for preparation of the hydrocarbons.

The major solvolysis product was identified as a bicyclo[3.3.1]non-2-yl acetate in the following way.[14] The alcohol **11a** obtained from it by saponification or reduction with lithium aluminum hydride was converted to a crystalline brosylate which on reduction with lithium aluminum hydride afforded bicyclo[3.3.1]-nonane (contaminated with a small amount of easily separated olefin).

The alcohol **11a** was oxidized to a crystalline ketone, m.p. 128.5–130.5°. Comparison of the properties of this ketone and its derivatives with those of the three possible bicyclo[3.3.1]nonanones (2-,[15] 3-,[16] and 9-[11]) indicated that it was bicyclo[3.3.1]nonan-2-one. Further support for this assignment was afforded by a deuterium-exchange study which indicated the presence of two easily enolizable hydrogen atoms per molecule. Reduction of the ketone with sodium borohydride produced predominantly the alcohol **11a**, showing that the oxidation proceeded without rearrangement.

The bicyclo[3.3.1]non-2-yl brosylate from the alcohol **11a** obtained from the solvolysis of **5** was treated with

(11) C. S. Foote and R. B. Woodward, *Tetrahedron*, 20, 687 (1964).
(12) C. D. Gutsche and T. D. Smith, *J. Am. Chem. Soc.*, 82, 4067 (1960).
(13) L. Caglioti and P. Grasselli, *Chem. Ind.* (London), 153 (1964).
(14) After this manuscript had been prepared, a note appeared, [M. Hanack and W. Kaiser, *Angew. Chem.*, 76, 572 (1964)] reporting the isolation of bicyclo[3.3.1]nonan·2·ol from a solvolysis of 4·cyclooctene·1·methyl tosylate. No experimental detail or proof of configuration was given.
(15) H. Meerwein, F. Kiel, G. Klosgen, and E. Schloch, *J. prakt. Chem.*, [2] 104, 161 (1922).
(16) H. K. Hall, Jr., *J. Org. Chem.*, 28, 3213 (1963).

tetraethylammonium acetate to produce an epimeric acetate **10b**, which was not separated from the major solvolysis product by gas chromatography. Reduction of this acetate with lithium aluminum hydride afforded an alcohol **11b**, which had a gas chromatographic retention time identical with that of the minor (3%) alcoholic product of shortest retention time from the solvolysis of **5**. Oxidation of this alcohol **11b** produced the same ketone that was obtained from its epimer **11a**.

The other minor (7%) acetate product from the solvolysis of **5** was tentatively identified as bicyclo-[4.2.1]non-2-yl acetate of unspecified stereochemistry on the basis of its infrared spectrum and on mechanistic grounds.

In order to establish the stereochemistry of the epimeric acetates **10a** and **10b**, two points were considered. First, the equatorial or axial nature of the acetoxy or hydroxy substituents was established spectroscopically. Second, a chair conformation was assigned to the substituted, six-membered ring, thus correlating the equatorial functional group with the *endo* configuration and the axial functional group with the *exo* configuration.

The major solvolysis product **10a** showed infrared absorption at 1250 and 1240 cm.$^{-1}$, while its epimer **10b** absorbed at 1260, 1250, and 1220 cm.$^{-1}$. These absorptions are consistent with the assignment of an equatorial acetate structure to **10a** and an axial acetate structure to **10b**.[17] The alcohol **11a** from the major solvolysis product absorbed at 1060 and 1025 cm.$^{-1}$, and its epimer **11b** showed strong absorption at 985 and weak absorption at 1045 cm.$^{-1}$. The latter spectra are consistent with the assignment of equatorial and axial conformations to the hydroxyl groups in the two alcohols **11a** and **11b**, respectively.[17,18]

N.m.r. spectra of the acetates and alcohols confirm these assignments. It has been shown that in substituted cyclohexanes the width at half-height of an n.m.r. absorption band can be used to determine whether the corresponding proton is axial or equatorial,[19] since axial protons give rise to significantly broader absorption bands than do equatorial protons. The axial proton on C-2 in the equatorial acetate **10a** absorbs at τ 4.90 with a width at half-height of 16–17 c.p.s., and the proton at C-2 in its epimer **10b** absorbs at τ 4.95 with a width at half-height of 7 c.p.s. The corresponding data for the hydrogen at C-2 in the alcohols **11a** and **11b** are τ 6.02 (width 18 c.p.s.) and 5.98 (width 7 c.p.s.), respectively.

Since the major solvolysis product **10a** has an equatorial acetoxy group and its epimer **10b** has an axial acetoxy group, the substituted cyclohexane rings must be chair forms in both epimers or boat forms in both epimers. In the latter case, the axial acetate **10b** would be either of the conformers **12** or **13** below.
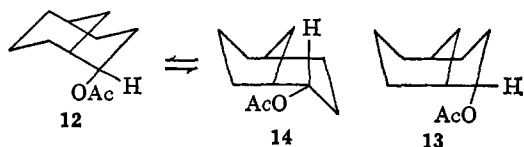
The boat–boat conformer **13** is considered very unlikely because of the unfavorable nonbonded interactions characteristic of boat cyclohexanes.[20] The chair–boat conformer **12** is unlikely for another reason. It would be expected to be in equilibrium with the other chair–boat form **14**, which differs only in that an axial acetoxy group on the boat ring in **12** becomes an equatorial acetoxy group on the chair ring in **14**. Since the conformational preference for an acetoxy group is relatively small (0.4–0.7 kcal.[20b]) one would expect a mixture of conformers with the equatorial acetate predominating; this is not observed. Thus one may conclude that the substituted ring in these compounds is in a chair conformation.

In two recent reports, 9-hydroxy-5-methylbicyclo-[3.3.1]nonane-1-methyl brosylate[21] and 3-azabicyclo-[3.3.1]nonane hydrobromide[22] were shown by X-ray crystallographic studies to possess a chair–chair conformation. In the former case, infrared absorptions at 1490 and 2990 cm.$^{-1}$ were assigned to vibrations of the "crowded" hydrogens in the 3- and 7-positions of chair–chair forms of saturated bicyclo[3.3.1]nonane derivatives. In the present work, absorptions at 1485 ± 5 and 2985 ± 5 were observed for bicyclo-[3.3.1]nonane and several of its 2-substituted derivatives (*i.e.*, **10a**, **11a**, **11b**, etc.) but not for bicyclo[4.2.1]-nonane or bicyclo[3.3.1]nonan-2-one. These results provide strong support for the assignment of a chair conformation to the substituted rings in the present work, and for the assignment of the *endo* configuration to the major product of the solvolysis of **5**.

The exclusive formation of bicyclic products and the stereochemistry of the major product are both rationalized on the basis of a nonclassical ion **15**.

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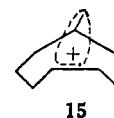
A synthetic route to bicyclo[3.3.1]nonan-2-ol was developed starting from cyclohexanone. It was found that 1-N-pyrrolidylcyclohexene could be condensed with acrolein to produce the keto aldehyde **16** rather than the usual product isolated from this reaction, 2-N-pyrrolidylbicyclo[3.3.1]nonan-9-one.[23] The use of freshly distilled enamine and a short reaction time at 0° followed by immediate hydrolysis afforded **16** in

16

17   11

(17) (a) R. N. Jones, P. Humphries, F. Herling, and K. Dobriner, *J. Am. Chem. Soc.*, 73, 3215 (1951); (b) A. R. H. Cole, R. N. Jones, and K. Dobriner, *ibid.*, 74, 5571 (1952).
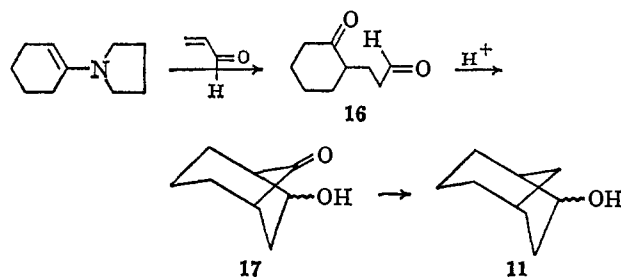(18) (a) A. A. Youseff, M. E. Baum, and H. M. Walborsky, *ibid.*, 81, 4709 (1959); (b) R. A. Pickering and C. C. Price, *ibid.*, 80, 4931 (1958).
(19) J. I. Musher, *ibid.*, 83, 1146 (1961).

(20) E. L. Eliel, "Stereochemistry of Carbon Compounds," McGraw-Hill Book Co., Inc., New York, N. Y.: (a) 1962, p. 204 ff; (b) p. 236.
(21) W. A. C. Brown, G. Eglinton, J. Martin, W. Parker, and G. A. Sim, *Proc. Chem. Soc.*, 57 (1964).
(22) M. Dobler and J. D. Dunitz, *Helv. Chim. Acta*, 47, 695 (1964).
(23) G. Stork and H. K. Landesman, *J. Am. Chem. Soc.*, 78, 5130 (1956).

28–35% yield.[24] Cyclization of **16** to the keto alcohol **17** was effected with 7 N hydrochloric acid. Treatment of the tosylhydrazone p-nitrobenzoate derivative of **17** with sodium borohydride produced in 67% yield a mixture consisting largely of $endo$-bicyclo[3.3.1]nonan-2-ol (**11a**, >90%) with <10% of the exo isomer **11b**.

Experimental[25]

4-Cyclooctene-1-methyl Brosylate. To a cold solution of 1.73 g. of freshly distilled 4-cyclooctene-1-methanol[26] in 7 ml. of pyridine was added a cold solution of 6.4 g. of p-bromobenzenesulfonyl chloride in 14 ml. of pyridine. The mixture was kept at 5° for 25 hr., and was then cooled in an ice bath while 8 ml. of water was added slowly with stirring. The solution was diluted with 70 ml. of ice water and extracted with five 25-ml. portions of ether. The combined ether extracts were washed with four 25-ml. portions of 6 N hydrochloric acid and two 25-ml. portions of 5% sodium bicarbonate solution, and dried over magnesium sulfate. Removal of the solvent under reduced pressure afforded 3.9 g. (88%) of a viscous oil which crystallized on standing at −10° overnight, m.p. 30–34°. One recrystallization from pentane gave material melting at 38.0–39.2°.

Anal. Calcd. for $C_{15}H_{19}BrO_3S$: C, 50.14; H, 5.33. Found: C, 50.35; H, 5.42.

This compound decomposed to a brown oil on standing at room temperature for a few days.

Solvolysis of 4-Cyclooctene-1-methyl Brosylate. Freshly recrystallized 4-cyclooctene-1-methyl brosylate, 25 g., was solvolyzed in 125 ml. of acetic acid 0.3 N in sodium acetate at 80° for 6 hr. The cooled solution was diluted with 150 ml. of water and extracted with five 50-ml. portions of ether. The combined ether extracts were washed with saturated sodium carbonate solution until the washings were basic and dried over magnesium sulfate. Cautious removal of solvent under reduced pressure left 11 g. of a fragrant oil which was separated by gas chromatography on silicone oil at 232° into one olefinic and two acetate fractions.

The olefin, m.p. 87–89° (15% of the mixture), had infrared absorption at 705 and 3000 cm.$^{-1}$ (cis-disubstituted double bond). The major acetate component (79% of the mixture), n^{25}D 1.4783, showed no evidence of unsaturation in its infrared spectrum. The minor acetate component (7% of the mixture) had a slightly longer retention time than the major product, and its infrared spectrum also indicated no unsaturation. The mixture of acetates was used for microanalysis.

Anal. Calcd. for $C_{11}H_{18}O_2$: C, 72.49; H, 9.96. Found: C, 72.29; H, 9.86.

Hydride Reduction of the Crude Solvolysis Products. To a stirred suspension of 1.6 g. of lithium aluminum hydride in 200 ml. of dry ether was added slowly 8.0 g. of the crude solvolysis product. The mixture was stirred at room temperature for 1 hr. and then refluxed

for 1.5 hr. After cooling, cautious addition of water was followed by addition of enough 10% hydrochloric acid to dissolve the solid (about 150 ml.). The layers were separated and the aqueous layer was extracted with two 100-ml. portions of ether. The combined ether layers were washed with 10% sodium bicarbonate solution and dried. The solution was concentrated, and gas chromatographic analysis on an 8-ft. 20% LAC 728 column at 140° indicated the presence of bicyclo[3.3.1]non-2-ene (11%) and three alcohols (3, 80, and 5% in order of increasing retention time). The minor alcoholic products were not sufficiently resolved from the major one to enable separate collection of each.

Hydrogenation of Olefinic Solvolysis Product. A 40-mg. sample of the olefinic solvolysis product collected by gas chromatography was hydrogenated in 5 ml. of ether with 35 mg. of 10% palladium on charcoal at atmospheric pressure and room temperature. After hydrogen absorption had ceased (3 hr.), the mixture was filtered and the solvent was carefully removed by distillation at atmospheric pressure. Collection of the single peak shown by gas chromatography of the residue afforded a solid, m.p. 141–142°, which showed a retention time and an infrared spectrum identical with those of authentic bicyclo[3.3.1]nonane and different from those of authentic bicyclo[4.2.1]nonane.

Bicyclo[3.3.1]nonane. *Method A.* Bicyclo[3.3.1]-nonan-9-one (1.1 g.), 85% hydrazine hydrate (2.0 g.), and potassium hydroxide (1.1 g.) were refluxed in 25 ml. of diethylene glycol.[27] Nitrogen evolution began above 125° (bath temperature). The mixture was heated to 180–190° for 3 hr., then cooled to room temperature, diluted with 35 ml. of water, and extracted with four 20-ml. portions of pentane. The combined pentane extracts were washed with two 25-ml. portions of 6 N hydrochloric acid, then with water, and dried. The solution was concentrated by distilling the pentane through a semimicro column at atmospheric pressure, and the products were analyzed by gas chromatography on silicone oil at 232°. The original ketone and a hydrocarbon, m.p. 142–144°, were present in approximately equal amounts. The melting point of bicyclo[3.3.1]nonane has been reported previously as 143.0–144.5°[11] and 145–146°.[15,28]

Method B.[13] A solution of 0.81 g. of bicyclo[3.3.1]-nonan-9-one and 1.4 g. of p-toluenesulfonylhydrazide[29] in 30 ml. of absolute ethanol was refluxed for 15 min., and then allowed to crystallize at +5°. The collected, air-dried crystals (1.05 g.) melted at 186.5–189°. A sample was recrystallized from ethanol, m.p. 188.0–190.2°.

Anal. Calcd. for $C_{16}H_{22}N_2O_2S$: C, 62.72; H, 7.24; N, 9.14. Found: C, 62.66; H, 7.31; N, 9.37.

To a solution of 561 mg. of the crude tosylhydrazone in 30 ml. of dioxane was added 1.4 g. of sodium borohydride at room temperature. An exothermic reaction took place immediately. The mixture was heated to reflux for 1 hr., then cooled, and 60 ml. of water was added. The solution was extracted with three 40-ml. portions of pentane. The combined

(24) J. Colonge, J. Dreux, and M. Thiers, *Bull. soc. chim. France,* 370 (1959), reported the preparation of **16** in 20% yield *via* a sodium methoxide catalyzed condensation of cyclohexanone and acrolein.

(25) Melting points of the volatile bicyclic hydrocarbons, ketones, and alcohols were taken in sealed capillaries. All melting points are corrected. Gas chromatographic analyses were carried out with an F M Model 720 instrument using LAC-728 (diethylene glycol succinate) and XF-1150 (silicone nitrile fluid) as the liquid phases.

(26) A. C. Cope and G. L. Woo, *J. Am. Chem. Soc.,* **85,** 3601 (1963).

(27) Huang-Minlon, *ibid.,* **68,** 2487 (1946).

(28) A. C. Cope and M. E. Synerholm, *ibid.,* **72,** 5228 (1950).

(29) L. Friedman, R. L. Litle, and W. R. Reichle, *Org. Syn.,* **40,** 93 (1960).

pentane extracts were dried and concentrated by careful distillation of the solvent at atmospheric pressure.

Analysis of the residue by gas chromatography on silicone oil at 145° indicated two products. The desired bicyclo[3.3.1]nonane, m.p. 144.2–145.4°, had a retention time of 6.4 min. and represented 93% of the products. The other product, retention time 15.6 min. (7%), was not identified.

Bicyclo[4.2.1]nonane. Method A. A solution of 460 mg. of bicyclo[4.2.1]nonan-9-one[12] and 620 mg. of *p*-toluenesulfonylhydrazide[29] in 7 ml. of absolute ethanol was refluxed for 45 min., then kept at 5° for 40 hr. Filtration afforded 905 mg. of solid, m.p. 185.5–187.5°. A sample was recrystallized from ethanol, m.p. 188.8–190.0°.

Anal. Calcd. for $C_{16}H_{22}N_2O_2S$: C, 62.72; H, 7.24; N, 9.14. Found: C, 62.51; H, 7.23; N, 9.21.

To a mixture of 835 mg. of the tosylhydrazone and 25 ml. of dioxane at room temperature was added 2.0 g. of sodium borohydride. An immediate exothermic reaction took place, and after it had subsided, the mixture was refluxed for 1.5 hr., then cooled and worked up as described above for the preparation of bicyclo[3.3.1]nonane (method B).

Analysis of the product by gas chromatography on silicone rubber at 150° showed only a single peak in addition to solvent. Collection of this peak afforded 167 mg. of solid, m.p. 98.0–99.1°.

Anal. Calcd. for C_9H_{16}: C, 87.02; H, 12.98. Found: C, 87.13; H, 12.92.

Method B. Bicyclo[4.2.1]nonan-9-one semicarbazone had m.p. 196.0–197.5° after recrystallization from aqueous ethanol (lit.[30] m.p. 207–208°).

Anal. Calcd. for $C_{10}H_{17}N_3O$: C, 61.50; H, 8.78; N, 21.52. Found: C, 61.51; H, 8.89; N, 21.61.

The air-dried semicarbazone, 420 mg., was added to a warm solution prepared from 0.3 g. of sodium and 15 ml. of diethylene glycol. The solution was heated gradually to a bath temperature of 215–225°, refluxed for 3 hr., and cooled. Water (100 ml.) and pentane (20 ml.) were added, the layers were separated, and the aqueous layer was extracted with three 15-ml. portions of pentane. The combined extracts were dried and concentrated by careful distillation at atmospheric pressure. The residue was separated by gas chromatography on silicone rubber at 170° into two products. The first, 23% of the product mixture, was the desired hydrocarbon, m.p. 102.8–103.7°. The product with longer retention time, 77% of the mixture, melted at 169–172° and showed strong infrared absorption at 3620 and 3380 (O–H) cm.$^{-1}$, consistent with the structure of bicyclo[4.2.1]nonan-9-ol. A *p*-nitrobenzoate of the alcohol was prepared and recrystallized from 95% ethanol, m.p. 115.8–116.8°.

Anal. Calcd. for $C_{16}H_{19}NO_4$: C, 66.42; H, 6.62; N, 4.84. Found: C, 66.40; H, 6.59; N, 4.88.

Alcohol from the Major Solvolysis Product. A suspension of 0.6 g. of the acetate products from the solvolysis of 4-cyclooctene-1-methyl brosylate in 5 ml. of methanol and 10 ml. of 23% aqueous sodium hydroxide was refluxed for 6 hr. and then cooled. After addition of 15 ml. of water, the suspension was extracted with four 25-ml. portions of ether. The combined ether extracts were washed twice with 25-ml. portions of water and dried. Removal of the solvent under reduced pressure left 0.5 g. of a white solid, m.p. 166–170°. After two recrystallizations from pentane at −60°, it melted at 170.5–171.5° (bicyclo[3.3.1]nonan-2-ol).

Anal. Calcd. for $C_9H_{16}O$: C, 77.09; H, 11.50. Found: C, 76.97; H, 11.55.

A *p*-nitrobenzoate had m.p. 102–103° after recrystallization from aqueous ethanol.

Anal. Calcd. for $C_{16}H_{19}NO_4$: C, 66.42; H, 6.62; N, 4.84. Found: C, 66.49; H, 6.68; N, 4.85.

Bicyclo[3.3.1]non-2-yl Brosylate. A cooled solution of 15.0 g. of *p*-bromobenzenesulfonyl chloride in 50 ml. of pyridine was added to a cooled solution in 25 ml. of pyridine of 4.0 g. of the major product from the reduction described above. The resulting solution was kept at −10° for 2 days, then cooled in an ice bath and stirred while 200 ml. of cold water was added. The solution was extracted with three 100-ml. portions of ether. The extracts were combined, washed with 6 N hydrochloric acid and 10% sodium bicarbonate solution, and dried, and the solvent was removed. Recrystallization of the residue (7.9 g.) from pentane afforded 4.7 g., m.p. 79–80.5°.

Anal. Calcd. for $C_{15}H_{19}BrO_3S$: C, 50.14; H, 5.33. Found: C, 50.34; H, 5.47.

Hydrogenolysis of Bicyclo[3.3.1]non-2-yl Brosylate. A solution of 1.6 g. of the brosylate derived from the major solvolysis product in 40 ml. of ether was added to a stirred suspension of 0.65 g. of lithium aluminum hydride in 40 ml. of ether. The mixture was refluxed for 6 hr. and cooled, and water was added cautiously. An additional 80 ml. of ether and 50 ml. of concentrated hydrochloric acid were added to dissolve the solids, and the layers were separated. The aqueous layer was extracted with 50 ml. of ether, and the combined ether extracts were washed with two 75-ml. portions of 10% aqueous potassium hydroxide and with water. Removal of the ether from the dried extracts left 250 mg. of solid. Gas chromatography on silicone rubber at 150° separated two components. The first was an olefin (13%) and the second was a solid, m.p. 141.5–143.0°, which showed infrared spectrum identical with that of authentic bicyclo[3.3.1]nonane and distinctly different from that of authentic bicyclo[4.2.1]-nonane.

Oxidation of the Alcohol from the Major Solvolysis Product. A solution of the alcohol (141 mg.) from saponification of the acetate solvolysis products in 7 ml. of acetone was cooled in an ice bath and treated with 0.3 ml. of chromic acid–sulfuric acid–acetone oxidant, 2.67 M, in chromic acid.[31] The mixture was stirred during the addition and for 5 min. longer. After filtration, a small amount of anhydrous potassium carbonate was added and stirring was continued for 1 hr. at room temperature. The colorless solution was filtered and the solvent was removed. Analysis of the residual solid (122 mg.) by gas chromatography on silicone oil at 225° showed one symmetrical peak. Collection of this peak afforded bicyclo[3.3.1]nonan-2-one with m.p. 128.5–130.5° (lit.[15] m.p. 150°).

(30) C. D. Gutsche and D. M. Bailey, *J. Org. Chem.*, **28**, 607 (1963).

(31) K. Bowden, I. M. Heilbron, E. R. H. Jones, and B. C. L. Weedon, *J. Chem. Soc.*, 39 (1946).

Anal. Calcd. for $C_9H_{14}O$: C, 78.21; H, 10.21. Found: C, 77.89; H, 10.07.

A 2,4-dinitrophenylhydrazone was prepared and recrystallized from 95% ethanol, m.p. 141.2–142.6°.

Anal. Calcd. for $C_{15}H_{18}N_4O_4$: C, 56.60; H, 5.70; N, 17.60. Found: C, 56.66; H, 5.82; N, 17.58.

A semicarbazone after crystallization from aqueous ethanol melted at 174–176° (lit.[15] m.p. 180–181°).

A condensation product with benzaldehyde[15] after crystallization from ethanol melted at 121–122° (lit.[15] m.p. 127–128°). The following data are reported[11] for bicyclo[3.3.1]nonan-9-one: m.p. 155–158.5°; 2,4-dinitrophenylhydrazone, m.p. 191.8–192.3°; semicarbazone, m.p. 202.5–203.2°. The following data are reported[16] for bicyclo[3.3.1]nonan-3-one: m.p. 180–182°; 2,4-dinitrophenylhydrazone, m.p. 208–209°.

Reduction of this ketone (55 mg.) in 1.0 ml. of methanol with 12 mg. of sodium borohydride at room temperature for 4 hr., followed by addition of 2 ml. of water and isolation of the product in the usual way, afforded a solid mixture, m.p. 140–167°. This solid had an infrared spectrum identical with that of the original alcohol mixture from the solvolysis of **5**.

Deuterium Exchange of the Ketone from the Major Solvolysis Product. The above ketone (32 mg.) was treated with 1.0 ml. of deuteriomethanol (CH_3OD *ca.* 98%) in which 45 mg. of sodium had been dissolved. The solution was allowed to stand at room temperature in a tightly stoppered flask for 22 hr., and then was diluted with 2 ml. of deuterium oxide and extracted with 18 ml. of pentane in four portions. The combined extracts were washed twice with 2-ml. portions of deuterium oxide and then with 4 ml. of water. The pentane solution was dried over magnesium sulfate and concentrated by carefully distilling the solvent at atmospheric pressure. The product was isolated by gas chromatography on silicone oil at 231°. The infrared spectrum and gas chromatographic retention time of this material were indistinguishable from those of the undeuterated ketone. A sample purified by gas chromatography was analyzed for deuterium content by mass spectrometry.[32] The results, expressed in terms of the per cent of ketone containing n deuterium atoms per molecule, are as follows: $n = 0$ (36%), $n = 1$ (40%), $n = 2$ (22%), $n = 3$ (2%), and $n = 4$ (<0.4%).

Inversion of the Major Solvolysis Product. Tetraethylammonium acetate[33] (3.6 g.) was transferred quickly from a desiccator to a dry flask, and 2.54 g. of bicyclo[3.3.1]non-2-yl *p*-bromobenzenesulfonate in 75 ml. of dry acetone was added. The solution, protected from moisture by a drying tube, was refluxed on a steam bath for 12 days. After cooling and removal of most of the acetone by distillation under reduced pressure, the residue was diluted with 75 ml. of water and 50 ml. of ether. The layers were separated and the aqueous layer was extracted with three 75-ml. portions of ether. The combined ether layers were dried and the ether was removed, leaving 1.0 g. of a brown oil. Analysis of the residual oil (1.0 g.) by gas chromatography on an 8-ft. LAC-728 column at 140° showed that the major component was in-

distinguishable from the major product of the solvolysis of 4-cyclooctene-1-methyl brosylate. A sample was collected for microanalysis.

Anal. Calcd. for $C_{11}H_{18}O_2$. C, 72.49; H, 9.96. Found: C, 72.24; H, 9.82.

Reduction of the Inverted Acetate. The crude inverted acetate from the above preparation (700 mg.) was reduced with lithium aluminum hydride to a mixture of solid alcohols by the procedure described above. Analysis by gas chromatography on an 8-ft. LAC 728 column at 140° showed that the major component of this mixture had a retention time slightly shorter than that of the major alcohol product from the solvolysis, and identical with that of the alcohol found as 3% of the solvolysis products. A collected sample had m.p. 180–192° (lit.[15] for bicyclo[3.3.1]-nonan-2-ol, m.p. 185°).

Anal. Calcd. for $C_9H_{16}O$: C, 77.09; H, 11.50. Found: C, 77.09; H, 11.25.

Oxidation of this alcohol (100 mg.) by the procedure described for its epimer afforded a ketone with infrared spectrum and gas chromatographic retention time identical with those of the bicyclo[3.3.1]nonan-2-one obtained from oxidation of its epimer.

4-Cyclooctene-1-methyl Acetate. 4-Cyclooctene-1-methanol (250 mg.), acetic anhydride (350 mg.), and pyridine (10 ml.) were combined and left at room temperature for 31 hr. The solution was poured into 100 ml. of ice–water and extracted with four 40-ml. portions of ether. The combined extracts were washed with three 50-ml. portions of 6 N hydrochloric acid and two 50-ml. portions of 10% sodium bicarbonate solution and dried. Removal of the ether afforded 135 mg. of liquid, $n^{25}D$ 1.4699, which had infrared absorption at 3000, 1735, 1240, and 725 cm.$^{-1}$. Analysis by gas chromatography on XF-1150 at 110° showed that this compound (99% pure) had a longer retention time than any of the products from the solvolysis of 4-cyclooctene-1-methyl brosylate.

Anal. Calcd. for $C_{11}H_{18}O_2$: C, 72.49; H, 9.96. Found: C, 72.56; H, 9.71.

β-2-Ketocyclohexylpropionaldehyde. A solution of 130 g. of freshly distilled 1-N-pyrrolidylcyclohexene in 650 ml. of anhydrous ether was cooled to −12° under a nitrogen atmosphere. With efficient stirring and cooling in an ice–salt bath, 49 g. of freshly distilled acrolein (containing 10 mg. of hydroquinone) in 50 ml. of ether was added over 1.8 hr. The temperature was kept between −7 and −2° during the addition, and then was kept at 0° for another hour, when 24 ml. of water was added. After the solution was stirred for 20 min., 140 ml. of 6 N hydrochloric acid was added to bring the pH to 5–6. The ether layer was separated, washed with saturated sodium bicarbonate solution, dried, and distilled. The fraction boiling at 83–85° (0.7 mm.) was collected, $n^{25}D$ 1.4730 [lit.[24] b.p. 141.5° (22 mm.), $n^{25}D$ 1.4820].

Anal. Calcd. for $C_9H_{14}O_2$: C, 70.10; H, 9.15. Found: C, 69.82; H, 9.26.

A 2,4-dinitrophenylhydrazone melted at 193–195° (lit.[24] m.p. 197°).

9-Oxo-bicyclo[3.3.1]nonan-2-ol. To 345 ml. of 7 N hydrochloric acid at 0° under an atmosphere of nitrogen was added with stirring 34.4 g. of β-2-ketocyclo-

(32) The calculation of the deuterium content from the mass spectrum was carried out with the assistance of Dr. A. S. Mehta.

(33) J. Steigman and L. P. Hammett, *J. Am. Chem. Soc.*, **59**, 2536 (1937).

hexylpropionaldehyde over a period of 2 hr. The mixture was stirred for 1 hr. more at 0°, then was allowed to stand at room temperature for 14 hr. It was neutralized (to pH 6) with sodium carbonate and extracted with five 150-ml. portions of ether. The extracts were dried and the ether was distilled, leaving 24.3 g. of crude solid, which showed strong OH absorption and C=O absorption (1710 cm.$^{-1}$) in its infrared spectrum. A sample was sublimed at 114–117° (6 mm.), m.p. 138–150°.

Anal. Calcd. for $C_9H_{14}O_2$: C, 70.10; H, 9.15. Found: C, 69.80; H, 9.32.

Bicyclo[3.3.1]nonan-2-ol. The crude keto alcohol from above, 24.3 g., was treated with 32 g. of p-nitrobenzoyl chloride in 70 ml. of dry pyridine. When the initial exothermic reaction had subsided, the mixture was heated on a steam bath for 20 min., then was poured into 800 g. of ice water. The gummy precipitate did not crystallize, and the mixture was extracted with 450 ml. of methylene chloride in three portions. The solution was washed with hydrochloric acid and dried, and the solvent was evaporated. The solid residue was separated by fractional crystallization into 3.4 g. of p-nitrobenzoic anhydride, m.p. 186–187°, and 33.2 g. (70%) of p-nitrobenzoate ester, m.p. 97–113°, showing strong infrared absorption at 1720 (C=O) and 1520 (NO_2), and medium absorption at 1605 cm.$^{-1}$.

A solution of 4.8 g. of the crude ester in 30 ml. of absolute ethanol was boiled with 3.0 g. of p-toluenesulfonylhydrazide for 25 min. Then 6 ml. of water was added, and the solution was cooled. Filtration afforded 8.5 g. of solid which was dried to a constant weight of 6.9 g., m.p. 125–147° (92% yield). This solid showed strong infrared absorption at 1720 (C=O), 1520 (NO_2), and 1170 cm.$^{-1}$ (tosyl), as well as weak absorption at 1605 and 1640 cm.$^{-1}$ (-C=N-).

The crude p-tosylhydrazone, 6.9 g., was treated with 4.5 g. of sodium borohydride and 50 ml. of dioxane according to the procedure described above.[13] Gas chromatography of the crude reduction product showed a mixture of ca. 82% endo-bicyclo[3.3.1]-nonan-2-ol, 4-7% of exo-bicyclo[3.3.1]nonan-2-ol (identified by retention time only), and 11% of an unidentified component of longer retention time. Recrystallization of the crude product from pentane gave 1.36 g. of an alcohol, m.p. 168–170°, which was identical (retention time, infrared spectrum, melting point, and mixture melting point of p-nitrobenzoate) with bicyclo[3.3.1]nonan-2-ol from the solvolysis of **5**.

# Conformations of Seven-Membered Rings. Benzocycloheptenes

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In order to study the conformations of the cycloheptene ring, 1,1,4,4-tetramethyl-6,7-benzocycloheptene (VIII) was synthesized. The final step involved cyclization of 2,4,4-trimethyl-6-phenyl-2-hexene (X) which, with aluminum chloride, gave only the tetralin XI, but with boron fluoride etherate gave XI and the desired VIII. The conformations of VIII are discussed, and it is shown by n.m.r. that the enantiomorphic conformations of VIII interconvert rapidly at 35°, but this interconversion can be stopped by lowering the temperature. Both VIII and 1,1,4,4-tetramethyl-6,7-benzocyclohepten-5-one (XIII) had abnormally low extinction coefficients in their electronic spectra.

Introduction

It has long been known that a seven-membered ring fused to a benzene ring is under certain geometric constraints which minimize the overlap of an orbital on atom X with the aromatic π-system, relative to what such overlap would be if X were part of a smaller or larger ring, or no ring at all. Early examples include the slow rate of electrophilic deuteration of I[1]
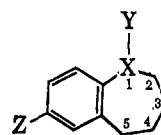
	X	Y	Z
I	N	CH₃	H
II	C	=O	H
III	O		H
IV	CH	Cl	H
V	O		CH₂Cl
VI	CH	H	H

and the decreased absorption intensities in the electronic spectra of I,[2] II,[3] III,[4] 5,5,-dimethyl-III,[5] and 2-carboxy-III,[6] when compared with five- and six-membered analogs. The solvolysis rates of IV[7,8] and V[4] are over two orders of magnitude slower than those of smaller ring analogs, presumably because of decreased charge delocalization in the benzylic car-

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