

Registry No.—III, 15292-78-1; IV, 15292-79-2; V, 15292-80-5; 2,4-DNPH of Me ester of V, 15292-81-6; VI, 15292-84-9; IX, 15292-82-7; X, 15292-83-8.

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The Solvolysis of 1-Chlorobicyclo[3.3.1]nonane¹

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Ever since the pioneering work on reactions of bridgehead substituted bicyclic systems by Bartlett and Knox in 1939,³ many studies of a wide variety of bicyclic compounds have provided valuable information about mechanisms and transition-state geometries of nucleophilic substitution reactions.⁴ Recently, Gleicher and Schleyer⁵ reported a correlation of experimental rate constants with the calculated energy difference between the hydrocarbon and the respective carbonium ion for five compounds. In addition, they used the correlation to predict the solvolytic rate constants of three bridgehead substituted compounds for which rate data had not been reported. One of these compounds was 1-bromobicyclo[3.3.1]nonane, whose predicted rate was approximately half the rate predicted for *t*-butyl bromide; the predicted rate of the latter compound was one-fifth the known experimental rate. We should like to report our results on the related 1-chlorobicyclo[3.3.1]nonane.

Recent work in this laboratory, related to the solvolysis of bicyclo[3.3.0]octane-1-carbinyl tosylate,⁶ provided a convenient synthesis of bicyclo[3.3.1]nonan-1-ol. The methyl ester of 1-carboxybicyclo[3.3.0]octane⁷ was converted into 1-hydroxymethylbicyclo[3.3.0]octane,⁶ mp 41–42°, with lithium aluminum hydride. The toluenesulfonate ester,⁶ mp 22–23°, was prepared in 91% yield from the bicyclic carbinol and tosyl chloride in pyridine at 0°. Hydrolysis of bicyclo[3.3.0]octane-1-carbinyl *p*-toluenesulfonate in 60% aqueous acetone gave bicyclo[3.3.1]nonan-1-ol⁶ (88%), mp 182.5–184°. The alcohol was easily converted in 84% yield into 1-chlorobicyclo[3.3.1]nonane, mp 87–88.5°, with thionyl chloride. Solvolytic studies were carried out in 60% aqueous ethanol, following a procedure similar to that of Winstein and Fainberg.⁸ Rate constants were calcu-

lated by the method of nonlinear least squares⁹ and are presented in Table I. Activation parameters were determined by a least-square analysis:⁹ $\Delta H^\ddagger_{25^\circ} = 22.8 \pm 0.4$ kcal/mol and $\Delta S^\ddagger_{25^\circ} = -8.2 \pm 1.0$ eu. Preparative scale solvolysis at 55° in 60% aqueous ethanol gave bicyclo[3.3.1]nonan-1-ol (90%) and 1-ethoxybicyclo[3.3.1]nonane (10%). The infrared spectrum of the alcohol was identical with that of an authentic sample and the ether was prepared from bicyclo[3.3.1]nonan-1-ol by a modified Williamson synthesis.

TABLE I
FIRST-ORDER RATE CONSTANTS^a IN 60% AQUEOUS ETHANOL

Substrate ^b	Temp., °C	$k_1 \times 10^4$, ^d sec ⁻¹
<i>t</i> -Butyl chloride	25.0	12.1 ^c
1-Chlorobicyclo[3.3.1]nonane	25.0	0.202 (calcd)
	44.9	2.34
	55.0	7.67
	65.0	21.2

^a Determined from two runs at each temperature. ^b 0.0008 $M \leq [\text{substrate}] \leq 0.0011 M$. ^c ± 0.1 . ^d $\pm 3\%$. ^e Previously reported as $12.3 \pm 0.10 \times 10^{-5} \text{ sec}^{-1}$.⁸

The experimental solvolytic rate of 1-chlorobicyclo[3.3.1]nonane is $\frac{1}{60}$ that of *t*-butyl chloride. The relative rates of a large number of tertiary alicyclic and bridged substrates with different halide leaving groups have been studied^{10,11} and no large variations in the halide rate ratios were reported. Also, a large body of evidence exists which suggests that solvent variations have little effect on the relative reactivities of alicyclic tertiary halides to bridgehead halides.^{4c} Thus, the difference in rates between *t*-butyl chloride and 1-chlorobicyclo[3.3.1]nonane should be a good approximation for the corresponding bromides. Consequently, the estimated rate of 1-bromobicyclo[3.3.1]nonane at 25° in 80% aqueous ethanol is $5.6 \times 10^{-6} \text{ sec}^{-1}$,¹² a rate which is seven times slower than predicted by Gleicher and Schleyer.⁵

A comparison of ΔH^\ddagger and ΔS^\ddagger for the solvolysis of the 1-chlorobicyclo[3.3.1]nonane with the values reported for *t*-butyl chloride¹³ indicates that in the former compound both terms make significant contributions to the decreased rate at 25°. The small difference in the free energies of activation (2.4 kcal/mol, 25°) of these two compounds may be anticipated in view of the conformation of the bicyclic system. The infrared spectrum of 1-chlorobicyclo[3.3.1]nonane had four sharp bands at 1484, 1464, 1449, and 1441 cm^{-1} , which were characteristic of the substituted bicyclo[3.3.1]nonanes encountered in this study. The band at 1490 cm^{-1} in the infrared spectrum of bicyclo[3.3.1]nonane has been assigned¹⁴ as a scissoring methylene vibration ($\delta(\text{CH}_2)$) which

(1) (a) This work was supported in part by Grant GP-3890, National Science Foundation. (b) After completion of this work, Professor P. von R. Schleyer kindly informed us of his study using the 1-bromo derivative; these two studies are being published simultaneously.

(2) National Institutes of Health Predoctoral Fellow, 1966–1967.

(3) P. D. Bartlett and L. H. Knox, *J. Amer. Chem. Soc.*, **61**, 3184 (1939).

(4) For excellent reviews, see (a) D. E. Applequist and J. D. Roberts, *Chem. Rev.*, **54**, 1065 (1954); (b) U. Schollkopf, *Angew. Chem.*, **72**, 147 (1960); (c) R. C. Fort, Jr., and P. von R. Schleyer, *Advan. Alicyclic Chem.*, **1**, 283 (1966).

(5) G. J. Gleicher and P. von R. Schleyer, *J. Amer. Chem. Soc.*, **89**, 582 (1967).

(6) R. A. Flath, Thesis, University of California at Berkeley, Berkeley, Calif., 1964.

(7) A. C. Cope and E. S. Graham, *J. Amer. Chem. Soc.*, **73**, 4702 (1951).

(8) A. H. Fainberg and S. Winstein, *ibid.*, **79**, 2770 (1956).

(9) We are indebted to Professor A. Streitwieser for providing copies of LSKINI and ACTENG computer programs, both of which were developed by Professor D. F. DeTar, Florida State University.

(10) A. Streitwieser, *Chem. Rev.*, **55**, 571 (1956).

(11) P. von R. Schleyer and R. D. Nicholas, *J. Amer. Chem. Soc.*, **83**, 2700 (1961).

(12) A value of $3.38 \times 10^{-4} \text{ sec}^{-1}$ was used for the rate of *t*-butyl bromide in 80% aqueous ethanol at 25°.¹⁰

(13) For *t*-butyl chloride in 60% aqueous ethanol, $\Delta H^\ddagger = 21.7$ kcal/mol and $\Delta S^\ddagger = -3.7$ eu [S. Winstein and A. H. Fainberg, *ibid.*, **79**, 5937 (1957)].

(14) G. Eglinton, J. Martin, and W. Parker, *J. Chem. Soc.*, 1243 (1965).

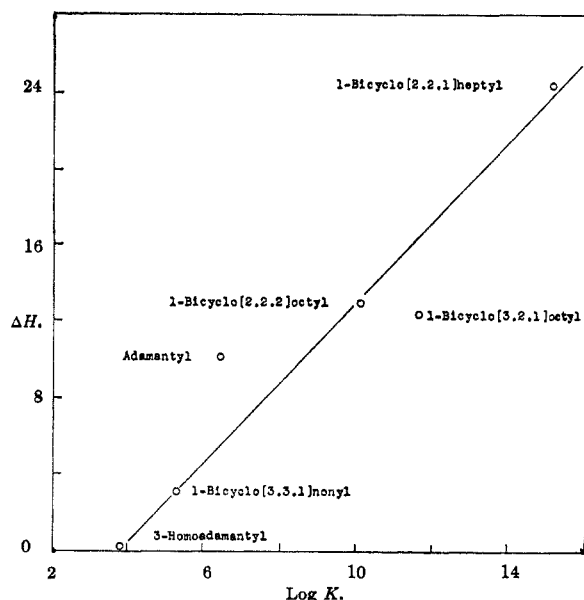


Figure 1.—Plot of the calculated hydrocarbon-carbonium ion strain differences (ΔH) against $-\log$ rate constants at 25° .

had been shifted to shorter wavelength because of steric interaction between C_3 and C_7 methylene groups in the chair-chair conformation. This shift is observed in both solid- and liquid-phase spectra. X-ray studies of substituted bicyclo[3.3.1]nonanes^{15,16} indicate that interactions between C_3 and C_7 methylene groups cause considerable "flattening" of the cyclohexane rings and distortion of the bond angles. In such a conformation, a developing bridgehead sp^2 center does not appear to introduce much additional strain into the bicyclic system.

Gleicher and Schleyer⁵ noticed an excellent linear correlation for 1-bromohomoadamantane, 1-bromobicyclo[2.2.2]octane, and 1-bromobicyclo[2.2.1]heptane and discussed, in detail, possibilities for the "anomalous" behavior of *t*-butyl bromide and 1-bromoadamantane; however, all five experimental rates were used for predictive purposes because of the limited rate data which were available. The rate predicted for 1-bromobicyclo[3.3.1]nonane by this method is in good agreement with our results. If the two "anomalous" points are excluded, the predicted rate calculated from eq 1, which represents the best

$$-\log k = 0.472\Delta H_{\text{strain}} + 3.78 \quad (1)$$

straight line through the three original points as determined by least-squares analysis, is $5.6 \times 10^{-6} \text{ sec}^{-1}$, identical with the experimental rate. From a recent report by Bly and Quinn,¹⁷ the extrapolated acetolysis rate of bridgehead substituted bicyclo[3.2.1]octyl *p*-bromobenzenesulfonate at 25° is 33 times slower than the corresponding [2.2.2] isomer, which represents a significant deviation from the predicted value, as shown in Figure 1. The validity of this comparison is somewhat mitigated by the series of long extrapolations necessary for a comparison of rates. The omis-

sion of the "anomalous" rate data might be open to question in view of the approximations which accompanied the strain calculations. It is evident, however, that the correlation of estimated strain energy differences with experimental rate constants is remarkable when factors which are not included in the calculations (*i.e.*, inductive effects, entropy of activation, etc.) are minimized by considering a family of similar compounds.

Experimental Section

Infrared spectra were recorded on a Perkin-Elmer Model 137 spectrometer as a 10% solution in carbon tetrachloride and nmr spectra were recorded on a Varian A-60 spectrometer as a 10% solution in carbon tetrachloride using tetramethylsilane as an internal standard.

Bicyclo[3.3.1]nonan-1-ol.—A solution of 3.741 g (0.013 mol) of bicyclo[3.3.0]octane-1-carbinyl tosylate and 2.0 g of calcium carbonate in 100 ml of 60% aqueous acetone was heated at 75° for 93 hr. The mixture was diluted with water and extracted with four portions of diethyl ether. The ether solution was washed with saturated sodium chloride solution and dried. The solvent was removed at reduced pressure and the remaining material sublimed at 85° (3 mm) to yield 1.607 g (88.4%) of a white solid: mp $182.5\text{--}184.0^\circ$; $\nu_{\text{max}}^{\text{CCl}_4}$ 3559, 3322, 2890, 2825 (sh), 1486, 1464, 1435, 1085, 1001, 932 cm^{-1} ; nmr (δ , ppm) 1.6 and 2.1 (15 H, multiplets), 3.6 (1 H, broad singlet, hydroxyl group).

1-Chlorobicyclo[3.3.1]nonane.—A solution of 0.999 g (7.15 mmol) of bicyclo[3.3.1]nonan-1-ol in 5 ml of thionyl chloride was heated at 34° for 14 hr. The solution was diluted with 150 ml of ice-water and extracted with four portions of pentane. The pentane solution was washed with two portions of saturated sodium bicarbonate solution and one portion of saturated sodium chloride solution. After drying, the pentane was removed at reduced pressure and the residue sublimed at 85° (20 mm) to give 0.948 g (84%) of a white solid: mp $87.0\text{--}88.5^\circ$; $\nu_{\text{max}}^{\text{CCl}_4}$ 2924, 1484, 1464, 1449, 1441, 1048, 963 cm^{-1} ; nmr (δ , ppm) 1.8 and 2.2 (multiplets).

Anal. Calcd for $C_8H_{15}Cl$ (158.69): C, 68.11; H, 9.55; Cl, 22.34. Found: C, 67.92; H, 9.35; Cl, 22.48.

Ethanolysis of 1-Chlorobicyclo[3.3.1]nonane.—Mixed ethanol-water solvent which consisted of 60% ethanol by volume was prepared from freshly distilled water and anhydrous ethanol.

A 100-ml volumetric flask which contained 1-chlorobicyclo[3.3.1]nonane (between 0.8×10^{-4} and 1.1×10^{-4} mol) and solvent was allowed to equilibrate. The reaction was followed through four half-lives by removing aliquots with a pipet and titrating liberated acid with $4.9 \times 10^{-4} N$ potassium hydroxide in 90% aqueous ethanol, using half-neutralized brom phenol blue as an indicator.⁸

In a preparative ethanolysis, a solution of 21.5 mg (0.136 mmol) of 1-chlorobicyclo[3.3.1]nonane in 4 ml of 60% aqueous ethanol was heated at 55° for 37 hr in a sealed tube. The solution was diluted with water and extracted with four portions of pentane. The pentane solution was washed with two portions of water and dried. Solvent was removed at reduced pressure to give 20 mg of a colorless semisolid, which consisted of bicyclo[3.3.1]nonan-1-ol (90%) and 1-ethoxybicyclo[3.3.1]nonane (10%).

1-Ethoxybicyclo[3.3.1]nonane.—A solution of 61 mg (0.44 mmol) of bicyclo[3.3.1]nonan-1-ol in 6 ml of anhydrous benzene was injected into a flask, under nitrogen, which contained 27 mg (1.13 mmol) of sodium hydride (obtained as a mineral oil dispersion from Metal Hydrides, Inc.). The suspension was heated at reflux for 1 hr and 0.624 g (4.00 mmol) of ethyl iodide was added. Heating was continued for 21 hr before the mixture was diluted with water and extracted with three portions of pentane. The pentane solution was washed with saturated sodium chloride solution and dried. Removal of solvent at reduced pressure gave 58 mg of a semisolid residue which consisted of bicyclo[3.3.1]nonan-1-ol (69%) and 1-ethoxybicyclo[3.3.1]nonane (31%). The components were separated by preparative vpc (10 ft \times 0.25 in. 10% Carbowax 6000 10% KOH, 150°); the ether was a colorless liquid: $\nu_{\text{max}}^{\text{CCl}_4}$ 2924, 1488, 1471, 1453, 1439, 1115, 1093 cm^{-1} ; nmr (δ , ppm) 1.05 (3 H, triplet, methyl group, $J = 7$ cps), 1.65 (13 H, multiplet),

(15) W. A. C. Brown, J. Martin, and G. A. Sim, *J. Chem. Soc.*, 1844 (1965).

(16) M. Dobler and J. D. Dunitz, *Helv. Chem. Acta*, **47**, 695 (1964).

(17) R. S. Bly and E. K. Quinn, Abstracts of the 153rd National Meeting of the American Chemical Society, Miami, Fla., April 1967, p 910.

2.1 (2 H, multiplet), 3.36 (2 H, quartet, ethoxymethylene group, $J = 7$ cps).

Anal. Calcd for $C_{11}H_{20}O$ (168.27): C, 78.51; H, 11.98. Found: C, 78.75; H, 12.00.

Registry No.—1-Chlorobicyclo[3.3.1]nonane, 15158-55-1; bicyclo[3.3.1]nonan-1-ol, 15158-56-2; 1-ethoxybicyclo[3.3.1]nonane, 15158-57-3.

Bridgehead Reactivity in Bicyclo[3.3.1]nonane Systems

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Bridgehead substituted derivatives provide excellent substrates for the study of the relationship between structure and reactivity.² Variations in reactivity are extreme; more than twelve powers of ten separate the solvolysis rates of 1-bicyclo[2.2.1]heptyl (I) and 3-homoadamantyl bromides (II).² While qualitative rationalizations for such large differences can easily be given,² it was only recently that an attempt to achieve quantitative understanding has been made.³

By using an approach based on computer conformational analysis, Gleicher and Schleyer examined four bridgehead bromides: I, II, the 1-adamantyl (III), and the 1-bicyclo[2.2.2]octyl (IV). The calculated increases in strain in going from ground states (models, the parent hydrocarbons) to transition states (models, the carbonium ions) when plotted against $-\log$ of the relative solvolysis rates gave a satisfactory correlation; the average deviation was $10^{\pm 0.3}$. This result seemed encouraging in view of the many assumptions which were required.³

Calculations were made on three additional bridgehead systems. For one compound, 1-bicyclo[3.2.1]octyl bromide (V), some solvolysis data was already available in the literature² and an additional investigation has since been reported.⁴ A second system, the 1-bicyclo[3.3.1]nonyl, was unknown in the literature and the rate calculated³ for the bromide was thus a true prediction. This note deals with the preparation of 1-bicyclo[3.3.1]nonyl bromide (VI), the determination of its solvolysis rate constants, and an interpretation of the results.⁵

(1) Taken, in part, from the A.B. Thesis of P. R. I., Princeton University, 1967.

(2) R. C. Fort, Jr., and P. von R. Schleyer, *Advan. Alicyclic Chem.*, **1**, 283 (1966).

(3) G. J. Gleicher and P. von R. Schleyer, *J. Amer. Chem. Soc.*, **89**, 582 (1967).

(4) R. S. Bly and E. K. Quinn, 153rd National Meeting of the American Chemical Society, Miami, Fla., April 1967, Abstracts, 91-0; and personal communication from Professor Bly. The extrapolated acetolysis rate of V-OBs at 25° is 33 times slower than IV-OBs.

(5) During the course of this work, we were informed of the completion of a similar study on 1-bicyclo[3.3.1]nonyl chloride [W. G. Dauben and C. D. Poulter, *J. Org. Chem.*, **33**, 1237 (1968)]. The results of the two investigations are in excellent agreement. We would like to thank Professor Dauben for the information and for his courtesy in agreeing to simultaneous publication of our results.

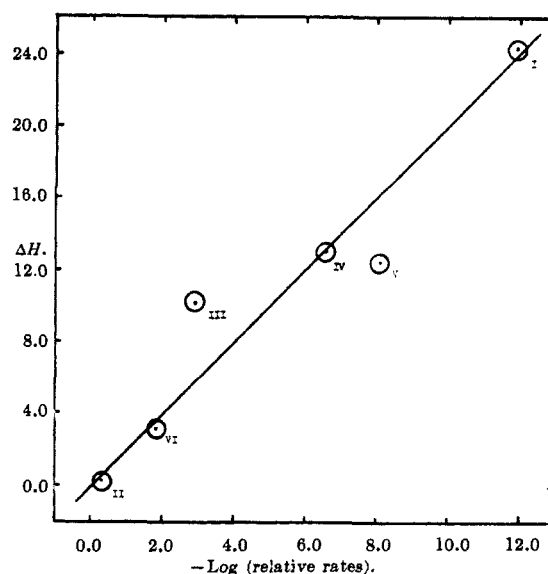
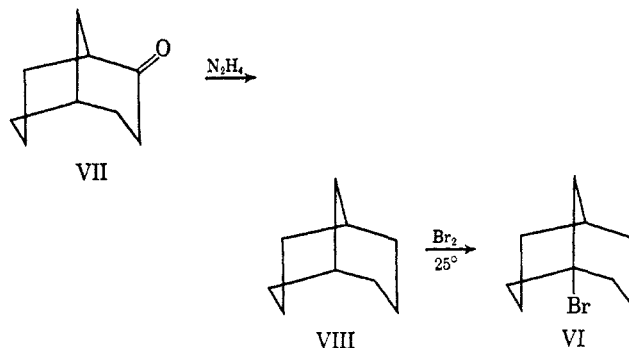


Figure 1.—Plot of the calculated hydrocarbon-carbonium ion strain differences (ΔH) plotted against $-\log$ of the experimental relative solvolysis rate constants.²

Bicyclo[3.3.1]nonan-2-one (VII)⁶ was reduced by the modified Wolff-Kishner method⁷ to give the parent hydrocarbon, VIII.⁸ Bicyclo[3.3.1]nonane (VIII)



could be brominated at the bridgehead position by stirring the hydrocarbon and bromine together at room temperature for 1 day. This observation provided the first indication of the relative reactivity of the bicyclo[3.3.1]nonane and adamantane systems, for adamantane is inert under these conditions and can only be brominated with elemental bromine at the reflux temperature.⁹ These brominations presumably are ionic reactions.⁹ 1-Bicyclo[3.3.1]nonyl bromide (VI), mp 52–53°, had an nmr spectrum somewhat reminiscent of that of 1-adamantyl bromide (IV).¹⁰ No $CHBr$ resonance characteristic of primary or secondary bromides was present, but rather two main absorptions centered at about δ 1.75 and 2.35 with some fine structure in the latter absorption (VIII, like adamantane,¹⁰ had essentially but one absorption position for the various kinds of protons, at δ 1.70). Hydrogenation of VI in the presence of Raney nickel¹¹ regenerated the parent hydrocarbon in 62% yield,

(6) M. Hartmann, *Z. Chem.*, **6**, 182 (1966).

(7) Huang-Minlon, *J. Amer. Chem. Soc.*, **68**, 2487 (1946).

(8) Cf., A. C. Cope, D. L. Nealy, P. Scheiner, and G. Wood, *ibid.*, **87**, 3130 (1965), and references therein cited.

(9) For a review, see R. C. Fort, Jr., and P. von R. Schleyer, *Chem. Rev.*, **64**, 277 (1964).

(10) R. C. Fort, Jr., and P. von R. Schleyer, *J. Org. Chem.*, **30**, 789 (1965).

(11) A procedure similar to that used by H. Stetter and P. Goebel, *Ber.*, **96**, 550 (1963), for the reduction of 3-homoadamantyl bromide was used.