(90%, xylene, 18 hours); Δ^7-5α-pregnen-3β-ol-20-one acetate (40%, xylene, 16 hours); 3α,12α-diacetoxybisnorcholanyldiphenyl ethylene (50%, *o*-dichlorobenzene, 16 hours).

(b) Δ^5-Cholestene-3-one was completely converted to $\Delta^{4,6}$-cholestadiene-3-one in 20 minutes when treated with chloranil in *t*-butyl alcohol.

Other Quinones.—Treatment of cortisol acetate (III) with various quinones at reflux temperature in the solvents indicated and examination of the ultraviolet absorption spectra of the crude products, isolated in the usual manner, gave the results described below:

(a) ***p*-Toluquinone in *n*-Amyl Alcohol.**—After 3 hours the product was a mixture of approximately 70% starting material III and 30% Δ^6-dehydro derivative IV.

(b) **1,2-Naphthoquinone in *n*-Amyl Alcohol.**—After 3 hours the product was a mixture of approximately 50% starting material III and 50% Δ^6-dehydro derivative IV.

(c) **2,6-Dichloro-*p*-benzoquinone in *sec*-Amyl Alcohol.**—After 2 hours the product was a mixture of approximately 50% each of Δ^6-bisdehydro and $\Delta^{1,6}$-bisdehydro derivatives (IV and VIII). No starting material was detected.

(d) **2,6-Dichloro-*p*-benzoquinone in *o*-Dichlorobenzene.**—After 3 hours the product was a mixture of approximately 40% starting material III and 60% Δ^6-dehydro derivative IV.

(e) ***p*-Benzoquinone in *n*-Amyl Alcohol.**—After 2 hours paper chromatographic analysis indicated the crude mixture contained Δ^6-dehydro derivative IV and starting material III in a ratio of 1:3.

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, MASSACHUSETTS INSTITUTE OF TECHNOLOGY]

Proximity Effects. XIX. Solvolysis of 4-Cycloöcten-1-yl Brosylate with Trifluoroacetic Acid[1,2]

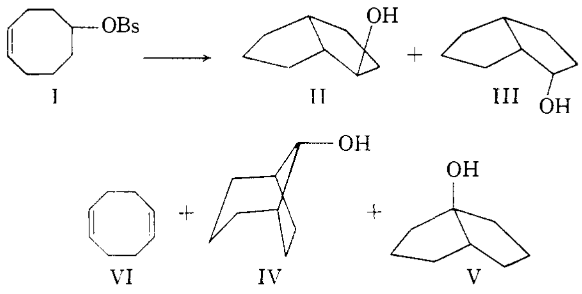
BY ARTHUR C. COPE, J. MARTIN GRISAR AND PAUL E. PETERSON[3]

RECEIVED NOVEMBER 10, 1959

Solvolysis of 4-cycloöcten-1-yl brosylate (I) with trifluoroacetic acid followed by hydrolysis gave the known alcohols *exo*- and *endo*-bicyclo[3.3.0]octan-2-ol (II and III) and the hitherto unknown alcohols *exo*-bicyclo[3.2.1]octan-8-ol (IV) and *cis*-bicyclo[3.3.0]octan-1-ol (V). Evidence for the structure and configuration of the unknown alcohols is presented and includes the synthesis of *endo*-bicyclo[3.2.1]octan-8-ol (X) from bicyclo[3.2.1]octan-8-one (VII) and *cis*-bicyclo[3.3.0]octan-1-ol (V) from bicyclo[3.3.0]oct-1(5)-ene oxide (XX). Solvolysis of *exo*-*cis*-bicyclo[3.3.0]oct-2-yl brosylate (XIV) also gave *exo*-bicyclo[3.2.1]octan-8-ol (IV) providing a basis for assignment of configuration to that alcohol. *trans*-2-Vinylcyclohexanol (XXIII) is obtained from solvolysis of 3-cycloöcten-1-yl brosylate but not from solvolysis of the 4-isomer I. 3-Cycloöcten-1-ol is therefore postulated to be a precursor of *trans*-2-vinylcyclohexanol (XXIII) in the solvolysis of *cis*-cyclooctene oxide and in the reaction of 1,5-cycloöctadiene (VI) with strong acids.

The solvolysis of 4-cycloöcten-1-yl brosylate (I) with acetic acid at 80° recently has been reported to give in 35% yield acetates of the alcohols *exo*- (32%) and *endo*-*cis*-bicyclo[3.3.0]octan-2-ol (48%) (II and III) and 4-cycloöcten-1-ol (20%).[4] The solvolysis of the brosylate I with trifluoroacetic acid and proof of the structure of two of the products are reported in this paper.

The solvolysis of 4-cycloöcten-1-yl brosylate (I) with trifluoroacetic acid at 25–30° followed by hydrolysis gave in 55% yield products that consisted of *exo*- (40%) and *endo*-*cis*-bicyclo[3.3.0]octan-2-ol (11%) (II and III), *exo*-bicyclo[3.2.1]-octan-8-ol (31%) (IV), *cis*-bicyclo[3.3.0]octan-1-ol (12%) (V) and 4-cycloöcten-1-ol (6%).



The crystalline brosylate I was solvolyzed by adding it to a twenty-fold molar excess of trifluoroacetic acid that contained sodium acetate to neutralize the *p*-bromobenzenesulfonic acid formed. The solvolysis products were separated from the reaction medium, hydrolyzed and distilled, and analyzed by gas chromatography. Alcohols III and V were isolated as separate fractions by distillation through a spinning band column, and IV was isolated from a distillation fraction that contained it together with II by repeated low temperature recrystallization. *exo*-Bicyclo[3.2.1]octan-8-ol (IV) was also obtained from 1,5-cycloöctadiene (VI) by treatment with 75% sulfuric acid. *exo*- and *endo*-*cis*-bicyclo[3.3.0]octan-2-ol (II and III) were identified by preparation of derivatives and comparison with authentic specimens.[5] The assignment of structures to alcohols IV and V is described in the following paragraphs.

***exo*-Bicyclo[3.2.1]octan-8-ol (IV).**—The structure of *exo*-bicyclo[3.2.1]octan-8-ol (IV) is shown by its oxidation to bicyclo[3.2.1]octan-8-one (VII). Its infrared spectrum is identical to that of the ketone obtained in 3.8% yield from cyclization of 2-(ω-bromopropyl)-cyclopentanone (VIII) following the procedure of Mayer, Wenschuh and Töpelmann.[6] The 2,4-dinitrophenylhydrazones of the ketone obtained by the two routes also had identical infrared spectra and showed no mixed melting point depression. To obtain evidence for the carbon skeleton of bicyclo[3.2.1]octan-8-one (VII), it was converted to its ethylenethioketal and desulfurized with Raney nickel to the known[7] bicyclo[3.2.1]octane (IX). The 8-position of the

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[1] Supported in part by a research grant (NSF-G5505) of the National Science Foundation.

[2] Paper XVIII, A. C. Cope, S. Moon and P. E. Peterson, THIS JOURNAL, **81**, 1650 (1959).

[3] National Institutes of Health Postdoctoral Fellow, 1956–1958.

[4] A. C. Cope and P. E. Peterson, THIS JOURNAL, **81**, 1643 (1959).

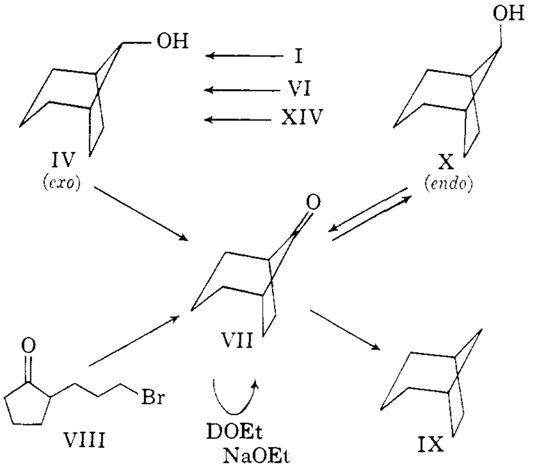
[5] A. C. Cope, M. Brown and H. E. Petree, *ibid.*, **80**, 2852 (1958).

[6] R. Mayer, G. Wenschuh and W. Töpelmann, *Chem. Ber.*, **91**, 1616 (1958).

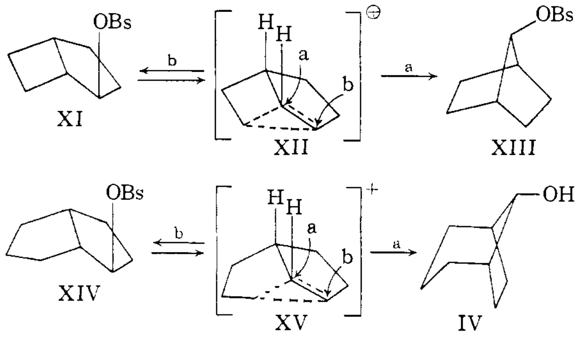
[7] M. S. Newman and Y. T. Yu, THIS JOURNAL, **74**, 507 (1952), and references cited therein.

keto group is indicated by Mayer's finding that no benzylidene derivative of VII is formed under conditions that normally introduce this function into ketones that have an α-methylene group,[6] and by our finding that no deuterium is incorporated into bicyclo[3.2.1]octan-8-one (VII) by treatment with alkaline deuterioethanol under conditions that cause exchange of α-carbonyl hydrogens unless they are situated at bridgehead positions as in VII (Bredt's rule).[8] The infrared spectrum of bicyclo[3.2.1]octan-8-one (VII) shows a split carbonyl peak with bands at 1740 and 1770 cm.$^{-1}$. The same split carbonyl band is observed in the infrared spectra of bicyclo[2.2.1]heptan-7-one[9] and in compounds containing that system.[10]

In an attempt to assign configuration to the bicyclo[3.2.1]octan-8-ol (IV or X), reductions that in other systems have known stereospecificity[11] were carried out on bicyclo[3.2.1]octan-8-one (VII). Catalytic reduction in acid solution, known to give predominantly the less stable isomer in many instances,[8a,11a] gave only *endo*-bicyclo[3.2.1]-octan-8-ol (X) and none of the *exo* isomer.[12] Sodium borohydride reduction in pyridine solution, generally known to give the product of "steric approach controlled" reaction,[11b] gave 64% of *endo*- and 36% of *exo*-bicyclo[3.2.1]octan-8-ol. Reduction with sodium in wet ether, reported to give the thermodynamically more stable product in other cases,[11c] gave 87% of the *endo* and 13% of the *exo* isomer. Reduction with sodium in isopropyl alcohol,[11c] following the procedure of Dev,[13] gave over 95% of *endo*-bicyclo[3.2.1]-octan-8-ol (X). Thus four reduction methods gave predominantly the same isomer in this case, and the reductions were of little value in establishing the configuration of the bicyclo[3.2.1]octan-8-ols (IV and X).



Assignment of the *exo* configuration to the bicyclo[3.2.1]octan-8-ol (IV) obtained from solvolysis of 4-cycloöcten-1-yl brosylate (I) and by reaction of 1,5-cycloöctadiene (VI) with sulfuric acid is based on the following experiments. Solvolysis of *exo*-bicyclo[3.2.0]hept-2-yl brosylate (XI) is reported to give bicyclo[2.2.1]hept-7-yl brosylate (XIII) and is postulated to proceed *via* a non-classical ion XII because of the observed internal ion return and the fact that the bicyclo-[3.2.0]hept-2-yl acetate found in the mixture of products has the *exo* configuration while none of the *endo* isomer was found to be present.[14] By analogy, it was postulated that if solvolysis of *exo*-bicyclo[3.3.0]oct-2-yl brosylate (XIV) gave bicyclo[2.2.1]octan-8-ol (IV or X), and if only one isomer with this structure was formed, it should have the *exo* configuration IV due to its formation *via* the non-classical ion XV (arrows indicate mode of attack by nucleophile). Similarly the bicyclo[3.3.0]octan-2-ol expected from that reaction should have the *exo* configuration (II). The solvolysis of *exo-cis*-bicyclo[3.3.0]oct-2-yl brosylate (XIV) with trifluoroacetic acid at 0° gave (after saponification) products in 59% yield that contained 29% of *exo*-bicyclo[3.2.1]octan-8-ol (IV), 32% of *exo-cis* bicyclo[3.3.0]octan-2-ol (II) (containing 3% of the *endo* isomer), 8% of *cis*-bicyclo-[3.3.0]octan-1-ol (V) and 31% of *cis*-bicyclo[3.3.0]-oct-2-ene (XVI). Samples of these compounds were obtained by collection from the gas chromatogram and identified by comparison of their infrared spectra with the spectra of authentic specimens. Since only one isomer of bicyclo[3.2.1]-octan-8-ol was found in the mixture of products (as shown by gas chromatography and the infrared spectrum), it is assigned the *exo* configuration (IV) and, since this alcohol is identical with the one obtained from 4-cycloöcten-1-yl brosylate (I) and 1,5-cycloöctandiene (VI), the bicyclo[3.2.1]-octan-8-ol obtained from these reactions also has the *exo* configuration (IV). Accordingly, the *endo* configuration (X) is assigned to the reduction product of bicyclo[3.2.1]octan-8-one (VII). To make certain that this reduction proceeds without rearrangement, *endo*-bicyclo[3.2.1]octan-8-ol (X) was oxidized and bicyclo[3.2.1]octan-8-one (VII) was



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[8] See (a) E. E. van Tamelen and C. I. Judd, THIS JOURNAL, **80**, 6305 (1958); (b) C. D. Gutsche, T. D. Smith, M. F. Sloan, J. J. Q. van Ufford and D. E. Jordan, *ibid.*, **80**, 4117 (1958).

[9] C. Norton, Ph.D. thesis, Harvard University, 1955.

[10] (a) C. F. H. Allen, T. Davis, D. W. Stewart and J. A. VanAllan, *J. Org. Chem.*, **20**, 306, 310 (1955); (b) P. Wilder, Jr., and A. Winston, THIS JOURNAL, **78**, 868 (1956); A. Winston, G. T. Youngblood and P. Wilder, Jr., *J. Org. Chem.*, **22**, 876 (1957).

[11] (a) D. H. R. Barton, *J. Chem. Soc.*, 1027 (1953), footnote 23; (b) W. G. Dauben, G. J. Fonken and D. S. Noyce, THIS JOURNAL, **78**, 2579 (1956); (c) W. Hückel, M. Maier, E. Jordan and W. Seeger, *Ann.*, **616**, 46 (1958).

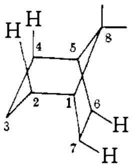
[12] The prefixes *exo* and *endo* refer to the relationship of a group on C_8 to the larger (6-membered) ring.

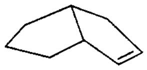
[13] S. Dev, *J. Indian Chem. Soc.*, **33**, 769 (1956); *cf.* M. R. Bell and S. Archer, THIS JOURNAL, **80**, 6147 (1958).

[14] S. Winstein, F. Gadient, E. T. Stafford and P. E. Klinedinst, Jr., *ibid.*, **80**, 5895 (1958).

obtained. Finally, it was shown that *endo*-bicyclo[3.2.1]octan-8-ol (X) is stable under the conditions under which the *exo* isomer is formed exclusively from I, VI and XIV.

This assignment of configuration is supported by the infrared spectra of the two isomers in carbon disulfide solution. It was found that the intensity of the band corresponding to hydrogen-bonded O–H stretching vibration (3370 cm.$^{-1}$) as compared to the band corresponding to free O–H stretching vibration (3650 cm.$^{-1}$) is greater for the *exo* (IV) than for the *endo* isomer (X). Since the *exo* isomer (IV) shows more hydrogen bonding, its hydroxyl group is less hindered than that of the *endo* isomer (X). This conclusion is in agreement with prediction based on inspection of Dreiding models. These models indicate that of the four axial hydrogen atoms (at C_2, C_4, C_6 and C_7) that influence the conformational stability of substituents at C_8, those at C_6 and C_7 are farther away from that substituent due to the tendency of the five-membered ring to be flattened compared to the six-membered ring.




XVI

The approximate relative rates of oxidation of *exo*- and *endo*-bicyclo[3.2.1]octan-8-ol (IV and X) with chromic anhydride in acetic acid were measured by a procedure of Schreiber and Eschenmoser.[15] The *endo* isomer (X) is oxidized faster than the *exo* isomer (IV) by a factor of approximately 15. To reach the same degree of completion, the *endo* isomer (X) required 1.4 hours, while the *exo* isomer (IV) required 22 hours under the same conditions. The rate-determining step in this reaction involves the abstraction of the hydrogen atom on the carbon atom bearing the hydroxyl group with simultaneous removal of the chromate ion of the intermediate chromate ester.[15,16] The degree to which approach to this hydrogen atom is conformationally obstructed and the relief of strain that accompanies removal of the chromate ion became apparent in the rate of oxidation. The alcohol that is oxidized more slowly (*exo*, IV) has the more hindered hydrogen atom at C_8 (in the *endo* position), approach to which is obstructed, and the less hindered hydroxyl group that allows less relief of strain on decomposition of the chromate ester. This result is in accord with the degree of hydrogen bonding, as shown by the infrared absorption spectra, and supports the assignment of configuration, based on the steric interpretation of the solvolysis of *exo-cis*-bicyclo[3.3.0]oct-2-yl brosylate (XIV).

endo-Bicyclo[3.2.1]octan-8-ol (X) was oxidized to bicyclo[3.2.1]octan-8-one (VII) with chromic anhydride in pyridine,[17] while the *exo* isomer (IV) was recovered unchanged when submitted to the same treatment.

An attempt to equilibrate the alcohols IV and X was unsuccessful. Both isomers were recovered unchanged after treatment with aluminum isopropoxide in isopropyl alcohol in the presence of acetone after ten days. This result can be understood when it is considered that the ketone through which the equilibration would have to proceed is considerably strained, while the alcohols are not. This strain is also evidenced by the slowness of oxidation of the bicyclo[3.2.1]octan-8-ols (particularly the *exo* isomer IV). The high carbonyl frequency at 1770 cm.$^{-1}$ in the infrared spectrum of bicyclo[3.2.1]octan-8-one (VII) approaches that of cyclobutanone (1775 cm.$^{-1}$) and suggests that the bond angle of the trigonal carbon atom in the 8-position is bent toward 90°. Finally, the fact that bicyclo[3.2.1]octan-8-one (VII) is formed in only very small yield by ring closure of 2-(ω-bromopropyl)-cyclopentanone (VIII)[6] may be compared with the ease of formation of other bicyclo-[3.2.1]octane derivatives in which the carbon atom in the 8-position is tetrahedral.[7,18] A striking example is the formation of bicyclo[3.2.1]-octane from *cis*-bicyclo[3.3.0]octane on treatment with aluminum chloride.[19] It is likely that the formation of *exo*-bicyclo[3.2.1]octan-8-ol (IV) from 4-cycloöcten-1-yl brosylate (I) also proceeds through a bicyclo[3.3.0]octyl carbonium ion (possibly XV) as indicated by the solvolytic conversion of *exo-cis*-bicyclo[3.3.0]-oct-2-yl brosylate (XIV) to *exo*-bicyclo[3.2.1]octan-8-ol (IV).

***cis*-Bicyclo[3.3.0]octan-1-ol (V).**—The unknown alcohol later identified as *cis*-bicyclo[3.3.0]octan-1-ol (V) was isolated from the solvolysis products of 4-cycloöcten-1-yl brosylate (I) and characterized. Its analysis ($C_8H_{14}O$), molecular weight (126, determined by the mass spectrum),[20] and a negative tetranitromethane test indicated that it is a bicyclic compound. The hydroxyl function was shown to be present by the infrared spectrum and by the formation of a phenylurethan, m.p. 98°. The tertiary character of the alcohol was made likely by unsuccessful attempts to oxidize V with chromic anhydride in pyridine,[17] chromic acid in sulfuric acid and N-bromosuccinimide in acetone, and by the mass spectrum that was shown to have a cracking pattern similar to that of bicyclo[2.2.1]heptan-1-ol.[20] Since a number of bicyclic C_8-alcohols are known to us or described in the literature[21–23] and could be eliminated as possible structures by comparison of physical properties with those of

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(15) J. Schreiber and A. Eschenmoser, *Helv. Chim. Acta*, **38**, 1529 (1955).

(16) H. Kwart and P. S. Francis, THIS JOURNAL, **81**, 2116 (1959).

(17) By a procedure described by G. I. Poos, G. E. Arth, R. E. Beyler and L. H. Sarett, *ibid.*, **75**, 422 (1953).

(18) (a) W. R. Vaughan and A. C. Schoenthaler, *ibid.*, **80**, 1956 (1958), and earlier papers; (b) W. C. Wildman and D. R. Saunders, *ibid.*, **76**, 946 (1954); (c) H. M. Walborsky, *Experientia*, **9**, 209 (1953).

(19) J. W. Barrett and R. P. Linstead, *J. Chem. Soc.*, 611 (1936), and earlier papers.

(20) We are indebted to K. Biemann and J. Seibl for mass spectra and their interpretation; *cf.* K. Biemann and J. Seibl, THIS JOURNAL, **81**, 3149 (1959).

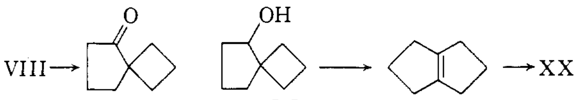
(21) Bicyclic alcohols *endo*- and *exo*-bicyclo[3.3.0]octan-2-ol (ref. 2), all seven isomers of bicyclo[4.2.0]octanol (ref. 22), *endo*- and *exo*-bicyclo[5.1.0]octan-2-ol (ref. 23) and *endo*- and *exo*-bicyclo[3.2.1]octan-8-ol (IV and X) are known, as well as one isomer each of bicyclo[3.3.0]-octan-3-ol (ref. 19), 2- and 6-bicyclo[3.2.1]octanol (ref. 7, footnote 4a-d).

(22) A. C. Cope and R. W. Gleason, unpublished work.

(23) Reference 1 and A. C. Cope and S. Moon, unpublished work.

the unknown alcohol, and since the formation of bicyclo[3.3.0]octan-1-ol (V) from bicyclo[3.3.0]-octan-2-ol (II or III) could be explained reasonably by a 1,2-hydride shift or by a dehydration and protonation process with formation of an intermediate tertiary carbonium ion, the synthesis of this alcohol was undertaken.

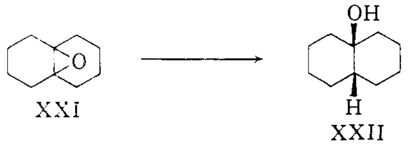
Spiro[3,4]octan-5-ol (XVIII) was prepared by reduction of spiro[3,4]octan-5-one (XVII), the main product of cyclization of 2-(ω-bromopropyl)-cyclopentanone (VIII), and bicyclo[3.3.0]oct-1(5)-ene (XIX) was obtained from XVIII by treatment with zinc chloride, following the procedure of Vogel.[24] The product obtained in this way contained 76% of XIX and two isomeric olefins (13 and 11%, respectively). Pure bicyclo[3.3.0]oct-1(5)-ene (XIX) was obtained by collection from the effluent gas of the gas chromatogram. The tetrasubstituted character of the double bond in XIX is evidenced by the infrared spectrum and by the formation of a blue nitrosochloride. From XIX bicyclo[3.3.0]oct-1(5)-ene oxide (XX) was obtained by treatment with peracetic acid at 10–15°. Catalytic hydrogenation of bicyclo[3.3.0]oct-1(5)-ene oxide (XX) over W-7 Raney nickel formed *cis*-bicyclo[3.3.0]octan-1-ol (V).



XVII XVIII XIX

Catalytic hydrogenations of epoxides have been reported to give the *cis* isomers. 5α-Cholestan-4α-ol was obtained by catalytic hydrogenation of 4α,5-epoxy-5α-cholestane.[25] To provide further analogy, 9,10-octalin oxide (XXI)[26] was treated with hydrogen at atmospheric pressure over W-7 Raney nickel catalyst. The alcohol obtained was *cis*-9-decalol (XXII).[27]

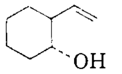
XX V



XXI XXII

cis-Bicyclo[3.3.0]octan-1-ol (V), obtained by catalytic reduction of bicyclo[3.3.0]oct-1(5)-ene oxide (XX), was found to be identical with the compound isolated from solvolysis of 4-cycloöcten-1-yl brosylate (I) and *exo-cis*-bicyclo[3.3.0]-oct-2-yl brosylate (XIV).

***trans*-2-Vinylcyclohexanol (XXIII).**—It is interesting to note that *trans*-2-vinylcyclohexanol (XXIII) is *not* formed in the solvolysis of 4-cycloöcten-1-yl brosylate (I). This compound had been found among the solvolysis products of *cis*-cycloöctene oxide and the products formed from 1,5-cycloöctadiene (VI) and formic acid containing perchloric acid.[4] As a test of possible mechanisms for the formation of *trans*-2-vinylcyclohexanol we were interested in finding whether this alcohol could be formed from 3-cycloöcten-1-ol or from 4-cycloöcten-1-ol. A mixture of these two alcohols was found to give *trans*-2-vinylcyclohexanol on treatment with trifluoroacetic acid at the reflux temperature. The same treatment of each of the two isomeric alcohols also gave *trans*-2-vinylcyclohexanol (XXIII), although more of XXIII was formed from 3-cycloöcten-1-ol. However, results of solvolysis of the brosylates of the alcohols in trifluoroacetic acid at room temperature indicated that 3-cycloöcten-1-ol or one of its derivatives is the more immediate precursor of *trans*-2-vinylcyclohexanol in its formation from 1,5-cycloöctadiene (VI), *cis*-cycloöctene oxide and 4-cycloöcten-1-ol.



XXIII

The solvolysis of 3-cycloöcten-1-yl brosylate was carried out under conditions similar to those described for the solvolysis of 4-cycloöcten-1-yl brosylate (I), and 7% of the product obtained in 61% yield was found to be *trans*-2-vinylcyclohexanol (XXIII). The remainder of the product was 3-cycloöcten-1-ol. To make sure that small amounts of *trans*-2-vinylcyclohexanol (XXIII) would survive the solvolysis of 4-cycloöcten-1-yl brosylate (I) and be found by gas chromatographic analysis, a sample of XXIII was added initially to that solvolysis reaction mixture. Analysis indicated that 47% survived the reaction and isolation. Solvolysis of 4-cycloöcten-1-yl brosylate (I) without prior addition of XXIII gave products containing no detectable amounts of XXIII. The mechanism described in a previous paper (ref. 4, Fig. 4) is in accord with the above findings and with the formation of *trans*-2-vinylcyclohexanol from the various starting materials.

Experimental[28]

Solvolysis of 4-Cycloöcten-1-yl Brosylate (I).—To a solution of 1.03 g. (0.012 mole) of anhydrous sodium acetate in 22.8 g. (0.2 mole) of trifluoroacetic acid was added 3.45 g. (0.01 mole) of 4-cycloöcten-1-yl brosylate (I)[4] over a period of 15 minutes and the mixture was stirred for 2 hours at 25–30° with exclusion of atmospheric moisture. The mixture was taken up in 100 ml. of ether, washed with ten 100-ml. portions of water, three 100-ml. portions of a 10% sodium carbonate solution and with 100 ml. of water. After drying over magnesium sulfate, the solvent was removed under reduced pressure. In order to saponify esters the mixture was shaken overnight with 100 ml. of a 10% sodium hydroxide solution at room temperature. The product was extracted with four 50-ml. portions of ether and the combined extracts were washed with three 50-ml. portions of water and dried over magnesium sulfate. Distillation through a short path

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[24] E. Vogel, *Chem. Ber.*, **85**, 25 (1952).

[25] P. A. Plattner, T. Petrzilka and W. Lang, *Helv. Chim. Acta*, **27**, 513 (1944).

[26] W. Hückel, R. Danneel, A. Schwartz and A. Gercke, *Ann.*, **474**, 121 (1929).

[27] W. Hückel and M. Blohm, *ibid.*, **502**, 114 (1933); W. Hückel, *ibid.*, **533**, 1 (1937).

[28] Melting points are corrected and boiling points are uncorrected. We are indebted to Dr. S. M. Nagy and his associates for analyses and to Mr. J. Nemeth, University of Illinois, for a deuterium analysis. Gas chromatography columns used are described in ref. 4, footnote 24. Base-washed columns were prepared by wasbing 25 g. of firebrick with 100 ml. of a 1% methanolic sodium hydroxide solution and evaporating the solvent under reduced pressure.

still gave 0.69 g. (55% yield) of product. Gas chromatography on a base-washed Silicone oil column (170°) and on a tris-(2-cyanoethoxy)-propane column (150°) showed the product to contain 40% of *exo-cis*-bicyclo[3.3.0] octan-2-ol (II), 11% of *endo-cis*-bicyclo[3.3.0]octan-2-ol (III), 31% of *exo*-bicyclo[3.2.1]-octan-8-ol (IV), 12% of *cis*-bicyclo[3.3.0]-octan-1-ol (V) and 6% of 4-cycloöcten-1-ol.

Variation of the reaction temperature showed that at 0–5° the formation of III, IV and 4-cycloöcten-1-ol is favored at the expense of the other two products, while at 75° increased amounts of II and V are formed and no 4-cycloöcten-1-ol. The yields in these two reactions were 50 and 48%, respectively.

The known *exo-cis*-bicyclo[3.3.0]octan-2-ol (II) was identified by its gas chromatographic retention time and preparation of a phenylurethan from a distillation fraction containing II, contaminated by III and IV. Although the m.p. (66–76°) of this derivative indicates that it is contaminated by the phenylurethans of III and IV (m.p. 88 and 125°, respectively), its infrared spectrum on comparison with that of an authentic sample, m.p. 76°,[5] showed that *exo-cis*-bicyclo[3.3.0]oct-2-yl phenylurethan was the major component.

A sample of *endo-cis*-bicyclo[3.3.0]octan-2-ol (III) was obtained by distillation through a spinning band column and from it a phenylurethan was prepared, m.p. 87–88°. The mixed m.p. with a known sample was undepressed, and the infrared spectrum was identical with that of an authentic sample.[5] The *endo* and *exo* isomers of this alcohol can be separated by gas chromatography on a tris-(2-cyanoethoxy)-propane column (150°).[4]

***exo*-Bicyclo[3.2.1]octan-8-ol (IV) from 4-Cycloöcten-1-yl Brosylate (I).**—*exo*-Bicyclo[3.2.1]octan-8-ol (IV) was isolated by repeated low temperature recrystallization from petroleum ether and hexane of a distillation fraction that contained it together with II. The m.p. (sealed tube) was 191.2–192.4°.

Anal. Calcd. for $C_8H_{14}O$: C, 76.14; H, 11.18. Found: C, 75.91; H, 11.07.

A phenylurethan was prepared by adding 65 mg. of phenyl isocyanate to 40 mg. of IV, heating the mixture to 90° for 1 hour in a closed tube and allowing the crude phenylurethan to stand overnight under reduced pressure at 70° to remove excess phenyl isocyanate. The crude phenylurethan was dissolved in *ca.* 40 ml. of pentane and filtered to remove diphenylurea. The product obtained upon evaporation of the pentane was recrystallized from petroleum ether (b.p. 37–52°) to a constant m.p. of 124.8–125.6°.

Anal. Calcd. for $C_{15}H_{19}NO_2$: C, 73.44; H, 7.81; N, 5.71. Found: C, 73.40; H, 7.69; N, 5.77.

A tosylate was prepared by adding a cooled solution of 1.52 g. (7.7 mmoles) of *p*-toluenesulfonyl chloride in 10 ml. of pyridine to a cooled solution of 504 mg. (4 mmoles) of IV in 10 ml. of pyridine, and allowing the mixture to stand in a refrigerator overnight. After dropwise addition of 50 ml. of water, the product was extracted with three 50-ml. portions of ether. The combined extracts were washed with four 70-ml. portions of 6 *N* hydrochloric acid, four 70-ml. portions of a saturated sodium bicarbonate solution and two 70-ml. portions of water, and dried over magnesium sulfate. The crude product obtained upon careful evaporation of the ether was recrystallized from pentane and 759 mg. (68% yield) of *exo*-bicyclo[3.2.1]oct-8-yl tosylate was obtained. A portion of this material was recrystallized from pentane to a constant m.p. of 78.4–79.0°. The infrared spectrum of *exo*-bicyclo-[3.2.1]octan-8-ol (IV) is described below together with that of the *endo* isomer.

Anal. Calcd. for $C_{15}H_{20}O_3S$: C, 64.27; H, 7.19. Found: C, 64.44; H, 7.08.

***cis*-Bicyclo[3.3.0]octan-1-ol (V) from 4-Cycloöcten-1-yl Brosylate (I).**—Pure *cis*-bicyclo[3.3.0]octan-1-ol (V) was isolated as a fraction from distillation through a 90 × 0.5-cm. spinning band column operated at 1550 r.p.m.; b.p. 88° (11 mm.), m.p. 45–46.5°. The infrared spectrum (carbon disulfide) showed major bands at 1315(s), 1295(m), 1210(s), 1175(m), 1125(m), 1080(m), 1055(w), 1015(s), 990(s), 935(m), 920(m), 875(m) and 830(w) cm.$^{-1}$.

Anal. Calcd. for $C_8H_{14}O$: C, 76.14; H, 11.18. Found: C, 76.03; H, 11.20.

A phenylurethan was prepared by the method described for the preparation of *exo*-bicyclo[3.2.1]oct-8-yl phenylurethan and was recrystallized from petroleum ether to a constant m.p. of 97.6–98.4°.

Anal. Calcd. for $C_{15}H_{19}NO_2$: C, 73.44; H, 7.81; N, 5.71. Found: C, 73.45; H, 7.73; N, 5.92.

***exo*-Bicyclo[3.2.1]octan-8-ol (IV) from 1,5-Cycloöctadiene (VI).**—To 500 g. of 75% sulfuric acid (390 g. of 96% sulfuric acid and 110 g. of water) was added 108 g. (1 mole) of *cis-cis*-1,5-cycloöctadiene at such a rate that a temperature of 5–10° could be maintained with an ice–salt-bath (18 minutes). The reaction mixture was stirred vigorously for 1 hour at 5–10° and then poured on 1 kg. of ice. A steam distillation was followed by extraction of the distillate with ether, washing with saturated sodium bicarbonate solution and water, drying over magnesium sulfate, and evaporation of solvent at atmospheric pressure, giving 94.1 g. of crude product. Distillation through a semi-micro column gave a hydrocarbon fraction, b.p. 41–75° (19 mm.), an ether fraction, b.p. 76–85° (19 mm.), and a fraction containing alcohols, b.p. 86–109° (19 mm.). Gas chromatography on a Silicone oil column (195°) showed that the product, 79.3 g. (64% yield), contained 17% (13.9 g.) of *exo*-bicyclo[3.2.1]octan-8-ol (IV) (little or none of the *endo* isomer was formed). Redistillation of the alcohol fraction through a 90 × 0.5-cm. spinning band column permitted isolation of 22.7 g. of material that contained *exo-cis*-bicyclo[3.3.0]octan-2-ol (II) (approximately 60%) and *exo*-bicyclo[3.2.1]octan-8-ol (IV) (approximately 40%). Low temperature recrystallizations (under nitrogen) were followed by gas chromatography. After four recrystallizations from petroleum ether (b.p. 37–52°) and two recrystallizations from hexane, 450 mg. of material was obtained that was homogeneous according to gas chromatography on a base-washed Silicone oil column (170°), m.p. (sealed tube) 189.4–191.4°. The infrared spectrum of this material was identical to that of *exo*-bicyclo[3.-2.1]octan-8-ol (IV) obtained from 4-cycloöcten-1-yl brosylate (I). Chromatography on alumina (activity I) permitted isolation of fractions enriched in IV from the mother liquors; IV is eluted faster than II.

Bicyclo[3.2.1]octan-8-one (VII) from *exo*-Bicyclo[3.2.1]-octan-8-ol (IV).—A solution of 625 mg. (5 mmoles) of *exo*-bicyclo[3.2.1]octan-8-ol (IV) in 10 ml. of acetone was stirred at 0° and to it was added dropwise a solution of 3.0 g. (10 mmoles) of sodium bichromate monohydrate and 2.0 g. of concd. sulfuric acid in 10 ml. of water. After stirring at 0° for 2 hours, 30 ml. of water was added and the mixture was extracted with three 50-ml. portions of ether. The combined ether layers were washed with three 50-ml. portions of water, two 50-ml. portions of saturated sodium bicarbonate solution and two 50-ml. portions of water, and dried over magnesium sulfate. Evaporation of the ether at atmospheric pressure gave the crude product (518 mg.), a portion of which was converted to the 2,4-dinitrophenylhydrazone which after recrystallization from ethanol was analytically pure and had a constant melting point of 175.2–176.2° (reported[6] 175–176°).

That the ketone still contained some of the alcohol IV was shown by an unsuccessful attempt to purify it by recrystallization from pentane or by sublimation. A portion of the product (119 mg.) was refluxed for 1.5 hours with 620 mg. of Girard Reagent T and 75 mg. of Amberlite IRC-50(H)$^+$ in 6 ml. of 96% ethanol. Water (20 ml.) was added, and the alcohol IV was extracted with two 25-ml. portions of ether. The water layer was added to 10 ml. of 37% formaldehyde and allowed to stand overnight under nitrogen. Extraction with three 25-ml. portions of ether, followed by washings with five 50-ml. portions of water, drying over magnesium sulfate, and evaporation of ether at atmospheric pressure, gave 77 mg. of crude product which upon sublimation at 80° under nitrogen at atmospheric pressure (closed apparatus) gave 46 mg. of bicyclo[3.2.1]octan-8-one (VII), m.p. 130–138° (sealed tube). The infrared spectrum (potassium bromide pellet) showed a characteristic split carbonyl band.

Bicyclo[3.2.1]octan-8-one (VII) from 2-(ω-Bromopropyl)-cyclopentanone (VIII).—Bicyclo[3.2.1]octan-8-one (VII) was obtained in 3.8% yield from VIII by the procedure described by Mayer, Wenschuh and Töpelmann.[6] After three sublimations, the ketone melted at 132–136.5° (sealed tube) and a sample collected from the effluent gas of the gas chromatogram on Silicone oil melted at 141.5–143.2° (sealed tube) (reported[6] 134–136°). The melting point was not depressed by admixture with the ketone obtained from *exo*-bicyclo-[3.2.1]octan-8-ol (IV), described above. The infrared spectra of the ketone obtained by the two routes were identical. Infrared spectra were taken in potassium bromide pellets, and as 10% solutions in carbon disulfide and carbon tetrachloride. All spectra showed the split carbonyl band with peaks at 1770, 1740 and 1705 cm.$^{-1}$, the 1740 band having about twice the intensity of the 1770 band while the 1705 band was weak (shoulder in potassium bromide).

A 2,4-dinitrophenylhydrazone was prepared, m.p. 175.2–176.2°. It showed no melting point depression when mixed with the 2,4-dinitrophenylhydrazone of the oxidation product of *exo*-bicyclo[3.2.1]octan-8-ol (IV), and the infrared spectra of the two derivatives were identical.

Bicyclo[3.2.1]octane (IX) from Bicyclo[3.2.1]octan-8-one (VII).—Boron trifluoride etherate (0.8 ml., freshly distilled, b.p. 127°) was added to a solution of 252 mg. (2 mmoles) of bicyclo[3.2.1]octan-8-one (VII) in 0.8 ml. of 1,2-ethanedithiol and the mixture was allowed to stand at room temperature for 13 hours.[8a] The resulting heterogeneous mixture was transferred to a separatory funnel with 2 ml. of glacial acetic acid, diluted with 30 ml. of water and extracted with three 30-ml. portions of ether. The combined ether extracts were washed with two 30-ml. portions of water and dried over magnesium sulfate. Evaporation of the ether under reduced pressure left 426 mg. of crude ethylenethioketal. Approximately 6 g. of W-5 Raney nickel in 10 ml. of absolute ethanol was added, and the mixture was refluxed for 1 hour. After cooling, 90 ml. of water was added, and the product was extracted with three 30-ml. portions of ether. The combined ether layers were washed with two 30-ml. portions of water, dried over magnesium sulfate and the ether was removed at atmospheric pressure. Sublimation of the crude product under nitrogen at 70° at atmospheric pressure (closed apparatus) gave 86 mg. (39% yield) of bicyclo[3.2.1]octane. After two resublimations over phosphorus pentoxide, an analytically pure sample of IX, m.p. 137.5–139.5° (sealed tube), was obtained.

Deuterium Exchange of Bicyclo[3.2.1]octan-8-one (VII).—Sodium (*ca.* 160 mg.) was dissolved in 8 ml. of deuterioethanol and to this solution was added 129 mg. (1.04 mmoles) of bicyclo[3.2.1]octan-8-one (VII). After allowing the solution to stand at room temperature for 24 hours, 4 ml. of deuterium oxide and 20 ml. of anhydrous ether were added. The supernatant layer was washed with another 4 ml. of deuterium oxide to remove alkali while ethanol was removed with three 20-ml. portions of water. After drying over magnesium sulfate, the ether was evaporated at atmospheric pressure and the product sublimed under nitrogen at 80° at atmospheric pressure (closed apparatus). The product (59 mg., 46% recovery) melted high (141–147°). The infrared spectrum identified it as bicyclo[3.2.1]octan-8-one (VII) but indicated a contamination with *endo*-bicyclo[3.2.1]octan-8-ol (X) that gas chromatography showed to amount to 13%.

Deuterium analysis showed that no deuterium had been exchanged (about 1% of the amount of deuterium corresponding to exchange of both α-hydrogen atoms, or 0.16% excess deuterium was found).

Reductions of Bicyclo[3.2.1]octan-8-one (VII). A. Catalytic Reduction in Acid Solution.—Bicyclo[3.2.1]octan-8-one (VII) (124 mg., 1 mmole) was dissolved in 10 ml. of acetic acid containing 2 drops of hydrochloric acid and hydrogenated in the presence of pre-reduced platinum oxide. In 2 hours 107% of the calculated amount of hydrogen was absorbed. The catalyst was removed by filtration, and the solution was diluted with 75 ml. of water and extracted with three 25-ml. portions of ether. The combined ether layers were washed with two 25-ml. portions of water, and the oil obtained after removal of the ether was refluxed for 1 hour with 5% sodium hydroxide in 50% aqueous methanol to hydrolyze acetates. The product was extracted with three 25-ml. portions of ether and the combined ether layers were washed with three 30-ml. portions of water and dried over magnesium sulfate. Sublimation under nitrogen at 80° at atmospheric pressure (closed apparatus) gave 80 mg. (65% yield) of *endo*-bicyclo[3.2.1]octan-8-ol (X).

Gas chromatography on a base-washed Silicone oil column (170°) showed the product to be homogeneous. The infrared spectrum (potassium bromide pellet) was identical to that of an analytical sample described below.

B. Reduction with Sodium Borohydride in Pyridine.—Sodium borohydride (100 mg., 2.65 mmoles) was dissolved in 5 ml. of pyridine and, while stirred at room temperature, a solution of 200 mg. (1.61 mmoles) of bicyclo[3.2.1]octan-8-one (VII) in 8 ml. of pyridine was added dropwise. The mixture was stirred at 100° for 12 hours. After cooling, 10 ml. of 5% sodium hydroxide was added, and stirring was continued for 2 hours. Ether (30 ml.) was added, and the aqueous phase was extracted with an additional 30-ml. portion of ether. To remove pyridine, the combined ether layers were washed with three 30-ml. portions of 6 *N* hydrochloric acid and with 30-ml. portions of saturated sodium bicarbonate solution, and dried over magnesium sulfate. After evaporation of the ether at atmospheric pressure, the crude product was sublimed under nitrogen at 80° at atmospheric pressure, (closed apparatus), and 112 mg. (56% yield) of product was obtained. The infrared spectrum (potassium bromide pellet) identified the product as *endo*- and *exo*-bicyclo[3.2.1]octan-8-ol (IV and X), and gas chromatography on a base-washed Silicone oil column (170°) showed the mixture to contain 36% of the *exo* and 64% of the *endo* isomer.

C. Reduction with Sodium in Wet Ether.—To a solution of 200 mg. (1.61 mmoles) of bicyclo[3.2.1]octan-8-one (VII) in 5 ml. of ether over 5 ml. of nearly saturated potassium carbonate solution was added *ca.* 0.5 g. of sodium in small pieces. The reaction was complete after 3 hours. Water (20 ml.) was added, and the ether layer was separated. After extraction of the aqueous layer with an additional 20-ml. portion of ether, the combined ether extracts were washed with two 20-ml. portions of water and dried over magnesium sulfate. After evaporation of the ether at atmospheric pressure, the product was sublimed under nitrogen at 80° at atmospheric pressure (closed apparatus) and 170 mg. (85% yield) of material was obtained. The infrared spectrum identified the product as *endo*- and *exo*-bicyclo-[3.2.1]octan-8-ol (IV and X) and gas chromatography on a base-washed Silicone oil column (170°) showed the mixture to contain 13% of the *exo* and 87% of the *endo* isomer.

D. Reduction with Sodium in Isopropyl Alcohol.—A suspension of 3.5 g. of sodium sand in 20 ml. of benzene was stirred at the reflux temperature under nitrogen, and a solution of 124 mg. (1 mmole) of bicyclo[3.2.1]octan-8-one (VII) in 9.0 g. (0.15 mole) of dry isopropyl alcohol was added dropwise over a period of 35 minutes. After the mixture was stirred for 1.3 hours and benzene was added to replace the amount evaporated by the nitrogen stream, an additional 10-ml. portion of isopropyl alcohol was added dropwise over a period of 50 minutes. After allowing the mixture to cool, 50 ml. of water was added carefully. The benzene layer was separated, and the water layer extracted with two 50-ml. portions of ether. The combined extracts were washed with three 50-ml. portions of water and 50 ml. of brine, and dried over magnesium sulfate. The solvents were evaporated under atmospheric pressure in a nitrogen stream and the crude product was sublimed at atmospheric pressure under nitrogen (closed apparatus) at 80° and 86 mg. (68% yield) of product was obtained. Gas chromatography on a base-washed Silicone oil column (170°) showed the product to be *endo*-bicyclo[3.2.1]-octan-8-ol (X) contaminated with less than 5% of the *exo* isomer IV. The infrared spectrum of the product was identical to that of *endo*-bicyclo[3.2.1]-octan-8-ol (X).

***endo*-Bicyclo[3.2.1]octan-8-ol (X).**—Pure *endo*-bicyclo-[3.2.1]octan-8-ol (X) was obtained by fractional sublimation at atmospheric pressure under nitrogen (closed apparatus) at 80° of the product from reduction of bicyclo[3.2.1]octan-8-one (VII) with hydrogen over platinum in an acidic medium (method A described above), m.p. 199–200.5° (sealed tube); the melting point was only slightly depressed (to 193–195°) by admixture with the *exo* isomer (m.p. 191–192°).

Anal. Calcd. for $C_8H_{14}O$: C, 76.14; H, 11.18. Found: C, 76.31; H, 11.20.

Gas chromatography on a base-washed Silicone oil column (170°) separated the two isomers. The *endo* isomer was retained longer.

Infrared spectra of pure samples of *exo*- and *endo*-bicyclo-[3.2.1]octan-8-ol (IV and X) in carefully prepared 10% solutions in carbon disulfide showed the following characteristic bands: *exo* isomer, 955, 1030 and 1058 cm.$^{-1}$; *endo* isomer, 955, 1040 and 1078 cm.$^{-1}$; the 955 cm.$^{-1}$ band of the *exo* isomer is stronger than that of the *endo* isomer. The ratio of the intensity of the band corresponding to hydrogen-bonded O–H (3370 cm.$^{-1}$) to that of free O–H stretching vibration (3650 cm.$^{-1}$) is: *exo* isomer, 3.24; *endo* isomer, 1.83.

Thus, the *exo* isomer shows more hydrogen bonding corresponding to a less hindered hydroxyl group.

The phenylurethan of *endo*-bicyclo[3.2.1]octan-8-ol was prepared as described for the *exo* isomer and found to have m.p. 136.7–137.0°; the melting point was depressed (to 114–118°) by admixture with the phenylurethan of the *exo* isomer (m.p. 124.8–125.6°).

Anal. Calcd. for $C_{15}H_{19}NO_2$: C, 73.44; H, 7.81. Found: C, 73.53; H, 7.86.

The tosylate of *endo*-bicyclo[3.2.1]octan-8-ol was prepared as described for the *exo* isomer and found to have m.p. 75.7–76.1°; the melting point was depressed (to 56–71°) by admixture with the tosylate of the *exo* isomer (m.p. 78.4–79.0°).

Anal. Calcd. for $C_{15}H_{20}O_3S$: C, 64.27; H, 7.19. Found: C, 64.30; H, 7.43.

The mass spectrum (Consolidated mass spectrometer CEC 21-103C, heated inlet system) of *endo*-bicyclo[3.2.1]-octan-8-ol is virtually identical with that of the *exo* isomer.[20]

Bicyclo[3.2.1]octan-8-one (VII) from *endo*-Bicyclo[3.2.1]-octan-8-ol (X).—To 4 ml. of dry pyridine was added 400 mg. (4 mmoles) of chromic anhydride. After formation of a yellow complex, 113 mg. (0.9 mmole) of *endo*-bicyclo[3.2.1]-octan-8-ol (X) was added, and the mixture was stirred at 0° for 1 hour. After allowing the mixture to stand at room temperature for 20 hours, 50 ml. of ice-water was added, and the suspension extracted with three 25-ml. portions of ether. The combined ether layers were washed with three 25-ml. portions of 6 *N* hydrochloric acid, 25 ml. of water, two 25-ml. portions of saturated sodium bicarbonate solution and 25 ml. of brine, and dried over magnesium sulfate. After careful evaporation of the solvent at atmospheric pressure, 63 mg. of crude material was obtained, and was sublimed at atmospheric pressure under nitrogen (closed apparatus) at 80°. The product (54 mg., 48% yield) had an infrared spectrum identical with that of bicyclo[3.2.1]octan-8-one (VII) described above.

Attempted Equilibration of *exo*- and *endo*-Bicyclo[3.2.1]-octan-8-ol (IV and X).—Solutions were prepared containing 50 mg. of IV or X, respectively, 5 ml. of dry isopropyl alcohol, 0.1 ml. of reagent acetone and 100 mg. of freshly distilled aluminum isopropoxide. Aliquots of 0.5 ml. of each solution were sealed in ampoules and heated to 80 ± 2° for 3, 5 and 10 days, respectively. The products were isolated by adding 1 ml. of 6 *N* hydrochloric acid to each, followed by extraction with three 10-ml. portions of ether, washing of the extracts with five 10-ml. portions of water, two 10-ml. portions of brine and drying over magnesium sulfate. The crude product, after removing the greater part but not all of the ether solvent, was analyzed by gas chromatography on a base-washed Silicone oil column (170°). Pure *exo*- or *endo*-bicyclo[3.2.1]octan-8-ol (IV and X), respectively, were recovered, showing that no equilibration took place under the conditions employed starting from either of the two isomers.

Relative Rates of Oxidation of *exo*- and *endo*-Bicyclo[3.2.1]-octan-8-ol (IV and X).[15]—A solution A was prepared containing 90.7% acetic acid and 9.3% water (by weight). With it were prepared solution B, containing 1.68 mg. of *exo*-bicyclo[3.2.1]octan-8-ol (IV) per ml.; solution C, containing 1.68 mg. of *endo*-bicyclo[3.2.1]octan-8-ol (X) per ml.; solution D, containing 0.251 mg. of chromic anhydride per ml.; and solution E, containing 0.526 mg. of chromic anhydride per ml. (no correction was made for possible hygroscopic contamination of the chromic anhydride).

Rates were followed by measuring % transmission at wave length 348 mμ (corresponding to chromic anhydride) with a Beckman quartz spectrometer, model DU, using 1-cm. cells. Solution A served as a standard (100% transmission).

For the first measurement, cells containing (a) 0.5 ml. of solution B plus 3 ml. of solution D and (b) 0.5 ml. of solution C plus 3 ml. of solution D were compared to a standard containing solution A (split width 0.36 mm.). Initially, cells a and b permitted 1.3% transmission. Toward the end of the reaction, the transmission approached a value of 50%. A 25% transmission corresponds to an optical density of $D = 0.600$. To reach that value the sample containing the *exo* isomer (cell a) required 22 hours, while the sample containing the *endo* isomer (cell B) required 1.4 hours. Thus the *endo* isomer reacted 16.1 times faster than the *exo* isomer.

For the second measurement, cells containing (c) 1 ml. of solution B plus 2 ml. of solution E, and (d) 1 ml. of solution C plus 2 ml. of solution E were compared to a standard containing solution A (slit width 0.65 mm.). Initially, cells c and d permitted *ca.* 0.5% transmission. Toward the end of the reaction, the transmission approached a value of 80%. A 40% transmission corresponds to an optical density of $D = 0.400$. To reach that value the sample containing the *exo* isomer (cell c) required 37.2 hours, while the sample containing the *endo* isomer (cell d) required 2.5 hours. Thus, the *endo* isomer reacted 14.8 times faster than the *exo* isomer.

***exo-cis*-Bicyclo[3.3.0]oct-2-yl Brosylate (XIV).**—To a refrigerated solution of 1.57 g. (12.5 mmoles) of *exo*-bicyclo-[3.3.0]octan-2-ol[5] in 10 ml. of pyridine was added a refrigerated solution of 6.37 g. (25 mmoles) of *p*-bromobenzenesulfonyl chloride in 10 ml. of pyridine, and the solution was allowed to stand in a refrigerator for 18 hours. To this solution was added dropwise and with ice-cooling 65 ml. of water, and the mixture was extracted with three 25-ml. portions of ether. The combined ether extracts were washed with four 40-ml. portions of 6 *N* hydrochloric acid and two 50-ml. portions of saturated sodium bicarbonate solution and dried over magnesium sulfate. The crude product obtained after evaporation of the solvent was recrystallized from pentane, giving 2.82 g. (64% yield) of *exo-cis*-bicyclo[3.3.0]-oct-2-yl brosylate (XIV), m.p. 46.6–47.8°. A sample was recrystallized to a constant melting point of 47.0–47.8°.

Anal. Calcd. for $C_{14}H_{17}BrO_4S$: C, 48.68; H, 4.96. Found: C, 48.37; H, 4.82.

Solvolysis of *exo-cis*-Bicyclo[3.3.0]oct-2-yl Brosylate (XIV). A. With Acetic Acid.—Anhydrous sodium acetate (82 mg., 1 mmole) was dissolved in 600 mg. (10 mmoles) of glacial acetic acid, and to it was added 172 mg. (0.5 mmole) of XIV. The solution became homogeneous on heating slightly. The solution was allowed to stand at 60° for 1 hour and, since no precipitation of sodium brosylate was observed, the temperature was increased to 90°. A white salt precipitated. After allowing the mixture to stand at 90° for 3 hours it was transferred to a separatory funnel with 15 ml. of ether, and washed with four 12-ml. portions of water, two 12-ml. portions of saturated sodium bicarbonate solution and two 12-ml. portions of water, and dried over magnesium sulfate. Evaporation of the solvent under reduced pressure gave 32 mg. of crude acetates (38% yield). To the acetates was added a solution of 250 mg. of sodium hydroxide in 2.5 g. of methanol, and the mixture was refluxed for 1 hour. Addition of 15 ml. of ether was followed by washing with four 12-ml. portions of water and drying over magnesium sulfate. After evaporation of the solvent, 17 mg. of a partly solid product was obtained (29% yield from XIV). Analysis of the crude product by gas chromatography on a Silicone oil column (140°) showed it to contain about 85% of *cis*-bicyclo[3.3.0]-octan-2-ols and about 15% of a compound corresponding in retention time to *exo*- but not to *endo*-bicyclo[3.2.1]octan-8-ol. Gas chromatography on a tris-(2-cyanoethoxy)-propane column (140°) showed the *cis*-bicyclo[3.3.0]octan-2-ols to be composed of about equal amounts of the *exo* and the *endo* isomers.

Repetition of the solvolysis at 80° using a procedure that omitted the isolation of acetates and avoided evaporation of solvent under reduced pressure gave a crude product that contained approximately 64% of hydrocarbons in addition to the alcohols obtained previously. The low yield of alcohols is thus accounted for.

B. With Trifluoroacetic Acid.—Anhydrous sodium acetate (0.271 g., 3.3 mmoles) was dissolved in 6.84 g. (60 mmoles) of trifluoroacetic acid and to the solution stirred at 0° was added 1.032 g. (3 mmoles) of XIV. All of the brosylate dissolved and a white salt precipitated after about 2 hours. After the reaction mixture was stirred at 0° for a total of 2 hours, 50 ml. of ether and 75 ml. of water were added. The aqueous layer was separated and extracted with an additional 25-ml. portion of ether. The combined ether extracts were washed with six 25-ml. portions of water, two 25-ml. portions of saturated sodium bicarbonate solution and 25 ml. of water. The solvent was evaporated without previous drying and to the wet oil obtained was added a solution of 0.6 g. of sodium hydroxide in 6 ml. of water and 10 ml. of methanol. This solution was refluxed for 1 hour to saponify esters. Extraction with three 25-ml. portions of ether was followed by washings of the combined extracts with a 50-ml. and four 25-ml. portions of water. The solution was dried over magnesium sulfate, and the solvent was evaporated carefully at atmospheric pressure. The crude product was distilled through a short path still collecting a low boiling fraction (59 mg. = 0.55 mmole of C_8H_{12}) and a higher boiling fraction (155 mg. = 1.23 mmoles of $C_8H_{14}O$). The total yield was 59%. Gas chromatography on a Silicone oil column (70°) showed the low boiling fraction (31% of total products) to be homogeneous and its infrared spectrum established its identity as *cis*-bicyclo[3.3.0]oct-2-ene (XVI).[4] The higher boiling fraction contained three components that had retention times corresponding to *exo*-bicyclo[3.2.1]octan-8-ol (IV) (42%) (no substance having the retention time of the *endo* isomer was found), *cis*-bicyclo[3.3.0]octan-2-ols (II, III) (47%) (gas chromatography on a tris-(2-cyanoethoxy)-propane column showed this fraction to contain 11% of the *endo* and 89% of the *exo* isomer), and *cis*-bicyclo[3.3.0]octan-1-ol (V) (11%). By collection from the effluent gas of the gas chromatogram a sample of *exo*-bicyclo[3.2.1]octan-8-ol (IV) was isolated and shown to have an infrared spectrum identical with that of the same compound obtained from the solvolysis of 4-cycloöcten-1-yl brosylate; bands corresponding to the *endo* isomer are absent in the infrared spectrum. A sample of *exo-cis*-bicyclo[3.3.0]octan-2-ol (II) was collected from the effluent gas of the gas chromatogram. The sample obtained was contaminated by *exo*-bicyclo[3.2.1]octan-8-ol (IV) (as shown by gas chromatography) and the infrared spectrum of that sample contained all of the bands characteristic of II and, in addition, three minor bands characteristic of IV. A pure sample of *cis*-bicyclo[3.3.0]octan-1-ol (V) was obtained in the same manner and its infrared spectrum established its identity with the same compound obtained from the solvolysis of 4-cycloöcten-1-yl brosylate.

Stability of *endo*-Bicyclo[3.2.1]octan-8-ol (X) toward Trifluoroacetic Acid.—A solution of 0.136 g. (1.65 mmoles) of anhydrous sodium acetate in 3.42 g. (30 mmoles) of trifluoroacetic acid was cooled in an ice-bath and 63 mg. (0.5 mmole) of *endo*-bicyclo[3.2.1]octan-8-ol (X) was added to it. After allowing the solution to stand at 0° for 2 hours, 25 ml. of ether and 35 ml. of water were added, and the separated aqueous layer was extracted with an additional 25-ml. portion of ether. The combined ether extracts were washed with four 25-ml. portions of water, two 25-ml. portions of saturated sodium bicarbonate solution and 25 ml. of water. Without previous drying the ether was evaporated, a solution of 0.6 g. of sodium hydroxide in 6 ml. of water and 10 ml. of methanol was added, and the solution was refluxed for 1.5 hours. After cooling, the solution was extracted with three 25-ml. portions of ether and the combined ether layers were washed with four 25-ml. portions of water and two 25-ml. portions or brine, and dried over magnesium sulfate. The crude product obtained after careful evaporation of solvent at atmospheric pressure was sublimed at atmospheric pressure under nitrogen (closed apparatus) at 80°, and 50 mg. (79% recovery) of material was obtained. Gas chromatography showed the product to be homogeneous with the same retention time as the starting material X, and the infrared spectrum was identical with that of *endo*-bicyclo[3.2.1]octan-8-ol (X).

endo-Bicylo[3.2.1]octan-8-ol (X) was recovered unchanged from a medium that caused exclusive formation of the *exo* isomer from 4-cycloöcten-1-yl brosylate (I) and *exo-cis*-bicyclo[3.3.0]oct-2-yl brosylate (XIV).

Bicyclo[3.3.0]oct-1(5)-ene (XIX) from Spiro[3,4]octan-5-ol (XVIII).[24]—To 1.510 g. (12 mmoles) of spiro[3,4]octan-5-ol (XVIII) in a short path still was added *ca.* 1.7 g. (15 mmoles) of finely granulated anhydrous zinc chloride. The mixture was heated to 100° under 35 mm. pressure for 45 minutes, and the product together with the water formed in the reaction was collected as it was formed. After addition of ether, drying over magnesium sulfate, and careful evaporation of the ether, 512 mg. (40% yield) of product was obtained. Gas chromatography on a Silicone oil column (70°) showed the product to contain 76% of bicyclo[3.3.0]oct-1(5)-ene (XIX) and two other components in amounts of 13 and 11%, respectively (see below).

Pure bicyclo[3.3.0]oct-1(5)-ene (XIX) was obtained by collection from the effluent gas of the gas chromatogram (27% yield from XVIII) and shown to be homogeneous by gas chromatography on Silicone oil, n^{25}D 1.4802. The infrared spectrum (pure liquid) contained no bands in the regions 1000–800, 1680–1620, and around 3000 cm.$^{-1}$, consistent with the structure containing a tetrasubstituted, highly symmetrical double bond. When 5 drops of a solution of 0.5 g. of butyl nitrite in 0.75 g. of glacial acetic acid was added to 1 drop of XIX, a dark blue solution resulted after addition of 2 drops of concentrated hydrochloric acid and 10 drops of acetone. The blue nitrosochloride, typical for a tetrasubstituted double bond, does not crystallize on chilling but separates as an oil, as observed previously by Vogel.[24]

The by-product present in an amount of 13% in the mixture of products had the gas chromatographic retention time of *cis*-bicyclo[3.3.0]oct-2-ene (XVI).[4] By collection from the effluent gas of the gas chromatogram a sample of 96% purity (as shown by gas chromatography) was obtained (42 mg., 3.0% yield), n^{25}D 1.4628. The infrared spectrum (pure liquid) of that sample had characteristic bands of a disubstituted *cis* double bond (705 cm.$^{-1}$), and contained all bands of an authentic sample of *cis*-bicyclo[3.3.0]oct-2-ene (XVI),[4] but the intensity of these bands differed considerably so that the presence of the *trans* isomer (ring juncture) cannot be excluded.

The other by-product, present in an amount of 11% in the mixture of products, was collected from the effluent gas of the gas chromatogram and a sample of 92% purity (as shown by gas chromatography) was obtained (35 mg., 2.5% yield), n^{25}D 1.4781. The infrared spectrum (pure liquid) of that sample had bands at 3070, 1665 and 793 cm.$^{-1}$. This olefin is probably bicyclo[3.3.0]oct-1(2)-ene, but it structure was not proved.

Bicyclo[3.3.0]oct-1(5)-ene Oxide (XX) from Bicyclo-[3.3.0]oct-1(5)-ene (XIX).—To 304 mg. (2.8 mmoles) of bicyclo[3.3.0]oct-1(5)-ene (XIX) and 1 ml. of glacial acetic acid was added 1.0 g. of 40% peracetic acid (*ca.* 5 mmoles) containing 500 mg. of sodium acetate trihydrate. The reaction mixture was stirred for 1.5 hours at 10 to 15° (ice-water-bath). To it a solution of 3.0 g. of sodium hydroxide in 20 ml. of water was added slowly and the mixture was extracted with a 50-ml. and two 25-ml. portions of ether. The combined extracts were washed with four 25-ml. portions of water and dried over magnesium sulfate. After the solvent was evaporated at atmospheric pressure, the product was distilled through a micro column. A center cut had b.p. 92° (74 mm.), n^{25}D 1.4687. A yield of 67% (234 mg.) was obtained. The infrared spectrum (pure liquid) showed major bands at 1460(s), 1440(s), 1403(s), 1375(w), 1335(s), 1285(s), 1248(m), 1190(m), 1105(s), 1000(s), 915(s), 895(m), 878(s), 800(s), 720(w) and 650(s) cm.$^{-1}$.

Anal. Calcd. for $C_8H_{12}O$: C, 77.33; H, 9.74. Found: C, 77.39; H, 10.02.

***cis*-Bicyclo[3.3.0]octan-1-ol (V) from Bicyclo[3.3.0]oct-1(5)-ene Oxide (XX).**—To freshly prepared W-7 Raney nickel[29] in approximately 5 ml. of absolute ethanol was added 124 mg. (1 mmole) of bicyclo[3.3.0]oct-1(5)-ene oxide (XX), and the mixture was stirred under hydrogen at atmospheric pressure for 27 hours. An additional portion of catalyst was added after 12 hours. The catalyst was separated by filtration and to the filtrate was added 100 ml. of ether. The ethereal solution was washed with a 100-ml. and three 50-ml. portions of water and 25 ml. of brine, and dried over magnesium sulfate. Gas chromatography on tris-(2-cyanoethoxy)-propane (150°) of the crude product obtained upon evaporation of the solvent at atmospheric pressure showed that no epoxide XX remained in the reaction mixture, and that the alcohol formed had the same retention time as *cis*-bicyclo[3.3.0]octan-1-ol (V), obtained from 4-cycloöcten-1-yl brosylate (I). The crude product was distilled through a short path still at 17 mm. and gave 84 mg. (67% yield) of product. The infrared spectrum was identical with that of *cis*-bicyclo[3.3.0]octan-1-ol (V), obtained from 4-cycloöcten-1-yl brosylate (I) and *exo-cis*-bicyclo [3.3.0]oct-2-yl brosylate (XIV). A phenylurethan, m.p. 98.7–99.2°, also had an infrared spectrum identical to that of the phenylurethan of V obtained from 4-cycloöcten-1-yl brosylate, and a mixed melting point of the two samples was undepressed.

***cis*-9-Decalol (XXII) from 9,10-Octalin Oxide (XXI).**—To a suspension of platinum, obtained by reduction of 50 mg. of platinum oxide in 5 ml. of absolute ethanol, was added 76 mg. (0.5 mmole) of 9,10-octalin oxide (XXI),[26] and the mixture was stirred under hydrogen at atmospheric pressure for 14 hours. Since no hydrogen was taken up, freshly prepared W-7 Raney nickel catalyst[29] was added, and stirring was continued for 8 hours. The catalyst was separated by filtration, and 40 ml. of ether was added to the filtrate.

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(29) H. R. Billica and H. Adkins, "Organic Syntheses," Coll. Vol. III, John Wiley and Sons, Inc., New York, N. Y., 1955, p. 176, note 1.

The ethereal solution was washed with a 75-ml. and three 25-ml. portions of water and with 25 ml. of brine, and dried over magnesium sulfate. The solvent was evaporated and the crude product was recrystallized from petroleum ether (35 mg., 46% yield). It melted at 65.4–66.2° after two more recrystallizations. The residue from evaporation of the mother liquor (17 mg.) was shown by gas chromatography on base-washed Silicone oil to contain no 9,10-octalin oxide (XXI). The m.p. was that reported by Hückel (65°) for *cis*-9-decalol (XXII) (the *trans* isomer melts at 54°).[27]

Solvolysis of 3-Cycloöcten-1-yl Brosylate with Trifluoroacetic Acid.—To a solution of 1.03 g. (0.0125 mole) of anhydrous sodium acetate in 22.8 g. (0.2 mole) of trifluoroacetic acid was added 3.45 g. (0.01 mole) of 3-cycloöcten-1-yl brosylate[4] over a period of 3 minutes, and the mixture was stirred for 70 minutes at 30–34° with exclusion of atmospheric moisture. A white solid precipitated. A solution of 25 g. of sodium hydroxide in 100 ml. of water was added dropwise to the mixture, which was cooled in an ice-bath. The mixture was shaken for 44 hours at room temperature to saponify esters. The product was extracted continuously with methylene chloride, and the extract was dried over magnesium sulfate. The crude product was distilled in a short path still at 0.3 mm. pressure; 0.765 g. (60.5% yield) of product was obtained and analyzed by gas chromatography on Silicone oil. *trans*-2-Vinylcyclohexanol (XXIII) (6.7%) was found to be present and was collected from the effluent gas of the gas chromatogram. The infrared spectrum of this sample was identical with that of authentic *trans*-2-vinylcyclohexanol (XXIII).[4] The remainder of the product was 3-cyclöcten-1-ol, identified by comparison of the infrared spectrum with that of an authentic sample.

Solvolysis of 4-Cycloöcten-1-yl Brosylate (I) in the Presence of *trans*-2-Vinylcyclohexanol (XXIII).—To a solution of 1.03 g. (0.0125 mole) of anhydrous sodium acetate in 22.8 g. (0.2 mole) of trifluoroacetic acid was added 3.28 g. (0.0095 mole) of 4-cycloöcten-1-yl brosylate (I)[4] and 0.060 g. (0.0005 mole) of *trans*-2-vinylcyclohexanol.[4] The mixture was stirred at room temperature for 2 hours, taken up in ether, washed free of acid, saponified and distilled in a short path still as described previously. Gas chromatography of the product (on Silicone oil at 190°), obtained in 55% yield, showed the presence of 4.0% of *trans*-2-vinylcyclohexanol (5.0% was added initially), which corresponds to an actual recovery of 47%. The other products were those described previously.

CAMBRIDGE, MASS.

[CONTRIBUTION FROM THE CHANDLER LABORATORY OF COLUMBIA UNIVERSITY]

The Synthesis of Substituted 1-Methylcyclohexanecarboxylic Acids and the Stereochemistry of the Favorskii Rearrangement

BY GILBERT STORK AND IRVING J. BOROWITZ

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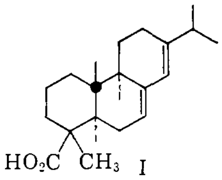
The stereoelectronic requirements of the Favorskiĭ reaction are examined. It is concluded that the formation of the cyclopropanone intermediate is *concerted*, (at least in the case of 1-chloro-1-acetylcylclohexane), in disagreement with a recent proposal. Some extensions of the reaction are also described.

The synthesis of 1-methylcyclohexanecarboxylic acids presents a certain interest because of the presence of this structural unit in, *e.g.*, the terpene acids (*cf.* abietic acid, I) and in precursors (*e.g.* III) of the C/D ring system of the steroid 17-ketones (*cf.* androsterone, II) in which the cyclopentanone ring can be formed by cyclization.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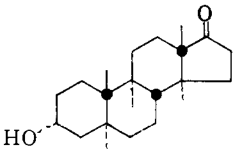
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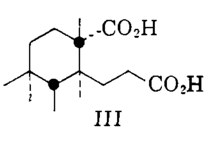
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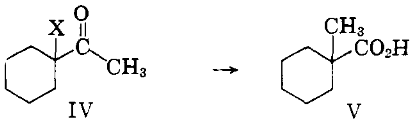
Various methods are available for the synthesis of 1-methylcyclohexanecarboxylic acid itself, among which may be mentioned Diels–Alder addition with methyl methacrylate and butadiene, followed by reduction[1]; the introduction of a 1-substituent into a suitable methylcyclohexane derivative, followed by its transformation into a carboxyl[2,3]; and the converse method of introducing a 1-methyl into a properly constituted derivative of cyclohexanecarboxylic acid.[4–6] The penultimate method has been used in the resin acid field while the last has been frequently employed in steroid syntheses.

Still another method attracted our interest: The Favorskiĭ rearrangement of 1-halo-1-acetylcyclohexane (IV) which has been shown to give the anticipated tertiary acid V on treatment with base.[7a,b] This result is consonant with the mechanism of the rearrangement


IV V

proposed, and elegantly supported, by Loftfield.[8] According to this scheme, a cyclopropanone is first formed, and this then opens to produce the less unstable carbanion,[9] leading to V in this particular case.

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[1] J. D. Roberts, A. K. Jeydel and R. Armstrong, THIS JOURNAL, **71**, 3248 (1949); V. N. Ipatieff, J. E. Germain and H. Pines, *Bull. soc. chim. France*, 259 (1951).

[2] G. Stork and J. W. Schulenberg, THIS JOURNAL, **78**, 250 (1956).

[3] T. Reichstein, H. R. Rosenberg and R. Eberhardt, *Helv. Chim. Acta*, **18**, 721 (1935).

[4] H. M. E. Cardwell, J. W. Cornforth, S. R. Duff, H. Holtermann and R. Robinson, *J. Chem. Soc.*, 361 (1953).

[5] R. Robinson and J. Walker, *ibid.*, 747 (1936).

[6] W. E. Bachmann, W. Cole and A. L. Wilds, THIS JOURNAL, **62**, 824 (1940).

[7] (a) B. Tchoubar and O. Sackur, *Compt. rend.*, **208**, 1020 (1939). (b) B. Tchoubar, *Bull. soc. chim. France*, **10**, 1363 (1955), gives an excellent review of reactions of nucleophilic agents on α-haloketones.

[8] R. B. Loftfield, THIS JOURNAL, **73**, 4707 (1951).

[9] That tertiary carbanions are less stable than secondary, and these in turn less than primary, is well illustrated, *e.g.*, by the order of stability of the metal alkyls (methyllithium is stable in ether while *t*-butyllithium decomposes it to ethylene; methyllithium does not add to ethylene while *t*-butyllithium does (*cf.* P. D. Bartlett, S. Friedman and M. Stiles, THIS JOURNAL, **75**, 1771 (1953)). For another illustration, see base-opening of cyclic ketones such as camphor or estrone in which a primary carbanion is involved rather than the alternative tertiary.