I. HOMOCONJUGATION IN SOME 7-CHLORONORBORNANE DERIVATIVES.

II. ELECTROSTATIC EFFECTS IN SOME 7-CHLORONORBORNANE DERIVATIVES.

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ABSTRACT

I

A review of carbonium-ion reactions of bornyl and norbornyl derivatives involving non-classical intermediates and a discussion of various "homoallylic" systems are given.

7-Chloronorbornane and syn-7-chloronorbornene have been found to possess very unreactive chlorine under conditions where exo-norbornyl and cyclopentyl chloride solvolyze readily. In contrast, anti-7-chloronorbornene is quite reactive. The solvolysis of anti-7-chloronorbornene is probably facilitated through stabilization of the carbocationic transition state by electron delocalization analogous to that predicted theoretically for the cyclopropenyl cation. First-order molecular orbital and steric strain calculations provide support for this formulation.

Molecular orbital calculations predict a substantial delocalization energy for the carbocation expected from the solvolysis of 7-chlorobicyclo[2.2.1]heptadiene. Several attempts to synthesize this chlorodiene are described.

syn-7-Chloro-endo-norbornyl p-toluenesulfonate has been prepared and its acetolysis rate determined. The relative magnitude of the first-order acetolysis rate constant is taken as further evidence for the substantial participation of a non-classical hydrogen-bridged cationic intermediate in the solvolysis of syn- and anti-7-chloro-exo-norbornyl p-toluenesulfonates.

ABSTRACT

II

A review of theoretical and experimental efforts to evaluate the inductive and field effects of substituents on reactivity is presented.

Nuclear magnetic resonance spectroscopy has been used to determine the relative base strengths of very weak bases.

The rates of bromination of several substituted norcamphors are interpreted in terms of the steric and electrical effects of the substituents.

The ultraviolet spectra of a number of substituted norcamphor derivatives are rationalized in terms of the inductive and field effects of the substituents.

Several substituted norcamphoroximes have been prepared and their relative acidities measured.

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To my wife for her encouragement, love and understanding.

I

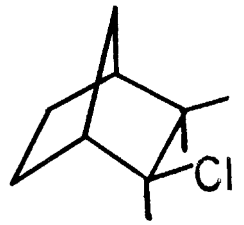
HOMOCONJUGATION IN SOME 7-CHLORONORBORNANE DERIVATIVES.

INTRODUCTION

This chapter presents the results of synthetic, solvolytic and theoretical studies on several 7-chlornorbornane derivatives. In view of the large body of literature dealing with mechanistic studies in this field, a review is presented in the following section on (a) carbonium ion rearrangements involving "non-classical" intermediates in the bornyl and norbornyl systems; and (b) rearrangements in the dehydronorbornyl and related systems by way of "homoallylic" carbonium ion intermediates.

Bornyl and Norbornyl Systems.

Wilson (1) and co-workers observed that camphene hydrochloride (I) (Fig. 1) in chloroform solution rearranged to isobornyl chloride (II) one fifteenth as fast as the chlorine was exchanged with added hydrogen chloride. The authors (1) concluded that an equilibrium was rapidly established between classical cationic intermediates (III and IV) followed by a slow bimolecular reaction with hydrogen chloride. Bartlett (2) made a thorough kinetic study of this interconversion and concluded (3) that the rate-determining step was the reaction of III or IV or their equivalent with the complex ion HCl_2^-. The mesomeric, non-classical ion V was first suggested by Wilson (1) and subsequently proposed by Ingold (4) as an intermediate in this reaction and represents the first example of a bridged ion in an all-carbon system. This intermediate accounts for the exclusive formation of the exo chloride II rather than the more stable bornyl chloride (IX). Similar stereospecificity is observed in the reaction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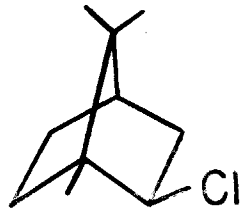
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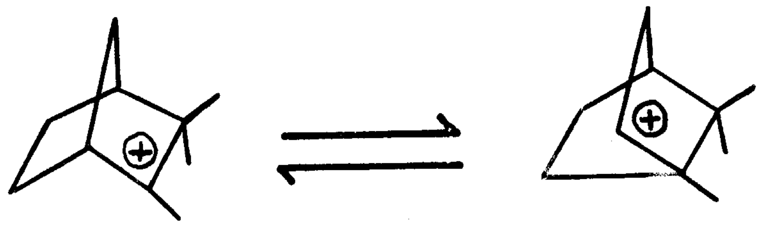
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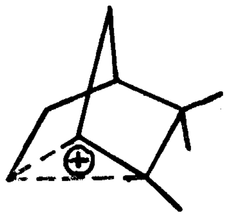
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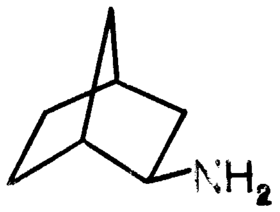
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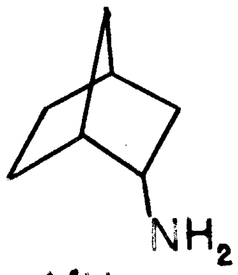
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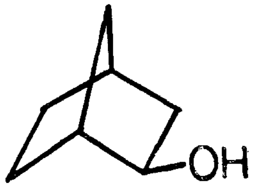
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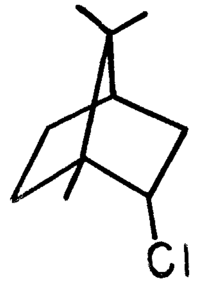

IX

Fig. I

of nitrous acid with both exo- and endo-norbornylamines (VI and VII) which yield entirely exo-norborneol (VIII) (5,6).

The phenomenon of "synartetic" acceleration in saturated systems was first described by Hughes, Ingold and co-workers (7) who found that camphene hydrochloride (I) had an ethanolysis rate some 6000 times that of t-butyl chloride. Further support for this type of acceleration was deduced (8) from the factor of 10^5 between the aqueous ethanolysis rates of isobornyl chloride (II) and bornyl chloride (IX). exo-Norbornyl chloride (X, X = Cl) (Fig. 2) was found (9,10) to solvolyze about 70 times faster than the corresponding endo isomer XI (X = Cl). Analogously, exo-norbornyl p-bromobenzenesulfonate (X, X = p - Br $C_6H_4SO_3$) acetolyzed some 350 times faster than endo-norbornyl p-bromobenzenesulfonate (XI, X = p - Br $C_6H_4SO_3$) (8,11) and both gave the same product, exo-norbornyl acetate (X, X = CH_3COO). These solvolyses can be pictured as proceeding through the symmetrical "norbornonium" ion XII, since the exo-norbornyl acetate obtained from optically active p-bromobenzenesulfonate was racemic in both cases (12,13).

Polarimetric and titrimetric rate constants were found to be the same (12) for endo-norbornyl p-bromobenzenesulfonate (XI, X = p - Br $C_6H_4SO_3$), but the rate of racemization (13) of the exo (X, X = p - Br $C_6H_4SO_3$) was found to exceed the acetolysis rate by a factor of 3.5. Similar results were obtained (14) in the erythro-3-phenyl-2-butyl system and led to the postulation of an intermediate ion-pair which would have the symmetry of XII and thus lead to racemization. This ion-pair could either react with solvent at C_1 and C_2 to give racemic product (X, X = CH_3COO) or revert to starting sulfonate ester by an "internal return" process. Solvent effects play an important role in the internal return process as shown by the decrease in the ratio of polarimetric to titrimetric rates from 3.5 in acetic acid to 1.4 in 75% aqueous acetone (14). The high ionizing power (15) and increased nucleophilicity (16,17) of the latter solvent effectively decreases the amount of internal return.

From salt effect studies (18,19,20,21), Winstein concluded that all of the internal return in norbornyl derivatives is from "tight" or "intimate" (18) ion-pairs because of the absence of abnormal salt effects in acetic acid and common ion depression (20,21).

Evidence for intermediates of the norbornonium type is available from synthetic work. For example, the addition of chlorine or hypochlorous acid to norbornene XIII (22) may be visualized as proceeding through an unsymmetrical norbornonium ion (XIV, X = exo-Cl). Similarly, the hydrolysis of trans-2,3,-dichloronorbornane (XV) to yield anti-7-chloro-exo-norborneol (XVI) (22) is adequately accounted for by intermediate XIV (X = endo-Cl). Bromination of norbornene (XIII) follows a similar path (XIV, X = exo-Br) (23).

In these cases (22,23), as well as in others (24), halonortricyclenes (XVII) are invariably obtained from the loss of a proton from C_6. Early work (25,26) on the acid-catalyzed racemization of isobornyl chloride (II) (Fig. 1) was accounted for by a 1,3-hydride shift. Hydrogen-bridged intermediate XVIII was proposed (27) to account for the results of a rate and deuterium tracer study on the acid-catalyzed dehydration of β-fenchol (XIX).

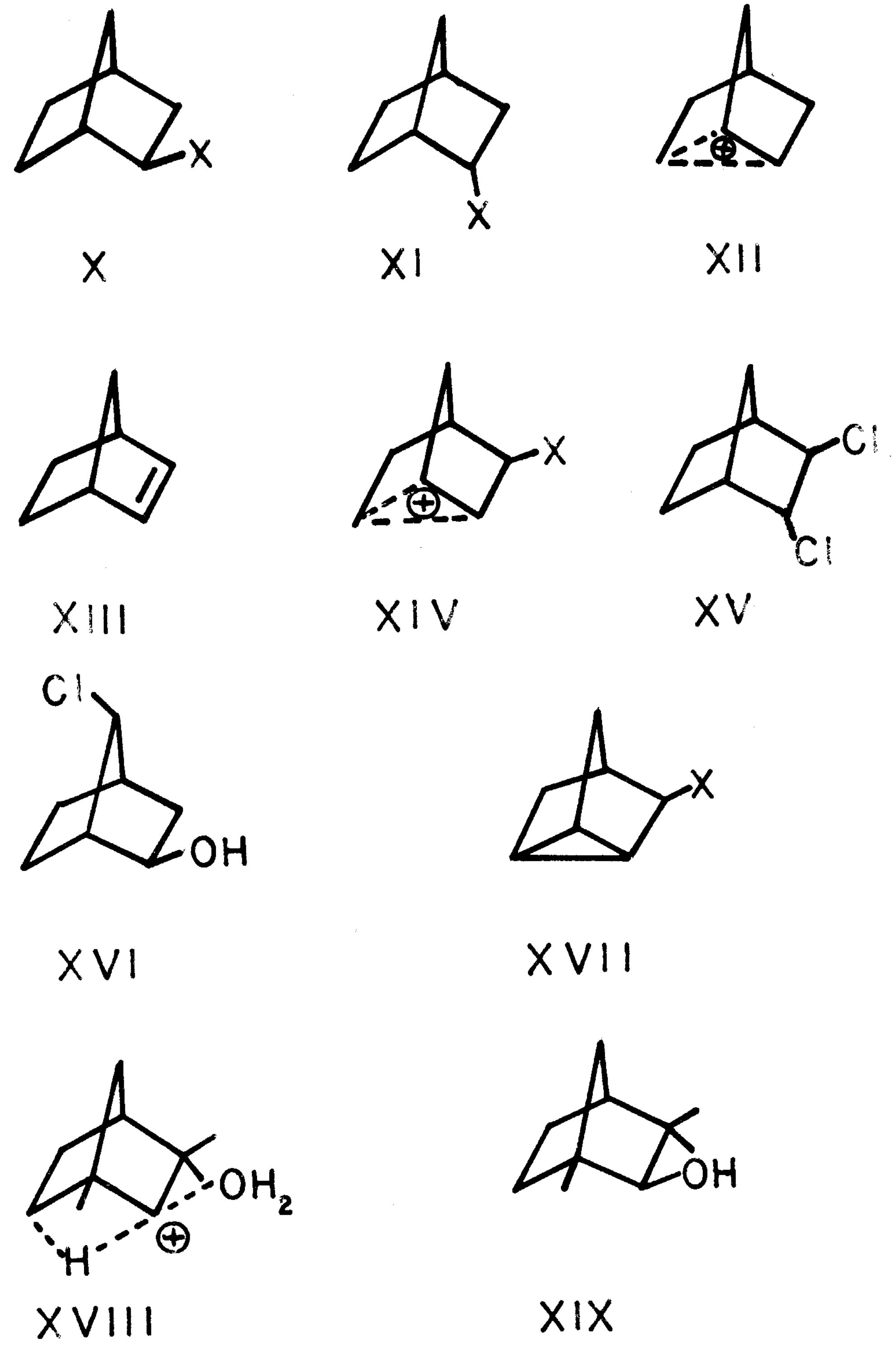
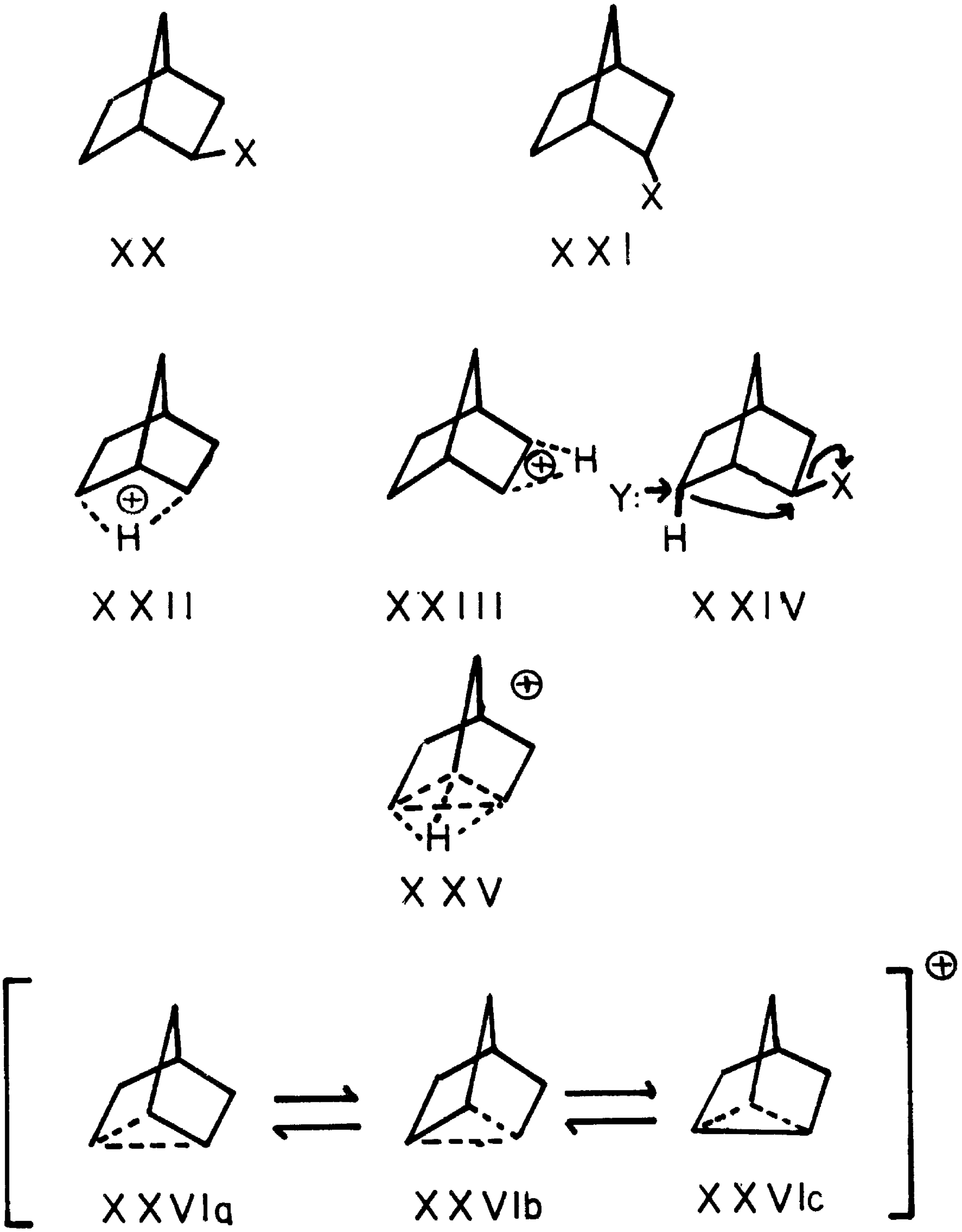


Fig. 2

The results of Roberts (28,29) on the C^{14} distribution in the acetolysis products of exo- and endo-norbornyl-2,3-C^{14} p-bromobenzenesulfonates (XX and XXI, X = p - Br $C_6H_4SO_3$) (Fig. 3) cannot be explained simply by employing the "norbornonium" ion of Winstein (11). Furthermore, the presence of 58% isotope-position rearrangement with 15% of the activity in C_5 and C_6 of the exo-norbornyl acetate product (XX, X = CH_3COO) cannot be explained by the intermediate XII (Fig. 2) or XXII, XXIII or XXIV (Fig. 3) or any combination of these. This possibility was anticipated (30), since the norbornonium ion (XII) (Fig. 2) did not uniquely account for Winstein's (11) data. All of the C^{14} rearrangement (28,29) can be adequately accounted for (29) by assuming that 55% of the reaction proceeds by way of XII and 45% through a hydrogen- and carbon-bridged "nortricyclonium" ion intermediate (XXV) (Fig. 3). As yet, no evidence is available to differentiate between XXV and a facile equilibrium of norbornonium ions, XXVIa-XXVIc (31).

Support of intermediates of the nortricyclonium type (XXV) is found in the racemization of 8-substituted camphenes (32) (XXVII) (Fig. 4) which may be pictured as involving the substituted nortricyclonium ion XXVIII. Furthermore, the results of two studies (33,34) on the acid-catalyzed racemization of camphene-8-C^{14} (XXIX) indicated (33) that at least part of the rearrangement proceeded by way of XXVIII (R = H). It should be noted in these cases that a norbornonium ion of type XII (Fig. 2) cannot account for the racemizations since the methyl groups prohibit the development of a plane of symmetry unless one allows equilibration to occur as in XXVI (Fig. 3).



XX XXI

XXII XXIII XXIV

XXV

XXVIa XXVIb XXVIc

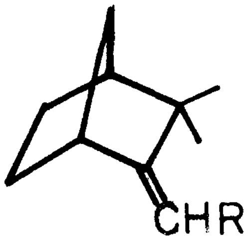
Fig. 3

An interesting case of an unsymmetrical nortricyclonium ion (XXXII) (Fig. 4) has been proposed (35,36) to account for the identical 1:1 mixture of syn- and anti-7-chloro-exo-norbornyl acetates (XXX and XXXI) obtained from the acetolysis of syn- and anti-7-chloro-exo-norbornyl p-toluenesulfonates (XXXIII and XXXIV). This case will be discussed in detail in the Results and Discussion section.

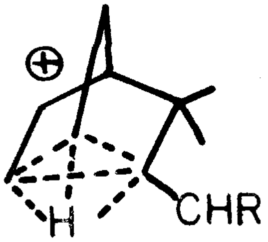
Homoallylic Systems.

The first example of an interaction of the π-electrons of an unsaturated linkage with a reaction center removed by one saturated carbon atom was found in the cholesteryl-i-cholesteryl interconversion. Certain cholesteryl derivatives (XXXV) (Fig. 5) were found to undergo unimolecular displacement reactions at C_3 to give products with retention of configuration (37,38,39). Cholesteryl p-toluenesulfonate (XXXV, X = p - $CH_3C_6H_4SO_3$) solvolyzes in methanol containing acetate ion to give some i-cholesteryl methyl ether (40), (XXXVI, X = CH_3O) with inversion at C_3 (41). Most i-cholesteryl derivatives (XXVI) are unstable and readily isomerize to cholesteryl derivatives (XXXV) in the presence of acid (42).

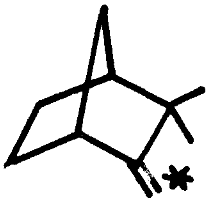
Evidence for the participation of the π-electrons of the C_5 - C_6 double bond in the ionization of the substituent at C_3 is found in the 40-fold higher ethanolysis rate of cholesteryl p-toluenesulfonate (XXXV, X = p - $CH_3C_6H_4SO_3$) relative to its saturated analog, cholestanyl p-toluenesulfonate (XXXVII, X = p - $CH_3C_6H_4SO_3$) (43). Even more striking is the observation (44) that i-cholesteryl chloride (XXXVI, X = Cl) solvolyzes at a rate 10^{10} more rapidly than cholestanyl chloride (XXXVII, X = Cl). As expected, i-cholesteryl



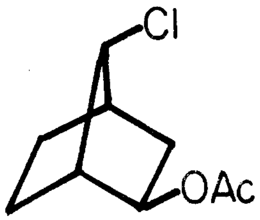
XXVII



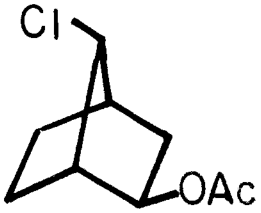
XXVIII



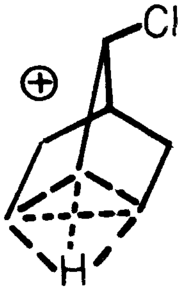
XXIX



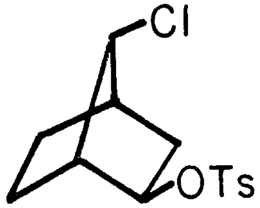
XXX



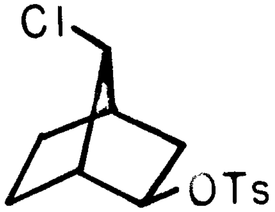
XXXI



XXXII



XXXIII



XXXIV

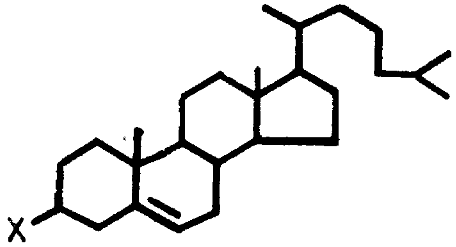
Fig. 4

chloride (XXXVI, X = Cl) gave exclusively the cholesteryl solvolysis product (44). The above observations are consistent with the formation of a cholesteryl-i-cholesteryl homoallylic cationic intermediate (XXXVIII).

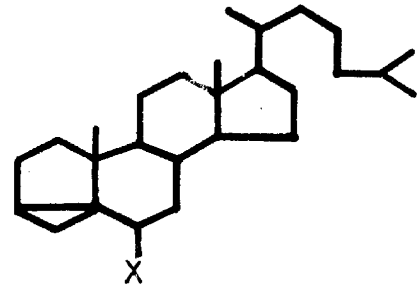
Cyclopropylcarbinyl chloride (XXXIX, X = Cl) solvolyzes at 50° in 50% ethanol at a rate 40 times that of allyl chloride (45,46). Similarly, cyclopropylcarbinyl benzenesulfonate (XXXIX, X = $C_6H_5SO_3$) solvolyzes in ethanol at 20° about 15 times as fast as allyl benzenesulfonate (47). Cyclopropylcarbinyl benzenesulfonate was found to isomerize readily into a mixture composed of mainly allylcarbinyl benzenesulfonate (XL, X = $C_6H_5SO_3$) which had an ethanolysis rate some 20 times less than that of allyl benzenesulfonate (47). An intermediate (XLI) has been postulated (45) analogous to that found in the i-sterol system (XXXVIII).

Partial equivalence of the three methylene groups of cyclopropylcarbinylamine-α-C^{14} (XXXIX, X = NH_2) seems to be achieved in its reaction with nitrous acid (48). This result, along with the ease of interconversion of cyclobutyl and cyclopropylcarbinyl derivatives in carbonium ion-type reactions (49) and the abnormally large solvolytic reactivities of cyclobutyl and cyclopropylcarbinyl halides (49) and sulfonate esters (47,50) led to the suggestion (48) of the non-classical cationic intermediate XLII (Fig. 5).

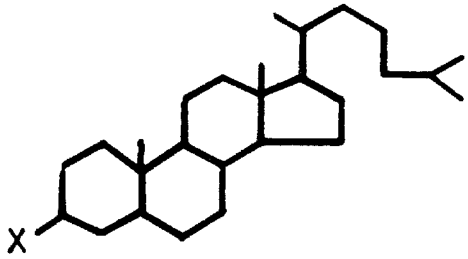
endo-Dehydronorbornyl p-bromobenzenesulfonate (51) (XLIII, X = p - Br $C_6H_4SO_3$) (Fig. 6) and chloride (9) (XLIII, X = Cl) were both found to be quite unreactive in solvolysis relative to the corresponding endo-norbornyl derivatives (XXI) (Fig. 3). This decreased reactivity was attributed (51) to the inductive effect of



XXXV



XXXVI



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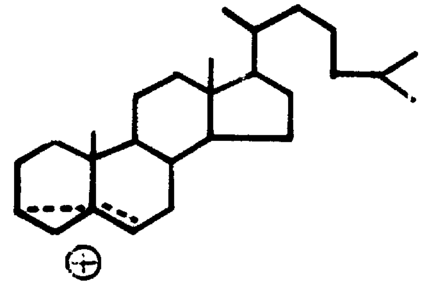
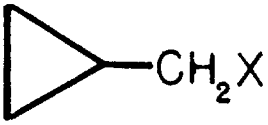


XXXVIII



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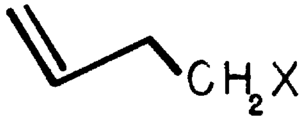
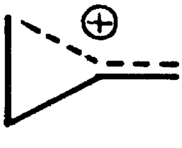
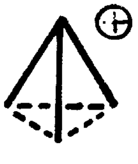


XL



XLI



XLII

Fig. 5

the ethylenic link in the dehydronorbornyl series. On the other hand, exo-dehydronorbornyl chloride (XLIV, X = Cl) was found to be quite reactive relative to the endo (9) and exo-dehydronorbornyl p-bromobenzenesulfonate (XLIV, X = p - Br $C_6H_4SO_3$) was actually found (51) to be 7000 times more reactive in acetolysis than the endo-isomer (XLIII, X = p - Br $C_6H_4SO_3$). Nortricyclyl acetate (XLV, X = CH_3COO) was shown (52) to account for 83 and 89% of the product, respectively, in the latter two cases.

Nortricyclyl p-bromobenzenesulfonate (XLV, X = p - Br $C_6H_4SO_3$) was found (51) to acetolyze at a rate some 2000 times faster than endo-dehydronorbornyl p-bromobenzenesulfonate (XLIII, X = p - Br $C_6H_4SO_3$). A similar result was obtained for the corresponding chloride (9). A non-classical "dehydronorbornonium" ion (XLVI) was proposed (9,53) to account for the rearrangements and rate enhancements found in the dehydronorbornyl-nortricyclyl systems. However, the results (52) on the solvolysis of exo- and endo-dehydronorbornyl-2,3-C_2^{14} p-bromobenzenesulfonates indicated that an intermediate of the type XLVII or its equivalent was necessary in order to account for the isotope-position rearrangement observed in the exo-dehydronorbornyl acetate (XLIV, X = CH_3COO) portion of the products.

The low reactivity of dehydronorbornyl derivatives relative to cholesteryl compounds as well as the abnormally high reactivity observed in the cyclopropylcarbinyl system has been interpreted (9) in terms of the stereochemical orientation of the orbitals involved in participation. Thus, the p-orbital at C_5 in the cholesteryl system (XXXV) (Fig. 5) is well situated to overlap effectively with the developing cationic center at C_3. In the dehydronorbornyl series (XLIV) (Fig. 6), the p-orbital at C_5 is not oriented as favorably to interact at C_2. Similarly, the low reactivity of nortricyclyl compounds as compared to that of the i-cholesteryl derivatives can be attributed to "steric inhibition of hyperconjugation" (9).

Simple molecular orbital theory has been applied (54) to the problem (55) of electron delocalization through 1,3-interaction of a cationic center with a π-electron-bearing β-substituent. A method of minimizing the total energy by straining the bond system to increase overlap was employed (54). Values of 11, 7 and 5 kcal./mole were calculated respectively, for the net stabilization of a cationic center by β-dienyl, β-vinyl and β-phenyl groups and were found to reflect the actual relative rate-enhancing abilities of these groups (56). These values, as well as the solvolytic data cited above, clearly show that "homoconjugation" (54) can be of considerable importance in enhancing reactivity if the proper geometry for overlap is available.

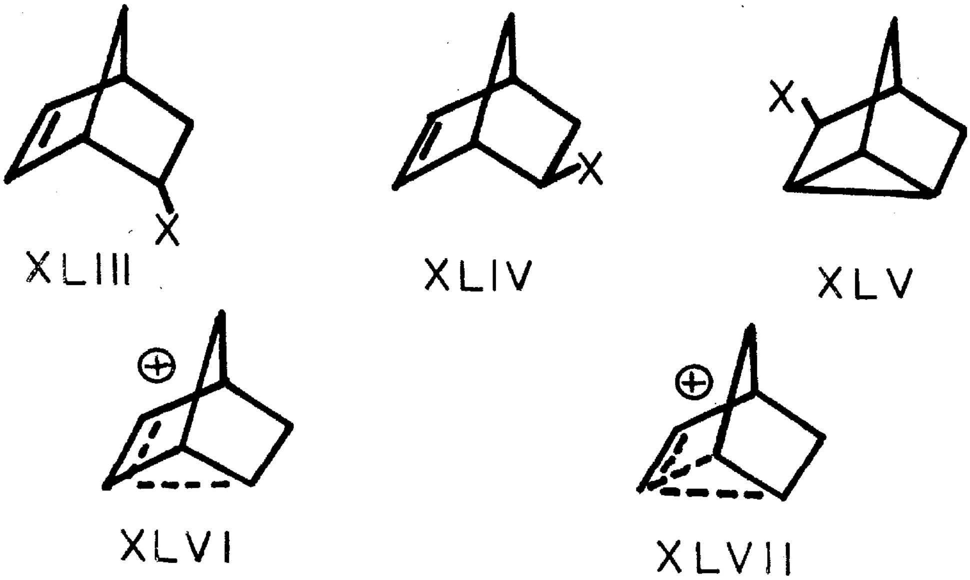


Fig. 6

RESULTS AND DISCUSSION (35)

In a preliminary report (22), Roberts, Johnson and Carboni observed that both 7-chloronorbornane (XLVIII) (Fig. 7) and *syn*-7-chloronorbornene (XLIX) solvolyzed very slowly in aqueous ethanol. However, *anti*-7-chloronorbornene (L) was not investigated. A study of the solvolytic reactivity of XLVIII, XLIX and L was thought to be of interest in view of the possibility of homoconjugation (54) in these compounds.

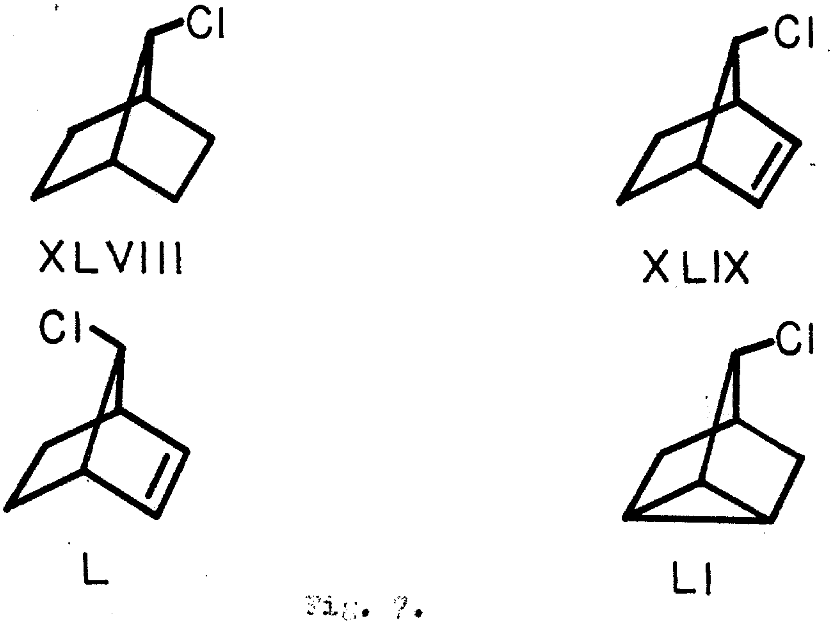
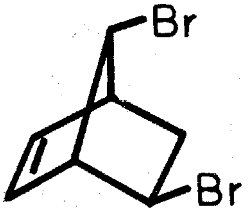


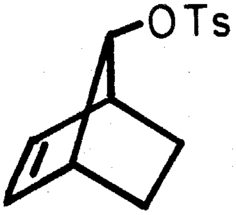
Fig. 7.

Preparations of *syn*- and *anti*-7-chloronorbornene (XLIX and L) by the pyrolysis of the corresponding 2-β-naphthoate esters have been previously described (22). Quantitative hydrogenation, yielding 7-chloronorbornane (XLVIII), indicated XLIX and L to have 75 ± 2% and 97 ± 2%, respectively, of the theoretical unsaturation. *syn*-7-Chloronorbornene (XLVIII) prepared by hydrogenation of XLIX contained 23 ± 2% of a much more reactive chloride as judged by its solvolytic behavior. In each case, the infrared spectra indicated the impurity to be nortricyclyl chloride (LI) (22). After completion of this work, a method was found for preparing XLIX in 30% yield by treating *syn*-7-*exo*-2-dichloronorbornane with potassium *t*-butoxide in *t*-butyl alcohol. The resulting chloroolefin was completely free of nortricyclyl chloride (LI).

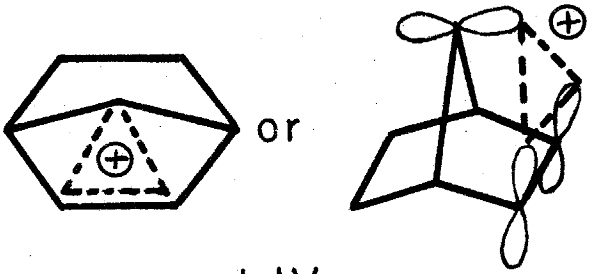
Solvolysis rate constants in 80% and 50% aqueous ethanol for XLVIII-LI and some suitable reference compounds are given in Tables I and II. As expected (22), XLVIII and XLIX solvolyze very slowly in aqueous ethanol--at least two, and possibly more, orders of magnitude slower than cyclopentyl chloride. In contrast, L is very reactive as would be anticipated from the discovery by Winstein, Woodward and co-workers (57,58) of high solvolytic reactivity for *anti*-7-*exo*-5-dibromonorbornene LII (Fig. 8) and *anti*-7-norbornenyl *p*-toluenesulfonate LIII.



LII



LIII



LIV

LV

Fig. 8.

TABLE I

Solvolysis Rates of Chlorides in 80 Volume Percent Ethanol

Chloride	Temp., °C	$\underline{k}_1$, sec.$^{-1}$	Rel. $\underline{k}_1$	°/o Reaction[a]	°/o Purity
α-Methylallyl	99.7	1.4×10^{-3} [b]	1	—	—
anti-7-Norbornenyl (XLX)	50.2	$8.7 \pm 0.3 \times 10^{-5}$	—	67	97 ± 2
anti-7-Norbornenyl (XLX)	61.2	$2.7 \pm 0.2 \times 10^{-4}$	—	73	97 ± 2
anti-7-Norbornenyl (XLX)	99.7	$1.0 \pm 0.5 \times 10^{-2}$ [c]	7	—	—
exo-Norbornyl	99.7	$1.75 \pm 0.06 \times 10^{-4}$	0.13	63	100

(a) Degree of completion of reaction during kinetic experiments. (b) Calculated from data at lower temperatures obtained by C.A. Vernon, J. Chem. Soc., 423-428 (1954) and W.G. Young and L.J. Andrews, J. Am. Chem. Soc., 66, 421-425 (1944) with the aid of the rate-solvent correlations of E. Grunwald and S. Winstein, *ibid.*, 70, 846-854 (1948). (c) Calculated from the data at lower temperatures.

TABLE II

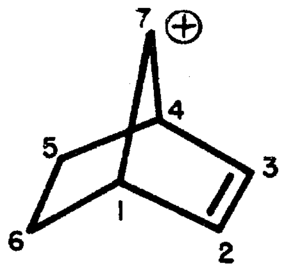
Solvolysis Rates of Chlorides in 50 Volume Percent Ethanol

Chloride	Temp., °C.	k_1, sec.$^{-1}$	Rel. k_1	°/o Reaction[a]	°/o Purity
Cyclopentyl	99.7	1.9×10^{-4} [b]	1.0	---	---
Cyclohexyl	99.7	1.4×10^{-5} [b]	0.07	---	---
anti-7-Norbornenyl (XLX)	24.9	$2.3 \pm 0.2 \times 10^{-4}$	---	57	97 ± 2
anti-7-Norbornenyl (XLX)	50.2	$4.0 \pm 0.1 \times 10^{-3}$	---	89	97 ± 2
anti-7-Norbornenyl (XLX)	99.7	$3.6 \pm 1.4 \times 10^{-1}$ [c]	1900	---	---
syn-7-Norbornenyl (XLIX)	99.7	$< 2 \times 10^{-6}$ [d]	< 0.01	25[e]	75 ± 2
7-Norbornyl (XLVIII)	99.7	$< 1 \times 10^{-6}$ [d]	< 0.005	8[e]	77 ± 2
Nortricyclyl (XLXI)	99.7	$8.2 \pm 0.5 \times 10^{-4}$	4.3	87	90

(a) Degree of completion of reaction during kinetic experiments. (b) Calculated from the data of J.D. Roberts and V.C. Chambers, J. Am. Chem. Soc., 73, 5034-40 (1951) and unpublished results of J.D. Roberts at 100°. (c) Calculated from the data at lower temperatures. (d) Upper limit for rate after correction for the ethanol-hydrochloric acid reaction (see Experimental). (e) Maximum extent of solvolysis after all of nortricyclyl chloride impurity had reacted.

The unusual reactivity of L, LII and LIII may be ascribed to stabilization of the carbocationic transition state by delocalization of the unsaturation electrons which would be more effective if the leaving group is anti with respect to the double bond (57,58). Solvolysis of L or LIII can be presumed to involve the intermediate cation LIV (Fig. 8) which is inferred from the reaction rates to be relatively stable as carbocations go. Although LIV can be described as a "homoallylic" cation (54,57,58), classification is here preferred as a "bis-homocyclopropenyl" cation to emphasize its relationship to the cyclopropenyl cation LV which is predicted by simple molecular orbital theory to have a very stable π-electron system (calculated delocalization energy = 2.00β) (59). The arrangement of the 2*p*-orbitals at C_2, C_3 and C_7 of LIV may not appear to be very favorable for effective overlap, but the net stabilization energy (taking into account angle strain) computed by a molecular orbital procedure based on that of Simonetta and Winstein (54) is substantially greater than that predicted for the most favorable open-chain "homoallylic" carbocation (54).

The calculations of the net stabilization energy of LIV relative to the corresponding classical cation LVI were based on a geometrical model for the carbon skeleton of LVI derived from an



LVI

electron diffraction study of bicyclo[2.2.1]heptadiene (60). In particular, the five-membered ring defined by carbons 1,2,3,4 and 7 of LVI was considered to be identical with the analogous portion of the bicyclo[2.2.1]heptadiene framework. The structural parameters are listed in Table III.

TABLE III

Structural Parameters Assumed for Cation LVI

Angle	Value, °	Bond	Length, Å
C_1-C_2-C_3	109.1	C_1-C_2	1.522
C_2-C_1-C_7	96.4	C_1-C_4	2.329
C_1-C_7-C_4	96.7	C_1-C_7	1.558
C_6-C_1-C_2	99.3[a] (102.2)	C_2-C_3	1.333
C_6-C_1-C_7	99.3[a] (96.4)	C_2-C_7	2.296

(a) Averaged values used.

With Θ_2 and Θ_7 as the angles between the line joining the C_2, C_7 nuclei and the p-orbital axes at C_2 and C_7, respectively, the overlap integral S_{27} was obtained from Eq. 1 where γ is the angle between the p-orbital axes at C_2 and C_7 as seen by an observer sighting along the C_2-C_7 internuclear line. If ϕ_{27} is the angle in space between the C_2 and C_7 p-orbital axes, cos γ may

$$S_{27} = \cos\Theta_2 \cos\Theta_7 S_{\sigma\sigma} + \sin\Theta_2 \sin\Theta_7 \cos\gamma\, S_{\pi\pi} \qquad (1)$$

be computed from Eq. 2.

$$\cos \gamma = \frac{\sin^2 \theta_2 + \sin^2 \theta_7 - 4 \sin^2 \phi_{27}/2 + (\cos \theta_2 + \cos \theta_7)^2}{2 \sin \theta_2 \sin \theta_7} \quad (2)$$

The integrals $S_{\sigma\sigma}$ and $S_{\pi\pi}$ were taken from Kopineck's tables (61) on the assumption of an effective nuclear charge of 3.09 (54). The resonance integral β_{27} was evaluated by Mulliken's approximation (54) with S and β for a normal ethylenic bond set equal to 0.28 and -20 kcal./mole respectively. β_{23} was assigned the normal value. The π-electron energy calculations were made using the simple molecular orbital (LCAO) procedure (54, 62-64) with neglect of overlap in the off-diagonal terms. The electron delocalization energies (DE) were computed by subtracting $2(\alpha + \beta)$ from the energy of the lowest electronic configuration.

The strain energies (SE) were calculated wit[illegible] aid of equations 3 and 4, with θ_b as the half-angle of bending [illegible] the normal value of 109° 28' for a given bond angle. Equation 3 a[illegible]s to bonds which can be considered to involve carbon sp^2 orbitals

$$\text{SE per angle} = 118 \left[0.996 - \frac{(0.5+1.5 \cos \theta_b)(0.577+ \sqrt{2} \cos \theta_b)}{4} \right] \quad (3)$$

$$\text{SE per angle} = 118 \left[1.000 - \frac{(0.5 + 1.5 \cos \theta_b)^2}{4} \right] \quad (4)$$

one carbon and sp^3 orbitals on the other carbon (65). Equation 4 applied to bonds where bond formation may be regarded as a result of overlap of sp^3 orbitals on both atoms (65). In the calculation of SE and DE, LIV (Fig. 8) was considered to be distorted solely through changes of the dihedral angle between the C_1-C_2-C_3-C_4 plane and the C_1-C_7-C_4 plane symmetrically with respect to the C_4-C_5-C_6-C_1 plane. SE for unperturbed LIV was calculated to be 5.2 kcal./mole considering only the three pairs of angles about the line connecting the C_1-C_4 nuclei. With this value as a zero point, SE was calculated for smaller values of R_{27} by taking into account the small decrease in the strain of angles C_{543}, C_{547}, C_{612} and C_{617} accompanying the larger increase of strain in angles C_{217} and C_{347}. The "net SE" and the DE data are given in Table IV.

Dunitz and Schomaker (66) have shown that the strain energy of cyclobutane can be adequately accounted for by considering the sizable repulsions between non-bonded carbons, in addition to the angle bending and torsional strain. In the present case, the non-bonded carbon-carbon distances are rather comparable to those in cyclobutane, but these repulsions have not been considered because of uncertainties in treating partial relief of the C_2-C_7 and C_3-C_7 repulsions (LVI). For this reason, the "net SE" values must be considered as approximate minima.

The maximum value of the net stabilization energy E (10.5 kcal./mole) approaches that calculated for the allyl cation (16.6 kcal./mole) and is considerably greater than the value of 7.2 kcal./mole for the maximized delocalization energy computed for the homoallylic cation (54). On this basis, it is not surprising that the first-order solvolysis rate for L (Fig. 7) is approximately 110 times greater than that for <u>exo</u>-dehydronorbornyl chloride at 85°

TABLE IV

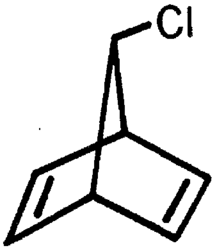
Summary of Calculations for Cation LIV

R_{27}, Å	θ_2	θ_7	γ	S_{27}	β_{27}/β_{23}	DE, kcal./mole	Net SE, kcal./mole	Net E, kcal./mole
2.296	68° 10'	58° 55'	17° 29'	0.0802	0.3394	7.7	0.0	7.7
2.200	64° 44'	53° 39'	24° 10'	.0994	.4133	10.8	3.2	7.7
2.000	59° 10'	44° 37'	33° 12'	.1454	.5803	18.4	7.9	10.5
1.800	55° 9'	37° 29'	47° 25'	.1852	.7143	25.1	15.6	9.5

in 80% ethanol (9). This correlation is made assuming that the "dehydronorbornonium" ion (XLVI) (Fig. 6) represents the best case of an open-chain "homoallylic" cation (54). That this is a reasonable assumption is shown by a calculation on unperturbed XLVI ($\beta_{26} = 0.3769\beta$) yielding a DE of 2.8 kcal./mole which is to be compared with the DE of 7.7 kcal./mole found for unperturbed cation LIV (Table IV).

Perhaps even more striking than the high reactivity of L are the low reactivities of XLVIII and XLIX. Both of these substances are very substantially less reactive than cyclopentyl chloride. At least three factors may be regarded as attributing to their low reactivity. First, there may be some steric hindrance to solvation of the 7-norbornyl cation by repulsions involving C_5 and C_6 and their associated hydrogens. Second, an increase in steric strain may be expected to be associated with the change in hybridization at C_7 during carbocationic formation and should be substantially greater than that accompanying the corresponding change in the cyclopentyl system. Finally, and probably most important, would be steric inhibition of hydrogen hyperconjugative stabilization (10,22) of the cation which, though possible for the cyclopentyl cation is suggested by Bredt's rule (67) to be prohibited for a 7-norbornyl cation. Such loss of hyperconjugative stabilization should be comparable at least to the effect produced by substitution of a single α-methyl group at the carbinyl carbon of an alkyl halide and could result in a decrease of $10^4 - 10^5$ in alcoholysis rate (68,69,70).

The rate-enhancing effect of one unsaturated link in the solvolysis of cholesteryl, exo-dehydronorbornyl and anti-7-norbornenyl derivatives and the reasonable correlation between calculated delocalization energy and relative rate leads one to suspect that two double bonds might have an even greater effect on the DE of the carbonium ion. Such a cation might well arise from the solvolysis of 7-chloronorbornadiene (LVII). The predicted π-electron energies of some cations of interest in this connection are given in Table V.

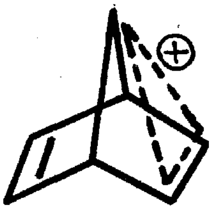
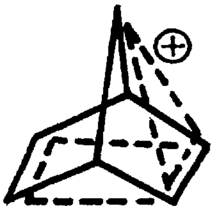
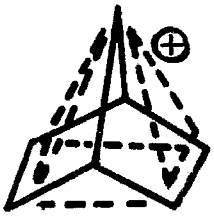


LVII

The slightly increased DE value for LIX relative to LVIII (0.7 kcal./mole) (Table V) shows that the added participation of the $C_5 - C_6$ double bond probably would contribute to a slightly increased solvolysis rate for LVII relative to that of anti-7-chloronorbornene (L) (Fig. 7). On the other hand, the inductive effect of the $C_5 - C_6$ unsaturation might well be expected (51) to decrease the rate of LVII relative to L. Consequently, one might predict that LVII would solvolyze at roughly the same rate as L. The value of 17.4 kcal./mole for the DE of the "7-norbornadienylium" ion (LX) (Table V) anticipates a considerable stability for the intermediate from the solvolysis of LVII. However, from stereoelectronic considerations, LIX is expected to be a superior model for the transition state in such a solvolysis.

TABLE V

Calculations for Unperturbed 7-Norbornenyl Cations[a]

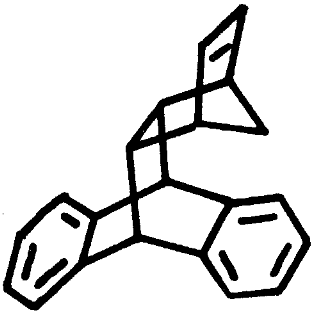
Ion	β_{23}	β_{27}	β_{26}^{b}	β_{56}	β_{57}	DE kcal./mole
 LVIII	β	0.3394β	0	0	0	7.7
 LIX	β	0.3394β	0.3769β	β	0	8.4
 LX	β	0.3394β	-0.3769β	β	0.3394β	17.4
	β	-0.3394β	0.3769β	β	0.3394β	17.4

(a) For purposes of calculation, the ions are all assumed to have the carbon framework of bicyclo[2.2.1]heptadiene (60) (see Table III).
(b) Calculated from the value of 0.08985 found for S_{26}.

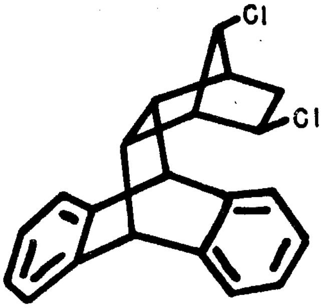
In partial confirmation of the predicted reactivity of LVII is the recent observation by McBee and co-workers (71) that the chlorines on the methylene bridge in 1,4,5,6,7,7-hexachloro-2-phenylbicyclo[2.2.1]-2,5-heptadiene exhibit unique lability toward sodium methoxide in methanol.

Several synthetic routes were explored for the preparation of 7-chloronorbornadiene (LVII). One promising series of reactions appeared to be via the Diels-Alder adduct of anthracene and norbornadiene (LXI) (Fig. 9) followed by chlorination to yield the rearranged dichloride LXII. Treatment of LXII with potassium t-butoxide in t-butyl alcohol would be expected (72) to give the chloroolefin LXIII which on pyrolysis would presumably yield the reverse Diels-Alder products--anthracene and LVII. It was found that the condensation of norbornadiene and anthracene would not take place after 11 hours in boiling benzene solution. The condensation did proceed at 225-230° in a sealed tube to give a 20% yield of a high-melting material which analyzed correctly for an adduct of two moles of anthracene to one of the diene. In addition, there was obtained 71% of an impure, lower-melting fraction which yielded a small amount of material which analyzed fairly well for the 1:1 adduct (LXI). This approach was discontinued due to the unavailability of norbornadiene.

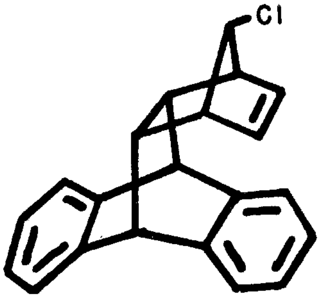
The addition of hypochlorous acid to endo-dehydronorbornyl acetate (LXIV) would be expected (22) to yield exo-5-(or exo-6-) hydroxy-anti-7-chloro-exo-norbornyl acetate (LXV) in addition to some chloronortricyclyl acetate (LXVI). Preparation of the β-naphthoate ester of LXV followed by pyrolysis (22,73) might yield 7-chloronorbornadiene plus acetic and β-naphthoic acids. It was found that the addition of hypochlorous acid to LXIV gave 47% of LXV as shown by analysis and infrared spectrum. The naphthoate ester (m.p. 149-150°) was prepared and heated at 320 ± 10° for 3-6 hours. The pyrolysis product, obtained in low yield, was a complex mixture,



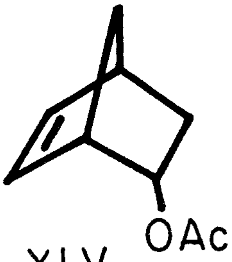
LXI



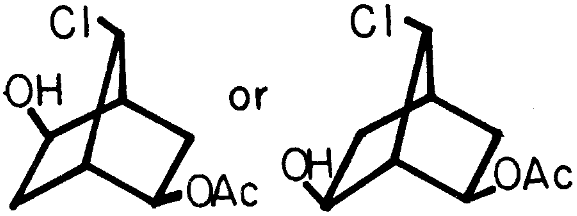
LXII



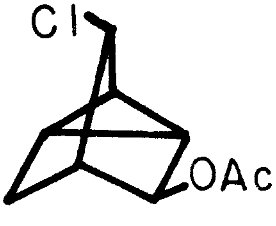
LXIII



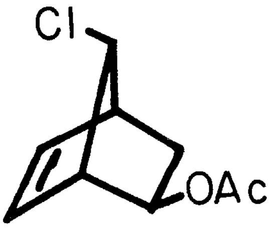
LXIV



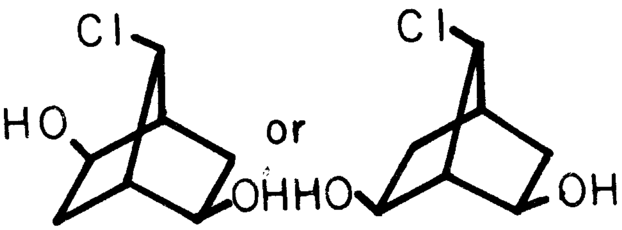
LXV



LXVI



LXVII

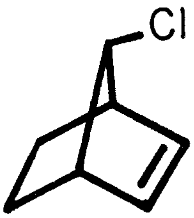


LXVIII

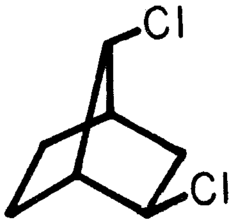
Fig. 9

one fraction of which was indicated by its analysis to be LXVII. However, no material having the properties expected of 7-chloronorbornadiene could be detected. In view of the marked superiority of the β-naphthoate group to eliminate in this series over various other ester groupings (22, 36), it appeared desirable to replace the acetate group in LXV with a β-naphthoate function. Lithium aluminum hydride reduction of LXV gave two chlorodiols, one an impure, waxy solid and the other a crystalline solid (m.p. 167-170.5°) (LXVIII). Preparation of the di-β-naphthoate ester of the lower melting isomer proceeded in poor yield and pyrolysis gave a small amount of material which was shown by analysis not to be the desired 7-chloronorbornadiene.

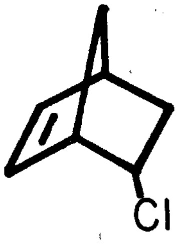
Still another approach to this problem was suggested by the successful preparation of _syn_-7-chloronorbornene (LXIX) (Fig. 10) by the treatment of Schmerling's dichloride (_syn_-7-chloro-_exo_-norbornyl chloride) (LXX) with potassium _t_-butoxide. The chlorination of _endo_-dehydronorbornyl chloride (LXXI) in pentane solution at Dry Ice temperatures gave, in addition to 29% nortricyclyl chloride, 37% dichloronortricyclene (LXXIII) and 29% trichloronorbornane (LXXII). The trichloride LXXII was a waxy solid, m.p. 34-34.5°. Treatment of LXXII with two equivalents of potassium _t_-butoxide in _t_-butyl alcohol resulted in a 66% yield of an isomeric mixture of unsaturated dichlorides and dichloronortricyclenes, presumed to be LXXIII and LXXIV on the basis of analyses, infrared spectra and chemical evidence. An attempt to eliminate an additional molecule of hydrogen chloride from LXXIV by reaction with a suspension of potassium _t_-butoxide in



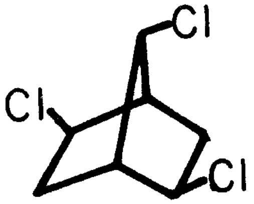
LXIX



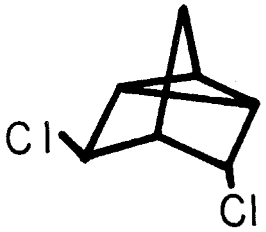
LXX



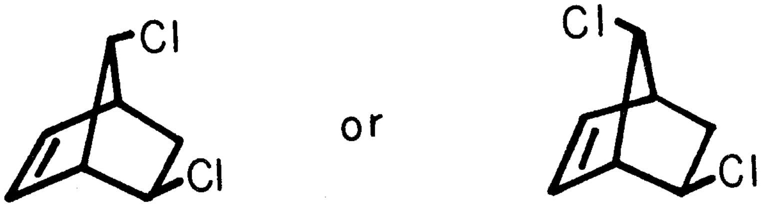
LXXI



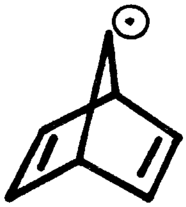
LXXII



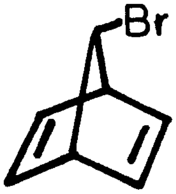
LXXIII



LXXIV



LXXV



LXXVI

Fig. 10

benzene resulted in the recovery of unchanged starting material. In the hope that a base stronger than t-butoxide ion might enhance the dehydrohalogenation LXXII was treated with two equivalents of lithium diethylamide in ether solution. This resulted in a 37% yield of essentially the same mixture of LXXIII and LXXIV as obtained from the t-butoxide elimination. In addition, a considerable amount of lower boiling material was obtained which was partially unsaturated and chlorine-free, but was not further characterized.

The formation of the dichloronortricyclene LXXIII in these reactions is interesting. Although it is conceivable that LXXIII could have been produced from LXXII by solvolysis followed by loss of a proton (E_1) in the t-butyl alcohol solution, this possibility is completely ruled out in the lithium diethylamide - ether experiment. Consequently, one must conclude that we are dealing with an E_2 elimination across an intervening saturated carbon atom. The first example of this type of elimination occurring in the norbornyl system was found by Johnson (151), who observed that exo-norbornyl bromide gave a mixture of norbornene and nortricyclene when it was dehydrobrominated in boiling quinoline. Such 1,3-dehydrohalogenations are well known in cyclopropane chemistry (76). However, the hydrogen γ to the halogen in the latter cases is always activated by another group as in γ-haloketones, -esters and -nitriles (76). In this case, the hydrogen is apparently activated by the β-chlorine atom.

From the results given in Table V, it can be shown that the 7-norbornadienyl radical (LXXV) has a DE of 8.7 kcal./mole. On this basis, an attempt was made to prepare 7-bromonorbornadiene

(LXXVI) by the Ziegler (74,75) bromination of norbornadiene. The reaction of norbornadiene and N-bromosuccinimide was exothermic and gave a complex mixture of products. The elemental analysis indicated the presence of mono-, di- and tribromides, contaminated with about 4% succinimide.

Due to limitations on time, attempts to prepare 7-chloronorbornadiene were discontinued. Since norbornadiene will soon be commerically available (77), the most promising route to 7-substituted norbornadienes would appear to be through the anthracene adducts (LXI, LXII) (Fig. 9) described above or through direct substitution in the 7-position.

Carboni (35,36) found that syn- and anti-7-chloro-exo-norbornyl p-toluenesulfonates (LXXVII and LXXVIII, X = p - $CH_3C_6H_4SO_3$) (Fig. 11) solvolyzed in acetic acid some 280 times more slowly than exo-norbornyl p-toluenesulfonate (LXXXIX, X = p - $CH_3C_6H_4SO_3$). These esters (LXXVII and LXXVIII) were about as reactive in acetolysis at 25° as cyclohexyl p-toluenesulfonate. Infrared analysis of the acetolysis products of LXXVII and LXXVIII (X = p - $CH_3C_6H_4SO_3$) *indicated that each gave almost the same mixture of syn- and anti-*7-chloro-exo-norbornyl acetates (LXXVII and LXXVIII, X = CH_3COO). Lithium aluminum hydride reduction of either acetate mixture gave an approximately equimolal mixture of chlorohydrins (LXXVII and LXXVIII, X = OH) as shown by comparison of the infrared spectra of the reduction products with each other and with synthetic mixtures of the two chlorohydrins. In other experiments, it was found that, although the p-toluenesulfonate esters were not significantly interconverted during the first 10% of acetolysis, after 70% acetolysis,

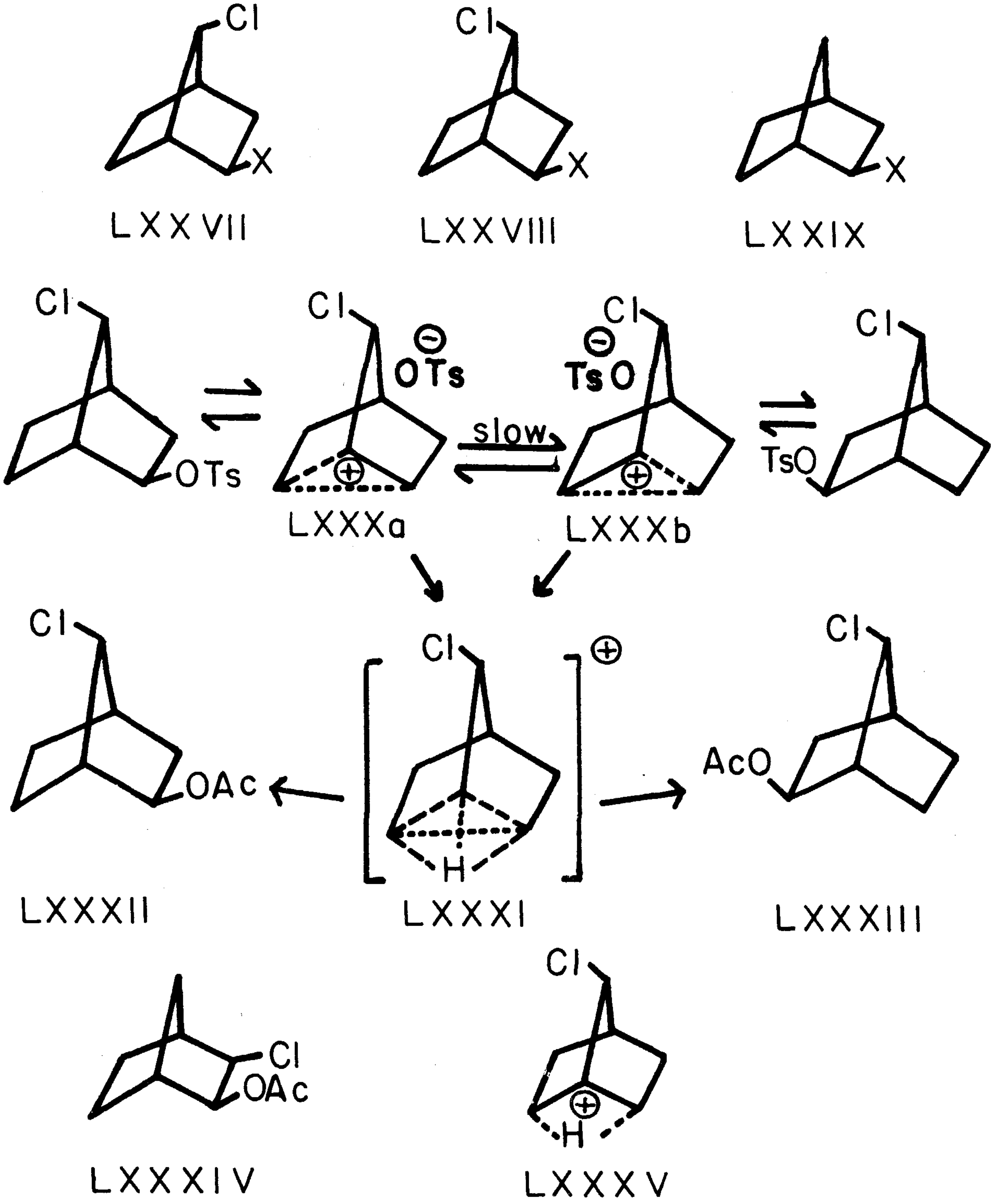
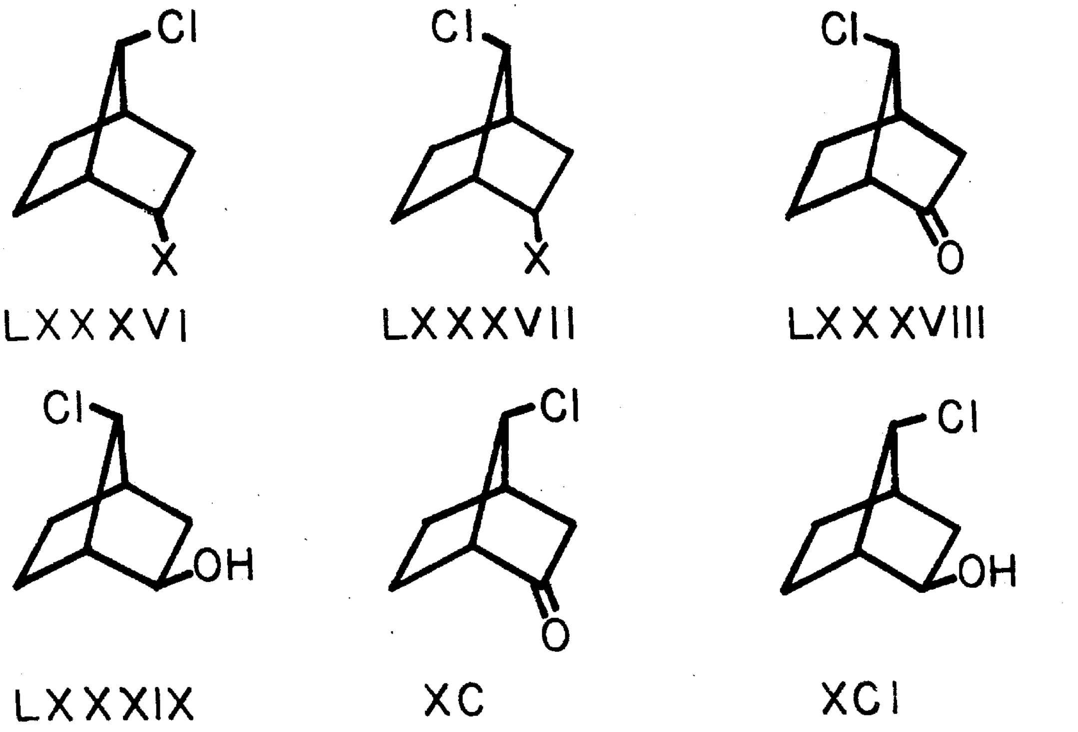

Cl
X
LXXVII
Cl
X
LXXVIII
X
LXXIX
Cl
OTs
Cl
⊖
OTs
⊕
LXXXa
slow
Cl
⊖
TsO
⊕
LXXXb
Cl
TsO
Cl
OAc
LXXXII
Cl
H
⊕
LXXXI
Cl
AcO
LXXXIII
Cl
OAc
LXXXIV
Cl
⊕
H
LXXXV

Fig. 11

the unsolvolyzed esters were 20-25% isomerized. The isomerization and acetolysis product mixtures suggested a reaction path involving a "tight" ion-pair intermediate (LXXX) which could lead to some isomerized p-toluenesulfonate via "internal return" (13,14). Dissocation of LXXX to a hydrogen-bridged cation (LXXXI) (29) could then lead to an approximately equimolal mixture of the syn- and anti-7-chloro-exo-norbornyl acetates (LXXXII and LXXXIII). The apparently inconsequential formation of Wagner-Meerwein rearrangement products like 3-chloro-exo-norbornyl acetates (LXXXIV) in these and similar (22) reactions can be rationalized on the basis that the attack by solvent on intermediates like LXXXI would occur preferentially at the 2- and 6-positions since the 1-positions would have but slight cationic character because of the proximity of the adjacent carbon-chlorine dipole at C_7.

The above results can also be adequately accounted for by the simple hydrogen-bridged intermediate LXXXV. One might, in fact, prefer intermediate LXXXV to LXXXI on the grounds that the low acetolysis rates of LXXVII and LXXVIII (X = p - $CH_3C_6H_4SO_3$) indicate "carbon participation" to be of small importance and also the absence of Wagner-Meerwein rearrangement products makes carbon-bridging of questionable importance. In order to distinguish between intermediates LXXXI and LXXXV, it seemed of interest to prepare either syn- or anti-7-chloro-endo-norbornyl p-toluenesulfonate (LXXXVI or LXXXVII, X = p - $CH_3C_6H_4SO_3$) (Fig. 12) and determine its acetolysis rate. A substantially lower reactivity of either endo-isomer relative to its exo-analog would be evidence in favor of intermediate LXXXI (Fig. 11). If the endo p-toluenesulfonate ester were found to possess an acetolysis rate essentially equal to that of the *exo*, one would be forced to introduce intermediate LXXXV or its equivalent.

The lithium aluminum hydride reduction of *anti*-7-chloronorcamphor (LXXXVIII) gave 91% of a product whose infrared spectrum, when compared with that of *anti*-7-chloro-*exo*-norborneol (LXXXIX), definitely showed the presence of another constituent. The elemental analysis revealed that only about 5% of the chlorine had been lost during the reduction. It was concluded, therefore, that the reduction had given a fair amount of *anti*-7-chloro-*endo*-norborneol (LXXXVII, X = OH). An attempt to prepare the *p*-toluenesulfonate ester of this mixture gave an oil which could not be purified either by crystallization or by repeated washing with pentane to remove unreacted alcohol.



LXXXVI LXXXVII LXXXVIII

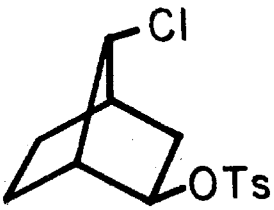
LXXXIX XC XCI

Fig. 12

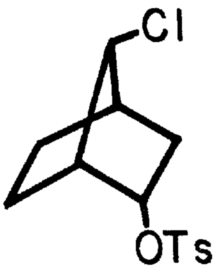
In contrast to the above results, the lithium aluminum hydride reduction of the stereoisomeric syn-7-chloronorcamphor (XC) proceeded smoothly to give a 95% yield of syn-7-chloro-exo-norborneol (XCI), as shown by the identity of its infrared spectrum with that of an authentic sample. The stereochemistry of hydride reductions has been recently scrutinized by Dauben, Fonken and Noyce (78), who found that both "steric approach control" and "product development control" were important in determining the stereochemical outcome of lithium aluminum hydride (LAH), sodium borohydride (SBH) and aluminum isopropoxide reductions. Reductions with LAH have been quite generally found to yield predominantly the more stable of two possible stereoisomeric products (78,79,80,81) and have led Umland and Jefraim (80) to very recently conclude that product development control determines the course of such reductions. It was pointed out (78) that the importance of steric approach control greatly increases as the steric requirements of the reducing agent increases. Thus, in the reduction of 2-methylcyclohexanone, 82% trans-2-methylcyclohexanol was obtained (78) by LAH reduction, while SBH and Meerwein-Ponndorf-Verley reductions gave 69% and 42% (79), respectively, of the more stable trans alcohol. Since it is generally considered that steric approach control, i.e., the ease of formation of the organometallic complex between the carbonyl group and the hydride (82), is only of major importance in highly hindered ketones (81), the formation of strictly exo-alcohol from the LAH reduction of XC is surprising. In this case, as will be seen later (Chapter II), syn-7-chloro-exo-alcohol (XCI) may be stabilized by intramolecular hydrogen bonding.

It is questionable, however, whether stabilization of this type involving the free alcohol would be product-determining since the alcohol exists as an alkoxide salt in the hydride reaction mixture (84). One is led to the conclusion that the aluminum hydride complex of the carbonyl group of XC, in addition to the _syn_-7-chlorine atom, effectively prevents _exo_-attack by hydride ion and consequently only _endo_-attack can occur, yielding entirely _exo_-alcohol. The absence of the _syn_-7-chlorine atom in _anti_-7-chloronorcamphor (LXXXVIII) apparently allows for considerable _exo_-attack by hydride ion, giving rise to the observed mixture of _endo_- and _exo_-alcohols.

Employing the technique of Dauben (78), it was found possible to partially isomerize XCI to the _endo_-isomer (LXXXVI, X = OH). The presence of LXXXVI (X = OH) was shown by the infrared spectrum of the product obtained by boiling an isopropyl alcohol solution of XCI and aluminum isopropoxide for 72 hours in the presence of a trace of acetone. Preparation of the _p_-toluenesulfonate ester of the mixture gave an oil which was shown by infrared to be free of unreacted alcohol and also analyzed correctly for the expected isomeric mixture of _syn_-7-chloro-_exo_- and _endo_-norbornyl _p_-toluenesulfonates (XCII and XCIII). Acetolysis of this mixture at 78.2° gave



XCII



XCIII

the first order curve shown in Fig. 13. From Carboni's date (35,36) for the acetolysis of XCII under identical conditions, it was calculated that less than 0.5% of XCII was present after 1300 minutes(Fig. 13). A least squares fit of the points after 1300 minutes (Fig. 13) gave the rate constant for the endo p-toluene sulfonate XCIII and the intercept allowed the evaluation of the percent composition of the mixture. The composition was found to be 47.5% XCIII and 52.2% XCII. Assuming no isomer fractionation of the chlorohydrins XCI and LXXXVI (X = OH) (Fig. 12) had occurred during the preparation of XCIII and XCII, and assuming internal return to be unimportant, these percentages are a true measure of the equilibrium composition of the chlorohydrin mixture obtained from the aluminum isopropoxide isomerization of XCI. Furthermore, the lithium aluminum hydride reduction of XC is substantiated as a case of steric approach control (78) because of the absence of any endo alcohol, which is now seen to be of comparable thermodynamic stability to the exo.

The method of Brown and Fletcher (84) was used to isolate the first-order acetolysis constant for the exo-p-toluenesulfonate XCII. The linearity of the first-order plot in Fig. 14 attests to the applicability of the method to the present case, as does the agreement between the constant found here and that determined by Carboni (36) for the pure exo p-toluenesulfonate. Table VI summarizes the acetolysis results for XCII and XCIII along with data for some suitable reference compounds.

TABLE VI

p-Toluenesulfonate Acetolysis Rate Constants at 78.2°.

p-Toluenesulfonate	[KOAc], M	k_1, sec.$^{-1}$	Rel. k_1
syn-7-Chloro-exo-norbornyl (XCII)	0.035 0.035	$6.6 \pm 0.2 \times 10^{-5}$ [a] $6.1 \pm 0.4 \times 10^{-5}$ [b]	1 0.9
syn-7-Chloro-endo-norbornyl (XCIII)	0.035	$1.81 \pm 0.01 \times 10^{-6}$ [b]	0.027
exo-Norbornyl	0.035	2.15×10^{-2} [c,d]	316
endo-Norbornyl	--	7.7×10^{-5} [c,d]	1.1
Cyclohexyl	--	6.8×10^{-5} [c]	1.0

(a) Value obtained by Carboni (35,36). (b) This work. (c) Calculated from the data of S. Winstein, *et. al*. (8). (d) One third of the rate for the p-bromobenzenesulfonate.

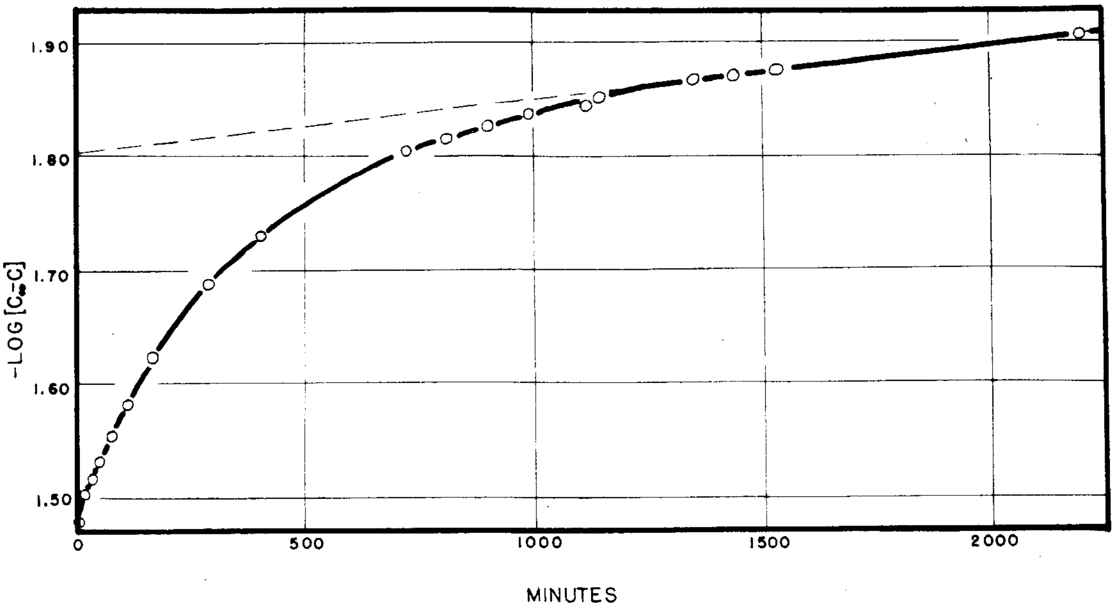


Fig. 13

First-order acetolysis of syn-7-chloronorbornyl p-toluenesulfonates at 78.2°. The dashed line is that used to evaluate $\underline{k}_{\text{endo}}$.

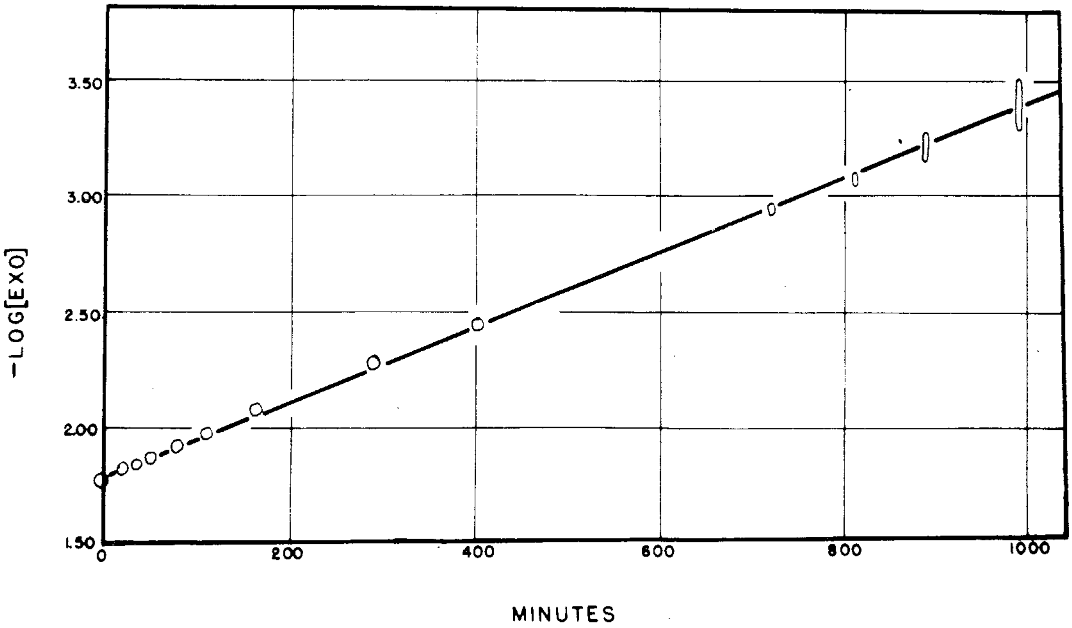


Fig. 14

First-order acetolysis of syn-7-chloro-exo-norbornyl p-toluenesulfonate at 78.2°. See Table XXXII (Appendix).

syn-7-Chloro-endo-norbornyl p-toluenesulfonate (XCIII) is seen to be some 35 times less reactive than the exo-isomer XCII. By way of comparison, exo-norbornyl p-toluenesulfonate is acetolyzed (8) 280 times faster than its endo-isomer at this temperature. The presence of the carbon-chlorine dipole at C_7 in XCII apparently substantially lessens the ability of the C_1-C_6 bonding electrons to participate in the rate-determining ionization. However, carbon participation is undoubtedly still of importance in the ionization of XCII in view of the considerably lower reactivity of the endo-isomer XCIII. This leads to the conclusion that intermediate LXXXI (Fig. 11) is to be preferred over intermediate LXXXV in the acetolysis of XCII.

Perhaps the most interesting feature of Table VI is the low reactivity of XCIII relative to endo-norbornyl p-toluenesulfonate. A β-chlorine atom has been shown (92,93) to decrease the acetolysis rate of trans-2-chlorocyclohexyl p-bromobenzenesulfonate by a factor of 2200 at 75° relative to cyclohexyl p-bromobenzenesulfonate. In the present case we have a γ-chlorine atom which has the effect of reducing the acetolysis rate of XCIII by a factor of 40 relative to endo-norbornyl p-toluenesulfonate. Since inductive and field effects fall off rapidly with distance, it is expected that a γ-chlorine should have a considerably smaller effect such as is observed.

II

ELECTROSTATIC EFFECTS IN SOME 7-CHLORONORBORNANE DERIVATIVES.

INTRODUCTION

The electrical effects of substituents on the reactivity of organic compounds have been the subject of many experimental and theoretical studies. Perhaps the most challenging problem in this field today is the disentanglement of the "inductive" effect, considered as transmitted through the covalent bonds of the molecule, and the "direct" or "field" effect, which may be regarded as acting directly through space. Both of these modes of transmission of electrical effects are discussed below with emphasis on recent efforts to evaluate their relative magnitude.

Inductive Effect

In a rationalization of the high acidity of chloroacetic acid relative to acetic acid, G.N. Lewis (95) stated:

> "The electrons, being drawn towards the chlorine, permit the pair of electrons joining the methyl and carboxyl groups to approach nearer to the methyl carbon. This pair of electrons, of the hydroxyl oxygen, permit these also to shift in the same direction. (This shift produces) a greater separation of the electrons from the hydrogen of the hydroxyl, and thus a stronger acid."

This appears to be the first concise statement of the "inductive" effect. Lucas (96) utilized the concept of a "screening" effect whereby the chlorine atom, by virtue of its increased electronegativity, was visualized as withdrawing the screening electrons from the methyl carbon causing the electrons in the rest of the molecule to be redistributed in such a way as to increase the polarity of the O-H bond. These classical considerations were expanded by Ingold and others (97) to form the basis of an elaborate electronic theory of organic reactions.

One of the features of the English electronic theory was the "alternating" inductive effect in aromatic systems (98). To account for the directive influences of substitutents on electrophilic aromatic substitution, a substituent group was considered to preferentially alter the electron density at the _ortho_ and _meta_ positions of the ring. Recent work by Roberts and co-workers (99) on the reactivities of a number of anilines and benzoic acids substituted in the _meta_ and _para_ positions with trimethylammonium groups has shown clearly that the alternating inductive effect is untenable and that the inductive effect appears to fall off smoothly with increasing distance of the substituent from the reaction site. A similar conclusion was reached as the result of a study (100) on the rates of exchange of _ortho_-, _meta_-, and _para_-deuterated fluorobenzenes, benzotrifluorides, and anisoles in liquid ammonia solution containing potassium amide. Bartlett (101) has given an analogous interpretation to the polar effects of methyl and _t_-butyl groups.

Many theoretical and empirical attempts have been made to evaluate the inductive effect quantitatively. By considering the polarizability of covalent bounds, Waters (102) calculated that the inductive effect should fall off (in terms of electrostatic energy) to one fortieth of its value over a saturated carbon-carbon bond. This "transmission" coefficient rises to one-fifth for the ethylenic linkage and approaches unity for the highly polarizable acetylenic bond. Using an empirical approach, Branch and Calvin (103) assigned "inductive constants" to various groups and were able to arrive at rough values for the acidities of substituted fatty acids. In their calculations, a transmission coefficient of 1/2.8 was employed. For the dissociation of a proton in aqueous solution at 25°, a standard free energy change of ±16.8 kcal./mole was assigned for the effect of a unit charge on the atom carrying the O-H group.

A similar treatment has been developed by McGowan (104,105) in which "effective charges" are assigned to various substituents. As in the Branch and Calvin (103) treatment, a value of ± 14 kcal./mole was introduced for the standard free energy change associated with a full unit charge on the α-carbon of the O-H group. By using a value of 1/2 for the transmission coefficient, considerably better agreement between calculated and observed acidities for the fatty acids was found. Application of the effective charge treatment to a variety of rates and equilibria (105) was possible since a simple relationship was found to exist between the effective charge values and Hammett's sigma constants (106,107).

As Roberts has pointed out (108), most of the methods for the quantitative evaluation of the inductive effect in saturated systems have parameters which are fixed by experiment and actually take account of the total polar effect, including both the inductive and field effects. As we shall see, however, workers considering the field effect tend to consider the transmission of electrostatic effects as occurring entirely through space.

An elegant treatment of the inductive effect has been carried out by Eyring, Smith and co-workers (109). The problem was set up in a qualitative way using bond orbital theory, but recourse was taken to a semi-classical model in order to obtain a working theory similar to that of Remick (110). Using covalent bond radii, longitudinal polarizabilities, screening constants and dipole moments of the methyl halides, dipole moments were calculated with excellent accuracy for a number of haloalkanes. The charge distributions found in these calculations were correlated with the activation free energies for the reaction of sodium atoms with alkyl halides (111), yielding a linear relationship when bond polarizabilities for the different halogens were taken into account. A further success of this theory was illustrated by the linear relationship between the calculated charges on the chlorine for several aliphatic chlorides and the dissociation energies of the corresponding hydrocarbons and free radicals (112). Future correlations of reactivity in aliphatic derivatives by this method are anticipated (112).

Field Effect.

If a substituent has a permanent electric pole or dipole moment and is situated at a distance r from an ionizable group in the same molecule, its electrostatic potential can be expected to effect the energetics of an ionization or an ionic reaction at that group. From classical electrostatics, a pole will produce the potential shown in Eq. 5 and a dipole that shown in Eq. 6,

$$\phi_p = \frac{e}{Dr} \tag{5}$$

$$\phi_D = \frac{\mu \cos \theta}{Dr^2} \tag{6}$$

where D is the dielectric constant of the medium, e the electronic charge, μ the dipole moment and θ the angle of orientation of the dipole. Consequently, the change in free energy per mole associated with the production or removal of a unit charge at the ionizable group is given by multiplying Eqs. 5 and 6 by $\pm Ne$, where N is Avogadro's number and e the electronic charge. It can be seen that the effect of a polar substituent should decrease less rapidly with increasing distance than that of a dipolar group.

An early application of these concepts was made by Bjerrum (113) in calculations of the second ionization constants of dicarboxylic acids. His calculations were based on Eq. 7,

$$\log \frac{K_1}{4K_2} = \frac{Ne^2}{RTDr^2} \tag{7}$$

where K_1 and K_2 are the first and second ionization constants of the dibasic acid, respectively. The factor 4 arises from statistical considerations (114). It is frequently observed that K_2 is much less than $K_1/4$. Bjerrum attributed this decrease in K_2 to the energy required to remove the second proton from the electrostatic field of the carboxylate anion formed from the dissocation of the first proton. His values of the distance r between the carboxylate anion and the dissocating proton in the mono-anion were based on a fully extended, zig-zag polymethylene chain. His calculated K_2 values for the long-chain dicarboxylic acids were in fair agreement with those observed, but the correlation was very poor for the short-chain acids and those with alkyl groups in the chain (*e.g.* malonic and β,β -diethylglutaric acids). Gane and Ingold (115) found for an extensive series of dibasic acids that the Bjerrum equation (Eq. 7) could be satisfied if one assumes that the highly branched acids exist in "bent" rather than zig-zag configurations, resulting in a considerably lower value of *r*. The abnormally high ratios of K_1 to K_2 for maleic and *cis*-caronic acids, as well as for the highly alkylated short-chain dicarboxylic acids, have been recently interpreted in terms of internal hydrogen bonding in the half-ionized form (116). This effect was very recently shown (168) to be generally unimportant and of minor importance even in extreme cases (*e.g.* maleic acid).

Eucken (117) extended the treatment to a consideration of dipolar substituents. For the case of the ionization constant (K_s) of a substituted carboxylic acid relative to that of the unsubstituted acid (K_o), the K_s to K_o ratio can be calculated from Eq. 8,

$$\log \frac{K_s}{K_o} = \frac{\underline{Ne}\,\mu \cos \theta}{\underline{RTD}\ \underline{r}^2} \qquad (8)$$

where *r* is the distance from the center of the dipole axis to the ionizing proton and θ is the angle between *r* and the dipole axis. Good agreement was found between the calculated and observed ionization constants of *meta*-substituted benzoic acids utilizing an arbitrary value of the dielectric constant between that for a hydrocarbon and that of the solvent.

An empirical expression (Eq. 9) was developed by Nathan and Watson (118) for calculating the dissociation constants of substituted acetic acids (K_s) relative to that of acetic acid (K_o) as a function of the dipole moments (μ) of the corresponding halomethanes. Equation 9 was found to accurately fit the data and Waters

$$\log \frac{K_o}{K_s} = A\mu + B\mu^2 \qquad (9)$$

(102) interpreted the term $A\mu$ as the contribution of the direct field effect and the smaller term $B\mu^2$ as due to the inductive effect.

Most early workers in this field considered the dielectric constant to be that of the solvent for purposes of calculation. However, on a molecular level it can be seen that many of the lines of force must pass through the molecule, a region of low dielectric constant. Smallwood ignored the solvent entirely in some calculations for small molecules (119) and considered $\underline{D}$ as equal to unity in his treatment.

The dielectric constant problem was elegantly attacked by Kirkwood and Westheimer (120,121). These authors assumed that the molecules occupy homogeneous spheroidal or ellipsoidal cavities of low dielectric constant in the solvent and they proceeded to define and evaluate an "effective" dielectric constant $(\underline{D}_e)$ which was a function of the size and shape of the cavity, the dielectric constant inside the cavity and the dielectric constant of the solvent. The theory attempted to account for the expectation that in long, thin molecules the lines of force must pass largely through the solvent in transmitting electrostatic effects from the substituent to the reaction site while with short, broad molecules, most of the lines of force pass through the molecule itself, a region of low dielectric constant ($\underline{D}$ = 2.0)(120).

The interprotonic distances for short chain dicarboxylic acids were calculated from the theory and were consistent with limits determined by a free-rotation model and the fully extended, zig-zag configuration. In contrast to the Eucken theory (Eq. 8), the proton-dipole distances were correctly predicted for chloroacetic and β-chloropropionic acids. A large number of interprotonic and proton-dipole distances were calculated for a variety of acids and reasonable agreement was found (122). The ionization constants for substituted benzoic acids, phenols and anilines were found to be well accounted for by the theory (123), except in those cases where resonance effects are of considerable importance (_e.g._ _p_-hydroxybenzoic acid, _p_-nitrophenol and _p_-phenylenediamine).

In a further extension to the relative rates of saponification of the mono- and diethyl esters of dibasic acids (124), the distance between a dipolar substituent and the negative charge in the activated complex was predicted and found to be close to that calculated for a reasonable model. Moderately good agreement with the theory was found for the saponification rates of various _para_-substituted phenylacetates, hydrocinnamates, cinnamates and benzoates, in addition to the reaction of para-substituted benzyl chlorides with sodium iodide and the alkaline hydrolysis of benzamides (125). Deviations were again encountered for compounds with a para-amino or methoxyl group. The equations used in dealing with rates are the same as Eqs. 7 and 8 except that the equilibrium constants (K) are replaced by rate constants ($\underline{k}$) and the dielectric constant ($\underline{D}$) by the effective dielectric constant ($\underline{D}_e$).

The treatment was extended to include the case of a neutral molecule with a dipolar substituent which reacts to give a dipolar transition state (125). Equation 10 was applied to cases where the dipolar substituent (μ_1) and the dipolar transition state (μ_2)

$$\log \underline{k} = \frac{2\mu_1\mu_2}{2.303\ \underline{kTr}^3\ \underline{D}_e} \qquad (10)$$

are colinear. For the general case of a dipolar substituent and transition state dipole in an arbitrary geometrical arrangement (126), Eq. 11 was used by Winstein (92) in calculating the rates of solvolysis of various cis- and trans-2-substituted cyclohexyl p-bromobenzenesulfonates. In Eq. 11, the electrostatic work (W)

$$W = \frac{1.439 \times 10^{13}\ \mu_1\mu_2(\cos\phi - 3\cos\theta\cos\theta')}{\underline{D}_e\ \underline{r}^3} \qquad (11)$$

in kcal./mole associated with the introduction of the dipolar substituent (μ_1) is given as a function of the angle ϕ between the dipoles μ_1 and μ_2 and as a function of the angles θ and θ' between μ_1 and $\underline{r}$ and μ_2 and $\underline{r}$, respectively.

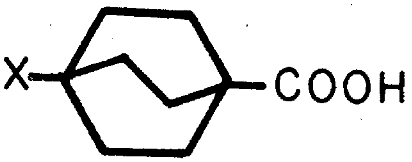
An extensive criticism of the Kirkwood and Westheimer theory has appeared (127). Some of the more important criticisms are that the theory is not reliable in solvents other than water because the effective dielectric constant ($\underline{D}_e$) is not sensitive enough to changes in the solvent dielectric constant (128). The theory does not account for the dependence of rate and equilibrium constants on temperature and its application to mixed solvent systems is questionable because of the tendency for the preferential orientation of one component of the solvent near a polar molecule (129,130). In answering these criticisms, Westheimer and Kirkwood (131) pointed out that, regardless of its limited applicability, their theory provides an order of magnitude improvement over the Bjerrum and Eucken formulations.

Recent Work.

Much can be gained from the above discussion in the design of a series of compounds in which to study the electrostatic effects of substituents on reactivity. In order to eliminate the complication of resonance, the system must be either saturated or be such that any aromatic portion of the molecule is well "insulated" from resonance effects. To reduce the problem of evaluating the distance and angle of orientation between the substituent and the reaction site, some sort of rigid framework, preferably of accurately known structure, should be used. The substituent and the reaction center must be far enough apart or be oriented in such a way as to avoid undesirable steric effects, thereby assuring that reactivity differences will be true measures of free energy differences (106).

Conversely, the two groups should not be so far apart as to make the effect itself too small for measurement (110). Ideally, the type of reactions employed and the solubility properties should be such that reactivity measurements can be made in solvents of widely different dielectric constant. Several studies fulfilling many of these criteria are discussed below.

Undoubtedly the most definitive study in this field is that of Roberts and Moreland (108) on the reactivities of some 4-substituted bicyclo[2.2.2]octane-1-carboxylic acids (XCIV). With X = H, OH, $CO_2C_2H_5$, Br and CN, the ionization constants of the acids in 50% ethanol (K_A), the reactivities towards diphenyldiazomethane in absolute ethanol ($\underline{k}_{DDM}$) and the saponification rates of the ethyl esters in 87.83% ethanol ($\underline{k}_{sap}$) were measured. Linear free energy relationships for log K_A versus log $\underline{k}_{DDM}$ and log K_A versus log $\underline{k}_{sap}$ clearly showed that the effects of the substituents were exerted through changes of potential energy (106) and that entropy terms remain essentially constant throughout the series. By comparison of their data with that for analogous meta- and para-substituted benzoic acids, the authors concluded that in aromatic compounds,



XCIV

the π-electron system is not the predominant path for the transmission of the electrical effects of dipolar groups.

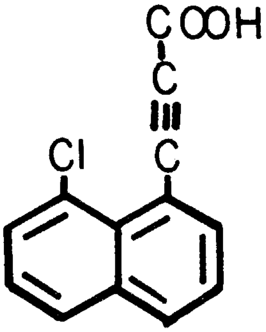
If one accepts the low value given by Waters (102) for the transmission coefficient of the inductive effect, it must be concluded that the influence of a 4-substituent on the reactivity of XCIV is transmitted entirely through space. Calculation of the ΔpK_A in 50% ethanol between the substituted bicyclic acids (XCIV, X = Br, CN) and the unsubstituted (XCIV, X = H) by the Kirkwood and Westheimer theory (120,121) gave values about half as large as those observed. However, similar deviations were found in calculations for para-bromo- and para-cyanobenzoic acids, indicating that the theory is not reliable when dealing with mixed solvents. The ΔpK_A value observed for the 4-bromo acid (XCIV, X = Br) was some 5 times that for δ-bromovaleric acid. This observation was taken as evidence for a substantial contribution of the field effect.

In a study of the dissociation constants of cis- and trans-2-hydroxy-, cis- and trans-3-hydroxy- and cis- and trans-4-hydroxycyclohexanecarboxylic acids, Kilpatrick and Morse (132) also found serious deviations from the Kirkwood and Westheimer theory (120,121). Although the calculated pK_A values in water solution were fairly close to those observed, the agreement between experiment and theory was quite poor in the three solvents of lower dielectric constant which were studied. This observation is in accord with the above-mentioned criticism of the Kirkwood and Westheimer theory (127).

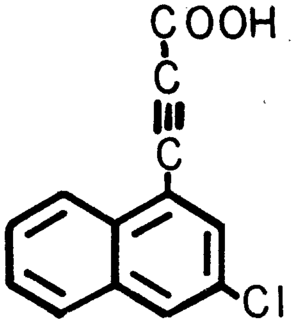
In connection with the results of Roberts and Moreland (108), Siegel and Duffy (133) have observed a similar set of reactivity data for a series of 3-substituted cyclohexanecarboxylic acids. Linear free-energy relationships were found between the pK_A values and the logarithms of the rate constants. The observed order of reactivity of the 3-substituents was: $>C = O \gg Br > OH > COOH(Me) > OMe > H > COO^{-}$. The effects on reactivity were as large as those in meta-substituted benzoic acids.

In a hypothetical discussion of possible pairs of compounds which could be used to distinguish between the inductive and field effects, Roberts (134) suggested the isomeric pair XCV and XCVI (Fig. 15) for a reactivity study. In both XCV and XCVI the inductive effect would be expected to be the same, since the same number of carbon atoms separate the chlorine and carboxyl groups. Any difference in reactivity between XCV and XCVI could unambiguously be attributed to the field effect and the relative magnitude of the field and inductive effects could be approximated from the reactivity of XCV relative to the unsubstituted (1-naphthyl)-propiolic acid. An "ideal" isomeric pair for this type of study would be XCVII and XCVIII, but preparative difficulties for such substances are likely to be prohibitive.

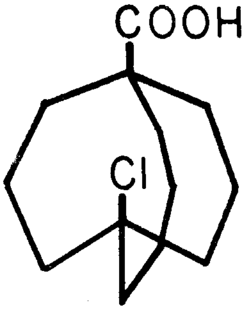
In an effort to obtain a rigid system, Roberts and Carboni (134) prepared and studied the ortho-, meta- and para-substituted phenylpropiolic acids XCIX (X = Cl or NO_2). The apparent dissociation constants in 50% ethanol, the reactivities towards diphenyldiazomethane in ethanol and dioxane and the saponification rates in 87.83% ethanol were measured. The order of acidities and



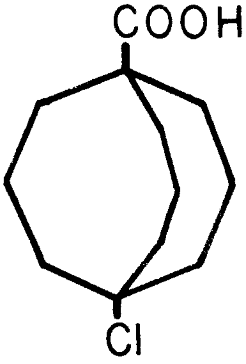
XCV



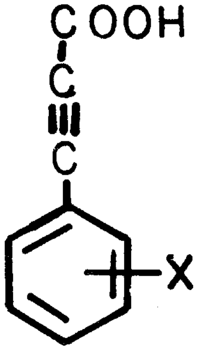
XCVI



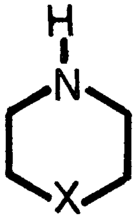
XCVII



XCVIII



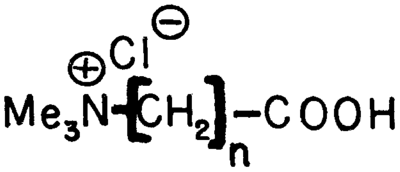
XCIX



C

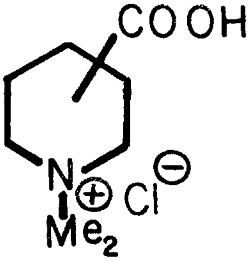
$HXCH_2CH_2NH_2$

CI

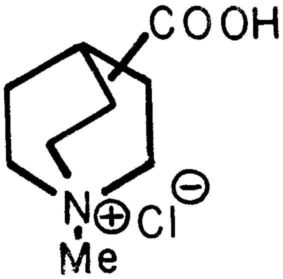


$Me_3\overset{\oplus}{N}\overset{Cl^{\ominus}}{-}[CH_2]_n-COOH$

CII



CIII



CIV

Fig. 15

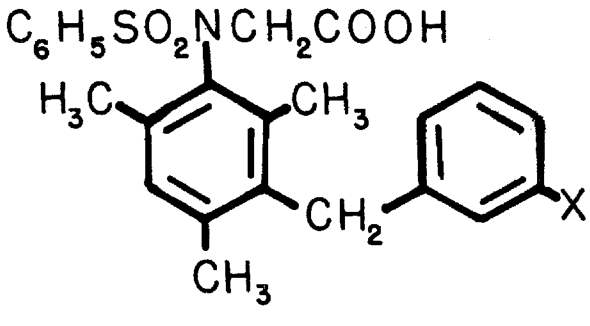
diphenyldiazomethane reactivities were $\underline{m} > \underline{p} > \underline{o} > H$ for chlorine and $\underline{p} > \underline{m} > \underline{o} > H$ for nitro. If only the inductive effect were operating, the expected order would be $\underline{o} > \underline{m} > \underline{p} > H$ and if only the field effect were important, the order would be $\underline{m} \sim \underline{p} > H > \underline{o}$. The observed reactivity orders were interpreted as qualitative evidence for roughly equal contributions of the field and inductive effects in determining the reactivity of substituted phenylpropiolic acids, recognizing that the order $\underline{m} > \underline{p}$ for chlorine is indicative of a resonance effect. Newman and Merrill (135) have obtained parallel reactivity results in a similar study of phenylpropiolic acids (XCIX, X = Cl, NO_2 and OCH_3).

An interesting study of the base strengths in two parallel series of amines (C and CI) has been made by Hall 9136). Comparable data were obtained for X = CH_2, NH, NH_2^+, O, S, $NCOCH_3$ and $NCOC_6H_5$. A linear relationship was found between the pK_A values for the two series and also between the pK_A values and Hammett's (106) σ_{meta} constants. Substituents in the piperazines (C) had a much greater effect on base strength than they did in the 2-position of the ethylamines (CI). Similar large effects of substituents were observed in the 1-methylpiperazine series (137). This larger change for the piperazines was taken by the author (136) as evidence for the operation of the field effect, since the path for the inductive effect is about the same for C and CI. No consideration was given to the existence of two paths for the inductive effect in C.

A study of field effects on three series of acids with a substituent carrying a full positive charge was made by Grob and co-workers (138). In three types of betaines (CII, CIII and CIV)

(Fig. 15), it was possible to compare the relative acidities of three sets of three acids in which the inductive effect might be considered as equal; namely CII (n = 1,2, and 3), CIII (COOH in 2,3 and 4 position) and CIV (COOH in 2,3 and 4 position), respectively. For all nine compounds a linear plot of $1/\underline{r}$ versus log K_A was obtained as would be predicted (Eq. 7) if a strictly field effect were operative. No data were given to indicate how the $\underline{r}$ values were calculated for CII. This linear relationship is surprising from the standpoint of the Kirkwood and Westheimer theory since it implies that CII, CIII and CIV occupy cavities of about the same size in the solvent. More conclusive evidence for the operation of the field effect was given by the order of decreasing acidity: CIV > CIII > CII. This is the order expected for a field effect situation since $\underline{r}$ most certainly decreases along the series CII to CIII to CIV.

A final example of a recent attempt to evaluate the field effect is a study by Adams and Brower (139) on the effect of remote substituents on the stability of optically active N-benzenesulfonyl-N-carboxymethyl-3-benzylmesidine (CV), where X = H, CH_3, Br, CN and OCH_3. The half-lives of racemization in dimethylformamide at 118°

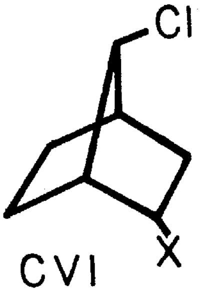


CV

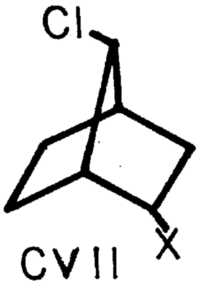
were all found to be nearly equal. Undoubtedly the great distance between the substituent X and the reaction center, by way of the bonds, is sufficient to make the inductive effect negligible. The authors state that free rotation of the benzyl group reduces the probability that the charge (presumably in the coplanar transition state) and the dipole were properly oriented for the operation of an appreciable field effect.

RESULTS AND DISCUSSION

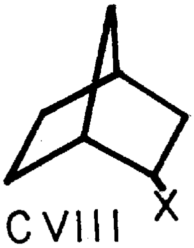
In light of the above discussion, it can be seen that *syn*- and *anti*-7-chloronorbornane derivatives (CVI and CVII) are well suited for a study of the field and inductive effects. The bicyclo[2.2.1]heptane carbon skeleton is rigid and its structure has been established by electron diffraction (140). Resonance effects can be considered negligible and the inductive effect of the chlorine on the electron density at the group X in CVI and CVII is identical. However, the field effect of the carbon-chlorine dipole at C_7 is anticipated (Eq. 8) to be different for CVI and CVII due to differences in the distance *r* between X and the center of the carbon-chlorine dipole and in the angles of orientation between the dipole and *r*. For example, calculations on *syn*- and *anti*-7-chloro-*exo*-norbornylamines (CVI and CVII, X = *exo*-NH_2) showed that while the distance between the nitrogen and the center of the dipolar group was not very different for the two isomers, the angle θ changes from 104° to 68° in going from CVI to CVII (X = *exo*-NH_2). Consequently, reactivity measurements which reflect changes in electron density at the group X should show differences between CVI and CVII if the field effect is of major importance. If only the inductive effect is of importance in transmitting the electrostatic



CVI



CVII



CVIII

effect of the chlorine, CVI and CVII would be expected to exhibit the same reactivity and both should differ from their unsubstituted norbornane analog (CVIII).

One reactivity comparison in such a series of compounds has been made by Carboni (35,36). It was found that syn-7-chloro-exo-norbornyl p-toluenesulfonate (CVI, X = exo-p - $CH_3C_6H_4SO_3$) acetolyzed in acetic acid about 1.5 times faster than the anti-isomer (CVII, X = exo-p - $CH_3C_6H_4SO_3$). This difference is reactivity is reasonable on electrostatic grounds since the carbon-chlorine dipole of CVI would be more favorably disposed toward development of the carbon-p-toluenesulfonate dipole in the transition state than would be the case for the anti-isomer (CVII). It might also be argued (36) that relief of steric strain (210,211) could enhance the rate of ionization of CVI relative to CVII.

Nuclear Magnetic Resonance Studies.

A method of evaluating the relative basicities of norcamphor (CVIII, X = =O) and syn- and anti-7-chloronorcamphor (CVI and CVII, X = =O) was sought which would be sensitive enough to distinguish the subtle differences which were expected. The infrared methods of Gordy (141,142,143) for determining relative basicities of ketones and other organic compounds were judged to be of insufficient sensitivity. The H_o method of Hammett (144) has been restricted to aromatic compounds for which the free base and its conjugate acid differ appreciably in their ultraviolet absorption. This method has not been applied to aliphatic carbonyl compounds, even though they exhibit a low intensity absorption in the ultraviolet which might be expected to be substantially absent in the conjugate acid. However, the probability of acid-catalyzed aldol condensations made the latter method unattractive.

The application of nuclear magnetic resonance (NMR) spectroscopy to a variety of chemical problems has been recently reviewed (145). It was observed by Ogg (146) that the proton resonance of liquid ammonia appeared at substantially lower fields than that of ammonia vapor. Since liquid propane and propane vapor showed essentially the same position of the proton resonance, it was assumed (146) that association or hydrogen bonding in liquid ammonia was responsible for the observed "chemical shift" to lower field strength relative to the vapor. In general, any interaction of a proton which tends to decrease its diamagnetic shielding (145) will cause a chemical shift to lower field strength.

In an attempt to clarify the results of an infrared study (147) on the strengths of hydrogen bonds in deuterochloroform solutions, Huggins, Pimentel and Shoolery (148) carried out an NMR investigation on two similar systems. It was found that solutions of chloroform in triethylamine exhibited striking chemical shifts of the chloroform hydrogen resonance to lower field strengths as the concentration of chloroform was decreased. A similar shift was observed for the acetone-chloroform system. The authors postulated an equilibrium involving a 1:1 hydrogen-bonded complex (Eq. 12) whose proton

$$Cl_3CH + B: \xrightleftharpoons{K} Cl_3CH:B \qquad (12)$$

resonance would occur at considerably lower field strength than that of free chloroform. By treating the observed chemical shift for a particular composition as a colligative property of the system (149, 150), it was found possible to evaluate roughly the equilibrium constant K (Eq. 12) for both the chloroform-triethylamine and the chloroform-acetone systems.

By utilizing a very strong carboxylic acid such as trifluoroacetic acetic acid (TFA), it was hoped that a study of the chemical shift of the acid hydrogen in solutions of a variety of very weak bases would lead to a correlation of chemical shift and base strength. Accordingly, the chemical shift of the acid proton resonance relative to the benzene peak was measured in 1:1 molal solutions of TFA and various oxygenated compounds. The results in Table VII are given in cycles/second (c.p.s.) at a field strength of about 9411 gauss.

The NMR spectra were measured in spinning 5-mm. sample tubes fitted with a sealed in, concentric capillary containing the benzene reference. A sweep time of twelve seconds was used and the scale was calibrated by superposition of a known audio-frequency and use of the "side band" technique (161). No difficulty was encountered in any case in identifying the acid hydrogen of TFA since it was well displaced to lower field strength relative to the other peaks. Bulk diamagnetic susceptibility corrections (145,152) were calculated and found to be the same, within experimental error, for all the compounds studied. Therefore no corrections were applied since a constant shift would not alter the value of the data for the present application.

TABLE VII

Chemical Shifts of the Trifluoracetic Acid Proton Resonance Relative to Benzene for 1:1 Molal Solutions at 34 ± 3°.

Compound	$-\Delta$, c.p.s.[a]	$\Delta\mu$,[b] microns	K_i[c]
Benzene	151.5 ± 0.9	0.00	1×10^{-37}
Dichlorotetrafluoroacetone	180.9 ± 2.1	--	2×10^{-24}
Trifluoroacetic acid	181.5 ± 1.3	--	2.5×10^{-24}
Chloroacetone	199.8 ± 1.1	0.08	3×10^{-22}
Ethyl acetate	217.9 ± 1.4	0.12	4×10^{-20}
_d_-Camphor	219.5 ± 1.3	0.12[d]	6×10^{-20}
syn-7-Chloronorcamphor	226.0 ± 1.2	--	3×10^{-19}
anti-7-Chloronorcamphor	226.6 ± 3.2	--	3×10^{-19}
Cyclohexanone	235.6 ± 1.1	0.17	4×10^{-18}
Acetone	236.7 ± 1.0	0.14	5×10^{-18}
Isopropyl ether	239.1 ± 0.7	0.18	1×10^{-17}
_p_-Bromoacetophenone	242.8 ± 1.7	--	2.5×10^{-17}
Acetophenone	243.5 ± 1.0	0.11	3×10^{-17}
Norcamphor	247.7 ± 1.1	--	1×10^{-16}

(a) Errors are expressed as standard deviations from the average of 8 to 12 determinations. (b) Infrared shifts of the O-D band for deuteromethanol solutions (142). (c) Calculated from Eq. 15. (d) Gordy's value for fenchone (142).

For those compounds common to this study and that of Gordy (142), a plot of chemical shifts versus infrared shifts of the O-D band in deuteromethanol solutions is given in Fig. 16 and is seen to be reasonably linear. A least-squares fit of the data in Fig. 16 yielded Eq. 13. The linear relationship between infrared

$$\Delta\mu = -0.001685\Delta - 0.2523 \qquad (13)$$

shift and basicity constant was expressed (142) by Eq. 14 which was

$$\Delta\mu = 0.0147 \log K_b + 0.194 \qquad (14)$$

verified as valid by Hammett (152) for very weak aromatic bases.

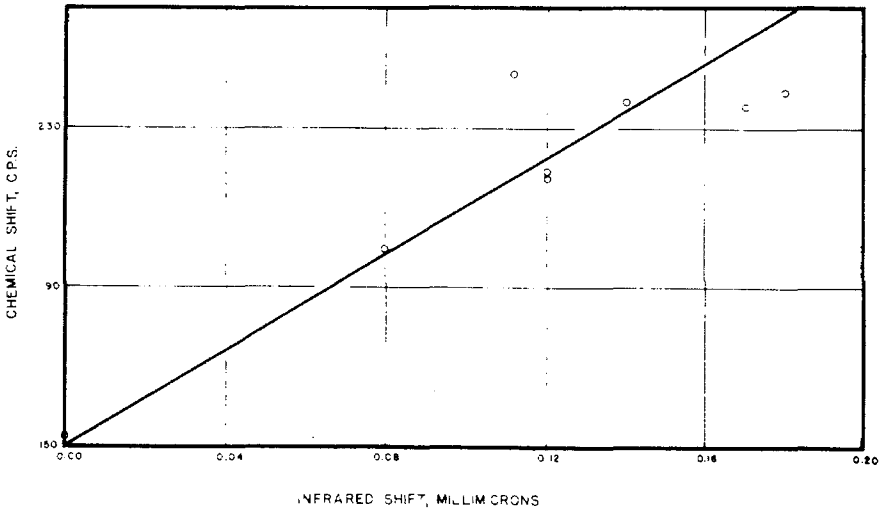


Fig. 16

Infrared shifts versus chemical shifts (Table VII).

Combining Eq. 13 and Eq. 14 yields Eq. 15 which allows

$$\log K_b = -0.1146\,\Delta - 30.4 \qquad (15)$$

the evaluation of basicity constants from chemical shifts. The constants K_i given in the fourth column of Table VII were calculated from Eq. 15 and are equal to K_b values times 10^{-14}.

Although acetophenone deviates rather badly from the line in Fig. 16, it is noteworthy that Jaffé (154), using the data of Pratt (155,156), has calculated that p-bromoacetophenone should have a K_i value of 0.67 times that of acetophenone, in agreement with relative results given in Table VII. As expected from the inductive effect, TFA and dichlorotetrafluoracetone are very very weak bases and of about the same strength. Although the present method is capable of higher sensitivity than the infrared method (142), it fails to distinguish between the basicities of syn- and anti-7-chloronorcamphor (Table VII). However, norcamphor is seen to be about 300 times stronger than either of its 7-chloro derivatives. Although this latter difference may appear to be unreasonably large, it should be noted that acetone is some 6000 times stronger than chloroacetone, in pleasing accord with previous observations (p.41) concerning relative acetolysis rates in two similar situations. One is forced to conclude in this case that the inductive effect of the 7-chlorine atoms is of predominant importance and the field effect contribution is at best small.

Incidental to the above study, it was found that the chemical shift of the TFA proton resonance from the benzene reference was a sensitive function of concentration in benzene solutions of the acid. In this case, the solvent was used as the reference. The observed shifts are given in Table VIII.

TABLE VIII

Chemical Shifts of the TFA Proton Resonance for Benzene Solutions at 34±3°

Mole Fraction CF_3COOH	Mole Fraction $(CF_3COOH)_2$	$-\Delta$, c.p.s.
1.000	1.000	181.5 ± 1.3
0.895	0.810	167.7 ± 1.7
0.744	0.592	162.1 ± 1.7
0.607	0.435	157.5 ± 1.2
0.508	0.340	151.9 ± 0.7
0.391	0.243	145.8 ± 1.0
0.297	0.162	136.5 ± 1.2
0.1065	0.0562	107.8 ± 1.0
0.0872	0.0456	98.9 ± 1.4

The striking shifts to higher field strength with decreasing trifluoroacetic acid (TFA) concentration are similar to the results obtained by Huggins, Pimentel and Shoolery (214) for the acetic acid - acetone system. Maryott, Hobbs and Gross (157) have determined the dimerization constants for a number of carboxylic acids in benzene solution at 30°, but the dimerization constant of TFA has not been measured under these conditions. A roughly linear relationship was observed (157) between the logarithms of the dimerization constants and the dissociation constants of the acids studied. The dissociation constant of TFA was recently determined by an NMR procedure (158) and found to be 1.8, somewhat higher than the previously reported value of 0.588 (159). Using the higher value for the dissociation constant of TFA, the linear relationship yielded a calculated value of about 25 for the dimerization constant of TFA. At the lowest concentration of TFA used in this study (mole fraction of TFA = 0.0872), the amount of monomer in equilibrium with dimer can be calculated to be only about 2.3 percent of the total TFA present.

A plot of chemical shift versus mole fraction TFA dimer is given in Fig. 17. The steep slope at low TFA concentrations suggests an association between the TFA and the benzene. Assuming that trimers and all higher polymeric species are present in minor amounts, the systems may be treated as an equilibrium between TFA dimer, benzene and a 1:1 TFA - benzene complex. This equilibrium is expressed by Eq. 16, where D is the number of moles of TFA dimer present, B the moles of benzene and C the

$$D + 2B \overset{K}{\rightleftharpoons} 2C \qquad (16)$$

moles of TFA - benzene complex formed.

In terms of mole fractions (148), the equilibrium constant K is given by Eq. 17, where D_o is the moles of TFA dimer originally present

$$K = \frac{C^2(D_o + B_o - C/2)}{(D_o - C/2)(B_o - C)} \qquad (17)$$

and B_o the original number of moles of benzene.

The observed chemical shifts (Δ_{obs}) are given by Eq. 18 (147,150),

$$\Delta_{obs} = 2\Delta_D \frac{(D_o - C/2)}{D_o} + \Delta_C(\frac{C}{D_o}) \qquad (18)$$

where $(D_o - C/2)/D_o$ is the fraction of TFA present as dimer and C/D_o is the fraction TFA converted to complex. Δ_D and Δ_C are the chemical shifts for pure dimer and pure complex, respectively. The method of Huggins, Pimentel and Shoolery (148) could be used to evaluate K, but the

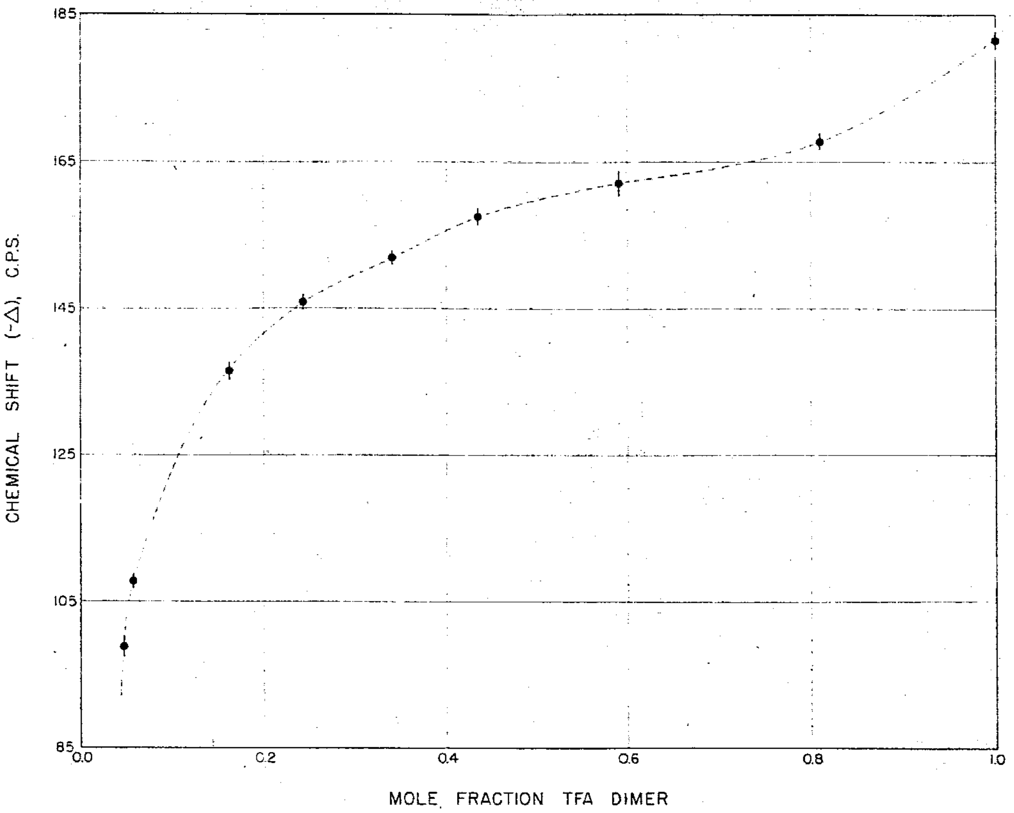


Fig. 17

Chemical shifts of the TFA proton resonance in benzene solutions

assumptions used in obtaining Eqs. 16, 17 and 18 and the lack of data at very low TFA concentrations make such a treatment unwarranted in the present case.

Liddel and Ramsey have proposed (160) that NMR be used to study hydrogen bonding in alcohols and phenols, since the hydroxyl hydrogen resonance should be particularly sensitive to diamagnetic shielding effects. These same authors also predicted (160) that the proton resonance of alcohols should be quite temperature dependent, a prediction which was born out experimentally by Arnold and Packard (161) in a study of the temperature dependence of the hydroxyl proton resonance of methanol and ethanol.

Since the relative acidities of alcohols is still in some doubt (162), an attempt was made to correlate acidities and chemical shifts by NMR. The chemical shift data for 1:1 molal solutions of several alcohols in triethylamine and cyclohexane are given in Table IX. The use of solutions of constant mole fraction was necessitated by the observation (161) that the chemical shift of the hydroxyl proton resonance in alcohols is quite concentration dependent.

TABLE IX

Chemical Shifts of the Hydroxyl Proton Resonance for Alcohols from the Methyl Peak of Triethylamine at 34 ± 1°.

Alcohol	$-\Delta$, 1:1 solution in Et_3N	$-\Delta$, 1:1 solution in cyclohexane [a]
Methyl	155.4 ± 2.6	--
Ethyl	166.2 ± 1.8	--
_t_-Butyl	132.7 ± 1.7	--
exo-Norbornyl	160.9 ± 2.7	140.1
syn-7-Chloro-_exo_-norbornyl	116.8 ± 3.5	123.8
anti-7-Chloro-_exo_-norbornyl	166.8 ± 2.1	137.4

(a) These values were obtained using the Super Stabilizer (163) and are precise to ± 0.3 c.p.s.

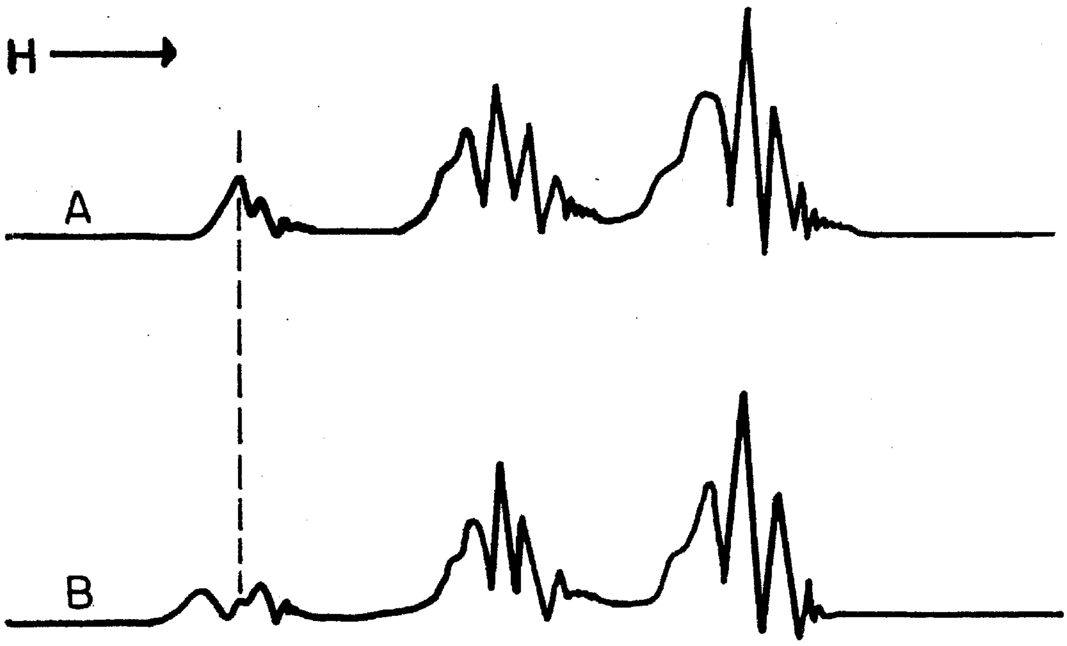


Fig. 18

NMR Spectrum of syn-7-Chloro-exo-norborneol.

A. Initial spectrum of a 1:1 solution in triethylamine.
B. Same spectrum after the addition of deuterium oxide. Note the disappearance of the hydroxyl peak and the appearance of the water peak due to exchange.

The chemical shifts in the triethylamine solutions were measured by the side-band technique (151,161) relative to the methyl peak of the amine. For the cyclohexane solutions, the stability of the field allowed calibration against the CH_2-CH_3 separation in the ethanol spectrum. The value of 102.8 c.p.s. at about 9411 gauss was used for the separation (152). In order to have all of the data referred to the methyl peak of triethylamine, the separation of the cyclohexane hydrogen resonance from the methyl resonance in triethylamine was measured in a 1:1 molal solution and found to be -20.1 c.p.s.

In order to determine which of a pair of peaks appearing at low field strength in the spectrum of syn-7-exo-norborneol was due to the hydroxyl hydrogen, a deuterium exchange method was employed. The results are illustrated by Fig. 18.

For reference purposes, the relative acid strengths of the simple alcohols are given in Table X. It is seen that the relative acidities are consistent with the inductive effect of alkyl groups, but Seubold has pointed out that the differences in acidity are too great to be entirely accounted for on this basis (166).

TABLE X

Relative Acidities of Alcohols

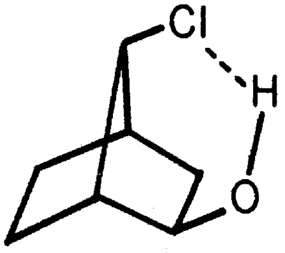
Alcohol	pK_A[a]	K_E[b]
Methyl	16	4.0
Ethyl	18	0.95
n-Propyl	---	0.5
iso-Propyl	18	0.076
sec-Butyl	---	0.2
tert-Butyl	19	0.2
Water	---	1.20

(a) From the data of W.K. McEwen, J. Am. Chem. Soc., 58, 1124-29 (1936), arbitrary pK scale. Also see J.B. Conant and G.W. Wheland, ibid., 54, 1212-29 (1932). (b) Data of Hine and Hine (162).

It would be predicted that the more acidic alcohols would exhibit hydroxyl proton resonances at relatively low field strength. Inspection of the results in Table IX reveals that ethanol and methanol are reversed, an order previously observed for the pure liquids (167). The application of bulk magnetic susceptibility corrections did not materially improve the situation. However, it is of interest to note that _t_-butyl alcohol appears at higher field strength than either methanol or ethanol and that _anti_-7-chloro-_exo_-norborneol appears at slightly lower field strengths than _exo_-norborneol, two results consistent with relative acidities.

The most striking result in Table IX is the appearance of the hydroxyl proton resonance of _syn_-7-chloro-_exo_-norborneol at abnormally high field strength. Perhaps even more significant was the small shift of -7 c.p.s. observed for the position of the hydroxyl proton resonance of _syn_-7-chloro-_exo_-norborneol in going from triethylamine solution to cyclohexane solution. The corresponding shifts for _exo_-norborneol and _anti_-7-chloro-_exo_-norborneol were + 21 c.p.s. and + 29 c.p.s., respectively.

The abnormal behavior of _syn_-7-chloro-_exo_-norborneol suggests an intramolecular stabilization, possibly of the type shown in CIX. Such an intramolecular hydrogen bond involving a chlorine



CIX

atom has been inferred by infrared spectroscopy to be present in o-chlorophenol (212). In contrast to the observed appearance of the hydroxyl proton resonance of CIX at abnormally high field strength, the intramolecularly hydrogen bonded proton in the enol form of acetylacetone was found at abnormally low field strength (213). Apparently hydrogen bonding with a halogen atom has the effect of increasing the diamagnetic shielding of the proton, in contrast to the decrease in shielding found to accompany association with nitrogen (146) or oxygen (213).

Kinetic Investigation of Bromination.

It has been well established (169) that the rate-determining step in the base-catalyzed bromination of ketones is the removal of the α-hydrogen by the base to give an enolate ion. This enolate ion is instantaneous brominated to give the α-bromoketone. Since the acidity of the α-hydrogen is expected to be a function of the electrostatic effects of substituents other than the carbonyl group, it was hoped that base-catalyzed rate constants for brominations would be of value in assessing the electrostatic effects of such substituents.

A study has been made of the relative sodium acetate-catalyzed rates of bromination of norcamphor (CX) (Fig. 19), *syn*- and *anti*-7-chloronorcamphor (CXI and CXII), *exo*-3-bromonorcamphor (CXIII), *d*-camphor (CXIV) and *endo*-3-bromo-*d*-camphor (CXV).

Ketones CX, CXI and CXII were prepared from the corresponding alcohols by chromic acid oxidation and were purified by regeneration from their pure semicarbazones. *d*-Camphor (CXIV) was

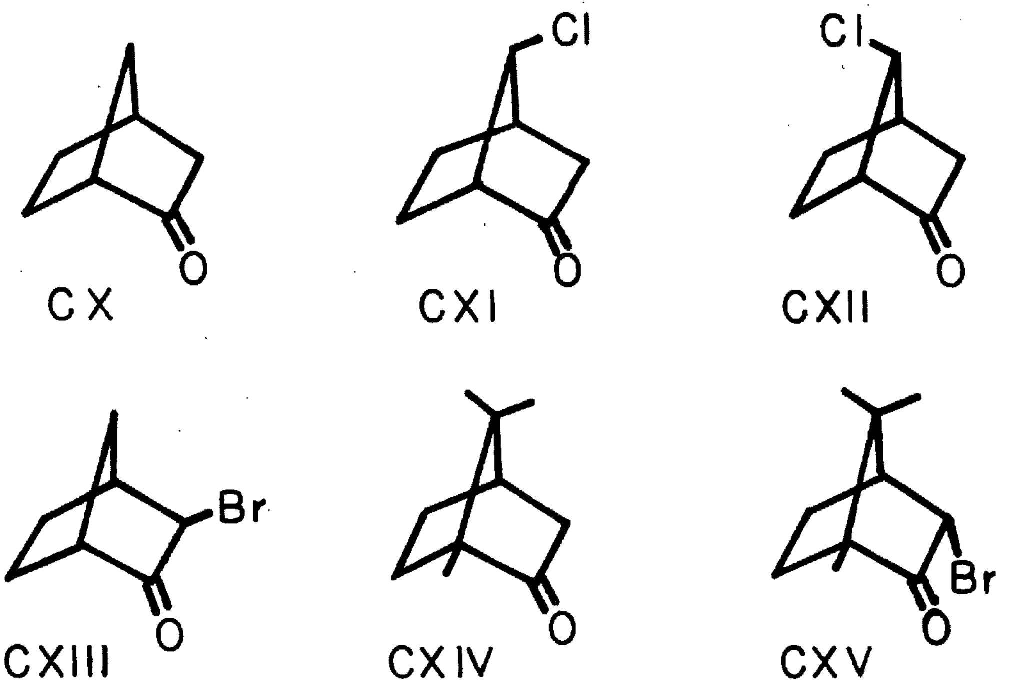
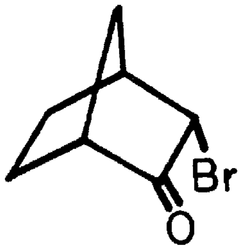


Fig. 19

brominated under acid-catalyzed conditions to give CXV (170,171), whose structure has been unequivocally established by an X-ray crystal structure determination (172,173). *exo*-3-Bromonorcamphor (CXIII) was prepared by a similar method (170,171) and was isolated as an analytically pure material, m.p. 30°.

For comparison purposes, an attempt was made to prepare *endo*-3-bromonorcamphor (CXVI). In a study of the sodium ethoxide-



CXVI

catalyzed isomerization of endo-3-chloro- and endo-3-bromo-d-camphor (CXV), Lowry and co-workers (174,175) demonstrated that the exo/endo equilibrium ratio is about 0.1. A similar equilibration of CXIII resulted in the formation of a substance or substances with an ultraviolet spectrum which was different from that of CXIII and strongly suggested that isomerization to CXVI had occurred (Table XI). In experiments run on a preparative scale, a liquid product was obtained whose ultraviolet spectrum (Table XI) was essentially the same as that found in the *in situ* isomerization, but analysis revealed only 88% bromoketone to be present. The NMR and infrared spectra indicated the presence of an unknown contaminant when compared to those obtained from CXIII. The ultraviolet spectral data obtained are given in Table XI along with that for the corresponding d-camphor derivatives used for comparison.

The data in Table XI are interpreted as evidence that the acid-catalyzed bromination product of CX is CXIII. Since acid-catalyzed brominations of ketones proceed by way of the enol (169) and since the addition of chlorine, hypochlorous acid or bromine (22,23) to norbornene is initiated by exo-attack on the double bond, it is mechanistically reasonable to suppose that the kinetically controlled bromination product be CXIII. Apparently, the sodium ethoxide-catalyzed equilibration of either CXIII or exo-3-bromo-d-camphor (175) gives predominantly the more stable endo-α-bromoketones (CXVI and CXV). Further evidence for the configuration of CXIII is given below.

TABLE XI

Ultraviolet Spectral Data[a]

Compound	Solvent	λ_{max}, mμ	ϵ, l. mol.$^{-1}$ cm.$^{-1}$
d-Camphor	95% EtOH	289.5[c]	32
	CH[b]	292 [c]	23
exo-3-Bromo-*d*-camphor	CH	312 [c]	89
endo-3-Bromo-*d*-camphor (CXV)	95% EtOH	306 [c]	100
	CH	307.5[c]	95.5
Norcamphor (CX)	95% EtOH	287	30.9
exo-3-Bromonorcamphor (CXIII)	95% EtOH	313.7	84.4
	CH	317	73.2
"*endo*-3-Bromonorcamphor (CXVI)"	95% EtOH	307.4	(78.5)[d,e]
	95% EtOH	307.4	(70.1)[d,f]
	CH	313.5	(67.9)[d,f]

(a) Determined with a Cary Model 11M Recording Spectrophotometer using 1 cm. quartz cells. (b) Cyclohexane. (c) Data from R.C. Cookson, J. Chem. Soc., 282-86 (1954) and references cited therein. (d) Calculated on the basis of pure bromoketone. (e) An ethanol solution of CXIII containing sodium ethoxide. A comparable concentration of sodium ethoxide had no effect on the spectrum of norcamphor in 95% ethanol. (f) Obtained on solutions of impure CXVI isolated from the isomerization of CXIII.

The kinetic method of Evans and co-workers (176,177) was employed. Pseudo-first-order rates of bromination of CX-CXV were determined at 35° in 75% aqueous acetic acid containing 0.238 M sodium acetate. Low reactivities of these compounds towards base-catalyzed enolization necessitated a correction for the bromine-solvent reaction. The rate of disappearance of bromine in the absence of ketone was found to be cleanly first-order (Fig. 20) and a least-squares fit of the data gave $9.56 \pm 0.20 \times 10^{-4}$ hr.$^{-1}$ for the rate constant at 35°.

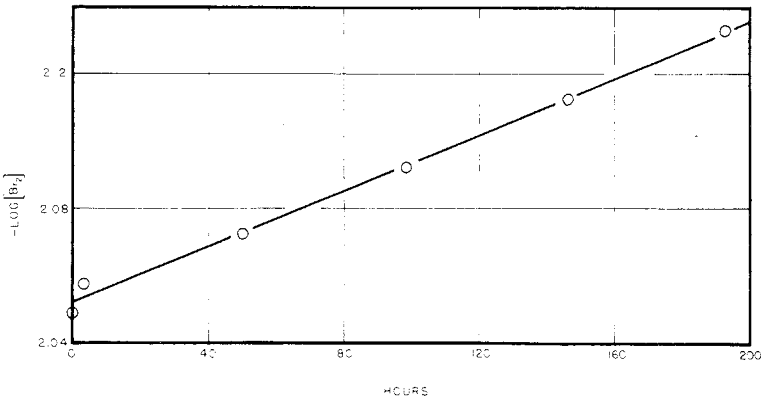


Fig. 20

Reaction of bromine and 75% aqueous acetic acid containing 0.238 M sodium acetate at 35°.

The following parameters are defined:

B = concentration of bromine at time t.

B_o= initial concentration of bromine.

K = concentration of ketone at time t.

K_o= initial concentration of ketone.

k_2= rate constant for the bromine-solvent reaction.

c = slope obtained from plots of $\ln[K_o-B_o+B]$ versus time.

k_1= rate constant for the ketone bromination.

The total rate of disappearance of bromine is given by Eq. 19 and the rate of disappearance of ketone by Eq. 20. Integration

$$\frac{dB}{dt} = -k_2B - k_1K \tag{19}$$

$$\frac{dK}{dt} = -k_1K \tag{20}$$

of Eq. 20 yields Eq. 21 for the concentration of ketone at time t.

$$K = e^{\ln K_o - k_1 t} \tag{21}$$

It was found for all the compounds studied that the plots of $\log[K_o-B_o+B]$ versus time were strictly linear except for a minor, sharp curvatuve in the initial stages (*e.g.* see Fig. 21 for a typical example). This linearity is expressed by Eq. 22 which yields Eq. 23

$$\frac{d[\ln(K_o-B_o+B)]}{dt} = -c \tag{22}$$

$$\ln\left[\frac{K_o - B_o + B}{K_o}\right] = -\underline{c}t \tag{23}$$

on integration. Rearranging and differentiating Eq. 23 gives Eq. 24 for the slope at any time t. Substituting Eq. 21 and Eq. 24 into

$$\frac{dB}{dt} = -K_o\underline{c}\ e^{-\underline{c}t} \tag{24}$$

Eq. 19 gives Eq. 25, which allows the evaluation of $\underline{k}_1$ for various

$$\underline{k}_1\ e^{\ln K_o - \underline{k}_1 t} = K_o\underline{c}\ e^{-\underline{c}t} - \underline{k}_2 B \tag{25}$$

pairs of B and t values, since K_o, $\underline{c}$ and $\underline{k}_2$ are known. Table XII gives the results obtained for the bromination of norcamphor (Fig. 21).

TABLE XII

Kinetic Analysis of the Data from the Bromination of Norcamphor at 35° in 75% Acetic Acid (0.238 $\underline{M}$ NaOAc).

t, hr.	10^2B, mol.l.$^{-1}$	10^5dB/dt, mol.l.$^{-1}$hr.$^{-1}$	$10^4\underline{k}_1$, hr.$^{-1}$
0	1.1066	- 2.0307	3.55
50	1.0072	- 1.9568	3.70
100	0.9114	- 1.8855	3.85
150	0.8192	- 1.8171	4.01
200	0.7303	- 1.7508	4.18

* B values evaluated from the least-squares equation.

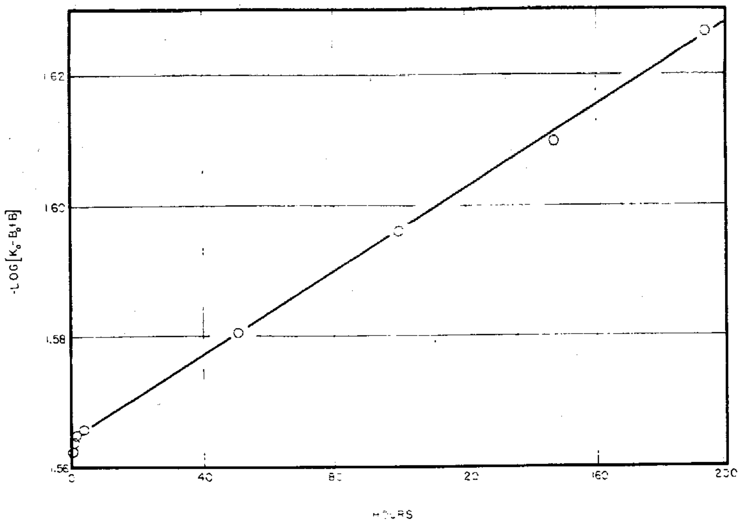


Fig. 21

Pseudo-first-order bromination of norcamphor in 75% aqueous acetic acid containing 0.238 M sodium acetate at 35°.

As expected from the results of other workers (177), the $\underline{k}_1$ values are found to increase linearly with time. However, the rate constants can be evaluated with assurance at zero time and are reported in Table XIII for all of the ketones studied.

In general, the results of Table XIII appear to reflect the importance of steric effects in determining reactivity towards acetate ion. In particular, the extremely low rate for d-camphor can be interpreted as being due to the steric hindrance of the methyl groups, in addition to their inductive effect. The low reactivity of CXIII relative to CX is taken as evidence for steric hindrance to attack on the endo-hydrogen, since the introduction of an α-bromine atom generally greatly increases the base-catalyzed bromination rate (178). Such acceleration is shown by the high rate of CXV relative to CXIV.

TABLE XIII

Pseudo-first-order Bromination Rate Constants at 35° in 75% Acetic Acid Containing 0.238 M Sodium Acetate.

Ketone	K_o, M	10^4 k_1, hr.$^{-1}$	Rel. k_1
Norcamphor (CX)	0.0273	3.54 ± 0.25	1.00
syn-7-Chloro-norcamphor (CXI)	0.0173	1.15 ± 0.17	0.3
anti-7-Chloro-norcamphor (CXII)	0.0174	4.14 ± 0.21	1.2
exo-3-Bromo norcamphor (CXIII)	0.0181	0.97 ± 0.14	0.3
d-Camphor (CXIV)	0.0217	0.10[a]	0.03
endo-3-Bromo-*d*-Camphor (CXV)	0.0161	1.86 ± 0.24	0.5

(a) Maximum value of experimental error.

It is interesting to note that CXII is slightly more reactive that CX, in line with the expectation that the chlorine atom should enhance the acidity of the α-hydrogen by its inductive and/or field effect. Unfortunately, the steric effect of the *syn*-7-chlorine atom in CXI apparently causes its low rate, making any electrostatic comparison of reactivities for CXI and CXII impossible.

In order to reduce the steric effects associated with a large basic ion and, also, to eliminate the troublesome bromine-solvent reaction, the rates of bromination of norcamphor (CX) (Fig. 19) and exo-3-bromonorcamphor (CXIII) were followed in aqueous sodium hypobromite solution (178,179). To keep the rates low enough for convenient measurement at 35°, it was not possible to maintain conditions of zero-order dependence on the hydroxide ion concentration. A typical set of data for CX is given in Table XIV. It is seen that the second-order rate constant drifts upward with time. Infinity titres conclusively showed that three moles of bromine were consumed ultimately per mole of norcamphor (CX).

TABLE XIV

Second-order Rate Data for the Bromination of Norcamphor at 35° in Aqueous Sodium Hypobromite.

t, sec.	$\log\left[\frac{a(b+y)}{b(a-y)}\right]$ a	10^3 k_2 b, l. mole.$^{-1}$ sec.$^{-1}$
0	0.0000	---
300	0.0380	4.67
503	0.0739	5.42
740	0.1151	5.74
924	0.1551	6.19
1138	0.1830	5.93
1424	0.2392	6.20
1728	0.2958	6.32
2700	0.4996	6.83
2780	0.5178	6.87
3376	0.6450	7.05

(a) The initial concentration of ketone is a, that of sodium hydroxide b and the amount of bromine consumed at time t is y.

(b) Calculated by the equation: $k_2 = \frac{2.303}{t(a+b)} \log \frac{a(b+y)}{b(a-y)}$.

In view of the inexplicable consumption of three moles of bromine by CX, the reaction product was isolated by a preparative-scale experiment. At 35°, norcamphor reacted with an excess of sodium hypobromite to give an uncrystallizable oil. This oil was shown <u>not</u> to be <u>cis</u>-cyclopentane-1,3-dicarboxylic acid by comparison of infrared spectra. The oil reacted with thionyl chloride followed by ammonia to give an unidentified amide, m.p. 113.5-115°. This amide was insoluble in sodium bicarbonate solution and was saturated to permanganate. It did not react with 2,4-dinitrophenylhydrazine test solution and the elemental analysis suggested $C_8H_{12}NBr_2O$ as the empirical formula.

The kinetic data for the <u>exo</u>-3-bromonorcamphor are given in Table XV. Infinity titres showed that two moles of bromine were consumed per mole of CXIII, in agreement with the result for CX. In this case, the second-order rate constant is seen to <u>decrease</u> markedly with time. This downward trend may be due to some fast secondary reactions which consume hydroxide ion. The kinetics here observed for both CX and CXIII are not entirely unexpected in light of a recent study by Hammett (180), which revealed that the base-catalyzed bromination of acetone is kinetically complex.

Although the second-order rate constants at zero time cannot be evaluated accurately for CX (Table XIV) and CXIII (Table XV), it is evident that CXIII is at least twice as reactive towards hydroxide ion as CX. This comparison is interesting in light of the results from the sodium acetate-catalyzed rates (Table XIII), where CXIII was found to be substantially <u>less</u> reactive than CX. Apparently, the smaller size of the hydroxide ion facilitates its attack on the *endo*-hydrogen of CXIII. The faster rate of CXIII relative to CX may be responsible for the upward drift in the rate constant for CX (Table XIV) during the course of the reaction.

TABLE XV

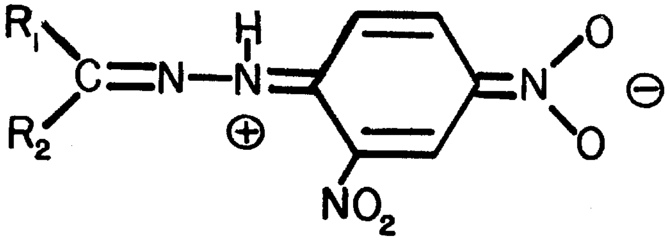
Second-order Rate Constants for the Bromination of *exo*-3-Bromonorcamphor at 35° in Aqueous Sodium Hypobromite.

t, sec.	$\log[\frac{a(b+y)}{b(a-y)}]$	10^3 $\underline{k}_2$ [a], l. mol.$^{-1}$ sec.$^{-1}$
0	0.0000	---
200	0.0740	13.5
400	0.1158	10.6
600	0.1728	10.5
800	0.1929	8.8
1000	0.2222	8.1
1200	0.2380	7.3
2000	0.3130	5.7
2500	0.3498	5.1

(a) As defined in Table XIV.

Absorption Spectra.

In a study of the absorption spectra of some 2,4-dinitrophenylhydrazones, Roberts and Green (181) pointed out that the carbonyl part of the molecule should influence the contribution of forms such as CXVII to the resonance hybrid. One might extend this



CXVII

hypothesis and predict that, in the absence of direct resonance effects, increasing the electronegativity of R_1 and/or R_2 should cause a hypsochromic shift (182) of the absorption maximum. This prediction is borne out by the data in Table XVI taken from a recent study by Johnson (183). Only meta derivatives are listed for the aromatic carbonyl compounds because of the complication of resonance in the ortho and para isomers. All of the shifts in Table XVI are in accord with the above hypothesis. The larger hypsochromic shift of ω-chloroacetophenone relative to ω-bromoacetophenone is in agreement with the relative electronegativities of the halogens (184).

On the basis of the above results, it was felt that the absorption spectra of norcamphor 2,4-dinitrophenylhydrazone (CXVIII) and of syn- and anti-7-chloronorcamphor 2,4-dinitrophenylhydrazone (CXIX and CXX, resp.) might be used as a tool to assess the electrostatic effect of the chlorine substituents. The observed data are given in Table XVII Although the shifts are small, they are of the magnitude expected, since the substitution of an α-chlorine atom in acetone results in a hypsochromic shift of 9-10 mμ in the

TABLE XVI

Absorption Spectra of 2,4-Dinitrophenylhydrazones in Chloroform Solution.[a]

2,4-Dinitrophenylhydrazone of	λ_{max}, mμ	log ϵ
Benzaldehyde	377	4.48
m-Nitrobenzaldehyde	370	4.50
m-Tolualdehyde	381	4.47
Acetophenone	378	4.40
ω-Bromoacetophenone	377	4.42
ω-Chloroacetophenone	373-374	4.44
m-Nitroacetophenone	371	4.45
Acetone	363-364	4.35
α-Chloroacetone	354	4.36
α, α'-Dichloroacetone	348	4.38

(a) Taken entirely from reference 183.

TABLE XVII

Absorption Spectra of Some 2,4-Dinitrophenylhydrazones

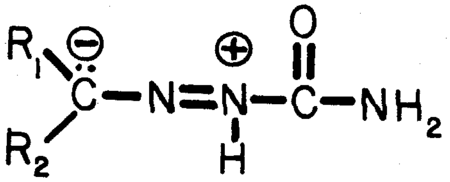
2,4-Dinitrophenylhydrazone of	M.p., °C.	M.p., °C, Lit.	Solvent	λ_{max}, mμ	log ϵ
Norcamphor	131.5-132.5	131.5-132.5[a]	95%EtOH	361.3	4.39
			IO[c]	346.1	4.42
syn-7-Chloronorcamphor	193-194	192-193[b]	95%EtOH	357.7	4.38
			IO	342.4	4.41
anti-7-Chloronorcamphor	147.5-148	143.5-145[b]	95%EtOH	358.1	4.39
			IO	341.4	4.44

(a) From Wildman and Hemminger, J. Org. Chem., *17*, 1641 (1952). (b) See reference 22. (c) Isooctane.

λ_{max} of the 2,4-dinitrophenylhydrazones (Table XVI). In the present case (Table XVII) the chlorine is in the β position and electrostatic effects are attenuated accordingly.

In 95% ethanol solution, CXIX and CXX absorb at the same wavelength within the precision of the measurements (± 0.3mμ), but the average position of their absorptions exhibits a significant hypsochromic shift from that of CXVIII (3.4 ± 0.6 mμ). In osooctane solution, CXIX and CXX are seen to show a small but significant difference in the position of their absorptions. Here again the average λ_{max} for CXIX and CXX is hypsochromically shifted from that of CXVIII (4.2 ± 0.6 mμ). The data can be adequately accounted for by assuming that both the inductive and field effects are operating to inhibit the contribution of forms such as CXVII to the ground state resonance hybrid. The inductive effect, measured as proportional to the average hypsochromic shifts of CXIX and CXX from the λ_{max} of CXVIII, is seen to be independent of the solvent. The low dielectric constant of isooctane can be said to increase the importance of the field effect, giving rise to the small shift observed between CXIX and CXX in this solvent.

Since the spectra of semicarbazones appear to be somewhat more sensitive than those of 2,4-dinitrophenylhydrazones to structural changes in the carbonyl moiety of the derivatives (181, 185), the absorption spectra of norcamphor semicarbazone (CXXI) and of <u>syn</u>- and <u>anti</u>-7-chloronorcamphor semicarbazone (CXXII and CXXIII, resp.) were measured. The absorption maxima in isooctane solution for CXXI, CXXII and CXXIII were found at 227.4, 228.6 and 229.4 mμ, respectively. The order of appearance is the opposite of that observed for the 2,4-dinitrophenylhydrazones and might be taken as qualitative evidence for the contribution of a form like CXXIV to the ground state stabilization of semicarbazones. N-Methylsemicarbazones are found to absorb at longer wavelengths than the corresponding semicarbazones (185).



CXXIV

Corey and co-workers (186) have interpreted the bathochromic shifts of 11 to 31 mμ observed in cyclohexanones upon α-chlorination as evidence for the axial conformation of the halogen atom. Slight hypsochrmoic shifts of -2 to -4 mμ were associated with an equatorial chlorine atom. However, recent dipole moment studies (187) have cast doubt on the validity of Corey's conformational assignments. In any event, it was found that norcamphor and syn- and anti-7-chloronorcamphor all exhibited absorption maxima in 95% ethanol at 287 mμ within experimental precision, indicating that this absorption is not sensitive to the electrostatic effects of remote substituents.

Relative carbonyl stretching frequencies for several norcamphor derivatives are given in Table XVIII. It is seen that the halonorcamphors absorb at about the same frequency, but they are all shifted 11.5 to 12.5 cm.$^{-1}$ from norcamphor. If electrostatic effects were predominant in determining the position of the absorption, it is evident that the α-bromoketones should exhibit a greater shift than the 7-chloroketones. Corey suggests (188) that the large effect of the 7-chloro substituents may be a geometrical one which changes the C_1-C_2-C_3 angle.

TABLE XVIII

Carbonyl Stretching Vibrations for Some Substituted Norcamphors.

Ketone	Concen., M[a]	Freq., cm.$^{-1}$ [b]	ϵ, l.mol.$^{-1}$ cm.$^{-1}$
Norcamphor	0.157	1757.5	490
syn-7-Chloronorcamphor	0.157	1770	520
anti-7-Chloronorcamphor	0.152	1770	530
exo-3-Bromonorcamphor	0.158	1769	420
"endo-3-Bromonorcamphor"	0.153[c]	1769	410[c]
d-Camphor	----	1745[d]	---
exo-3-Bromo-d-camphor	----	1757[d]	---

(a) Carbon tetrachloride solutions. (b) Determined with a Perkin-Elmer Model 21 Spectrophotometer using an expanded wavelength scale. (c) On the basis of pure material. (d) E.J. Corey, see reference 188.

Oxime Acidities.

In a further effort to elucidate the electrostatic effect of a 7-chloro substituent in the bicyclo[2.2.1]heptane system, norcamphoroxime (CXXV) and syn- and anti-7-chlorocamphoroxime (CXXVI and CXXVII, resp.) were prepared and their relative acidities measured. The apparent dissociation constants obtained by potentiometric titration are given in Table XIX. In accord with previous measurements in solvents of high dielectric constant, CXXVI and CXXVII are seen to be of the same acid strength, and both are slightly stronger than CXXV. A correlation has been noted (189) between an increase in the number of carbon atoms in aliphatic oximes and a decrease in relative acid strength as expected from the inductive effect of alkyl groups.

TABLE XIX

Relative Apparent Acid Dissociation Constants of Norcamphoroximes in 20.4 Volume Percent Ethanol at 25.0° and Ionic Strength 0.0835.

Oxime	pK'_a [a]
Norcamphoroxime (CXXV)	12.12 ± 0.04
syn-7-Chloronorcamphoroxime (CXXVI)	11.96 ± 0.04
anti-7-Chloronorcamphoroxime (CXXVII)	11.94 ± 0.04

(a) Reading on pH scale at half-neutralization point of a pH meter calibrated against aqueous buffer solution at pH 10.00 (see Experimental).

To avoid the mixed solvent and substantial ionic strengths required by the above measurements, an attempt was made to determine the acid dissociation constants of CXXV, CXXVI and CXXVII in pure water at zero ionic strength. The spectrophotometric method of Judson and Kilpatrick (190) was employed, using phenol as the indicator. Although activity coefficients (Debye-Hückel), Beer's law deviations for phenoxide ion and changes of the pK_a of phenol with ionic strength were taken into account, a rather erratic dependence of the calculated pK_a values for the oximes on ionic strength was observed (see Experimental). Least-squares extrapolations of plots of pK_a values versus ionic strength gave the data in Table XX.

TABLE XX

Acid Dissociation Constants at Zero Ionic Strength in Water at 25.0°.

Oxime	pK_a
Norcamphor (CXXV)	10.9 ± 0.2
syn-7-Chloronocamphor (CXXVI)	10.7 ± 0.2
anti-7-Chloronorcamphor (CXXVII)	9.8 ± 0.3

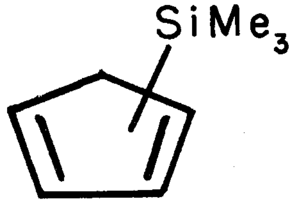
The results in Table XX can be rationalized with respect to the data in Table XIX since it is known that the pK_a values for carboxylic acids and phenols increase markedly in going from pure water to aqueous alcoholic solvents (191). Furthermore, oximes are generally considered (192) to have pK_a values ranging from 10 to 12. Even though the dielectric constant is quite high, it is interesting to note (Table XX) that the extrapolated pK values indicate CXXVII to be a significantly stronger acid than either CXXV or CXXVI, in agreement with the operation of a field effect.

Miscellany.

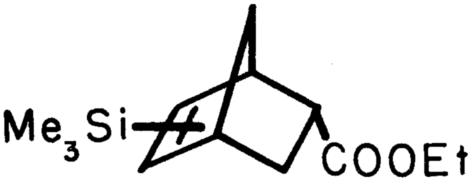
In an effort to obtain 7-substituted *exo*- and *endo*-norbornylcarboxylic acids, cyclopentadienyltrimethylsilane (193) (CXXVIII) (Fig. 22) was condensed with ethyl acrylate to give an 83.5% yield of *x*-trimethylsilyl-*endo*-carboxyethylnorbornene (CXXIX). CXXIX exhibited no change of refractive index during fractional distillation, a possible indication that it was only one of the six possible isomers. Since Frisch (193) had assumed, without proof, that the Diels-Alder adducts of CXXVIII had the trimethylsilyl group in the 7-position, an attempt whould be made to apply the elegant method of Verson and Swidler (194). The method would entail preparing the half-acid ester CXXX by treating the maleic anhydride adduct of CXXVIII with one equivalent of methanol. Partial optical resolution of CXXX followed by saponification should yield an optically inactive diacid if the substituent is in the 7-position. This was not done, since even if the substituent were found to be in the 7-position, it would not be known whether the trimethylsilyl group were in the *syn*- or *anti*- conformation. Also, the small electrical effect of the trimethylsilyl group (195,196) made it an unattractive substituent for a field effect study.

A more promising possibility for the preparation of a series of compounds suited for reactivity studies was offered by stereospecific reductions of syn- and anti-norcamphoroxime to the isomeric chloroamines; CXXXI, CXXXII, CXXXIII and CXXXIV (Fig. 22). Norcamphoroxime was used as a model with which to determine the stereospecificity of various reduction methods, since exo- and endo-norbornylamine (CXXXV and CXXXVI, resp.) are known and have been characterized as their acetyl derivatives (29, 197). The lithium aluminum hydride reduction of norcamphoroxime in tetrahydrofuran solution gave a 53% yield of relatively pure CXXXVI as judged by its melting point and that of its acetyl derivative. The infrared spectrum was of no value in the product analysis, since CXXXV and CXXXVI exhibited very similar absorptions. A small-scale hydrogenation of norcamphoroxime over Raney nickel in absolute ethanol resulted in the uptake of 45% of the theoretical hydrogen and gave a mixture of CXXXV and CXXXVI, as shown by the melting point of the acetyl derivative.

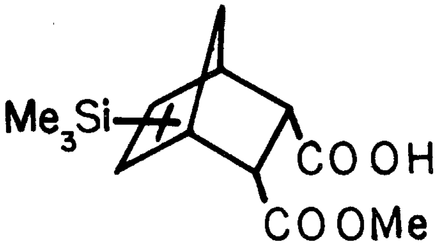
Skita and Faust (198) found that the reduction of 2-methylcyclohexanone in acetic acid over Adam's catalyst gave 75% cis-2-methylcyclohexanol, the least thermodynamically stable product. Hydrogenation of norcamphoroxime under the same conditions resulted in the uptake of 48% of the theoretical hydrogen in 21 hours. However, the product was quite pure CXXXVI, since two fractions of the acetyl derivative had the proper melting points. The hydrogenation of d-camphoroxime in acetic acid over Raney nickel gave a 74% yield of a mixture of bornylamine (exo-2-aminocamphane) (CXXXVII) and neobornylamine (endo-2-aminocamphane) (CXXXVIII).



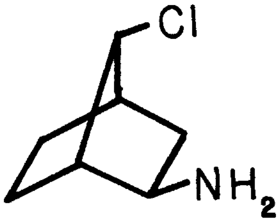
CXXVIII



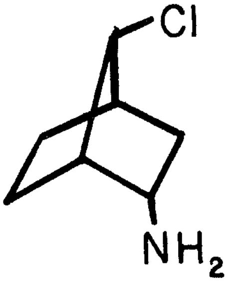
CXXIX



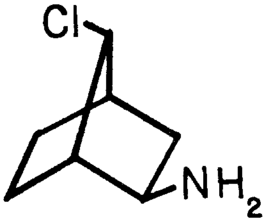
CXXX



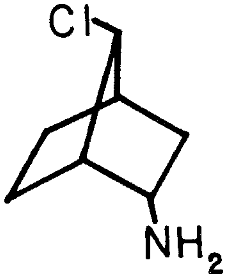
CXXXI



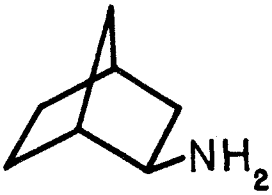
CXXXII



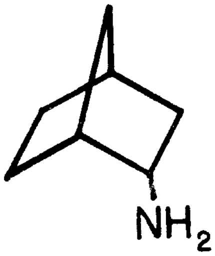
CXXXIII



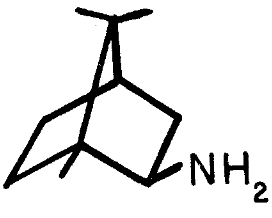
CXXXIV



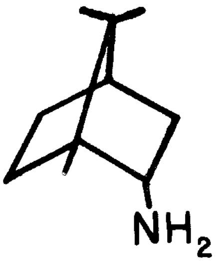
CXXXV



CXXXVI



CXXXVII



CXXXVIII

Fig. 22

Attempted hydrogenation of syn-7-chloronorcamphoroxime by the method of Hartung (199) in absolute ethanol in the presence of hydrogen chloride resulted in no detectable hydrogen absorption. However, hydrogenation over Adam's catalyst in acetic acid solution resulted in partial hydrogenolysis of the carbon-chlorine bond, as shown by the analysis of the corresponding hydrochloride. Liberation of the amine mixture from the hydrochloride, followed by distillation, gave only a small amount of liquid which analyzed fairly well for CXXXI or CXXXII.

Lithium aluminum hydride reduction of syn-7-chloronorcamphoroxime in tetrahydrofuran solution gave a 21.5% yield of an amine mixture, m.p. 41.4-43.0°. The product was shown to be an isomeric mixture by the fact that the acetyl derivative, even after some six recrystallizations from several solvents, had m.p.90.5-114°. This material analyzed correctly for a mixture of acetyl derivatives of CXXXI and CXXXII. The α-naphthylurea and benzamide derivatives required exhaustive recrystallizations to attain constant melting points.

Due to the low yields and the difficulties encountered in attaining the desired stereospecificity of reduction, this line of research was discontinued.

EXPERIMENTAL

Analyses are by A. Elek, Elek Microanalytical Laboratories, Los Angeles, California. Melting points are not corrected unless otherwise specified.

syn-7-Chloronorbornene. *A*. - The method of Roberts, Johnson and Carboni (22) was employed and 47.9 g. (0.159 mole) of *syn*-7-chloro-*exo*-norbornyl β-naphthoate were pyrolyzed in nine portions at 330-360°. The products were swept with a slow nitrogen stream into a Dry Ice trap, taken up in ether and combined. The combined ether washings were washed twice with dilute sodium bicarbonate solution and twice with water. The ethereal solution was dried over calcium sulfate and filtered. The ether was evaporated and the residue was distilled through a Holzman column (85). The product, aside from a small forerun, was collected in four fractions, b.p. 73-81.2° (56.2 mm.), $n^{25.8}$ D 1.4929-1.4958, 5.12 g. (0.0399 mole, 25%); lit. b.p. 45° (50 mm.), n^{25} D 1.4920 (22). An attempt to purify this material at high reflux ratio by fractionation through a 24 in. Podbielniak column gave six fractions, b.p. 77.3-79.2° (53.9 mm.), whose infrared spectra indicated that no substantial separation could be obtained by distillation. Material of b.p. 80.3° (54.6 mm.) n^{25} D 1.4953, was used in the kinetic experiments. The infrared spectrum (plate A, Appendix) showed nortricyclyl chloride to be the contaminant. Quantitative semimicro hydrogenation over Adam's catalyst in acetic acid solution showed the presence of 75 ± 2% of the theoretical unsaturation.

B. - A procedure similar to that described by Hine, *et. al.* (72) for the preparation of norbornadiene from *endo*-dehydronorbornyl chloride was employed. Schmerling's dichloride (syn-7-exo-2-dichloronorbornane) was prepared in 27% yield by the chlorination of norbornene (22,86), b.p. 71.5-88° (2.2 mm.); lit. b.p. 97-110° (11 mm.) (22). From the residue of the latter distillation, a small amount of crystalline solid separated which, after crystallization from 95% ethanol, had m.p. 178.3-179.1° (corr.).

Anal. Calcd. for $C_7H_9Cl_3$: C, 42.14; H, 4.55; Cl, 53.31. Found: C, 42.36; H, 4.51; Cl, 51.20, 52.57.

To a solution of 6.2 g. (0.158 g.-atom) of potassium metal in 125 ml. of dry t-butyl alcohol was added 25 g. (0.151 mole) of Schmerling's dichloride in 25 ml. of t-butyl alcohol. The brown solution was boiled under reflux for 19 hrs. and the resulting slurry diluted with 1000 ml. of water and extracted with three 250-ml. portions of ether. The combined extracts were dried twice over magnesium sulfate, filtered and the ether and most of the t-butyl alcohol were removed through a Vigreux column on the steam bath. The residue was distilled through a semimicro, vacuum-jacketed, concentric tube, 8.0-mm. I.D. by 30-cm. long, total condensation, partial takeoff column with a solenoid-operated head. After considerable forerun, the product was obtained in two fractions, b.p. 149.5-193° (741.8 mm.), n^{25} D 1.4941-1.4977, 5.75 g. (0.0448 mole, 30%). Redistillation of the latter fractions at a reflux ratio of 53:1 gave 2.4 g. liquid, b.p. 161.0° (741.8 mm.), n^{25} D 1.4970. The infrared spectrum of this material (plate A, Appendix) shows it to be essentially free of nortricyclyl chloride. The NMR spectrum is given in plate D (Appendix) along with that of norbornene.

Anal. Calcd. for $C_7H_9Cl_3$: C, 65.37; H, 7.00; Cl, 27.63. Found: C, 65.39; H, 7.10; Cl, 27.51.

The nuclear magnetic resonance (NMR) spectrum is quite characteristic, as shown by comparison with that of norbornene (plate D, Appendix).

anti-7-Chloronorbornene was prepared as in method A above. In two runs, 16.8 g. (0.0559 mole) of β-naphthoate ester were pyrolyzed to give 2.42 g. (0.0188 mole, 33.7%) of chloronorbornene. Redistillation through a Holzman column (85) gave two fractions, b.p. 69-71° (54.7 mm.), n^{25} D 1.4913-1.4922; lit. n^{25} D 1.4928 (22). The infrared spectrum showed the impurity to be nortricyclyl chloride and quantitative semimicro hydrogenation resulted in the uptake of 97 ± 2% of the theoretical amount of hydrogen.

7-Chloronorbornane. - The combined acetic acid solutions from the hydrogenation of 0.0938 g. (0.000729 mole) of anti-7-chloronorbornene and 0.7281 g. (0.005662 mole) of syn-7-chloronorbornene were combined, carefully neutralized in the cold with 17.5% aqueous sodium hydroxide solution and extracted with two 40-ml. portions of ether. The combined extracts were washed with 15% hydrochloric acid, three times with water and dried over calcium sulfate. Removal of the ether and distillation of the residue through a Holzman column (85) gave 0.30 g. (0.0023 mole, 36%) of colorless liquid, b.p. 67-75° (47.5 mm.), n^{25} D 1.4871; lit. n^{25} D 1.4878 (22). From the amounts of the isomeric chloronorbornenes used in the preparation, the nortricyclyl chloride content was judged to be 77 ± 2%.

Nortricyclyl Chloride. - The material used in the kinetic experiments had b.p. 85.5° (69.4 mm.), n^{25} D 1.4918; lit. b.p. 60.4-61.0° (32 mm.), n^{25} D 1.4947 (9). The solvolysis experiments showed this material to be of better than 90% purity (Appendix). The infrared spectrum is given in plate A, Appendix.

Reaction Rate Measurements. - The chloride solvolysis rates shown in Tables I and II were determined with the aid of a potentiometric method employing a glass electrode for measurement of the hydrochloric acid liberated in the reaction. This technique was helpful because many of the compounds were only available in small quantities and it was desirable to use rather dilute halide solutions (about 0.005 M). Except for the solvolysis of anti-7-chloronorbornene in 50% ethanol, the solvolyses were carried out in sealed ampoules, zero time being taken as the time of immersion in the constant temperature bath. At appropriate intervals, samples were cooled to 25° and in the 80% ethanol experiments, the increase in acidity during the reactions was followed by introducing samples into a vessel equipped with a glass electrode and connected by means of 1 M potassium chloride - 2.4% agar bridge to a vessel containing 1 M potassium chloride and a standard calomel electrode. The e.m.f. between the glass and calomel electrodes was measured with a Beckman Model G pH meter. The salt bridge and the 1 M potassium chloride solution were eliminated in measurements with the 50% ethanol solutions. The method was calibrated by measuring the "pH" of ten or more solutions of known hydrochloric acid concentration in the appropriate solvent compositions. Figure 23 illustrates the calibration curve for the 80% ethanol solvent. anti-7-Chloronorbornene reacted so rapidly in 50% ethanol that the increase of acidity could be measured continuously at 25° with the glass electrode. Zero time was taken as the time of dissolving the chloride in the thermostatted solvent. In view of the limited accuracy of the potentiometric method, the best visual fit was made to first-order plots and standard deviations were calculated from the deviations of the experimental points from the lines.

With the very slowly reacting chlorides, complications were introduced by the reaction of the liberated hydrochloric acid with the ethanolic medium, particularly in the latter stages. This was particularly true with *syn*-7-chloronorbornene and 7-chloronorbornane which gave complicated rate curves in consequence of the substantial contamination with nortricyclyl chloride, the reaction between ethanol and hydrochloric acid and the very low reactivities of the chlorides themselves. Figure 24 shows a typical plot of $-\log(a-x)$ against time. The steep initial slope results from a relatively rapid initial liberation of hydrochloric acid by the nortricyclyl chloride contaminant. When the concentration of nortricyclyl chloride becomes small, the hydrochloric acid concentration passes through a maximum because the rate of reaction of the acid with the ethanol is faster than the rate of solvolysis of *syn*-7-chloronorbornene (or 7-chloronorbornane). Evaluation of the percent compositions from the observed maxima agreed within experimental error with those obtained from the quantitative hydrogenations. With approximate reaction rates obtained for hydrochloric acid with 50% aqueous ethanol under the experimental conditions at three initial concentrations comparable to those calculated to be

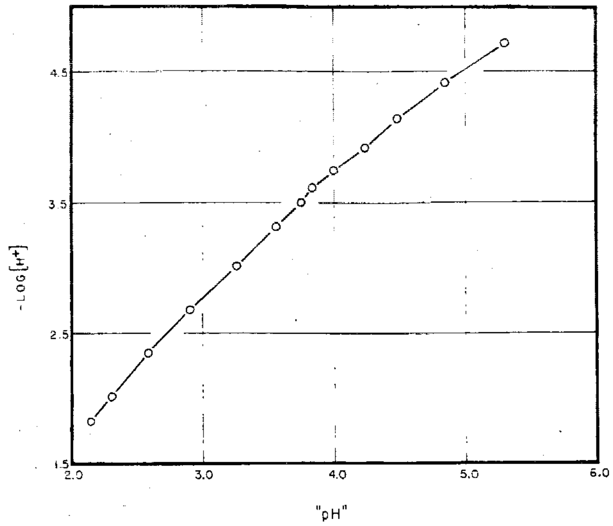


Fig. 23.

Calibration curve for 80% aqueous ethanol solutions.

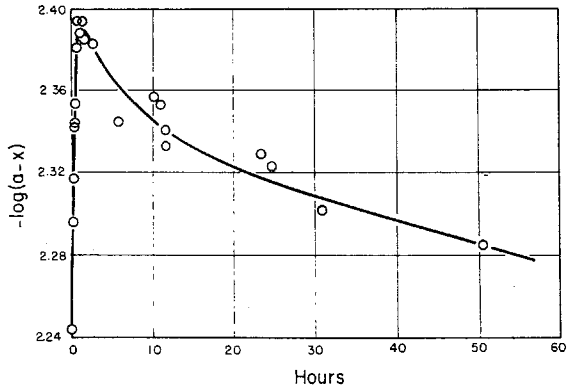


Fig. 24.

Solvolysis of syn-7-chloronorbornene in 50% aqueous ethanol at 99.7°.

present at the maximum in Fig. 24 and two points at longer times, it was possible to make a rough empirical correction of the rate data and obtain upper limits for the rate constants of syn-7-chloronorbornene. A similar procedure was followed for 7-chloronorbornane. Pertinent data are given in Tables XXI - XXXI (Appendix).

Diels-Alder Adducts of Norbornadiene and Anthracene. A mixture of 1.5 g. (0.0094 mole) and of anthracene, 1.0 g. (0.0109 mole) of norbornadiene (77), 0.1 g. hydroquinone and 10 ml. of benzene was heated in a sealed tube at 225-230° for 9 hours. Filtration of the resulting pale yellow solution gave 0.04 g. of hydroquinone, m.p. 170-173°, soluble in dilute sodium hydroxide. Absolute ethanol was added to the filtrate which resulted in the precipitation of 0.75 g. (0.00167 mole, 20%) of a white, granular solid, m.p. 355.5-356°.

Anal. Calcd. for $C_{35}H_{28}$: C, 93.71; H, 6.29. Found: C, 93.94; H, 6.41.

The filtrate was concentrated and allowed to stand at 0° to give 0.80 g. (0.00296 mole, 35%) of a pale yellow solid, m.p. 135-290°. Water was added to the second filtrate to cause the quantitative precipitation of an additional 0.40 g. (0.00148 mole, 17.5%) of an off-white solid, m.p. 131-151°. The intermediate fraction, m.p. 135-290°, was boiled with ethanol and filtered. Water was added to the filtrate to give 0.6 g. of off-white crystals, m.p. 143.5-155°. Recrystallization from absolute ethanol yielded white crystals, m.p. 144.5-158.5°.

Anal. Calcd. for $C_{21}H_{28}$: C, 92.29; H, 6.71. Found: C, 92.88; H, 6.81.

An attempt to carry out this condensation in boiling benzene for 11 hours resulted in a quantitative recovery of anthracene.

endo-Dehydronorbornyl Acetate. - In a total of five runs, 330 g. (5.00 equiv.) of dicyclopentadiene and 925 ml. (10.0 mole) of vinyl acetate were heated in a 500-ml. stainless steel bomb for 16-19 hours at 190°. The products were combined, thoroughly washed with saturated aqueous sodium bicarbonate solution and dried over magnesium sulfate and potassium carbonate. The excess vinyl acetate was removed at reduced pressure. Lithium carbonate was added to the residue which was then distilled and yielded 376 g. (49.5%) of liquid acetate in two fractions, b.p. 88-105° (29 mm.), n^{25} D 1.4692-1.4700; lit. b.p. 73-77° (14 mm.) (87).

exo-5(or *exo*-6)-Hydroxy-*anti*-7-chloro-*exo*-norbornyl Acetate. *A*. - To a stirred slurry of 32.3 g. (0.212 mole) of *endo*-dehydronorbornyl acetate and 50 ml. of water in an ice-cooled, 500-ml., three-necked flask was added 0.324 *M* hypochlorous acid solution (88) in portions over a period of three hours. When a positive potassium iodide test for excess hypochlorous acid was obtained, the aqueous mixture was saturated with sodium chloride and extracted with three 300-ml. portions of ether. The combined extracts were washed with sodium bicarbonate and dried over calciuum sulfate and potassium carbonate. The dry extracts were filtered, the ether evaporated and the residue distilled through a small Claisen head to give 5.8 g. (0.031 mole, 14.5%) of a yellow liquid forerun, b.p. 110-133° (2.5 mm.). In addition to the forerun, 20.4 g. (0.10 mole, 47%) of a viscous, tan syrup were obtained, b.p. 126-140° (2.2 mm.). This material exhibited hydroxyl (2.77μ) and ester carbonyl (5.72μ) peaks in the infrared.

Anal. Calcd. for $C_9H_{13}O_3Cl$: C, 52.82; H, 6.40. Found: C, 52.67; H, 6.52.

B. - Hypochlorous acid was added to *endo*-dehydronorbornyl acetate by the calcium hypochlorite-carbon dioxide method of Kadesch (89), as modified by Wittcoff, Roach and Miller (90), to give 20-24% of a viscous liquid, b.p. 105-112° (0.4 mm.).

The β-naphthoate ester of *exo*-5-(or *exo*-6-) hydroxy-*anti*-7-chloro-*exo*-norbornyl acetate prepared by method A above was prepared as follows. To a solution of 30 g. (0.157 mole) of β-naphthoyl chloride in 150 ml. of pyridine was added 15.0 g. (0.073 mole) of the acetoxychlorohydrin. The mixture was cooled and swirled for 30 min. and then let stand at room temperature overnight. The addition of 800 ml. of ice water resulted in the precipitation of a greyish solid which was filtered, washed with water and pressed dry with a rubber dam. The solid was boiled in 1 l. of ether and the insoluble β-naphthoic anhydride was removed by filtration. The filtrate was washed with dilute hydrochloric acid, sodium bicarbonate and water. The ether solution was dried with sodium sulfate, filtered and partially evaporated. Successive evaporations, addition of pentane and cooling yielded a total of 24.5 g. of material, m.p. 115-140°. Repeated recrystallization from 85-100° ligroin failed to substantially alter the melting point. An infrared spectrum indicated the presence of about 40% β-naphthoic anhydride. On this basis the overall yield was 55%. Purification of a small amount of the above by several recrystallizations from methanol gave white needles, m.p. 149-150°.

Anal. Calcd. for $C_{20}H_{19}ClO_4$: C, 66.95; H, 5.34. Found: C, 66.94; H, 5.28.

Attempted Preparation of 7-Chloronorbornadiene. - In three runs, a total of 19.5 g. (0.0737 mole) of the above exo-5-(or exo-6) naphthoxy-anti-7-chloro-exo-norbornyl acetate of 60% purity was pyrolyzed at 320 ± 10° for 3-6 hours with a slow nitrogen stream to sweep the product into the attached Dry Ice trap. After each pyrolysis, the dark liquid product was rinsed from the system with pentane. The combined pentane solutions were washed with dilute sodium bicarbonate solution and dried over potassium carbonate. A small amount of hydroquinone was added and the pentane was distilled through a Holzman column (85). Distillation of the residue gave fraction I, 0.23 g., b.p. 48-70° (57.5 mm.), fraction II, 0.24 g., b.p. 69-135° (56.0 mm.) and fraction III, b.p. 135-155° (56.0 mm.). Fraction I exhibited carbonyl (5.82μ) absorption in the infrared and its ultraviolet spectrum showed the presence of about 5% naphthalene.

Anal. Calcd. for $C_9H_{11}ClO_2$: C, 57.92; H, 5.94; Cl, 19.00. Found: C, 57.80; H, 6.21; Cl, 20.54.

Fraction II showed a weak split carbonyl peak in the infrared (5.73 and 5.81μ) and the ultraviolet spectrum showed the presence of 13% naphthalene. This material reacted rapidly with ethanolic silver nitrate, sodium permanganate and bromine in carbon tetrachloride. Comparison of infrared spectra eliminated benzyl chloride and ortho-, meta- and para-chlorotoluene as possible isomeric constituents. Using the method of Long (91), a rapidly mixed solution of iodine and norbornadiene in cyclohexane gave an ultraviolet spectrum with a small shoulder at 274 mμ and increased absorption at near 253 mμ. This same solution, after 15 sec. irradiation with a small ultraviolet arc, gave a large peak at 274 mμ and negligible absorption in the 255 mμ region. An identical qualitative test failed to alter the ultraviolet spectrum of fraction II, even after 5 min. irradiation.

Anal. Calcd. for C_7H_7Cl: C, 66.42; H, 5.57; Cl, 28.01. Found: C, 59.35; H, 5.34; Cl, 24.74.

Fraction III displayed a strong carbonyl peak at 5.72 in the infrared and the ultraviolet spectrum showed about 8% naphthalene to be present.

Anal. Found: C, 61.93; H, 6.43; Cl, 16.30.

exo-5-(or exo-6-)-Hydroxy-anti-7-chloro-exo-norborneol. - A suspension of 10.4 g. (0.275 mole) of lithium aluminum hydride in 400 ml. of dry ether was stirred and boiled in a 1-l., three-necked flask for 0.5 hr. A solution of 25 g. (0.122 mole) of exo-5-(or exo-6-)hydroxy-anti-7-chloro-exo-norbornyl acetate, prepared by method A above, in 200 ml. of ether was added to the ice-cooled slurry with stirring over a period of 1.5 hrs. The mixture was stirred and boiled for an additional 3.5 hrs. It was then cooled to 0° and 36 ml. of ethyl acetate was added slowly followed by the careful addition of water until the aluminum hydroxide coagulated and adhered to the sides of the flask. The yellow ether solution was decanted and the residual paste washed with three 100-ml. portions of ether. The combined ether solutions were dried over magnesium sulfate, filtered and the ether distilled through a Vigreux column. Upon removal of the residual ether under reduced pressure, a tan solid separated from the tan oil. The tan oil was separated by filtration (10 g.) and distilled through a Holzman column (85) to give a forerun of 0.98 g. of liquid, b.p. 78-100° (0.6 mm.), an intermediate fraction of 1.56 g. of solid and liquid, b.p. 100-118° (0.7 mm.) and 4.53 g. (0.0279 mole, 23%) of waxy solid, b.p. 118-122° (0.7-1.0 mm.), m.p. 58-70°. This latter material exhibited infrared hydroxyl absorption at 2.92μ in chloroform solution.

Anal. Calcd. for $C_7H_{11}ClO_2$: C, 51.70; H, 6.82; Cl, 21.80. Found: C, 48.57; H, 5.98; Cl, 35.53.

The di-3,5-dinitrobenzoate ester was prepared by the pyridine method. Recrystallization from ethyl acetate gave microcrystals, m.p. 253.5-254.5° (corr.).

Anal. Calcd. for $C_{21}H_{15}N_4O_{12}Cl$: N, 10.17; Cl, 6.44. Found: N, 10.31; Cl, 6.38.

The tan solid (10 g., 0.0615 mole, 50%) was crystallized from chloroform to give tan crystals, m.p. 168.5-171.5°. After another crystallization from chloroform, treatment with charcoal in hot ethanol and two more recrystallizations from ethanol, white crystals, m.p. 167-170.5°, were obtained.

Anal. Calcd. for $C_7H_{11}ClO_2$: C, 51.70; H, 6.82; Cl, 21.80. Found: C, 51.20; H, 6.73; Cl, 22.39.

The di-3,5,-dinitrobenzoate ester was prepared as above. Several recrystallizations from ethyl acetate gave very slightly greenish microcrystals, m.p. 237-238.5°.

Anal. Calcd. for $C_{21}H_{15}N_{4}O_{12}Cl$: N, 10.17; Cl, 6.44. Found: N, 9.71; Cl, 6.61.

A similar reduction of 65.5 g. (0.32 mole) of exo-5-(or exo-6-)hydroxy-anti-7-chloro-exo-norbornyl acetate (obtained by method B) gave 44 g. (0.27 mole, 84.5%) of a tan oil. No solid could be obtained from this preparation, even after prolonged standing at 4°. The infrared spectrum was similar to that of the lower melting chlorodiol obtained above.

The di-β-naphthoate ester was prepared by the pyridine method in low yield (4%). Several crystallizations from chloroform and 60-70° ligroin were required to yield white microplates, m.p. 198.7-200.7°.

Anal. Calcd. for $C_{29}H_{23}O_{4}Cl$: C, 73.96; H, 4.92; Cl, 7.53. Found: C, 73.56; H, 5.10; Cl, 8.02.

The ultraviolet spectrum exhibited the following peaks, indicative of a dinaphthoate ester

λ_{max}, mμ	336	323	322	282.5	273	250
ϵ, l. mol.$^{-1}$cm.$^{-1}$	3370	11,500	2700	11,500	13,400	high

The majority of the product in this preparation was obtained as a very viscous tan oil whose infrared spectrum showed the complete absence of unreacted alcohol.

Anal. Calcd. for $C_{29}H_{23}O_{4}Cl$: C, 73.96; H, 4.92; Cl, 7.53. Found: C, 67.12; H, 5.09; Cl, 16.44.

The analysis indicated that method B for the addition of hypochlorous acid to endo-dehydronorbornyl acetate gave considerable chlorination.

Attempted Preparation of 7-Chloronorbornadiene. Into a 50-ml., round-bottomed flask fitted with a nitrogen inlet tube and a Dry Ice trap was put 3.7 g. (0.0079 mole) of the above crystalline dinaphthoate ester. The material was pyrolyzed at 325° for 2 hours at slightly reduced pressure. The system was thoroughly rinsed with pentane, the combined washings filtered and the pentane evaporated. The dark residue was flash distilled at 1 mm. pressure and 100° into a receiver at -70°. The small amount of yellow oil obtained reacted with ethanolic silver nitrate, gave a positive Baeyer test and absorbed bromine in carbon tetrachloride solution. The infrared spectrum exhibited a peak at 5.83 microns.

Anal. Calcd. for $C_{10}H_{10}Cl_2$: C, 59.73; H, 5.01; Cl, 35.26. Found: C, 56.78; H, 5.48; Cl, 35.20.

The calculated analysis is for dichlorodicyclopentadiene, a conceivable decomposition product of 7-chloronorbornadiene.

endo-Dehydronorbornyl Chloride. - To 160 g. (2.42 mole) of dicyclopentadiene in a 1-l., stainless steel bomb cooled to the Dry Ice-acetone temperature was added 325 ml. (4.79 mole) of vinyl chloride. The bomb was quickly sealed, allowed to warm to room temperature and then slowly heated to 190°, at which temperature it was rocked mechanically for 11 hrs. The excess vinyl chloride was released and the residue distilled through a 35-cm. Vigreux column to give (three fractions) 196.4 g. (1.53 mole, 63%) of product, b.p. 58.2-60.5° (24.5 mm.), n^{25} D 1.4934-1.4938; lit. b.p. 46-47° (12 mm.); (87); b.p. 69-70° (40 mm.), n^{25} D 1.4927 (9).

The above preparation is patterned after the procedure of Meinwald and Hudak for norbornene (94).

exo-5-anti-7-Dichloro-exo-norbornyl Chloride. - Chlorine was bubbled into a stirred, Dry Ice-cooled solution of 175 g. (1.36 mole) of endo-dehydronorbornyl chloride in 500 ml. of pentane. During the chlorination, copious quantities of hydrogen chloride were evolved. After 45 min., excess chlorine was observed and the chlorination was discontinued. The excess chlorine, the hydrogen chloride and most of the pentane were removed on the steam bath and the residue distilled through a 35-cm. Vigreux column. After 15.9 g. of forerun, b.p. 34-57° (25.5 mm.), n^{25} D 1.4379, there was obtained 51.4 g. (0.40 mole, 29%) of impure nortricyclyl chloride, b.p. 40° (7.8 mm.), n^{25} D 1.4930; lit. b.p. 60.4-61.0° (32 mm.), n^{25} D 1,4947 (9), followed by 73.1 g. (0.45 mole, 33%) (two fractions) of dichloronortricylene, b.p. 47-56.5° (1.1 mm.), n^{25} D 1.5186-1.5206. This material was saturated to permanganate and exhibited the characteristic nortricylenic absorption (24) at 12.3 μ in the infrared (plate A, Appendix). The NMR spectrum is given in plate D (Appendix).

Anal. Calcd. for $C_7H_8Cl_2$: C, 51.56; H, 4.95; Cl, 43.49. Found: C, 49.39; H, 4.51; Cl, 45.24.

The analysis indicated some contamination with trichloride.

The residual trichloride was collected as a waxy solid in two fractions, 87.3 g. (0.44 mole, 32%), b.p. 76.5-93° (1.1 mm.). Redistillation gave a center cut, m.p. 34-34.5°.

Anal. Calcd. for $C_7H_9Cl_3$: C, 42.14; H, 4.55; Cl, 53.31. Found: C, 41.98; H, 4.55; Cl, 53.14.

Attempted Preparation of 7-Chloronorbornadiene. A. - A solution of 10.2 g (0.261 g.-atom) of potassium metal in 150 ml. of dry t-butyl alcohol was prepared. To this solution was added 25 g. (0.125 mole) of 2,5,7-trichloronorbornane and the resulting dark solution was boiled under reflux (drying tube) for 40 hrs. The dark suspension was poured into 1500 ml. of water and addition of 200 ml. of ether gave an emulsion. The emulsion was separated from the dark aqueous phase and filtered. The aqueous phase was extracted with three 200-ml. portions of ether. The precipitates were washed thoroughly with ether and all of the combined ether solutions were filtered, washed with water and dried twice over magnesium sulfate and calcium sulfate. After filtration, the ether and most of the t-butyl alcohol were removed on the steam bath through a Vigreux column. The residue was distilled through a Holzman column (85) to give in five fractions 13.45 g. (0.0825 mole, 66%) of a mixture of dichlorides, b,p. 44.5-53.5° (1.1 mm.), n^{25} D 1.5187-1.5247. Both the first and fifth fractions reacted slowly with ethanolic silver nitrate and were unsaturated to permanganate. The first fraction (b.p. 44.8-45.2° at 1.2 mm., n^{25} D 1.5187) had a small peak at 5.9μ in addition to a sharp spike at 6.27μ and strong absorption in the 12.1-12.4μ region of the infrared (plate A, Appendix). The NMR spectrum is given in plate D (Appendix).

Anal. Calcd. for $C_7H_8Cl_2$: C, 51.56; H, 4.95; Cl, 43.49. Found: C, 51.78; H, 5.02; Cl, 43.44.

The fifth fraction (b.p. 50.3-53.5° (1.1 mm.), n^{25} D 1.5247) had an infrared spectrum very similar to that of the first fraction except for intensity differences (plate A, Appendix). The NMR spectrum is given in plate D (Appendix).

Anal. Calcd. for $C_7H_8Cl_2$: C, 51.56; H, 4.95; Cl, 43.49. Found: C, 51.48; H, 5.20; Cl, 43.32.

All of the above fractions were combined and 10 g. (0.0615 mole) of the mixture was added to a stirred suspension of 0.064 mole of potassium t-butoxide in 150 ml. of dry benzene. The mixture was stirred and heated under reflux for 40 hrs., then filtered to give a water-soluble precipitate containing a small amount of insoluble polymer. The benzene was removed from the filtrate and the residue was distilled through a Holzman column (85) to give 8.50 g. (0.0521 mole, 85%) of unchanged starting material (four fractions), b.p. 103-111.5° (25.3-28.3 mm.). The infrared spectra of the first and last fractions were identical with those of the starting material.

B. - To a stirred slurry of 6.4 g. (0.92 g.-atom) of lithium metal in 400 ml. of dry ether in a 1-l., round-bottomed flask was added 57.5 g. (0.420 mole) of n-butyl bromide over a period of 1 hr. The resulting grey suspension was stirred an additional 1 hr. at room temperature and 22 g. (0.30 mole) of diethylamine (distilled from barium oxide) was added in the cold. After 2 hrs., a solution of 25 g. (0.125 mole) of 2,5,7-trichloronorbornane in 50 ml. of ether was added and the solution stirred at room temperature for 13.5 hrs. Ammonium carbonate (40 g., 0.35 mole) was added to the tan slurry which was filtered, the precipitate washed with ether and the combined ether solutions partially evaporated on the steam bath through a Vigreux column. Pentane was added to precipitate the lithium chloride which was removed by filtration. The ether and pentane were removed at reduced pressure

pressure and the residue was flash distilled. The material boiling below 63° at 1 mm. pressure was collected in a Dry Ice-cooled receiver and redistilled through a Holzman column (85). A forerun (2.10 g.) was collected in five fractions, b.p. 34-61° (64.5 mm.). The first of these fractions, b.p. 34-47° (64.5 mm.) was unsaturated to permanganate and with ethanolic silver nitrate gave silver metal. The infrared spectrum is given in plate C (Appendix).

Anal. Found: C, 71.12; H, 2.88.

After 0.95 g. of intermediate fractions were collected, b.p. 61.1-70° (65.2-14.7 mm.), there was obtained 6.55 g. (0.0402 mole, 32%) of product (three fractions), b.p. 70-85.5° (14.7 mm.). The NMR spectrum is given in plate D (Appendix). The infrared spectrum of the latter fraction (plate B, Appendix) was very similar to that obtained from the *t*-butoxide elimination (plate A, Appendix). The infrared spectrum of the dichloride product from the chlorination of norbornadiene (58), b.p. 48.5-50.0° (2.0 mm.), n^{26} D 1.5195, is given in plate B (Appendix) for comparison.

Attempted Preparation of 7-Bromonorbornadiene. To a solution of 25 g. (0.272 mole) of norbornadiene (77) in 40 ml. of carbon tetrachloride was added 10.0 g. (0.0562 mole) of N-bromosuccinimide. After the mixture was boiled under reflux for 20 min., an exothermic reaction set in and cooling was necessary to control the boiling. The solution remained clear for about 1 min. after the initiation of the reaction and then rapidly turned dark red and crystals appeared on the surface. The mixture was stirred and boiled for 10 min., cooled and filtered. The solvent was partially distilled at atmospheric pressure and the residue filtered. The solvent was removed from the filtrate and an attempt to flash distill the dark residue at 2 mm. and 100° gave only a trace of distillate. The dark residue was thoroughly washed with ether and the washings combined. The ether was removed and the residue distilled through a Holzman column (85) to give four fractions, b.p. 70-110° (3 mm.) (3.7 g.). To remove the succinimide which had separated from this material, a small amount of ether was added and the solid was filtered off. The ether was evaporated and the residue flash distilled to give a yellow liquid which reacted instantaneously with ethanolic silver nitrate and was unsaturated to permanganate.

Anal. Calcd. for C_7H_7Br: C, 49.15; H, 4.13; Br, 46.72. Found: C, 37.18; H, 3.85; Br, 55.60; N, 0.51.

The analysis indicated the presence of about 4% succinimide plus a complex mixture of mono-, di- and tribromides.

anti-7-Chloro-endo-norborneol. - To a stirred slurry of 1.6 g. (0.042 mole) of lithium aluminum hydride in 50 ml. of ether was added a solution of 3.85 g. (0.0266 mole) of anti-7-chloronorcamphor in 60 ml. of ether. The stirred mixture was boiled under reflux for 2 hrs. and then stirred at room temperature for an additional 2 hrs. The mixture was cooled to 0° and 17 ml. of water was carefully added until the paste adhered to the sides of the flask. The ether solution was decanted and the residual paste washed with three 35-ml. portions of ether. The combined washings were dried over sodium sulfate, filtered and most of the ether removed on the steam bath through a Vigreux column. The residue was sublimed at 2 mm. in a "rocket gun" to give 3.56 g. (0.0243 mole, 91%) of chlorohydrin, m.p. 60-74°. The infrared spectrum was similar to that of authentic anti-7-chloro-exo-norborneol, but had different intensities (plate B, Appendix).

Anal. Calcd. for $C_7H_{11}ClO$: C, 57.34; H, 7.51; Cl, 24.23. Found: C, 58.25; H, 7.76; Cl, 23.15.

The analysis showed that about 5% of the chlorine was lost in the reduction.

An attempt to prepare the p-toluenesulfonate ester by the pyridine method gave an uncrystallizable oil which was contaminated with unreacted alcohol as shown by its infrared spectrum.

Lithium Aluminum Hydride Reduction of the syn-7-Chloronorcamphor. - As above, 15 g. (0.104 mole) of syn-7-chloronorcamphor gave 14.55 g. (0.0993 mole, 95.5%) of waxy chlorohydrin, m.p. 50-63°. The infrared spectrum of this material was identical with that of authentic syn-7-chloro-exo-norborneol (plate B, Appendix).

Aluminum Isopropoxide Isomerization of syn-7-Chloro-exo-norborneol. - The method of Dauben and Noyce (78,79) was used. A solution of 14.2 g. (0.097 mole) of syn-7-chloro-exo-norborneol in 100 ml. of dry isopropyl alcohol (distilled from barium oxide) containing 8 g. (0.0392 mole) of freshly distilled aluminum isopropoxide (b.p. 120-124° at 5 mm.) and 0.5 ml. of acetone was boiled under reflux. After 24 hrs., another 0.5 ml. of acetone was added and boiling was continued for another 48 hrs. Most of the alcohol solvent was removed at atmospheric pressure through a center-rod column, the residue was cooled and a cold solution of 14 ml. of concentrated hydrochloric acid in 70 ml. of water was slowly added. The resulting suspension was extracted with three 100-ml. portions of ether.

The combined extracts were washed with water and dilute sodium bicarbonate solution and dried over magnesium sulfate. Filtration of the ether solution followed by removal of the ether on the steam bath and sublimation of the residue gave 9.05 g. (64%) of chlorohydrin. The infrared spectrum was clearly different from that of the starting material, exhibiting a shift of the hydroxyl peak to longer wavelengths and various intensity differences (plate C, Appendix).

p-Toluenesulfonate Ester of syn-7-Chloronorborneols. - A solution of 7.0 g. (0.0477 mole) of isomerized alcohol and 10.0 g. (0.0525 mole) of recrystallized p-toluenesulfonyl chloride in 35 ml. of dry pyridine was allowed to stand for 24 hrs. at room temperature. Pyridine hydrochloride crystals had separated after this time and the mixture was poured into 200 ml. of ice water containing 37 ml. of concentrated hydrochloric acid. A clear oil separated and the whole was rapidly extracted with three 50-ml. portions of ether. The combined extracts were washed twice with dilute hydrochloric acid, once with water and finally with dilute sodium bicarbonate solution. The washed ether solution was dried over magnesium sulfate, filtered and the ether evaporated to about 35 ml. Repeated efforts to crystallize this residue from pentane-ether gave only oils. Chromatography of a small amount of the oil on a 4:1 silicic acid-Decalite column using pentane as a developer failed to give a crystallizable fraction. Consequently, the oil was taken up in ether, dried thoroughly over calcium sulfate and filtered. After removal of most of the ether at aspirator pressure, the clear residual oil was film-dried at 2 mm. and room temperature for 3 hrs. to give

12.3 g. (0.0409 mole, 86%) of p-toluenesulfonate ester which formed a glass on cooling to -75°.

Anal. Calcd. for $C_{14}H_{17}O_3SCl$: C, 55.90; H, 5.70; Cl, 11.79; S, 10.66. Found: C, 55.31; H, 5.87; Cl, 12.02; S, 10.07.

The solvolysis rates of these p-toluenesulfonate esters were determined as described by Winstein and co-workers (92) and interpreted as indicated earlier (p. 38). The data are given in Table XXXII (Appendix).

exo-Norborneol. - The method of Bruson and Riener (199) was employed. To a stirred solution of 13 ml. of concentrated sulfuric acid in 50 ml. of water was added 18 g. (0.191 mole) of norbornene (94). This mixture was heated at 100° and stirred for 5 hrs. During the course of the reaction, the norbornene which sublimed into the condenser was scraped back into the reaction flask with the aid of a stirring rod and additional water. The reaction mixture was cooled and extracted with two 150-ml. portions of ether. The combined extracts were washed with water and saturated sodium bicarbonate solution. They were then dried over magnesium sulfate and potassium carbonate. The ether was removed and the residue distilled to give 13.7 g. (0.122 mole, 64%) of alcohol, b.p. 175-179°, m.p. 127.5-129°; lit., m.p. 126° (199).

Norcamphor. - To an ice-cooled, stirred solution of 99.5 g. (0.338 mole) of potassium dichromate, 136 g. of concentrated sulfuric acid and 600 ml. of glacial acetic acid in 1500 ml. of water was added 115 g. (1.025 mole) of endo-norborneol (87). This mixture was stirred for 6 hrs. and let stand at room temperature overnight. A cold solution of 500 g. of technical-grade sodium hydroxide in 800 ml.

of water was slowly added with cooling and the resultant green slurry was steam distilled. A total of 1500 ml. of steam distillate was collected, saturated with sodium chloride and extracted with three 500-ml. portions of ether. The combined extracts were dried over magnesium sulfate and calcium sulfate, filtered and the ether removed on the steam bath through a Vigreux column. The residue was distilled through a Vigreux column to give 84.5 g. (0.744 mole, 75%) of ketone, b.p. 89-119° (60-67 mm.). The NMR spectrum is given in plate D (Appendix).

Norcamphor Semicarbazone. - A solution of 7.5 g (0.068 mole) of norcamphor in 35 ml. of ethanol was added to a solution of 13.1 g. (0.117 mole) of semicarbazide hydrochloride and 19.7 g. of sodium acetate in 50 ml. of water. This solution was heated on the steam bath for 9 hrs. and the ethanol removed under reduced pressure. The white residue was washed thoroughly with water and removed by filtration to give 9.0 g. (0.054 mole, 79%) of crude product. Recrystallization from absolute ethanol gave white needles, m.p. 195.7-196.7°; lit., m.p. 196-196.5° (200).

Regeneration of Norcamphor from its Semicarbazone. - To a solution of 14.5 g. (0.115 mole) of oxalic acid dihydrate in 200 ml. of water was added 18.7 g. (0.112 mole) of norcamphor semicarbazone, m.p. 194-195.4°. This mixture was steam distilled and 350 ml. of steam distillate was collected. Sodium chloride was added and the milky suspension extracted with three 75-ml. portions of ether. The combined extracts were dried over magnesium sulfate and again over calcium sulfate and filtered. Most of the ether was removed on the steam bath and the residue was sublimed in a "rocket gun" to give 10.4 g. (0.0945 mole, 84%) of waxy sublimate, m.p. 95.5-96.5°; lit., m.p. 91-92° (201); 95° (86).

syn-7-Chloronorcamphor. - Prepared by the chromic acid oxidation of syn-7-chloro-exo-norborneol (22) as described above for norcamphor in 59% yield. Regeneration from its semicarbazone gave the pure ketone in 76% yield, m.p. 69-70°.

anti-7-Chloronorcamphor. - Prepared as described for norcamphor from the chromic acid oxidation of anti-7-chloro-exo-norborneol (22) in 43.5 to 65% yields. Regeneration from the semicarbazone gave the pure ketone in 73% yield, m.p. 68-70.5°.

Nuclear Magnetic Resonance Measurements. - Trifluoroacetic acid containing five volume percent of trifluoroacetic anhydride was distilled (drying tube) and a center fraction collected, b.p. 70.2-70.9° (744 mm.). This very hygroscopic material was stored in a glass stoppered container in a phosphorous pentoxide-dried dry box. The dichlorotetrafluoroacetone was obtained as a gift from the General Chemical Company and was distilled before use. All other liquids were the best commerical products distilled from an appropriate drying agent and center cuts of narrow boiling range were used. The norcamphors were regenerated from their pure semicarbazones and sublimed as described above. Eastman White Label p-bromoacetophenone was used without further purification.

All measurements were made with a Varian (163) Model V-4300 High Resolution NMR spectrometer utilizing a field of about 9411 gauss at a fixed radio frequency of 40 megacycles/sec. The samples were contained in 5 mm.-O.D. glass tubes with a sealed-in, 1.7mm.-O.D., concentric capillary containing benzene as the reference. Appropriate amounts of the oxygenated component were weighed accurately into 1-ml. volumetric flasks which were put into a nitrogen-flushed dry box through an air lock. The trifluoroacetic acid was introduced volumetrically and the flasks reweighed. In all cases, two solutions were prepared in order to obtain chemical shifts at an interpolated mole ratio of 1.000. The solutions were again introduced into the dry box and transferred to the sample tubes by means of a capillary dropper. Rubber policemen were then applied to protect the samples from contamination during subsequent handling. The NMR spectra were measured on spinning samples with an audio calibration frequency applied by means of a Hewlett-Packard Model 200AB variable audio oscillator. Eight to twelve spectra were then run using a sweep time of twelve seconds. The oscillator-produced side bands of the benzene peak were used as a calibration for each spectrum. In no case was any difficulty encountered in identifying the carboxyl hydrogen resonance of trifluoracetic acid which was well displaced to lower field strength from all other peaks. All measurements were made at 34 ± 3°C.

endo-3-Bromo-d-camphor. - The method of Kipping and Pope (171) was used. Two recrystallizations from absolute ethanol gave beautiful white needles, m.p. 75.3-76.3°; lit., 74° (171).

exo-3-Bromonorcamphor. - A. - The method of Kipping and Pope (171) was employed. The addition of 7.3 g. (0.0455 mole) of bromine to 5.0 g. (0.0455 mole) of norcamphor heated on the steam bath resulted in a copious evolution of hydrogen bromide. The reaction mixture was swirled and heated for 20 min. and then allowed to stand at room temperature for 30 min. The resulting yellow oil was taken up in 75 ml. of ether and the ethereal solution was washed with water and saturated sodium bicarbonate solution. The washed solution was dried over magnesium sulfate, filtered and the ether removed on the steam bath through a Vigreux column. Distillation of the residue through a Holzman column (85) gave 0.4 g. of solid norcamphor as a forerun, b.p. 110° (53 mm.) followed by two intermediate liquid fractions, b.p. 100-126.2° (23 mm.), 0.80 g. The remaining material was collected as 2.75 g. (38% after correcting for recovered norcamphor) of liquid, b.p. 126.2-128.5° (23 mm.) which solidified on cooling to give a waxy solid, m.p. 30°.

Anal. Calcd. for C_7H_9OBr: C, 44.47; H, 4.80; Br, 42.27. Found: C, 44.27; H, 4.70; Br, 42.17.

The NMR spectrum (plate D, Appendix) exhibited three peaks with area ratios of 1:2:6. B. - To a stirred solution of 5.0 g. (0.0455 mole) of norcamphor in 25 ml. of boiling carbon tetrachloride was added 7.3 g. (0.0455 mole) of bromine over a period of 1.5 hrs. The mixture was boiled and stirred for an additional 2 hrs. then extracted with dilute sodium bicarbonate solution and dried over magnesium sulfate. The carbon tetrachloride was removed and distillation of the residue through a Holzman column (85) gave 0.88 g. of low-boiling forerun and 2.46 g. of intermediate fractions (three fractions), b.p. 85-102.3° (7.4-7.0 mm.). The remainder of the material was collected as 3.41 g. (64%) of liquid, b.p. 102.3-102.5° (7.0 mm.), n^{25} D 1.5219. This material had the same ultraviolet spectrum as that prepared by way of method A above. The infrared spectrum is given in plate C, Appendix.

endo-3-Bromonorcamphor. - The method of Lowry and Steele (174) was used. A solution of 3.0 g. (0.0159 mole) of exo-3-bromonorcamphor prepared by method B above in 20 ml. of 95% ethanol was brought to a boil. Five ml. of 0.175 N ethanolic sodium ethoxide solution was added and the solution was boiled for 30 sec. then quickly quenched in an ice bath. Titration of the resulting solution with 0.1 N hydrochloric acid showed that no more than 2×10^{-4} equivalents of ethoxide ion had been consumed. About 18 ml. of the ethanol was distilled off and 50 ml. of water was added to the residue. The resulting oily dispersion was extracted with three 35-ml. portions of ether and the combined extracts were dried over magnesium sulfate and again over calcium sulfate. The ether was removed through a Vigreux column and the residue was distilled through a Holzman column (85) to give 2.31 g. (77%) of liquid, b.p. 103-104° (6.5 mm.), n^{25} D 1.5231.

Anal. Calcd. for C_7H_9OBr: C, 44.47; H, 4.80; Br, 42.27. Found: C, 48.73; 48.88; H, 5.45, 5.66; Br, 37.58, 37.63.

The second analysis is for a redistilled sample, since the material discolored on standing. The NMR spectrum is given in plate D and the infrared spectrum in place C, Appendix.

Bromination Rate Measurements. - The acetic acid was purified by the method of Orton and Bradfield (202) and had b.p. 115.5° (739 mm.), m.p. 16.35°. The sodium acetate was reagent grade material and was fused before use. The 75% aqueous acetic acid solvent was prepared by dissolving 20.000 g. of fused sodium acetate in 750 ml. of pure acetic acid at 35° and making up to

1000.9 ml. with conductivity water, also at 35°, in the 35° thermostat. The norcamphors were purified by regeneration from their semicarbazones. d-Camphor was recrystallized twice from aqueous ethanol and sublimed.

The method of Evans and Gordon (176) was used for the kinetic measurements in aqueous acetic acid. Ketone concentrations were low enough (0.02-0.03 M) so that the kinetics were first rather than zero-order in ketone. The ketone sample was weighed out and washed into a 100-ml. volumetric flask with solvent at 35°. The solution was thermostatted at 35.00° and made up to the mark. Sufficient bromine was added to give a roughly 0.01 M solution, the solution was quickly and thoroughly mixed and a 10-ml. aliquot immediately withdrawn for the zero time titer. All samples were pipetted into a solution of 0.2 g. of potassium iodide in 10 ml. of water and the liberated iodine was titrated to a starch end point with 0.01 N thiosulfate solution. The sodium thiosulfate solution was prepared and standardized against potassium iodate by the method of Swift (203).

For the reactions in aqueous sodium hypobromite solution, 100 ml. of carbonate-free 1 N sodium hydroxide solution was pipetted into a 1-l. volumetric flask and bromine was added to give a 0.005 M solution when made up to the mark with freshly boiled water at 25°. When stored in a dark bottle, this solution was found to lose about 1% of its titer per day. Ketone solutions (0.01 M) were prepared at 35° in water and stored in the thermostat at 35°. Five-ml. aliquots of hypobromite solution were pipetted into each of 10 tubes at 25° and these were then immersed in the thermostat at

35°. The time was recorded at the instant of immersion in order to correct for the small loss of titer during a run. Aliquots of thermostatted ketone solution were blown into the tubes by means of a 2-ml. pipet which was calibrated by blowing and found to be reproducible to ± 0.003 ml. The timer was started when half of the aliquot had been added, the total time of addition amounting to only 3 sec. Quenching was accomplished by blowing in 1 ml. of a freshly prepared 2 N hydrochloric acid solution containing 0.1 g. of potassium iodide per ml. The timer was stopped at the time of addition of the acid, the total addition time amounting to less than 1 sec. The liberated iodine was titrated as above. This method is a modification of that of Bell and Longuet-Higgins (179).

In both of the above sets of measurements, the rate tubes were protected from light by blackening the thermostat and covering the top with a black cloth during the runs. The pertinent rate data are given in Tables XXXIII-XXXIX(Appendix).

Isolation of the Product from the Sodium Hypobromite Bromination of Norcamphor. - To a solution of 4.5 g. (0.11 mole) of sodium hydroxide and 4.5 g. (0.0273 mole) of bromine in 125 ml. of water in a 200-ml., two-necked flask was added 1.0 g. (0.0091 mole) of norcamphor. This mixture was magnetically stirred and heated at 35° for 46 hrs. The tan solid which separated initially slowly dissolved to give a clear solution which was extracted with two 50-ml. portions of carbon tetrachloride to remove any unreacted starting material or intermediate bromination products. The aqueous phase was acidified with 5 ml. of concentrated hydrochloric acid and the resulting suspension extracted with two 50-ml. portions of ether. The combined extracts were dried over calcium sulfate, filtered and the ether removed on the steam bath to give a residual syrup which would not crystallize. This oil was taken up in ether, treated with charcoal and filtered through a pad of Celite. Two more treatments with charcoal were required to give a water-white solution. Removal of the ether at room temperature and reduced pressure gave a clear oil which would not crystallize. The infrared spectrum of this oil (plate C, Appendix) showed the characteristic peaks of a carboxylic acid, but was not similar to that of cis-cyclopentane-1,3-dicarboxylic acid.

The remaining oil was boiled under reflux with 3 ml. of thionyl chloride for 20 min. and the resulting yellow solution cautiously poured into 10 ml. of cold concentrated ammonia. The tan solid which separated was filtered off, washed with cold water and crystallized from hot water to give fluffy white plates, m.p. 113.5-115.° This material was insoluble in dilute sodium bicarbonate solution, gave a negative permanganate test for unsaturation and did not react with 2,4-dinitrophenylhydrazine reagent, Sodium fusion analysis showed the presence of nitrogen and bromine, but no sulfur or chlorine.

Anal. Calcd. for $C_8H_{12}NBr_2O$: C, 32.24; H, 4.03; N, 4.71; Br, 53.63. Found: C, 32.78, H, 3.88; N, 5.63; Br, 53.01.

The infrared spectrum showed that the product was an unsubstituted amide.

Norcamphoroxime. - This material was prepared by the method of Alder and co-workers (197) in 70% yield. Redistillation of the crude material through a Holzman column (85) gave a clear, viscous syrup, b.p. 145-146° (55 mm.).

Anal. Calcd. for $C_7H_{11}NO$: N, 11.19. Found: N, 10.81.

syn-7-Chloronorcamphoroxime. - A mixture of 18.3 g. (0.126 mole) of syn-7-chloronorcamphor, 13.1 g. (0.189 mole) of hydroxylamine hydrochloride and 4.5 g. (0.113 mole) of sodium hydroxide in 250 ml. of 70% aqueous ethanol was boiled under reflux for 20 hrs. After several days at 4°, 15.4 g. (0.0965 mole, 76%) of crude oxime was obtained by filtration and extraction of the filtrate with methylene chloride. Recrystallization from 30-60° ligroin followed by sublimation gave white crystals, m.p. 113.4-114.5°.

Anal. Calcd. for $C_7H_{10}NOCl$:C, 52.67; H, 6.32; N, 8.78. Found: C, 52.74; H, 6.41; N, 8.75.

anti-7-Chloronorcamphoroxime was prepared by the method of Alder and co-workers (204) in low yield. Crystallization from 60-70° ligroin gave white crystals, m.p. 113-114° (corr.).

Anal. Calcd. for $C_7H_{10}NOCl$: C, 52.67; H, 6.32; N, 8.78. Found: C, 52.79; H, 6.30; N, 8.82.

pK_a Measurements on Oximes. - For the potentiometric titrations, solutions were prepared by weighing out 0.0021-0.0027 mole of oxime, washing the samples into a 100-ml. volumetric flask with 25 ml. of pure ethanol (distilled from barium oxide) and adding distilled water almost to the mark. The solution was brought to 25.0° in a thermostat and made up to the mark with water. A 10-ml. aliquot was pipetted into the 50-ml., nitrogen-flushed reaction cell followed by a 1-ml. aliquot of 1.000 M potassium chloride and 1 ml. of 0.05 M hydrochloric acid solution. The titrations were carried out with a pH-Stat Recording Titrator (205) made by International Instruments Company, Canyon, California. Carbonate-free 0.9 N sodium hydroxide solution was used as the titrant and a plot of pH versus volume of base added was obtained on the recorder chart. The Leeds and Northrup Catalogue 7664 pH Indicator was standardized against pH 10.00 aqueous buffer before each run and at frequent intervals between consecutive runs in a series. The apparent dissociation constants were taken as the pH at the half-neutralization point, found by calculating the volume of titrant base required to neutralize the added hydrochloric acid and half of the oxime which was present. These $pH_{1/2}$ values could be reproduced within 0.02 pH unit on the same day and within 0.04 pH units on different days. The averaged values are considered reproducible to ± 0.04 pH unit.

For the measurements in water at low ionic strengths, the spectrophotometric method of Judson and Kilpatrick (190) was employed. A Cary Model 11M Recording Spectrophotometer was used for all optical density measurements. The temperature was maintained at 25.0° by means of a circulating system through the cell compartment. Matched 1-cm. cylindrical quartz cells with ground-glass stoppers were used. Carbonate-free 0.01 N sodium hydroxide was prepared by diluting 0.1 N stock solution, which was standardized against potassium acid phthalate. Freshly boiled and cooled distilled water was used in preparing all solutions.

The best commercial grade of phenol was sublimed and transferred from the sublimation tube to a ground-glass stoppered weighing bottle in a dry box. Stock solutions were prepared by quickly weighing out an appropriate amount and making up to the mark in a volumetric flask with water. Various size aliquots of this stock solution were pipetted into a 100-ml. volumetric flask, 10 ml. of 0.1 N sodium hydroxide solution added and the solution made up to the mark. The same concentration of base was used in the blank cell. The variation of molar extinction coefficient with optical density for the phenoxide ion at 287.4 millimicrons was measured and found to be slightly greater than 1% in the range 0.3 to 2.3 (see Appendix).

The molar extinction coefficient of phenol was determined in 0.001 N hydrochloric acid solution and found to be 20.3 l. mole^{-1}cm.$^{-1}$ at 287.4 millimcrons.

The pK_a of phenol at various ionic strengths was determined under the same conditions used for the oxime determinations. A plot of pK_a versus ionic strength is given in the Appendix. In calculating these pK_a values, activity coefficients were approximated by the DeBye-Hückel theory and the dissociation constant of water taken as 1.008×10^{-14} (206).

The procedure of Judson and Kilpatrick (190) was followed in the dissociation constant determinations for the oximes. Stock solutions of the oximes were prepared in concentrations of about 0.004 M. Six solutions were then prepared by pipetting aliquots of the stock solution into 100-ml. volumetric flasks followed by aliquots of the stock phenol solution and 0.01 N sodium hydroxide solution and making up to the mark. Six additional solutions were obtained by diluting the latter solutions 50:50. Blank solutions for the optical density measurements contained the same concentration of base and oxime. The method of calculation is exemplified by the data for anti-7-chloronorcamphoroxime given below, where ØOH is phenol, $\text{Ø}O^-$ is phenoxide ion, RNOH is undissociated oxime and RNO^- is the oxime anion.

pK_a Data for anti-7-Chlornorcamphoroxime

Quantity	Value
Optical density	1.2550
Ext. Coeff.	2571.5
$[\text{ØOH}]_{\text{initial}}$	6.5190×10^{-4}
$[\text{ØO}^-]_{\text{final}}$	4.8675×10^{-4}
$[\text{ØOH}]_{\text{final}}$	1.6515×10^{-4}
$[OH^-]_{\text{initial}}$ (ionic strength)	10.002×10^{-4}
Act. Coeff. (DeBye-Hückel)	0.9636
Act. H^+ (using K_a phenol)	2.6193×10^{-11}
Act. OH^- (from K_w)	3.8484×10^{-4}
$[OH^-]_{\text{final}}$	3.9938×10^{-4}
$[RNO^-]_f + [\text{ØO}^-]_f$	6.0082×10^{-4}
$[RNO^-]_{\text{final}}$	1.1407×10^{-4}
$[RNOH]_{\text{initial}}$	7.5680×10^{-4}
$[RNOH]_{\text{final}}$	6.4273×10^{-4}
Act. RNO^-	1.0092×10^{-4}
K_a	4.48×10^{-12}
pK_a	11.35

Any determination was discarded which gave either of the ratios $[\phi O^-]_{final}/[\phi OH]_{final}$ and $[RNO^-]_{final}/[RNOH]_{final}$ a value less than 0.1 or greater than 10. The pertinent data are given in Tables XL-XLII (Appendix).

Cyclopentadienyltrimethylsilane. - The method of Frisch (193) was used, except that the product isolation was modified. The benzene solution was separated from the inorganic salts by filtration and the filtrate was extracted with ammonium chloride solution. The precipitate was taken up in ammonium chloride solution and extracted with ether. The combined benzene and ether solutions were dried, filtered and the solvents removed through a Vigreux column. Distillation of the residue gave a small forerun, b.p. 39° (20 mm.), n^{25} D 1.4713 and an intermediate fraction, b.p. 39-42.5° (20 mm.), n^{25} D 1.4609. The product was obtained in two fractions, b.p. 42.5-45° (20 mm.), n^{27} D 1.4603, in 28% yield.

The maleic anhydride adduct was recrystallized from ether-ligroin, m.p. 104.8-105.3°; lit., 105° (193).

Ethyl Acrylate Adduct of Cyclopentadienyltrimethylsilane. - In two runs, a total of 48.3 g. (0.349 mole) of cyclopentadienyltrimethylsilane and 35.0 g. (0.349 mole) of freshly distilled ethyl acrylate was boiled under reflux in 70 ml. of benzene overnight. The benzene was removed and the residue distilled through a vacuum-jacketed Vigreux column to give 2.3 g. of forerun, b.p. 87-91° (2 mm.), n^{21} D 1.4702 followed by 69.5 g. (0.292 mole, 83.5%) of product (four fractions), b.p. 91-93° (2 mm.), n^{21} D 1.4680-1.4680.

Anal. Calcd. for $C_{13}H_{22}O_2Si$: C, 65.49; H, 9.30. Found: C, 65.62; H, 9.35.

This material was hydrogenated with difficulty over Adam's catalyst in ethyl acetate solution to give 82% of the saturated ester, b.p. 86-90° (1.3 mm.), n^{25} D 1.4667.

Lithium Aluminum Hydride Reduction of Norcamphoroxime. - The method of Smith and co-workers (209) was followed. To a solution of 3.34 g. (0.088 mole) of lithium aluminum hydride in 55 ml. of tetrahydrofuran (dried over potassium hydroxide, sodium and distilled from lithium aluminum hydride) in a 300-ml., three-necked flask fitted with a stirrer, condenser and dropping funnel was slowly added 5.0 g. (0.040 mole) of norcamphoroxime in 60 ml. of tetrahydrofuran. After all of the oxime solution had been added, the solution was stirred and boiled under reflux for 1 hr. Water was carefully added to decompose the excess hydride, followed by 100 ml. of 20% Rochelle's salt solution and 20 ml. of 10% sodium hydroxide. After continuous extraction of the slurry for 2 days, the ether was washed to remove the tetrahydrofuran and dried over potassium carbonate. Removal of the ether and sublimation of the residue gave 2.35 g. (0.0212 mole, 53%) of endo-norbornylamine, m.p. 75-80° (softened at 67°); lit., m.p. 53-59° (softened at 43°) (29). The acetyl derivative had m.p. 122.5-124.5°; lit., m.p. 124° (208); 125-126° (29). The infrared spectrum of the amine was indistinguishable from that of either exo- or endo-norbornylamine.

Hydrogen-Raney Nickel Reduction of Norcamphoroxime. - To a pre-reduced suspension of 0.25 g. of Raney nickel catalyst in 20 ml. of absolute ethanol was added 0.4799 g. (0.0039 mole) of norcamphoroxime. Hydrogenation in a semimicro apparatus resulted in the absorption of 44.8% of the theoretical amount of hydrogen in 6.5 hrs. The catalyst was filtered off, 1 ml. of concentrated hydrochloric acid was added and the solvent was removed on the aspirator. Water was added to the white residue and the milky solution extracted with ether. After basification, the aqueous phase was extracted with ether (white precipitate dissolves), dried over potassium carbonate, filtered, evaporated to about 5 ml. and 2 ml. of acetic anhydride in 3 ml. of ether was added. After 2 hrs. of reflux, the ether solution was washed with saturated sodium bicarbonate solution, dried over potassium carbonate, filtered, evaporated to about 1 ml. and pentane was added. Cooling in ice gave white needles, m.p. 120-121°.

Hydrogentation of Norcamphoroxime Under Acidic Conditions. The method of Skita and Faust (198) was used. To a pre-reduced suspenion of 0.060 g. of Adam's catalyst in 10 ml. of acetic acid and 6 ml. of water containing 1 ml. of a 10% chloroplatinic acid solution and 1.5 ml. of 10% gum arabic solution was added 0.595 g. of norcamphoroxime. Hydrogenation in semimicro apparatus resulted in the absorption of 48% of the theoretical hydrogen in 21 hrs. After partial neutralization (pH 6) and steam distillation the reaction mixture was made strongly basic and 50 ml. of steam distillate was collected. The steam distillate was saturated with sodium bicarbonate, extracted with two 35-ml. portions of ether and dried over potassium carbonate. The volume of the ether solution was reduced to about 5 ml. and 1.2 ml. of acetic anhydride in 3 ml. of ether was added and the solution was boiled under reflux for 1.5 hrs. After a thorough washing with saturated sodium bicarbonate solution, the ether solution was dried over potassium carbonate. The volume was then reduced and pentane added. The product crystallized as white plates, m.p. 126-128°. A second crop had m.p. 126.5-128°, indicating that the reduction gave entirely endo-norbornylamine.

Hydrogenation of d-Camphoroxime Over Raney Nickel in Acetic Acid. - To a solution of 0.672 g. of oxime in 30 ml. of glacial acetic acid was added 2 g. of Raney nickel. The mixture was hydrogenated in a semimicro apparatus, the hydrogen uptake being uncertain due to the nickel-acetic acid reaction. After hydrogenation overnight, the mixture was made strongly basic and steam distilled. The white solid in the condenser and in the 15 ml. of steam distillate was taken up in ether and dried over potassium carbonate. Evaporation of the ether and sublimation of the residue gave 0.454 g. (74%) of sublimate, m.p. 165-176.5°, indicating a mixture of bornylamine (m.p. 163°) and neobornylamine (m.p. 186°) (208).

Attempted Hydrogenation of syn-7-Chloronorcamphoroxime Under Acidic Conditions. - The method of Hartung (209) was employed. A solution of 9.7 g. of syn-7-chloronorcamphoroxime in 150 ml. of absolute alcohol containing 6.7 g. of hydrogen chloride absorbed a negligible amount of hydrogen after shaking for 3 hrs. over 0.5 g. of 10% palladium-on-carbon catalyst. A small amount of absorption took place after the addition of 0.14 g. of Adam's catalyst, but only the starting oxime was recovered.

Hydrogenation of syn-7-Chloronorcamphoroxime Over Adam's Catalyst in Acetic Acid. - A suspension of 0.2 g. of Adam's catalyst in 30 ml. of glacial acetic acid containing 4.0 g. (0.0251 mole) of syn-7-chloronorcamphoroxime absorbed the theoretical amount of hydrogen after 23 hrs. shaking under 2 atm. of hydrogen. The mixture was filtered and 1 ml. of concentrated hydrochloric acid was added. The solvent was removed at reduced pressure and the residual hydrochloride was taken up in ethanol and precipitated with ether to give 3.2 g. (70%) of amine hydrochloride, m.p. 248-254° (dec.) after sublimation. Recrystallization from acetone gave white needles, m.p. 270.3-272.4 (dec.).

Anal. Calcd. for $C_7H_{13}NCl_2$: C, 46.17; H, 7.20; N, 7.69. Found: C, 54.13; H, 7.16; N, 5.25.

The molecular weight was found to be 166.5 (cryoscopic in water). Both the analysis and molecular weight indicate that hydrogenolysis of the carbon-chlorine bond had occurred.

A portion of the above amine hydrochloride mixture (2.7 g.) was treated with an excess of 10% sodium hydroxide solution. The resulting solution was extracted with ether and the combined extracts were dried over magnesium sulfate. Removal of the ether gave 1.6 g. of a tan liquid which was distilled through a Holzman column (85) to give 0.153 g. of an initial fraction, b.p. 112-115° (40.8 mm.), n^{25} D 1.5087, 0.296 g. of an intermediate fraction, b.p. 115-117° (40.8 mm.), n^{25} D 1.5095 and 0.067 g. of a final fraction, b.p. 118° (38.3 mm.). These materials turned to white solids on exposure to air. The latter fraction was submitted for analysis.

Anal. Calcd. for $C_7H_{12}NCl$: C, 57.73; H, 8.30. Found: C, 56.03; H, 8.54.

Lithium Aluminum Hydride Reduction of syn-7-Chloronorcamphoroxime. - To a stirred solution of 5.0 g. (0.125 mole) of lithium aluminum hydride in 100 ml. of dry tetrahydrofuran was added 9.6 g. (0.0766 mole) of syn-7-chloronorcamphoroxime in 50 ml. of tetrahydrofuran over a period of 20 min. The solution was boiled under reflux for 15 min. and then allowed to cool slowly to room temperature. Water was cautiously added to decompose all excess hydride and the white suspension was allowed to stand overnight. The addition of 80 ml. of 7.42 N sulfuric acid resulted in the separation of a second phase. Sodium chloride and additional water were added and the layers were separated. The organic phase was washed with 3 N sulfuric acid saturated with sodium chloride and the combined acidic extracts were made basic and steam distilled. Two hundred ml. of steam distillate were collected, saturated with sodium chloride and extracted with three 75-ml. portions of ether. The combined extracts were dried over potassium carbonate, filtered and the ether evaporated. Distillation of the residue through a Holzman column (85) gave 0.51 g. of forerun, b.p. 61-103° (22.6 mm.), and 1.88 g. (21.5%) of amine, b.p. 84-87° (8.3 mm.), m.p. 41.4-43.0°. The amine gave a positive Beilstein test for chlorine, was very hygroscopic and was soluble in water. The infrared spectrum checked well for a primary amine. Attempted recrystallization from pentane failed and the material was characterized via several derivatives.

The α-naphthylthiourea derivative required seven recrystallizations from methanol-water to give white needles, m.p. 157-159°.

Anal. Calcd. for $C_{18}H_{19}N_2ClS$: C, 65.34; H, 5.79. Found: C, 65.93; H, 5.87.

The benzamide derivative was recrystallized three times from methanol-water to give crystals, m.p. 173.5-178°. Recrystallization from pure water gave white needles, m.p. 183.5-184.5°.

Anal. Calcd. for $C_{14}H_{16}NOCl$: C, 67.33; H, 6.46. Found: C, 67.29; H, 6.51.

Acetyl Derivative of syn-7-Chloronorbornylamine. - An ether solution of the amine was boiled under reflux with acetic anhydride for 2 hrs. The ether solution was washed five times with sodium bicarbonate and then dried over potassium carbonate. Filtration and evaporation of the ether gave white crystals, m.p. 90-108°. Repeated crystallizations from pentane-ether and water failed to substantially improve the melting point. A total of five recrystallizations from 60-70° ligroin gave white rhombhedra, m.p. 90.5-114°. The infrared spectrum was consistent with expectation for an acetamide derivative.

Anal. Calcd. for $C_9H_{14}NOCl$: C, 57.60; H, 7.52. Found: C, 57.89; H, 7.46.

APPENDIX

TABLE XXI

Solvolysis of anti-7-Chloronorbornene in 80% Ethanol at 50.18 ± 0.04°.

a = Initial concentration = 5.49×10^{-3} M

t, hrs.	"pH"	-log(a-x)
0.000	5.03	2.263
0.083	4.04	2.274
0.167	3.71	2.289
0.250	3.56	2.301
0.333	3.42	2.317
0.417	3.34	2.329
0.500	3.265	2.344
0.600	3.20	2.358
0.725	3.13	2.376
0.833	3.08	2.391
1.083	3.015	2.415
1.167	2.975	2.432
1.333	2.94	2.450
1.667	2.86	2.498
2.167	2.825	2.527
2.500	2.77	2.586
3.083	2.715	2.665
3.500	2.70	2.691

$k_1 = 0.313 \pm 0.012$ hr.$^{-1}$ ($8.7 \pm 0.3 \times 10^{-5}$ sec.$^{-1}$)

TABLE XXII

Solvolysis of *anti*-7-Chloronorbornene in 80% Ethanol at 61.23±0.07°.

$a = 4.83 \times 10^{-3}$ *M*

t, hrs.	"ph"	-log[a-x]
0.000	4.865	2.320
0.050	4.23	2.331
0.100	3.66	2.356
0.150	3.46	2.379
0.200	3.275	2.414
0.250	3.21	2.430
0.300	3.155	2.447
0.350	3.09	2.470
0.400	3.035	2.492
0.450	2.985	2.519
0.500	2.95	2.539
0.567	2.915	2.563
0.633	2.905	2.569
0.700	2.86	2.608
0.817	2.81	2.665
0.908	2.79	2.693
1.000	2.77	2.723
1.175	2.72	2.822
1.350	2.69	2.901

$\underline{k}_1 = 0.973 \pm 0.064$ hr.$^{-1}$ ($2.7 \pm 0.2 \times 10^{-4}$ sec.$^{-1}$)

TABLE XXIII

Solvolysis of exo-Norbornyl Chloride in 80% Ethanol at 99.66±0.06°.

$a = 5.83 \times 10^{-3}$ M

t, hrs.	"pH"	-log[a-x]
0.000	---	2.234
0.050	7.4 (drift)	---
0.108	4.39	2.241
0.167	3.825	2.255
0.250	3.29	2.307
0.350	3.21	2.323
0.417	3.10	2.350
0.517	2.98	2.392
0.608	2.95	2.405
0.750	2.87	2.448
0.925	2.82	2.484
1.083	2.80	2.503
1.250	2.715	2.601
1.417	2.695	2.632
1.584	2.685	2.646
1.833	2.65	2.712
2.083	2.63	2.759
2.333	2.62	2.784
2.500	2.615	2.813
2.667	2.60	2.846

$k_1 = 0.631 \pm 0.020$ hr.$^{-1}$ ($1.75 \pm 0.06 \times 10^{-4}$ sec.$^{-1}$)

TABLE XXIV

Solvolysis of *anti*-7-Chloronorbornene in 50% Ethanol at 24.90±0.02°.

$a = 5.12 \times 10^{-3}$ *M*

t, min.	"pH"	$-\log(a-x)$
0.00	---	2.291
2.00	4.265	2.300
3.55	3.935	2.308
5.12	3.744	2.318
5.98	3.674	2.324
7.07	3.599	2.331
8.10	3.529	2.340
9.25	3.479	2.347
10.00	3.439	2.352
11.23	3.94	2.357
12.52	3.334	2.366
13.58	3.308	2.370
15.35	3.263	2.378
17.05	3.213	2.389
18.05	3.183	2.398
19.02	3.168	2.403
21.05	3.123	2.419
23.08	3.097	2.432
24.12	3.067	2.447
27.28	3.022	2.476
30.17	3.002	2.487
34.00	2.961	2.511
37.00	2.931	2.531
39.00	2.906	2.550
43.00	2.900	2.554
45.00	2.885	2.566
50.00	2.869	2.581
56.00	2.824	2.624
60.00	2.813	2.636

$\underline{k}_1 = 2.3 \pm 0.2 \times 10^{-4}$ sec.$^{-1}$

TABLE XXV

Solvolysis of anti-7-Chloronorbornene in 50% Ethanol at 50.18±0.04°.

$a = 3.85 \times 10^{-3}$ M

t, min.	"pH"	-log(a-x)
0.00	---	2.414
1.27	3.305	2.524
1.47	3.230	2.544
1.93	3.126	2.594
2.60	3.016	2.690
3.08	2.961	2.741
3.53	2.921	2.790
4.15	2.866	2.871
4.75	2.832	2.936
5.43	2.812	2.986
5.88	2.792	3.046
6.50	2.777	3.095
7.27	2.767	3.135
8.15	2.748	3.222
9.15	2.733	3.313

$k_1 = 4.0 \pm 0.1 \times 10^{-3}$ sec.$^{-1}$

TABLE XXVI

Solvolysis of syn-7-Chloronorbornene in 50% Ethanol at 99.66±0.06°.

$a = 5.71 \times 10^{-3}$ M

t, hrs.	"pH"	-log(a-x)
0.00	---	2.244
0.200	3.420	2.296
0.267	3.282	2.317
0.339	3.165	2.342
0.400	3.158	2.344
0.500	3.125	2.353
0.700	3.045	2.381
0.933	3.015	2.394
1.100	3.025	2.388
1.333	3.015	2.394
1.683	3.035	2.385
2.658	3.040	2.383
5.833	3.155	2.345
10.22	3.120	2.357
11.00	3.135	2.353
11.57	3.180	2.341
11.67	3.215	2.333
23.33	3.235	2.329
24.78	3.265	2.323
30.88	3.390	2.302
50.53	3.525	2.285

$k_1 = 0.002 \pm 0.005$ hr.$^{-1}$ after correction for the hydrochloric acid-ethanol reaction. $k_{1(max.)} = 2 \times 10^{-6}$ sec.$^{-1}$

TABLE XXVII

Solvolysis of 7-Chloronorbornane in 50% Ethanol at 99.66 ± 0.06°.

$a = 5.76 \times 10^{-3}$ M

t, hrs.	"pH"	-log(a-x)
0.000	---	2.240
0.275	3.419	2.292
0.616	3.179	2.334
1.233	3.110	2.353
1.567	3.109	2.353
2.083	3.115	2.352
3.117	3.124	2.349
4.150	3.118	2.351
5.267	3.134	2.346
6.075	3.165	2.338
8.067	3.150	2.342
9.100	3.201	2.328
10.06	3.160	2.340
10.05	3.240	2.320
12.17	3.218	2.325
12.17	3.273	2.315
14.23	3.155	2.341
24.00	3.425	2.291

$k_1 = -0.0005 \pm 0.004$ hr.$^{-1}$ after correction for the hydrochloric acid-ethanol reaction. $k_{1\,(max)} = 1 \times 10^{-6}$ sec.$^{-1}$

TABLE XXVIII

Solvolysis of Nortricyclyl Chloride in 50% Ethanol at 99.66 ± 0.06°.

$a = 5.23 \times 10^{-3}$ M

t, hrs.	"pH"	-log(a-x)
0.000	---	2.274
0.050	4.42	2.280
0.100	3.33	2.343
0.150	3.01	2.439
0.200	2.845	2.551
0.250	2.79	2.610
0.317	2.735	2.696
0.433	2.66	2.865
0.517	2.605	2.974
0.600	2.62	2.995
0.867	2.59	3.153
1.883	2.57	3.267

$\underline{k}_1 = 2.91 \pm 0.21$ hr.$^{-1}$ ($8.1 \pm 0.6 \times 10^{-4}$ sec.$^{-1}$)

Another determination ($a = 3.73 \times 10^{-3}$ M) gave a value of $\underline{k}_1 = 3.01 \pm 0.13$ hr.$^{-1}$ ($8.3 \pm 0.4 \times 10^{-4}$ sec.$^{-1}$).

TABLE XXIX

Reaction of Hydrochloric Acid and 50% Ethanol at 99.66 ± 0.06°.

$a = 0.986 \times 10^{-3}$ M

t, hrs.	"pH"	$-\log(H^+)$
0.000	3.24	3.015
0.542	3.24	3.010
1.317	3.28	3.043
2.000	3.275	3.045
3.083	3.310	3.081
4.067	3.315	3.085
5.333	3.33	3.102
6.167	3.33	3.102
7.983	3.32	3.092
9.217	3.415	3.187
10.267	3.32	3.077
10.267	3.42	3.158
12.30	3.41	3.150
12.30	3.36	3.109
23.87	3.58	3.348
30.02	3.575	3.343

TABLE XXX

Reaction of Hydrochloric Acid and 50% Ethanol at 99.66 ± 0.06°.

$a = 1.48 \times 10^{-3}$ M

t, hrs.	"pH"	$-\log[H^+]$
0.000	3.065	2.831
0.467	3.117	2.886
1.133	3.126	2.896
1.883	3.173	2.947
2.966	3.185	2.958
3.966	3.170	2.942
5.033	3.215	2.988
5.966	3.205	2.979
7.900	3.275	3.049
8.983	3.390	3.161
9.900	3.270	3.036
9.900	3.325	3.081
11.950	3.373	3.120
11.950	3.523	3.252
14.13	3.26	3.028
23.60	3.325	3.098
29.87	3.735	3.500

TABLE XXXI

Reaction of Hydrochloric Acid and 50% Ethanol at 99.66 ± 0.06°.

$a = 1.62 \times 10^{-3}$ M

t, hrs.	"pH"	$-\log[H^+]$
0.000	3.020	2.790
0.500	3.120	2.882
1.267	3.165	2.925
1.933	3.145	2.906
13.62	3.615	3.369
15.10	3.715	3.466
21.18	4.035	3.775

TABLE XXXII

Solvolysis of a Mixture of *syn*-7-Chloro-*exo*- and *endo*-norbornyl *p*-Toluenesulfonates in Acetic Acid Containing 0.0349 *M* Potassium Acetate at 78.2 ± 0.1°.

$a = 0.03312$ *M*

t, min.	$-\log[C\ \ -C]^a$	10^2[*endo*]	10^2[*exo*]
0	1.4800	1.574	1.738
16	1.5041	1.571	1.561
30	1.5172	1.569	1.470
45	1.5310	1.566	1.378
75	1.5566	1.561	1.215
106.5	1.5824	1.556	1.060
165	1.6228	1.546	0.837
287	1.6884	1.526	0.523
400	1.7286	1.507	0.361
720	1.8046	1.456	0.112
810	1.8163	1.442	0.085
900	1.8269	1.428	0.062
990	1.8373	1.414	0.041
1113	1.8447	1.395	---
1142	1.8506	1.391	---
1350	1.8667	1.360	---
1440	1.8702	1.346	---
1530	1.8757	1.333	---
2203	1.9067	1.239	---

(a) See reference 84.

$k_{endo} = 1.085 \pm 0.006 \times 10^{-4}$ min.$^{-1}$ ($1.81 \pm 0.01 \times 10^{-6}$ sec.$^{-1}$)

$k_{exo} = 3.69 \pm 0.24 \times 10^{-3}$ min.$^{-1}$ ($6.1 \pm 0.4 \times 10^{-5}$ sec.$^{-1}$)

TABLE XXXIII

Reaction of Bromine with 75% Aqueous Acetic Acid Containing 0.238 M Sodium Acetate at 35.0 ± 0.1°.

$B_o = 8.92 \times 10^{-3}$ M

t, hrs.	Vol. of 0.02001 N[a] $Na_2S_2O_3$, ml.	10^3B, M	-log B
0.0	8.92	8.924	2.0494
3.2	8.76	8.764	2.0573
50.1	8.46	8.463	2.0725
98.4	8.08	8.083	2.0922
146.3	7.725	7.728	2.1121
192.6	7.355	7.358	2.1332

(a) Required for 10-ml. aliquots.

$k_2 = 9.56 \pm 0.20 \times 10^{-4}$ hr.$^{-1}$

TABLE XXXIV

Bromination of Norcamphor in 75% Aqueous Acetic Acid Containing 0.238 $\underline{M}$ Sodium Acetate at 35.0 ± 0.1°.

$K_o = 0.0273\ \underline{M}^a$

t, hrs.	Vol. 0.02001 $\underline{N}$ $Na_2S_2O_3$, ml.	$-\log [K_o - B_o + B]$
0.00	11.14	1.5624
0.33	11.05	1.5639
1.02	10.99	1.5648
3.70	10.93	1.5658
50.60	10.02	1.5806
99.62	9.09	1.5962
147.25	8.31	1.6098
193.65	7.38	1.6266

$\underline{c} = 7.41 \pm 0.15 \times 10^{-4}$ hr.$^{-1}$ [a]

$\underline{k}_1 = 3.54 \pm 0.25 \times 10^{-4}$ hr.$^{-1}$

(a) Evaluated by a least squares fit.

TABLE XXXV

Bromination of syn-7-Chloronorcamphor in 75% Aqueous Acetic Acid Containing 0.238 M Sodium Acetate at 35.0 ± 0.1°.

$K_o = 0.0173$ M[a]

t, hrs.	Vol. 0.00754 N $Na_2S_2O_3$, ml.	$- \log [K_o - B_o + B]$
0.00	8.155	1.7542
2.04	7.80	1.7610
18.95	7.51	1.7665
41.48	7.29	1.7708
69.97	7.035	1.7757
91.80	6.79	1.7805
116.38	6.54	1.7855
141.88	6.32	1.7899
190.9	5.885	1.7988

$c = 4.36 \pm 0.09 \times 10^{-4}$ hr.$^{-1}$ [a]

$k_1 = 1.15 \pm 0.17 \times 10^{-4}$ hr.$^{-1}$

(a) Evaluated by a least squares fit.

TABLE XXXV

Bromination of anti-7-Chloronorcamphor in 75% Aqueous Acetic Acid Containing 0.238 M Sodium Acetate at 35.0 ± 0.1°.

$K_o = 0.0174\ \underline{M}$ [a]

t, hrs.	Vol. 0.00754 N $Na_2S_2O_3$, ml.	$-\log[K_o - B_o + B]$
0.00	6.95	1.7491
3.01	6.505	1.7572
22.21	6.035	1.7662
50.81	5.61	1.7744
72.58	4.81	1.7903[b]
97.14	4.495	1.7967[b]
122.62	4.105	1.8048[b]
171.6	3.445	1.8188[b]

$\underline{c} = 6.78 \pm 0.14 \times 10^{-4}$ hr.$^{-1}$ [a]

$\underline{k}_1 = 4.14 \pm 0.21 \times 10^{-4}$ hr.$^{-1}$

(a) Evaluated by a least squares fit. (b) Due to the loss of some bromine by volatilization between 50 and 72 hrs., these values are lowered by a constant amount from the least squares line.

TABLE XXXVII

Bromination of exo-3-Bromonorcamphor in 75% Aqueous Acetic Acid Containing 0.238 M Sodium Acetate at 35.0 ± 0.1°.

$K_o = 0.0181\ \underline{M}$ [a]

t, hrs.	Vol. 0.00754 N $Na_2S_2O_3$, ml.	$-\log[K_o - B_o + B]$
0.00	7.04	1.7373
2.05	6.815	1.7414
19.15	6.56	1.7462
41.95	6.36	1.7498
68.92	6.12	1.7542
92.30	5.915	1.7580
116.71	5.715	1.7618
142.37	5.485	1.7662
191.4	5.115	1.7733

$\underline{c} = 3.65 \pm 0.08 \times 10^{-4}$ hr.$^{-1}$ [a]

$\underline{k}_1 = 9.7 \pm 1.4 \times 10^{-5}$ hr.$^{-1}$

(a) Evaluated by a least squares fit.

TABLE XXXVIII

Bromination of d-Camphor in 75% Aqueous Acetic Acid Containing 0.238 M Sodium Acetate at 35.0 ± 0.1°.

$K_o = 0.0217$ [a]

t, hrs.	Vol. 0.0754 N $Na_2S_2O_3$, ml.	$-\log[K_o - B_o + B]$
0.00	7.415	1.6474
42.42	6.165	1.6660
69.50	5.915	1.6698
92.90	5.74	1.6725
117.29	5.61	1.6745
192.0	5.18	1.6812

$c = 2.10 \pm 0.04 \times 10^{-4}$ hr.$^{-1}$ [a]

$k_1 = 4.5 \pm 99 \times 10^{-7}$ hr.$^{-1}$

$k_{1\,(max)} = 1 \times 10^{-5}$ hr.$^{-1}$

(a) Evaluated by a least squares fit.

TABLE XXXIX

Bromination of endo-3-Bromo-d-camphor in 75% Aqueous Acetic Acid Containing 0.238 M Sodium Acetate at 35.0 ± 0.1°.

$K_o = 0.0161$ M [a]

t, hrs.	Vol. of 0.00754 N $Na_2S_2O_3$, ml.	$-\log[K_o - B_o + B]$
0.00	10.245	1.7886
1.98	9.95	1.7945
19.57	9.170	--
42.07	9.415	1.8055
69.10	9.105	1.8122
92.44	8.82	1.8182
116.93	8.48	1.8257
191.6	7.54	1.8468

$c = 6.34 \pm 0.13 \times 10^{-4}$ hr.$^{-1}$ [a]

$k_1 = 1.86 \pm 0.24 \times 10^{-4}$ hr.$^{-1}$

(a) Evaluated by a least squares fit.

TABLE XL

Molar Extinction Coefficient of the Phenoxide Ion in 0.01 N Sodium Hydroxide at 287.4 Millimicrons, 25°.

Optical Density	ϵ, $l.mol.^{-1}cm.^{-1}$
0.332	2548
0.841	2581
1.516	2566
2.270	2561

TABLE XLI

The Dissociation Constant of Phenol as a Function of Ionic Strength in Aqueous Solution at 25°.

Ionic Strength x 10^4	K_a x 10^{11} [a]
5.00	6.21
7.50	6.70
10.00	7.44
15.00	8.81
20.00	10.38
25.00	12.02

(a) Calculated using activity coefficients as approximated by the Debye-Hückel theory (190).

TABLE XLII

Spectrophotometrically Determined Acid Dissociation Constants of Norcamphoroxime and *syn*- and *anti*-7-Chloronorcamphoroxime at 25°.

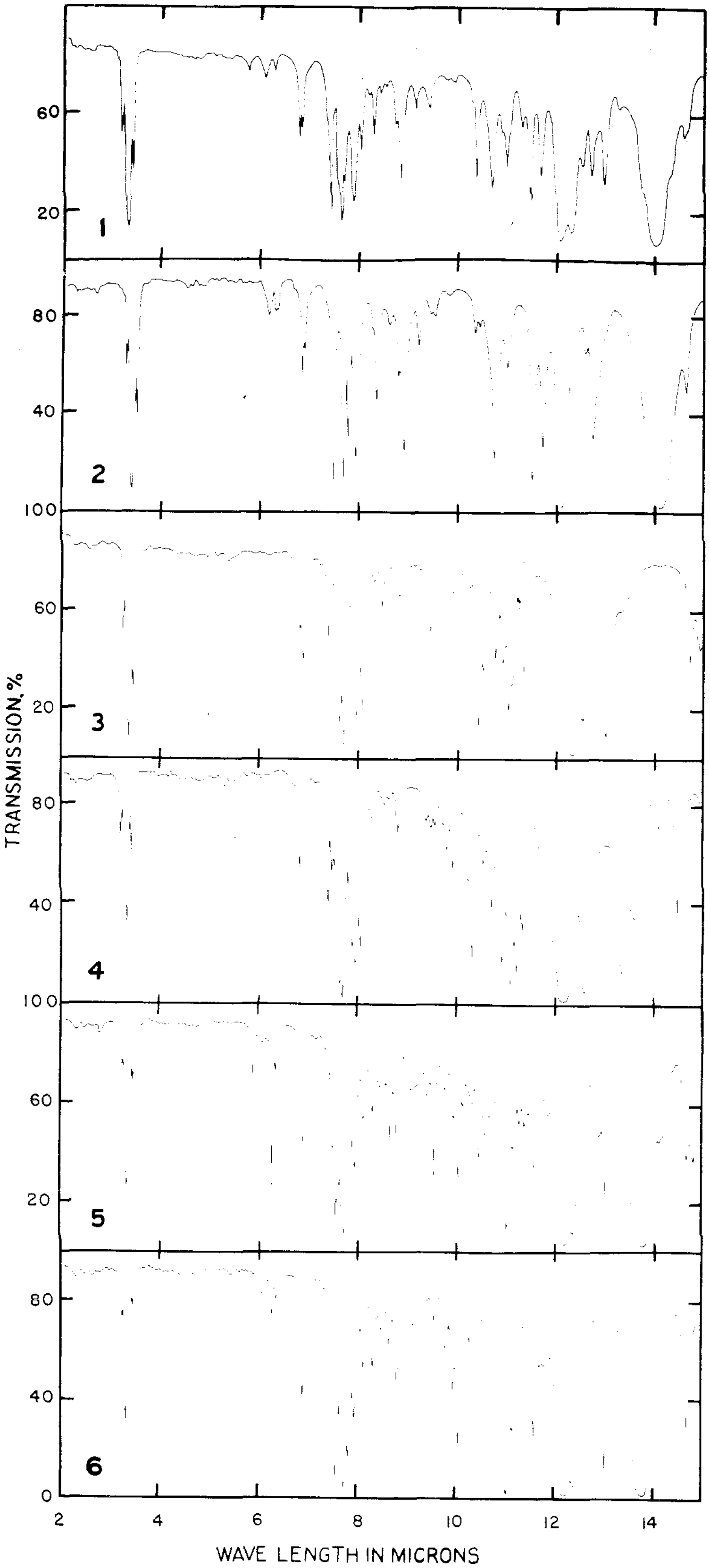
Oxime	Ionic Strength × 10^4	pK_a
Norcamphoroxime	0.00	10.9 ± 0.2[a]
	5.00	11.1
	5.00	11.2
	7.50	10.8
	7.50	10.9
	7.50	11.5
	10.00	11.4
	15.00	11.4
	15.00	11.6
syn-7-Chloronorcamphoroxime	0.00	10.8 ± 0.2[a]
	5.00	10.8
	5.00	11.0
	7.50	11.0
	7.50	11.0
	7.50	11.2
	10.00	11.4
	15.00	11.5
	15.00	11.5
	17.55	11.3
anti-7-Chloro norcamphoroxime	0.00	9.8 ± 0.3[a]
	5.00	10.2
	5.00	10.2
	5.00	10.3
	7.50	10.5
	7.50	10.6
	7.50	10.7
	10.00	11.1
	10.00	11.3
	10.00	11.4
	15.00	11.1
	15.00	11.4
	15.00	11.5

(a) Evaluated by a least squares extrapolation.

Plate A

Curve	Compound
1	*syn*-7-Chloronorbornene from the pyrolysis of *syn*-7-chloro-*exo*-norbornyl β-naphthoate.
2	*syn*-7-Chloronorbornene from the potassium *t*-butoxide dehydrochlorination of *syn*-7-*exo*-2-dichloronorbornane.
3	Nortricyclyl chloride.
4	Dichloronortricyclene product from the chlorination of *endo*-dehydronorbornyl chloride.
5	First fraction of the potassium t-butoxide dehydrochlorination product of 2,5,7-trichloronorbornane.
6	Fifth fraction of the potassium *t*-butoxide dehydrochlorination product of 2,5,7-trichloronorbornane.

The infrared spectra were obtained with a model 21 Perkin-Elmer double beam recording spectrophotometer, using pure liquid samples in a 0.0213 mm. NaCl cell.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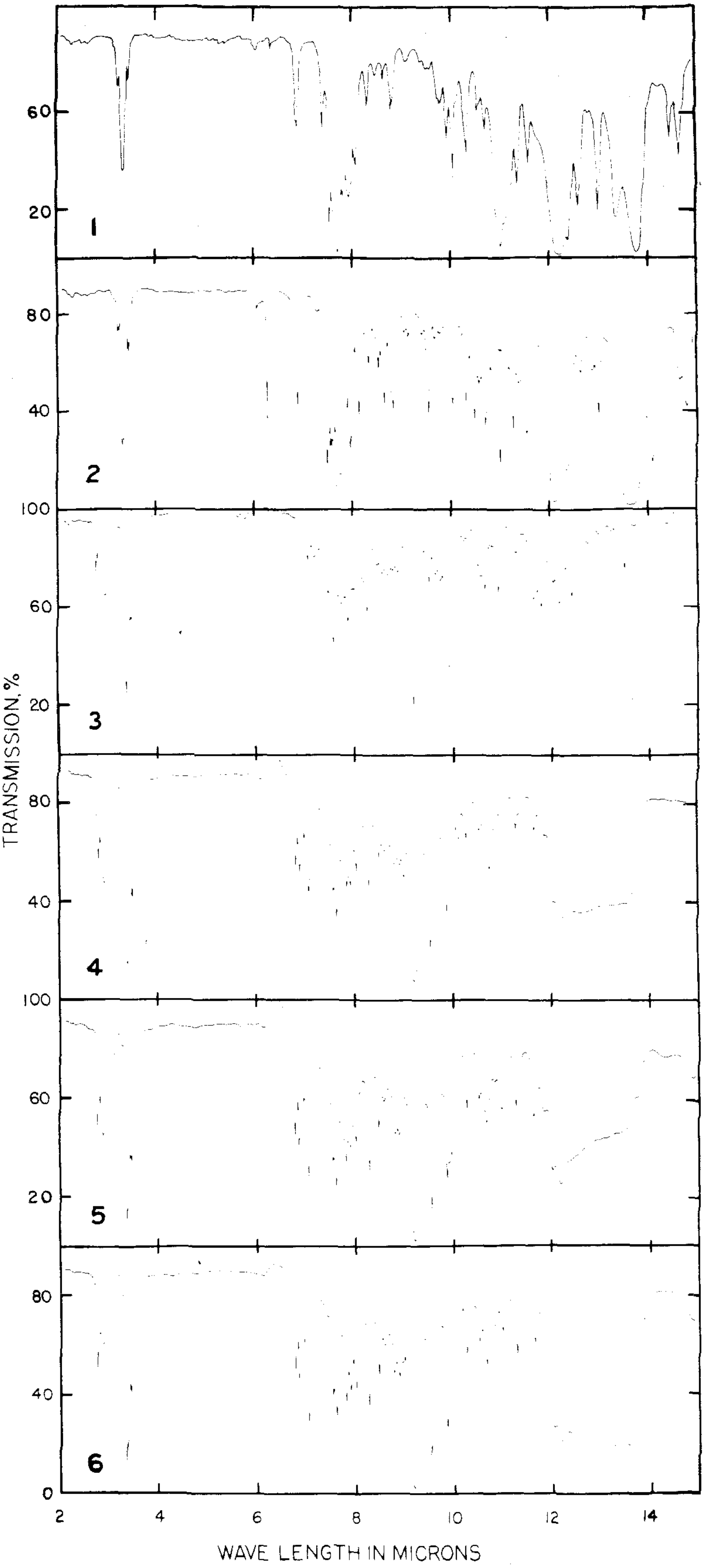
WAVE LENGTH IN MICRONS

PLATE A

Plate B

Curve	Compound
1	Product from the chlorination of norbornadiene, pure liquid, 0.0213 mm. NaCl cell.
2	Product from the lithium diethylamide dehydrochlorination of 2,5,7-trichloronorbornane, pure liquid, 0.0213 mm. NaCl cell.
3	*anti*-7-Chloro-*exo*-norborneol, carbon disulfide solution, 0.1 mm. NaCl cell.
4	Product from the lithium aluminum hydride reduction of *anti*-7-chloronorcamphor, carbon tetrachloride solution, 0.1 mm. NaCl cell.
5	*syn*-7-Chloro-*exo*-norborneol, carbon tetrachloride solution, 0.1 mm. NaCl cell.
6	Product from the lithium aluminum hydride reduction of syn-7-chloronorcamphor, carbon tetrachloride solution,

The infrared spectra were obtained with a model 21 Perkin-Elmer double beam recording spectrophotometer.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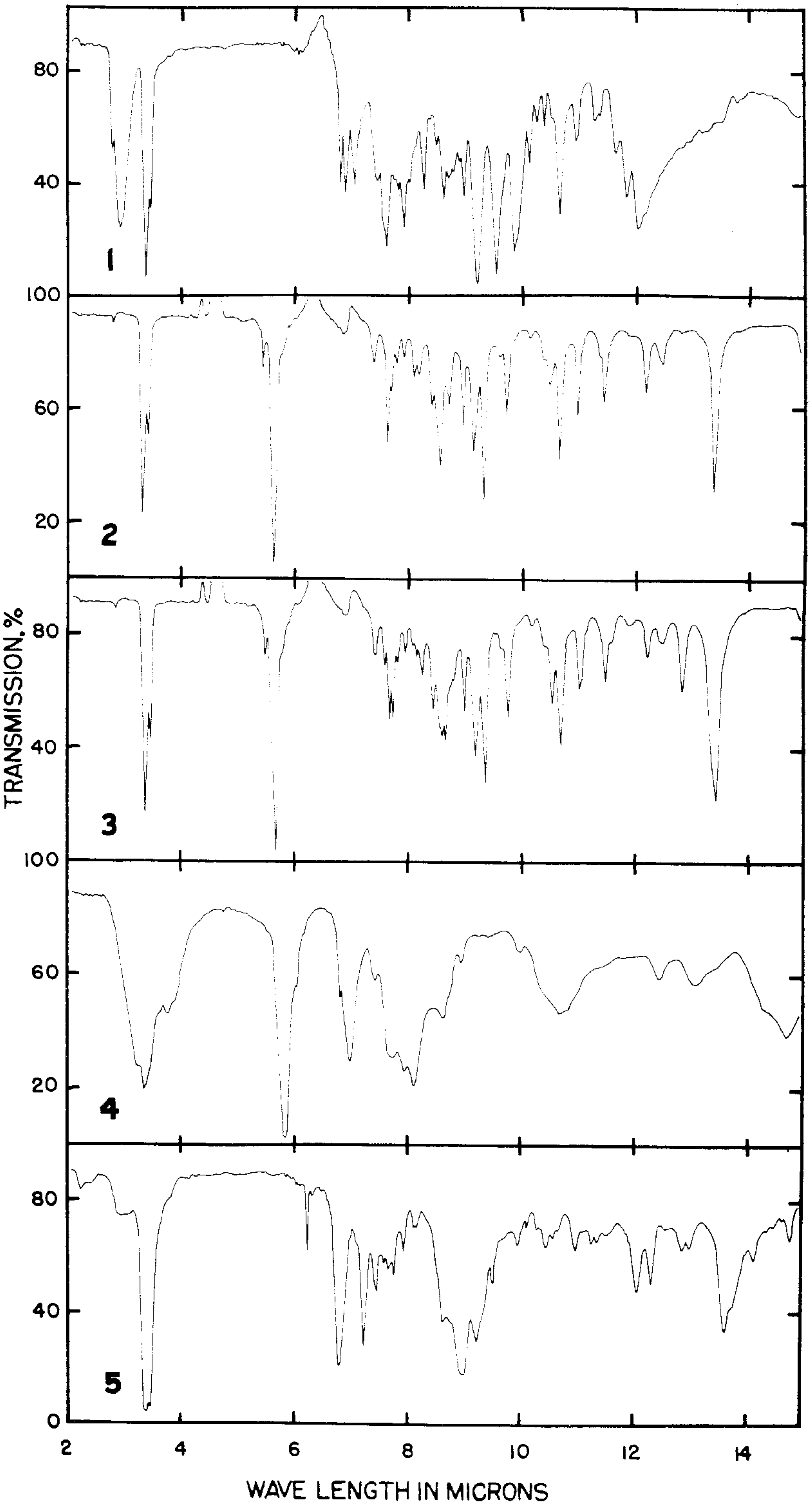
WAVE LENGTH IN MICRONS

PLATE B

Plate C

Curve	Compound
1	Product from the aluminum isopropoxide isomerization of *syn*-7-chloro-*exo*-norborneol, carbon tetrachloride solution, 0.1 mm. NaCl cell.
2	*exo*-3-Bromonorcamphor, carbon disulfide solution, 0.1 mm. NaCl cell.
3	Product from the sodium ethoxide-catalyzed isomerization of *exo*-3-bromonorcamphor, carbon disulfide solution, 0.1 mm. NaCl cell.
4	Carboxylic acid product from the sodium hydrobromite bromination of norcamphor, pure oil pressed between two NaCl plates.
5	Low boiling component from the lithium diethylamide dehydrochlorination of 2,5,7-trichloronorbornane, pure liquid, 0.0213 mm. cell.

The infrared spectra were obtained with a model 21 Perkin-Elmer double beam recording spectrophotometer.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WAVE LENGTH IN MICRONS

PLATE C

Plate D

Curve	Compound
1	Norbornene, carbon tetrachloride solution.
2	*syn*-7-Chloronorbornene from the potassium *t*-butoxide dehydrochlorination of *syn*-7-*exo*-2-dichloronorbornane, pure liquid.
3	Dichloronortricyclene product from the chlorination of *endo*-dehydronorbornyl chloride, pure liquid.
4	First fraction from the potassium *t*-butoxide dehydrochlorination of 2,5,7-trichloronorbornane, pure liquid.
5	Fifth fraction from potassium *t*-butoxide dehydrochlorination of 2,5,7-trichloronorbornane, pure liquid.
6	Dichloride product from the lithium diethylamide dehydrochlorination of 2,5,7-trichloronorbornane, pure liquid.
7	Norcamphor, carbon tetrachloride solution.
8	*exo*-3-Bromonorcamphor, pure liquid
9	Isomerized *exo*-3-bromonorcamphor, pure liquid.

The NMR spectra were obtained with a Varian Model V-4300 NMR Spectrometer at a field of about 9411 gauss and a fixed radio frequency of 40 megacycles/sec. The samples were held in spinning 5-mm. glass tubes. The distance between markers is equivalent to 100 cycles/sec. For spectra 1-6, the marker to the left designates the relative position of the benzene resonance.

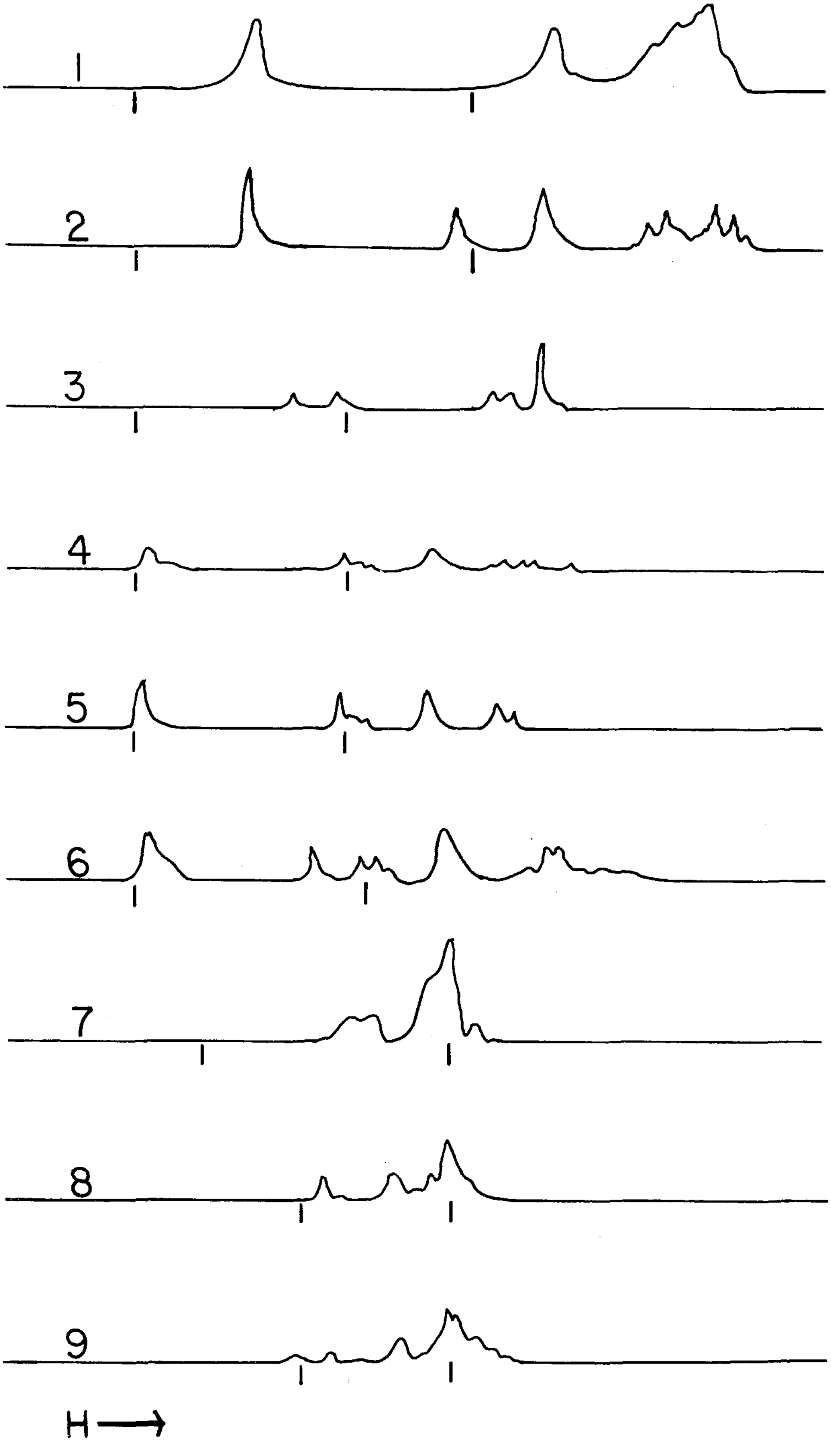

PLATE D

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PROPOSITIONS

1. The recent results of Bartlett (1) on the solvolytic reactivity of _exo_- and _endo_-2-chloro-1,4-endoxycyclohexanes are adequately accounted for by assuming oxygen participation in the ionization of the _exo_-2-chloro isomer.

2. In order to evaluate the relative reactivities of _exo_- and _endo_-hydrogen in the norbornane system to attack by base, it is proposed that the kinetic method of Stone and co-workers (2) be applied to _exo_- and _endo_-2-nitronorbornane.

3. The allylic rearrangement of 1,1,1-trichloro-2-methyl 2-propene to 1,1,3-trichloro-2-methyl-1-propene in the presence of thionyl chloride is proposed to involve an intramolecular rearrangement through an ion-pair intermediate (3), in contrast to the cyclic transition state suggested by Kundiger and Haney (4).

4. A mechanism for the formation of sydnones from N-substituted-N-nitrosoglycines (5) via a ketene intermediate is proposed. All of the facts (5,6,7) are accounted for by assuming the initial formation of a mixed anhydride followed by the rate-determining loss of acetic acid to give the ketene which rapidly cyclizes to yield the sydnone.

5. A synthesis of the theoretically interesting (8) cyclohepta-1,3,5-triene-7-cyclopenta-2,4-dienylidene (I) is proposed. In analogy to cyclopenta-1,3-diene-5-cyclopropenylidene (II), simple LCAO molecular orbital calculations are expected (9) to predict a

high resonance energy and a substantial dipole moment for I.

6. It is proposed that Hammett's H_o method (10,11) be applied to determine the basicities of very weakly basic aliphatic carbonyl compounds.

7. The resonance structures suggested by Soffer and DeVries (12) as contributing to the stabilization of substituted trisilylbenzenes are proposed to be incompatible with dipole moment, rate, sigma constant and acid and base strength data.

8. It is proposed that nuclear magnetic resonance spectroscopy be applied to detect "anionic hyperconjugation" (13) in alkoxide ions.

9. It is proposed that the structure of the novel compound S_2N_2 be determined by electron diffraction. The proposed structure (14) entails the non-equivalence of the N-S distances. This determination would provide insight into the structure of S_2V_2 (15).

10. It is proposed that the recent kinetic study by Kemp and Rohwer (15) of the iodometric copper reaction be extended in order to establish the mechanism, which is probably of a free-radical nature.

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