Tetrahedron Letters No.29, pp. 2767-2771, 1967. Pergamon Press Ltd. Printed in Great Britain.

STEREOCHEMISTRY OF THE CYCLOPROPYL-ALLYL REARRANGEMENTS

1. THERMAL RING OPENING OF CYCLOPROPYL CHLORIDES

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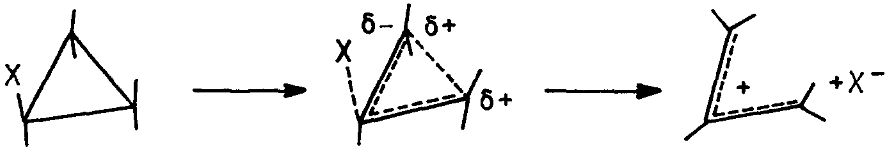
(Received 27 March 1967)

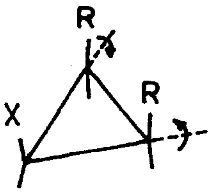
Although the cyclopropyl cation is not easily formed, a certain number of halo- and gem.-dihalo-cyclopropanes ionize readily leading either to chain lengthening or to ring expansion(2). Very few quantitative studies are available but an examination of the known cases indicates that these rearrangements are only observed with molecules which show appreciable strain or possess at C-2 or C-3 substituents capable of stabilising efficiently a developing positive charge. This latter effect is well substantiated by recent quantitative studies of the solvolysis of cyclopropyl tosylates(3). The data are best explained by a mechanism involving simultaneous ring opening and ionization with a transition state (II) showing appreciable relief of strain and partial positive charges at C-2 and C-3:



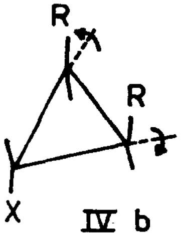
I II III

$X = Cl, Br, OTs, N_2^+$ Transition state

The theoretical calculations of Woodward and Hoffmann(4) predict a disrotatory mode as the favored process for a cyclopropyl-allyl cationic rearrangement. Moreover they point out the operation of stereoelectronic factors on the direction of rotation of the substituents, a suggestion made also independently(3c, d) by DePuy: substituents cis to the leaving group should rotate inward (IVa) whereas those trans should rotate outward (IVb).



IV a

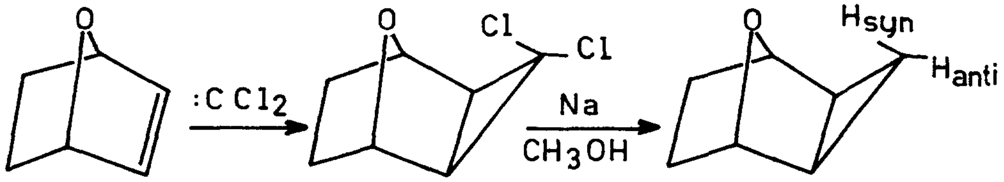


IV b

We wish to report a study$^{(5)}$ of the thermal ring opening of cyclopropyl chlorides which shows the operation of these stereoelectronic factors and their effects on the stereochemistry of the products.

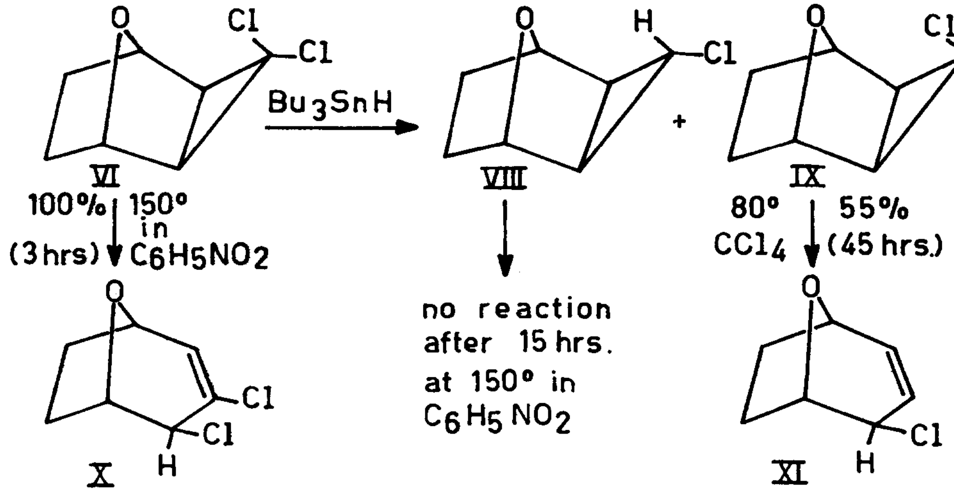
Reaction of 7-oxa-norbornene (V) with methyl trichloroacetate and sodium methoxide$^{(6)}$ at 0°C gave an adduct $C_7H_8Cl_2O$ (VI), m.p. 68-70°C (65 % based on starting olefin)$^{(7)}$. Structural assignment was based on the spectral properties of the compound and its facile dehalogenation to exo 8-oxabicyclo $[3.2.1.0^{2,4}]$ octane- $C_7H_{10}O$ (VII), n_D^{25} 1.4669. The exo configuration of the cyclopropane ring was clearly demonstrated by the non-equivalence of the two C-3 protons in the n.m.r. spectrum$^{(8)}$: the syn proton experienced a net deshielding resulting from the proximity of the oxygen of the bridge (9.62 τ, 6 lines, integr. 1) whereas the anti proton gave rise to a highly split resonance upfield from tetramethylsilane (10.1 τ, integr. 1).

$$Cl_3C-COOCH_3 + CH_3O^- Na^+ \longrightarrow :CCl_2 + (CH_3O)_2CO + NaCl$$



V VI VII

Partial dehalogenation of (VI) with tributyltin hydride$^{(9)}$ yielded a 2:1 mixture of C_7H_9ClO isomers. The major product was purified by preparative g.l.p.c. and identified as trans 3-chloro-8-oxatricyclo $[3.2.1.0^{2,4}]$octane (VIII) on the basis of the n.m.r. spectrum which showed a triplet at 7.13 τ (J = 2 cps) arising from the trans coupling$^{(10)}$ of the C-3 proton with the two equivalent cyclopropyl protons at C-2 and C-4. The minor product which decomposed partially on the preparative column was purified by chromatography on silica gel; in this case the C-3 proton gave rise to a triplet at 7.03 τ with a cis coupling constant J = 6.7 cps. Both isomers could be further reduced to (VII).



Heating VI at 150° in nitrobenzene yielded quantitatively a solid isomer m.p. 64°C exhibiting spectral data in agreement with structure (X): I.R. absorption at 1630 cm^{-1} ($>C=C<$); n.m.r. signals at 3.9τ (olefinic H; doublet : J = 4.5 cps) and 6.12τ (endo allylic H, doublet : $J_{4,5}$ = 1 cps).

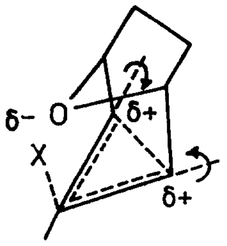
First order kinetics were observed for the rearrangement in nitrobenzene studied between 100° and 150°. The activation parameters were respectively $\Delta H^{\ddagger}$ = 15.7 Kcal and $\Delta S^{\ddagger}$ = -13 cal/deg. Cis 4-chloro-8 oxatricyclo $[3.2.1.0^{2,4}]$ octane (IX) was even more reactive and rearranged under experimental conditions (refluxing CCl_4, 55 %) in 48 hrs which left (VI) completely unaffected. The n.m.r. spectrum of the product suggested structure (XI): a doublet further split at 6.05τ (H_4 : $J_{3,4}$ = 4.2 cps, $J_{4,5}$ = 1 cps), a double doublet centered at 4.39τ (H_3: $J_{3,2}$ = 9.5 cps, $J_{1,2}$ = 4 cps, $J_{3,1}$ = 2 cps) and a double doublet at 3.94τ (H_2: $J_{1,3}$ = 9.5 cps).

Thus in both cases, a chlorine substituent moved specifically to the 4-exo position.

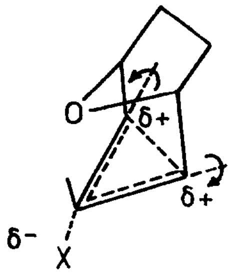
Both (VI) and (IX) gave immediately a precipitate of silver chloride in the presence of silver ion. In contrast the trans isomer (VIII) was very unreactive: it remained unaffected in the presence of silver ion or after prolonged (18 h) heating at 150° in nitrobenzene.

The rate of rearrangement of a similar molecule(11) has been shown to depend strongly on the dielectric constant of the solvent but was not affected by free radical initiator such as benzoyl peroxide. Moreover as the tributyltin hydride reduction of alkylhalides has been shown to involve the formation of free radicals(12) our results indicate that the cyclopropyl radical formed in the reduction of (VI) showed no tendency to rearrange to an allyl radical(13).

A cationic mechanism involving simultaneous ring opening and ionization accounts readily for our observations. The high tendency of (VI) and (IX) toward thermal or acid catalysed (Ag$^+$) rearrangement as compared to the inertness of dichloronorcarane favors a "protoallylic"(3d) transition state showing appreciable relief of strain.



XII



XIII

Both (VI) and (IX) can react readily by a concerted mechanism since the departure of the syn chlorine is accompanied by the inward rotation of the two C-C bonds yielding an unstrained cis allylic configuration (XII). On the other hand (VIII) is completely inert because the expulsion of the trans chlorine should lead to the very strained trans allylic configuration (XIII). Thus, in the latter case, a concerted mechanism is impossible and any cationic rearrangement should first lead to the highly strained cyclopropyl cation. It is not yet clear whether the migration of the cis chlorine to the exo position is a one-step concerted process or a two-step reaction involving a configurationally stable ion pair intermediate. More detailed investigations on these rearrangements are in progress.

Acknowlegment.

We are much indebted to Prof. G. SMETS for his constant interest and to Prof. C.W. JEFFORD for useful discussions and for information prior to publication. This work has been supported by the F.R.F.C.

Note added in proof.

As pointed out by a referee, in (VII)H-cis to O bridge is deshielded w.r.t. trans- H in (VII) but when H is cis in (VIII), it is upfield of absorption from trans- H in (IX). These results are not anomalous: in similar structures (see ref. (5a) and M.S. BAIRD, C.B. REESE Tetrah. letters 1379 (1967)) the cis- H is always upfield of absorption from trans- H ($\Delta\tau$ = 0.5 - 0.6). The smaller difference ($\Delta\tau$ = 0.1) observed for H cis and trans in our system is probably due to the deshielding effect of the O bridge on H-cis.

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13. This observation is consistent with previous studies on cyclopropyl radicals (see ref. 2a, p. 289).