Carbonium Ions. XVI. The Question of Protonated Cyclopropanes in the Reactions of Zinc Chloride with 1-Propanol and 1-Chloropropane

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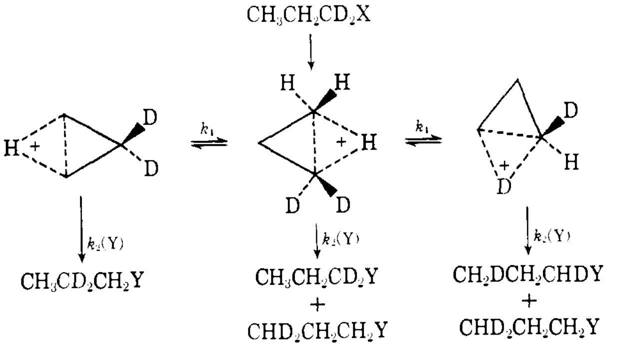
Abstract: The reaction of 1-propanol-1,1-d_2 with zinc chloride and hydrochloric acid gave a 70% yield of chloropropane consisting of 89% 1-chloropropane and 11% 2-chloropropane. The mixture obtained from the corresponding reaction of 1-propanol-2,2-d_2 consisted of 95% 1-chloropropane and 5% 2-chloropropane. This difference in the chloropropane ratio has been ascribed to k_H/k_D isotope effect of the intramolecular 1,2-hydride shift. The 1-chloropropane obtained from the reaction of 1-propanol-1,1-d_2 consisted of 98.3% C_2H_5-CD_2Cl, 0.2% C_2H_4D–$CHDCl$, and 1.5% $C_2H_3D_2$–CH_2Cl. That from the reaction of 1-propanol-2,2-d_2 consisted entirely of C_2H_3-D_2–CH_2Cl molecules. These results have been interpreted in terms of the intervention (about 2%) of a protonated cyclopropane path, where the rate of the intramolecular rearrangements of the protonated cyclopropane is slower than the rate of reaction of the protonated cyclopropane with nucleophile. In this sense, the isotope-position rearrangement resembles a nominal 1,3-hydride shift. Protonated cyclopropane intermediates were detected neither in the reactions of labeled 1-propanols with thionyl chloride in pyridine, nor in the reactions of labeled 1-chloropropanes with silver nitrate or zinc chloride and hydrochloric acid. None of these reactions gave any detectable 2-propyl product.

We have pointed out[2] that a single process, as pictured in Scheme I, is responsible for scrambling both the carbons and the hydrogens of protonated cyclopropane intermediates. In all authenticated cases of protonated cyclopropanes arising by the "σ route," k_1 is greater than k_2 (with k_2 containing a nucleophilic term). In the aqueous acid deamination of 1-aminopropane the ratio k_1/k_2 was estimated to be between five and ten.[2a] It was somewhat smaller in the reaction of 1-bromopropane with aluminum bromide,[3] but still greater than one. The only reported case that could be interpreted in terms of $k_2 \gg k_1$, *i.e.*, a case corresponding to a nominal 1,3-hydride shift, was the reaction of 1-chloropropane-1-^{14}C with zinc chloride,[4] where it was found that the recovered 1-chloropropane contained about 7% label at C-3 with no label at C-2.

Scheme I



We will present results that we have obtained from our investigations that were designed to find cases where $k_2 > k_1$.

Results and Discussion

1-Propanols labeled with two deuterium atoms at C-1 or C-2 were converted to the corresponding 1-chloropropanes by treatment with either thionyl chloride or zinc chloride and hydrochloric acid. The 1-chloropropanes were treated with zinc chloride and hydrochloric acid and were hydrolyzed back to 1-propanols with aqueous silver nitrate. The 1-propanols were converted to the trimethylsilyl ethers[5] for mass-spectral analysis. These reactions are summarized in Scheme II.

The reaction of 1-propanol-1,1-d_2 with zinc chloride and hydrochloric acid gave a mixture of 1-chloropropane (89%) and 2-chloropropane (11%). The composition of the mixture from the corresponding reaction of 1-propanol-2,2-d_2 was 95% 1-chloropropane and 5% 2-chloropropane. The smaller amount of 2-chloropropane from the reaction of the 2,2-d_2 alcohol can be safely ascribed to a k_H/k_D isotope effect for the intramolecular 1,2-hydride shift. No 2-chloropropane was detected either in the reactions of the alcohols with thionyl chloride or in the reaction of the 1-chloropropanes with zinc chloride and hydrochloric acid.

Table I summarizes the label distributions in the parent − methyl and parent − ethyl ion fragments of the trimethylsilyl ethers shown in Scheme II.

The results (entries **1**, **2**, **3**, and **1′**, **2′**, **3′**) unambiguously establish that the reaction of 1-propanol with thionyl chloride, as well as the reaction of 1-chloropropane with zinc chloride and hydrochloric acid, proceed without the intervention of protonated cyclo-

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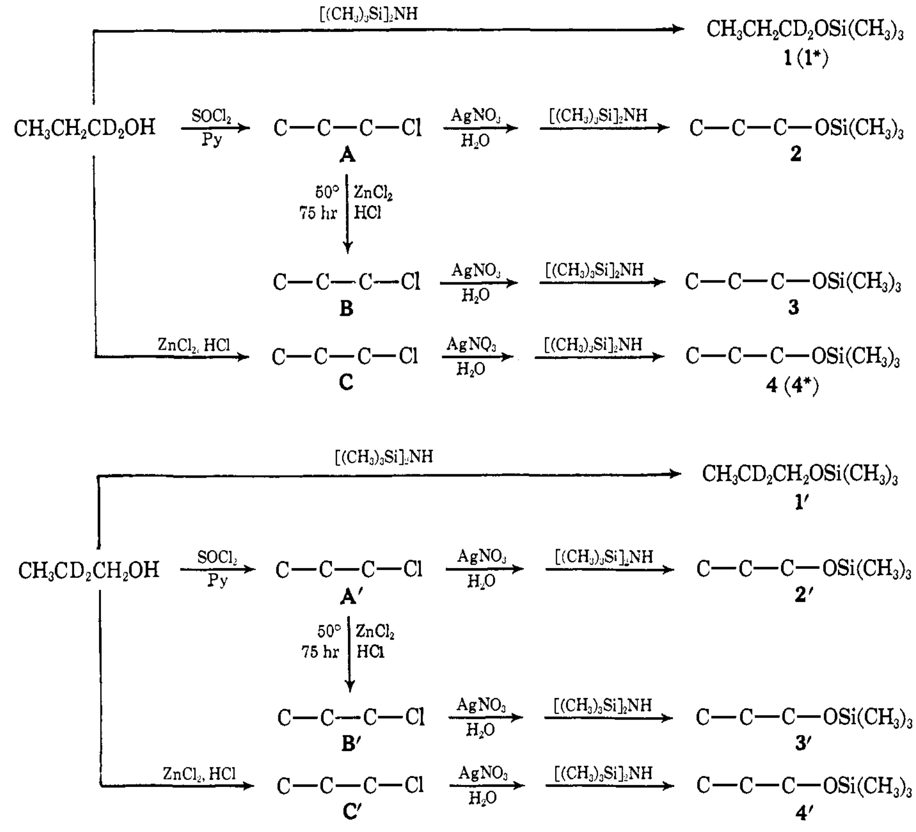
(2) (a) G. J. Karabatsos, C. E. Orzech, Jr., J. L. Fry, and S. Meyerson, *J. Amer. Chem. Soc.*, 92, 606 (1970); (b) J. L. Fry and G. J. Karabatsos in "Carbonium Ions," Vol. 2, G. A. Olah and P. von R. Schleyer, Ed., Interscience, New York, N. Y., 1970, Chapter 14.

(3) G. J. Karabatsos, J. L. Fry, and S. Meyerson, *J. Amer. Chem. Soc.*, 92, 614 (1970).

(4) O. A. Reutov and T. N. Shatkina, *Izv. Akad. Nauk SSSR, Otd. Khim. Nauk*, 195 (1963); *Bull. Acad. Sci. USSR, Div. Chem. Sci.*, 180 (1963).

(5) S. H. Langer, S. Connell, and I. Wender, *J. Org. Chem.*, 23, 50 (1958).

Scheme II



propanes. The recovered product from both reactions is isotope-position unrearranged.[6]

The only reaction in Scheme II that has led to isotope-position rearranged product (about 1.5%) is that of 1-propanol-1,1-d_2 with zinc chloride and hydrochloric acid (compare entries **1** *vs.* **4** and **1*** *vs.* **4***). The results, when normalized[1a] on the basis of 100% d_2, may be summarized as follows

$$CH_3CH_2CD_2OH \xrightarrow[HCl]{ZnCl_2} \underset{\substack{I\\98.3\%}}{C_2H_5\text{-}CD_2Cl} + \underset{\substack{II\\0.2\text{-}0.3\%}}{C_2H_4D\text{-}CHDCl} + \underset{\substack{III\\1.4\text{-}1.5\%}}{C_2H_3D_2\text{-}CH_2Cl}$$

Of special significance is the ratio II/III, *ca.* 0.2, which in the deaminating reaction was found to be about 3. On the basis of this ratio and Scheme I, we thus draw the firm conclusion that $k_2 > k_1$, *i.e.*, this rearrangement has the appearance (almost) of a simple 1,3-hydride shift.

The results from the corresponding reaction of 1-propanol-2,2-d_2 are not quite consistent with those from the reaction of 1-propanol-1,1-d_2. If the 0.2–0.3% of II is real, then the reaction of the 1-propanol-2,2-d_2 should have produced about 0.4–0.6% I, as shown in Scheme III. We were unable, however, to detect any I (see entry **4′**). Although the 0.2–0.3% value of II was obtained from two independent reactions,[7] we cannot discount the possibility that this small value is an artifact.[8]

Scheme III

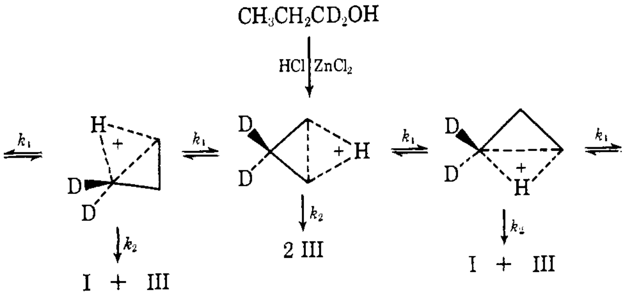


Table I. Label Distributions[a] in the Trimethylsilyl Ether Derivatives of 1-Propanols

No.[b,c]	Parent − methyl d_2	d_1	d_0	Parent − ethyl d_2	d_1	d_0
1	98.7	1.3	0.0	98.3	1.7	0.0
1*	98.3	1.7	0.0	97.8	2.2	0.0
2	98.7	1.3	0.0	98.1	1.9	0.0
3	98.6	1.4	0.0	98.4	1.6	0.0
4	98.1	1.8	0.1	96.6	2.0	1.4
4*	98.2	1.8	0.0	96.0	2.5	1.5
1′	96.7	3.3	0.0	0.0	0.0	100.0
2′	96.7	3.3	0.0	0.0	0.0	100.0
3′	96.7	3.3	0.0	0.0	0.0	100.0
4′	96.4	3.6	0.0	0.0	0.0	100.0

[a] Calculated from 70-V mass spectra. [b] To identify the trimethylsilyl ethers see Scheme II. [c] Entries **1*** and **4*** are analogous to **1** and **4**. They differ in the sense that the 1-propanols in **1** and **1*** were prepared from different samples of propionic acid and lithium and aluminum deuteride.

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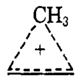
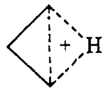
(6) C. C. Lee, B. S. Hahn, K. M. Wan, and D. J. Woodcock, *J. Org. Chem.*, **34**, 3210 (1969), also concluded that the reaction of 1-chloropropane with zinc chloride and hydrochloric acid proceeds without the intervention of protonated cyclopropanes.

(7) The reactions were run 6 months apart and with different samples of 1-propanol-1,1-d_2.

(8) Our results differ somewhat from those reported by C. C. Lee, W. K. Y. Chwang, and K. M. Wan, *J. Amer. Chem. Soc.*, **90**, 3778

The above results confirm further the previously drawn conclusion[3] that the corner-protonated cyclopropane IV—if involved in these reactions—does not


IV


V

precede the edge-protonated cyclopropane V in the reaction. Had it done so, the 1-propanol-2,2-d_2 would have produced extensively isotope-position rearranged, mainly I, 1-chloropropane.

The nonintervention of protonated cyclopropanes in the reaction of 1-chloropropane with aqueous silver nitrate is consonant with our previous finding that no protonated cyclopropanes intervene in the analogous reaction of 1-bromopropane with silver nitrate.[3]

Experimental Section

Synthesis of Labeled Compounds. The 1-propanol-1,1-d_2 was prepared by reduction of propionic anhydride with lithium aluminum deuteride. The 1-propanol-2,2-d_2 was prepared by repeated exchange of methylmalonic acid with deuterium oxide, decarboxylation of this acid to propionic acid, and reduction of the propionic acid with lithium aluminum hydride.

Trimethylsilyl ether derivatives of the alcohols were prepared by warming overnight a 2:1 molar mixture of the alcohol and hexamethyldisilazane (Metallomer Laboratories) with a drop of trimethylchlorosilane. Purification was achieved by gas chromatography on a 20 ft × $^1/_4$ in. 20% Carbowax 20M on 60–80 Chromosorb W column at 60–80°.

Reactions of 1-Propanols with Thionyl Chloride in Pyridine. To a mixture of 1-propanol (0.1 mol) and pyridine (0.1 mol) was added slowly, under cooling, thionyl chloride (0.4 mol). The mixture was then heated to reflux for 45 min. About 5.3 g (69%) of 1-chloropropane was obtained which was shown by gas chromatography to be uncontaminated by any 2-chloropropane (less than 0.2%). The reactions of the labeled propanols gave similar results.

Reactions of 1-Propanols with Zinc Chloride and Hydrochloric Acid. To 18 ml of concentrated hydrochloric acid was dissolved, under cooling, 27.2 g (0.2 mol) of zinc chloride which had been heated to melting under vacuum (0.1 mm). To this solution was added 7.5 ml (0.1 mol) of 1-propanol. The apparatus, which was fitted with jacketed column, thermometer and condenser, was heated to 130–140°. The chloropropane product (70% yield) consisted (gas chromatography) of 89% 1-chloropropane and 11% 2-chloropropane. Under identical conditions 1-propanol-1,1-d_2 gave 89% 1-chloropropane and 11% 2-chloropropane, whereas 1-propanol-2,2-d_2 gave 95% 1-chloropropane and 5% 2-chloropropane.

Reactions of 1-Chloropropanes with Zinc Chloride and Hydrochloric Acid. To a solution of 10 g (0.08 mol) of fused, anhydrous zinc chloride in 7 ml (0.08 mol) of concentrated hydrochloric acid was added 3 g (0.038 mol) of 1-chloropropane that was prepared by the reaction of 1-propanol with thionyl chloride in pyridine. The reaction flask, which was fitted with a long reflux condenser (Grahm type) stoppered tightly at the top, was heated at 50° for 72 hr. The recovered chloropropane (34%) was shown by gas chromatography to consist only of 1-chloropropane (less than 0.2% 2-chloropropane). The labeled 1-chloropropanes gave similar results.

Reactions of 1-Chloropropanes with Silver Nitrate. To a solution of 7.6 g (0.045 mol) of silver nitrate in 50 ml of water was added 3 g (0.038 mol) of 1-chloropropane. The mixture was stirred for 4 days at room temperature, and in the absence of light. After filtration of the silver chloride, saturation of the aqueous solution with potassium fluoride and extraction with ether, 0.9 g (40% yield) of 1-propanol (less than 0.2% 2-propanol by gas chromatography) was obtained. The labeled 1-chloropropanes gave similar results.

Mass spectra of the trimethylsilyl ethers were measured with 70-V electrons on a Consolidated Model 21-103C instrument.

Acknowledgment. We thank the National Science Foundation and the Petroleum Research Fund, administered by the American Chemical Society, for support of the research carried out at Michigan State University.

(1968). From the reaction of 1-propanol-1-*t* with zinc chloride and hydrochloric acid they obtained about 1% isotope-position rearranged 1-chloropropane, which compares favorably with our 1.5–1.8% rearranged product. They, however, found the rearranged label to be about equally distributed between positions 2 and 3.

Evidence for Hydrogen-Bonded Transition States in the Rate-Determining Step of the Reaction of Benzoyl Chlorides with Ethanol in Acetone and Chloroform

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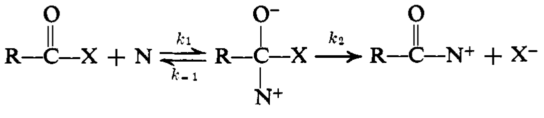
Received February 25, 1970

Abstract: The reactions of benzoyl chloride and mononitrobenzoyl chlorides with ethanol in acetone are mixed second- and third-order reactions. In chloroform the reaction of ethanol with *o*-nitrobenzoyl chloride is also mixed second and third order, but the reaction of *p*-nitrobenzoyl chloride is third order only. These results can be rationalized by assuming that every rate-determining transition state contains the substrate, the nucleophile, ethanol, and an acceptor for hydrogen bonding. Suitable acceptors are another ethanol molecule, an acetone molecule, and a chloride ion.

The reactions of carboxylic acid derivatives, which entail a substitution at the carbonyl carbon atom, almost invariably proceed through an addition–elimination mechanism, in the first step of which the carbonyl carbon atom assumes a tetrahedral configuration.[1] The general mechanism may be written as follows,



$$R-\overset{O}{\overset{\|}{C}}-X + N \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} R-\underset{\underset{N^+}{|}}{\overset{O^-}{\overset{|}{C}}}-X \xrightarrow{k_2} R-\overset{O}{\overset{\|}{C}}-N^+ + X^-$$

where N is the nucleophile and X is the leaving group.

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[1] M. L. Bender, *Chem. Rev.*, **60**, 53 (1960).