J. Org. Chem. **1980**, *45*, 641-644

$J = 7$ Hz, 2 H), 3.59 (s, 3 H); semicarbazone, mp 187-188 °C. Anal. Calcd for $C_{12}H_{19}O_3N_3$: C, 56.90; H, 7.56; N, 16.59. Found: C, 56.66; H, 7.58; N, 16.39.

13b: MS *m/e* (relative intensity) 210 (5, M^+), 182 (45), 179 (27), 150 (66), 108 (100), 93 (52); ^{1}H NMR δ 1.20-2.12 (m, 13 H), 2.24 (t, $J = 7$ Hz, 2 H), 3.59 (s, 3 H); semicarbazone, mp 169-170 °C. Anal. Calcd for $C_{13}H_{21}O_3N_3$: C, 58.41; H, 7.92; N, 15.72. Found: C, 58.26; H, 7.92; N, 15.69.

13c: MS *m/e* (relative intensity) 224 (22, M^+), 196 (25), 193 (22), 164 (63), 122 (69), 95 (91), 81 (100); ^{1}H NMR δ 1.00-2.05 (m, 15 H), 2.25 (t, $J = 7$ Hz, 2 H), 3.59 (s, 3 H); semicarbazone, mp 200-201 °C. Anal. Calcd for $C_{14}H_{23}O_3N_3$: C, 59.76; H, 8.24; N, 14.94. Found: C, 59.65; H, 8.26; N, 15.08.

13d: MS *m/e* (relative intensity) 238 (30, M^+), 207 (21), 178 (24), 95 (94), 81 (100); ^{1}H NMR δ 1.00-2.10 (m, 17 H), 2.22 (t, $J = 7$ Hz, 2 H), 3.58 (s, 3 H); semicarbazone, mp 184-185 °C. Anal. Calcd for $C_{15}H_{25}O_3N_3$: C, 60.99; H, 8.53; N, 14.23. Found: C, 60.81; H, 8.67; N, 14.32.

Dehydration of the Alcohols 9a-d. To the solutions of **9a-d** in pyridine and methylene chloride (1:3) was added dropwise a 1.5 molar excess of thionyl chloride with stirring at 0 °C, and the solutions were stirred for 30 min at 0 °C and for 4 h at room temperature. The solutions were poured into ice-water, the organic layer was separated, and the aqueous layer was extracted with methylene chloride. The combined extracts were washed with 1 N hydrochloric acid, sodium carbonate solution, and water and dried over calcium chloride. Evaporation of the solvent followed by distillation gave the olefins **7a-d** (71-80%), which were identical with the sample obtained by acetolysis of the tosylates **1a-d** and **2a-d** (^{1}H NMR spectra and GLC retention times).

Registry No. 1a, 72378-11-1; **1b**, 72390-09-1; **1c**, 72378-12-2; **1d**, 72378-13-3; **2a**, 72402-28-9; **2b**, 72441-81-7; **2c**, 72402-29-0; **2d**, 72402-30-3; **3a**, 68457-30-7; **3b**, 68457-31-8; **3c**, 68457-32-9; **3d**, 68457-33-0; **4a**, 68509-83-1; **4b**, 68509-84-2; **4c**, 68509-85-3; **4d**, 68509-86-4; **5**, 72378-14-4; **6**, 72402-31-4; **7a**, 72378-15-5; **7b**, 72390-10-4; **7c**, 72378-16-6; **7d**, 72378-17-7; **8a**, 72378-18-8; **8b**, 72378-19-9; **8c**, 72378-20-2; **8d**, 72378-21-3; **9a**, 72378-22-4; **9b**, 72378-23-5; **9c**, 72378-24-6; **9d**, 72378-25-7; **10a**, 72378-26-8; **10b**, 72378-27-9; **10c**, 72378-28-0; **10d**, 72378-29-1; **11a**, 72378-30-4; **11b**, 72378-31-5; **11c**, 72378-32-6; **11d**, 72378-33-7; **12a**, 72378-34-8; **12b**, 72378-35-9; **12c**, 72378-36-0; **12d**, 72378-37-1; **13a**, 72378-38-2; **13a** semicarbazone, 72378-39-3; **13b**, 72378-40-6; **13b** semicarbazone, 72378-41-7; **13c**, 72378-42-8; **13c** semicarbazone, 72378-43-9; **13d**, 72378-44-0; **13d** semicarbazone, 72378-45-1; **14a**, 72378-73-5; **14b**, 72378-74-6; **14c**, 72378-75-7; **14d**, 72378-76-8.

Special Salt Effect upon the Products of the Acetolysis of 1-Phenylpropyl 2-Tosylate

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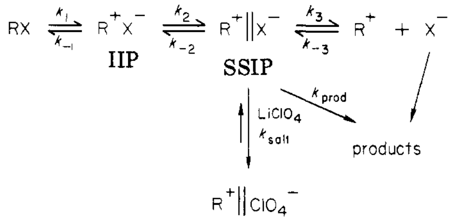
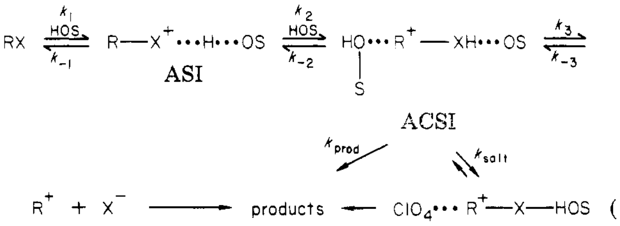
Addition of increasing amounts lithium perchlorate to the acetolysis of optically active 1-phenylpropyl 2-tosylate causes an initial rapid increase in the proportion of retained (k_Δ) acetate produced by phenyl assistance. When more than 0.02 M $LiClO_4$ is added, no further changes in the proportion of retained acetate are observed. This result is believed to be the first reported "special-salt" effect upon product distribution. The results are interpreted in terms of a common first intermediate for the two competing (solvent- and aryl-assisted) pathways rather than for two completely independent competing reactions.



(1)



(2)

The special-salt effect upon the rates of solvolysis reactions was originally reported by Winstein et al.[1] and has since been observed in several other systems.[2] This effect is manifested by a large slope of rate vs. salt concentration for lower rather than higher concentrations of "special salt". The accepted explanation for this phenomenon has been that the solvent-separated ion pair (SSIP)[1] is intercepted by the nonnucleophilic anion of the special salt to form a new ion pair (reaction 1). However, Winstein's essentially kinetic evidence did not define the geometries of the two intermediates, the intimate ion pair (IIP) and the solvent-separated ion pair (SSIP), that he proposed.[1] An equivalent explanation using an alternative reaction scheme has recently been proposed by Dannenberg.[3] This explanation is a result of an interpretation of reaction paths for nucleophilic substitution reactions calculated by using molecular orbital theory, which defines, within limits, the geometry of these intermediates. In this scheme, the anion-cation-stabilized intermediate (ACSI) is trapped as indicated in reaction 2. We shall refer to the more recent scheme in the discussion that follows. Both of these schemes involve trapping of the second intermediate along the reaction path to complete dissociation. The mani-

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[1] S. Winstein, E. Clippinger, H. H. Fainberg, R. Heck, and G. C. Robinson, *J. Am. Chem. Soc.*, **78**, 328 (1956).

[2] (a) S. Winstein and E. Clippinger, *J. Am. Chem. Soc.*, **78**, 2784 (1956); (b) A. H. Fainberg, and S. Winstein, *ibid.*, **78**, 2777 (1956); (c) S. Winstein, P. E. Klinedienst, Jr., and E. Clippinger, *ibid.*, **83**, 4986 (1961).

[3] J. J. Dannenberg, *J. Am. Chem. Soc.*, **98**, 6261 (1976).

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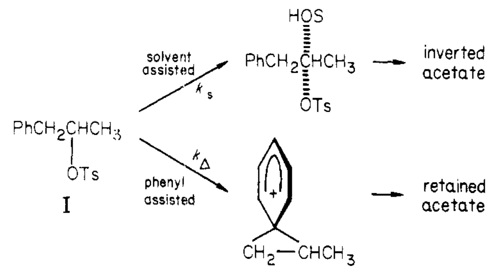
festation of the special salt upon the reaction rate is due to the essentially irreversible k_{salt} reaction, which successfully competes with the k_{-2} and k_{-1} return processes. No "*special*" salt effect should be observable if k_{-2} and k_{-1} are not competitive with k_3 and k_{prod}, even if the k_{salt} process is very efficient. A special-salt effect upon *product distribution* is possible (a) when competing reaction paths leading to different products have different special-salt effects, since the two different special effects will probably differ in intensity (the observed effect will be the difference between the two separate special-salt effects), (b) when more than one product is formed via a common ACSI and the ACSI/ClO$_4$ gives rise to a different product distribution than does the ACSI, since the product distribution of the ACSI/ClO$_4$ will be increasingly observed as the ACSI/ClO$_4$ increases in concentration at the expense of the ACSI, i.e., as the ACSI is trapped by ClO$_4^-$, or (c) when the competing paths have a common ASI but different ACSI's and k_{-2} (but not necessarily k_{-1}) is competitive with k_3 and k_{prod}, since in this case the ACSI's can equilibrate via the common ASI. More favorable trapping of one of the ACSI's would raise the proportion of the latter ACSI. The two last cases can arise even when no special-salt effect upon the overall rate is observed. The existence of such effects on product distribution has been suggested in the recent report that the ratio substitution/elimination for the acetolysis of cyclohexyl tosylate is significantly increased by addition of 0.005 M LiClO$_4$.[4] However, the effect of varying the LiClO$_4$ concentration upon this ratio was not studied.

In order to more clearly demonstrate a special-salt effect upon products, we chose to investigate the acetolysis of 1-phenylpropyl 2-tosylate (I). This reaction has been studied by many investigators[5] and is thought to proceed via two independent competitive pathways that do not have a crossover mechanism.[6] The solvent-assisted path leads to inverted acetate, while the phenyl-assisted path leads to retained acetate (reaction 3). In the absence of added salt, acetolysis of optically active I at 75 °C proceeds 70% via the solvent-assisted and 30% via the phenyl-assisted route.



(3)

Results

The acetolyses of optically active 1-phenylpropyl 2-tosylate (0.15 M), prepared according to methods previously described,[7-10] with varying amounts of added LiClO$_4$ were carried out at 75 °C. The optical rotations upon completion (5.5 days) of the reactions were recorded. Observation of the rotations at several intermediate periods indicated a steady and uneventful progression toward the final reading. The optical purity of the acetate product was determined by comparison with optically active acetate made directly from the same batch of resolved 1-phenyl-2-propanol that was used to make the tosylate. The optically active acetate was subjected to the same reaction conditions used for solvolysis (0.15 M NaOTs, 0.80 M LiClO$_4$ in acetic acid at 75 °C) for 5 days without any observable loss in optical activity (<1%), although some olefin (~4%) was formed. Figure 1 illustrates the dependence of the percent retention of the acetate product (corrected for olefin formation) upon the concentration of LiClO$_4$.

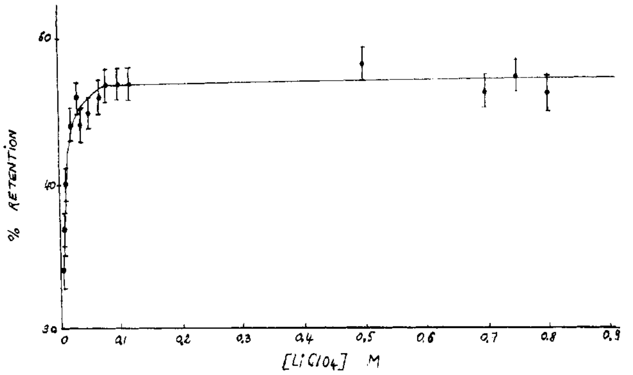


Figure 1. Percent acetate product formed with retention of configuration (100 × retained acetate/total acetate) as a function of added LiClO$_4$.

The amounts of olefinic products present were determined by gas chromatography after distillation. Only *trans-β*-methylstyrene was observed in significant amounts, although traces (<0.5%) of *cis-β*-methylstyrene and 3-phenylpropene were also observed. The individual olefinic isomers were independently found to be stable to the solvolysis reaction conditions. The relative yields of the three major products, determined by assuming complete reaction and mass balance, are presented in Table I.

Discussion

Figure 1 displays a relationship between observed rotation of the acetate produce and [LiClO$_4$] that is quite similar to the relationships between rate and [LiClO$_4$] reported for documented cases of the special-salt effect at low LiClO$_4$ concentrations. In particular, the concentration of LiClO$_4$ at which the slope of Figure 1 changes (~0.02 M) is typical of those reported for special-salt effects. To our knowledge, this is the first report of such a concentration-dependent special-salt effect upon product.

The most straightforward explanation for this phenomenon is that the ACSI(Δ) is selectively trapped by LiClO$_4$, preventing return and thereby increasing the observed fraction of retained acetate. It appears that if an ACSI(s) exists, it must either return less frequently than the ACSI(Δ) in the absence of LiClO$_4$ or not be trapped by ClO$_4^-$. One might expect that the ACSI(Δ) and the ACSI(Δ)/ClO$_4^-$ would be characterized by stabilization of charge, via the medium or the anion, through delocalization into the phenyl ring. This is in agreement with recent suggestions about the stabilization of protonated aryls by trifluoroacetic acid.[11] These results similarly support the

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[4] M. Gillard, F. Metras, S. Tellier, and J. J. Dannenberg, *J. Org. Chem.*, 41, 3920 (1976).

[5] See, for example, C. J. Lancelot and P. v. R. Schleyer, *J. Am. Chem. Soc.*, 91, 4291 (1969), and the four papers that follow it.

[6] F. L. Schadt and P. v. R. Schleyer, *J. Am. Chem. Soc.*, **95**, 7860 (1973); P. v. R. Schleyer, and C. J. Lancelot, *ibid.*, 91, 4297 (1969); F. L. Schadt, C. J. Lancelot, and P. v. R. Schleyer, *ibid.*, **100**, 228 (1978).

[7] R. H. Pickard and J. Kenyon, *J. Chem. Soc.*, **99** 45 (1911); **105**, 1115, (1914).

[8] J. E. Nordlander and W. J. Kelly, *J. Am. Chem. Soc.*, **91**, 996 (1969).

[9] S. Winstein et al., *J. Am. Chem. Soc.*, **74**, 1140 (1952).

[10] H. C. Brown, *J. Am. Chem. Soc.*, **78**, 2735 (1956).

[11] J. J. Dannenberg, *Angew. Chem., Int. Ed. Engl.*, **14**, 641 (1975). J. C. Rayez and J. J. Dannenberg, *Tetrahedron Lett.*, 671 (1977).

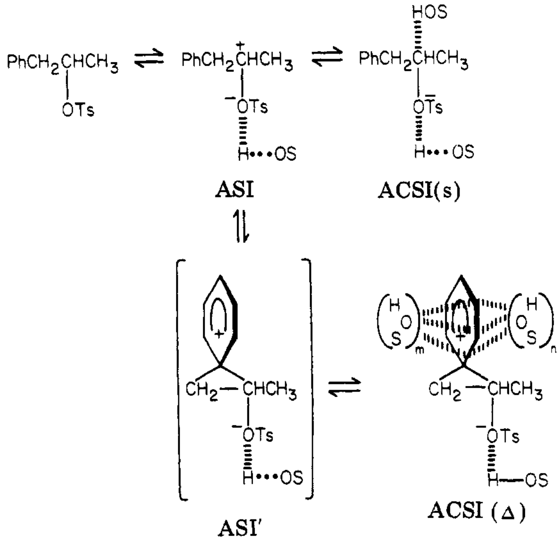
Table I. Variation of Product Distribution

$[LiClO_4]$, M	yields, % inv ester	ret ester	olefin	% retn of ester prod[a]	ret/inv[a]
0.000	61	28	11	32	0.45
0.001	58	29	13	33	0.50
0.005	56	32	12	37	0.56
0.010	57	38	5	40	0.67
0.020[b]	51	40	10	44	0.78
0.030[b]	51	42	7	46	0.82
0.040	53	41	6	44	0.78
0.050	51	42	7	45	0.82
0.070	45	37	18	46	0.82
0.080	48	42	11	47	0.88
0.100	47	42	11	47	0.89
0.120	47	42	11	47	0.89
0.500	48	45	8	48	0.94
0.700	50	44	6	46	0.88
0.750	48	42	9	47	0.88
0.800	47	41	12	46	0.87

[a] These values were calculated before rounding to two significant figures; ret/inv is the ratio of retained ester to inverted ester. [b] Average of two points, both of which were ± 1% of average values.

contention that the absence of special-salt effects for simple solvent-assisted reaction paths may be due to (a) failure of the salt to trap the ACSI, (b) nonexistence of an ACSI, or (c) essential irreversibility of ACSI formation in these cases.

The rotation of the acetate product is insensitive to $[LiClO_4]$ at higher salt concentrations (≥0.08 M). The percent retention of the acetate product for the seven points with $[LiClO_4] \geq 0.08$ M can be fitted to a line with a slope of −0.0875 and an intercept of 47.2. If the data are treated as the ratio of retained to inverted acetate, a line with a slope of −0.010 and an intercept of 0.894 results. Thus, the salt has no *selective* effect upon the transition states for at least the first steps of the two reaction paths despite the known large normal-salt effect of $LiClO_4$ for such reactions.[12] One can explain this observation by assuming that the salt effects are coincidentally the same for the two different processes. A second explanation might be the occurrence of a common first transition state leading to a common intermediate (ASI) during the first step of the reaction process. Divergence of the two reaction paths would then occur upon formation of the two ACSI's (see reaction 4). (The free energy of the transition state for the trapping of the ACSI(Δ) by perchlorate must be lower than that for the formation of the ASI. Thus the formation of the ASI would be rate determining in the presence of perchlorate.) The second explanation seems preferable. Since the ratio of retained to inverted ester is close to unity, this ratio is an extremely sensitive measure of the changes in the relative rates of formation of the two products. Relative changes of ±0.1 kcal/mol in the activation energies would result in the amount of retained ester varying from 43 to 57% of the total amount or the inversion/retention ratio varying from 0.77 to 1.02. If two completely independent reaction paths compete with each other, as proposed by Schleyer,[6] it is highly unlikely that these relative activation energies would not change by at least 0.1 kcal/mol over the range of $[LiClO_4]$ used. In addition, the existence of a common ASI accords well with the suggestion that formation of the ASI resembles protonation of the leaving group (anion stabilization) and occurs prior to cation stabilization.[3] Although Winstein had no direct evidence for the geometries of the IIP and SSIP, he imagined the IIP to involve the solvent stabilizing the *backside* of the α-carbon (i.e., cation stabilization) in at least one case, the acetolysis of 4-*tert*-butylcyclohexyl tosylate.[13] Such a structure could not describe an intermediate that is common to both the k_s and k_Δ reaction paths, as the stabilizing solvent molecule would have to leave before the neighboring phenyl group could participate, thereby regenerating the starting reactant. Thus, any interpretation of the data that requires the two reaction paths corresponding to k_s and k_Δ to diverge after formation of a common intermediate favors the mechanistic scheme involving the ASI and ACSI (reaction 2) over reaction 1, at least if the IIP is imagined to be analogous to that suggested in ref 13. Nevertheless, our data do not unambiguously rule out two completely independent reaction paths. Either solvent participation or phenyl-bridging followed by solvent stabilization of the positive charge primarily delocalized into the bridging phenyl group would occur subsequent to anion stabilization. The reasonable amount of solvent reorganization that might be required to go from ASI to ACSI(Δ) could give rise to another potential intermediate, ASI′. The ASI′ could correspond to the bridged IIP postulated by Winstein to explain $k > k_t$ for the *threo*-3-phenyl-2-butyl system.[1]



(4)

It is clear, nevertheless, that $LiClO_4$ is trapping an intermediate, rather than selectively lowering the activation energy for the phenyl-assisted process by directly participating in the transition state. If the latter is true, one should expect a new term in the overall rate expression for formation of retained product that is at least first order in $[LiClO_4]$. Such a term should give rise to an increase in the slope of Figure 1 as $[LiClO_4]$ increases, since this new term will eventually become dominant. This behavior is not observed.

The considerable scatter in the data for the yields of olefin makes it difficult to perform a detailed analysis of the competition between olefin formation and the two substitution paths. Part of the olefinic product must come from elimination of the product acetate as 4% olefin formation was observed upon exposing the acetate to solvolysis conditions for 5 days (see above). The scatter in the data very likely comes from differing amounts of elimination of the product as well as inefficiencies in the process of distilling the product mixtures. Neither of these

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(12) D. J. Raber, J. M. Harris, and P. v. R. Schleyer, "Ions and Ion Pairs in Organic Reactions", Vol 2, M. Swarc, Ed., Wiley-Interscience, New York, 1974, 247.

(13) S. Winstein and N. J. Holness, *J. Am. Chem. Soc.*, 77, 5562 (1955).

problems should affect the percent retention of the acetate.

Experimental Section

Acetic acid used for solvolysis reactions was distilled and stored with 1% distilled acetic anhydride added. $LiClO_4$ was predissolved in the acetic acid. *cis*- and *trans*-1-phenyl-1-propene and 3-phenyl-3-propene were purchased from Chemical Samples and Aldrich Chemical Co.

GLC was done on a Hewlett-Packard 5700A utilizing a 6 ft × $^1/_4$ in. glass column (OV-17) with a column temperature of 130 °C, an injection temperature of 200 °C, and a detector temperature of 300 °C. A flame-ionization detector was used. All peaks were compared to authentic materials synthesized in an unambiguous way. Optical rotations were determined by using a Perkin-Elmer 141 polarimeter with a water-jacketed cell at 25 °C. Proton magnetic resonance spectra were obtained on a Hitachi Perkin-Elmer R-24 spectrometer.

Preparation of Optically Active Materials. 1-Phenyl-2-propanol (Columbia Organic Chemical Co.) was resolved via the brucine salts of its phthalic acid half-ester.[7] Alcohols having $[\alpha]^{25}_{\mathrm{D}}$ +40.8, +40.2, and +39.7 ($CHCl_3$) were obtained. Previous literature reported $[\alpha]^{25}_{\mathrm{D}}$ +36.68[8] and +38.7[9] ($CHCl_3$). Less pure enantiomeric alcohol, $[\alpha]^{25}_{\mathrm{D}}$ −20.2, −22.1 ($CHCl_3$), was obtained from the filtrates of the brucine salt recrystallizations.

Optically active 1-phenyl-2-propyl acetate and tosylate[10] were prepared by standard procedures. All products were checked by proton NMR and boiling point or melting point.

Solvolysis Reactions. A 10-mL sample of 0.15 M optically active 1-phenyl-2-propyl tosylate dissolved in acetic acid (with or without added salt) was reacted at 75 °C for 5.5 days. The reactions were quenched with ice–water and the organic materials extracted with several portions of ether. The combined ether phases were washed carefully with saturated $NaHCO_3$ until all of the acid was removed. The organic phase was then washed with saturated NaCl and dried over Na_2SO_4, and the ether was evaporated on a rotary evaporator. In all cases the product was a yellow to amber oil. The product was distilled in a microdistillation apparatus at 1 mm. The distillate was a colorless oil.

A weighed amount of distillate was dissolved in exactly 2 mL of $CHCl_3$, and its optical rotation was determined. Another portion of the distillate was dissolved in CCl_4 and analyzed by GLC.

The GLC analysis showed only the expected olefins and the acetate product in all cases; the relative amounts of olefin products were determined from the GLC data. The specific rotation ($[\alpha]^{25}_{\mathrm{D}}$ in $CHCl_3$) was calculated by using a weight of distillate which had been corrected for the amount of olefin present.

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Registry No. I, 14135-71-8.

Stopped-Flow Trapping of the Hemiacetal Intermediates of the Hydrolysis of Acetals

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Received August 15, 1979

Stopped-flow experiments are described where partially hydrolyzed acetals in dilute acid solutions are mixed with various buffers to give final solutions of pH 7–10. A relatively rapid first-order reaction is observed, with rate constants mainly dependent on hydroxide ion concentration. This reaction is attributed to hemiacetal intermediates which have accumulated during the hydrolysis of the acetals in the acetate buffer, corroborating a similar suggestion by Jensen and Lenz (*J. Am. Chem. Soc.* **1978**, *100*, 1291). Second-order rate constants for hydroxide ion catalyzed decomposition of a series of hemiacetals are reported. A substantial dependency of leaving group is seen in the series $4\text{-}ClC_6H_4CH(OH)OR$ with $\beta_{lg} = -1.3$. Very little dependency on aromatic substituent is found in the series ArCH(OH)OEt.

The hydrolysis of acetals is now generally accepted[1] to occur via a three-stage reaction mechanism: (1) generation of an oxocarbonium ion, (2) hydration of this cation to form a hemiacetal, and (3) decomposition of the hemiacetal. Until recently, simple acyclic acetals were considered to undergo hydrolysis with the first reaction stage being rate limiting, the two subsequent stages being rapid. This means that the two intermediates, the oxocarbonium ion and the hemiacetal, are present during hydrolysis only in small stationary-state amounts and cannot be detected.

In 1975, Capon and co-workers[2] reported that the acylals α-acetoxy-α-methoxytoluene and α-(chloroacetoxy)-α-methoxytoluene have the third reaction stage rate limiting in the overall hydrolysis. That is, the hemiacetal intermediate, benzaldehyde methyl hemiacetal, is formed from the acylals more rapidly than it decomposes. Addition of the acylals to aqueous solutions results in the (rapid) formation of this hemiacetal, and what is obtained by following spectroscopically the rate of benzaldehyde formation is the rate of hemiacetal decomposition. The acylals of that study are unusual in that there is present a carboxylate group, a relatively good leaving group, and this results in a first reaction stage which is considerably accelerated relative to the third reaction stage. Hemiacetals have also been detected during hydrolysis of other acetals where there is an accelerated first reaction stage, this being due in one system to release of steric conjestion[3] and in other systems to release of ring strain.[4,5]

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(1) Cordes, E. H.; Bull, H. G. *Chem. Rev.* **1974**, *74*, 581.

(2) Capon, B.; Hall, J. H.; Grieve, D. M. A. *J. Chem. Soc., Chem. Commun.* **1976**, 1034.

(3) Capon, B. *Pure Appl. Chem.* **1977**, *94*, 1001.

0022-3263/80/1945-0644$01.00/0