The Acid- and Water-Catalyzed Hydrolysis of *p*-Nitrophenyl Esters

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Abstract: The acid-catalyzed hydrolysis of a series of *p*-nitrophenyl esters of aliphatic carboxylic acids has been studied in moderately concentrated HCl solutions at 30° with acid concentration being varied from 1.36 to 6.24 *M*. Reasonably linear plots of log k_{obsd} *vs.* log HCl concentration were obtained while degrees of curvature and small slopes were seen in plots of log k_{obsd} *vs.* $-H_0$. Plots of log $k_{\text{obsd}} + H_0$ *vs.* the logarithms of the activity of water in these solutions were linear in each case. The values of w were highly positive ranging from +4.40 with the butyrate ester to +5.15 for the trimethyl acetate ester. When ionic strength was held constant at 4.80 *M* with LiCl linear plots of k_{obsd} *vs.* HCl concentration were obtained. A plot of the logarithms of the second-order rate constants for hydrolysis at constant ionic strength *vs.* E_s, the Taft steric effects constants, was linear with a slope, δ, of 0.59. Thus, there is less sensitivity to steric hindrance in the acyl group with these *p*-nitrophenyl esters than in the case of ethyl esters. A facile water catalysis was observed in the hydrolysis of the *p*-nitrophenyl and *p*-methoxyphenyl esters of dichloroacetic acid. Increasing the acid concentration produces a pronounced decrease in rate with the nitro-substituted ester but only a slight decrease with the methoxy-substituted compound. Thus, the magnitude of ρ for water catalysis is highly dependent on the ionic strength of the medium. The hydrolysis of bis(4-nitrophenyl) carbonate was also studied at 50°. There is a pH-independent reaction at pH values greater than 1. This reaction involves water catalysis and has a D_2O solvent isotope effect (k_{H_2O}/k_{D_2O}) of 2.88. As with *p*-nitrophenyl dichloroacetate there is no apparent acid catalysis, the rate of the reaction decreasing greatly as acid concentration is increased from 1.0 to 5.29 *M*.

Unexpected effects of increased alkyl group branching in the acyl group have previously been observed on the rates of hydrolysis in moderately concentrated acid for two series of compounds, N-acylimidazolium ions[1] and acyl phosphates.[2] With both series the reaction involves attack of water on a protonated intermediate, but a steric order of reactivity abnormal for bimolecular reactions is encountered. Also, increasing acid concentration has no effect on the rate of hydrolysis of N-3,3-dimethylbutyrylimidazolium ion at 30° in contrast to the large rate decreases seen with other fully protonated N-acylimidazoles,[1] and increasing acid concentration produces larger rate increases in the hydrolysis of 3,3-dimethylbutyryl phosphate than seen in the acid-catalyzed hydrolysis of less branched acyl phosphates.[2]

It was suggested that solvation effects were probably of great importance in these reactions with water structuring in the ground state induced by the highly branched acyl groups possibly being a key factor.[1,2] Alkyl groups will cause water around a molecule to be more highly ordered.[3] The observation of effects due to structured water in hydrolytic reactions in liquid water is of considerable importance since these effects have been postulated to be important in determining protein behavior and could explain in part the efficiency of enzymatic catalysis.[3]

With both series of compounds where unusual effects have been observed, the leaving group is quite good. On the other hand, the acid-catalyzed esterification of methanol[4] or acid-catalyzed hydrolysis of ethyl esters[5] where the pK_a of the leaving group is high would appear to be cases of completely normal steric orders of reactivity. It was, therefore, considered that pK_a of the leaving group might be of great importance in giving rise to these effects. We have, as a consequence, studied the acid-catalyzed hydrolysis of a series of esters of *p*-nitrophenol where the leaving group pK_a is intermediate (7.1) between that of ethyl esters and acyl phosphates. We have also studied the effects of increasing acid concentration on the hydrolysis of *p*-nitrophenyl dichloroacetate and bis(4-nitrophenyl) carbonate to determine the influence of strong electron withdrawal in the acyl group. While the specific and general base-catalyzed reactions of *p*-nitrophenyl esters have been extensively studied,[6] there has been little work reported on the acid-catalyzed hydrolysis of these compounds.[7] Likewise, kinetic studies of the hydrolysis of bis(4-nitrophenyl) carbonate in acid or buffer solutions have not been previously reported.

Experimental Section

Materials. The *p*-nitrophenyl esters of aliphatic carboxylic acids were those previously studied.[8] The esters of dichloroacetic acid were prepared by the same procedure. *p*-Nitrophenyl dichloroacetate had mp 31–31.5° (lit.[9] mp 30.5°). *p*-Methoxyphenyl dichloroacetate has mp 62–63°.

Anal. Calcd for $C_9H_8Cl_2O_3$: C, 45.98; H, 3.43; Cl, 30.17. Found: C, 46.12; H, 3.68; Cl, 29.93.

Bis(4-nitrophenyl) carbonate was prepared from *p*-nitrophenol and phosgene. *p*-Nitrophenol (21.0 g, 0.15 mole) was dissolved in 50 ml of benzene. To this stirred solution was added 30 ml of a 20% aqueous solution of NaOH. The mixture was heated to 50°, and 80 ml of a 12.5% phosgene solution (0.1 mole) in benzene was slowly added dropwise. The mixture was allowed to stir for 2–3

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[1] J. A. Fee and T. H. Fife, *J. Phys. Chem.*, 70, 3268 (1966).

[2] D. R. Phillips and T. H. Fife, *J. Am. Chem. Soc.*, 90, 6803 (1968).

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[4] K. L. Loening, A. B. Garrett, and M. S. Newman, *J. Am. Chem. Soc.*, 74, 3929 (1952).

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[6] T. C. Bruice and S. Benkovic, "Bioorganic Mechanisms," Vol I, W. A. Benjamin, Inc., New York, N. Y., 1966.

[7] The hydrolysis of *p*-nitrophenyl acetate has been studied in concentrated sulfuric acid solutions: K. Yates and R. A. McClelland, *J. Am. Chem. Soc.*, 89, 2686 (1967).

[8] T. H. Fife, *ibid.*, 87, 4597 (1965); T. H. Fife and J. B. Milstien, *Biochemistry*, 6, 2901 (1967); J. B. Milstien and T. H. Fife, *J. Am. Chem. Soc.*, 90, 2164 (1968).

[9] R. Buyle, *Helv. Chim Acta*, 47, 2449 (1964).

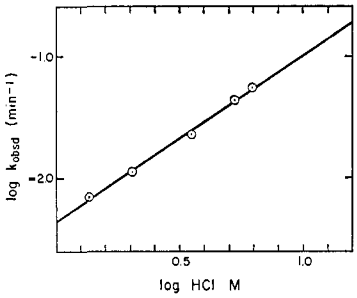

Figure 1. Plot of log k_{obsd} *vs.* log HCl concentration for hydrolysis of *p*-nitrophenyl acetate at 30°.

hr. The water layer was then separated and washed with benzene. The combined benzene extracts were dried over anhydrous sodium sulfate. Evaporation of the benzene left a solid which after recrystallization from benzene melted at 138–140° (lit.[10] mp 140°).

Acetonitrile was Eastman Kodak Spectrograde and was further purified by distillation from P_2O_5 and K_2CO_3. Deuterium oxide (99.8%) was obtained from Bio-Rad Laboratories. Hydrochloric acid was Baker Reagent grade. The concentration of HCl solutions was determined by titration of standard base. All other chemicals were reagent grade.

Kinetic Measurements. The rates of hydrolysis of the *p*-nitrophenyl esters were followed by measuring the appearance of *p*-nitrophenol at 330 mμ with a Zeiss PMQ11 spectrophotometer. The esters were dissolved in acetonitrile and 1 drop of this solution from a calibrated dropping pipet was added to 3.5 ml of aqueous acid solution in the cuvette with vigorous stirring. The reactions were generally followed to greater than 75% completion and infinity points were taken at ten half-lives. Infinity points were stable. Pseudo-first-order rate constants (k_{obsd}) were calculated on an Olivetti-Underwood Programma 101 programmed to calculate a least squares evaluation of the slope and intercept of a plot of ln $((OD_\infty - OD_0)/(OD_\infty - OD_t))$ *vs.* time. Constant temperature (±0.1°) was maintained by circulating water from a Precision Scientific Lo-Temptrol 154 circulating water bath through a Zeiss constant-temperature cell holder. The pH measurements were made with a Radiometer Model 22 pH meter. To determine pD the glass electrode correction equation of Fife and Bruice was employed.[11]

Results

The values of k_{obsd} for hydrolysis of the *p*-nitrophenyl esters at 30° and at various HCl concentrations (1.36–6.24 *M*, ionic strength not held constant) are presented in Table I. In Figure 1 is shown a typical plot of log k_{obsd} *vs.* log HCl concentration. With all of the esters reasonably linear plots were obtained with slopes varying from 1.13 to 1.48. However, plots of log k_{obsd} *vs.* $-H_0$, the Hammett acidity function,[12] generally showed slight curvature and least squares slopes much less than 1.0, ranging from 0.37 with the trimethyl acetate ester to 0.49 for the acetate and propionate esters. The rate of hydrolysis of the 3,3-dimethyl butyrate ester was also determined in 6.65 *M* DCl in D_2O, and the rate constant is reported in Table I. Employing a value of k_{obsd} in 6.65 *M* HCl determined by extrapolation of the plot of log k_{obsd} *vs.* log HCl concentration, the ratio k_{D_2O}/k_{H_2O} = 1.56 was obtained.

In Table II are values for all the esters of *w*, the slope of a plot of log $k_{obsd} + H_0$ *vs.* the logarithms of the activity of water[13] in the acid solutions. A typical example of such a plot is shown in Figure 2. The *w* values are all highly positive ranging from +4.40 with the butyrate ester to +5.15 for the trimethyl acetate ester.

Table I. Rate Constants for Hydrolysis of *p*-Nitrophenyl Esters at Various HCl Concentrations at 30°

Ester	HCl, *M*	$k_{obsd} \times 10^2$, min^{-1}
Acetate	1.36	0.706
	2.03	1.12
	3.53	2.28
	5.29	4.34
	6.24	5.44
Propionate	1.36	0.737
	2.03	1.17
	3.53	2.36
	5.29	4.09
	6.24	5.63
Butyrate	2.03	0.734
	3.53	1.51
	4.80	2.50
	5.23	2.99
	6.24	3.75
Isobutyrate	2.03	0.781
	3.53	1.53
	4.80	2.55
	5.29	2.95
	6.24	3.58
Trimethyl acetate	2.03	0.171
	3.53	0.253
	4.80	0.411
	5.29	0.486
	6.24	0.601
3,3-Dimethyl butyrate	1.36	0.066
	2.03	0.104
	3.53	0.197
	5.29	0.376
	6.24	0.442
	6.65 (D_2O)[a]	0.752

[a] DCl in D_2O.

Table II. Slopes of Plots of Log k_{obsd} *vs.* Log HCl Concentration and Values of *w* for Hydrolysis of *p*-Nitrophenyl Esters in Moderately Concentrated HCl at 30°

Ester	Slope[a]	*r*[b]	*w*[c]	*r*[d]
Acetate	1.35	0.998	4.62	0.999
Propionate	1.31	0.998	4.73	0.998
Butyrate	1.48	0.998	4.40	0.999
Isobutyrate	1.38	0.998	4.62	0.999
Trimethyl acetate	1.13	0.982	5.15	0.992
3,3-Dimethyl butyrate	1.27	0.998	4.90	0.999

[a] Slopes of plots of log k_{obsd} *vs.* log HCl concentration. [b] Correlation coefficient of plots of log k_{obsd} *vs.* log HCl concentration. [c] Slopes of plots of log $k_{obsd} + H_0$ *vs.* log a_{H_2O}: J. F. Bunnett, *J. Am. Chem. Soc.*, **83**, 4956, 4968, 4973, 4978 (1961). [d] Correlation coefficient of plots of log $k_{obsd} + H_0$ *vs.* log a_{H_2O}.

In Table III are given rate constants at various HCl concentrations for reactions in which the ionic strength was held constant at 4.80 *M* with LiCl. The activity of water in these solutions is nearly constant.[14] Plots of k_{obsd} *vs.* HCl concentration are now nicely linear. The slopes of these plots, the second-order rate constants at μ = 4.80 *M*, are also given in Table III. A plot of the logarithms of these second-order rate constants *vs.* E_s, the Taft steric effects constants,[15] is shown in Figure 3. The slope is 0.59 with a correlation coefficient of 0.993.

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(13) See Table II, footnote *c*.

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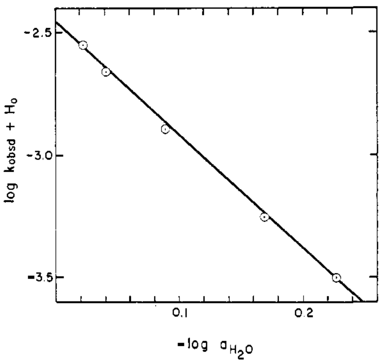


Figure 2. Plot of log $k_{obsd} + H_0$ vs. the logarithms of the activity of water[13] for hydrolysis of *p*-nitrophenyl acetate in moderately concentrated HCl at 30°.

Rate constants for hydrolysis of *p*-nitrophenyl and *p*-methoxyphenyl dichloroacetate at 30° are given in Table IV. A facile pH independent reaction is observed for both compounds. This reaction is slower in D_2O than H_2O, k_{H_2O}/k_{D_2O} being 3.10 for the nitrophenyl ester. Increasing the acid concentration markedly decreases the rate of hydrolysis of the nitro-substituted ester but only slightly decreases the rate for the *p*-methoxyphenyl derivative. At a constant ionic strength of 4.80 *M* with LiCl increasing acidity has little effect.

Table III. Rate Constants for Hydrolysis of *p*-Nitrophenyl Esters at Various HCl Concentrations at 30° with Ionic Strength Held Constant at 4.80 *M* with LiCl

Ester	HCl, *M*	$k_{obsd} \times 10^2$, min^{-1}	$k_H \times 10^3$,[a] l. mol^{-1} min^{-1}	$k_0 \times 10^3$,[b] min^{-1}
Acetate	1.08	1.12	7.25	4.17
	1.94	1.91		
	2.87	2.56		
	3.82	3.12		
	4.80	3.90		
Propionate	1.08	1.19	7.45	3.99
	1.94	1.85		
	2.87	2.70		
	3.82	2.98		
	4.80	4.10		
Isobutyrate	1.08	0.97	4.33	5.03
	1.94	1.32		
	2.87	1.76		
	3.82	2.20		
	4.80	2.55		
Butyrate	1.94	1.27	4.33	4.74
	2.87	1.75		
	3.82	2.19		
	4.80	2.50		
Isovalerate	1.08	0.190	2.48	*c*
	1.94	0.383		
	2.87	0.689		
	3.82	0.847		
	4.80	1.11		
Trimethyl acetate	1.94	0.166	0.884	0.04
	2.87	0.258		
	3.82	0.369		
	4.80	0.411		

[a] Slope of plots of k_{obsd} vs. HCl concentration. [b] Ordinate intercept of plot of k_{obsd} vs. HCl concentration. [c] The intercept is -0.0007 min^{-1}.

Rate constants for hydrolysis of bis(4-nitrophenyl) carbonate in various acidic solutions at 50° are also reported in Table IV. The rate constants determined in formate or acetate buffer ($\mu = 0.5$ *M*) were obtained by extrapolation to zero buffer concentration. It can be seen that the rate constants decrease greatly as HCl concentration is increased from 1.0 to 5.29 *M*. At pH values above 1.0 the rate constants are invariant with pH. The pH-independent reaction is much slower in D_2O than H_2O; the ratio k_{H_2O}/k_{D_2O} is 2.88 for hydrolysis in 0.1 *M* HCl and 0.1 DCl in D_2O.

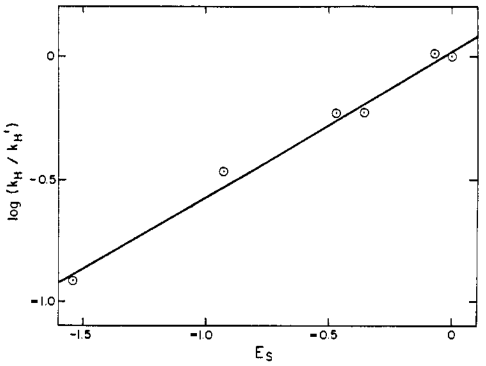


Figure 3. Plot of log (k_H/k_H') vs. E_s, the Taft steric effects constants;[15] k_H' is the second-order rate constant for acid-catalyzed hydrolysis of *p*-nitrophenyl acetate at 30°, μ = 4.80 *M* with LiCl.

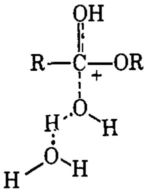
Table IV. Rate Constants (k_{obsd}, min^{-1}) for the Hydrolysis of Dichloroacetate Esters at 30° and Bis(4-nitrophenyl) Carbonate at 50°

pH or pD	HCl, *M*	*p*-Methoxyphenyl dichloroacetate	*p*-Nitrophenyl dichloroacetate	Bis(4-nitrophenyl) carbonate
3.60[a]				0.154[b]
4.03[a] (D_2O)				0.058[b]
4.65[c]				0.159[b]
	0.001	0.212	4.80	0.174
	0.01	0.212	4.68	0.168
	0.10 (H_2O)	0.211	4.78	0.165
	0.10 (D_2O)[d]		1.54	0.0572
	1.00		3.59	0.146
	1.36	0.189	3.32	
	2.03	0.171	2.79	0.0860
	3.53	0.258	1.51	0.0449
	4.80			0.0169
	5.29	0.158	0.963	0.0179
	1.08 (μ = 4.80 *M*)		0.852	
	3.82 (μ = 4.80 *M*)		1.14	

[a] Formate buffer, μ = 0.5 *M* with KCl. [b] Rate constants were obtained by extrapolation to zero buffer concentration. [c] Acetate buffer, μ = 0.5 *M* with KCl. [d] DCl in D_2O.

Discussion

The high positive values of *w* (4.4–5.1) for the acid-catalyzed hydrolysis of *p*-nitrophenyl esters might indicate according to Bunnett's criteria of mechanism[13] that water is involved in the critical transition state as a proton transfer agent. Similar large values of *w* have also been obtained for acid-catalyzed hydrolysis of esters of aliphatic alcohols in moderately concentrated HCl.[13] A kinetic order of 2.0 was found previously for water in the hydrolysis of ethyl acetate in H_2SO_4 solution, and a proton transfer role was suggested[16] as in I or II. Serious ambiguities have been noted previously in attempting to interpret Bunnett-type plots in terms of mechanism,[1,2] but it might be considered that the large w values are indicating the relative differences in ground state and transition state solvation on a scale determined by the indicator bases and their conjugate acids employed for measurement of H_0 values.[13] It is apparent from Table II that these differences are about the same for all the compounds in the series. There could, of course, be significant differences among the compounds in regard to hydration of the respective unprotonated species, conjugate acids, and transition states, with the similar w values being the result of cancellation of effects.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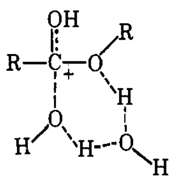
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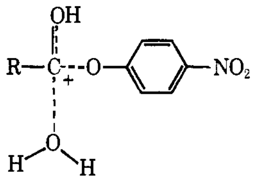
The ratio $k_{D_2O}/k_{H_2O} = 1.56$ found for hydrolysis of the 3,3-dimethyl butyrate ester is in complete accord with the A2 mechanism generally assumed for acid-catalyzed ester hydrolysis and is similar to the ratio reported for aliphatic esters.[17] In the hydrolysis of N-acylimidazolium ions, compounds that are completely protonated in moderately concentrated acid, the rate is much slower in D_2O than H_2O,[18,19] as would be expected if proton transfer was taking place in the transition state. Similar D_2O solvent isotope effects are observed in the hydrolysis of *p*-nitrophenyl dichloroacetate and bis(4-nitrophenyl) carbonate in acid solution where the reaction involves water catalysis. With these compounds kinetically significant protonation by hydronium ion does not occur since acid catalysis is not observed. Much slower rates of hydrolysis in D_2O than H_2O have invariably been observed in other water-catalyzed reactions.[6] Thus, in hydrolytic reactions of esters and amides, whenever the D_2O solvent isotope effects are not complicated by a preequilibrium protonation step, either because protonation is complete or because it has not occurred, the rate of hydrolysis is much slower in D_2O than H_2O. The faster rates of hydrolysis in D_2O for acid-catalyzed ester hydrolysis reactions are probably due to the effect of D_2O on the dissociation constant of the conjugate acid.[17] It is therefore likely that the smaller ratios of k_{D_2O}/k_{H_2O} for these A2 reactions than normally encountered in typical A1 reactions[17] are at least partially due to proton transfer in the step involving attack of water on the protonated ester, in support of the mechanistic interpretations that might be drawn from the large w values.

The plot of log k_H, the second-order rate constant for acid-catalyzed hydrolysis at constant ionic strength, *vs.* E_s has a slope of only 0.59. This is considerably less than that in the acid-catalyzed hydrolysis of ethyl esters ($\delta = 1.0$), which is a standard series in the Taft treatment (eq 1).[15] In acid-catalyzed ester hydrolysis reactions opposing inductive effects on the preequilibrium protonation step and the subsequent attack of water

$$\log\left(\frac{k_H}{k_0}\right) = \rho^*\sigma^* + \delta E_s \qquad (1)$$

should nearly cancel so that a plot of log k_H *vs.* E_s should give δ directly. Thus, the hydrolysis of *p*-nitrophenyl esters is much less susceptible to steric bulk in the acyl group than is the hydrolysis of ethyl esters. This implies that the respective transition states are considerably different, in accord with the greater electron withdrawal in the leaving group and ease of C–O bond breaking which would be the case with the *p*-nitrophenyl esters. Electron withdrawal in the leaving group will hinder electron release by the ester oxygen toward the positively charged carbonyl center. Thus, with *p*-nitrophenyl esters there should be greater positive charge on the carbonyl carbon and, therefore, less bond making with water necessary to attain the transition state than with the ethyl esters. Accordingly, there would be less susceptibility to steric hindrance since the new C–O bond would not be as well formed. The smaller sensitivity to steric hindrance for *p*-nitrophenyl esters in comparison to ethyl esters could also be explained in terms of a concerted displacement of the leaving group with the former compounds. The relative ease of C–O bond breaking would make possible a transition state in which bond formation with the attacking water molecule had not progressed extensively. The transition state IV for ethyl ester hydrolysis should resemble a tetrahedral intermediate with bond angles approaching 109°. Steric crowding should therefore be severe. Apparently both formation and breakdown of a tetrahedral intermediate is kinetically important in ethyl ester hydrolysis.[13] Breakdown of the tetrahedral intermediate to products is not rapid with ethyl esters in respect to breakdown to starting material since ^{18}O exchange of the carbonyl oxygen and solvent is observed.[16]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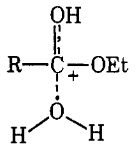
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The lack of acid catalysis in the hydrolysis of the dichloroacetate esters and bis(4-nitrophenyl) carbonate is probably due to (1) the strong electron withdrawal from the carbonyl group which greatly reduces the equilibrium concentration of protonated ester, and (2) the magnitude of the very rapid pH independent reaction with which acid catalysis apparently cannot compete. Acid catalysis has been reported in hydrolysis of diphenyl carbonate.[20] Thus, the observed effect of acid with bis(4-nitrophenyl) carbonate is undoubtedly a function of the strongly electron withdrawing nitro substituents.

The large decreases in the rate of hydrolysis of *p*-nitrophenyl dichloroacetate and bis(4-nitrophenyl) carbonate as acid concentration is increased are similar to those previously observed in several reactions where complete protonation of the substrate has occurred, examples being the hydrolysis reactions of amides,[21]

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[17] F. A. Long, *Ann. N. Y. Acad. Sci.*, **84**, 596 (1960).

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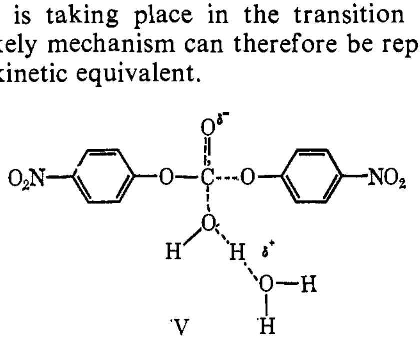
N-acylimidazoles,[1,18] and Schiff bases.[22] These reactions all involve participation by water in the transition state. The observed rate decreases have been explained by the decrease in water activity as acid concentration is increased[18] or by a possible change in rate-determining step.[18]

The pH-independent reactions are undoubtedly water-catalyzed reactions, and, as discussed above, the large D_2O solvent isotope effect indicates that proton transfer is taking place in the transition state. The most likely mechanism can therefore be represented by V or a kinetic equivalent.


V

The Hammett ρ value[23] for water-catalyzed hydrolysis of the dichloroacetate esters is 1.3 calculating it from the k_0 values for the nitro- and methoxy-substituted compounds. It can be seen in Table IV that the value of ρ is highly dependent on the ionic strength of the medium since the rate decrease produced by increasing acid concentrations is much greater for the nitrophenyl ester than for the methoxyphenyl ester. This is again very likely a reflection of the importance of solvation factors in the hydrolysis of nitrophenyl esters.

The magnitude of the water-catalyzed reactions is of considerable interest since such large water catalysis is not observed with other nitrophenyl esters (see the k_0 values in Table III). Thus, the carbonate ester is especially susceptible to water catalysis. This indicates a very low Brønsted coefficient for classical general base catalysis of carbonate ester hydrolysis. A Brønsted coefficient of 0.3 was observed for bis(4-nitrophenyl) carbonate.[24] An enhanced water catalysis has been noted previously with acyl activated esters by a positive deviation from Brønsted plots for nucleophilic catalysis.[25]

Acknowledgment. This work was supported by a research grant from the National Institutes of Health.

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Diimide Reduction of Porphyrins

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Abstract: A study of the diimide reduction of $\alpha,\beta,\gamma,\delta$-tetraphenylporphyrin and 1,2,3,4,5,6,7,8-octaethylporphyrin has been carried out. Diimide selectively *cis*-hydrogenates porphyrins. The stereoselective synthesis of *cis*- and *trans*-octaethylchlorin is described.

The central role played by oxidation/reduction reactions of porphyrins in photosynthesis and electron-transport mechanisms[1] coupled with the well-recognized cryptoolefinic nature of the peripheral double bonds in porphyrins[2-5] has prompted us to investigate the diimide reduction of *meso*-tetraphenylporphyrin and 1,2,3,4,5,6,7,8-octaethylporphyrin. We have been able to demonstrate that (1) porphyrins and chlorins are indeed readily reduced by diimide produced from the standard diimide precursor *p*-toluenesulfonylhydrazine,[6] (2) reduction of octaethylporphyrin proceeds with a high degree of stereoselectivity to *cis*-octaethylchlorin, (3) diimide reduction is the best synthetic procedure for preparing reduced derivatives of the tetraphenyl porphyrin ring system. These results are to be compared with one electron reduction of metal-free porphyrins which, with the possible exception of photoreduction of tetraphenylporphyrin with benzoin,[7] normally[8-11] afford the isomeric but less stable[10] phlorins. (See Figure 1.)

To the extent that one can equate ring currents and "aromaticity" with lack of reactivity toward nonpolar cycloaddition reagents we view the surprisingly facile diimide reduction of porphyrins as strong evidence for the picture of them as having marked and mutually distinct regions of π localization and aromaticity suggested by X-ray crystallographers.[2-4] An interesting

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