Hydrolysis of 4-Fluoroaniline Phosphate Monoester in Acid Solutions

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Hydrolysis of 4-fluoroaniline phosphate monoester has been carried out in HCl solution at $97 \pm 0.5°C$ and the inorganic phosphate obtained during hydrolysis has been estimated colorimetrically. Pseudo first order rate coefficients have been calculated. Conjugate acid species along with neutral species have been found to be reactive and contribute to overall hydrolysis in the acid region. The calculated rate coefficients are in good agreement with the experimentally observed ones. The effects of temperature, solvent and [substrate] on the rate have been studied. The results suggest that the hydrolysis of monoester occurs by cleavage of P-N bond.

INTRODUCTION

Bunton and coworkers[1] found that the acid-catalysed hydrolysis occurred only when electron-attracting substituent was present in the aryl moiety, as in 4-nitrophenyl phosphate monoester; 4-chlorophenyl phosphate[2] showed only feeble acid catalysis while 4-chloro-3,5-dimethyl phenyl phosphate[3] showed absence of acid catalysis. In view of this we envisaged that 4-fluoroaniline phosphate monoester also should not undergo acid-catalysed hydrolysis. The title investigation has been undertaken to provide support to our contention.

EXPERIMENTAL

4-Fluoroaniline phosphate monoester was obtained by the method of Auger and Dupis[4], m.p. 120°C (from absolute ethyl alcohol). It was fully characterised by elemental analysis and IR spectrum.

The acid hydrolysis of 4-fluoroaniline phosphate monoester $(5.0 \times 10^{-4}$ mol $dm^{-3})$ in the acid range $(0.1-6.0$ mol dm^{-3} HCl at $97 \pm 0.5°C)$ was carried out in aqueous solution. The inorganic phosphate obtained during hydrolysis was estimated colorimetrically by Allin's modified method[5]. Pseudo-first order rate coefficients calculated using integrated form of the corresponding rate equation are summarised in Table-1.

RESULT AND DISCUSSION

A plot of log (rate constants) *vs* pH showed that rates decreased with decrease

in pH up to 1.0 mol dm^{-3} HCl, then increased with increase in acid molarity up to 4.0 mol dm^{-3} HCl. Further rise in acidity, however, brought about lowering in rate.

TABLE-1
OBSERVED AND CALCULATED FIRST ORDER RATE COEFFICIENTS FOR THE HYDROLYSIS OF 4-FLUOROANILINE PHOSPHATE MONOESTER IN AQUEOUS MEDIA AT 97 ± 0.5°C.

HCl mol dm^{-3}	$10^5 K_N$ min^{-1}	$10^5 K_{H^+} C_{H^+}$ min^{-1}	$K_e \cdot 10^5$ min^{-1} (Calcd)	$K_e \cdot 10^5$ min^{-1} (Obsd)	$-n \log a_{H_2O}$
1.0	19.27	12.64	31.91	32.19	
2.0	20.41	26.54	46.95	45.22	
2.5	41.01	33.49	54.49	53.49	
3.0	21.62	41.30	62.92	63.08	
4.0	22.90	58.88	81.78	80.27	
5.0	11.88	37.15	49.03*	50.39	0.155
6.0	5.98	28.21	34.19*	29.80	0.211

N* = 2, 3 for 5.0 and 6.0 mol dm^{-3} HCl.

Initial decrease in rate of hydrolysis may be attributed to a decrease in the concentration of more reactive mono-negative species. Increase in rate in the region 1.0 to 4.0 mol dm^{-3} HCl may be due to either acid catalysed hydrolysis or increase in the reactivity of neutral species by ionic strength effect or by both. Therefore, effect of ionic strength[7] was studied by carrying out kinetic run at different ionic strength, maintained constant by adding appropriate mixture of KCl and HCl. The plots of rate constants of acid hydrolysis *vs* acid molarity at different ionic strength are linear curves. The three linear curves which make positive slope with the acid axis show positive salt effect and presence of acid catalysed hydrolysis. The slopes of these curves increase with increase of ionic strength. Similarly the intercepts on the rate axis which are netural rates (K$_N$) increase with the increase in the ionic strength showing the rate maxima at 4.0 mol dm^{-3} HCl is due to increase in the acid rates as well as increase in the natural rates. Therefore, the calculated rates were obtained by equation (1).

$$K_e = K_{H^+} \cdot [C_{H^+}] + K_N \qquad (1)$$

where K$_e$, K$_{H^+} \cdot C_{H^+}$ and K$_N$ are experimental rates, acid catalysed rates and neutral rates respectively. Since the monoester undergoes hydrolysis by both,

conjugate acid species and neutral species in the acid region. These rates may be calculated using second empirical term of Debye-Hückel equation and modifying it logarithmically (eqn 2).

$$\log K_{H^+} \cdot C_{H^+} = \log K_{H_0^+} + \log C_{H^+} + ub_{H^+} \tag{2}$$

$$\log K_N = \log K_{N_0} + ub_N \tag{3}$$

Here in equation (2), K_{H^+}, $K_{H_0^+}$, b_{H^+} are specific acid catalysed rates at that ionic strength, specific acid catalysed rates at zero ionic strength and the slope of the linear plot $\log K_{H^+}$ and ionic strength. In equation (3) K_N, K_{N_0}, b_N respectively are specific natural rates at that ionic strength, specific netural rates at zero ionic strength and the slope of the linear plot of $\log K_N$ and ionic strength. The intercept on the rate axis of such a plot i.e. $\log K_{H_0^+}$ and $\log K_{N_0}$ is found to be constant. Thus the increase in rates is due only to b_{H^+} u factor supporting (hydrogen ion) along with acid-catalysed hydrolysis and ionic acceration effect. The calculated rates by using equations (1), (2) and (3) are almost similar to the experimental rates up to 4.0 mol dm^{-3} HCl as shown in Table-1. The rates above 4.0 mol dm^{-3} HCl, however, deviate probably due to decrease in the reactivity of the neutral form as a result of decrease in water activity. Therefore the rates beyond 4.0 mol dm^{-3} HCl were calculated employing Bronsted-Bjerrum equation[1].

$$K_{H^+} = K_{H_0^+} \exp b_{H^+} \cdot u(a_{H_2O})^n \tag{4}$$

$$K_N - K_{N_0} \exp b_N \cdot u(a_{H_2O})^n \tag{5}$$

where $(a_{H_2O})^n$ represents the water activity term[9]. The values of $n = 2$ and 3 for 5.0 and 6.0 mol dm^{-3} HCl were found to be $E = 22.88$ kcals $mole^{-1}$, $\lambda = 34.27 \times 10^9$ s^{-1}, $S^{\pm} = -21.90$ e.u. The corresponding values at 5.0 mol dm^{-1} HCl were $E = 24.71$ kcals $mole^{-1}$, $\lambda = 32.94 \times 10^9$ s^{-1}, $S^{\pm} = -17.40$ e.u. These values are indicative of the bimolecular nature of hydrolytic reaction.

Solvent effect[11] has been studied using different water-dioxane mixtures. The results show that there is insignificant decrease in rate as a result of changeover from pure water to 20% aq. dioxane (63.08×10^5 to 46.47×10^{-1} min^{-1} at 3.0 mol dm^{-3} HCl). Due to bimolecular nucleophilic attack of solvent water molecule, the unit positive charge created is dispersed in the transition state; consequently the rates are higher in more polar medium (pure water) than in aqueous dioxane.

Since the rate coefficients are fairly similar and are independent of initial [monoester] the reaction may be taken to be kinetically of first order[12]. The hydrolysis of the monoester, which occurs by the cleavage of P—N bond, follows the isokinetic relationship[13].

The acid hydrolysis of the monoester, therefore, involves bimolecular nucleophilic attack of water molecule on phosphorus of conjugate acid species and neutral species as shown by Scheme I and Scheme II.

Scheme I
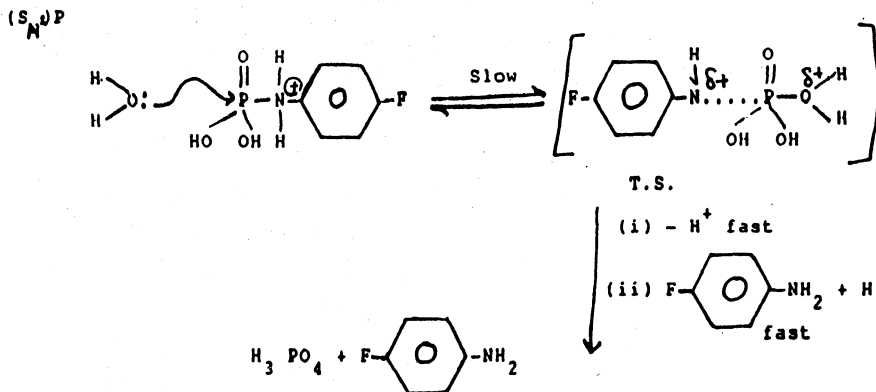
Scheme II
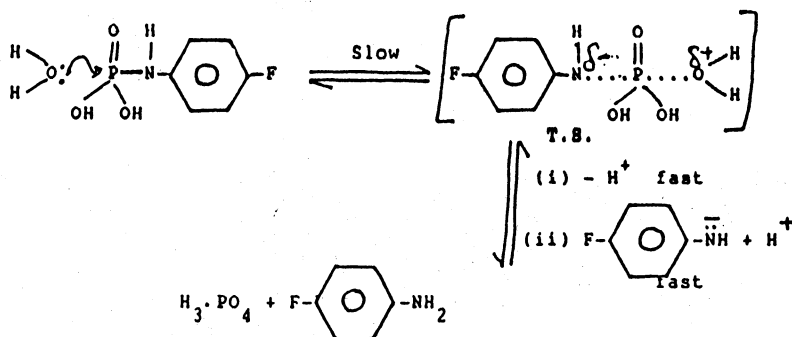
R' = phenyl, 4-methyl phenyl, 4-chlorophenyl, 4-methoxyphenyl, 4-N-N-dimethylphenyl, 2-furfuryl.

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