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DIRECT OBSERVATION OF A TETRAHEDRAL INTERMEDIATE DURING AMIDINE HYDROLYSIS (1)

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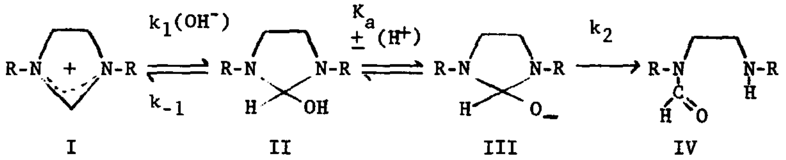
Recent experiments have led to the conclusion that the hydrolysis of the formamidinium compound, diphenylimidazolinium chloride (I, R = C_6H_5) proceeds through the rate determining decomposition of a tetrahedral intermediate (III) according to the mechanism of eq.1 (2). General acid base catalysis is observed and was interpreted as general acid catalysis of the k_2 step. We have now examined this reaction under more alkaline conditions than in the previous work and have directly observed the formation and decomposition of an intermediate during the course of the reaction.



(1)

The reaction was followed spectrophotometrically in a stopped flow mixing apparatus in dilute aqueous potassium hydroxide solutions at 25.0°. Ionic strength was maintained at 1.0 with added KCl. At 255 mμ there is a rapid increase in absorbance which is followed by a slower decrease (Fig. 1). The extent of the initial increase in absorbance is larger at higher pH. The changes in absorbance after the initial increases follow pseudo first order kinetics and the rate constants for these reactions increase with increasing pH. When the reaction is followed at 320 mμ, there is a rapid partial loss of absorbance followed by a slower first order decrease. The extent of the initial loss of absorbance at 320 mμ is greater with increasing pH. Over 90% of the total absorbance disappears during the initial reaction at pH 13.0. These results indicate that an intermediate accumulates in a reversible pH dependent reaction and decays to products by a slow base catalyzed step. This conclusion and the data below, indicating the accumulation of both forms of the intermediate (II and III), provide direct support for the mechanism of eq. 1, which was postulated previously for other reasons (2).

The concentrations of I, total intermediate, and IV were calculated as a function of time at given pH values with the aid of a computer using the general equations derived for two consecutive reversible first order reactions (3). The rate constants which give the best fit to the experimental data are listed in Table I. Apparent first order rate constants (k' terms) at given pH values which were used in the calculations were obtained as indicated in the second column of the table. *The calculated absorbance at 255 mμ* (Fig. 1) is based on the calculated concentrations of I, total intermediate, and IV. The extinction coefficient of the intermediate increases with increasing pH, which is consistent with the accumulation of both forms of the intermediate, II and III. Apparent extinction coefficients used for the intermediate at 255 mμ are 1.94×10^4 $M^{-1}cm^{-1}$ at pH 11.76, and 2.26×10^4 $M^{-1}cm^{-1}$ at pH 12.38. The absorbance at 320 mμ as a function of time and pH was *determined from the calculated* concentrations *of I since only this species absorbs* appreciably at this wavelength. Plots were made

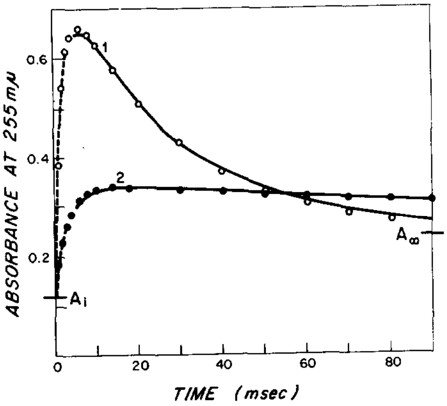


FIG.1. Absorbance changes at 255 mμ during the hydrolysis of diphenylimidazolinium chloride (I) at 25.0°. Solid lines are the <u>observed</u> absorbance; points and dashed lines are calculated as described in the text. Curve 1, pH 12.38; curve 2, pH 11.76. The absorbance of the starting material (t = 0) is A_i; the end point is A_∞.

TABLE I

Rate Constants for the Hydrolysis of Diphenylimidazolinium Chloride (I) at 25.0°

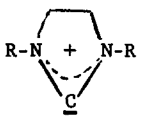
$k_1 = 1.6 \times 10^4\ M^{-1}\ sec^{-1}$	$k'_1 = k_1\ (OH^-)$
$k_{-1} = 250\ sec^{-1}$	$k'_{-1} = k_{-1}\ \alpha^a$
$k_2 = 180\ sec^{-1}$	$k'_2 = k_2\ \beta^a$
$K_a = 1.8 \times 10^{-13} M$	

[a] The terms α and β are the fractions of the intermediate in the acidic (II) and basic (III) forms, respectively.

of absorbance at 320 mμ as a function of time at five different pH values over the pH range 11.6 - 13.0. The absorbance at 320 mμ which was calculated from the values of the constants in Table I, agreed with the observed results with the same degree of accuracy as the data at 255 mμ.

In addition, pseudo first order rate constants for the slower reactions were determined from runs both at 320 mμ and at 260 mμ. Forty-one rate constants were obtained over the pH range 12.4 - 13.1 and these agree with the calculated rate constants within experimental error of 10%. These rate constants become nearly independent of pH at values above 12.8, the pK_a of the intermediate, as predicted by the mechanism of eq. 1. Therefore, both this pH-rate behavior and the pH dependence of the extinction coefficient provide evidence for the accumulation of both forms of the intermediate, II and III.

The ultraviolet absorbance spectrum of the intermediate was determined from two series of measurements over the range of wavelengths 225 - 340 mμ at both pH 12.00 and 12.38. The concentrations of I, total intermediate, and IV were calculated at 6 msec after the time of mixing from the values of the constants given in Table I. The absorbance of the calculated concentrations of I and IV at each wavelength were subtracted from the observed absorbance at t = 6 msec. The resulting differences give a spectrum which is attributed to the intermediate (II and III). The spectra at each pH are similar with peaks at 250 $\pm$ 2 mμ and shoulders at approximately 290 mμ, and a ratio $\epsilon_{250}/\epsilon_{290}$ approximately equal to 8. The extinction at all wavelengths was greater at the higher pH. Approximate extinction coefficients may be determined using the value of K_a given in Table I. The data are consistent with values of $\epsilon_{II,250\ m\mu} = 1.7 \times 10^4\ \underline{M}^{-1}\ cm^{-1}$ and $\epsilon_{III,250\ m\mu} = 3.2 \times 10^4\ \underline{M}^{-1}\ cm^{-1}$. These spectra may be compared to the spectrum of dimethylaniline in water (λ_{max} = 244 mμ; $2 \times \epsilon_{244} = 1.8 \times 10^4\ \underline{M}^{-1}\ cm^{-1}$; $\epsilon_{244}/\epsilon_{290} \simeq 8$), and to the spectrum of the adduct of N,N'diphenylethylenediamine with glyoxal in water (λ_{max} = 247 mμ; $\epsilon_{247} = 2.1 \times 10^4\ \underline{M}^{-1}\ cm^{-1}$; $\epsilon_{247}/\epsilon_{290} \approx 7.5$), (4). The spectra appear consistent with the tetrahedral intermediate (II and III). The possibility that the intermediate could be the carbanion (ylid) V is unlikely, both on the basis of the ultraviolet spectrum and the observed kinetics.



V

A large amount of evidence from kinetic and exchange experiments indicates that many nucleophilic reactions of compounds at the acyl level of oxidation proceed through tetrahedral addition intermediates (5). These intermediates have not been directly observed previously under the conditions of these reactions, with the possible exception of the alkaline hydrolysis of γ-butyrolactam (6). We believe that the experiments described here may represent the first clear example of the direct observation of the formation and decomposition of a tetrahedral intermediate at the acyl level of oxidation during the course of a hydrolysis or transfer reaction in aqueous solution.

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References

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