Kinetics and Mechanism of the Acid-catalysed Hydrolysis of Diazomethane

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Summary The mechanism of the acid-catalysed hydrolysis of diazomethane in aqueous tetrahydrofuran has been elucidated and the rate constant for protonation by the hydronium ion has been evaluated as being *ca.* 10^8 l mol^{-1} s^{-1}.

The kinetics of proton transfer to aliphatic diazo-compounds have been extensively studied recently[1] in attempts to separate the factors which determine the rate of protonation of carbon bases. Systematic kinetic investigation of the reactions of strong acids with the simplest diazoalkane (diazomethane) have presumably been frustrated until now by their rapidity.

$$CH_2N_2 + H_3O^+ \underset{k_{-H}}{\overset{k_H}{\rightleftharpoons}} CH_3N_2^+ + H_2O \xrightarrow[H_2O]{k_2} CH_3OH + H_3O^+ \qquad (1)$$

We have investigated the hydrolysis of diazomethane in aqueous tetrahydrofuran (THF–H_2O; 60:40 v/v), with dilute perchloric acid as catalyst, at 25 °C on a Durrum 110 stopped-flow spectrophotometer. The reaction was followed by observing the decrease in the absorption band at 237 nm (ϵ 3650 in THF), of CH_2N_2. The reaction was initiated by mixing equal volumes of THF–H_2O (20:80) containing $HClO_4$, and THF containing CH_2N_2. Such a dilution of the THF solution was found to generate a temperature rise of 3 °C which fell to within 0·5 °C of the thermostatted temperature after 3 s. When the initial concentrations of diazomethane and hydronium ion were 10^{-4}M the reaction was complete within 3—5 ms, *i.e.* the dead-time of the apparatus. When the diazomethane concentration was increased to 10^{-3}M, (*i.e.* a ten-fold excess) the reaction time increased to 5 s. This allowed a 3 s delay for the temperature to re-equilibrate before monitoring the disappearance of diazomethane. The decays thus observed followed kinetics that were zero order in diazomethane (for 90% reaction) for a range of initial hydronium ion concentrations, $[H_3O^+]_{init.}$, between 10^{-4} and 10^{-5}M. Furthermore the observed rate constants, $k_{obs.}$ (given by the zero-order slope divided by the extinction coefficient of diazomethane), were first order in $[H_3O^+]_{init.}$. The slope of this relation was found to be 2·1 ± 0·1 s^{-1}. The upper limit for values of $[H_3O^+]_{init.}$ investigated, $1{\cdot}4 \times 10^{-4}$M, was set by the evolution of nitrogen in the mixing chamber, with resultant distortion in the observation chamber.

The observed zero-order kinetics imply that the rate-controlling step is not the protonation of diazomethane, and that the concentration of an intermediate, presumably the methyldiazonium ion, remains constant throughout the hydrolysis. This in turn is a consequence of the unusual starting conditions involving an excess of substrate.†

A further consequence of these starting conditions is that the hydronium ion concentration falls to a low value, 10^{-9}M, at the onset of hydrolysis and returns to its original value, $[H_3O^+]_{init.}$, at the end of the reaction. This change was followed by the addition of Bromocresol Green indicator (pK_a 8 in this solvent) to the reaction mixture. The duration of the change in absorption of the indicator anion was the same as that of the zero-order kinetics as illustrated in the Figure. A precise measure of the effective hydronium ion concentration during hydrolysis, $[H_3O^+]_{hyd.}$, was achieved by the incorporation of a fast-response micro-capillary glass electrode on to the stopped-flow instrument. The electrode was previously calibrated with standard acid solutions in the solvent system for the low pH region; it obeyed the Nernst equation. This calibration was extrapolated to the high pH region. The errors involved in this approach are unlikely to be greater than those in the kinetic measurements. A continuous flow of the reaction solution (immediately after mixing) through the electrode provided a correct response. The precision and reproducibility of

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† A similar kinetic situation has been observed for certain *E*1c*B* eliminations [Z. Rappoport and E. Shohomy, *J. Chem. Soc.* (*B*), 1971, 2060].

these readings were found to be improved when a *ca.* 100-fold initial excess of diazomethane was employed. The values of $[H_3O^+]_{hyd.}$ were small, *e.g.* $[H_3O^+]_{hyd.} = 4{\cdot}67 \times 10^{-11}$M for $[H_3O^+]_{init.} = 7{\cdot}08 \times 10^{-4}$M, and $[CH_2N_2] = 1{\cdot}65 \times 10^{-1}$M after 0·5 s, implying that for the equilibrium in equation (1) $k_H > k_{-H}$. This equilibrium is not established, however, at pH values less than 5; when the hydrolysis is carried out in THF–D_2O (60:40), only CH_2DOD is formed, indicating that no exchange has occurred, *i.e.* $k_2 > k_{-H}$.

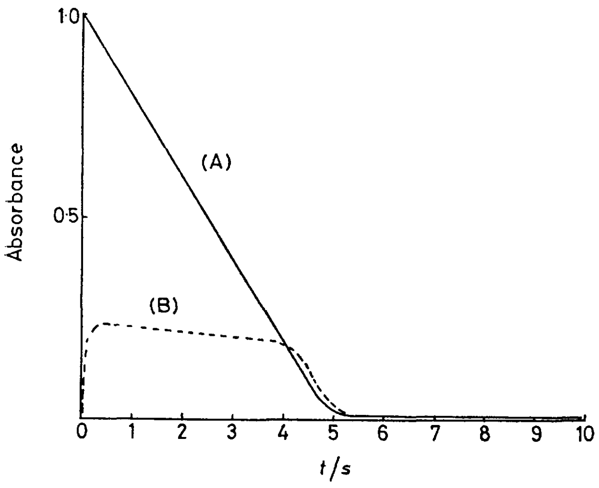

FIGURE. (A) absorbance at 237 nm due to diazomethane; (B) absorbance at 625 nm due to the anion of Bromocresol Green (B.C.G.), for $[H_3O^+]_{init.} = 1{\cdot}36 \times 10^{-5}$M, $[CH_2N_2] = 1{\cdot}4 \times 10^{-4}$M and $[B.C.G.] = 2{\cdot}81 \times 10^{-6}$M.

The rate-determining step in the hydrolysis sequence under the above conditions is the regeneration of H_3O^+. As $[H_3O^+]_{hyd.}$ is negligible compared to $[H_2O^+]_{init.}$, practically all the original hydronium ions have been converted into diazonium ions, and $k_{obs.}$ will be given by equation (2),‡ where $k_2 = 2{\cdot}1 \pm 0{\cdot}1$ s^{-1}.

$$k_{obs.} = k_2[CH_3N_2^+] = k_2[H_3O^+]_{init.} \qquad (2)$$

The protonation rate constant, k_H, is inaccessible from the kinetic data uniquely. A lower limit of 10^7 l mol^{-1} s^{-1} is indicated however by the observation that when $[CH_2N_2] = [H_3O^+]_{init.} = 10^{-4}$M, the reaction was complete in $<$ 5 ms. An independent measure of this rate constant is possible from the observed values of $[H_3O^+]_{hyd.}$. If the rate of consumption of H_3O^+ is equal to its rate of regeneration, then equation (3) holds. The observed values of

$$k_H[CH_2N_2][H_3O^+]_{hyd.} = k_2[CH_3N_2^+] = k_2[H_3O^+]_{init.} \qquad (3)$$

$[H_3O^+]_{hyd.}$ were proportional to $[H_3O^+]_{init.}$ and inversely proportional to $[CH_2N_2]$ as predicted by equation (3), for a ten-fold change in each initial concentration.

The value of k_H thus derived, $(2{\cdot}0 \pm 0{\cdot}1) \times 10^8$ l mol^{-1} s^{-1}, is surprisingly large for the protonation of a formally neutral carbon base.[2] Furthermore, a useful lower limit of 8 for the pK_a of the methyldiazonium ion emerges from equation (4).

$$K_a = k_{-H}/k_H < k_2/k_H = 2{\cdot}1/(2 \times 10^{-8})\ \text{M} \qquad (4)$$

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‡ The steady-state diazonium ion concentration for the above starting conditions ($=[H_3O^+]_{init.}$), is unaffected by protonation of CH_2N_2 by water, which becomes significant only at pH > 5. This is shown by the deviation from the value of 1 of the slope of the plot of log $k_{obs.}$ *vs.* log $[H_3O^+]_{init.}$, and by hydrogen isotope exchange for pH > 5.

[1] A. I. Hassid, M. M. Kreevoy, and T-M. Laing, *Faraday Symposium Chem. Soc.*, **1975**, **10**, 69; W. J. Albery, C. W. Conway, and J. A. Hall, *J.C.S. Perkin II*, 1976, 473, and references therein.

[2] A. J. Kresge, *Accounts Chem. Res.*, 1975, **8**, 354.