RATE OF HYDROLYSIS OF SOME ESTERS

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بسم الله الرحمن الرحيم

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ABSTRACT

The kinetics of hydrolysis ethyl nicotinate and isonicotinate were studied in three different solvents at different temperatures ranging from 10 – 35 °C in order to study the effect of changing dielectric constant of the medium and specific solvent effect and also to calculate the activation parameters and structural effect on such a reaction .

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SUMMARY

SUMMARY

Ethyl nicotinate and isonicotinate are very important in medical treatments . Thus it was of great interest to study their rates of base-catalyzed hyrdolysis at temperatures ranging from 10° to 35° in three series of aqueous dioxane, acetone and ethanol, containing 10-95 % by volume of organic solvent under isodielectric conditions. Since the nature of the solvent is crucial in deciding which route will be energetically most favourable for a given substrate, thus in the present investigation the electrostatic effects are studied and the rate constants are correlated to the dielectric constant of the solvent. This is particularly true for bimolecular reactions where the solvent influence can be explained satisfactorily by treating the solvent as a continuous dielectric and by assuming that the solvent acts solely by virtue of its dielectric effect.

Application of the differential method shows that the rate follows the second-order kinetic equation, first-order with respect to both the ester and hydroxide ion and the reaction proceeds by $B_{Ac}2$ mechanism. The measurements at different temperatures were carried out under isodielectric conditions to ensure the same macroelectrical environment during the formation of the transition state. A theory is developed which relates the rate constant of a reaction to the dielectric constant of the medium. It is applicable to reactions that are of such a character that the electrostatic interactions are more important than nonelectrostatic ones such as ion-ion, ion-dipole and certain dipole- dipole interactions, and recently enzyme reactions.

The theory is based on the Kirkwood expression for the activity

coeffecient of spherical solute molecule bearing a particular charge. The resulting equation predicts a linear dependence of the logarithm of the rate constant on the reciprocal of the dielectric constant; the proportionality constant depends on the net charges on the reactant molecules and also on the distribution of charges in the reactant molecules and the activated complex. The increase in the rate of hydrolysis of esters by increasing the dielectric constant of the medium and the linear variation of the logarithm of specific rate constants with the reciprocal of the dilectric constant of the medium with negative slopes in all aquo_organic solvents, indicate the negative ion_dipolar interaction.

However, the departure from linearity of the curves at high values of 1/D indicates the ion_ion interaction of like charge sign.

Thus according to Bronsted_Christiansen_ Scatchard equation :

$$\ln k = \ln k_o^{\infty} - \frac{Z_A Z_B e^2}{DkTr}$$

The plots of the logarithm of the measured rate constant in all the binaries at all temperatures against 1/D for both esters, are partly linear where a departure from linearity takes place at a certain value of water compositions depending on temperature and solvent, except at 10 °C where it gives a good straight line . This point of departure reaches at about 25 to 28 gm moles/litre in all the binaries.

The average values of b^* , the size of the[73] active group of the activated complex in the reaction are calculated from the slopes of the graphs of log k_{obs} VS 1/D and found to be 1.92 , 1.33 and 0.82 Å for nicotinate and 1.89 , 1.29 and 0.85 Å for isonicotinate in aqueous acetone

, dioxane and ethanol, respectively.

In all cases studied, deviating points have been purposely drawn on a second straight line resulting in a break for each temperature. Also the corresponding curves of k_{obs} Vs the concentration of water in the binary mixtures, display breaks at about the same concentration of water as in the dielectric constant curves.

However, the experimental points can be accomodated, more or less on two intersecting straight lines indicating a change in the meachanism of reaction with variation of the solvent component due to a preferential solvation (solvent sorting) by the higher dielectric component of the binary . This can also be attributed to higher water content in the organo_aqueous binary or to specific solvent effect results from partial break down of the water structure in the binaries .

However, since in our investigation macro electrical surroundings were sought to be ensured through maintainance of isodielectric media, the importance of solvent composition takes on an additional weightage.

A number of trial plots of k_{obs}Vs $[H_2O]^n$ with varying n shows that when n = 1 two intersecting straight lines with certain intercept for solvents containing more than 60% of organic solvent. The straigh lines display breaks in the range 25 – 28 gm mole / l of water depends on temperature which ascertains the role of water in the mechanism of hydrolysis.

However, in the organic solvent –rich composition, extrapolation of the lines plotted between k_{obs} and mole fraction of the water to zero water concentration shows intercepts which indicate that the mechanism of hydrolysis of the two esters studied in all the binaries at all temperatures except at temperature 10° in dioxane follows a mixed order process, i.e., proceeds simultaneously along two mechanistic paths with different rate constants for solvent composition up to the point of break. Thus the rate constant k_{obs} can split into two parts as :

$$k_{obs} = k_1 + k_2[H_2O] = k_1 + k'_2.$$

The first part (k_1) representing water independent "true second – order bimolecular acyl – fission mechanism (B'2) and the second part (k'_2) "apparent second – order termolecular process" or alternatively an apparent second – order bimolecular one" in which a water molecule is a participant in the rate – determining step. This result is substantiated by Bunnett's plot between log k_{obs} and log $[H_2O]$ where in the organic solvent composition 65 – 95% by volume the value of n is very small (from 0 to 0.2) and at 30 – 60% , till the point of break , n = 1 indicating that a water molecule is participant in the rate – determining step.

However from the magnitudes of entropy of activation and frequency factor, termolecular term is preferrable.

The kinetic parameters, the split rate constants and the relative proportions of hydrolysis proceeding simultaneously along the two mechanistic paths show that the true second order bimolecular process is directly proportional with rise of temperature. Further at any particular temperature the true second – order mechanism becomes more effective with decrease in dielectric constant.

However, for water concentration shooting beyond the break at 28 to 49 gm moles/litre (depending on temperature) in the solvent pairs, n = 2, rate determining process becomes a termolecular one with an apparent second order dependence on ester hydroxide adduct concentration and two water molecules are involved in the transition state. This result is substantiated by Bunnett's plot where n = 2. Thus the rate constant equation can be given as :

$$\begin{aligned} k_{obs}[\bar{O}H]\ [ester] &= k\ [adduct]\ [H_2O]^2 \\ &= k\ K[\bar{O}H]\ [ester]\ [H_2O]^2 \\ &= k'\ [\bar{O}H]\ [ester]\ [H_2O]^2 \\ \therefore\ k_{obs} &= K'\ [H_2O]^2 \end{aligned}$$

The concentration of the adduct, which is in equilibrium with the reactant molecules, is expressed in terms of the concentrations of the reactants and the corresponding equilibrium constant K. The observed rate constant thus becomes linearly dependent on the concentration of water.

The hydrolytic mechanism of simultaneous addition of $\bar{O}H$ and H_2O is possibly operative for the remaining parts of the curves, i.e., for portions prior to breaks. The observed rate constant would then depend as is experimentally found on the concentration of water.

$$Rate = k'\ [ester]\ [\bar{O}H]\ [H_2O]^2$$

However, the deviation from linearity decreases as the temperature lowered until at 10° where in dioxane only a singl straight line is obtained.

Thus, as regards, the portion beyond the break, the hydrolytic process involves only a second order termolecular mechanism with a water molecule involved in the rate – determining step or alternatively a bimolecular mechanism in which two water molecules are involved in the rate–determining step. The magnitudes of the entropies of activation and frequency factors for the two esters indicate that the apparent second order termolecular process rather than the second – order bimolecular process is operative in the hydrolysis mechanism.

Specific solvent effect :

To study the specific effects exterted by different solvents, both protic and aprotic rates are measured at 10° – 35° with fixed dielectric constants in binary mixtures of water with dioxane, acetone or ethanol. The rate constants in different aquo–organic media lie in the order dioxane > acetone > ethanol till about 60% by volume of organic solvent after which it lies in the order acetone > dioxane > ethanol.

This specific effects of the solvent mixtures can be traced to interactions between solvent dipoles in the mixed media as well as to selective solvation of the reacting species. The heats of mixing of dioxane– water and acetone–water systems are anomalous exothermic at low organic solvent component and endothermic at low water concentration. Acetone is considered as a strong hydrogen bond acceptor for water than dioxane where NMR studies indicate the >CO ... HO–H bond to be quite strong so that in dilute acetone solution, each acetone molecule may be associated with four water molecules and acetone can also interact with water forming dioles. Thus the higher rate in aqueous dioxane than in aqueous acetone under isodielectric conditions can be attributed to the stronger forces associating water with more polarisable acetone than with dioxane. The reactant ions should therefore preferentially be solvated by the more polar water molecules, i.e., the ions will, on average, be surrounded by water molecules to a larger extent in water – dioxane than in water–acetone mixtures, thus increasing the reaction rate in the former mixed solvent because of the higher dilectric constant in the immediate environment of the reacting ion.

In ethanol, the above factor may not be sufficient for its lowering of the rate. It supresses the rate of alkaline hydrolysis more than acetone and dioxane although its dielectric constant is higher than acetone (25.0 Vs 19.56 at 20). Protic and dipolar aprotic solvents are very different in their ability to solvate anions. The difference arises because protic solvents have a general hydrogen–bonding interaction with small anions, so that in ethanol–water solvent the organic solvent component takes part in solvating $\bar{O}H$ ions to some extent in addition to the hydration of ions, thus lowering the rates in comparison to the other two mixed media.

Moreover, the retarding effect may be attributed in part to the equilibrium :

$$EtOH + \bar{O}H \rightleftharpoons Et\,\bar{O} + H_2O$$

In dioxane–water and acetone– water mixtures, however, such equilibrium is not existing. Moreover, dioxane is the most basic of the three organic solvents used, hence, apart from other considerations the hydroxyl ion may reasonably be expected to possess the highest reactivity in the most basic dioxane–water medium.