

# KINETICS AND MECHANISM OF REACTION OF SUBSTITUTED N-PHENYLPYRIDINIUM IONS WITH OH<sup>-</sup> ION

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The reaction of substituted N-phenylpyridinium ions with hydroxyl ion leading to substituted anils of glutamic aldehyde (*V*) has been studied in 50–90% aqueous ethanol. At higher concentrations of OH<sup>-</sup> ion its addition to the pyridine nucleus is rate-determining, whereas at lower concentrations the splitting of pyridine nucleus into the substance *IV* is rate-determining. The reaction order with respect to OH<sup>-</sup> ion is maximum 2, and it decreases with increasing both OH<sup>-</sup> and ethanol concentrations to be ultimately zero (with nitro derivatives). Logarithms of equilibrium and rate constants have been correlated with the Hammett  $\sigma$  constants. The reaction mechanism and the influence of substituents on individual reaction steps are discussed in detail.

Reactions of quaternary pyridinium salts with nucleophilic agents lead to derivatives of glutamic aldehyde. Thus N-(2,4-dinitrophenyl)pyridinium chloride reacts with hydroxyl ions to give glutamic aldehyde 2,4-dinitroanil<sup>1</sup>. Kinetics of these reactions were studied with 1-methoxypyridinium<sup>2</sup> and 1-(N,N-dimethylcarbamoyl)pyridinium ions<sup>3</sup>. In both the cases the reaction was found to be first order in pyridinium ion and second order in OH<sup>-</sup> ion.

The aim of this work was to study the kinetics and mechanism of the reactions of substituted phenylpyridinium ions *Ia–Ig* with OH<sup>-</sup> ion. The following Scheme 1 describes this reaction.

## EXPERIMENTAL

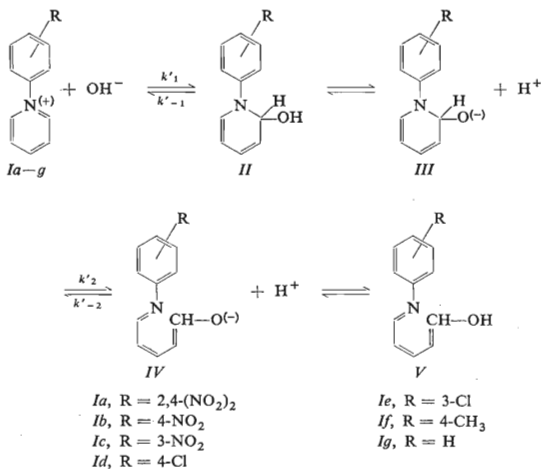
### Reagents

N-(2,4-Dinitrophenyl)pyridinium chloride (*Ia*) was obtained by a known procedure<sup>4</sup>. N-(3-Chlorophenyl)pyridinium chloride (*Ie*) was prepared from the corresponding dianil of glutamic aldehyde by the following route: 6 ml 1-butanol and 0.28 g ( $2.8 \cdot 10^{-3}$  mol) triethylamine were added to 1 g ( $2.8 \cdot 10^{-3}$  mol) of the dianil. The mixture was heated 15 min at 80°C, and then ethyl acetate was added drop by drop until turbidity appeared (about 30 ml). From this solution the crystalline product gradually separated. It was filtered off and washed with ethyl acetate; yield 0.45 g (71%); m.p. 102–103°C; for C<sub>11</sub>H<sub>9</sub>Cl<sub>2</sub>N (226.0) calculated: 58.40% C, 3.98% H, 6.19% N; found: 57.90% C, 4.14% H, 6.24% N. Analogous procedure was used for preparation of N-(4-methylphenyl)pyridinium chloride (*If*) melting at 204–206°C (ref.<sup>5</sup> m.p. 206°C), N-(4-chlorophenyl)pyridinium chloride (*Id*) melting at 126–127°C (ref.<sup>5</sup> m.p. 127–128°C), and the

unsubstituted N-phenylpyridinium chloride (*Ig*) melting at 105–106°C (ref.<sup>1</sup> m.p. 105–106°C). In the case of preparation of nitro derivatives the reaction mixture was heated 5 min only, and the products were crystallized from ethanol: N-(3-nitrophenyl)pyridinium bromide (*Ic*) melted at 233–234°C as it is given in ref.<sup>6</sup>, and N-(4-nitrophenyl)pyridinium bromide melted at 205 to 207°C; for  $C_{11}H_9BrN_2O_2$  (281.0) calculated: 47.0% C, 3.20% H, 9.96% N; found: 46.62% C, 3.46% H, 9.98% N. The starting dianils were prepared by reaction of the corresponding anilines with the dinitro derivative *Ia* (ref.<sup>5</sup>), except for 3- and 4-nitro derivatives which were prepared by reaction with cyanogen bromide<sup>5,6</sup>. The other chemicals used were commercial products.

### Kinetic Measurements

The reaction was carried out in 50 to 90% (by vol.) aqueous ethanol at 20°C, and the constant ionic strength 0.5 was adjusted by addition of potassium chloride or lithium fluoride. In experiments having the resulting lyate ion concentration higher than 0.025M sodium hydroxide or ethoxide was added in the reaction solution. In other cases pH of the solution was adjusted by addition of buffers (ethylpiperidine-ethylpiperidine hydrochloride, borax-sodium hydroxide, phenol-phenolate). The reaction rate was followed photometrically by extinction change of the reaction products; the analytical wavelengths were 420 and 550 nm for the derivative *Ia* at pH < 11.5 and pH > 11.5, respectively, 440 and 520 nm for the derivative *Ib* at pH < 12.5 and pH > 12.5, respectively, and 400 nm for the other derivatives. The reactions having the half-lives  $\tau_{1/2} > 5$  s were measured by means of a spectrophotometer VSU-2P (Zeiss, Jena) and the rate constants values were calculated from the time dependence of  $\log(E_\infty - E_t)$ , resp.  $\log(E_t - E_\infty)$



SCHEME 1

in cases where the reverse reaction was followed. The reactions having  $\tau_{1/2} < 5$  s were measured by means of a Durrum stopped flow spectrophotometer and the rate constants were computed from the half-lives measured according to the relation  $k = 0.693/\tau_{1/2}$ . In the reaction course spectra of ethanolic solutions (50% ethanol; for derivatives *Ic* and *Ie* 90% ethanol, too) were measured in the ranges 350–650 nm and 250–450 nm for the derivatives *Ia–Ib* and the other derivatives, respectively.

The dissociation constants of the reaction products were determined spectrophotometrically<sup>7</sup>. The spectra of the dissociated and undissociated forms were measured in 0.5M-NaOH and acetate buffer, respectively. The other spectra were measured in phenolate buffers (*Ia*) and in the mixtures of sodium hydroxide and potassium chloride (*Ib–Ig*). In the cases where the extinction changed with time, it was extrapolated to zero time. After finishing each experiment pH's of the reaction mixtures were measured by means of a pH-meter Radiometer using a glass and a saturated calomel (type RLB) electrodes.

## RESULTS AND DISCUSSION

*Kinetics and mechanism of reaction of Ia with  $\text{OH}^-$  ion.* The time dependence of logarithm of the product extinction change was linear in all cases (concentrations of ethanol and pH) and in all the range studied. It means that the reaction takes

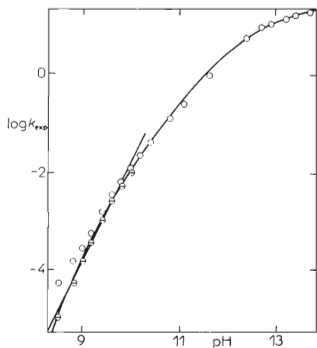


FIG. 1

Dependence of Logarithms of Experimental Rate Constants  $k_{\text{exp}}$  ( $\circ$ ) and  $k_2[\text{OH}^-]^2$  ( $\ominus$ ) on pH for Reaction of Compound *Ia* with  $\text{OH}^-$  Ion in 50% Aqueous Ethanol at 20°C and Ionic Strength 0.5

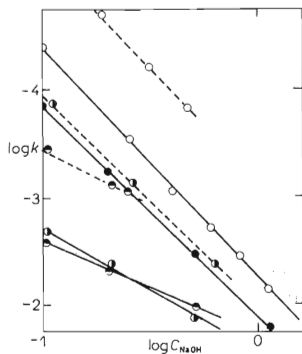


FIG. 2

Effect of Ethanol Concentration on Rates of Reaction of Compounds *Id* (—) and *If* (---) with  $\text{OH}^-$  Ion at 20°C and Ionic Strength 0.5

Ethanol: 50% ( $\circ$ ), 60% ( $\bullet$ ), 80% ( $\ominus$ ), 90% ( $\oplus$ ).

the pseudomonomolecular course, and concentration of no intermediate increases during reaction. Fig. 1 gives the dependence of the logarithms of experimental rate constants on pH in the pH range 8.5–14 in 50% ethanol. The  $\log k_{\text{exp}}$  values become independent of  $\text{OH}^-$  at the highest  $\text{OH}^-$  ion concentrations. In the pH range 11 to 12.5 the dependence is almost linear, the slope being unity. Further decrease of pH resulted in increase of the slope which, however, did not attain the value 2 corresponding to the second order with respect to  $\text{OH}^-$ . The reason can be seen in that the reaction is reversible, and the reverse reaction becomes relatively more significant with decreasing pH. In accordance with this finding also the  $E_\infty$  values become smaller with decreasing pH, and at a given pH they are the same irrespective of whether *Ia* or *Va* was used as the starting substance. The fact, that the values of experimental rate constants of the both reactions ( $\vec{k}_{\text{exp}}$  and  $\overleftarrow{k}_{\text{exp}}$ ) are practically the same (Table I), gives further evidence for the reaction proceeding according to Scheme 1.

TABLE I

Rate Constants ( $k_{\text{exp}}$ ,  $\text{s}^{-1}$ ;  $k_2[\text{OH}^-]^2$ ,  $\text{s}^{-1}$ ) and Equilibrium Constants ( $K$ ,  $\text{l mol}^{-1}$ ;  $K'$ ,  $\text{l}^2 \cdot \text{mol}^{-2}$ ) of Reaction of Compound *Ia* with  $\text{OH}^-$  Ion ( $\text{mol l}^{-1}$ ) According to Scheme 1 in 50% Ethanol at 20°C and Ionic Strength 0.5

$[\text{OH}^-] \cdot 10^6$	$\vec{k}_{\text{exp}} \cdot 10^3$	$\overleftarrow{k}_{\text{exp}} \cdot 10^3$	$K'$	$K \cdot 10^{-5}$	$k_2[\text{OH}^-]^2 \cdot 10^3$
10.0	6.2	4.9	4.85	4.85	4.75
8.0	3.5	3.6	3.75	4.75	2.82
4.4	1.75	1.66	2.21	5.05	1.15
4.7	1.48	1.33	2.15	4.63	0.96
3.0	0.67	0.82	1.41	4.68	0.44
1.9	0.25	0.26	0.84	4.52	0.12

After reaching the equilibrium the both opposite velocities are equal, and hence the Eqs (1)–(3) hold for the pH region where the rate of the product formation is proportional to the square of hydroxyl ion concentration:

$$k_2[\text{OH}^-]^2 [Ia] = k_{-2}[\text{OH}^-] [Va], \quad (1)$$

$$K = k_2/k_{-2} = [Va]/[Ia] [\text{OH}^-] = K'[\text{OH}^-], \quad (2)$$

$$k_{\text{exp}} = k_2[\text{OH}^-]^2 + k_{-2}[\text{OH}^-]. \quad (3)$$

The value  $K'$  for a given pH was determined as a ratio of the extinction changes of the two reactions. From the values  $K'$  and  $k_{\text{exp}}$  the equilibrium constants  $K$  and the

products  $k_2[\text{OH}^-]^2$  (Table I) were computed with the use of Eqs (2) and (3). The dependence  $\log k_2[\text{OH}^-]^2$  vs pH (Fig. 1) is linear with the slope 2. (Deviations from linearity at the highest pH values are caused by a change in the rate-determining step and, consequently, in the reaction order with respect to OH<sup>-</sup> ion.) It corresponds to the presumption that the conversion *IIIa* → *IVa* is rate-limiting (Scheme 1).

The reaction rate does not depend on buffer concentration. It means that the reaction is not base-catalyzed (in contrast to the reaction of *Ia* with aniline<sup>4</sup> which has a similar reaction mechanism, but the rate-limiting step is, under these conditions, the splitting off of the proton by bases from the adduct *Ia* with aniline corresponding to the intermediate *IIa*). Thus the rate constants  $k_2$  and  $k_{-2}$  (Table II)\* are defined by Eqs (4) and (5).

$$k_2 = k'_1 k'_2 K_{IIa} / k'_{-1} K_s, \quad (4)$$

$$k_{-2} = k'_{-2} K_{Va} / K_s. \quad (5)$$

$K_{IIa}$  and  $K_{Va}$  are the dissociation constants of the compounds *IIa* and *Va*, respectively,  $K_s$  stands for the products of the proton and lyate ion concentrations, and it has the value  $10^{-14.7}$  in the medium given.

The region, in which the reaction rate becomes pH-independent, changes according to ethanol concentration. With increasing ethanol content in the reaction mixture the reaction rate becomes pH-independent at gradually lower and lower OH<sup>-</sup> ion concentrations, and the rate constant  $k_0$  of this pH-independent reaction gradually decreases (Table II). In 90% ethanol it is almost 40 times smaller.

TABLE II  
Rate Constants of Reaction of *Ia* with OH<sup>-</sup> Ion According to Scheme 2 in Aqueous Ethanol at 20°C and Ionic Strength 0.5

[HO <sup>-</sup> ] · 10 <sup>2</sup>	$k_{\text{exp}}$ (s <sup>-1</sup> ) in aqueous ethanol (% by vol.)					
	50 <sup>a</sup>	55	60	70	80	90
0.25	3.1	10.6	8.7	6.1	2.5	0.68
0.50	6.0	12.8	9.0	6.6	2.3	0.57
1.0	11.5	14.4	10.0	5.4	2.3	0.58

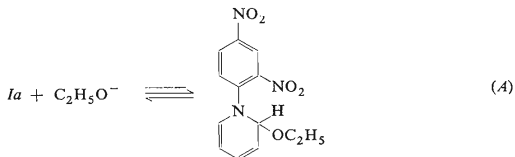
<sup>a</sup> The limit  $k_{\text{exp}}$  value is  $23 \text{ s}^{-1}$ .

\* The constants  $K$  and  $k_2$  are calculated in such a way as if all the lyate ion were OH<sup>-</sup>. According to the papers of Murto<sup>11</sup> about 20% of lyate ion should be in the form of OC<sub>2</sub>H<sub>5</sub><sup>-</sup> in the medium given, so that the values of constants should be higher by about 20%.



content) the reaction rate should increase<sup>9</sup>. In fact, the reaction rate is almost 40 × lower in 90% ethanol.

Although 1-(2,4-dinitrophenyl)-1,4-dihydro-4-hydroxypyridine could be considered as a product of the reversible side reaction, we presume that the by-product is formed by addition of ethoxide ion in 2 position of *Ia*, Eq. (A), the following being



the reasons: a) The adducts having a hydroxyl group in 2 position are more stable than the corresponding 4-isomers<sup>8</sup>. The reaction of pyridinium salts with lyate ions proceeds much faster in the position 2 than in 4 (ref.<sup>10</sup>). b) In aqueous alcoholic media, as a rule, ethoxide ion reacts with an activated aromatic nucleus much faster than hydroxyl ion<sup>11</sup>, and it gives more stable complexes<sup>12</sup>. c) The rate constant is given by Eq. (6) for this case:

$$k_0 = k'_1 K_0 [OH^-] / [C_2H_5O^-], \quad (6)$$

here  $K_0$  stands for the equilibrium constant of formation of the adduct *VIa*. On going from 50% to 90% ethanol the ratio  $[OH^-] / [C_2H_5O^-]$  decreases by about one order of magnitude, and this is the main reason of the considerable  $k_0$  decrease found. The concentration of the adduct *VIa* decreases continuously in the same way as, in 50% ethanol, the reaction order with respect to OH<sup>-</sup> ion is changed from 0 to 1. In the cases where the reaction order equals unity the presence of the compound *VI* was no longer observed, which means that the side reaction (A) is kinetically insignificant. Then the only reaction coming practically into consideration is that of *Ia* with OH<sup>-</sup> ions giving the final products *IVa* and *Va*. The formation of the compound *IIa* is rate-limiting. The rate constant  $k_1 = k'_1 = 1.2 \cdot 10^3 \text{ l mol}^{-1} \text{ s}^{-1}$ . From the rate constants  $k'_1$  and  $k_0$  and from the determined ratio  $[OH^-] / [C_2H_5O^-]$  (ref.<sup>11</sup>) it can be calculated using Eq. (6) that the equilibrium constant  $K_0$  of the reaction (A) is  $2.5 \cdot 10^3 \text{ mol/l}$ .

Activating effect of the ring N—C<sub>6</sub>H<sub>3</sub>(NO<sub>2</sub>)<sub>2</sub> group is comparable with that of three nitro groups<sup>10</sup>. The rate constant of addition reaction of OH<sup>-</sup> ion to *sym* trinitrobenzene in 19% aqueous ethanol at 25°C is  $70.2 \text{ l mol}^{-1} \text{ s}^{-1}$  (ref.<sup>12</sup>) which is about 17 lower value than that of the rate constant  $k_1$ . The equilibrium constant of the adduct formation from *sym* trinitrobenzene and ethoxide ion in the same medium is  $241 \text{ mol} \cdot \text{l}^{-1}$  (ref.<sup>12</sup>) which is about 10 × lower than the equilibrium constant  $K_0$  found for the reaction (A) by us.

*Reactions of N-(3- and 4-substituted phenyl)pyridinium ions with OH<sup>-</sup> ion.* As the monosubstituted phenylpyridinium ions *Ib–Ig* are substantially less reactive than the dinitro derivative *Ia*, all the kinetic experiments (except for several ones with 4-nitro derivative *Ib*) were carried out in aqueous alcoholic solutions of sodium hydroxide and potassium or lithium chloride.

Similarly to the dinitro derivative *Ia* the reaction order with respect to OH<sup>-</sup> ion changes with the change of ethanol concentration (and, in the case of nitro derivatives, with the change of lyate ion concentration, too). The influence of ethanol concentration was studied in more detail with 4-chloro and 4-methyl derivatives *Id* and *If* (Fig. 2). In both 50% and 60% ethanol the reactions are second order in OH<sup>-</sup> ion. In 60% ethanol the reaction velocity is higher, since the accelerating effect caused by the change of the dielectric constant is greater than the opposite effect caused by the change of the ratio [OH<sup>-</sup>]/[C<sub>2</sub>H<sub>5</sub>O<sup>-</sup>]. In 80% ethanol the velocity is further increased, but, whereas the reaction order is about 2 with the methyl derivative *If*, it approaches unity with the chloro derivative *Id*. In 90% ethanol the reaction order of the both derivatives is unity, and at the highest hydroxide concentrations the experimental rate constants are lower than those in 80% ethanol. On the basis of these results, 50% and 90% ethanol were chosen as the medium for quantitative evaluation of substituent effects.

In 50% ethanol the reaction order in OH<sup>-</sup> ion equals 2 with all the derivatives *Ib–Ig*, and the reaction mechanism is the same as that of the dinitro derivative *Ia*. Table III gives the logarithms of the calculated rate constants  $k_2$  which correlate well with the Hammett  $\sigma$  constants according to Eq. (7).

$$\log k_2 = 5.05\sigma - 3.58. \quad (7)$$

The value  $\sigma_{p-\text{NO}_2}$  calculated from the correlation is 1.15, and the including of the dinitro derivative *Ia* in the correlation gives  $\sigma_{o-\text{NO}_2} = 1.1$ .

The reaction is reversible here, too, as it was with the dinitro derivative *Ia*, but the reverse step is significant already at much higher OH<sup>-</sup> ion concentrations. In the case of the four most reactive derivatives *Ib–Ie* the equilibrium constants  $K$  were determined and the rate constants  $k_{-2}$  calculated (Table III) in analogous way as those of the dinitro derivative *Ia*.

In 90% ethanol the reaction order in OH<sup>-</sup> ion was unity for all the derivatives except for *Ib* (4-nitro) where it was lower than 1 at the lowest hydroxide concentrations used (0.0025M), and it gradually changed into zero order with respect to OH<sup>-</sup> ion. The same change of the reaction order was found also with 3-nitro derivative *Ic*, however, first at hydroxide concentrations higher by two orders of magnitude.

The both nitro derivatives *Ib* and *Ic* gave linear dependences  $1/k_{\text{exp}}$  vs  $1/[\text{OH}^-]$ . The intercept at x-axis is equal to the reciprocal of the rate constant of the reaction which is zero order in OH<sup>-</sup> ion, and the angular coefficient is equal to the reciprocal of the rate constant of the first order reaction with respect to OH<sup>-</sup> ion.

Again the reaction in 90% ethanol proceeds in two steps as it was the case with the dinitro derivative *Ia* (in the case where the reaction was zero order in OH<sup>-</sup> ion).



The very fast first step (which was always finished before the first record could be taken on the spectrophotometer) generates the adduct *VI* having its extinction maximum at the wavelength 400 nm for the 4-nitro derivative *VIb* and at 320–330 nm for the derivatives *VIc*–*VIg*.

In the slower second step the adduct *VI* is transformed into an equilibrium mixture of the products *IV* and *V*. In the reaction which is first order in OH<sup>-</sup> ion the rate-limiting step is the conversion of *III* into *IV* (the rate constant  $k_{01}$  in Table III). In the reaction of zero order in OH<sup>-</sup> ion the rate-limiting step is the conversion of *I* into *II*, and the reaction mechanism is the same as that of the derivative *Ia*. The rate constants  $k_0$  (0.90 and 0.72 s<sup>-1</sup> for derivatives *Ib* and *Ic*, resp.) differ very slightly from each other and are comparable with the value  $k_0 = 0.64$  s<sup>-1</sup> of the derivative *Ia*. Therefrom it follows that the influences of substituents on both the equilibrium constant of the formation of *VI* and the rate constant of the formation of *II* are almost the same, so that they cancel each other to considerable extent.

The Hammett correlation of log  $k_{01}$  with the  $\sigma$  constants (Eq. (8)) is very good. The calculated value  $\sigma_{p-\text{NO}_2} = 1.24$  corresponds to the literature value<sup>13</sup> for  $\sigma_p^-$ .

$$\log k_{01} = 3.55\sigma - 2.53. \quad (8)$$

The difference between the  $\rho$  constants from Eqs (7) and (8) gives the  $\rho_0$  constant (1.5) of the correlation of equilibrium constants of the reaction  $I + \text{C}_2\text{H}_5\text{O}^- \rightleftharpoons VI$

TABLE III

Rate Constants  $k_2, k_{-2}$  (l<sup>2</sup> mol<sup>-2</sup> s<sup>-1</sup>),  $k_{01}$  (l mol<sup>-1</sup> s<sup>-1</sup>) and Equilibrium Constants  $K$  (l mol<sup>-1</sup>) of Reactions of Compounds *Ia*–*Ig* with OH<sup>-</sup> Ion According to Scheme 2 in 50% Aqueous Ethanol at 20°C and Ionic Strength 0.5

Substance	$k_2$	$k_{-2}$	$K$	$\rho K_a^a$	$k_{01}^b$
<i>Ia</i> (4.5 ± 0.6) · 10 <sup>7</sup>	(9.5 ± 1.5) · 10 <sup>1</sup>	(4.75 ± 0.1) · 10 <sup>5</sup>	11.79 ± 0.05	—	—
<i>Ib</i> (1.53 ± 0.25) · 10 <sup>2</sup>	15 ± 1	(1.03 ± 0.1) · 10 <sup>2</sup>	12.6 ± 0.2	(9.5 ± 1) · 10 <sup>1</sup>	—
<i>Ic</i> 0.97 ± 0.08	(8 ± 1.5) · 10 <sup>-2</sup>	12 ± 2	12.4 ± 0.1	1.1 ± 0.15	—
<i>Id</i> (4.15 ± 0.2) · 10 <sup>-3</sup>	—	—	—	12.85 ± 0.15	(2.0 ± 0.1) · 10 <sup>-2</sup>
<i>Ie</i> (1.85 ± 0.2) · 10 <sup>-2</sup>	(7.5 ± 1.5) · 10 <sup>-3</sup>	2.5 ± 0.5	12.7 ± 0.1	(5.8 ± 0.3) · 10 <sup>-2</sup>	—
<i>If</i> (5.0 ± 1.0) · 10 <sup>-5</sup>	—	—	—	—	(1.17 ± 0.08) · 10 <sup>-3</sup>
<i>Ig</i> (2.65 ± 0.25) · 10 <sup>-4</sup>	—	—	—	—	(3.0 ± 0.2) · 10 <sup>3</sup>

<sup>a</sup> For the compounds of the type *V*; <sup>b</sup> in 90% ethanol.

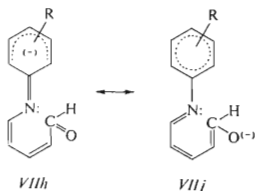
(Scheme 2) (This value is somewhat affected by that the comparison involves both the values obtained in 50% and 90% ethanol.).

The reactions of nucleophilic agents with substituted aromatic compounds (the substituent being directly attached to the nucleus at which the reaction occurs) have the  $\rho$  constant values about 5 (ref.<sup>14</sup>). The decrease of  $\rho$  to the value 1.5 in our case (where the substituted benzene nucleus is connected with the nitrogen atom of the reacting heterocycle) is reasonable. 1-Cyanoquinolinium ions having the substituted benzene ring fused with the reacting heterocycle exhibit the  $\rho$  constant about 6 (ref.<sup>8</sup>).

Although the  $\rho$  value of the correlation of  $k_2$  is about 5, the  $\rho$  constant of the overall reaction  $I \rightleftharpoons V$  (calculated for the derivatives *Ib*, *Ic*, *Ie*) has a value only about 2, and that of the reverse reaction ( $k_{-2}$ ) has the value 3. It means that the substituents affect the reaction rate similarly in the both directions – the higher is the  $\sigma$  constant value the faster are the reactions in the both directions. If we consider the  $\rho$  value of the reaction  $I \rightleftharpoons II$  to be about 1.5 and that of acid–base reaction  $II \rightleftharpoons III$  to be about 0.5–1, then it follows for the reaction  $III \rightarrow IV$  ( $k'_2$ )  $\rho = 2.5-3$ . The overall  $\rho$  value (+3) of the reverse reaction  $V \rightarrow III$  is a sum of the  $\rho$  constants of reactions  $V \rightleftharpoons IV$  and  $IV \rightarrow III$  ( $k'_{-2}$ ). From the  $pK_a$  values measured (Table III) the  $\rho$  constant of the former reaction ( $V \rightleftharpoons IV$ ) is about 1, so that that of the latter one ( $IV \rightarrow III$ ) has the value 2. It means that both the conversion of *III* to *IV* and the reverse step are very strongly accelerated by substituents with positive  $\sigma$  constants.

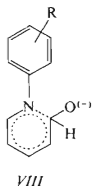
The formation of the activated complex of the reaction  $III \rightarrow IV$  involves a nucleophilic attack of a free electron pair of oxygen atom of the compound *III* on the neighbouring carbon atom with simultaneous splitting of C–N bond. The electron-withdrawing substituents on the benzene nucleus facilitate the C–N bond splitting and thus the reaction, too. The compound formed is a resonance hybrid with predominant structure *VIIj*.

The more the substituent *R* attracts the electrons the greater is the contribution of the resonance structure *VIIh* with reactive carbonyl group and the easier is the reverse reaction of the  $sp^2$  electron pair of nitrogen with carbonyl carbon atom



giving the compound *III*. The overall reaction *III* → *IV* can then be represented as follows: In the first reaction phase the attraction of electrons into the regions of both benzene nucleus and the substituent R is energetically advantageous, the C—N bond splitting being hereby facilitated. If this electron shift continued until the end of the reaction, the compound of the structure *VIIIh* would be formed. This product is, however, less favoured energetically as compared to the structure *VIIj*. It means that, on the contrary, at a certain point of the reaction coordinate (perhaps near the activated complex) an opposite electron shift up towards the oxygen atom of the carbonyl group being formed begins to be favourable for the reaction.

The second possible reaction mechanism of the conversion *III* → *IV* is an electrocyclic reaction<sup>15</sup> having the activated complex *VIII* which continuously leads to the compound with predominant resonance structure *VIIj*. The explanation of high positive  $\rho$  values of electrocyclic reactions belongs to the competence of quantum chemistry.



The equilibrium constant  $K = k_2/k_{-2}$  of the reaction  $Ia \rightleftharpoons Va$  is much greater than it should be according to the  $\rho$  constant (+2) determined for the monosubstituted derivatives. The reason is that the reverse reaction ( $k_{-2}$ ) is far slower than it should be according to polar effects of the both nitro groups, whereas the value of  $k_2$  does not substantially differ from the theoretical one calculated from Eq. (7). The reverse reaction is obviously affected in the step *IV* → *III* by a strong unfavourable steric effect of *o*-nitro group.

The reaction products *Va–g* can exist in two tautomeric forms *viz.* that with hydrogen at oxygen (*V*) or the corresponding ketonic form having hydrogen atom at nitrogen. The magnitude of the  $\rho$  value of dissociation constants of the compounds *Va–e* can contribute to the decision as to which of the mentioned structures is more likely. The substituted formanilides or acetanilides would be the most suitable reference substances, but we failed to find their dissociation constants in literature. However, data are available<sup>16</sup> for the dissociation constants of substituted sulfanilides ( $\rho = 2.6$ ). This value is roughly 3 times higher than our  $\rho$  value for the compounds *Va–e*, which would suggest that the reaction product has the structure *V*. We intend to continue research on this problem.

## REFERENCES

1. Zincke T.: An. 330, 361 (1903); Ann. 333, 296 (1904).
2. Eisenthal R., Katritzky A. R.: Tetrahedron 21, 2205 (1965).
3. Johnson S. L., Ruman K. A.: Tetrahedron Letters 1966, 1721.
4. Kaválek J., Štěrba V.: This Journal 38, 3506 (1973).
5. Marvell E. N., Shahidi I.: J. Am. Chem. Soc. 92, 5646 (1970).
6. König W.: J. Prakt. Chem. 69, 105 (1904).
7. Albert A., Serjeant E. P.: *Ionization Constants of Acids and Bases*. Methuen, London 1962.
8. Cooksey C. J., Johnson M. D.: J. Chem. Soc. B, 1968, 1191.
9. Ingold C. K.: *Structure and Mechanism in Organic Chemistry*. Cornell University Press, New York 1953.
10. Miller J.: *Aromatic Nucleophilic Substitution*. Elsevier, London 1968.
11. Murto J.: Acta Chim. Scand. 18, 1028 (1964).
12. Bernasconi C. F.: J. Org. Chem. 36, 1325 (1971).
13. Biggs A. I., Robinson R. A.: J. Chem. Soc. 1961, 388.
14. Šejn S. M., Kozorez L. A.: Reakc. Sposob. Org. Sojed. 3, (4), 45 (1966).
15. Marwell E. N., Caple G., Shahidi I.: J. Chem. Soc. 92, 5641 (1970).
16. Dauphin G., Kergomard A., Veschambre H.: Bull. Soc. Chim. France 1967, 3404.

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