

# Stereochemical evidence for the mechanism of alkaline solvolysis of the diesters of amidophosphoric acids

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The mechanism of alkaline solvolysis of the alkyl phenyl esters of anilidophosphoric acid has been discussed on the basis of the measured optical inversion and entropies of activation.

На основе величин энтропий активации и обнаруженной оптической инверсии обсуждается механизм щелочного сольволиза алкил-фениловых эфиров анилидфосфорной кислоты.

The alkaline hydrolysis of the triesters of phosphoric acid [1], diesters of anilidophosphoric acid [2—7], and esters of dianilidophosphoric acid [8] follows the  $S_N2$  mechanism and a substance with five-bonded phosphorus is assumed to be an intermediate. It seems that the collected experimental material is sufficient for verifying the  $S_N2$  mechanism of this reaction. Unfortunately, the information about the geometry of the arising intermediate is very poor though the knowledge of its spatial arrangement would certainly contribute to a better comprehension of that reaction. For this reason, it is useful to pay further attention to this problem.

## Experimental

The ethyl phenyl (*I*) [9] and n-propyl phenyl ester of anilidophosphoric acid (*II*) [10] were prepared according to literature. The methyl phenyl (*III*), isopropyl phenyl (*IV*), and 2-methylpropyl phenyl ester of anilidophosphoric acid (*V*) were prepared from chloride of the phenyl ester of anilidophosphoric acid and alcohol. For the preparation, chloride of the phenyl ester of anilidophosphoric acid (26.7 g; 0.1 mol) was dissolved in 300 cm<sup>3</sup> of benzene and triethylamine (13.9 cm<sup>3</sup>; 0.1 mol) and dry alcohol (0.1 mol) dissolved in 100 cm<sup>3</sup> of benzene were added under stirring into the solution. After adding the total amount of alcohol, the mixture was stirred for 2 h and subsequently heated under reflux for 2 h. On cooling, triethylammonium chloride was sucked, benzene evaporated on a water bath, and the crude product was recrystallized. The results of analyses and the melting points of the substances which have not been described yet are given in Table 1.

The kinetic measurements were performed by using the ampoule technique. The alkaline solvolysis of the alkyl phenyl esters of anilidophosphoric acid was investigated

Table 1  
Characterization of the prepared new compounds

| Compound | Formula<br>$M_r$   | $w_i(\text{calc.})/\%$<br>$w_i(\text{found})/\%$  |       |      |      | M.p.<br>°C | Solvent |               |
|----------|--|---|-------|------|------|------------|---------|---------------|
|          |  | C   | H     | N    | P    |            |         |               |
| III      | (CH <sub>3</sub> O)(C <sub>6</sub> H <sub>5</sub> O)PO(NHC <sub>6</sub> H <sub>5</sub> )                   | C <sub>13</sub> H <sub>14</sub> NO <sub>3</sub> P | 59.32 | 5.36 | 5.32 | 11.77      | 75      | Ether         |
|          |  | 263.22  | 59.00 | 5.20 | 5.39 | 11.65      |         |               |
| IV       | (iso-C <sub>3</sub> H <sub>7</sub> O)(C <sub>6</sub> H <sub>5</sub> O)PO(NHC <sub>6</sub> H <sub>5</sub> ) | C <sub>15</sub> H <sub>18</sub> NO <sub>3</sub> P | 61.85 | 6.23 | 4.81 | 10.63      | 154—155 | Ethanol       |
|          |  | 291.27  | 61.73 | 6.30 | 4.72 | 10.58      |         |               |
| V        | (sec-C <sub>4</sub> H <sub>9</sub> O)(C <sub>6</sub> H <sub>5</sub> O)PO(NHC <sub>6</sub> H <sub>5</sub> ) | C <sub>16</sub> H <sub>20</sub> NO <sub>3</sub> P | 62.95 | 6.60 | 4.59 | 10.14      | 109—111 | Ethanol       |
|          |  | 305.30  | 63.13 | 6.54 | 4.72 | 10.01      |         |               |
| VI       | (CH <sub>3</sub> O)(C <sub>2</sub> H <sub>5</sub> O)PO(NHC <sub>6</sub> H <sub>5</sub> )                   | C <sub>9</sub> H <sub>14</sub> NO <sub>3</sub> P  | 50.24 | 6.56 | 6.51 | 14.39      | 57      | Acetone—water |
|          |  | 215.17  | 51.02 | 6.54 | 6.40 | 14.26      |         |               |

spectrophotometrically by measuring the absorbance of solution at the wavelength of 289.5 nm (absorption maximum of the phenolate ions) in 50 mass % ethanol by means of an instrument Pye-Unicam 8—100. The dependence of  $\log(k_{\text{exp}}/s^{-1})$  on pH was examined in glycinate buffer solutions at  $(70 \pm 0.1)^\circ\text{C}$ . The pH values of buffer solutions were measured with an instrument Radelkis OP-205 by using a hydrogen electrode and silver/silver chloride electrode. The function of the electrode system was checked by the buffer solutions recommended in literature [11]. The temperature dependence was investigated in an NaOH solution of  $0.01 \text{ mol dm}^{-3}$  concentration for three temperatures in the temperature range  $60^\circ\text{C}$ — $80^\circ\text{C}$ . The rate constant  $k_{\text{exp}}$  was calculated from the equation  $\ln[(E_\infty - E_0)/(E_\infty - E)] = k_{\text{exp}}t$  by using the method of least squares. The value of  $E_\infty$  necessary for calculation was obtained by measuring the absorbance after the time equal to the tenfold value of reaction half-life. The rate constant thus obtained was dependent on activity of the lyate ions. The dependence of  $\log(k_{\text{exp}}/s^{-1})$  on pH is given in Table 2. The error of the resulting values was less than  $\pm 5\%$ .

Table 2

Rate constants of solvolysis of the alkyl phenyl esters of anilidophosphoric acid in 50 mass % ethanol at different pH values and the activation parameters of this reaction at 343.14 K and pH 12.74

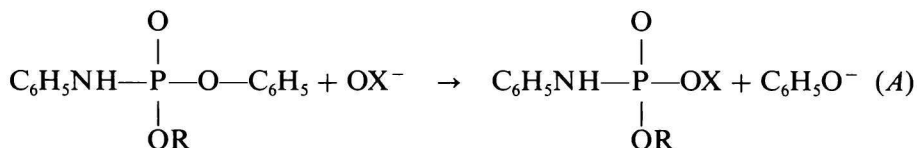
| pH   | $k_{\text{exp}} \text{ } 10^5/s^{-1}$ |           |            |           |
|--|---------------------------------------|-----------|------------|-----------|
|  | <i>I</i>                              | <i>II</i> | <i>III</i> | <i>IV</i> |
| 10.51  | 1.03                                  | —         | 0.746      | —         |
| 10.81  | 1.21                                  | —         | 0.834      | —         |
| 11.19  | 1.81                                  | —         | 2.06       | —         |
| 11.64  | 3.21                                  | 1.31      | 3.34       | 0.624     |
| 12.14  | 4.76                                  | 2.33      | 5.84       | 0.830     |
| 12.74  | 10.22                                 | 7.94      | 22.31      | 2.75      |
| $\Delta H^\ddagger/(kJ \text{ mol}^{-1})$                | 52.6                                  | 67.5      | 68.6       | 66.1      |
| $-\Delta S^\ddagger/(J \text{ mol}^{-1} \text{ K}^{-1})$ | 154                                   | 110       | 100        | 124       |

The optically active phenyl ester of anilidophosphoric acid (*I*) was obtained from an isolated nucleus of monocrystal by free crystallization in acetone solution. The optical activity was measured in methanol solution by using a full-circle polarimeter equipped with a 20 cm cell (Metra, Blansko). The concentration of *I* was equal to  $0.0767 \text{ g cm}^{-3}$ . The optical rotation of this solution was  $[\alpha] (\text{D}, 20^\circ\text{C}) = +8.27^\circ$ . The reaction of *I* with sodium methanolate in the medium of absolute methanol is a transesterification reaction. A chromatographic control (Silufol UV 254-Kavalier, Votice, elution by an ether—benzene mixture with volume ratio = 2:1, detection by iodine vapour) of the progress of methanolysis carried out at laboratory temperature afforded quantitative result after six days. The optically active methyl ethyl ester of anilidophosphoric acid (*VI*) was isolated by the following procedure. A methanolic solution of *VI* and sodium phenolate was saturated with a stream of carbon dioxide up to neutral reaction. After evaporating to

dryness on a water bath, the ester and phenol were extracted with ether and the mixture was chromatographically separated on a silica gel column. The measured optical rotation of *VI* was  $[\alpha]_D(20^\circ\text{C}) = -7.62^\circ$ . The results of analysis and melting points of *VI* are given in Table 1.

### Results and discussion

It results from spectral measurements and syntheses carried out in methanol that the reaction is governed by eqn (A) ( $X = \text{H, alkyl}$ ) and further consecutive reactions involving proton transfer are possible.



The results of kinetic measurements are listed in Table 2. The data corresponding to substance *V* were not measured because of rather slow reaction course. In comparison with diphenyl esters [5], it is obvious that the replacement of aryl by alkyl resulted approximately in a tenfold retardation of the reaction. However, the value of activation entropy as well as the dependence of  $\log(k_{\text{exp}}/\text{s}^{-1})$  on pH of the buffer solution made us draw equal conclusions for both groups of substances. The positive value of the  $\rho^*$  constant in the Taft equation ( $\rho^* = +4.55$ ) also confirms the  $\text{S}_{\text{N}}2$  mechanism of the reaction of this group of substances which is identical with the mechanism observed for other diesters of anilidophosphoric acids [2—7].

This mechanism is based on the idea of a five-bonded phosphorus in the intermediate for which the following possible geometrical arrangements have been proposed: five-sided pyramid, pentagon, trigonal bipyramid, tetragonal pyramid [12], and coin tors [13]. As for these arrangements, however, only trigonal bipyramid allows optical inversion. The energetic differences between individual geometrical formations are small [14] and thus a mutual transformation of each other cannot be excluded. Likewise, we may expect an intramolecular exchange of positions of individual substituents [15]. A sufficiently rapid exchange of positions of individual substituents in the intermediate exhibiting the form of trigonal bipyramid as well as the presence of all other geometrical arrangements of the intermediate should result in racemization of reaction products. The kinetic experiments of this study were carried out with a mixture of optical isomers. They are not sufficient for identification of the assumed intermediate. For this reason, substance *I* was separated in optical isomers. After their solvolysis in methanolate, we observed optical inversion. This observation gives evidence that the intermediate had the structure of trigonal

bipyramid and a change in geometrical arrangement of this structure was kinetically insignificant. It may be that the mutual exchange of positions of the substituents of trigonal bipyramid is very slow because the optical inversion was also observed for the derivatives of phosphoric acid containing much simpler substituents [16]. These experiments confirm the  $S_N2$  mechanism of alkaline solvolysis of the diesters of anilidophosphoric acid and point out that only the trigonal bipyramid may be regarded as an ascertained intermediate. Its origination may be due to a stereospecific attack of nucleophile. This view is also supported by the data in Table 2. Substances *I*—*IV* differ from one another only by alkyls the induction effects of which are not too different. Nevertheless, the rate constants of their solvolysis are quite different. This fact is to be comprehended only if the steric effects of alkyls have significant influence on the rate of reaction which may, however, manifest itself merely in a stereospecific attack of nucleophile. Therefore the smallest rate constant found for *IV* may be interpreted as a consequence of steric screening of the nucleophilic centre. The dependence of the rate constant of solvolytic reaction on steric relations observed by other authors, too [17] confirms the idea of stereospecific attack of nucleophile [18]. Thus we may assume that not only the mechanism but also the direction of attack of nucleophile and the structure of intermediate in solvolytic reaction are equal for a wide class of compounds on the base of the esters of phosphoric acid.

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