Solvolysis Reactions of 3-Pyridyl and 8-Quinolyl Phosphate

By YUKITO MURAKAMI,* JUNZO SUNAMOTO, and HIROMI SADAMORI
(*Department of Organic Synthesis, Faculty of Engineering, Kyushu University, Hakozaki, Fukuoka* 812, *Japan*)

Summary The reactive species in the hydrolysis reactions of 3-pyridyl and 8-quinolyl phosphate are the neutral zwitterion and the monoionic form, the thorium(IV) ion having a marked catalytic effect on the hydrolysis of both phosphates.

RECENTLY, the solvolysis of various organic phosphates has been investigated to study their biological significance. However, only limited investigations on the hydrolysis of organic phosphates which contain heteroaromatic moieties have been performed. Even though the effect of metal ions on the hydrolysis of phosphate monoesters is one of the interesting aspects of metal-ion catalysis, there is little mechanistic information on this catalytic reaction. The hydrolyses of 2-, 3-, and 4-pyridylmethyl phosphate, the first example of organic phosphates containing the pyridine moiety, have been investigated by us, in the absence and in the presence of metal ions.[1,2]

We report kinetic data for the spontaneous and the metal-ion-catalysed hydrolyses of 3-pyridyl (3-PP) and 8-quinolyl phosphate (8-QP) as well as evidence for the participation of the neighbouring ring nitrogen in the catalytic reaction. The spontaneous hydrolyses of both phosphates were carried out at 60°, 70°, and 80°, at an ionic strength of 0·10 in aqueous media, over the pH range 1·0—7·0. Excellent pseudo-first-order plots were obtained for the hydrolyses in the absence of metal ions. The specific rate constants for each ionic species of the phosphates were calculated and assigned using fractional molar concentrations evaluated from the acid dissociation constants. They are listed in Table 1, along with the evaluated activation parameters.

The reactive species are clearly the neutral zwitterion (H_2L) and the monoionic form (HL); the following relationship is valid:

$$k_{\mathrm{obs}} = k_{\mathrm{H_2L}} \cdot X_{\mathrm{H_2L}} + k_{\mathrm{HL}} \cdot X_{\mathrm{HL}} + k_{\mathrm{H^+}} \cdot [\mathrm{H^+}]$$

where $X_{\mathrm{H_2L}}$ and X_{HL} refer to mole-fractions of the neutral and of the monoionic species, $k_{\mathrm{H_2L}}$ and k_{HL} are specific rate constants for each ionic species, respectively, and $k_{\mathrm{H^+}}$ stands for the rate constant for acid-catalysis.

The hydrolysis reactions in the presence of the metal ions, $\mathrm{Cu^{II}}$, $\mathrm{Ni^{II}}$, $\mathrm{Fe^{III}}$, and $\mathrm{Th^{IV}}$, for both phosphates were also carried out at an ionic strength of 0·10 and the results are given in Table 2. The copper ion showed a significant effect only on the hydrolysis of 8-QP and the apparent

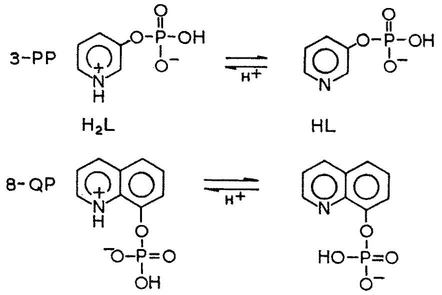

TABLE 1

Specific rate constants and activation parameters for the spontaneous hydrolysis reactions of 3-PP *and* 8-QP at 60°, 70°, and 80° and $\mu = 0{\cdot}10$

	T	$k_{\mathrm{H_2L}}$ hr.$^{-1}$	$E_{\mathrm{H_2L}}$ kcal. mol^{-1}	$\Delta H^{\ddagger}_{\mathrm{H_2L}}$ kcal. mol^{-1}	$\Delta S^{\ddagger}_{\mathrm{H_2L}}$ e.u.	k_{HL} hr.$^{-1}$	E_{HL} kcal. mol^{-1}	$\Delta H^{\ddagger}_{\mathrm{HL}}$ kcal. mol^{-1}	$\Delta S^{\ddagger}_{\mathrm{HL}}$ e.u.
3-PP	80°	0·901[a]	28·0	27·3	+2	0·207[a]	30·7	30·0	+7
	70°	0·277[a]				0·075[a]			
	60°	0·082[a]				0·015[a]			
8-QP	80°	0·2870[b]	27·0	26·3	+3	0·1430[b]	36·5	35·8	+22
	70°	0·0840[b]				0·0286[b]			
	60°	0·0286[b]				0·0063[b]			

[a] Rate constant calculated from: $\mathrm{p}K_{\mathrm{H_3L}} = 1{\cdot}0$; $\mathrm{p}K_{\mathrm{H_2L}} = 3{\cdot}85$; $\mathrm{p}K_{\mathrm{HL}} = 5{\cdot}62$, at 50°.
[b] Rate constant calculated from: $\mathrm{p}K_{\mathrm{H_3L}} = 1{\cdot}0$; $\mathrm{p}K_{\mathrm{H_2L}} = 4{\cdot}16$; $\mathrm{p}K_{\mathrm{HL}} = 6{\cdot}29$, at 80°.

TABLE 2

Metal-ion-catalysed hydrolysis reactions of 3-PP *and* 8-QP at $\mu = 0{\cdot}10$[a]

	$-\log[\mathrm{H^+}]$	T	M^{n+}	K_c^b, hr.$^{-1}$	k_o^c, hr.$^{-1}$	k_c/k_o
8-QP	2·03	80°	$\mathrm{Cu^{2+}}$	0·6699	0·2767	2·42
	2·02	80°	$\mathrm{Ni^{2+}}$	0·2791	0·2767	1·01
	1·90	80°	$\mathrm{Fe^{3+}}$	0·2635[e]	0·2751	0·96
	1·88	25°	$\mathrm{Th^{4+}}$	0·4305[e]	$3{\cdot}2 \times 10^{-4}$[d]	$1{\cdot}3 \times 10^{3}$
3-PP	2·03	70°	$\mathrm{Cu^{2+}}$	0·2603	0·2702	0·96
	2·02	70°	$\mathrm{Ni^{2+}}$	0·2681	0·2696	0·99
	1·90	70°	$\mathrm{Fe^{3+}}$	0·1034[e]	0·2672	0·39
	1·88	25°	$\mathrm{Th^{4+}}$	1·3265[e]	$5{\cdot}0 \times 10^{-4}$[d]	$2{\cdot}7 \times 10^{3}$

[a] $T_{\mathrm{E}} = T_{\mathrm{M}} = 2{\cdot}0 \times 10^{-3}$M, where T_{E} and T_{M} stand for the total molar concentration of the substrate species and of the metal ion, respectively. [b] k_c is the apparent rate constant of the metal-ion-catalysed hydrolysis. [c] k_o is the rate constant for spontaneous hydrolysis. [d] Calculated using the activation energy. [e] Deviated from the first-order plot.

first-order rate constant increased markedly as the hydrogen ion concentration was raised: $k_{\mathrm{Cu^{II}}} = 2{\cdot}00 \times 10^2$ hr.$^{-1}$ M^{-1} at 80°, according to the following equation:

$$k_{\mathrm{obs}} = k_{\mathrm{H_2L}} \cdot X_{\mathrm{H_2L}} + k_{\mathrm{H^+}}[\mathrm{H^+}] + k_{\mathrm{Cu^{II}}}[\mathrm{Cu^{2+}}]$$

This significant effect of the copper ion on the 8-QP hydrolysis may be attributed to the ease of complex-formation of the substrate with the metal ion at the first step where the seven-membered chelate ring conformation was attained, and to the large formation constant of the oxine–copper(II) complex.[3] The thorium ion also showed a remarkable catalytic effect on the hydrolyses of both phosphates even in an acidic medium ($\mathrm{pH} < 2{\cdot}0$) at relatively low temperatures ($< 25°$). Since the catalytic effect does not show the large structural dependency observed in the copper-ion-catalysed reaction, the primary process must involve the interaction between thorium(IV) and the phosphate moiety of the substrates.[2]

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[2] Y. Murakami and M. Takagi, *Bull. Chem. Soc. Japan*, in the press.

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