

989. Triazanaphthalenes. Part III.¹ Kinetics of the Reversible Addition of Water to 1,3,8-Triazanaphthalene, 2-Hydroxy-1,3,8-triazanaphthalene, and 3-Hydroxy-1,4,6-triazanaphthalene.

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Reversible addition of a molecule of water to the three triazanaphthalenes named in the title is acid-base-catalysed. Reaction rates are compared with those for pteridine and 2- and 6-hydroxypteridine, respectively, from which the triazanaphthalenes differ only in lacking one of the nitrogen atoms in the ring not directly concerned in addition of water.

CATIONS of 1,3,5-, 1,3,6-, 1,3,7-, 1,3,8-, and 1,4,6-triazanaphthalenes exist predominantly as the covalently hydrated species.²⁻⁴ Similarly, the neutral molecules of 2-hydroxy-1,3,8- and 3-hydroxy-1,4,6-triazanaphthalene are appreciably hydrated, while the anions are almost anhydrous (for equilibrium ratios of "hydrated" to "anhydrous" species, see ref. 1). Similar behaviour is shown by pteridine and its 2- and its 6-hydroxy-derivative, and kinetic studies of their reversible acid-base-catalysed hydration have recently been made.⁵⁻⁷ We have extended these studies to 1,3,8-triazanaphthalene, 2-hydroxy-1,3,8-triazanaphthalene, and 3-hydroxy-1,4,6-triazanaphthalene which differ from pteridine and 2- and 6-hydroxypteridine, respectively, only in lacking one of the nitrogen atoms in the ring not directly concerned in addition of water.

Materials, methods, and calculations followed those described previously.^{5,8}

RESULTS

Table 1 summarises first-order rate constants, obtained at 20° and an ionic strength of 0.1 (adjusted by addition of sodium chloride) for the reversible hydration of 1,3,8-triazanaphthalene. Where the final pH exceeded 4.4, $\sim 8 \times 10^{-5}$ M-solutions in 4×10^{-3} M-hydrochloric acid were mixed with buffer solutions in the rapid-reaction apparatus and the time-dependent optical-density changes were recorded on a Shimadzu model RS-27 spectrophotometer. Otherwise, neutral solutions of 1,3,8-triazanaphthalene were mixed with buffered acidic solutions. The composite rate constants, k_h and k_d , for hydration and dehydration were obtained from

¹ Part II, Albert and Barlin, preceding paper.

² Armarego, *J.*, 1962, 4094.

³ Perrin and Inoue, *Proc. Chem. Soc.*, 1960, 342.

⁴ Albert, Howell, and Spinner, *J.*, 1962, 2595.

⁵ Inoue and Perrin, *J.*, 1963, 2648.

⁶ Inoue and Perrin, *J. Phys. Chem.*, 1962, **66**, 1689.

⁷ Inoue and Perrin, *J.*, 1963, 4803.

⁸ Inoue and Perrin, *J.*, 1963, 3936.

k_{obs} in the same way as for pteridine.⁵ Although k_{h} varies over a 90,000-fold range, the pH-rate profile for hydration can be represented, with an average deviation of 9%, by the equation

$$k_{\text{h}} = \alpha a_{\text{H}^+} + \beta + \gamma/a_{\text{H}^+},$$

when $\alpha = 248$, $\beta = 4 \times 10^{-6}$, and $\gamma = 9.37 \times 10^{-15}$. The minimum in the reaction rate occurs at pH 8.2. The corresponding values for pteridine⁵ are $\alpha = 354$, $\beta = 2.40 \times 10^{-5}$, $\gamma = 4.06 \times 10^{-13}$, and minimum pH = 7.47.

Similar measurements, after addition of solutions of the neutral molecule of 2-hydroxy-1,3,8-triazanaphthalene to alkaline buffers (final pH >9.69), or of solutions of the anion in 8×10^{-3} M-sodium hydroxide to neutral or weakly alkaline buffers (pH <10), afforded the first-order rate constants in Table 2. For 3-hydroxy-1,4,6-triazanaphthalene the corresponding pH regions

TABLE 1.

First-order rate constants (sec.⁻¹) for hydration and dehydration of 1,3,8-triazanaphthalene at 20° and $I = 0.1$. Analytical wavelength = 303 m μ if pH <4.2, otherwise 280 m μ .

pH	$10^3 k_{\text{obs}}$	$10^3 k_{\text{h}}$	$10^3 k_{\text{d}}$	pH	$10^3 k_{\text{obs}}$	$10^3 k_{\text{h}}$	$10^3 k_{\text{d}}$	pH	$10^3 k_{\text{obs}}$	$10^3 k_{\text{h}}$	$10^3 k_{\text{d}}$
2.39	791	766	25.9	4.48	35.9	7.00	28.9	6.63	17.8	0.0658	17.7
2.67	550	516	33.3	4.67	36.6	4.99	31.7	6.82	16.7	0.0515	16.7
2.86	370	336	33.6	4.88	30.2	2.70	27.5	7.02	12.3	0.0330	12.3
3.06	280	242	38.2	5.08	33.1	1.95	31.2	7.59	4.93	0.0108	4.92
3.25	190	153	37.4	5.27	30.7	1.21	29.5	8.44	3.20	0.00605	3.19
3.44	150	103	38.9	5.46	28.2	0.690	27.5	9.16	9.18	0.0185	9.16
3.66	70.0	46.6	27.0	5.61	26.6	0.637	26.0	9.53	18.5	0.0370	18.5
3.95	55.6	25.0	30.7	5.95	27.7	0.279	27.5	9.71	25.0	0.0500	25.0
4.09	44.7	16.6	28.1	6.20	24.8	0.163	24.7	9.95	37.0	0.0740	36.9
4.14	51.4	17.8	33.7	6.43	21.3	0.0998	21.2	10.29	82.8	0.166	82.6
4.32	47.0	12.2	34.8								

TABLE 2.

First-order rate constants (in sec.⁻¹) for hydration and dehydration of 2-hydroxy-1,3,8-triazanaphthalene and 3-hydroxy-1,4,6-triazanaphthalene at 20° and $I = 0.1$.

2-Hydroxy-1,3,8-triazanaphthalene; λ (analyt.) = 350 m μ .

pH	$10^3 k_{\text{obs}}$	$10^3 k_{\text{h}}$	$10^3 k_{\text{d}}$	pH	$10^3 k_{\text{obs}}$	$10^3 k_{\text{h}}$	$10^3 k_{\text{d}}$	pH	$10^3 k_{\text{obs}}$	$10^3 k_{\text{h}}$	$10^3 k_{\text{d}}$
4.80	1200	1080	120	7.58	3.96	3.63	0.329	9.85	2.84	1.66	1.18
5.03	815	733	81.5	7.84	2.59	2.32	0.272	9.90	2.76	1.56	1.21
5.26	479	432	47.9	8.09	1.92	1.71	0.208	10.05	3.00	1.47	1.53
5.48	292	263	29.2	8.28	1.69	1.50	0.191	10.19	3.18	1.36	1.85
5.78	150	135	15.0	8.43	1.57	1.38	0.186	10.37	4.14	1.42	2.73
6.30	51.9	46.7	5.20	8.67	1.56	1.30	0.258	10.50	5.24	1.51	3.72
6.46	39.7	35.7	3.99	8.95	1.62	1.36	0.257	10.62	5.77	1.42	4.36
6.64	27.2	24.5	2.74	9.12	2.08	1.70	0.383	11.00	11.2	1.66	9.53
6.84	18.7	16.8	1.88	9.25	2.18	1.72	0.457	11.24	18.6	2.11	16.5
7.06	11.9	10.7	1.20	9.46	2.60	1.91	0.687	11.43	28.8	2.74	26.0
7.28	7.05	6.32	0.715	9.68	2.53	1.67	0.863	11.79	51.6	3.93	47.8

3-Hydroxy-1,4,6-triazanaphthalene; λ (analyt.) = 355 m μ at pH <7.06, otherwise 350 m μ .

pH	$10^4 k_{\text{obs}}$	$10^4 k_{\text{h}}$	$10^4 k_{\text{d}}$	pH	$10^4 k_{\text{obs}}$	$10^4 k_{\text{h}}$	$10^4 k_{\text{d}}$	pH	$10^4 k_{\text{obs}}$	$10^4 k_{\text{h}}$	$10^4 k_{\text{d}}$
3.69	2010	624	1390	7.06	3.53	0.794	2.74	9.65	134	0.301	133
4.02	977	303	673	7.28	2.78	0.531	2.25	9.85	186	0.275	186
4.39	447	139	309	7.35	2.46	0.439	2.02	10.05	201	0.200	201
4.80	160	49.7	110	7.79	2.95	0.301	2.65	10.19	397	0.306	397
5.03	111	34.3	76.6	8.09	2.57	0.158	2.41	10.37	433	0.244	433
5.48	35.5	10.9	24.6	8.04	3.87	0.261	3.61	10.50	822	0.378	822
5.48	32.9	10.3	22.8	8.41	6.86	0.225	6.62	11.00	1870	0.482	1870
6.20	6.71	1.98	4.73	8.77	13.1	0.200	12.9	11.24	2940	0.640	2940
6.30	7.73	2.25	5.48	9.14	34.5	0.236	34.4	11.43	3840	0.760	3840
6.75	4.43	1.16	3.27	9.30	49.7	0.238	49.4	11.63	6300	1.17	6300
6.84	4.63	1.17	3.46	9.32	62.4	0.286	62.1	11.79	8410	1.50	8410
7.06	3.73	0.840	2.89	9.49	88.7	0.281	88.3				

TABLE 3.
Individual rate constants * to fit the pH-rate profiles at 20° for hydration and dehydration.

(i) Hydration				
	$10^{-2}k_1$	$10^4(k_2[\text{H}_2\text{O}] + k_3K_a^X)$	$10^{13}(k_4K_w + k_5K_a^X[\text{H}_2\text{O}])$	k_6
<i>Triazanaphthalene</i>				
2-OH-1,3,8-	859	8.42	8.29	0.89
3-OH-1,4,6-	3.26	0.617	9.72	4.3
<i>Pteridine</i>				
2-OH- †	630	110	100	0.22
6-OH- ‡	18.1	9.81	113	4.29
(ii) Dehydration				
	k_{-1}	$10^6(k_{-2}[\text{H}_2\text{O}] + k_{-3}K_a^Y)$	$10^{14}(k_{-4}K_w + k_{-5}K_a^Y[\text{H}_2\text{O}])$	k_{-6}
<i>Triazanaphthalene</i>				
2-OH-1,3,8-	9550	93.5	9.21	14.0
3-OH-1,4,6-	724	137	216	286
<i>Pteridine</i>				
2-OH- †	196	34.2	3.11	1.55
6-OH- ‡	13.8	7.49	8.63	91.2

* k_1 , k_2 , and k_4 refer to hydration of HX as catalysed by hydronium ions, water molecules, and hydroxyl ions, respectively; k_3 , k_5 , and k_6 are for the corresponding reactions of the anion, X^- .
† Inoue and Perrin, *J. Phys. Chem.*, 1962, **66**, 1689. ‡ Inoue and Perrin, *J.*, 1963, 4803.

were >7.35 and <7.06 , respectively. Analyses of the pH-rate profiles enabled the coefficients in equations (1) and (2) * to be evaluated.

$$k_h(a_{\text{H}^+} + K_a^X) = k_1 a_{\text{H}^+}^2 + (k_2[\text{H}_2\text{O}] + k_3 K_a^X) a_{\text{H}^+} + (k_4 K_w + k_5 K_a^X [\text{H}_2\text{O}]) + \frac{k_6 K_a^X K_w}{a_{\text{H}^+}}; \quad (1)$$

$$k_d(a_{\text{H}^+} + K_a^Y) = k_{-1} a_{\text{H}^+}^2 + (k_{-2}[\text{H}_2\text{O}] + k_{-3} K_a^Y) a_{\text{H}^+} + (k_{-4} K_w + k_{-5} K_a^Y [\text{H}_2\text{O}]) + \frac{k_{-6} K_a^Y K_w}{a_{\text{H}^+}}; \quad (2)$$

where K_a^X and K_a^Y are the proton dissociation constants of the "anhydrous" and the "hydrated" species, respectively. These coefficients are given in Table 3, where previous values for 2- and 6-hydroxypteridine are included.

DISCUSSION

The ring of the cation of "hydrated" 1,3,8-triazanaphthalene is opened much more slowly than that of the corresponding cation of pteridine,^{2,5} so that this reaction did not interfere in the present kinetic studies.

Comparison of the coefficients, α , β , and γ , shows that the acid-catalysed hydrations of 1,3,8-triazanaphthalene and pteridine have comparable rates but that the neutral and the base-catalysed reaction of the former are, respectively, only 1/6 and 1/43 as fast as those of the latter. In discussing the dehydration of 3,4-dihydro-4-hydroxypteridine it was suggested⁵ that the levelling-out of values of k_d , but not of k_h , as solutions were made more acid, was due to hydronium-ion catalysis which occurred only by formation of the corresponding cations, the pK_a value of the anhydrous species lying below the pH region in which measurements could be made. Results for hydrated 1,3,8-triazanaphthalene (pK_a 6.56) confirm this interpretation. The pH-rate profile for k_d , shown in the Figure, is V-shaped between pH 6.82 and 10.29, but levels out and remains constant over the pH

range 2.39—5.27. The maximum ratio $k_h : k_d$ provides, therefore, a lower estimate of the degree of hydration of the cations. From results at pH 2.39 we obtain

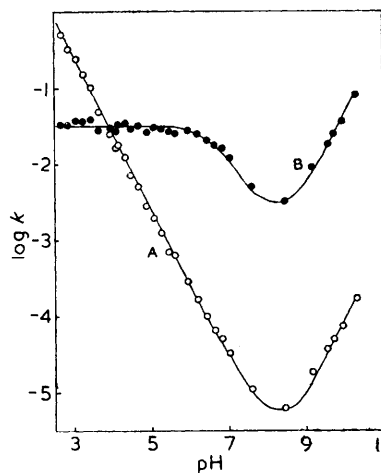
$$[\text{HY}^+]_{\text{eq}}/[\text{HX}^+]_{\text{eq}} > 29.$$

The pH-rate profile can be fitted by the equation⁵

$$k_d(K_a^Y + a_{\text{H}^+}) = k_d' a_{\text{H}^+} + k_d'' K_a^Y + k_d''' K_w K_a^Y / a_{\text{H}^+},$$

with $k_d' = 3.23 \times 10^{-2}$, $k_d'' = 2 \times 10^{-3}$, and $k_d''' = 615$. The corresponding figures for pteridine are 2.36×10^{-2} , 8.45×10^{-5} , and 210, respectively,⁵ so that the acid-catalysed rates of dehydration are similar, but the uncatalysed and the base-catalysed dehydration of hydrated 1,3,8-triazanaphthalene are appreciably the faster. The diminished hydration

pH-rate profiles at 20° and $I = 0.1$ for the reversible hydration of 1,3,8-triazanaphthalene. (A) $\log k_h$. (B) $\log k_d$.



of the neutral molecule of 1,3,8-triazanaphthalene, relative to pteridine (about 0.2% and 22%, respectively) is thus due to slower hydration and faster dehydration than for pteridine.

The extent of hydration of 2-hydroxy-1,3,8-triazanaphthalene (90%) is also less than for 2-hydroxypteridine (99.7%); this is also true of the pair, 3-hydroxy-1,4,6-triazanaphthalene (32%) and 6-hydroxypteridine (99.2%). Table 3 shows that in both these cases the triazanaphthalene is dehydrated faster than the pteridine, and also that 3-hydroxy-1,4,6-triazanaphthalene is hydrated more slowly than 6-hydroxypteridine.

These facts are explicable in terms of diminished electron-withdrawal from the carbon atom at the site of addition of water, consequent upon the replacement of one of the nitrogen atoms in the other ring by a CH group. The reduction in positive charge retards the nucleophilic attack by a water molecule or a hydroxyl ion which has been suggested as the rate-determining step.⁶ This makes hydration more difficult. For the same reason, loss of water from the covalently hydrated species is facilitated. However, differences in the observed rates and equilibria cannot be discussed quantitatively.⁸

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