# Hydrolysis of Nitrophenyl Sulphates

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THE biological importance of aryl sulphate esters has prompted many workers in recent years to investigate the mechanism of their hydrolysis.[1-4] The spontaneous,[1] perchloric acid-,[2] base-,[1] and amine-catalyzed[1] hydrolyses of *p*-nitrophenyl sulphate and carboxyl group participation in salicyl sulphate[3] hydrolysis have been reported. Very recently a considerable copper(II) ion catalysis has been observed in 8-hydroxyquinoline sulphate hydrolysis.[4] It has been suggested that the hydrolysis of sulphate esters containing good leaving groups might substantiate the unimolecular

TABLE

*Hydrolysis of nitrophenyl sulphates in aqueous solutions*

| | | *o*-Nitrophenyl sulphate | *m*-Nitrophenyl sulphate | *p*-Nitrophenyl sulphate | 2,4-Dinitrophenyl sulphate | 2,5-Dinitrophenyl sulphate |
|---|---|---|---|---|---|---|
| *Spontaneous hydrolysis*[a] | | | | | | |
| | $10^6 k_0$ (sec.$^{-1}$) at 100·00° | 6·94 | 0·310 | 3·9[b] | 22,900 | 1170 |
| | $E$ (kcal. mole$^{-1}$)[c] | 24·7 | | 18·5[e] | 18·8 | 19·4 |
| | $\Delta S^{\ddagger}$ (e.u.)[d] | −17·4 | | −18·5[e] | −18·0 | −17·0 |
| *Base-catalysed hydrolysis* | | | | | | |
| | $\frac{k(1{\cdot}00\text{M-NaOH})}{k_0}$ | 10·3[f] | | | 16·3[g] | 8·2[f] |
| *Acid-catalysed hydrolysis* | | | | | | |
| 1·00M-$HClO_4$ | $10^5 k_{\psi}$ (sec.$^{-1}$) at 25·00° | 1·70 | 0·958 | 2·35 | 12·4 | 5·17 |
| | $E$ (kcal. mole$^{-1}$)[c] | 23·9 | 25·2 | 22·2 | 21·6 | 21·8 |
| | $\Delta S^{\ddagger}$ (e.u.)[h] | −5·5 | 1·6 | −6·0 | −5·0 | −4·0 |
| $\phi$[i] | HCl | −0·07 | −0·03 | −0·05 | −0·10 | −0·10 |
| | $HClO_4$ | −0·20 | −0·39 | −0·39 | −0·46 | −0·38 |
| | $H_2SO_4$ | −0·15 | −0·20 | −0·20 | −0·32 | −0·14 |

[a] Mean of several rate constants in the pH 5—10 region.
[b] Extrapolated from ref. 1.
[c] Calculated from the corresponding rate constants obtained at 75·00° or 45·00°.
[d] Calculated at 75·00°.
[e] From ref. 1.
[f] Calculated at 100·00°.
[g] Calculated at 45·00°.
[h] Calculated at 25·00°.
[i] $\phi$ = slope of plots of $\log k_{\psi} + H_0$ against $\log C_{H^+} + H_0$ at 25·00° in the 1·00—6·00M-acid range.

mechanism.[1] Although 2,4- and 2,5-dinitrophenyl sulphates provide such good leaving groups, their preparation and consequently the kinetic investigation of their hydrolysis have so far eluded the attention of chemists. We, therefore, have undertaken a systematic investigation of both mono- and di-nitrophenyl sulphates and report our initial observations.

The *o*-, *m*-, and *p*-nitrophenyl sulphates were prepared by the method of Burkhardt and Wood.[5] For the dinitrophenyl sulphates this procedure was modified to minimize solvolysis, and purification was effected by the addition of acetonitrile, centrifugation, and rotary evaporation followed by the same procedure but using a minimum amount of cold ethanol–water. The hydrolyses were followed spectroscopically to at least 90% completion; excellent pseudo-first-order plots were obtained. The results are summarized in the Table. The pH–rate profile for all the sulphate esters is characterized by a plateau in the pH 4—10 region. At lower pH values the hydrolysis is acid-catalyzed and at higher ones it is base-catalyzed, the former being more pronounced. A very good linear free-energy plot of $\log k_0$ at 100·00° (mean of several rate constants in the pH 5—10 region) against the p$K_a$ of the corresponding phenol was obtained with a slope of 1·2, which indicates the importance of the electron-withdrawing power of the leaving group. The addition of sodium chloride (up to 3·00 M) and sodium sulphate (up to 1·00 M) does not appreciably change $k_0$ for 2,4-dinitrophenyl sulphate; however, the presence of 0·01M-CTAB (cetyltrimethylammonium bromide) increases both $k_0$ and the base-catalyzed rate by a factor of 2. The present data for the spontaneous hydrolysis are compatible with a unimolecular elimination of $SO_3$, but the negative entropies of activation clearly indicate considerable involvement of water molecules in the transition state.

Moderately concentrated acids (1·00—6·00M) greatly enhance the rate of aryl sulphate hydrolysis. Once again, a plot of $\log k_{\psi}$ at 25·00° for 1·00M-$HClO_4$ against the p$K_a$ of the phenol is linear with a slope of 0·23. It is apparent that $k_0$ is more sensitive than $k_{\psi}$ to the electron-withdrawing power of the leaving group. The entropies of activation, Hammett plots, and the $\phi$ values obtained[6] are consistent with a unimolecular mechanism with little or no water participation in the transition state. The parameter $\phi$ is related to the effect of activity coefficients on reaction rate,[6] and the values obtained (Table) signify that different acids catalyze the hydrolysis of aryl sulphates to a different extent.[7]

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[1] S. J. Benkovic and P. A. Benkovic, *J. Amer. Chem. Soc.*, 1966, **88**, 5504.

[2] J. L. Kice and J. M. Anderson, *J. Amer. Chem. Soc.*, 1966, **88**, 5242.

[3] S. J. Benkovic, *J. Amer. Chem. Soc.*, 1966, **88**, 5511.

[4] R. W. Hay and J. A. G. Edmonds, *Chem. Comm.*, 1967, 967.

[5] G. N. Burkhardt and H. Wood, *J. Chem. Soc.*, 1929, 141.

[6] J. F. Bunnett and F. P. Olsen, *Canad. J. Chem.*, 1966, **44**, 1917.

[7] C. A. Bunton and J. H. Fendler, *J. Org. Chem.*, 1966, **31**, 3767, have reported similar effects in the acid-catalyzed hydrolysis of carboxylic anhydrides and interpreted their observations in terms of electrolyte effects of the acids on the activity coefficients of the anhydrides.