Neutral and Alkaline Hydrolysis of 2,4,6-Trimethylbenzenesulphonyl Chloride

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The kinetics of the alkaline hydrolysis of 2,4,6-trimethylbenzenesulphonyl chloride have been re-studied. Contrary to a previous report, the reaction does depend on the concentration of nucleophile. This eliminates the only hitherto undisputed example of an S_N1 mechanism in nucleophilic substitution at sulphur.

THE kinetics of the neutral and alkaline hydrolysis of aromatic sulphonyl chlorides have been investigated previously.[1-5] However, there has been no agreement hitherto about the mechanism. Solvent and substituent effects on the rate of the neutral hydrolysis have been interpreted as suggesting either a mixed S_N1–S_N2 mechanism or a change in mechanism from S_N2, for substrates with electron-withdrawing substituents, to S_N1, for substrates with electron-releasing substituents in the organic system. Much of the argument in favour of the S_N1 mechanism was based on estimation of the number of water molecules involved in the formation of the transition complex from a plot of log *k vs.* log[H_2O]. This mechanistic approach is generally unwarranted as long as the effect of water as solvent cannot be separated from its effect as nucleophile. This is particularly so in the case of nucleophilic substitution of a sulphonyl sulphur atom: it has been shown recently that specific solvation by water is also very important in unmistakably bimolecular reactions.[5]

However, the interpretation of one experimental observation was fairly straightforward. The hydrolysis of 2,4,6-trimethylbenzenesulphonyl chloride was found to be independent of [OH^-] within experimental error.[1] This result shows that the alkaline hydrolysis is not faster than the neutral hydrolysis or, in other words, that the substrate shows little selectivity with regard to the nucleophile. Since a much higher rate of reaction would be expected for the alkaline hydrolysis than for the neutral hydrolysis if the latter follows the S_N2 mechanism,[6] 2,4,6-trimethylbenzenesulphonyl chloride has been considered to react by an S_N1 mechanism and this interpretation has already been included in an organic chemistry textbook.[7] More recently, Hambly,[3] even though disagreeing with some of the previous interpretations of the mechanism of hydrolysis of sulphonyl chlorides in general, supported the S_N1 mechanism for the neutral hydrolysis of 2,4,6-trimethylbenzenesulphonyl chloride because of the linearity of the plot of log *k vs.* Y, the ionizing power of the solvent.[8]

However, we found it difficult to believe that a sulphonyl derivative would be able to react unimolecularly, since experiments on sulphenyl derivatives, which should be more prone to follow such a mechanism, have failed so far to produce a single example which could suggest the formation of sulphenium ions in nucleophilic substitutions.[9] We therefore repeated Vizgert's experiment[1] using the same experimental conditions † except for a slightly lower temperature and higher OH^- concentrations. The alkaline hydrolysis of 2,4,6-trimethylbenzenesulphonyl chloride was found to be first-order in both substrate and OH^-. The second-order rate constant is 15·1 l mol^{-1} s^{-1} in water–dioxan (x_{H_2O} = 0·825). The rate of the neutral hydrolysis at the same temperature, in the same solvent medium, is $1{\cdot}25 \times 10^{-3}$ s^{-1}. These data eliminate the otherwise undisputed proof of an S_N1 mechanism in nucleophilic substitution at sulphur. The previous observation[1] might have arisen from the experimental difficulties involved in following very fast reactions at a time when stopped-flow spectrophotometers were not readily available.

Velocity constants for the neutral and the alkaline hydrolysis of 2,4,6-trimethylbenzenesulphonyl chloride[a] in water–dioxan at 25 °C

Nucleophile	x_{H_2O}	k/l mol^{-1} s^{-1}	$10^2k'$/s^{-1}
OH^-[b]	0·825	15·1	
H_2O	0·825	$4{\cdot}43 \times 10^{-5}$[c]	0·125
H_2O	0·950		2·0
H_2O	0·975		4·1
H_2O	0·986		5·5
H_2O	0·994		6·9
H_2O	0·998		8·1

[a] Substrate concn. *ca.* 10^{-4} mol l^{-1}. [b] [OH^-] = 0·023—0·046 mol l^{-1}. [c] [H_2O] = 28·2 mol l^{-1}.

Thus, the linearity of the plot of log *k vs.* Y remains the only experimental datum in accord with an S_N1 mechanism, as suggested by Hambly.[3] We have extended the range of water concentration in the water–dioxan solvent system measured by Hambly (x_{H_2O} = 0·823—0·903) up to almost pure water and we confirm that such a plot is almost linear from x_{H_2O} = 0·823 to 0·998. However, this evidence is too scanty for us to maintain that the neutral hydrolysis follows the S_N1 mechanism, especially if one considers the large difference in rates between the alkaline and the neutral

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† Some of the data in the Chemical Abstract[1] may be misleading. Consult the original reference (Table 4) or ref. 2.

[1] R. V. Vizgert, *Zhur. obshchei Khim.*, 1962, **32**, 628 (*Chem. Abs.*, 1963, **58**, 428f).

[2] R. V. Vizgert, *J. Gen. Chem.* (*U.S.S.R.*), 1962, **32**, 619; R. V. Vizgert, *Russ. Chem. Rev.*, 1963, **32**, 1, 14.

[3] M. L. Tonnett and A. N. Hambly, *Austral. J. Chem.*, 1971, **24**, 703, and references therein.

[4] O. Rogne, *J. Chem. Soc.* (*C*), 1968, 1294.

[5] L. J. Stangeland, L. Senatore, and E. Ciuffarin, *J.C.S. Perkin II*, 1972, 852.

[6] A. Streitwieser, jun., 'Solvolytic Displacement Reactions,' McGraw-Hill, New York, 1962.

[7] J. March, 'Advanced Organic Chemistry: Reactions, Mechanisms, and Structure,' McGraw-Hill, New York, 1968, p. 372.

[8] E. Grunwald and S. Winstein, *J. Amer. Chem. Soc.*, 1948, **70**, 846.

[9] E. Ciuffarin and A. Fava, *Progr. Phys. Org. Chem.*, 1968, **6**, 81.

hydrolysis: if we take into account the actual concentration of water, k_{OH^-}/k_{H_2O} is about $3{\cdot}5 \times 10^5$. This value is almost identical with that measured by Rogne for unsubstituted benzenesulphonyl chloride ($3{\cdot}0 \times 10^5$), which is generally recognized to react bimolecularly both in the neutral and in the alkaline hydrolysis.[4]

EXPERIMENTAL

Materials.—2,4,6-Trimethylbenzenesulphonyl chloride, prepared as described,[10] was recrystallized several times from light petroleum (b.p. 30—50°) and had m.p. 56—57° (lit.,[10] 56—57°). The purification of water and dioxan has been described.[11]

Kinetics.—The alkaline hydrolysis reactions were followed by use of a Durrum stopped-flow spectrophotometer. The solution containing the substrate was prepared immediately before use by mixing 0·05 ml of a solution of the substrate in dioxan with the already thermostatted solvent. The data were recorded as soon as possible to limit to a maximum of 10% the neutral hydrolysis of the substrate, which at room temperature has a half life of about 9 min. Duplicate runs displayed a maximum error of ±3%.

The neutral hydrolysis in water-dioxan, $x_{H_2O} = 0{\cdot}825$, was followed with a Unicam recording spectrophotometer equipped with a thermostatted cell compartment.

When the solvent mixture contained more than 75% w/w water, the neutral hydrolysis reactions were too fast to be followed with the necessary precision by use of a mechanically operated spectrophotometer. We therefore used the stopped-flow apparatus in order to be able to use the oscilloscope as a recording device. The solutions were prepared immediately before use by mixing 0·05 ml of a solution of substrate in dioxan with the appropriate thermostatted water–dioxan mixture (5 ml). The resulting mixture was introduced directly into the reaction cell. Duplicate runs showed a maximum error of ±5%.

This investigation was supported by the C.N.R. (Rome).

[3/2173 *Received*, 21*st October*, 1973]

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[11] E. Ciuffarin, L. Senatore, and M. Isola, *J. Chem. Soc.* (*B*), 1971, 2187.