573. *The Mechanism of Hydrolysis of Acid Chlorides. Part X.**
Salt Effects.

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The different salt effects observed in the solvolysis of *p*-nitrobenzoyl chloride and 2,4,6-trimethylbenzoyl chloride are in agreement with previous conclusions that these two chlorides react by bimolecular and ionisation mechanisms, respectively. Thus lithium perchlorate decreases the rate of hydrolysis of the *p*-nitro-compound, but increases the rate of hydrolysis of the trimethyl compound. Chloride ions, however, increase the rate of hydrolysis of the former, but have no effect on the rate of hydrolysis of the latter. However, tetraethyl ammonium chloride reduces the rate of solvolysis of the trimethyl compound in the presence of tetraethylammonium bromide.

THE detailed mechanism of the solvolysis of acyl halides is now known to be complex,[1] and conflicting interpretations of some of the data have been given. In particular, the ionisation mechanism suggested [2] for the hydrolysis of 2,4,6-trimethylbenzoyl chloride has been criticised by several workers,† and bimolecular mechanisms have been suggested.[3,4]

There is no doubt however that alternative mechanisms are possible, and whatever the detailed structures of the transition states may be, we do not agree with Peeling's conclusions,[5] that one can " rule out the possibility that even 2,4,6-trimethylbenzoyl chloride reacts by an S_N1-like mechanism." †

For reasons that will be discussed in a theoretical analysis of salt effects in liquid mixtures to be published elsewhere,[6] we consider that the influence of the solvent-sorting process [7] is small for S_N1 reactions in 90% aqueous acetone. Since ion-pairing can probably be neglected in solutions more dilute than 0·1N, the observed salt effect, k_c/k_o, is given semiquantitatively by the effect of the ion-atmosphere on the activity coefficent of the transition state.[8] The same interpretation does not hold, however, for dioxan–water (because of the low dielectric constant of dioxan), and acetone–water of high water content (because of the extensive solvent sorting).

The present data summarised in Table 1 show that the salt effects for 2,4,6-trimethyl-benzoyl chloride (I) and *p*-nitrobenzoyl chloride (II) are completely different, and support previous conclusions that (I) is hydrolysed by an S_N1 mechanism (either through RCO^+ or $RC(OH)_2{}^+$), whereas (II) is hydrolysed by a bimolecular mechanism.

The rate increases for (I) are probably due to an ionic strength effect,[8] since anionic displacement is greatly retarded ‡ by steric hindrance (cf. the low rate of reaction with chloride ions in acetone [3]). Moreover, the perchlorate and bromide salts produce comparable rate increases, which would not be the case if the latter reacted bimolecularly. By applying the electrostatic treatment used by Bateman *et al.*,[8] values of $10^8 \sigma$ of 1·38 and 1·77 are obtained for lithium perchlorate and tetraethylammonium bromide, respectively.

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* Part IX, *J.*, 1962, 5157.
† The recent detailed investigations of Bender and Chen (*J. Amer. Chem. Soc.*, 1965, **85**, 30), completely support the interpretation given in this Paper.
‡ In some conditions, however, hydroxide [3] and alkoxide [5] ions may react by bimolecular displacement.

[1] Hudson, *Chimia*, 1961, **15**, 394.
[2] Brown and Hudson, *J.*, 1953, 3352.
[3] Bunton and Lewis, *Chem. and Ind.*, 1956, 180.
[4] Hall, *J. Amer. Chem. Soc.*, 1955, **77**, 5993.
[5] Peeling, *J.*, 1959, 2307.
[6] Hudson, to be published elsewhere.
[7] Butler and Grunwald, *J. Amer. Chem. Soc.*, 1960, **82**, 5647.
[8] Bateman, Church, Hughes, Ingold, and Taher, *J.*, 1940, 979.

TABLE 1.

Salt effects in the solvolysis of acyl chlorides in 95% aqueous acetone at 0°.

2,4,6-*Trimethylbenzoyl chloride* (I)   *p-Nitrobenzoyl chloride* (II)

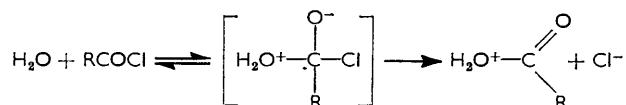| MX		k_c/k_o	MX		k_c/k_o
LiCl	0·05N	1·00	LiCl	0·05N	0·84
Et₄NCl	0·03N	0·93	Et₄NCl	0·05N	1·29
Et₄NBr	0·05N	2·10	LiClO₄	0·281N	0·40
Et₄NBr	0·088N	2·66			
Et₄NBr	0·093N	2·90	*Benzoyl chloride*		
LiClO₄	0·10N	2·47			
LiClO₄	0·25N	4·06	Et₄NCl *	0·05N	1·45
LiClO₄	0·50N	8·22	Et₄NCl †	0·05N	1·40

* 25°.   † 27°.

These are similar to the corresponding values for t-butyl chloride (1·44) given by Taft,[9] and benzhydryl chloride [8] (1·61). The decreases in rate produced by chloride ions may be due to mass-action repression,[8] opposing the ionic strength effect, in accord with an ionisation mechanism, although other effects due to the influence of the salt on the medium cannot be eliminated.

These salt effects are similar to those recorded by Peeling [5] for the solvolysis of this chloride in 80% ethanolic acetone, and are comparable to the salt effects observed by Bateman *et al.*[8] for the solvolysis of benzhydryl chloride in 90% aqueous acetone, a reaction which is known to proceed by an ionisation mechanism.

Tetraethylammonium chloride reduced the rate of solvolysis in the presence of added bromide ions (Table 3), an effect which may be explained by the competition between bromide and chloride ions for the intermediate acylium ion, either in the free state [10] or as an ion-pair.[11] In view of the uncertainty of the interpretation, and the inaccuracy of these data, it is not proposed to develop this interpretation further.

In contrast to the large rate acceleration produced in the solvolysis of 2,4,6-trimethylbenzoyl chloride, lithium perchlorate reduces the rate of hydrolysis of *p*-nitrobenzoyl chloride (Table 1). Lithium chloride has a similar effect, whereas tetraethylammonium chloride increases the rate. It is evident therefore that lithium ions exert a specific

$$H_2O + RCOCl \rightleftharpoons \left[H_2O^+ - \underset{R}{\overset{O^-}{\underset{|}{C}}} - Cl \right] \longrightarrow H_2O^+ - \overset{O}{\underset{R}{C}} + Cl^-$$

retarding effect. The mechanism of reaction in this case is not in doubt,[2] and in the bimolecular reaction the activity of water enters into the rate equation,

$$k_2 = k_0 (f_{RX}/f^*_{RX}) f_{H2O}$$

The rate decreases may be attributed to hydration of the lithium ions, which reduces the nucleophilic reactivity of the water molecules, and hence the rate through a decrease in f_{H_4O}, apparently to a greater extent than the ion-atmosphere reduces f^*_{RX}. On the other hand, the hydration of the chloride ion increases the effective basicity of the water molecules according to the structure $\overset{(-)}{Cl} \longrightarrow H \overset{(\delta-)}{\longrightarrow} O-H$. The hydrolyses of *p*-nitrobenzoyl and benzoyl chlorides are known to be very sensitive to bases,[2] and the effect of chloride ions in these reactions can therefore be regarded as a mild general base catalysis, similar to the catalysis of the hydrolysis of acetic anhydride by acetate ions.[12] (The acetate ion is of course more basic than the chloride ion, and its influence is detected in more aqueous solutions.)

[9] Clarke and Taft, *J. Amer. Chem. Soc.*, 1962, **84**, 2295.
[10] Benfey, Hughes, and Ingold, *J.*, 1952, 2488.
[11] Winstein, Clippinger, Fainberg, and Robinson, *J. Amer. Chem. Soc.*, 1954, **76**, 2597.
[12] Kilpatrick, *J. Amer. Chem. Soc.*, 1928, **50**, 2891; Butler and Gold, *Proc. Chem. Soc.*, 1960, 15.

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2984   *The Mechanism of Hydrolysis of Acid Chlorides.   Part X.*

It is noted that, according to Peeling,[5] lithium chloride similarly increases the rate of alcoholysis of *p*-nitrobenzoyl chloride in 80% alcoholic acetone, in which medium the specific solvation of the cation by alcohol molecules is probably less important.* The rate increase observed by Peeling on the addition of lithium bromide is presumably due to the displacement reaction, giving the unstable bromide as follows,

$$RCOCl + Br^- \rightleftharpoons RCOBr + Cl^- \xrightarrow{\textbf{H}_2\textbf{O}} RCO_2H + HBr + Cl^-$$
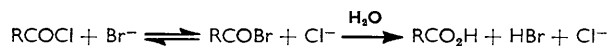
The rate of hydrolysis of benzoyl chloride is increased similarly, and the kinetics of these simultaneous reactions have already been analysed and discussed.[13]

<center>EXPERIMENTAL</center>

Preparation of Reactants.—Acetone, 2,4,6-trimethylbenzoyl chloride, benzoyl chloride, and *p*-nitrobenzoyl chloride were purified as described previously.[2]   The liquid acid chlorides were handled in specially constructed weighing bottles of *ca.* 5 ml. capacity, with flat bottoms, and necks in the form of capillary tubes, 3 mm. in diam.   The tapered ends were sealed with short lengths of polythene tubing.   A suitable quantity (0·02—1·0 g.) of liquid could be dispensed by touching the flat base of a bottle with a piece of warmed asbestos paper.   This procedure was found to be more satisfactory than use of the conventional Lunge-Rey pipette.

To ensure a constant solvent composition, the solvent corresponding to x ml. of water in 100 ml. of reaction mixture at 20° was prepared gravimetrically.

Lithium chloride (B.D.H. reagent) and tetraethylammonium bromide (analytical grade) were used directly.   Both were analysed for halide, and the water content of each salt was determined.

Lithium perchlorate was dried to constant weight (at 100°), and chloride found to be absent. A concentrated solution was prepared gravimetrically, and this was further diluted as required.

Tetraethylammonium chloride was prepared by treating an aqueous solution of the bromide with fresh silver oxide.   The hydroxide was then neutralised with hydrochloric acid, the water removed, and the tetraethylammonium chloride dissolved in chloroform.   The salt was dried by several azeotropic distillations of chloroform solutions, and the residual water in the final sample determined by chloride analysis.   Allowance was made for the water content of each salt when the corresponding reaction mixtures were prepared.

<center>TABLE 2.</center>

<center>The solvolysis of 2,4,6-trimethylbenzoyl chloride in 95% aqueous acetone (6·16% by weight), containing tetraethylammonium chloride at 0°.</center>

Preparation of solvent.   Tetraethylammonium chloride, 0·5196 g.;   Water introduced with the salt, 0·0286 g.;   Water added from burette, 4·9725 g.;   Acetone added   76·1 g.;   2,4,6-Trimethylbenzoyl chloride added, 0·5687 g.

Time (min.) ...	1·88	3·21	6·20	10·80	15·55	20·75	30·80	51·10	83·80
Titre (ml.)	0·54	0·75	1·10	1·56	1·92	2·29	2·69	3·08	3·26
10^2k (min.$^{-2}$) ...	4·78	5·16	5·13	5·02	5·04	5·28	5·20	5·13	5·16

<center>$k = 5·11 \times 10^{-2}$ min.$^{-1}$ (obtained graphically).</center>

Rate Measurements.—Known weights of reactants were added as liquids to the reaction mixture from the weighing bottles described above.   *p*-Nitrobenzoyl chloride was introduced as a crust on the tip of a glass rod which was dipped into the reaction mixture in which the substrate rapidly dissolved.   Samples were withdrawn periodically with safety pipettes, and quenched in AnalaR acetone (*ca.* 25 ml.) containing lacmoid as indicator at −70°.   The liberated hydrochloric acid was titrated with triethylamine in toluene as described previously.[2]

Results.—The rate constants were obtained graphically from the first-order rate equation, all the reactions being pseudo-unimolecular.   Catalysis by hydrochloric acid of the solvolysis of 2,4,6-trimethylbenzoyl chloride was negligible, owing to the low concentration employed.

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* Because of the greater concentration of alcohol, and greater decrease of entropy on specific solvation by alcohol than by water.

[13] Archer, Hudson, and Wardill, *J.*, 1953, 888.

TABLE 3.

Hydrolysis of acyl chlorides at 0° in acetone containing 5% of water (v/v at 20°)
i.e. 6·16% by weight of water.

[Acid chloride] (10² mole/l.)	Salt		10²k (min.⁻¹)	[Acid chloride] (10² mole/l.)	Salt		10²k (min.⁻¹)
2,4,6-Trimethylbenzoyl chloride				*2,4,6-Trimethylbenzoyl chloride*			
2·95	—		5·31	2·25	Et$_4$NBr,	0·05N	6·9
3·25	—		5·34		+ Et$_4$NCl,	0·04N	
2·20	—		5·40	2·16	,,	,,	7·1
2·33	LiCl,	0·51N	5·36	2·56	Et$_4$NBr,	0·05N	8·87
3·25	LiCl,	0·51N	5·16		+ Et$_4$NCl,	0·017N	
3·12	Et$_4$NCl,	0·03N	5·11	*p-Nitrobenzoyl chloride*			
2·42	Et$_4$NCl,	0·03N	4·92	3·34	—		2·72
5·10	LiClO$_4$,	0·5N	43·3	4·30	—		2·53
5·84	LiClO$_4$,	0·5N	44·7	4·50	—		2·42
4·22	LiClO$_4$,	0·25N	21·7	5·90	—		2·50
1·20	LiClO$_4$,	0·10N	13·2	4·76	LiClO$_4$,	0·281N	1·02
2·95	Et$_4$NBr,	0·05N	11·2	3·50	LiCl,	0·05N	2·12
2·10	Et$_4$NBr,	0·05N	11·7	3·45	LiCl,	0·05N	2·15
2·24	Et$_4$NBr,	0·05N	10·8	4·30	Et$_4$NCl,	0·06N	3·33
2·15	Et$_4$NBr,	0·088N	14·26	4·40	Et$_4$NCl,	0·06N	3·17
2·10	Et$_4$NBr,	0·093N	15·5	4·25	Et$_4$NCl,	0·06N	3·35

TABLE 4.

Hydrolysis of benzoyl chloride in acetone containing 5% of water (v/v) and tetra-
ethylammonium chloride (MCl).

[Acid chloride] (10² mole/l.)	Temp.	MCl	10³k (sec.⁻¹)	[Acid chloride] (10² mole/l.)	Temp.	MCl	10³k (sec.⁻¹)
3·15	27°	0·05N	8·05	3·05	25°	0·05N	7·29
3·15	27	—	5·55	3·25	25	—	5·18

This is shown by the data for a typical experiment (Table 2). The results are summarised in Table 3 and 4.

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