Kinetics of Protiodeacylation of Mono- and Di-acylmesitylenes in 89.8% Sulphuric Acid

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Rate and activation data have been obtained for the protiodeacylation in 89.8% (w/w) sulphuric acid of 10 alkyl mesityl ketones, with straight chain or branched chain alkyl groups, and of four diacylmesitylenes. The reactions have been analysed in terms of a sequence of two or three component ψ-first-order processes.

IT has been known for many years that acyl groups can be displaced from sterically hindered aromatic positions through the agency of syrupy phosphoric acid [1] or concentrated sulphuric acid.[2] Until recently [3] the only ketones whose reactions have been investigated kinetically comprised acetylmesitylene,[4,5] 2,6-dimethylacetophenone,[4] 2,4-dimethylacetophenone,[5] and 2-methylacetophenone.[5] We present here our kinetic study of the protiodeacylation of several mono- and di-acylmesitylenes. 89.8% (w/w) (16.6 mol dm^{-3}) Sulphuric acid was chosen as medium, since for several ketones the rate observed at this acid concentration is maximal.[6]

Monoacylmesitylenes.—Early work by Schubert and Zahler [4a] had shown that mesitaldehyde, the first member of the acylmesitylene series, required sulphuric acid at relatively high temperatures (70—100 °C) for the deformylation reaction to be measured conveniently. Acetylmesitylene [3a,4,5] or propionylmesitylene,[3b] however, reacted smoothly at lower temperatures. Consequently, it was anticipated that protiodeacylation of higher alkyl mesityl ketones would also occur under mild reaction conditions. We now report the kinetics of these reactions for a range of monoketones observed spectrophotometrically in 89.8% (w/w) sulphuric acid (Tables 1 and 2).

A previous kinetic analysis of the reaction of a mesityl ketone (*B*) (Scheme) had shown [3a] that the initial protiodeacylation step (k_2), resulting in the formation of mesitylene (*C*), is followed by rapid sulphonation (k_3), the change actually observed being that of a conversion of an acylmesitylene (*B*) into mesitylenesulphonic acid (*D*). Interference by intermediate (*C*) can here be ignored, since, first, it does not absorb significantly at the wavelength (320—340 nm) used to follow the reactions, and secondly, calculations show that its concentration at maximum is always < 3% (mean value 1.1%) of the initial concentration of species (*B*).

The rate data presented in Table 1 show that the rate constant for protiodeacylation depends on the chain length of the acyl side-chain. The rate is very low for mesitaldehyde, rapidly increases for acetylmesitylene and more slowly to propionylmesitylene, which is the most reactive ketone. Thereafter (nos. 4—8) a virtually constant rate value obtains, up to a C_{10} side chain.

TABLE 1

Rate and activation data for the protiodeacylation of alkyl mesityl ketones in 89.8% (w/w) sulphuric acid

No.	$Me_3C_6H_2COR$ (R =)	k/s^{-1} (298.15 K, computed)	$\Delta H^{\ddagger}$ [a]/ kJ mol^{-1}	$\Delta S^{\ddagger}$ [a]/ J K^{-1} mol^{-1}	$\Delta G^{\ddagger}$ [a]/ kJ mol^{-1}
1	H [b]	8.8×10^{-8}	120	+12 [c]	
2	Me [d]	4.60×10^{-3}	87.4	+3.7	86.3
3	CH_2Me	1.891×10^{-2}	77.1	−19	82.8
4	$(CH_2)_2Me$	1.080×10^{-2}	77.8	−21	84.2
5	$(CH_2)_3Me$	1.114×10^{-2}	74.9	−31	84.2
6	$(CH_2)_4Me$	1.069×10^{-2}	75.5	−29	84.2
7	$(CH_2)_6Me$	1.050×10^{-2}	77.7	−22	84.3
8	$(CH_2)_8Me$	1.047×10^{-2}	77.9	−22	84.3

[a] Estimated error limits (s.d.) in $\Delta H^{\ddagger} \pm$ 1—2 kJ mol^{-1}, in $\Delta S^{\ddagger} \pm$ 3—4 J K^{-1} mol^{-1}, and in $\Delta G^{\ddagger} \pm$ 2—3 kJ mol^{-1}. [b] Calculated from rate data given in ref. 4*a*. [c] At 80 °C. [d] Recalculated, using data in ref. 3*a* and additional rate constants.

This suggests that here the $+I$ effect of the alkyl side chain, which is known to vary little with increasing chain length beyond C_3 (as, for example, with the dissociation constants of the corresponding carboxylic acids), is mainly responsible. Further, for reactions (Nos. 3—8) the activation parameters obtained appear not to differ significantly from one another.

For the first members of the series (nos. 1—4) one observes a progressive effect, presumably resulting from a combination of electronic and steric effects, causing a decrease both in the enthalpy of activation ($\Delta H^{\ddagger}$) and the entropy of activation ($\Delta S^{\ddagger}$) (see below).

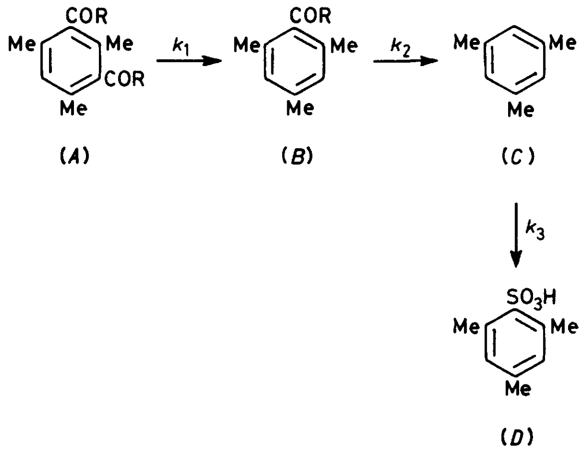
If one accepts the notion that the process of aromatic

TABLE 2

Rate and activation data for the protiodeacylation of mesityl ketones with branched alkyl chains in 89.8% (w/w) sulphuric acid

No.	$Me_3C_6H_2COR$ (R =)	k/s^{-1} (298.15 K, computed)	$\Delta H^{\ddagger}$/kJ mol^{-1}	$\Delta S^{\ddagger}$/J K^{-1} mol^{-1}	$\Delta G^{\ddagger}$/kJ mol^{-1}
9	$CHMe_2$	1.42×10^{-2}	58.3	−85	83.6
10	CMe_3	3.06×10^{-2}	81.4	−1.0	81.7
11	CH_2CHMe_2	1.061×10^{-2}	44.9	−132	84.3
12	CH_2CMe_3	5.51×10^{-3}	71.7	−48	85.9
13	$CHMeCH_2Me$	8.89×10^{-3}	71.9	−43	84.7

acylation is subject to appreciable steric retardation,[7] then the reverse process (of protiodeacylation) will then be subject to appreciable steric acceleration. Such may be seen to be absent in the case of mesitaldehyde, but quite effective for medium-sized groups like propionyl (no. 3) or pivaloyl (no. 10). Steric acceleration has been demonstrated for a related reaction, *viz.* the protiodesilylation of 2,6-dimethylphenyltrimethylsilane,[8] where a *ca.* 10-fold steric enhancement of the rate of reaction has been deduced.



SCHEME

For several alkyl mesityl ketones having branched alkyl chains (Table 2) the computed rate constants at 298.15 K are reasonably constant, with the neopentyl ketone (no. 12), the slowest of the set, reacting slightly faster than acetylmesitylene (no. 2). In contrast with the behaviour of the straight chain ketones (nos. 3—8), however, the corresponding activation parameters appear wildly irregular. The activation enthalpies span a range of *ca.* 40 kJ mol^{-1}, and the activation entropies vary correspondingly, and except for no. 10 are much more negative than for the straight chain ketone series (nos. 2—8). The data provide a good example of compensation between $\Delta H^‡$ and $\Delta S^‡$: for all reactions (nos. 2—13) one obtains an excellent rectilinear relationship (r 0.9942) between the activation parameters. Since there have been claims[9] that in certain cases such high correlations between these parameters may be due to true chemical compensation, the present data were submitted to the enthalpy–entropy analysis of Krug *et al.*[10] This showed that our data represent a classical case of the propagation of experimental errors along a statistical compensation line; it may be concluded that chemical compensation is here absent.

A more detailed analysis of the mechanism of the protiodeacylation of monoacylmesitylenes will be the subject of a future paper.

Diacylmesitylenes.—Kinetic measurements were also carried out for a series of diacylmesitylenes (*A*) (Table 3). Each reaction in the sequence (*A*) ⟶ (*D*) (Scheme) is characterised by a relatively slow first protiodeacylation reaction (k_1), being followed by the much faster second protiodeacylation reaction (k_2). Concentrations of the intermediate products [(*B*) and (*C*)] of these reactions could be evaluated, by solving the appropriate kinetic equations for different values of time, t. Since the total of intermediates (*B*) and (*C*) present in these reactions never exceeds 0.25%, it follows that their presence does not interfere with a straightforward measurement of the reaction rates.

TABLE 3

Rate and activation data for the protiodeacylation of diacylmesitylenes in 89.8% (w/w) sulphuric acid

No.	$Me_3C_6H(COR)_2$ (R =)	k/s^{-1} [a] (298.15 K, computed)	$\Delta H^‡$ [b]/ kJ mol^{-1}	$\Delta S^‡$ [b]/ J K^{-1} mol^{-1}	$\Delta G^‡$ [b]/ kJ mol^{-1}
14	Me [c]	9.88×10^{-6}	102	+2.0	101.5
15	CH_2Me [d]	2.34×10^{-5}	75.8	−79	99.4
16	$(CH_2)_2Me$	2.68×10^{-5}	71.8	−92	99.1
17	$(CH_2)_3Me$	2.33×10^{-5}	78.0	−72	99.4
18	$(CH_2)_4Me$	2.31×10^{-5}	73.6	−87	99.4
19	$(CH_2)_6Me$	2.37×10^{-5}	77.4	−74	99.4

[a] The rate constant for each (equivalent) acyl group = ½ of total rate. [b] Estimated error limits (s.d.) in $\Delta H^‡ \pm$ 3—4 kJ mol^{-1}, in $\Delta S^‡ \pm$ 8—12 J K^{-1} mol^{-1}, and in $\Delta G^‡ \pm$ 7—8 kJ mol^{-1}. [c] Data from ref. 3*a*. [d] Data from ref. 3*b*.

The protiodeacylation of diacetylmesitylene (no. 14) is characterised by a relatively high value of $\Delta H^‡$ and a positive $\Delta S^‡$. The higher diacylmesitylenes (nos. 15—19) all proceed at very similar rates, which are higher than for diacetylmesitylene. This increase in rate must be due to the lower $\Delta H^‡$ observed. It can be seen that the presence of a second acyl group causes a *ca.* 1 000-fold reduction in the rate of protiodeacylation, *viz.* k_1/k_2, due exclusively to a lowering of $\Delta S^‡$ by *ca.* 50 J K^{-1} mol^{-1}.

Kinetic Equations.—The basic equations are those given earlier;[3a] the expression used for the ratio D/A_0 (where D = [(D)], *etc.*) in the earlier paper was in error and is here given correctly as in (1).

$$\frac{D}{A_0} = 1 - \left[\frac{k_2k_3}{(k_2 - k_1)(k_3 - k_1)}\,e^{-k_1t} + \frac{k_1k_3}{(k_1 - k_2)(k_3 - k_2)}\,e^{-k_2t} + \frac{k_1k_2}{(k_1 - k_3)(k_2 - k_3)}\,e^{-k_3t}\right] \quad (1)$$

EXPERIMENTAL

The kinetic procedures used were described earlier.[3a,c] Experimental rate constants are given in Supplementary Publication No. SUP 23324 (3 pp).*

Materials.—Pentyl 2,4,6-trimethylphenyl ketone and propyl 2,4,6-trimethylphenyl ketone were obtained in previous work.[11]

2′,4′,6′-Trimethylacetophenone had b.p. 68–70 °C at 0.05 mmHg (lit.,[12] 120 °C at 12 mmHg), n_D^{20} 1.5175, $\nu_{max.}$ (film) 1 703 cm^{-1} (C=O); τ($CDCl_3$) τ 3.21 (s, 3′- and 5′-H), 7.60 (s, $COCH_3$), 7.72 (s, 2′- and 6′-CH_3), and 7.80 (s, 4′-CH_3).

n-Butyl 2,4,6-trimethylphenyl ketone had b.p. 85 °C at

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* For details of Supplementary Publications see Notice to Authors No. 7 in *J. Chem. Soc., Perkin Trans. 2*, 1981, Index issue.

0.05 mmHg (lit.,[11] 130—132 °C at 2.2 mmHg), n_D^{22} 1.5039, $\nu_{max.}$ (film) 1 701 cm^{-1} (C=O), τ (CDCl$_3$) 3.28 (s, 3′- and 5′-H), 7.37 (t, 2-CH$_2$), 7.78 (s, 4′-CH$_3$), 7.85 (s, 2′- and 6′-CH$_3$), 8.40 (m, 3- and 4-CH$_2$), and 9.02 (t, 5-CH$_3$).

n-Heptyl 2,4,6-*trimethylphenyl ketone* had b.p. 106—108 °C at 0.05 mmHg (Found: C, 83.0; H, 10.9. $C_{17}H_{26}O$ requires C, 82.85; H, 10.6%); n_D^{21} 1.4993; $\nu_{max.}$ (film) 1 695 cm^{-1} (C=O); τ(CDCl$_3$) 3.28 (s, 3′- and 5′-H), 7.35 (t, 2-CH$_2$), 7.75 (s, 4′-CH$_3$), 7.83 (s, 2′- and 6′-CH$_3$), 8.67 (m, 3- to 6-CH$_2$), and 9.15 (t, 7-CH$_3$).

n-Nonyl 2,4,6-trimethylphenyl ketone had b.p. 155 °C at 0.2 mmHg (lit.,[11] b.p. 184—186 °C at 1.5 mmHg); n_D^{22} 1.4945; $\nu_{max.}$ (film) 1 701 cm^{-1}; τ(CDCl$_3$) 3.27 (s, 3′- and 5′-H), 7.38 (t, 2-CH$_2$), 7.80 (s, 4′-CH$_3$), 7.83 (s, 2′- and 6′-CH$_3$), 8.68 (m, 3- to 8-CH$_2$), and 9.14 (t, 9-CH$_3$).

1-Methylethyl 2,4,6-trimethylphenyl ketone had b.p. 80 °C at 0.03 mmHg (lit.,[11] 106 °C at 3.5 mmHg); n_D^{22} 1.4951; $\nu_{max.}$ (film) 1 699 cm^{-1} (C=O); τ(CDCl$_3$) 3.21 (s, 3′- and 5′-H), 7.02 (m, CH), 7.74 (s, 4′-CH$_3$), 7.80 (s, 2′- and 6′-CH$_3$), and 8.84 (d, β-CH$_3$) ($J_{1.2}$ 6.2 Hz).

1-*Methylbutyl* 2,4,6-*trimethylphenyl ketone* had b.p. 80 °C at 0.01 mmHg (Found: C, 82.75; H, 10.0. $C_{14}H_{20}O$ requires C, 82.3; H, 9.85%); n_D^{21} 1.5101; $\nu_{max.}$ (film) 1 685 cm^{-1} (C=O); τ(CDCl$_3$) 3.06 (s, 3′- and 5′-H), 7.25 (m, CH), 7.68 (s, 4′-CH$_3$), 7.75 (s, 2′- and 6′-CH$_3$), 8.37 (m, CH$_2$), 8.90 (d, α-CH$_3$), and 9.12 (t, 3-CH$_3$).

2-Methylpropyl 2,4,6-trimethylphenyl ketone had b.p. 70 °C at 0.01 mmHg (lit.,[13] 151 °C at 20 mmHg); n_D^{21} 1.5150; $\nu_{max.}$ (film) 1 685 cm^{-1}; τ(CDCl$_3$) 3.27 (s, 3′- and 5′-H), 7.23 (d, CH$_2$), 7.53 (m, CH), 7.80 (s, 4′-CH$_3$), 7.86 (s, 2′- and 6′-CH$_3$), and 9.06 (d, ω-CH$_3$) ($J_{\mathrm{CH.CH_3}}$ 7.4 Hz).

2,2-*Dimethylpropyl* 2.4,6-*trimethylphenyl ketone* had b.p. 61 °C at 0.02 mmHg (Found: C, 82.1; H, 10.3. $C_{15}H_{22}O$ requires C, 82.5; H, 10.15%); n_D^{21} 1.4930; $\nu_{max.}$ (film) 1 700 cm^{-1} (C=O); τ(CDCl$_3$) 3.20 (s, 3′- and 5′-H), 7.39 (s, CH$_2$), 7.74 (s, 4′-CH$_3$), 7.80 (s, 2′- and 6′-CH$_3$), and 8.90 (s, ω-CH$_3$).

1,3-Dibutanoyl-2,4,6-trimethylbenzene had m.p. 33—33.5 °C (lit.,[13] 36 °C); $\nu_{max.}$ (film) 1 704 cm^{-1}.

1,3-Dipentanoyl-2,4,6-trimethylbenzene distilled as an oil b.p. 160—162 °C at 2.0 mmHg (lit.,[13] 210—211 °C at 18—20 mmHg), m.p. 56 °C (lit.,[13] 55 °C); $\nu_{max.}$ (KBr) 1 703 cm^{-1} (C=O); τ(CDCl$_3$) 3.05 (s, 5-H), 7.27 (t, 2′-CH$_2$), 7.82 (s, 2- and 6-CH$_3$), 7.92 (s, 4-CH$_3$), 8.48 (m, 3′- and 4′-CH$_2$), and 8.94 (t, 5′-CH$_3$).

1,3-*Dihexanoyl*-2,4,6-*trimethylbenzene* had b.p. 212—214 °C at 3.0 mmHg (Found: C, 79.5; H, 10.1. $C_{21}H_{32}O_2$ requires C, 79.7; H, 10.2%); $\nu_{max.}$ (film) 1 703 cm^{-1} (C=O).

1,3-*Dioctanoyl*-2,4,6-*trimethylbenzene* was a viscous oil, b.p. 164 °C at 0.2 mmHg (Found: C, 80.6; H, 11.15. $C_{25}H_{40}O_2$ requires C, 80.6; H, 10.8%); n_D^{22} 1.4960; $\nu_{max.}$ (film) 1 700 cm^{-1} (C=O); τ(CDCl$_3$) 3.17 (s, 5-H), 7.37 (t, 2′-CH$_2$), 7.82 (s, 2- and 6-CH$_3$), 7.93 (s, 4-CH$_3$), 8.50 (m, CH$_2$), and 9.10 (t, 7′-CH$_3$).

All ketones were prepared by standard Friedel–Crafts acylations[12] in yields between 72 and 82%.

[1/1756 *Received*, 13*th November*, 1981]

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