Reactions of Carbonyl Compounds in Basic Solutions. Part 8.[1] Mechanism of Alkaline Hydrolysis of Methyl Pseudo-8-(3- or 4-substituted benzoyl)-1-naphthoates and Pseudo-2-(3- or 4-substituted benzoyl)-benzoates

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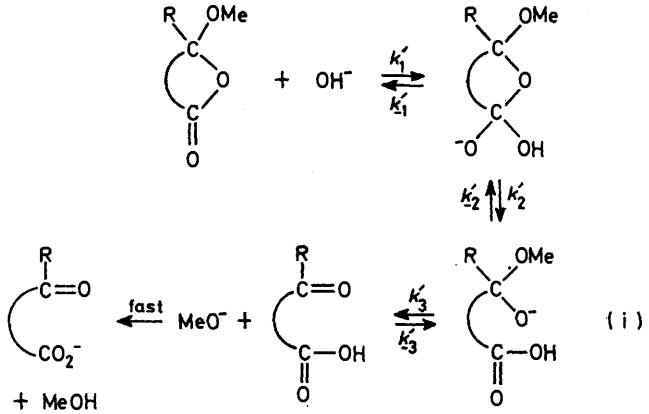
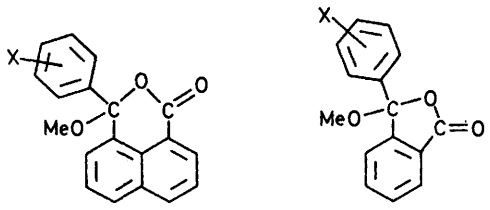
Rate coefficients have been measured for the alkaline hydrolysis of a series of methyl pseudo-8-benzoyl-1-naphthoates and pseudo-2-benzoylbenzoates in 70% (v/v) dioxan–water at 60.0 °C. The entropies and enthalpies of activation for the parent pseudo-esters have been evaluated, as have the solvent isotope and solvent (aqueous dioxan and dimethyl sulphoxide) effects for these esters. The reaction constants, ρ, for the naphthoates and benzoates are *ca.* 0.6 and 0.8, respectively. The evidence is consistent with hydrolysis occurring by a stepwise mechanism, with rate-determining attack of hydroxide ion. The greater reactivity of the five- than of the six-membered ring arises from greater ring strain in the former.

A DISCUSSION of the mechanism of alkaline hydrolysis of methyl pseudo-8-acyl-1-naphthoates and pseudo-5-formylphenanthrene-4-carboxylate has been presented previously.[1] A preliminary report [2] has indicated the effect of several leaving groups on the alkaline hydrolysis of pseudo-2-benzoylbenzoates. A mechanism has been suggested [1] that involves stepwise addition of hydroxide ion to the carbonyl group (i). A concerted mechanism is



(i)

also possible in which the transition state for the rate-determining step will entail development of negative charge on ring and/or methoxide oxygen atoms.



(1) (2)

The rate coefficients for the alkaline hydrolysis of some methyl-substituted methyl pseudo-2-benzoylbenzoates have been measured,[3] but there has been no previous report of a study of polar substituent effects on the alkaline hydrolysis of pseudo-esters. We now describe an investigation of the alkaline hydrolysis of a series of methyl pseudo-8-benzoyl-1-naphthoates (1) and pseudo-*o*-benzoylbenzoates (2) with *meta*- and *para*-substitution in the benzoyl rings.

RESULTS AND DISCUSSION

The alkaline hydrolysis of all the methyl pseudo-esters studied is of the first order in both pseudo-ester and hydroxide ion. Rate coefficients for the alkaline hydrolysis of the methyl pseudo-esters in 70% (v/v) dioxan–water at 60.0 °C are shown in Table 1. Table 2 shows the rate coefficients for the parent pseudo-esters at several temperatures in 70% (v/v) dioxan–water, in 70% (v/v) dioxan–deuterium oxide at 60.0 °C, in aqueous

TABLE 1

Rate coefficients for the alkaline hydrolysis of methyl pseudo-8-(substituted benzoyl)-1-naphthoates and pseudo-2-(substituted benzoyl)benzoates in 70% (v/v) dioxan–water at 60.0 °C,* together with the physical constants of the esters

Naphthoate subst.	$10k_2$/ l mol^{-1} s^{-1}	M.p. (*t*/°C)	Lit. m.p. (*t*/°C)	Ref.	λ/nm [d]
H	3.77 †	130 [a]	132—133	*e*	324
4-Me	3.26	140—141 [a]	140—141	*e*	320
3-Me	3.20	146—148 [b]			320
4-Cl	5.94	158—162 [a]			320
3-Cl	6.05	140—142 [a]			320
4-Br	6.36	150 [a]	150	*e*	320
3-CF_3	6.67	140—142 [b]			320
Benzoate subst.					
H	15.6	82 [c]	81—82	*f*	252
4-Me	11.8	66—67 [c]	70—71	*g*	265
4-$CHMe_2$	12.3	76—78 [c]			266
4-CMe_3	11.8	92—93 [c]			26
4-OMe	11.0	77—78 [c]			288
4-F	23.5	56—58 [c]			256
4-Cl	25.6	98—101 [c]	101—102	*g*	263
4-I	23.2	87—89 [c]			277
3-NO_2	53.5	136—138 [c]	136—138	*g*	260

* Rate coefficients reproducible to within ±3%. † Lit.[1] 0.340 l mol^{-1} s^{-1}. [a] From methanol. [b] From benzene–light petroleum (b.p. 60—80 °C). [c] From light petroleum (b.p. 60—80 °C). [d] Used in kinetic measurements (*not* $\lambda_{max.}$ values for the esters). [e] Ref. 16. [f] Ref. 17. [g] Ref. 18.

[1] Part 7, K. Bowden and A. M. Last, *J.C.S. Perkin II*, 1973, 358.

[2] M. V. Bhatt, G. Venkoba, and K. S. Raja Rao, *Chem. Comm.*, 1971, 842.

[3] M. S. Newman and S. Hishida, *J. Amer. Chem. Soc.*, 1962, **84**, 3582.

dioxan at 60.3 °C, and in aqueous dimethyl sulphoxide (DMSO) at 60.3 °C. The activation parameters for the reactions of the parent esters are shown in Table 3.

The rate coefficients of the methyl pseudo-*o*-benzoylbenzoates were greater than those of the corresponding methyl pseudo-8-benzoyl-1-naphthoates by a factor of *ca.* 4 at 60 °C. Both systems are more reactive than methyl benzoate, the rate coefficient at 30 °C in 70% (v/v) dioxan–water for the latter being 0.017 4 l mol^{-1} s^{-1}.[4] This effect arises from the same source as the greater reactivity of simple, up to seven-membered ring lactones,

TABLE 2

Rate coefficients for the alkaline hydrolysis of methyl pseudo-8-benzoyl-1-naphthoate and pseudo-2-benzoylbenzoate *

	$10k_2$/l mol^{-1} s^{-1}				
	in 70% (v/v) dioxan–water				in 70% (v/v) dioxan–deuterium oxide
	30.0 °C	40.0 °C	50.0 °C	60.0 °C	60.0 °C
Naphthoate	0.520	1.04	2.15	3.77	4.41
Benzoate	1.90	3.80	8.23	15.6	20.0

	in aqueous dioxan at 60.3 °C (mol % indicated)				
	5.01	12.34	24.05	33.01	45.79
Naphthoate	8.33	4.23	3.58	3.74	4.72
Benzoate	38.7	23.1	15.6	16.0	23.3

	in aqueous dimethyl sulphoxide at 60.3 °C (mol % indicated)					
	5.94	14.45	27.54	50.33	69.51	82.80
Naphthoate	8.54	15.9	22.4	65.4	124	323
Benzoate	40.9	62.6	80.3	218	787	

* Rate coefficients reproducible to within ±3%.

TABLE 3

Activation parameters for the alkaline hydrolysis of methyl pseudo-8-benzoyl-1-naphthoate and pseudo-2-benzoylbenzoate in 70% (v/v) dioxan–water at 30.0 °C *

	$\Delta H^{\ddagger}$/kcal mol^{-1}	$\Delta S^{\ddagger}$/cal mol^{-1} K^{-1}
Naphthoate †	12.8	−22
Benzoate	13.6	−17

* Values of $\Delta H^{\ddagger}$ accurate to within ±300 cal mol^{-1} and $\Delta S^{\ddagger}$ to within ±1 cal mol^{-1} K^{-1}. † Lit.,[1] 12.9 kcal mol^{-1} and −22 cal mol^{-1} K^{-1}

as compared with esters, the '*cis*' conformation being caused by the constraints of ring formation.[5,6] However, the greater reactivity of the five- than of the six-membered ring pseudo-esters contrasts with the behaviour of the five-membered ring butyrolactone which is hydrolysed more slowly than the six-membered ring valerolactone.[5,6] This appears to be a direct result of the different types of ring involved. The pseudo-esters are rigid systems of specific geometry, whereas the lactones exist in comparatively strain-free conformations. The resulting angle strain in the six-membered ring pseudo-ester, if planar, is about +21°, and +32° in the tetrahedral intermediate. In the five-membered ring pseudo-ester it is about −39°, and −28° in the intermediate. Thus in the six-membered ring the angle strain at the carbonyl group will not be severe, but will increase on addition of the hydroxide ion. The strain in the five-membered ring will be severe at the carbonyl group and *decreases* on addition of hydroxide. The greater reactivity of the five- than of the six-membered ring arises from relief of strain in formation of the tetrahedral intermediate; torsional strain does not appear to be a major factor. The greater ring strain in the five-membered ring benzoates than of the six-membered ring naphthoates is confirmed by the carbonyl stretching frequencies, which are in the ranges 1 780—1 788 and 1 730—1 740 cm^{-1}, respectively. A decrease in the endocyclic angle results in an increase in the stretching frequency.[7]

The activation parameters shown in Table 3 indicate that the greater reactivity of the five-membered ring arises from the entropy rather than the enthalpy term. This would arise if the latter ring lost less 'freedom of motions', in a relative sense, in forming the less strained transition state from a more strained initial state.

Substituent Effects.—The effects of *meta*- and *para*-substitution in the benzoyl ring can be assessed by using the Hammett equation.[8] Correlations with both σ and σ^n [9,10] are shown in Table 4. The greater success of σ^n

TABLE 4

Hammett reaction constants for alkaline hydrolysis of methyl pseudo-8-(3- and 4-substituted benzoyl)-1-naphthoates and pseudo-2-(3- and 4-substituted benzoyl)benzoates in 70% (v/v) dioxan–water at 60.0 °C *

System		ρ	log k_0	r	s	n
Naphthoates	(a)	0.599	−0.405	0.950	0.087	7
	(b)	0.625	−0.416	0.967	0.074	7
Benzoates	(a)	0.718	0.222	0.980	0.055	9
	(b)	0.801	0.174	0.990	0.050	9

* r = correlation coefficient, s = standard deviation, n = number of substituents used. Correlation (a) with σ and (b) with σ^n.

arises from the 'insulation' of the phenyl group from the reaction site which blocks any 'through-resonance' effects. The ρ values obtained indicate the nature of the rate-determining step. Of the three possible rate-determining steps for a stepwise mechanism the attack of hydroxide at the carbonyl group, k_1', would result in the observed value of ρ (0.6—0.8). By using the transmissive factors tabulate by one of us,[11] values of ρ/ρ_0 of 0.4 and 0.45 for the pseudo-naphthoates and -benzoates, respectively, can be calculated for such a transition state. The reaction constant, ρ_0, for the alkaline hydrolysis of methyl benzoates in 70% v/v dioxan–water can be

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calculated as 2.0 at 60 °C; *cf.* ref. 12. For a concerted path a similar calculation would only give this result if the charge was almost completely localised on the carbonyl oxygen and the oxygen of the attacking hydroxide ion. The agreement between the predicted values of ρ (0.8 and 0.9) and those found characterises the transition state so having no or *very* little ring fission. This behaviour corresponds closely to that observed in the methoxide-ion catalysed rearrangement of the pseudo-benzoates, but contrasts with that of the similar reaction of the pseudo-naphthoates.[13]

Kinetic Solvent and Solvent Isotope Effects.—For both parent esters the rates of hydrolysis increase with increasing DMSO content; those for reactions in aqueous dioxan decrease with increasing dioxan content to a minimum at about 25 mole % dioxan before increasing slightly. These results parallel closely those observed for the hydrolysis of methyl benzoate, the normal methyl 2-benzoylbenzoate, and related substrates.[4,14,15] The rate enhancements observed for both the pseudo-esters in deuterium oxide solvent, k_{H_2O}/k_{D_2O} being 0.78 and 0.85, are similar to each other and to those for related alkaline hydrolysis reactions.[4,14] These data all confirm the comparability of the present results with those for esters hydrolysed with rate-determining attack by hydroxide ion on a carbonyl group.

Mechanism.—The mechanism indicated is closely similar to that for related esters and lactones.[4,5] The evidence is all consistent with a step-wise pathway, with the rate-determining step as the attack of hydroxide ion on the pseudo-ester carbonyl group. The ring fission step appears to take place more readily because of the better leaving group, the anion of the hemiacetal, and relief of strain in the ring. A concerted pathway could be involved but the transition state would closely correspond to that for k_1' of the stepwise mechanism.

* For details see Supplementary Publication No. SUP 21955 (3 pp.). Information about Supplementary Publications is given in Notice to Authors No. 7, *J.C.S. Perkin II*, 1975, Index issue.

[12] K. Bowden and G. R. Taylor, *J. Chem. Soc.* (*B*), 1971, 145.
[13] K. Bowden and F. A. El Kaissi, unpublished studies.
[14] K. Bowden and A. M. Last, *J.C.S. Perkin II*, 1973, 345.
[15] D. D. Roberts, *J. Org. Chem.*, 1966, **31**, 4037.

EXPERIMENTAL

The methyl pseudo-8-(3- and 4-substituted benzoyl)-1-naphthoates and pseudo-2-(3- and 4-substituted benzoyl)-benzoates were obtained by the reaction of the appropriate acid chloride with anhydrous methanol containing urea.[16] After repeated recrystallisation and drying under vacuum (P_2O_5), the esters either had m.p.s in good agreement with literature values [16-18] or, if previously unreported, satisfactory elemental analyses.* The ^{1}H n.m.r. and i.r. spectra of the pseudo-esters confirmed their structures and indicated them to be pure by these criteria. The physical properties of the pseudo-esters are given in Table 1, together with their recrystallisation solvents and the λ values used in the kinetic measurements. Solvents were purified as previously described.[12,19] The carbonyl stretching frequencies, measured as described previously [12] with a Perkin-Elmer 225 spectrophotometer for 0.02M-solutions in carbon tetrachloride, were 1 730—1 740 for the naphthoate and 1 780—1 788 cm^{-1} for the benzoate pseudo-esters. The ^{1}H n.m.r. spectra were measured with a Varian Anaspect EM 360 spectrometer for 10% solutions in carbon tetrachloride containing 2% tetramethylsilane as internal standard. The methoxy-protons showed τ 6.6—6.8. Both of these spectroscopic techniques clearly differentiate the normal from the pseudo-esters and demonstrated that the pseudo-esters used in these studies were >98% pure isomers; *cf.* ref. 20.

Kinetic Procedure.—The kinetic procedure was as previously described.[14,19] The substrate and hydroxide anion concentration were 5×10^{-5} to 1×10^{-4}M and 5×10^{-4} to 5×10^{-2}M, respectively. The reactions were first-order in both species and were carried out in an excess of base; the resulting first-order behaviour was observed without deviation over at least three ' half-lives '. The products, the anions of the corresponding carboxylic acids, were obtained in quantitative yield in preparative scale reactions and their identities were confirmed by spectral comparison with the acid in basic solution.

[6/1365 *Received*, 12*th July*, 1976]

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