Reactions of Carbonyl Compounds in Basic Solutions. Part 13.[1] The Mechanism of the Alkaline Hydrolysis of 3-(3-Substituted Phenoxy)phthalides, -3-methylphthalides, -3-phenylphthalides, naphthalides, -3-phenylnaphthalides, and Phenanthralides,† and of 3-Substituted 3-Methoxyphthalides

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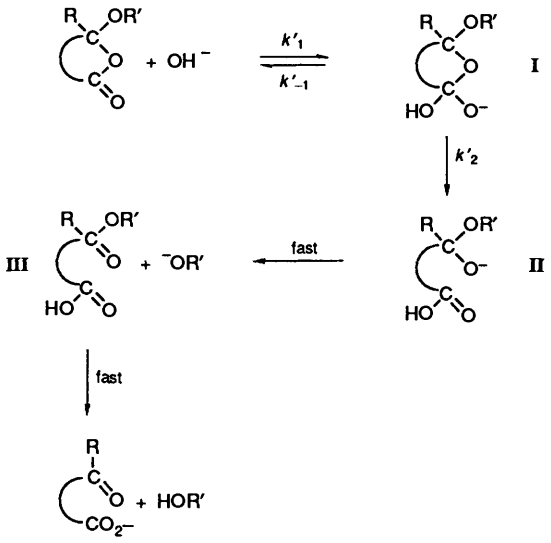
Rate coefficients have been measured for the alkaline hydrolysis of 3-(3-substituted phenoxy)-phthalides, -3-methylphthalides, -3-phenylphthalides, naphthalides, -3-phenylnaphthalides, and phenanthralides at 30.0 and 50.0 °C and for a series of methyl pseudo-2-acylbenzoates at several temperatures in 70% (v/v) dioxane–water. The enthalpies and entropies of activation have been evaluated. The effects of substitution on the phenoxy esters have been assessed by means of the Hammett equation. The results for the methyl esters are related to the steric effect of substituents using the Taft equation. All the pseudo-esters are hydrolysed with rate-determining attack by hydroxide anion at the carbonyl group, followed by rapid ring fission to form the carboxylate anion of the corresponding acid as the product. Reactivity–selectivity is not shown over the whole range of the six series of the phenyl pseudo-esters. These results are discussed in terms of the structure of the transition state and the steric, stereochemical and polar factors influencing reactivity.

The mechanism of the alkaline hydrolysis of alkyl pseudo-esters has been studied previously by ourselves[2,3] and others.[4,5] Aryl pseudo-esters have received only little attention.[4] A general mechanism is given for the alkaline hydrolysis of pseudo-esters in Scheme 1. This is shown as proceeding by tetrahedral



Scheme 1.

intermediates, although concerted reactions could occur. The nature of the rate-determining step and structure of the transition state in related reactions can be determined by study of the reactivity of a series of *meta*-substituted phenoxy substrates.[6,7] Only isolated studies[8–11] have been made of the alkaline hydrolysis of alkyl pseudo-2-formyl and 2-benzoyl-benzoates. However, the alkaline hydrolysis of a series of methyl pseudo-8-acyl-1-naphthoates,[2] methyl pseudo-8-(3- or 4-substituted benzoyl)-1-naphthoates and 2-(3- or 4-substituted benzoyl) benzoates[3] have been studied.

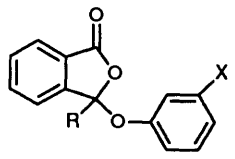
In the present study, the kinetics of the alkaline hydrolysis of a series of 3-(3-substituted phenoxy)phthalides (**1a**), -3-methylphthalides (**1b**), -3-phenylphthalides (**1c**), naphthalides (**2a**), -3-phenylnaphthalides (**2b**) and phenanthralides (**3**) and of a series of methyl pseudo-2-acylbenzoates (**4**) has been investigated. The effects of substitution, relative rates and activation parameters are discussed in terms of detailed mechanisms, and reactivity–selectivity in the hydrolysis of the phenyl pseudo-ester systems is considered.

Results and Discussion

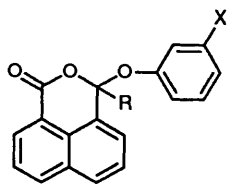
Phenyl Pseudo-esters.—The rate coefficients for the alkaline hydrolysis of the six series of phenyl pseudo-esters are shown in Table 1. The activation parameters are shown in Table 2. The order of reactivity of the phenyl pseudo-esters, *i.e.* H(naphthalides) > H(phthalide) > Me(phthalide) ~ Ph(phthalide) > Ph(naphthalide) > H(phenanthralide) is as found for methyl esters in previous studies[2] and here (see later). The phenyl pseudo-esters are hydrolysed at *ca.* 0.6–1.4 times the rates for the corresponding methyl pseudo-esters. This is in contrast with the factor of *ca.* 4 observed for ordinary esters[12] and clearly indicates the insensitivity of the pseudo-esters to the nature of the leaving group.

Substituent Effects in the Phenyl Pseudo-esters.—The effect of substituents in the phenyl ring of the phenoxy group has been assessed using the Hammett equation with *meta*- σ values,[13] as shown in Table 3. The ρ values range from *ca.* 0.5–1.0. If the three limiting states in Scheme 1 are considered, *i.e.* **I**, **II** and **III**, it is possible to estimate the ρ values that can be expected for their formation. For **I**, the known ρ value for the hydrolysis of methyl benzoates under the same conditions (ρ 2.20),[14] together with the transmission coefficients tabulated by Bowden,[15] results in

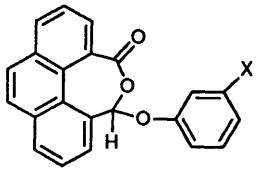
† 5-[1-Hydroxy-1-(3-substituted phenoxy)methyl]phenanthrene-4-carboxylic lactone esters.
‡ In part.



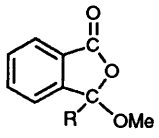
(1a) R = H
(1b) R = Me
(1c) R = Ph



(2a) R = H
(2b) R = Ph



(3)



(4)

Table 1. Rate coefficients (k_2) for alkaline hydrolysis of 3-(3-substituted phenoxy)phthalides, -3-methylphthalides, 3-phenylphthalides, naphthalides, -3-phenylnaphthalides, and phenanthralides in 70% (v/v) dioxane–water.[a]

3-Substituent	k_2/dm^3 mol^{-1} s^{-1}	
Phthalide	30.0 °C	50.0 °C
H	0.832	3.30
Me	0.695	2.80
Cl	1.26	4.63
NO_2	2.40	8.43
3-Methylphthalide		
H	0.225[b]	0.837[b]
Me	0.178	0.700
Br	0.405	1.41
NO_2	0.930	3.44
3-Phenylphthalide		
H	0.218	0.910
Me	0.177	0.710
Cl	0.427	1.69
NO_2	1.07	4.05
Naphthalide		
H	2.76	8.99
Me	2.32	7.38
Cl	3.86	12.0
NO_2	6.33	21.2
3-Phenylnaphthalide		
H	0.0275	0.126
Me	0.0232	0.0902
Cl	0.0513	0.207
NO_2	0.122	0.473
Phenanthralide		
H	0.0850	0.376
Me	0.0740	0.290
Cl	0.128	0.541
NO_2	0.276	1.06

[a] Rate coefficients are reproducible to within ±3%. [b] At 20.2 °C, k_2 = 0.111 dm^3 mol^{-1} s^{-1}; at 40.2 °C, k_2 = 0.428 dm^3 mol^{-1} s^{-1}.

Table 2. Activation parameters for the alkaline hydrolysis of 3-(3-substituted phenoxy)phthalides, -3-methylphthalides, -3-phenylphthalides, naphthalides, -3-phenylnaphthalides, and phenanthralides in 70% (v/v) dioxane–water at 30.0 °C.[a]

3-Substituent	$\Delta H^{\ddagger}$/kcal mol^{-1}	$\Delta S^{\ddagger}$/cal mol^{-1} K^{-1}
Phthalide		
H	12.8 (11.7)[b]	−17 (−21)[b]
Me	13.0	−17
Cl	12.1	−18
NO_2	11.6	−19
3-Methylphthalide		
H	12.1 (10.4)[b]	−22 (−27)[b]
Me	12.7	−20
Br	11.6	−22
NO_2	12.1	−19
3-Phenylphthalide		
H	13.3 (13.6)[b]	−18 (−17)[b]
Me	12.9	−19
Cl	12.8	−18
NO_2	12.3	−18
Naphthalide		
H	10.9 (11.8)[b]	−21 (−18)[b]
Me	10.7	−22
Cl	10.5	−21
NO_2	11.2	−18
3-Phenylnaphthalide		
H	14.2 (12.9)[b]	−19 (−22)[b]
Me	13.2	−22
Cl	13.0	−22
NO_2	12.3	−21
Phenanthralide		
H	13.9 (11.7)[b]	−18 (−24)[b]
Me	12.7	−22
Cl	13.4	−18
NO_2	12.5	−20

[a] Values of $\Delta H^{\ddagger}$ and $\Delta S^{\ddagger}$ are considered accurate to within ±300 cal mol^{-1} and ±2 cal mol^{-1} K^{-1}, respectively. [b] Values for corresponding methyl esters.[1-3]

Table 3. The Hammett reaction constants (ρ) for the alkaline hydrolysis of 3-(3-substituted phenoxy)phthalides, -3-methylphthalides, naphthalides, -3-phenylnaphthalides, and phenanthralides in 70% (v/v) dioxane–water at 30.0 °C.[a]

System	ρ	log k_0	r	s	n
Phthalides	0.657	−0.106	0.992	0.058	4
3-Methylphthalides	0.874	−0.681	0.992	0.078	4
3-Phenylphthalides	0.971	−0.684	0.995	0.066	4
Naphthalides	0.528	0.415	0.993	0.046	4
3-Phenylnaphthalides	0.899	−1.578	0.995	0.064	4
Phenanthralides	0.701	−1.091	0.986	0.085	4

[a] s is the standard deviation, r the correlation coefficient and n the number of substituents studied.

an estimate for ρ of *ca.* 0.7. For **II**, an estimate for ρ of *ca.* 1.4 is given, based on transmission, and of *ca.* 1.7, based on the hydrolysis of phenyl acetates[16] and benzoates[17]. For **III**, the ρ value for the ionisation of phenols[18] can be used as a model and results in an estimate for ρ of *ca.* 2.7.

Thus, the ρ values for all the pseudo-ester series are clearly consistent with a rate-determining step involving addition of

Table 4. Rate coefficients (k_2) for the alkaline hydrolysis of methyl pseudo-2-acylbenzoates in 70% (v/v) dioxane–water.[a]

	k_2/dm^3 mol^{-1} s^{-1}			
Acyl substituent	40.5 °C	51.6 °C	60.6 °C	70.8 °C
H	1.21	2.33[b]	4.01[c]	6.84
CH_3	0.530	0.965	1.51	2.51
CH_2CH_3	0.185	0.367[d]	0.657	1.14[e]
$CH(CH_3)_2$	0.158	0.305[b]	0.589	1.12
$C(CH_3)_3$	0.0185	0.0458	0.0898	0.176
CH_2Ph	0.188	0.350	0.589	1.02
Ph	0.380[f,g]			

[a] Rate coefficients are reproducible to within ±3%. [b] 50.8 °C. [c] 60.0 °C. [d] 50.4 °C. [e] 70.4 °C. [f] 40.0 °C. [g] Lit. values (ref. 3).

Table 5. Activation parameters for the alkaline hydrolysis of methyl pseudo-2-acylbenzoates in 70% (v/v) dioxane–water at 30.0 °C.[a]

	$\Delta H^{\ddagger}$/kcal mol^{-1}	$\Delta S^{\ddagger}$/cal mol^{-1} K^{-1}
H	11.7	−21
CH_3	10.4	−27
CH_2CH_3	12.3	−23
$CH(CH_3)_2$	13.3	−20
$C(CH_3)_3$	15.4	−18
CH_2Ph	11.4	−26
Ph	13.6[b]	−17[b]

[a] Values of $\Delta H^{\ddagger}$ and $\Delta S^{\ddagger}$ are considered accurate to within ±300 cal mol^{-1} and ±2 cal mol^{-1} K^{-1}, respectively. [b] Lit. values (ref. 3).

Table 6. The Taft reaction constants (δ) for the alkaline hydrolysis of 3-substituted 3-methoxyphthalides and 3-methoxynaphthalides in 70% (v/v) dioxane–water.[a]

System	δ	log k_0	r	s	n
Phthalides at 40.5 °C	0.651	−0.563	0.954	0.187	7
Naphthalides at 40.0 °C	1.556	−0.206	0.964	0.316	5

[a] s is the standard deviation, r the correlation and n the number of substituents studied.

hydroxide anion to the pseudo-ester carbonyl group, k'_1 in Scheme 1, followed by rapid ring fission. This is the same conclusion that has been derived from studies of the alkaline hydrolysis of methyl pseudo-8-(substituted benzoyl)-1-naphthoates and pseudo-2-(substituted benzoyl)benzoates[3] and methyl pseudo-8-acyl-1-naphthoates.[2] The approach described above is similar to that of Williams[6] in which effective charges are assigned. The latter can be completed by dividing the observed ρ by the ρ value for the ionisation of phenols under identical conditions.

The activation parameters for the phenyl pseudo-esters shown in Table 2 are typical for simple bimolecular reactions such as ester hydrolysis, *cf.* ref. 19. The variation in the entropy of activation only just exceeds the uncertainties. The enthalpy of activation does show more variation. However, only the naphthalides have a significant increase when steric 'bulk' interactions inhibit the formation of the transition state, *i.e.* when H is substituted by Ph. The naphthalides do appear to be much more 'crowded' than the phthalides (see later).

Reactivity–Selectivity.—The principle of reactivity–selectivity has a long history in physical organic chemistry.[20] However, the concept has been strongly criticised by Johnson[21] especially regarding the contrast between linear free energy relationships and the reactivity–selectivity principle. In the present study, there is no discernible relation between log k_2 for the parent pseudo-ester and ρ for substitution in the phenyl group. The latter can be considered to be a measure of charge development in the transition state, *cf.* ref. 6, and so characterises the transition state. For the phthalides and, separately, for the napthhalides, the transition state could be considered to become significantly more 'advanced' (more charge development) as reactivity decreases, which would be considered to be 'Hammond' behaviour.[21] However, it seems more likely that the dependence, in each series, of rate on steric effects is the factor that controls the reactivity and structure of the transition state[2] (also see later). Thus, the transition state appears to be 'set' in its structure by steric effects and its stability is then modified by the influence of polar effects from non-proximate substitution. For the phthalides and naphthalides, ring strain does not appear to significantly differ, as discussed later. Ring strain factors might be important in other studies.[22] It does appear that the reactivity–selectivity principle must be abandoned in systems such as those studied here and other related studies of reactivity.[23]

Lactones, which are cyclic esters and closely related to pseudo-esters, are hydrolysed by a mechanism similar to that described here and more readily than normal esters.[22] Simple lactones, up to seven-membered, and the pseudo-esters studied here exist in a '*cis*' conformation, in contrast with the preferred '*trans*' conformation of normal esters. The former conformation inhibits resonance interactions and increases the initial state energy of lactones compared with esters.[22] The phenyl pseudo-esters studied here are more reactive than the corresponding ordinary esters; *cf.* k_2 for the alkaline hydrolysis of phenyl benzoate in the same medium[24] is 0.0702 dm^3 mol^{-1} s^{-1} at 30 °C and those for the phenyl pseudo-esters in Table 1. The '*cis*' conformation appears to be the main factor causing the greater reactivity of lactones and pseudo-esters.[22] Ring strain does not appear to be a major factor in determining the reactivity for the five-membered phthalides and six-membered naphthalides studied here. The carbonyl stretching frequencies of the pseudo-esters have been considered to be function of such ring strain.[25] The values observed for the pseudo-esters in this study (five-membered, *ca.* 1 769 cm^{-1}; six-membered, *ca.* 1 713 cm^{-1}; and seven-membered, *ca.* 1 708 cm^{-1}) are significantly different from each other and do characterise the ring size. However, these values do not appear to be related to the results of the reactivity studies.

Methyl Pseudo-esters.—The alkaline hydrolysis of all the methyl pseudo-esters studied is first order both in the pseudo-ester and hydroxide anion. The product of the hydrolysis is the anion of the corresponding carboxylate anion. Rate coefficients for the methyl pseudo-esters in 70% (v/v) dioxane–water at several temperatures are shown in Table 4. The activation parameters for these reactions are shown in Table 5.

Substituent Effects in the Methyl Pseudo-esters.—The order of the reactivity for the acyl substituent shown in Table 4, *i.e.* H > CH_3 > Ph > CH_2CH_3 ~ CH_2Ph > $CH(CH_3)_2$ > $C(CH_3)_3$, is the same as that shown by a more limited series of methyl pseudo-8-acyl-1-naphthoates.[2] It would be expected that a combination of polar and steric affects control the reactivity.[2,3] Correlations have been attempted for the present results and those obtained previously[2] with σ* and E_s for the substituent at the 2- and 8-acyl groups. The steric substituent constant, E_s, is not ideal for the present purpose as it was defined from reactions involving nucleophilic attack at a carbonyl group directly bonded to the substituent.[26] However, the parameter has a fairly wide range of applicability.[27] The value used for Ph, 0.23, is based on that calculated for steric

Table 7. Solvent isotope effects on the alkaline hydrolysis of methyl pseudo-2-acylbenzoates.[a]

Acyl substituent	k_2/dm^3 mol^{-1} s^{-1} 70% (v/v) Dioxane–H_2O	70% (v/v) Dioxane–D_2O	k_{H_2O}/k_{D_2O}
H (60.3 °C)	3.75	5.40	0.69
Me (40.5 °C)	0.530	0.663	0.80
Ph (60.0 °C)	1.56[b]	2.00[b]	0.78[b]

[a] See Table 1. [b] Lit. value (ref. 3).

interactions perpendicular to the plane of this substituent ('thickness'),[28] rescaled to the original scale.[12] The correlations, using the Taft equation (1), are shown in Table 6. These are only barely satisfactory but are not significantly improved by the addition of σ^*.

$$\log (k/k_0) = \delta E_s \quad (1)$$

However, it is clear that steric 'bulk' effects mainly control the relative rates, as in ester hydrolysis.[12] The first conclusion is that the sensitivity to steric effects for pseudo-naphthoates is more than twice that for pseudo-benzoates. This is in distinct contrast with the previous[3] and present studies of polar effects which indicate clearly the closely comparable development of charge in the transition state for pseudo-naphthoates and -benzoates. These studies indicate again the rate-determining step to be k'_1 in Scheme 1. However, the present studies show that the pseudo-naphthoates appear to be much more 'crowded' in the initial state than the pseudo-benzoates and these 'bulk' interactions increase even more in the pseudo-naphthoates than in the pseudo-benzoates in forming the transition state. The second conclusion is that there is no general relation between ring size and reactivity for the five-membered pseudo-benzoates and six-membered pseudo-naphthoates, *cf.* ref. 22. Thus, for the substituent H, the pseudo-naphthoates are more reactive; whereas, for the substituent Me and Ph, the pseudo-benzoates are more reactive. The enthalpy changes for the alkaline hydrolysis of the five-membered coumaran-2-one and six-membered 3,4-dihydrocoumarin have been found in their hydrolysis reaction,[29] *cf.* ref. 22. Izbicka and Bolen[29] considered their results to indicate little difference in ring strain, unlike the more general conclusions of Kaiser and Kezdy.[22] The present results indicate no significant differences arising from ring strain on reactivity between the five- and six-membered pseudo-esters. However, the pseudo-esters all undergo alkaline hydrolysis readily, *cf.* k_2 for methyl benzoate in the same medium[14] is 0.0174 dm^3 mol^{-1} s^{-1} at 30 °C with those for the methyl pseudo-esters in Table 4. The pseudo-esters have a '*cis*' conformation, like simple five- and six-membered lactones,[22] caused by the constraints of ring formation. This appears to increase the initial state energy and is the main factor[22] causing increased reactivity.

The entropies and enthalpies of activation for the alkaline hydrolysis of the pseudo-esters, shown in Table 5, are all consistent with a bimolecular pathway. The variation in the enthalpy of activation appears mainly to be a function of increasing steric 'bulk' giving an increase in $\Delta H^{\ddagger}$. The changes in the entropy of activation are more minor and do not appear to have any systematic trends.

Kinetic Solvent Effects.—The kinetic deuterium solvent isotope effects were examined for the alkaline hydrolysis of methyl pseudo-2-formyl- and acetyl-benzoate in 70% aqueous dioxane in Table 7. In all cases, rate enhancements in the deuterium oxide solvent were observed and are very similar to those observed for pseudo-naphthoates[2] and found for related hydrolyses occurring by attack of hydroxide anion at a carbonyl group.[19]

Proposed Mechanism.—All the evidence clearly indicates that the rate-determining step is the addition of the hydroxide anion to the pseudo-ester carbonyl group, k'_1 in Scheme 1, followed by a rapid collapse of the intermediate to the final product of the reaction, the carboxylate anion of the normal acid.

Experimental

Materials.—The phenyl pseudo-esters were prepared by reaction of the acid chloride or bromide with the phenol.

3-*Phenoxynaphthalide.*—To 8-formyl-1-naphthoic acid (5.6 g, 28 mmol), was added freshly distilled thionyl chloride (6 cm^3, 84 mmol) and the solution was refluxed for 2 h. Excess thionyl chloride was removed under reduced pressure and the residue was dissolved in dry chloroform (20 cm^3). A solution of phenol (2.7 g, 29 mmol) in dry chloroform (5 cm^3) and a few drops of pyridine were added to the acid chloride and the mixture was refluxed for 6 h. The residue obtained on evaporation of the solution was subjected to chromatography on silica using benzene as the eluant. The product was obtained from the first fraction and, after evaporation, was recrystallised from light petroleum (b.p. 60–80 °C) to give 3-phenoxynaphthalide (0.93 g, 12%), m.p. 93–95 °C.

3-(3-*Substituted phenoxy*)*naphthalides.*—These esters were prepared by the method described above.

3-(3-*Substituted phenoxy*)*phenanthralides.*—Using 5-formyl-4-phenanthroic acid, these esters were prepared by the method described above.

3-(3-*Substituted phenoxy*)-3-*phenylphthalide.*—Using 2-benzoylbenzoic acid, these esters were prepared by the method described above.

3-(3-*Substituted phenoxy*)-3-*methylphthalide.*—Using 2-acetylbenzoic acid, these esters were prepared by the method described above.

3-*Phenoxy*-3-*phenylnaphthalide.*—8-Benzoyl-1-naphthoic acid (2 g, 7.2 mmol) in freshly distilled thionyl chloride (10 cm^3, 13.8 mmol) was refluxed for 4 h. The excess thionyl chloride was removed under reduced pressure and the acid chloride was dissolved in dry chloroform (10 cm^3). Sodium phenolate (0.84 g, 7.2 mmol) was added and the mixture was refluxed overnight. After filtration, the solvent was evaporated (× 3) with hot light petroleum (60–80 °C). Upon cooling, the product crystallised out from the combined extracts and was recrystallised from benzene (0.28 g, 14%), m.p. 144–147 °C.

3-(3-*Substituted phenoxy*)-3-*phenylnaphthalides.*—These esters were prepared by the method described above.

3-*Phenoxyphthalide.*—A mixture of 2-bromophthalide (3 g, 14.1 mmol), sodium phenolate (1.64 g, 14.1 mmol) and dry chloroform (20 cm^3) was refluxed for 4 h. After filtration and evaporation, the residue was subjected to chromatography on silica using chloroform as the eluant. The product was obtained from the first fraction and, after evaporation, was recrystallised from light petroleum (b.p. 60–80 °C) (0.76 g, 24%), m.p. 120–122 °C.

3-(3-*Substituted phenoxy*)*phthalides.*—The esters were prepared by the method described above.

Table 8. The physical constants of the 3-(3-substituted phenoxy)-phthalide, -3-methylphthalides, and -3-phenylphthalides, naphthalides and -3-phenylnaphthalides, and phenanthralides.

3-Substituent	M.p./°C	Formula	Found (%) C	H	Other	Required (%) C	H	Other	Recrystallisation solvent[b]
Phthalide									
H	120–122	$C_{14}H_{10}O_3$	74.4	4.5		74.3	4.5		Light petroleum
Me	100–102	$C_{15}H_{12}O_3$	75.1	5.0		75.0	5.0		Light petroleum
Cl	137–139	$C_{14}H_9ClO_3$	64.4	3.4	13.8(Cl)	64.5	3.5	13.6 (Cl)	Light petroleum
NO_2	148–149	$C_{14}H_9NO_5$	62.2	3.2	4.9(N)	62.0	3.3	5.2 (N)	Light petroleum
3-Methylphthalide									
H	67–69	$C_{15}H_{12}O_3$	74.9	5.1		75.0	5.0		Light petroleum–benzene
Me	71–72	$C_{16}H_{14}O_3$	75.6	5.6		75.6	5.6		Light petroleum–benzene
Br	74–75	$C_{15}H_{11}BrO_3$	56.4	3.4	24.9(Br)	56.0	3.5	25.0 (Br)	Light petroleum–benzene
NO_2	115–117	$C_{15}H_{11}NO_5$	62.8	3.8	4.5(N)	63.2	3.9	4.9 (N)	Light petroleum–benzene
3-Phenylphthalide									
H	169–170[a]	$C_{20}H_{14}O_3$	79.5	4.6		79.5	4.5		Light petroleum
Me	159–160	$C_{21}H_{16}O_3$	80.2	5.0		79.7	5.1		Light petroleum
Cl	129–130	$C_{20}H_{13}ClO_3$	71.8	3.8	10.8(Cl)	71.3	3.9	10.5 (Cl)	Light petroleum
NO_2	115–117	$C_{20}H_{13}NO_5$	69.4	3.5	4.3(N)	69.2	3.8	4.0 (N)	Light petroleum
Naphthalide									
H	93–95	$C_{18}H_{12}O_3$	78.3	4.3		78.3	4.4		Light petroleum
Me	100–102	$C_{19}H_{14}O_3$	78.6	4.9		78.7	4.8		Light petroleum
Cl	145–147	$C_{18}H_{11}ClO_3$	69.6	3.5	11.7(Cl)	69.6	3.6	11.4 (Cl)	Light petroleum–benzene
NO_2	187–189	$C_{18}H_{11}NO_5$	67.0	3.4	4.1(N)	67.3	3.5	4.4 (N)	Light petroleum–benzene
3-Phenylnaphthalide									
H	144–147	$C_{24}H_{16}O_3$	81.8	4.7		81.8	4.6		Benzene
Me	133–135	$C_{25}H_{18}O_3$	81.6	4.9		82.0	5.0		Benzene
Cl	137–139	$C_{24}H_{15}ClO_3$	74.7	3.9	9.4(Cl)	74.5	3.9	9.2 (Cl)	Benzene
NO_2	150–152	$C_{24}H_{15}NO_5$	72.5	3.8	3.5(N)	72.5	3.8	3.5 (N)	Methanol
Phenanthralide									
H	145–147	$C_{22}H_{14}O_3$	81.0	4.3		81.0	4.3		Methanol
Me	133–135	$C_{23}H_{16}O_3$	81.1	4.8		81.2	4.7		Methanol
Cl	146–148	$C_{22}H_{13}ClO_3$	72.9	3.7	9.6(Cl)	73.2	3.6	9.8 (Cl)	Methanol
NO_2	208–210	$C_{22}H_{13}NO_5$	71.0	3.4	3.7(N)	71.2	3.5	3.8 (N)	Methanol

[a] Lit.,[4,30] 158–160, 162–163 °C. [b] Light petroleum fraction boiling in the range 60–80 °C.

Table 9. The physical constants of the methyl pseudo-2-acylbenzoates.

Substituent	M.p./°C	Lit. m.p./°C	Ref.	Recrystallisation Solvent	λ/nm
H	42–44	44	33	Hexane	295
CH_3	44–46[a]	44–44.5	32	Methanol	295
CH_2CH_3	48–50[a]	49–51	32	Methanol	292
$CH(CH_3)_2$	48–50[a]	47–49	32	Methanol	292
$C(CH_3)_3$	45–46[a,b]			Methanol	290
CH_2Ph	113	113	34	Methanol	290

[a] See the text for purity and isolation. [b] Found: C, 71.0; H, 7.2. $C_{13}H_{16}O_3$ requires C, 70.9; H, 7.3%.

All the products had IR ^1H and ^{13}C NMR., and mass spectra in accord with the stated structures. The phenoxy phthalides, 3-methylphthalides, 3-phenylphthalides, naphthalides, 3-phenylnaphthalides and phenanthralides have carbonyl frequencies at 1768–1774, 1760–1785, 1760–1778, 1710–1719, 1710–1723, and 1703–1714 cm^{-1}, respectively. The m.p.s, elemental analyses, and recrystallisation solvents are shown in Table 8.

The methyl pseudo-2-acylbenzoates can be prepared by either treatment of the 2-acylbenzoic acid with thionyl chloride, followed by reaction with anhydrous methanol containing 1 mol equiv. of urea,[31,32] or esterification by refluxing in anhydrous methanol with dry hydrogen chloride.[14,32] 3-Methyl- and 3-benzyl-3-methoxyphthalides could be obtained by the latter method and gave pure products on recrystallisation (see Table 9). Both the methods gave the pseudo-esters, together with the corresponding normal esters, of the other four alkyl phthalides. These could be purified by fractional crystallisation or, better, distillation under reduced pressure. However, the pseudo-esters still contained traces of the normal esters, *cf.* ref. 35. Pure samples for kinetic studies were prepared using an Aerograph Autoprep GLC, employing a 30% SE30 on chromasorb W column. These were checked for purity using an analytical GLC, employing a 15% Apiezon L on chromasorb P column. The retention times for the pseudo esters were shorter than those for the normal esters. The ^1H and ^{13}C NMR, IR and mass spectra of all the esters were in accord with the stated structures. The carbonyl stretching frequencies in carbon tetrachloride of the pseudo-esters were in the range 1775–1785 cm^{-1}. The physical constants of the pseudo-esters were shown in Table 9, together with their recrystallisation solvent and the elemental analysis of the previously unreported ester.

The solvents for the kinetic studies were prepared as previously described.[14]

Measurements.—Rate coefficients for the alkaline hydrolysis of the pseudo-esters were determined spectrophotometrically by use of Unicam SP8000 and Pye Unicam SP8-100 spectrophotometers. The reactions were followed at 288–295 nm (phenoxy-

phthalides, 3-methylphthalides, 3-phenylnaphthalides, and phenanthralides), 310 nm (phenoxynaphthalides), 244–250 nm (phenoxy-3-phenylphthalides) and as shown in Table 9 (methyl esters). The procedure used was that described previously.[2,36] The products of the reactions were found to be the anions of the corresponding acids and, for the phenyl esters, phenols in quantitative yield in all cases. They were further confirmed spectrophotometrically by comparison of the spectrum of the acid and, for the phenyl esters, phenol in base with that of the reaction products.

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