

Substituent Effects on the Hydrolysis of 3-Methoxy-3-phenylphthalides<sup>1,2</sup>DANIEL P. WEEKS,\* JAMES CELLA,<sup>3</sup> AND LYNNE T. CHEN

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The effect of substituents on the para position of the 3-phenyl ring on the rate of acid-catalyzed hydrolysis of 3-methoxy-3-phenylphthalides has been determined. The rates correlate with  $\sigma^+$  and the reaction constant,  $\rho$ , is  $-1.2$ . The rate-enhancing effect of a methoxy group on the 6 position of the phthalide ring is more pronounced than that of a methoxy group on the para position of the 3-phenyl ring. All the compounds studied give Zucker-Hammett slopes of  $0.68 \pm 0.02$  and rather highly negative entropies of activation and several of the compounds show deuterium oxide solvent isotope effects of  $\sim 0.5$ . These data are consistent with an A1 hydrolysis mechanism in which hindered rotation in the transition state is a complicating factor. 3-Methoxy-3-phenyl-6-nitrophthalide suffers hydrolysis more rapidly than one would expect.

A paper<sup>4</sup> which precedes this one describes the unimolecular, acid-catalyzed hydrolysis of 3-methoxyphthalides having various substituents in the 3 position. It introduces an explanation for the apparently anomalous behavior of 3-methoxy-3-phenylphthalide (1) which was reported earlier.<sup>5</sup> We now present data on the hydrolysis of 3-methoxy-3-phenylphthalides having substituents on the para position of the 3-phenyl ring and on the 6 position of the phthalide ring. These two positions were chosen because they bear the same formal relationship to the cation which would form at the 3 position during the unimolecular (A1) hydrolysis reaction.

## Results

All of the substituted 3-methoxy-3-phenylphthalides form the corresponding 2-benzoylbenzoic acid when allowed to react in aqueous mineral acid. The reactions show straightforward pseudo-first-order behavior. Pseudo-first-order rate constants ( $k_{\psi}$ ) are shown in Table I.

Figure 1 shows a Hammett  $\sigma\rho$  treatment on the rate constants determined in 1 M sulfuric acid at 30°. Rate constants for the four compounds having substituents on the para position of the 3-phenyl ring (1-4) correlate nicely with  $\sigma^+, \rho = -1.2$ . However, the rate constants for the three compounds having substituents on the 6 position (1, 5, and 6) do not correlate with either  $\sigma$  or  $\sigma^+$  (Figure 1). The rate constants for 5 and 6 both lie above the line established by compounds 1-4.

When  $\log k_{\psi}$  for 1 was plotted against  $-H_0$  the result was a straight line with the surprisingly small slope of 0.67.<sup>5</sup> Figure 2 shows the same plots for 2-6. The slope established by each of these compounds is virtually identical with that for 1. The actual values for the slopes are presented in Table II.

When  $\log k_{\psi}$  is plotted against the reciprocal of the absolute temperature a straight line results. Activation parameters calculated from these plots are summarized in Table II.

The data in Table I make it possible to calculate

(1) Taken, in part, from the Senior Honors Thesis submitted by J. C. to Seton Hall University, 1968, and from the M.S. Thesis submitted by L. T. C. to Seton Hall University, 1969.

(2) Presented, in part, at the Third Middle Atlantic Regional Meeting of the American Chemical Society, Philadelphia, Pa., Feb 1968, Abstract No. H-58.

(3) National Science Foundation Undergraduate Research Fellow, 1967-1968.

(4) D. P. Weeks and J. P. Crane, *J. Org. Chem.*, **38**, 3375 (1973).

(5) D. P. Weeks, A. Grodski, and R. Fanucci, *J. Amer. Chem. Soc.*, **90**, 4958 (1968).

TABLE I  
HYDROLYSIS OF SUBSTITUTED 3-METHOXY-3-PHENYLPHthalIDES  
IN AQUEOUS ACID

Compd	—Substituents— X Y		[H <sub>2</sub> SO <sub>4</sub> ], M	Temp, °C	10 <sup>4</sup> $k_{\psi}$ , <sup>a</sup> sec <sup>-1</sup>
1	H	H	0.99	30.2	1.09 ± 0.02
			1.00 <sup>b</sup>	30.1	0.877 ± 0.02
2	OCH <sub>3</sub>	H	0.99	30.0	5.65 ± 0.02
			1.97	30.0	14.5 ± 0.04
			3.10	30.0	36.4 ± 0.08
			4.16	30.0	77.6 ± 0.07
			0.99	36.9	10.0 ± 0.01
			0.99	45.8	21.9 ± 0.05
			0.99	30.1	2.11 ± 0.02
3	CH <sub>3</sub>	H	1.98	30.0	5.64 ± 0.22
			3.10	30.0	12.2 ± 0.05
			4.16	30.0	30.5 ± 0.09
			5.22	30.0	72.5 ± 0.04
			0.99	36.8	4.28 ± 0.04
			0.99	47.1	10.1 ± 0.01
			0.99	29.9	0.746 ± 0.10
			1.98	30.0	1.58 ± 0.03
			3.10	30.0	4.73 ± 1.0
			4.00	30.0	10.5 ± 1.5
4	Cl	H	5.00	30.0	21.7 ± 1.6
			0.99	37.0	1.47 ± 0.01
			0.99	47.0	3.30 ± 0.01
			1.02	29.9	9.71 ± 0.10
			2.53	29.9	37.5 ± 0.10
			4.22	29.9	130.0 ± 1.0
			1.02	20.6	3.68 ± 0.09
			1.02	38.9	20.1 ± 0.20
			1.04 <sup>b</sup>	29.9	7.85 ± 0.03
			1.02 <sup>c</sup>	29.9	19.2 ± 0.20
5	H	OCH <sub>3</sub>	1.02	29.9	0.567 ± 0.005
			1.02	29.2	0.520 ± 0.009
			1.98	29.2	1.26 ± 0.01
			3.12	29.2	3.06 ± 0.02
			3.95	29.2	5.83 ± 0.21
			4.95	29.2	13.0 ± 0.20
			6.27	29.2	26.6 ± 0.90
			1.03	38.7	1.23 ± 0.01
			1.03	48.8	2.63 ± 0.07
			1.04 <sup>b</sup>	29.9	0.463 ± 0.001
6	H	NO <sub>2</sub>	1.02 <sup>c</sup>	29.9	1.06 ± 0.05

<sup>a</sup> Average of at least two runs. Confidence intervals are based on a 95% confidence level. <sup>b</sup> Catalyst acid is HClO<sub>4</sub>. <sup>c</sup> Catalyst acid is D<sub>2</sub>SO<sub>4</sub>.

the deuterium oxide solvent isotope effects,  $k_{\text{H}_2\text{O}}/k_{\text{D}_2\text{O}}$ , for 5 and 6. The values are very similar to that which was established for 1.<sup>5</sup>

Bunton<sup>6</sup> has suggested that the ratio of the rate

(6) C. A. Bunton, J. H. Crabtree, and L. Robinson, *J. Amer. Chem. Soc.*, **90**, 1258 (1968).

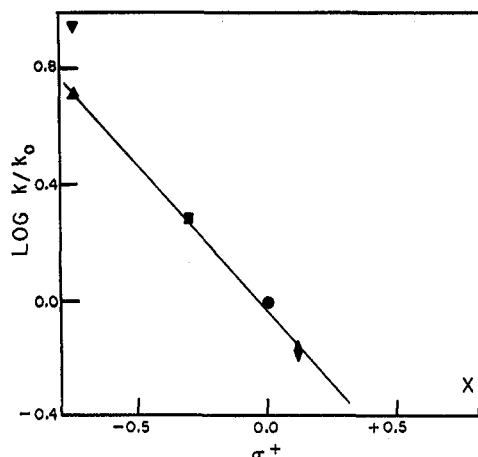


Figure 1.—Hydrolysis of substituted 3-methoxy-3-phenylphthalides: *p*-H (1), ●; *p*-OCH<sub>3</sub> (2), ▲; *p*-CH<sub>3</sub> (3), ■; *p*-Cl (4), ◆; 6-OCH<sub>3</sub> (5), ▼; 6-NO<sub>2</sub> (6), ×; plot of log  $k/k_0$  against  $\sigma^+$ .

TABLE II

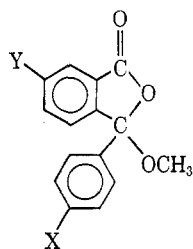
A SUMMARY OF EXPERIMENTAL RESULTS ON THE HYDROLYSIS OF SUBSTITUTED 3-METHOXY-3-PHENYLPHthalIDES

Compd	Zucker-Hammett slope <sup>a</sup>	$\Delta H^\ddagger$ , kcal mol <sup>-1</sup>	$\Delta S^\ddagger$ , eu	$k_{H_2O}/k_{D_2O}$	$k_p/k_s^b$
1	0.67 <sup>c</sup>	17.0 <sup>c</sup>	-20.6 <sup>c</sup>	0.50 <sup>c</sup>	0.80
2	0.69	16.3	-19.7		
3	0.68	16.7	-20.1		
4	0.67	16.3	-23.7		
5	0.67	16.3	-18.5	0.50	0.81
6	0.66	15.3	-27.8	0.52	0.82

<sup>a</sup> Slopes of plots of log  $k_p$  against  $-H_0$ . <sup>b</sup>  $k_p$  is the rate constant in perchloric acid and  $k_s$  is the rate constant in sulfuric acid.

<sup>c</sup> Taken from ref 5.

constants determined in perchloric acid and sulfuric acid at identical acid concentrations may distinguish between bimolecular and unimolecular hydrolysis mechanisms. These ratios for 1, 5, and 6 are listed in Table II.



Compd	X	Y
1	H	H
2	OCH <sub>3</sub>	H
3	CH <sub>3</sub>	H
4	Cl	H
5	H	OCH <sub>3</sub>
6	H	NO <sub>2</sub>

### Discussion

The data presented here support the proposal made in the two preceding papers<sup>4,7</sup> that 3-methoxyphthalides suffer hydrolysis *via* an A1 pathway. The effect of substituents on the para position of the 3-phenyl ring is correlated very well by  $\sigma^+$ . Thus, the intermediacy of a cation at the 3 position is established.

(7) D. P. Weeks and F. H. Field, *J. Org. Chem.*, **38**, 3380 (1973).

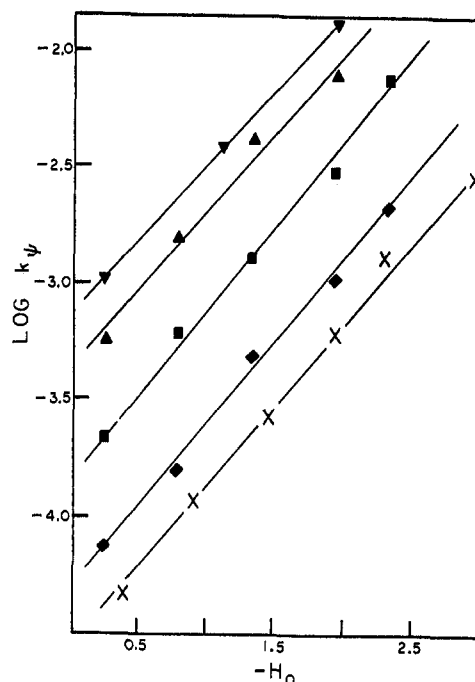


Figure 2.—Hydrolysis of substituted 3-methoxy-3-phenylphthalides: *p*-OCH<sub>3</sub> (2), ▲; *p*-CH<sub>3</sub> (3), ■; *p*-Cl (4), ◆; 6-OCH<sub>3</sub> (5), ▼; 6-NO<sub>2</sub> (6), ×; plot of log  $k_p$  against  $-H_0$ . The slopes are given in Table II.

The slope,  $\rho = -1.2$ , is not so negative as one might expect for an "acetal-like" compound. For the hydrolysis of 20 diethyl acetals and ketals,<sup>8</sup>  $\rho$  is  $-3.6$ , and for the hydrolysis of several diethyl acetals of meta-substituted benzaldehydes,<sup>9</sup>  $\rho$  is  $-3.35$ . Studies<sup>10,11</sup> of 2-substituted 1,3-dioxolanes give  $\rho$  values of about  $-4$ . Less negative values of  $\sigma$  have been obtained for the hydrolysis of 2-methyl-2-(substituted methyl)-1,3-dioxolanes<sup>12</sup> ( $\rho = -1.48$ ) and 2-(substituted methyl)-2,5,5-trimethyl-1,3-dioxanes<sup>12</sup> ( $\rho = -1.33$ ) but these are not strictly comparable, since the substituent is one methylene group removed from the cationic center.

We suggest that the smaller  $\rho$  value reported here is due to several factors which are not present in the systems discussed in the previous paragraph. The transition state leading to the cation is stabilized by several features, including the ring oxygen<sup>13</sup> and the two aryl rings. The effect of substituents will be diminished to the extent that these other features delocalize the positive charge. The only strictly comparable system on which data has been reported is the hydrolysis of 3-aryl-3-methoxyperinaphthalides<sup>14</sup> which correlate with  $\sigma^+$  and give a  $\rho$  value of  $-2.1$ . The remaining difference of one  $\rho$  unit is consistent with our observation that the 3-phenyl ring in the phthalide system cannot lie coplanar with the developing cation and, thus, the influence of substituents on the ring will be diminished even further. In the 3-aryl-3-methoxyperinaphthalides the aryl ring at position 3 can become coplanar with the

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(9) T. H. Fife and L. K. Jao, *J. Org. Chem.*, **30**, 1492 (1965).

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(11) F. Aftalion, M. Hellin, and F. Coussemant, *Bull. Soc. Chim. Fr.*, 1497 (1965).

(12) T. C. Bruice and D. Piszkiwicz, *J. Amer. Chem. Soc.*, **89**, 3568 (1967).

(13) D. S. Noyce and R. M. Pollack, *J. Amer. Chem. Soc.*, **91**, 119 (1969).

(14) D. P. Weeks and G. W. Zuorick, *J. Amer. Chem. Soc.*, **91**, 477 (1969).

cationic center because of the puckered shape of the six-membered hetero ring in these compounds.<sup>14</sup> This interpretation is supported by the fact that the rate constant for 3-phenyl-3,6-dimethoxyphthalide (**5**) is greater than that for 3-*p*-anisyl-3-methoxyphthalide (**2**). That is, in **5** the methoxy group will be better able to stabilize the developing cation, since the phthalide ring to which it is attached is compelled to lie in the same plane as the cation. The fact that the rate for the 6-nitro compound is also anomalously fast is puzzling and will be discussed later in this paper.

Throughout the course of this work on the hydrolysis of 3-methoxyphthalides the possibility of a change in mechanism with changing acidity of the medium has had to be considered. That is, the marked curvature<sup>5</sup> of a plot of  $\log k_p$  against  $\log a_{\text{H}_2\text{O}}$  (Bunnett *w*)<sup>15</sup> might be interpreted as indicating that at low acidity the compound is undergoing hydrolysis *via* an A2 pathway and at high acidity the mechanism has changed to an A1 process. Enough examples of such things occurring in aqueous hydrolysis studies have now appeared to make it an attractive possibility.<sup>16-18</sup>

The evidence, taken in balance, does not support such as interpretation in this case. If the mechanism were changing from A2 to A1 as the acidity increased, then one would predict that compounds whose structure encouraged the A1 reaction by stabilizing the intermediate cation, *e.g.*, **2** and **5**, ought to suffer the change in mechanism at an acidity which is substantially lower than that at which a compound such as **1** or **4** undergoes the change. However, the *w* plots of all of these compounds are very similar. This similarity of the response of rate to changing acidity is illustrated more precisely by the fact that the Zucker-Hammett slopes (Table II) are virtually identical for all the compounds in this study. In addition, the almost constant value of  $k_{\text{H}_2\text{O}}/k_{\text{D}_2\text{O}}$  for compounds **1**, **5**, and **6** and the equally constant value of  $k_p/k_s$  make a change in mechanism with changing substrate structure unlikely.

The observation that the rates in sulfuric acid are faster than in perchloric acid is not predictable by Bunton's<sup>6</sup> reasoning. However, we have proposed<sup>4</sup> that unusual solvation of the transition state will be present in these reactions, and this factor could well be responsible for this aberrant behavior as well as for the breakdown of the Zucker-Hammett hypothesis. Indeed, note that it is the entropy of activation which is the important factor in determining the relative rates of substituted 3-methoxy-3-phenylphthalides. This indicates that solvation is playing an important role in the stabilization of the transition state.

Finally, there remains the question of why the hydrolysis rate of 3-methoxy-3-phenyl-6-nitrophthalide (**6**) is unusually fast. It is especially tempting to propose a change to a bimolecular mechanism in this case. The very strongly electron-withdrawing nitro group could so discourage the formation of a cation at position 3 that a bimolecular process would become possible. A nitro substituent does induce a change in mechanism in the hydrolysis of enol acetates<sup>13</sup> but,

on the other hand, seems not to in the hydrolysis of the acetals of substituted benzaldehydes.<sup>9</sup> However, in the present case the deviation of **6** from the  $\sigma\rho$  relationship is not accompanied by meaningful changes in the other criteria. Thus, speculation seems dangerous at the moment.

### Experimental Section

**Materials.**—Deuteriosulfuric acid solutions were prepared by diluting sulfuric acid-*d*<sub>2</sub> (Merck Sharp and Dohme) with deuterium oxide (Stohler Isotope Chemicals). All sulfuric and perchloric acid solutions were standardized individually. Doubly distilled water was used for all aqueous solutions. Methanol which was freshly distilled from sodium methoxide was used in the preparation of stock solutions for the kinetics runs.

2-*p*-Anisoylbenzoic acid, 2-*p*-toluylbenzoic acid, and 2-(*p*-chlorobenzoyl)benzoic acid were prepared by a normal<sup>19</sup> Friedel-Crafts reaction of the appropriately substituted benzene and phthalic anhydride. Yields were greater than 75% and melting points agreed with those cited in the literature.<sup>20,21</sup>

**5-Methoxy-2-benzoylbenzoic Acid.**—A solution of 12 g of potassium permanganate, 40 ml of 5% sodium hydroxide, and 200 ml of water was allowed to react with 4 g (0.022 mol) of 2-methyl-4-methoxybenzophenone<sup>22</sup> by refluxing for 2 hr. The excess permanganate was destroyed by adding a few drops of ethanol and the manganese dioxide was removed by filtration. The filtrate was reduced to a volume of 50 ml and acidified with dilute sulfuric acid. The product crystallized on cooling. Upon recrystallization from benzene-ether 0.4 g (10%) of keto acid was obtained, mp 149–152° (lit.<sup>23</sup> mp 149–151.2°).

*Anal.* Calcd for C<sub>15</sub>H<sub>12</sub>O<sub>4</sub>: C, 70.31; H, 4.69. Found: C, 70.21; H, 4.77.

**5-Nitro-2-benzoylbenzoic Acid.**—Powdered aluminum chloride, 5.3 g (0.04 mol), was added cautiously with cooling and stirring to 3.86 g (0.02 mol) of 4-nitrophthalic anhydride<sup>24</sup> in 50 ml of benzene. The mixture was stirred at room temperature for 1 hr and then brought slowly to reflux and held there for 4 hr. After the careful addition of ice and concentrated HCl the organic material was extracted with ether. The ether was removed and the yellow oil crystallized on standing overnight. Recrystallization from benzene-ether gave 1.6 g (30%) of keto acid, mp 214–215° (lit.<sup>25</sup> mp 213–214.2°).

*Anal.* Calcd for C<sub>14</sub>H<sub>9</sub>NO<sub>5</sub>: C, 61.99; H, 3.32. Found: C, 62.17; H, 3.48.

Actually, two nitro-2-benzoylbenzoic acids are formed in the reaction of 4-nitrophthalic anhydride and benzene. We felt that the evidence for the isomer melting at 215° being 5-nitro-2-benzoylbenzoic acid was not completely convincing. Therefore, we established the identity of this isomer by decarboxylation.

**Decarboxylation of 5-Nitro-2-benzoylbenzoic Acid.**—The copper salt of the acid was prepared by allowing 0.05 g of the acid to dissolve in 7 ml of a solution of 30 ml of water containing 0.05 g of sodium hydroxide. Benzene was added and the water was removed as the azeotrope. Excess benzene was removed and the salt was redissolved in 4 ml of water. An aqueous solution of copper sulfate was added and the resulting blue precipitate was collected, washed with water, and dried in a vacuum oven. In a 10-ml flask was mixed 0.36 g of 5-nitro-2-benzoylbenzoic acid, 0.023 g of the copper salt, and 0.01 g of finely divided copper. A reflux condenser was attached and the mixture was stirred and heated to 250–270° for 1.5 hr. A yellow solid was removed from the walls of the condenser and recrystallized twice from absolute ethanol. The fine, light yellow crystals of 4-nitrobenzophenone weighed 0.06 g (21%), mp 134–136° (lit.<sup>25</sup> mp 138°). The ir spectrum was superimposable on that of a

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(17) K. Yates and R. A. McClelland, *J. Amer. Chem. Soc.*, **89**, 2686 (1967).

(18) D. P. Weeks and A. W. Levine, Abstracts, 5th Middle Atlantic Regional Meeting of the American Chemical Society, Newark, Del., April 1970, Or-17.

genuine sample of 4-nitrobenzophenone.<sup>26</sup> Spectral data for all keto acids may be found in Table III.

TABLE III  
SPECTRAL PROPERTIES OF *o*-KETOBENZOIC ACIDS

Compd	Infrared, <sup>a</sup> cm <sup>-1</sup>		Ultraviolet, <sup>b</sup> nm ( $\epsilon$ )
	RR'C=O	COOH	
2- <i>p</i> -Anisoylbenzoic acid	1660	1680	290 (14,400)
2- <i>p</i> -Toluybenzoic acid	1670	1690	264 (19,850)
2-( <i>p</i> -Chlorobenzoyl)- benzoic acid	1670	1690	262 (17,200)
5-Methoxy-2-benzoyl- benzoic acid	1675	1690	253 (14,780)
5-Nitro-2-benzoyl- benzoic acid	1680	1692	263 (32,860)

<sup>a</sup> Nujol mulls. <sup>b</sup> In water.

TABLE IV  
MELTING POINTS AND ANALYSES OF SUBSTITUTED  
3-METHOXY-3-PHENYLPHTHALIDES

Compd	Mp, <sup>a</sup> °C	Analysis, <sup>b</sup> %	
		Calcd	Found
2	77-80	C 70.12	70.40
	lit. <sup>c</sup> 80-81.5	H 5.22	5.11
3	66-67	C 75.57	75.44
	lit. <sup>d</sup> 71-72	H 5.55	5.46
4	100-101	C 65.58	65.82
	lit. <sup>e</sup> 101-102	H 4.04	4.05
5	66-68	C 71.11	71.24
		H 5.19	5.31
6	84-86	C 63.16	62.86
		H 3.86	4.01

<sup>a</sup> Uncorrected. <sup>b</sup> Microanalysis by Alfred Bernhardt, Germany. <sup>c</sup> V. Auwers and K. Heinz, *Ber. Bunsenges. Phys. Chem.*, **52**, 586 (1919). <sup>d</sup> H. Meyer, *Monatsh. Chem.*, **28**, 1236 (1907). <sup>e</sup> E. Egerer and H. Meyer, *ibid.*, **34**, 84 (1913).

(26) We thank Mr. Steven Szuos, a National Science Foundation Undergraduate Research Fellow, for carrying out this delicate and crucial experiment.

All of the substituted 3-methoxy-3-phenylphthalides were synthesized by allowing the appropriate keto acid to react with thionyl chloride followed by treatment with dry methanol containing 1 equiv of urea.<sup>27</sup> Pertinent data on each compound are given in Table IV. Spectral data are given in Table V.

TABLE V  
SPECTRAL PROPERTIES OF SUBSTITUTED  
3-METHOXY-3-PHENYLPHTHALIDES

Compd	Infrared, <sup>a</sup> cm <sup>-1</sup> (C=O)	Ultraviolet, <sup>b</sup> nm ( $\epsilon$ )	Kinetics wavelength, nm
3	1773	221 (19,600)	260
4	1775	224 (23,500)	260
5	1768	218 (31,350)	260
6	1790	304 (2670)	260
		260 (14,340)	

<sup>a</sup> Nujol mulls. <sup>b</sup> In water.

**Rate Determinations.**—The hydrolyses of 3-methoxy-3-phenylphthalides were followed in the ultraviolet at wavelengths listed in Table V. It was determined that all the compounds followed Beer's law in the region of concentration used ( $10^{-4}$ – $10^{-5}$  M). A full spectrum of the hydrolysis run after 10 half-lives was superimposable on a spectrum of the product at the same concentration. A larger sample of each 3-methoxyphthalide was allowed to hydrolyze in aqueous acid containing a suitable cosolvent. In each case the corresponding keto acid was recovered in yields of 95% or greater. The details of the kinetics method have been described previously.<sup>5,14</sup>

**Registry No.**—1, 7335-63-9; 2, 40893-30-9; 3, 40893-31-0; 4, 33433-81-7; 5, 40893-33-2; 6, 40893-34-3; 2-*p*-anisoylbenzoic acid, 1151-15-1; 2-*p*-toluoylbenzoic acid, 85-55-2; 2-(*p*-chlorobenzoyl)benzoic acid, 85-56-3; 5-methoxy-2-benzoylbenzoic acid, 2159-48-0; 5-nitro-2-benzoylbenzoic acid, 2159-46-8; 2-methyl-4-methoxybenzophenone, 40893-37-6; 4-nitrophthalic anhydride, 5466-84-2.

(27) V. Auwers and K. Heinz, *Ber. Bunsenges. Phys. Chem.*, **52**, 586 (1919)

## A Novel Synthesis of Disubstituted Maleic Anhydrides by the Pyrolysis of 1-Ethoxy-1-alkenyl Esters of $\alpha$ -Keto Acids<sup>1</sup>

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The preparation of a number of 1-ethoxy-1-alkenyl esters of pyruvic acid and benzoylformic acid was accomplished by addition to the corresponding ethoxyacetylenes without the use of a mercury catalyst. Pyrolysis of the esters thus formed produced the corresponding disubstituted maleic anhydride in moderate yields. This method is a general one and has the further advantage of being a one-pot reaction. The synthesis of *n*-butylphenylmaleic anhydride (20) and *n*-butylmethylmaleic anhydride (25), in yields of 45 and 44%, respectively, is reported for the first time. The major by-products of the reactions are monosubstituted  $\beta$ -keto esters and the ethyl esters of the starting  $\alpha$ -keto acids. All of the isolated products of the reactions may be explained by variations of an outlined general reaction scheme. The reactions described represent a new, and possibly the most efficient, method for the synthesis of unsymmetrically disubstituted maleic anhydrides.

Recent studies here indicated that the rearrangement of 1-ethoxy-1-alkenyl esters of carboxylic acids might be a useful route to the synthesis of monosubstituted  $\beta$ -keto esters. The pyrolysis of 1-ethoxyvinyl pyruvate (1) to ethyl acetoacetate (2) and carbon monoxide and of di-1-ethoxyvinyl oxalate to diethyl acetonedicarboxylate demonstrated a novel synthesis of esters of

$\beta$ -keto acids not substituted in the  $\alpha$  position.<sup>3</sup> The thermal decomposition of a variety of 1-ethoxyvinyl esters of carboxylic acids also was shown to give initially  $\beta$ -keto esters which, however, underwent further reaction before isolation.<sup>4</sup> Subsequent studies demonstrated that the heating of the 1-ethoxyvinyl ester of

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(2) Ohio State University Postdoctoral Fellow 1971.

(3) G. R. Banks, D. Cohen, and H. D. Springall, *Rec. Trav. Chim. Pays-Bas*, **83**, 513 (1964). A repetition of this experimental procedure gave only a moderate yield of ethyl acetoacetate (see Experimental Section).

(4) B. Zwanenburg, *ibid.*, **82**, 593 (1963).