rings) the increase is approaching 20 cps.[24] It is evident that the application of more general linear relationship better accounts for the experimental data. But is is not quite clear to what extent the reported improvement is due to the adoption of a linear relationship between J and a^2 (instead of the simple proportionality $J = 500a^2$) or to what extent it arises from inclusion of variations of bond overlaps.

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Registry No.—Benzocyclobutene, 4026-23-7; benzocyclopropene, 4646-69-9.

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Transmission of Substituent Effects in Heterocyclic Systems. The Rates of Solvolysis of Some Substituted 1-(2-Benzofuryl)ethanol Derivatives[1]

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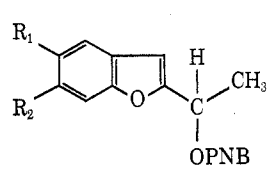
The rates of solvolysis for a series of 5-substituted and 6-substituted 1-(2-benzofuryl)ethanol derivatives (A) have been determined. Though there is excellent correlation of the rates for the 6-substituted compounds with σ_p^+, σ_m^+ fails to give a correspondingly good correlation for the 5-substituted series. Deviations show a clear regularity, with rates for compounds bearing electron donating substituents being too high. A modification of the Dewar–Grisdale equation which uses CNDO/2 molecular orbital parameters to calculate the change in regional charge at the point of attachment of the substituent gives a high quality correlation for both series. These results show that substituents in the 5 position exert their influence more by way of resonance interaction than σ_m^+ would predict.

A number of studies from these laboratories have examined the influence of substituents on reactivity in heterocyclic systems. Information has been presented for furans[3,4] and thiophenes,[5,6] with primary attention being given to solvolysis reactions of the 1-heteroarylethyl derivatives in 80% ethanol. In those studies it was observed that Brown's σ^+ substituent constants[7] were not uniformly successful in predicting relative reactivity in all structural situations. Useful correlations with σ_p^+ were obtained for "conjugating" positions; but σ_m^+ did not generally work well for "nonconjugating" positions.

We have extended these studies to the benzofuran system. A number of substituted 1-(2-benzofuryl)ethanol derivatives (**1**–**9**) have been prepared, and their rates of solvolysis in 80% ethanol have been measured. Table I presents relative rates at 75°. Consideration of these data in two subsets reveals the following. When the 6-substituted series (compounds **1**, **2**, **4**, **6**, **8**; subset A) is considered separately, σ_p^+ gives an excellent correlation (correlation coefficient 0.998) with ρ −3.61. However, the data for the 5-substituted series (compounds **1**, **3**, **5**, **7**, **9**; subset B) show only a fair correlation with σ_m^+. Furthermore, there is a definite trend to the deviations of the 5-substituted series from the least squares line which is defined by the 6-substituted series. Those substituents (methoxy, methyl, and chloro) which effectively donate electrons *via* resonance are clearly above the correlation line. We are therefore led to the conclusion that the 5 position in benzofuran differs from a meta position in benzene in that the sensitivity of the solvolysis reaction toward resonance-donating capability is greater.



A

1, $R_1 = R_2 = H$
2, $R_1 = H$; $R_2 = OCH_3$
3, $R_1 = OCH_3$; $R_2 = H$
4, $R_1 = H$; $R_2 = CH_3$
5, $R_1 = CH_3$; $R_2 = H$
6, $R_1 = H$; $R_2 = Cl$
7, $R_1 = Cl$; $R_2 = H$
8, $R_1 = H_2$; $R_2 = NO_2$
9, $R_1 = NO_2$; $R_2 = H$

TABLE I

RATES OF SOLVOLYSIS OF SUBSTITUTED 1-(2-BENZOFURYL)ETHYL *p*-NITROBENZOATES IN 80% ETHANOL AT 75°

Substituent (compound solvolyzed)	k, sec^{-1}	log k/k_0
H (1)	2.45×10^{-5}	0.00
6-OCH_3 (2)	7.67×10^{-3} [a]	2.50
5-OCH_3 (3)	8.23×10^{-5}	0.53
6-CH_3 (4)	2.87×10^{-4}	1.07
5-CH_3 (5)	6.80×10^{-5}	0.44
6-Cl (6)	6.30×10^{-6}	−0.59
5-Cl (7)	1.50×10^{-6}	−1.21
6-NO_2 (8)	1.87×10^{-8} [b]	−3.12
5-NO_2 (9)	5.12×10^{-8} [b]	−2.68

[a] Extrapolated from rates at lower temperatures. [b] Computed from the rate for the phenylphosphinate, using $k_{pp}/k_{OPNB} = 1.97 \times 10^3$.

The rate data given in Table I have also been fitted to the field and resonance substituent parameters ($\mathcal{F}$ and

(1) Supported in part by a grant from the National Science Foundation, GP-6133X.

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$\mathcal{R}$) introduced by Swain and Lupton.[8] For the rates in subset A regression eq 1 results.

$$-\log k = 2.029\mathcal{F} + 6.433\mathcal{R} + 4.596 \quad (1)$$

Following Swain and Lupton,[8] this defines the percentage resonance component (% $\mathcal{R}$) as 66.5 ± 2.9. Inasmuch as Swain determines that σ_p^+ has 66 + 5% $\mathcal{R}$, this explains the excellent correlation observed.

When the rate data for subset B are fitted, regression eq 2 results.

$$-\log k = 2.089\mathcal{F} + 2.665\mathcal{R} + 4.723 \quad (2)$$

From eq 2, it follows that % $\mathcal{R}$ is 44.35 ± 3.5. The larger resonance component is to be contrasted with that calculated by Swain and Lupton for σ_m^+, 33% $\mathcal{R}$. This quantifies the foregoing discussion on the nature of the deviations for subset B.

The Swain and Lupton treatment is excellent for analysis of information in this fashion; it suffers from a lack of providing a suitable basis for predictions.

We have investigated molecular orbital methods for providing a basis for prediction of reactivity in heterocyclic systems, and have had good success using CNDO/2 methods and a modification of the Dewar–Grisdale equation.[9] Alternative formulations using INDO methods have shown equal success.[10]

We have presented an outline of our procedure[6,11] previously, and there is no need to repeat it here. It is useful, however, to emphasize that we calculate the change in regional charge[12] at any position within the heterocyclic nucleus, Δq, which results from the transformation of the methylarene to the arylmethylene cation. For all heterocyclic systems we use the parameters of Pople, Santry, and Segal,[13] as fixed; we use experimental geometries where available, or those determined by reasonable analogy. The Δq's thus determined are incorporated in the modified Dewar–Grisdale equation (eq 3), where the F_X^+ and M_X^+ values

$$(\sigma_{ij})_X^+ = F_X^+/r_{ij} + \Delta q_{ij} M_X^+ \quad (3)$$

for each substituent are uniquely determined by the application of eq 3 to benzene and σ^+ constants.[4] For the benzofuran system $r_{6,2} = 3.27$, $\Delta q_{6,2} = 0.1377$, $r_{5,2} = 3.29$, $\Delta q_{5,2} = 0.0473$. From typical substituent constants[14] for the 5- and 6-substituted 2-benzofuryl system, it is easily predicted by regression analysis that 6-substituted 1-(2-benzofuryl)ethyl derivatives should show 66% $\mathcal{R}$ and 5-substituted 1-(2-benzofuryl)ethyl derivatives should show 47% $\mathcal{R}$ resonance component. Thus this method gives a good prediction of the observed results.

An important additional plus feature of this predicting framework is that using the substituent constants which are calculated by eq 3, plot of the observed rate data against σ_{ij}^+ gives a single correlation line for both subsets of data, A and B, with a ρ of −5.8, which is very similar to the ρ values for the solvolysis of 1-phenylethyl derivatives at 75°.[11b,15,16] Thus this method allows the prediction of rates of solvolysis for a very wide range of heterocyclic systems, given only the CNDO/2 calculations on the system, and a measured rate for the parent 1-(heteroaryl)ethyl derivative.

Experimental Section[17]

1-(2-Benzofuryl)ethyl *p*-Nitrobenzoate (1).—2-Acetylbenzofuran[18] was reduced with sodium borohydride in methanol to 1-(2-benzofuryl)ethanol.[19] This alcohol was converted to the *p*-nitrobenzoate using *p*-nitrobenzoyl chloride in pyridine. Crystallization from absolute ethanol afforded pure **1** as fine yellow needles: mp 112–113°; nmr (CCl_4) δ 1.82 (d, 3, J = 7 Hz, CH_3), 6.33 (q, 1, J = 7 Hz, $CHCH_3$), 6.76 (s, 1, HC_3), 7.08–7.62 (m, 4, phenyl protons), and 8.17 (s, 4, OPNB).

Anal. Calcd for $C_{17}H_{13}NO_5$: C, 65.59; H, 4.21; N, 4.50. Found: C, 65.52; H, 4.26; N, 4.74.

1-(6-Methoxy-2-benzofuryl)ethyl *p*-Nitrobenzoate (2).—From 2,4-dihydroxybenzaldehyde and methyl sulfate was prepared 4-methoxysalicylaldehyde, mp 40.5–41.5 (lit.[20] mp 41°), which was converted to 6-methoxy-2-acetylbenzofuran, mp 101–102° (lit.[21] mp 97–99°), in 71% yield. Reduction with sodium borohydride in methanol afforded 93% of 1-(6-methoxy-2-benzofuryl)ethanol as an oil: nmr (CCl_4) δ 1.48 (d, 3, J = 7 Hz, $CHCH_3$), 3.10 (s, 1 OH), 3.96 (s, 3, OCH_3), 4.82 (q, 1, J = 7 Hz, $CHCH_3$), 6.35 (s, 1, HC_3), 6.97 [AB q, ν_4 = 7.22 and ν_5 = 6.72, 2, J_{4-5} = 8.6 Hz, HC_4 and HC_5 (the upfield half of the AB quartet is meta split, J_{5-7} = 2 Hz)], and 6.82 ppm (m, 1, HC_7). Treatment with *p*-nitrobenzoyl chloride in pyridine afforded 1-(6-methoxy-2-benzofuryl)ethyl *p*-nitrobenzoate (**2**) as cottonlike crystals from hexane: mp 106–107°; nmr (CCl_4) δ 1.78 (d, 3, J = 7 Hz, $CHCH_3$), 6.62 (s, 1, HC_3), 7.02 [AB q, ν_4 = 7.30 and ν_5 = 6.74, 2, J_{4-5} = 8 Hz, HC_4 and HC_5 (the upfield half of the AB quartet is meta split, J_{5-7} = 2 Hz)], 6.90 (d, 1, J_{5-7} = 2 Hz, HC_7), and 8.16 ppm (s, 4, OPNB).

Anal. Calcd for $C_{18}H_{15}NO_6$: C, 63.34; H, 4.43; N, 4.10. Found: C, 63.28; H, 4.32; N, 4.01.

5-Methoxy-2-acetylbenzofuran.—5-Methoxysalicylaldehyde[22] (25 g, 0.164 mol), anhydrous potassium carbonate (22.8 g, 0.164 mol), and acetone (300 ml) were heated to reflux and chloroacetone (14 ml, 0.176 mol) was added over a 1-hr period. After another 1 hr of reflux, the reaction mixture was filtered and passed through a short column of alumina (Woelm, activity grade I), and the eluate was concentrated under reduced pressure, giving a yellow-red oil which soon solidified. Ethanol was added, and from the resulting solution 15.4 g (49%) of 5-methoxy-2-acetylbenzofuran crystallized as very small white plates: mp 85–85.5°; 100-MHz nmr (CCl_4) δ 2.48 (s, 3, $COCH_3$), 3.78 (s, 3, OCH_3), 7.17 [AB q, ν_6 6.99 and ν_7 7.35, 2, J_{6-7} = 10 Hz, HC_6 (the upfield half of the AB quartet is meta split, J_{4-6} = 2.5 Hz, and the downfield half is also split, J_{3-7} = 1 Hz)], 6.97 (d, 1, J_{4-6} = 2.5 Hz, HC_4), and 7.27 (d, 1, J_{3-7} = 1 Hz, HC_3).

Anal. Calcd for $C_{11}H_{10}O_3$: C, 69.46; H, 5.30. Found: C, 69.53; H, 5.50.

1-(5-Methoxy-2-benzofuryl)ethanol.—5-Methoxy-2-acetylbenzofuran (5 g, 0.0263 mol) and methanol 150 ml) were cooled to 0° in an ice bath. Sodium borohydride (0.5 g, 0.0180 mol) was added in small portions over a 1-hr period. After stirring at room temperature for 20 min the methanol was removed under reduced pressure, water was added, and the product was extracted into ether. The ether was dried ($MgSO_4$) and removed under reduced pressure to give 4.75 g (94%) of 1-(5-methoxy-2-benzofuryl)ethanol as a white solid: nmr (CCl_4) δ 1.52 (d, 1,

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(22) We are indebted to the Upjohn Co. for a generous sample of 5-methoxysalicylaldehyde.

J = 6 Hz, $CHCH_3$), 2.60 (b, 1, OH), 3.73 (s, 1, OCH_3), 4.82 (q, 1, J = 6 Hz, $CHCH_3$), 6.35 (s, 1, HC_3), 7.00 [AB q, ν_6 6.76 and ν_7 7.24, 2, HC_6 and HC_7 (the upfield half of the AB quartet is *meta*-split, J_{4-6} = 2 Hz)], and 6.78 ppm (s apparent, 1, HC_4). A sample recrystallized from petroleum ether (bp 30–60°)–ether had mp 62–63°.

Anal. Calcd for $C_{11}H_{12}O_3$: C, 68.73; H, 6.29. Found: C, 68.53; H, 6.39.

1-(5-Methoxy-2-benzofuryl)ethyl *p*-Nitrobenzoate (3).—1-(5-Methoxy-2-benzofuryl)ethanol was treated with *p*-nitrobenzoyl chloride in pyridine to give 1-(5-methoxy-2-benzofuryl)-ethyl *p*-nitrobenzoate as small, white crystals from hexane: mp 107–108°; nmr (CCl_4) δ 1.80 (d, 3, J = 6.5 Hz, $CHCH_3$), 3.77 (s, 3, OCH_3), 6.27 (q, 1, J = 6.5 Hz, $CHCH_3$), 6.63 (s, 1, HC_3), 7.05 [AB q, ν_6 6.81 and ν_7 7.29, 2, J_{6-7} = 9 Hz, HC_6 and HC_7 (the upfield half of the AB quartet is meta split, J_{4-6} = 2 Hz)], 6.89 (s apparent, 1, HC_4), and 8.18 ppm (s, 4, OPNB).

Anal. Calcd for $C_{18}H_{15}NO_6$: C, 63.34; H, 4.43; N, 4.10. Found: C, 63.47; H, 4.50; N, 3.93.

A mixture melting point determination of this compound with its 6-methoxy isomer (mp 106–107°) melted at 89–101°.

6-Methyl-2-acetylbenzofuran.—4-Methylsalicylaldehyde was prepared by the Duff[23] reaction, incorporating the refinements of Liggett and Diehl.[24]

4-Methylsalicylaldehyde (10 g, 0.074 mol), anhydrous potassium carbonate (10.0 g, 0.072 mol), and acetone (220 ml) were heated to reflux and chloroacetone (5.9 ml, 0.074 mol) was added over 30 min. Stirring and heating were continued for 1.25 hr. The orange reaction mixture was gravity filtered and passed through a short column of alumina (Woelm, activity grade I). The residue obtained by removal of the acetone under reduced pressure was recrystallized from ethanol to give 7.24 g (56%) of 6-methyl-2-acetylbenzofuran as yellow plates. Treatment with Norit and recrystallization from ethanol gave white plates (6.06 g, 47%): mp 76–79°; nmr (CCl_4) δ 2.47 (s, 6, $COCH_3$ and CH_3), 7.22 [AB q, ν_4 7.43 and ν_5 7.01, 2, $J_{4,5}$ = 8 Hz, HC_4 and HC_5 (the upfield half of the AB quartet is noticeably broadened)], and 7.25 ppm (m, 2, HC_3 and HC_7).

Sublimation at 68° (0.1 mm) raised the melting point to 79–80°.

Anal. Calcd for $C_{11}H_{10}O_2$: C, 75.84; H, 5.79. Found: C, 75.91; H, 5.82.

1-(6-Methyl-2-benzofuryl)ethyl *p*-Nitrobenzoate (4).—6-Methyl-2-acetylbenzofuran was reduced with sodium borohydride in methanol to give 1-(6-methyl-2-benzofuryl)ethanol: mp 40–41° from ether–petroleum ether; nmr (CCl_4) δ 1.50 (d, 3, J = 7 Hz, $CHCH_3$), 2.40 (s, 3, CH_3), 3.13 (b, 1, OH), 4.82 (q, 1, J = 7 Hz, $CHCH_3$), 6.34 (s, 1, HC_3), 7.05 [AB q, ν_4 7.21 and ν_5 6.89, 2, J_{4-5} = 8 Hz, HC_4 and HC_5 (the upfield half of the AB quartet is noticeably broadened)], and 7.07 (b, 1, HC_7).

1-(6-Methyl-2-benzofuryl)ethanol in dry pyridine was treated with *p*-nitrobenzoyl chloride to give flocculent, white crystals of 1-(6-methyl-2-benzofuryl)ethyl *p*-nitrobenzoate: mp 81–82° from hexane; nmr (CCl_4) δ 1.79 (d, 3, J = 6.5 Hz, $CHCH_3$), 2.42 (s, 3, CH_3), 6.27 (q, 1, J = 6.5 Hz, $CHCH_3$), 6.65 (s, 1, HC_3), 7.12 [AB q, ν_4 7.31 and ν_5 6.93, 2, J_{4-5} = 8 Hz, HC_4 and HC_5 (the upfield half of the AB quartet is broadened)], 7.16 (b, 1, HC_7), and 8.17 ppm (s, 4, OPNB).

Anal. Calcd for $C_{18}H_{15}NO_5$: C, 66.45; H, 4.65; N, 4.31. Found: C, 66.58; H, 4.81; N, 4.54.

5-Methyl-2-acetylbenzofuran.—5-Methylsalicylaldehyde [5.45 g, 0.04 mol, mp 48–56° (lit.[24] mp 55.8°), Aldrich Chemical Co.], anhydrous potassium carbonate (5.55 g, 0.04 mol), and acetone (100 ml) were refluxed and a solution of chloroacetone (3.90 g, 0.042 mol) in acetone (20 ml) was added over a period of 30 min. After 3 hr of refluxing the reaction mixture was filtered and passed through a short column of alumina (Woelm, activity grade I). Removal of the acetone left an oil which solidified on standing. Recrystallization from 80% aqueous ethanol gave 2.30 g (33%) of 5-methyl-2-acetylbenzofuran as plates with a greenish coloration that intensified on standing: mp 78–80°. Sublimation at 70° (0.1 mm) removed all color but did not change the melting point. The sublimed ketone was recrystallized from petroleum ether–ether, giving white platelets: mp 80–81°; nmr (CCl_4) δ 2.43 (s, 3, CH_3), 2.50 (s, 3, CH_3), and 7.07–7.50 (m, 4, aromatic protons).

Anal. Calcd for $C_{11}H_{10}O_2$: C, 75.84; H, 5.79. Found: C, 75.87; H, 5.73.

1-(5-Methyl-2-benzofuryl)ethyl *p*-Nitrobenzoate (5).—5-Methyl-2-acetylbenzofuran was reduced with sodium borohydride in methanol to give 1-(5-methyl-2-benzofuryl)ethanol (97%) as an oil: nmr (CCl_4) δ 1.47 (d, 3, J = 7 Hz, $CHCH_3$), 2.37 (s, 3, CH_3), 3.50 (b, 1, OH), 4.78 (q, 1, J = 7 Hz, $CHCH_3$), 6.30 (s, 1, HC_3), 7.02 [AB q, ν_7 7.16 and ν_6 6.88, 2, J_{6-7} = 8 Hz, HC_6 and HC_7 (the upfield half of the AB quartet is broadened)], and 7.08 (b, 1, HC_4).

The alcohol was converted to the *p*-nitrobenzoate without further purification. 1-(5-Methyl-2-benzofuryl)ethyl *p*-nitrobenzoate crystallized from hexane as white, flocculent crystals: mp 74–75°; nmr (CCl_4) δ 1.80 (d, 3, J = 7 Hz, $CHCH_3$), 2.41 (s, 3, CH_3), 6.28 (q, 1, J = 7 Hz, $CHCH_3$), 6.68 (s, 1, HC_3), 7.16 [AB q, ν_6 7.03 and ν_7 7.29, 3, J_{6-7} = 8 Hz, HC_6 and HC_7 [the upfield half of the AB quartet is broadened)], 7.25 (b, 1, HC_4), and 8.18 (s, 4, OPNB).

Anal. Calcd for $C_{18}H_{15}NO_5$: C, 66.45; H, 4.65; N, 4.31. Found: C, 66.49; H, 4.62; N, 4.46.

6-Chloro-2-acetylbenzofuran.—2-Methyl-5-chlorophenol[25] was converted to the acetate and brominated to give 5-chloro-2-dibromomethylphenyl acetate, mp 78–79°, in 87% yield following the procedure of Segesser and Calvin.[26] The benzal bromide was hydrolyzed to 4-chlorosalicylaldehyde, 88% yield, mp 47.5–48.5° (lit.[27] mp 47.0–47.8°).

4-Chlorosalicylaldehyde (10 g, 0.064 mol), anhydrous potassium carbonate (8.85 g, 0.064 mol), and acetone (250 ml) were heated to reflux and chloroacetone (5.1 ml, 0.064 mol) was added over a 1-hr period. Stirring and refluxing were continued for 3 hr. The deep red reaction mixture was filtered of salts and passed through a short column of alumina. The acetone was removed under reduced pressure to give a yellow solid that was recrystallized from ethanol to give 8.49 g (68%) of 6-chloro-2-acetylbenzofuran: mp 119–121° [sublimation (95%, 0.1 mm) raised the melting point to 120–121°, as did crystallization from petroleum ether–ether]; nmr (CCl_4) δ 2.50 (s, 3, $COCH_3$), 7.11 and 7.28 (m, 2, HC_5 and HC_3 or HC_7), and 7.62 and 7.48 (s, 2, HC_4 and HC_7 or HC_3).

Anal. Calcd for $C_{10}H_7ClO_2$: C, 61.71; H, 3.63; Cl, 18.22. Found: C, 61.86; H, 3.66; Cl, 18.38.

1-(6-Chloro-2-benzofuryl)ethyl *p*-Nitrobenzoate (6).—6-Chloro-2-acetylbenzofuran was reduced with sodium borohydride in methanol to give 93% of 1-(6-chloro-2-benzofuryl)ethanol as a white solid. Recrystallization from petroleum ether–ether gave a white powder: mp 53–55°; nmr (CCl_4) δ 1.52 (d, 3, J = 6.5 Hz, $CHCH_3$), 3.03 (b, 1, OH), 4.83 (q, 1, J = 6.5 Hz, $CHCH_3$), 6.39 (s, 1, HC_3), 7.16 [AB q, ν_4 7.25 and ν_5 7.07, 2, J_{4-5} = 8.5 Hz, HC_4 and HC_5 (the upfield half of the AB quartet is meta split, J_{5-7} = 2 Hz)], and 7.30 (m, 1, HC_7).

Anal. Calcd for $C_{10}H_9ClO_2$: C, 61.08; H, 4.61; Cl, 18.03. Found: C, 60.95; H, 4.63; Cl, 18.10.

The *p*-nitrobenzoate was prepared in the usual manner: mp 97–98° (needles from ethanol); nmr (CCl_4) δ 1.80 (d, 3, J = 6.5 Hz, $CHCH_3$), 6.27 (q, 1, J = 6.5 Hz, $CHCH_3$), 6.70 (s, 1, HC_3), 7.29 [AB q, ν_4 7.41 and ν_5 7.17, 2, J = 8.5 Hz, HC_4 and HC_5 (the upfield half of the AB quartet is meta split, J_{5-7} = 2 Hz)], 7.47 (m, 1, HC_7), and 8.19 (s, 4, OPNB).

Anal. Calcd for $C_{17}H_{12}ClNO_5$: C, 59.05; H, 3.50; Cl, 10.26; N, 4.05. Found: C, 59.24; H, 3.63; Cl, 10.30; N, 4.28.

1-(5-Chloro-2-benzofuryl)ethyl *p*-Nitrobenzoate (7).—5-Chloro-2-acetylbenzofuran, mp 99°,[28,29] was reduced with sodium borohydride in methanol to give 1-(5-chloro-2-benzofuryl)ethanol: mp 69.0–69.5° from ether–petroleum ether; nmr (CCl_4 δ 1.48 (d, 3, J = 6.5 Hz, $CHCH_3$), 3.83 (s, 1, OH), 4.83 (q, 1, J = 6.5 Hz, $CHCH_3$), 6.32 (s, 1, HC_3), 7.10 [m, 2, HC_6 and HC_7 (AB quartet near the limit of equivalence)], and 7.27 (m, 1, HC_4).

Anal. Calcd for $C_{10}H_9ClO_2$: C, 61.08; H, 4.61; Cl, 18.03. Found: C, 60.97; H, 4.69; Cl, 18.05.

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The *p*-nitrobenzoate was prepared in the usual fashion. 1-(5-Chloro-2-benzofuryl)ethyl *p*-nitrobenzoate had mp 106.5–107.5°; nmr (CCl_4) δ 1.82 (d, 3, J = 6.5 Hz, $CHCH_3$), 6.28 (q, 1, J = 6.5 Hz, $CHCH_3$), 6.68 (s, 1, HC_3), 7.28 [m, 2, HC_6 and HC_7 (AB quartet near the limit of equivalence)], 7.47 (m, 1, HC_4), and 8.18 (s, 4, OPNB).

Anal. Calcd for $C_{17}H_{12}ClNO_5$: C, 59.05; H, 3.50; Cl, 10.26; N, 4.05. Found: C, 58.97; H, 3.53; Cl, 10.42; N, 3.98.

1-(5-Chloro-2-benzofuryl)ethyl Phenylphosphinate.—The method of Virgilio and Noyce[30] was used. 1-(5-Chloro-2-benzofuryl)ethanol (2.0 g, 0.0102 mol), dicyclohexylcarbodiimide (2.10 g, 0.0102 mol), and phenylphosphinic acid (1.45 g, 0.0102 mol, Victor Chemical Works) were refluxed for 1 hr in dry benzene (100 ml). After the solution had stood for 2 hr at room temperature, it was cooled to the freezing point of benzene, and the dicyclohexylurea was filtered off on a Büchner funnel. The benzene was removed under reduced pressure and the residual oil was taken up in a small amount of ether, which caused precipitation of more dicyclohexylurea. The mixture was filtered, the ether was removed under reduced pressure, and the residual oil was placed under vacuum (0.1 mm) overnight. The yield of crude 1-(5-chloro-2-benzofuryl)ethyl phenylphosphinate was 3.21 g (98.5%). The nmr spectrum (CCl_4) showed the methine resonances of the ester at δ 5.87–5.43. A trace absorption (*ca.* 5% as large) possibly due to the methine resonances of the starting material was present at *ca.* 4.85. The resonance of HC_3 occurred at 6.50; the corresponding resonance of the starting alcohol at 6.32 was not present. The infrared spectrum (liquid film) showed the characteristic P–O–C band[31] at 1050 (s), the P=O band at 1220 (b), and the invariant *P*-phenyl band at 1440 cm^{-1} (s).

This compound was solvolyzed without further purification.

6-Nitro-2-acetylbenzofuran.—4-Nitrosalicylaldehyde was prepared by the method of Segesser and Calvin.[26]

4-Nitrosalicylaldehyde (1.70 g, 0.0102 mol), chloroacetone (0.95 g, 0.0103 mol), anhydrous potassium carbonate (1.41 g, 0.0102 mol), and methyl ethyl ketone (15 ml) were refluxed for 45 min (it was found necessary to substitute MEK for acetone in order to obtain a higher reflux temperature). The solvent was removed under reduced pressure, water was added to the dark residue, and the product was extracted into chloroform. The chloroform was dried ($CaCl_2$) and evaporated, leaving a brown solid that was sublimed at 120° (0.05 mm) to give 1.07 g of yellow crystals: mp 146–147°; nmr (CF_3CO_2H) δ 2.83 (s, 3, $COCH_3$), 7.85 (s, 1, HC_3), 8.13 [AB q, ν_4 7.96 and ν_5 8.30, 2, J_{4-5} = 8.6 Hz, HC_4 and HC_5 (the downfield half of the AB quartet is meta split, J_{5-7} = 2 Hz)], and 8.53 (m, 1, HC_7).

Anal. Calcd for $C_{10}H_7NO_4$: C, 58.54; H, 3.44; N, 6.85. Found: C, 58.34; H, 3.62; N, 6.63.

1-(6-Nitro-2-benzofuryl)ethanol.—6-Nitro-2-acetylbenzofuran suspended in methanol was reduced with sodium borohydride added in three portions, the ketone dissolving as the reduction progressed. Work-up in the usual fashion gave 92% of 1-(6-nitro-2-benzofuryl)ethanol as a pale yellow solid. A small sample was purified by chromatography on silica gel. Elution with 10% ether–hexane gave material with the following characteristics: mp 74–75°; nmr (CCl_4) δ 1.62 (d, 3, J = 6.5 Hz, $CHCH_3$), 2.50 (b, 1, OH), 4.98 (q, 1, J = 6.5 Hz, $CHCH_3$), 6.67 (s, 1, HC_3), 7.82 (AB q, ν_4 7.65 and ν_5 8.09, 2, J_{4-5} = 8.4 Hz (the downfield half of the AB quartet is meta split, J_{5-7} = 2 Hz)], HC_4 and HC_5), and 8.27 (m, 1, HC_7).

Anal. Calcd for $C_{10}H_9NO_4$: C, 57.97; H, 4.38; N, 6.76. Found: C, 58.02; H, 4.51; N, 6.77.

1-(6-Nitro-2-benzofuryl)ethyl Phenylphosphinate.—This ester was prepared by the method of Virgilio and Noyce.[30] 1-(5-Nitro-2-benzofuryl)ethanol (0.8 g, 0.0039 mol), dicyclohexylcarbodiimide (0.88 g, 0.0043 mol), and phenylphosphinic acid (0.55 g, 0.0039 mol, Victor Chemical Works) were refluxed in dry benzene (50 ml) for 1 hr. The solution was cooled in an ice bath and the dicyclohexylurea was filtered off on a Büchner funnel. Removal of the benzene under reduced pressure left a yellow oil in which some solid material was suspended. The oil was thinned with carbon tetrachloride and filtered to remove the solid material. Solvents were removed on a vacuum line (0.05 mm) overnight. The nmr spectrum (CCl_4) of the oil showed the methine resonance of the ester at δ 5.57–5.97 and the HC_3 resonance at 6.73. The corresponding methine resonance of the starting material at 4.98 was absent. The infrared spectrum (liquid film) showed bands at 1515 (s, NO_2), 1340 (s, NO_2), 1225 (s, P=O stretch), and 1060 cm^{-1} (s, P–O–C stretch). The crude 1-(5-nitro-2-benzofuryl)ethyl phenylphosphinate was solvolyzed without further purification.

5-Nitro-2-acetylbenzofuran.—5-Nitrosalicylaldehyde (5 g, 0.03 mol, Eastman Organic Chemicals), chloroacetone (3.3 g, 0.036 mol), anhydrous potassium carbonate (5.4 g, 0.039 mol), and methyl ethyl ketone (50 ml) were refluxed on a steam bath for 7 hr. The solvent was removed under reduced pressure, water was added to the dark residue, and the mixture was extracted with ether. Large amounts of insoluble material made extraction difficult. The mixture was extracted with chloroform, and the organic layer was combined with the ether extract, dried ($MgSO_4$), and evaporated to give a brown powder that was sublimed at 115° (0.05 mm) to give 1.70 g (28%) of yellow crystals: mp 175–177°; nmr (CF_3CO_2H) δ 2.83 (s, 3, $COCH_3$), 8.17 [AB q, ν_7 7.80 and ν_6 8.54, 2, J_{6-7} = 8.6 Hz (the downfield half of the AB quartet is meta-split, J_{4-6} = 2 Hz), HC_6 and HC_7], 7.98 (s, 1, HC_3), and 8.85 (d, 1, J_{4-6} = 2 Hz, HC_4).

Anal. Calcd for $C_{10}H_7NO_4$: C, 58.54; H, 3.44; N, 6.85. Found: C, 58.68; H, 3.59; N, 7.04.

1-(5-Nitro-2-benzofuryl)ethanol.—5-Nitro-2-acetylbenzofuran (1 g, 0.0049 mol) and methanol (25 ml) were equilibrated in an ice bath. Sodium borohydride (0.10 g, 0.0028 mol) was added in portions to the stirring slurry. After 10 min the ketone had dissolved. The hydride was added over 20 min, after which the ice bath was removed. When the solution had warmed to room temperature the solvent was removed under reduced pressure, water was added, and the product was extracted into ether. Drying ($MgSO_4$) and evaporation of the ether under reduced pressure left 0.97 g (96%) of a pale yellow solid. Recrystallization from methanol–water gave fine white needles of 1-(5-nitro-2-benzofuryl)ethanol, recrystallized from petroleum ether–ether: mp 73–76°; nmr ($CDCl_3$) δ 1.62 (d, 3, J = 6.5 Hz, $CHCH_3$), 2.30 (s, 1, OH), 4.98 (q, 1, J = 6.5 Hz, $CHCH_3$), 6.67 (s, 1, HC_3) [AB q, ν_4 7.47 and ν_5 8.13, 2, J_{6-7} = 9.2 Hz (the downfield half of the AB quartet is meta split, J_{4-6} = 2 Hz), HC_6 and HC_7], and 8.37 (d, 1, J_{4-7} = 2 Hz, HC_4).

Anal. Calcd for $C_{10}H_9NO_4$: C, 57.97: H, 4.38; N, 6.76. Found: C, 58.17; H, 4.61; N, 6.88.

1-(5-Nitro-2-benzofuryl)ethyl phenylphosphinate was prepared as described above for the 6-nitro isomer. The crude product was solvolyzed without further purification.

Kinetic Methods.—Three different methods were used, as appropriate for the temperature and reactivity being investigated. Method 1 is the usual aliquot method, with aliquots being withdrawn by syringe from a serum capped flask at appropriate time intervals. The samples were titrated for amount of developed acid with standardized KOH in ethanol. For more sluggish situations, method 2, involving sealed ampoules, was used. A few of the more rapid reaction rates were measured by maintenance of static pH (method 3), using a Radiometer automatic titrator, consisting of a TTT lc automatic titrator, an ABU lc autoburette, a TTT 3c titrator assembly, and SBR 2c recorder.

First-order rate constants were calculated by LSKIN 1,[32] a least squares program for computing the zero and infinity values of the reaction variable as well as the rate constant.

Generally, between 12 and 16 points were taken when methods 1 or 2 were used. The points were taken at intervals of *ca.* 5% reaction. Solvolyses were followed for at least 3 half lives. Each run was performed in duplicate, the agreement being within 3%. With 1-(5-nitro-2-benzofuryl)ethyl phenylphosphinate the quality of the titration curves was poor. In this case the rate constants differed by 7%.

(30) D. S. Noyce and J. Virgilio, *J. Org. Chem.*, **37**, 1052 (1972).

(31) L. W. Daasch and D. C. Smith, *Anal. Chem.*, **23**, 853 (1951). These authors found that P–O–C bands for a wide range of phosphorus esters were within 15 cm^{-1} of 1045 cm^{-1}. Bands in this area were absent in the case of phosphorus acids. With ethyl phenylphosphinate, a close analog, the P–O–C band came at 1052 cm^{-1}. When a phenyl group was substituted on a phosphorus atom, a band very near 1440 cm^{-1} occurred. The P=O band varied widely, being ill defined with acids, and being at 1236 cm^{-1} in ethyl phenylphosphinate.

(32) D. F. DeTar and C. E. DeTar in "Computer Programs for Chemistry," Vol. I, D. F. DeTar, Ed., W. A. Benjamin, New York, N. Y., 1968, Chapter 6.

TABLE II

RATE CONSTANTS FOR THE SOLVOLYSES OF SUBSTITUTED 1-(2-BENZOFURYL)ETHYL *p*-NITROBENZOATES

Substituent (compound)	Solvent	Temp, °C	Method[a]	K, sec^{-1}
Parent (1)	80% EtOH	75	2	$2.48 \pm 0.03 \times 10^{-5}$
Parent	80% EtOH	75	2	$2.43 \pm 0.02 \times 10^{-5}$
Parent	80% EtOH	100	2	$2.53 \pm 0.05 \times 10^{-4}$
Parent	80% EtOH	100	2	$2.55 \pm 0.07 \times 10^{-4}$
6-Methoxy (2)	80% EtOH	45	1	$4.53 \pm 0.10 \times 10^{-4}$
6-Methoxy	80% EtOH	45	3	$4.60 \pm 0.03 \times 10^{-4}$
6-Methoxy	80% EtOH	60	3	$1.87 \pm 0.02 \times 10^{-3}$
6-Methoxy	80% EtOH	60	3	$1.92 \pm 0.02 \times 10^{-3}$
6-Methoxy	80% EtOH	60	3	$1.92 \pm 0.02 \times 10^{-3}$
6-Methoxy	80% EtOH	25	1	$4.42 \pm 0.08 \times 10^{-5}$
6-Methoxy	80% EtOH	25	1	$4.58 \pm 0.07 \times 10^{-5}$
6-Methyl (4)	80% EtOH	75	1	$2.85 \pm 0.07 \times 10^{-4}$
6-Methyl	80% EtOH	75	1	$2.90 \pm 0.07 \times 10^{-4}$
6-Methyl	80% EtOH	60	1	$6.22 \pm 0.07 \times 10^{-5}$
6-Methyl	80% EtOH	60	1	$6.00 \pm 0.13 \times 10^{-5}$
6-Methyl	80% EtOH	45	1	$1.10 \pm 0.02 \times 10^{-5}$
6-Methyl	80% EtOH	45	1	$1.10 \pm 0.02 \times 10^{-5}$
6-Methyl	70% EtOH	60	1	$1.38 \pm 0.02 \times 10^{-4}$
6-Methyl	90% EtOH	60	1	$1.80 \pm 0.05 \times 10^{-5}$
5-Methyl (5)	80% EtOH	75	1	$6.72 \pm 0.05 \times 10^{-5}$
5-Methyl	80% EtOH	75	1	$6.88 \pm 0.03 \times 10^{-5}$
5-Methoxy (3)	80% EtOH	75	1	$8.25 \pm 0.08 \times 10^{-5}$
5-Methoxy	80% EtOH	75	1	$8.22 \pm 0.05 \times 10^{-5}$
5-Chloro (7)	80% EtOH	75	2	$1.50 \pm 0.03 \times 10^{-6}$
5-Chloro	80% EtOH	75	2	$1.49 \pm 0.02 \times 10^{-6}$
5-Chloro	80% EtOH	110	2	$4.45 \pm 0.05 \times 10^{-5}$
5-Chloro	80% EtOH	110	2	$4.50 \pm 0.05 \times 10^{-5}$
6-Chloro (6)	80% EtOH	110	2	$6.30 \pm 0.13 \times 10^{-6}$

[a] See description of kinetic methods.

Tables II and III give additional rate constants which were determined during the course of this work, which are supplementary to those recorded in Table I. Table IV gives some activation parameters, calculated from the relevant data by ACTENG.[33]

TABLE III

RATE CONSTANTS FOR THE SOLVOLYSIS OF 1-(X-2-BENZOFURYL)ETHYL PHENYLPHOSPHINATES IN 80% ETHANOL AT 75°

X	Method	k, sec^{-1}
5-Chloro	1	$2.90 \pm 0.08 \times 10^{-3}$
5-Chloro	1	$3.00 \pm 0.07 \times 10^{-3}$
5-Nitro	1	$9.62 \pm 0.30 \times 10^{-5}$
5-Nitro	1	$1.03 \pm 0.02 \times 10^{-4}$
6-Nitro	1	$3.68 \pm 0.12 \times 10^{-5}$

TABLE IV

CALCULATED RATE CONSTANTS AND ACTIVATION PARAMETERS FOR SUBSTITUTED 1-(X-2-BENZOFURYL)ETHYL *p*-NITROBENZOATES AT 25°

X (compound)	k, sec^{-1}	$\Delta H^{\pm}$, kcal	$\Delta S^{\pm}$, eu
6-Hydrogen (1)	7.08×10^{-1}	23.5 ± 0.2	-12.3 ± 0.6
6-Methoxy (2)	4.60×10^{-1}	20.5 ± 0.1	-9.6 ± 0.3
6-Methyl (4)	8.68×10^{-1}	23.4 ± 0.2	-7.9 ± 0.4
5-Chloro (7)	2.92×10^{-1}	25.2 ± 0.1	-13.2 ± 0.4

Registry No.—**1**, 36744-26-0; **2**, 36744-27-1; **3**, 36744-28-2; **4**, 36826-27-4; **5**, 36744-29-3; **6**, 36744-30-6; **7**, 36744-31-7; **8**, 36744-32-8; **9**, 36744-33-9; 1-(6-methoxy-2-benzofuryl)ethanol, 36744-34-0; 5-methoxy-2-acetylbenzofuran, 21587-39-3; 1-(5-methoxy-2-benzofuryl)ethanol, 36744-36-2; 6-methyl-2-acetylbenzofuran, 16564-18-4; 1-(6-methyl-2-benzofuryl)ethanol, 36744-38-4; 5-methyl-2-acetylbenzofuran, 17133-94-7; 1-(5-methyl-2-benzofuryl)ethanol, 36744-40-8; 6-chloro-2-acetylbenzofuran, 36744-41-9; 1-(6-chloro-2-benzofuryl)ethanol, 36739-78-3; 1-(5-chloro-2-benzofuryl)ethanol, 36739-79-4; 1-(5-chloro-2-benzofuryl)ethyl phenylphosphinate, 36739-80-7; 6-nitro-2-acetylbenzofuran, 36739-81-8; 1-(6-nitro-2-benzofuryl)ethanol, 36739-82-9; 1-(6-nitro-2-benzofuryl)-ethyl phenylphosphinate, 36739-83-0; 5-nitro-2-acetylbenzofuran, 23136-39-2; 1-(5-nitro-2-benzofuryl)ethanol, 36739-84-1; 1-(5-nitro-2-benzofuryl)ethyl phenylphosphinate, 36739-85-2.

(33) "Computer Programs for Chemistry," Vol. III, D. F. DeTar, Ed., W. A. Benjamin, New York, N. Y., 1969, Chapter 2.