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Aminolysis of Y-Substituted-phenyl 2-Methoxybenzoates in Acetonitrile: Effect of the *o*-Methoxy Group on Reactivity and Reaction Mechanism

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Supporting Information

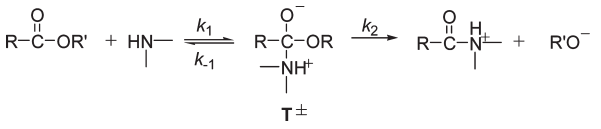
ABSTRACT: Second-order rate constants (k_N) were measured for aminolyses of Y-substituted-phenyl 2-methoxybenzoates **2a**−**i** and 4-nitrophenyl X-substituted-benzoates **3a**−**j** in MeCN at 25.0 °C. The Brønsted-type plot for the reactions of **2a**−**i** with piperidine curves downward, indicating that a change in rate-determining step (RDS) occurs. The Hammett plot for the reactions of **3a**−**j** with piperidine consists of two intersecting straight lines, which might be taken as evidence for a change in RDS. However, the nonlinear Hammett plot has been suggested not to be due to a change in RDS but rather to the stabilization of the ground state of substrates possessing an electron-donating group (EDG) (e.g., **3a**−**c**) through a resonance interaction, since the corresponding Yukawa−Tsuno plot exhibits an excellent linear correlation with $\rho = 0.54$ and $r = 1.54$. The ρ value found for the reactions of **3a**−**j** in MeCN is much smaller than that reported previously for the corresponding reactions in H_2O (i.e., $\rho = 0.75$). It is proposed that the reactions of **3a**−**j** in MeCN proceed through a forced concerted mechanism due to instability of $T^{\pm}$ in the aprotic solvent, while the reactions of **2a**−**i** proceed through a stepwise pathway with a stabilized $T^{\pm}$ through an intramolecular H-bonding interaction.

INTRODUCTION

Nucleophilic substitution reactions of esters with amines have extensively been investigated due to their importance in biological processes as well as synthetic applications.[1−12] Aminolyses of esters have generally been reported to proceed through a stepwise pathway with a zwitterionic tetrahedral intermediate $T^{\pm}$ as shown in Scheme 1. Curved Brønsted-type plots often observed for aminolyses of esters possessing a good leaving group have been taken to be diagnostic of changing the rate-determining step (RDS).[1−12] A change in RDS has been suggested to occur at pK_a^o, defined as the pK_a at the center of the Brønsted curvature.[6,7] It is now firmly understood that RDS changes from the breakdown of $T^{\pm}$ (the k_2 step in Scheme 1) to its formation (the k_1 step in Scheme 1) as the incoming amine becomes more basic than the leaving group by 4 to 5 pK_a units (or the leaving group becomes less basic than the amine).

However, the effect of non-leaving-group substituents on pK_a^o is controversial.[5−11] Gresser and Jencks have found that the pK_a^o in quinuclidinolysis of diaryl carbonates increases as the substituent in the nonleaving group of $T^{\pm}$ changes from an electron-donating group (EDG) to an electron-withdrawing group (EWG).[6] Similar results have been reported for pyridinolysis of 2,4-dinitrophenyl X-substituted benzoates,[7a−c] aminolysis of *S*-2,4-dinitrophenyl X-substituted thiobenzoates,[7d−g] pyridinolysis of aryl dithiobenzoates and related esters,[8a−d] and theoretical calculations on phenolysis of aryl acetates.[8e] It has been suggested that an EWG in the nonleaving group retards the rate of leaving-group departure from $T^{\pm}$ (the k_2 in Scheme 1) but accelerates the amine expulsion from $T^{\pm}$ (the k_{-1} in Scheme 1).[6] Thus, an EWG in the nonleaving group has been concluded to increase pK_a^o by decreasing the k_2/k_{-1} ratio.[6−8]

Scheme 1



In contrast, we have proposed that the rate of expulsion of the nucleofuges from $T^{\pm}$ (i.e., both the k_2 and k_{-1} processes) would be retarded by an EWG but accelerated by an EDG, since the nucleofuges depart from $T^{\pm}$ with their bonding electrons.[5,9−11] Thus, pK_a^o has been suggested to be independent of the electronic nature of the substituent in the nonleaving group.[5,9−11] In fact, we have shown that the k_2/k_{-1} ratio is not affected by the electronic nature of the substituent X for aminolysis of aryl X-substituted-benzoates.[5]

Aminolysis of Y-substituted-phenyl benzoates **1a**−**i** in H_2O has been suggested to proceed through a stepwise mechanism with $T^{\pm}$ as a reactive intermediate on the basis of a curved Brønsted-type plot.[5] In contrast, the corresponding reaction in MeCN has been proposed to proceed through a forced concerted mechanism; the term was proposed originally by Jencks,[1c−e]

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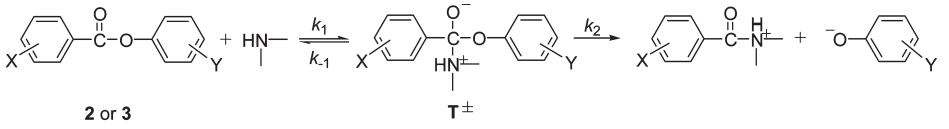
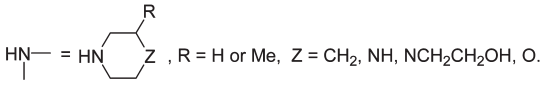
Scheme 2

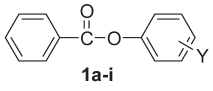


2 : X = 2-OMe
Y = 2,4-$(NO_2)_2$(**2a**), 3,4-$(NO_2)_2$(**2b**), 4-NO_2(**2c**), 4-CHO(**2d**), 4-CN(**2e**), 4-COMe(**2f**), 3-CHO(**2g**), 3-Cl(**2h**), 4-Cl(**2i**)

3 : Y= 4-NO_2
X = 4-NMe_2(**3a**), 4-OMe(**3b**), 4-Me(**3c**), H(**3d**), 3-OMe(**3e**), 4-Cl(**3f**), 3-Cl(**3g**), 4-CN(**3h**), 4-NO_2(**3i**), 3,5-$(NO_2)_2$(**3j**)



because the zwitterionic intermediate $T^{\pm}$ would be highly unstable in the aprotic solvent.[12] The proposed mechanism has also been supported by the following facts: (1) The Brønsted-type plot is linear with β_{nuc} = 0.40 for the reactions of 2,4-dinitrophenyl benzoate **1a** with a series of alicyclic secondary amines.[12] (2) The Hammett plot for the reactions of **1a**−**i** with piperidine results in a better correlation with σ^- constants than with σ^o.[12]



Y = 2,4-$(NO_2)_2$(**1a**), 3,4-$(NO_2)_2$(**1b**), 4-NO_2(**1c**), 4-CHO(**1d**), 4-CN(**1e**), 4-COMe(**1f**), 3-CHO(**1g**), 3-Cl(**1h**), 4-Cl(**1i**).

Our study has been extended to aminolyses of Y-substituted-phenyl 2-methoxybenzoates **2a**−**i** and 4-nitrophenyl X-substituted-benzoates **3a**−**j** in MeCN as shown in Scheme 2. Although scattered information on aminolyses of esters in MeCN is available, the reaction mechanisms are not yet clearly understood because more systematic studies are needed.[4a−c,12] We have employed substituents X and Y on the nonleaving benzoyl moiety and the leaving aryloxide, respectively, and alternative substituents at the Z-position of the incoming alicyclic amines, whose pK_a values in MeCN have recently been reported.[13] The findings in this study have revealed that the effect of the *o*-OMe group in **2a**−**i** on the reactivity and reaction mechanism is indeed significant, while the electronic nature of the meta- and para-substituent X in the benzoyl moiety of **3a**−**j** does not affect the reaction mechanism including the RDS.

RESULTS AND DISCUSSION

The kinetic study was performed under pseudo-first-order conditions in which the amine concentration was kept in excess of the substrate concentration. The reactions obeyed first-order kinetics, and the pseudo-first-order rate constants (k_{obsd}) were calculated from the equation, $\ln (A_\infty - A_t) = -k_{obsd}t + C$. The plots of k_{obsd} vs amine concentrations are linear and pass through the origin, indicating that general-base catalysis by a second amine molecule is absent. Thus, the second-order rate constants (k_N) were calculated from the slope of the linear plots. On the basis of the replicate runs, it is estimated that the uncertainty in the k_N values is less than ±3%. The k_N values are summarized in Tables 1−3.

Table 1. Summary of Second-Order Rate Constants for Nucleophilic Substitution Reactions of Y-Substituted-phenyl 2-Methoxybenzoates 2a−i with Piperidine in MeCN at 25.0 ± 0.1 °C

entry	Y	pK_a (Y-PhOH)[a]	k_N, $M^{-1}s^{-1}$
2a	2,4-$(NO_2)_2$	4.11	414
2b	3,4-$(NO_2)_2$	5.42	229
2c	4-NO_2	7.14	12.2
2d	4-CHO	7.66	1.44
2e	4-CN	7.95	2.35
2f	4-COMe	8.05	0.340
2g	3-CHO	8.98	0.0171
2h	3-Cl	9.02	0.0284
2i	4-Cl	9.38	0.00627

[a] The pK_a of Y-substituted-phenols were taken from ref 15.

Effect of Leaving-Group Basicity on Reactivity and Reaction Mechanism. As shown in Table 1, the k_N value for the reactions of **2a**−**i** with piperidine decreases rapidly as the leaving-group basicity increases, e.g., k_N decreases from 414 M^{-1} s^{-1} to 1.44 and 6.27 × 10^{-3} $M^{-1}s^{-1}$ as the pK_a of the conjugated acid of the leaving aryloxide increases from 4.11 to 7.66 and 9.38, in turn. Interestingly, the k_N values for the reactions of **2a**−**i** are much larger than those reported previously for the corresponding reactions of Y-substituted-phenyl benzoates **1a**−**i**, which possess no 2-OMe group in the benzoyl moiety. This is quite interesting because we expect that **2a**−**i** are less reactive than **1a**−**i** because of steric hindrance exerted by the 2-OMe group in the benzoyl moiety of **2a**−**i**. In fact, 4-nitrophenyl 2-methylbenzoate has been reported to be ca. 7 times less reactive than its isomer 4-nitrophenyl 4-methylbenzoate in the reaction with piperidine.[14] The cause of the high reactivity of **2a**−**i** will be discussed in detail in the last section.

The effect of leaving-group basicity on the reactivity is illustrated in Figure 1. The Brønsted-type plot is curved. Such a nonlinear Brønsted-type plot is typical for reactions reported previously to proceed through a stepwise mechanism with a change in RDS (e.g., piperidinolysis of Y-substituted-phenyl benzoates[5a] and quinuclidinolysis of diaryl carbonates[6] in H_2O). Accordingly, we propose that the reactions of **2a**−**i** with piperidine in MeCN also proceed through a stepwise mechanism

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Table 2. Summary of Second-Order Rate Constants for Nucleophilic Substitution Reactions of 4-Nitrophenyl 2-methoxybenzoate 2c with Secondary Alicyclic Amines in MeCN at 25.0 ± 0.1 °C[a]

	amines	pK_a	k_N, M^{-1} s^{-1}
1	piperidine	18.8	12.2
2	3-methylpiperidine	18.6	10.8
3	piperazine	18.5	11.5
4	1-(2-hydroxyethyl)piperazine	17.6	2.19
5	morpholine	16.6	0.370

[a] The pK_a values for the conjugate acids of amines in MeCN were taken from ref 13.

Table 3. Summary of Second-Order Rate Constants for Nucleophilic Substitution Reactions of 4-Nitrophenyl X-Substituted-benzoates 3a−j with Piperidine in MeCN at 25.0 ± 0.1 °C[a]

entry	X	σ	k_N, $M^{-1}s^{-1}$
3a	4-NMe_2	−0.83	0.0299
3b	4-OMe	−0.27	0.164
3c	4-Me	−0.17	0.281
3d	H	0	0.539
3e	3- OMe	0.12	0.620
3f	4-Cl	0.23	0.709
3g	3-Cl	0.37	1.03
3h	4-CN	0.66	1.41
3i	4-NO_2	0.78	1.59
3j	3,5-$(NO_2)_2$	1.42	2.94
2c	2-OMe	–	12.2

[a] The σ values were taken from ref 17.

with a change in RDS as shown in Scheme 2, e.g., from the breakdown of $T^{\pm}$ (the k_2 step) to its formation (the k_1 process) as the leaving-group basicity decreases.

Effect of Amine Basicity on Reactivity and Reaction Mechanism. To get further information on the reaction mechanism, reactions of 4-nitrophenyl 2-methoxybenzoate **2c** with a series of secondary alicyclic amines have been performed in MeCN. As shown in Table 2, the k_N value decreases gradually as the pK_a of the conjugate acid of the incoming amines decreases except for piperazine, which shows a larger k_N than 3-methylpiperidine although the former is less basic than the latter. The larger k_N exhibited by piperazine could be attributed to the two nucleophilic sites.

The effect of amine basicity on the reactivity is illustrated in Figure 2. The Brønsted-type plot for the reactions of **2c** exhibits an excellent linear correlation with $\beta_{nuc} = 0.70$, when the k_N and pK_a values are corrected statistically using p and q (i.e., $p = 2$ and $q = 1$ except $q = 2$ for piperazine).[16] The β_{nuc} value for the reactions of **2c** in this study is much larger than that reported previously for the corresponding reactions of 2,4-dinitrophenyl benzoate **1a** in MeCN (i.e., $\beta_{nuc} = 0.40$).[12] The aminolysis of **1a** in MeCN has been reported to proceed through a concerted mechanism on the basis of the small β_{nuc} value.[12]

The β_{nuc} value found for the reactions of **2c** in MeCN is slightly smaller than that reported for the corresponding reactions performed in H_2O (i.e., $\beta_{nuc} = 0.81$), which were proposed to proceed through a stepwise mechanism.[5c] Because a β_{nuc} value

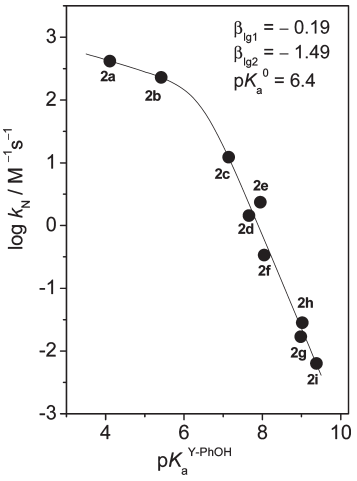

Figure 1. Brønsted-type plot for the reactions of Y-substituted-phenyl 2-methoxybenzoates **2a**−**i** with piperidine in MeCN at 25.0 ± 0.1 °C. The identity of points is given in Table 1.

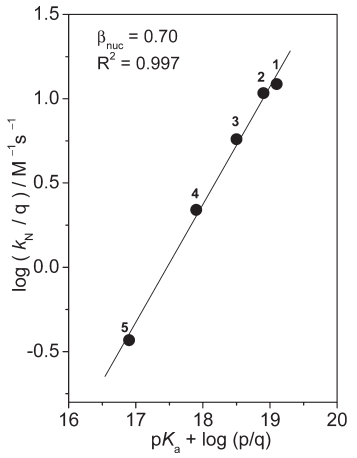

Figure 2. Brønsted-type plot for the reactions of 4-nitrophenyl 2-methoxybenzoate **2c** with secondary alicyclic amines in MeCN at 25.0 ± 0.1 °C. The identity of points is given in Table 2.

of 0.70 is considered to be the lower limit for a stepwise mechanism, the aminolysis of **2c** in MeCN could proceed through a stepwise mechanism, in which expulsion of the leaving group is the RDS. This idea is consistent with the preceding proposal that the reactions of **2a**−**i** with piperidine in MeCN proceed through a stepwise mechanism in which the RDS is dependent on the leaving-group basicity. The effect of the 2-OMe group in the benzoyl moiety of **2a**−**i** on the reaction mechanism will be discussed in detail in the last section.

Effect of Substituent X in Benzoyl Moiety on Reactivity and Reaction Mechanism. To investigate the effect of benzoyl substituent X on the reactivity and reaction mechanism, reactions of 4-nitrophenyl X-substituted benzoates **3a**−**j** with piperidine have been performed in MeCN. As shown in Table 3, k_N increases as the substituent X changes from a strong EDG to a strong EWG, e.g., it increases from 0.0299 M^{-1} s^{-1} to 0.539 and 2.94 M^{-1} s^{-1} as the substituent X changes from 4-NMe_2 to H and 3,5-$(NO_2)_2$, in turn.

The effect of substituent X on the reactivity is graphically demonstrated in Figure 3. The Hammett plot consists of two

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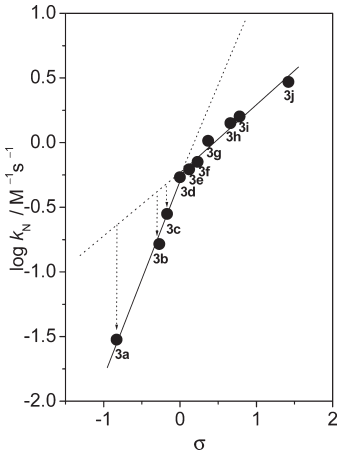


Figure 3. Hammett plot for the reactions of 4-nitrophenyl X-substituted-benzoates **3a**−**j** with piperidine in MeCN at 25.0 ± 0.1 °C. The identity of points is given in Table 3.

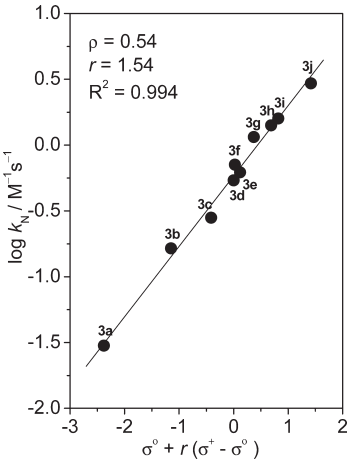
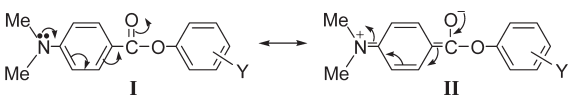


Figure 4. Yukawa−Tsuno plot for the reactions of 4-nitrophenyl X-substituted-benzoates **3a**−**j** with piperidine in MeCN at 25.0 ± 0.1 °C. The identity of points is given in Table 3.

intersecting straight lines. The ρ value decreases from 1.49 to 0.53 as the substituent X changes from EDGs to EWGs. Such a nonlinear Hammett plot has traditionally been taken as evidence for a change in RDS.[18] In fact, Jencks has found a downward Hammett plot for reactions of a series of X-substituted benzaldehydes with semicarbazide and concluded that a change in RDS is responsible for the nonlinear Hammett plot.[18c] Accordingly, we ascribe the nonlinear Hammett plot shown in Figure 3 to a change in RDS, i.e., from the formation of $T^{\pm}$ to its breakdown to yield the reaction products as the substituent X in the benzoyl moiety changes from EDGs to EWGs. This idea appears to be reasonable, since an EDG in the benzoyl moiety would retard nucleophilic attack (i.e., a decrease in k_1) but accelerate the departure of the negatively charged leaving group (i.e., an increase in k_2). In contrast, an EWG would increase k_1 but decrease k_2. Thus, the nonlinear Hammett plot might be interpreted as a change in RDS upon changing the substituent X in the benzoyl moiety of **3a**−**j**.

However, we propose that the nonlinear Hammett plot is not due to a change in the RDS. This is because the RDS is not governed by the magnitude of k_1 and k_2, but it rather is determined by the k_2/k_{-1} ratio (i.e., RDS = k_1 step when $k_2/k_{-1} > 1$ but RDS = k_2 process when $k_2/k_{-1} < 1$). Furthermore, k_1 and k_2 values cannot be compared directly, because the former is a second-order rate constant, while the latter is a first-order rate constant. We propose that the nonlinear Hammett plot shown in Figure 3 is caused by stabilization of the ground state (GS) of substrates through resonance interaction between the π-electron-donating substituent X and the carbonyl functionality as illustrated by resonance structures I and II. This argument is supported by the fact that the substrates possessing an EDG (e.g., **3a**−**c**) deviate negatively from the linear Hammett plot composed of those possessing an EWG (**3e**−**j**). Moreover, the negative deviation is more significant as the substituent X becomes a stronger EDG.



To examine the validity of the above argument, the Yukawa−Tsuno equation, eq 1, has been employed. We have shown that eq 1 is highly effective in clarifying ambiguities in the reaction mechanisms for nucleophilic substitution reactions of various esters.[10,19] The r value in eq 1 represents the resonance demand of the reaction center or the extent of resonance contribution, while the term $(\sigma^+ - \sigma^\circ)$ is the resonance substituent constant that measures the capacity for π-delocalization of the π-electron donor substituent.[20,21] eq 1 becomes the Hammett equation when r = 0, but becomes the Brown−Okamoto equation when r = 1.

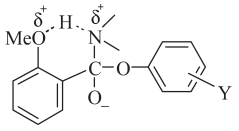
$$\log(k_X/k_H) = \rho[\sigma^\circ + r(\sigma^+ - \sigma^\circ)] \quad (1)$$

As shown in Figure 4, the Yukawa−Tsuno plot exhibits excellent linearity with ρ = 0.54 and r = 1.54. Such a linear Yukawa−Tsuno plot indicates that the nonlinear Hammett plot shown in Figure 3 is not due to a change in RDS but is caused by GS stabilization through a resonance interaction as illustrated by the resonance structures I and II. This argument is consistent with our previous report that the RDS for aminolyses of esters is not governed by the electronic nature of the substituents in the nonleaving group and that deduction of the reaction mechanism based solely on a linear or nonlinear Hammett plot can be misleading.[19]

Effect of *o*-OMe on Reactivity and Reaction Mechanism. It is well-known that ρ is much larger for reactions in MeCN than for those in H_2O (e.g., ρ = 1.00 and 2.4 for the dissociation of X-substituted benzoic acids in H_2O and MeCN,[22] respectively). Interestingly, the ρ value found for the reactions of **3a**−**j** with piperidine in MeCN (i.e., ρ = 0.54) is much smaller than that reported previously for the corresponding reactions performed in H_2O (i.e., ρ = 0.75).[5c] The reactions of **3a**−**j** in H_2O have been reported to proceed through a stepwise mechanism with $T^{\pm}$ as a reactive intermediate.[5c] However, we propose that the reactions of **3a**−**j** in MeCN proceed through a forced concerted mechanism,[1c−e,2b] because the zwitterionic intermediate $T^{\pm}$ is expected to be highly unstable in the aprotic solvent. The small ρ value found for the current reactions in MeCN also supports a concerted mechanism since ρ has been reported to be small for reactions which proceed through an S_N2 mechanism (e.g., ρ = 0.3 ± 0.1 for nucleophilic substitution reactions of diaryl chlorophosphates with anilines[23] and ρ = −0.2 ± 0.1 for solvolysis of 2-phenylethyl tosylates and benzyl tosylates.[24]

In contrast, the reactions of **2a**−**i** with piperidine in MeCN have been concluded to proceed through a stepwise mechanism

with a change in RDS on the basis of the curved Brønsted-type plot (Figure 1). Accordingly, we suggest that the $T^{\pm}$ for the reactions of **2a**−**i** is stable even in MeCN through a H-bonding interaction between the 2-OMe and the aminium moiety of $T^{\pm}$ as modeled by III, which is not possible for the reactions of **3a**−**j** due to the absence of 2-OMe in the benzoyl moiety of **3a**−**j**. Stabilization of $T^{\pm}$ through such a H-bonding interaction would accompany an increase in the reactivity of **2a**−**i**, because the transition state for a stepwise reaction is expected to be similar to an intermediate on the basis of the Hammond postulate.[25] This idea is consistent with the fact that the substrates possessing the 2-OMe group (e.g., **2a**−**i**) are significantly more reactive than those without 2-OMe, e.g., **2c** is ca. 74 and 20 times more reactive than its isomers **3b** and **3e**, respectively (Table 3). Thus, we conclude that stabilization of $T^{\pm}$ through a H-bonding interaction allows the reactions of **2a**−**i** in MeCN to proceed through a stepwise mechanism with significantly increased reactivity.



III

CONCLUSIONS

The current study has allowed us to conclude the following: (1) The curved Brønsted-type plot found for the reactions of **2a**−**i** with piperidine is indicative of a stepwise mechanism with a change in RDS. (2) The stepwise mechanism is also supported by the fact that the Brønsted-type plot for the reactions of **2c** is linear with $\beta_{nuc} = 0.70$. (3) The Hammett plot for the reactions of **3a**−**j** with piperidine consists of two intersecting straight lines, while the corresponding Yukawa−Tsuno plot exhibits an excellent linear correlation with $\rho = 0.54$ and $r = 1.54$, indicating that the nonlinear Hammett plot is not due to a change in RDS but is caused by GS stabilization through resonance interactions between the π-electron donating substituent and the carbonyl functionality of the substrate. (4) The reactions of **3a**−**j** are proposed to proceed through a forced concerted mechanism since the zwitterionic intermediate $T^{\pm}$ would be highly unstable in MeCN. The small ρ value found for the reactions of **3a**−**j** also supports the concerted mechanism. (5) Aryl benzoates possessing the 2-OMe group in the benzoyl moiety (e.g., **2a**−**i**) are significantly more reactive than those without 2-OMe substituent (e.g., **1a**−**i** and **3a**−**j**) in MeCN. Stabilization of $T^{\pm}$ through H-bonding interaction allows the reaction of **2a**−**i** in MeCN to proceed through a stepwise mechanism with significantly enhanced reactivity.

EXPERIMENTAL SECTION

Materials. Compounds **2a**−**i** and **3a**−**j** were readily prepared from the reaction of the respective 2-methoxybenzoyl chloride with Y-substituted phenol (**2a**−**i**) and from that of the respective X-substituted benzoyl chloride with 4-nitrophenol (**3a**−**j**) in anhydrous ether in the presence of triethylamine as reported previously.[4,12] Their purity was confirmed from melting points and ^{1}H NMR characteristics. MeCN was distilled over P_2O_5 and stored under nitrogen. The amines and other chemicals used were of the highest quality available.

3,4-Dinitrophenyl 2-Methoxybenzoate (2b). mp 88−90 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 3.96 (s, 3H), 7.074−7.089 (d, J = 7.5 Hz, 1H), 7.083−7.098 (d, J = 7.5 Hz, 1H), 7.614−7.629 (dd, J_1 = 7.5 Hz, J_2 = 1.5 Hz, 1H), 7.646−7.660 (dd, J_1 = 7.5 Hz, J_2 = 2.5 Hz, 1H), 7.830−7.835 (d, J = 2.5 Hz, 1H), 8.017−8.032 (dd, J_1 = 7.5 Hz, J_2 = 1.5 Hz, 1H), 8.041−8.059 (d, J = 7.5 Hz, 1H). Anal. Calcd for $C_{14}H_{10}N_2O_7$: C, 52.84; H, 3.17. Found: C, 52.73; H, 3.19.

3-Chlorophenyl 2-Methoxybenzoate (2h). mp 39−41 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 3.940 (s, 3H), 7.032−7.063 (t, J = 7.5 Hz, 2H), 7.127−7.147 (dd, J_1 = 7.5 Hz, J_2 = 1.5 Hz, 1H),7.230−7.247 (dd, J_1 = 7.5 Hz, J_2 = 1.5 Hz, 1H), 7.266−7.274 (t, J = 2.0 Hz, 1H), 7.321−7.353 (t, J = 8.0 Hz, 1H), 7.539−7.574 (dt, J_1 = 7.5 Hz, J_2 = 2.0 Hz, 1H), 7.990−8.010 (dd, J_1 = 7.5 Hz, J_2 = 1.5 Hz, 1H). Anal. Calcd for $C_{14}H_{11}ClO_3$: C, 64.01; H, 4.22. Found: C, 64.12; H, 4.20.

Kinetics. The kinetic study was performed using a UV−vis spectrophotometer for slow reactions (e.g., $t_{1/2} \geq 10$ s) or using a stopped-flow spectrophotometer for fast reactions (e.g., $t_{1/2} < 10$ s) equipped with a constant temperature circulating bath to keep the reaction temperature at 25.0 ± 0.1 °C. All the reactions were carried out under pseudo-first-order conditions in which the amine concentration was at least 20 times greater than the substrate concentration. Typically, the reaction was initiated by adding 5 μL of a 0.02 M of substrate stock solution in MeCN by a 10 μL syringe to a 10 mm UV cell containing 2.50 mL of the reaction medium and amine. The reactions were followed by monitoring the appearance of Y-substituted phenoxide up to 9 to 10 half-lives.

Product Analysis. Y-Substituted phenoxide (and/or its conjugate acid) was liberated quantitatively and identified as one of the reaction products by comparison of the UV−vis spectra obtained after completing the reactions with those of authentic samples under the same kinetic conditions.

ASSOCIATED CONTENT

Supporting Information. ^{1}H NMR spectra for substrates **2b** and **2h**. This material is available free of charge via the Internet at http://pubs.acs.org.

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