Ketene-Forming Elimination Reactions from Aryl Thienylacetates Promoted by $R_2NH/R_2NH_2^+$ in 70 mol % MeCN(aq). Effect of the β-Aryl Group

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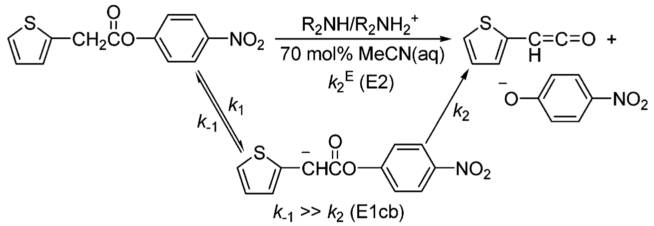

Ketene-forming eliminations from $ArCH_2CO_2C_6H_3$-2-X-4-NO_2 (Ar = thienyl, **1**) promoted by $R_2NH/R_2NH_2^+$ in 70 mol % MeCN(aq) have been studied kinetically. When X = CF_3 and NO_2, the reactions exhibit second-order kinetics as well as $\beta = 0.30-0.64$ and $|\beta_{lg}| = 0.31-0.52$ that decrease with a better leaving group. Hence, an E2 mechanism is evident. As the leaving group is made poorer (X = H, OCH_3, and Cl), E2 transition state becomes more skewed toward the proton transfer, as revealed by the increase in Brönsted β to 0.5−0.64, and the E1cb mechanism competes. The changes in the k_1 and k_{-1}/k_2 values with the reactant structure variation provide additional support for the competing E1cb mechanism. By comparing with existing data for 4-$YC_6H_4CH_2CO_2C_6H_3$-2-X-4-NO_2, the effect of β-aryl group on ketene-forming elimination is assessed.

Extensive studies of ketene-forming elimination reactions have revealed mechanistic diversity in the E2 and E1cb borderline.[1−6] The mechanism changed from E2 to E1cb via the competing E2 and E1cb mechanisms as the good leaving group was made poorer and as the electron-withdrawing ability of the β-aryl substituent increased.

Earlier, we investigated the effects of heterocyclic aromatic compounds on the nitrile- and imine-forming elimination reactions.[7−10] However, the rates and the E2 transition states were insensitive to the change of the β-aryl group from Ph to thienyl to furyl. The only significant difference was the smaller steric effect observed for the imine-forming elimination from $ArCH_2N(X)R$ when Ar = thienyl.[9,10] We thought that the effect of β-aryl group might be more pronounced in the ketene- than in the nitrile- and imine-forming eliminations for the following reasons: (1) the partial double bond character in the ketene-forming transition state may be better stabilized by the β-aryl group because the π orbitals are composed of the p-orbitals of carbon atoms rather than those of carbon and nitrogen atoms and (2) the heterocyclic groups may facilitate the mechanism change from E2 to E1cb by stabilizing the negative charge at the β-carbon. To assess the relative importance of these factors,

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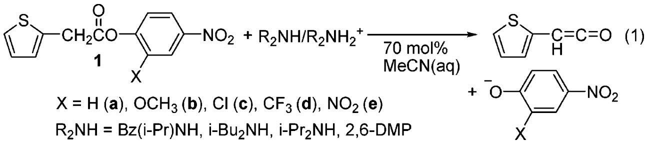
TABLE 1. Rate Constant for Ketene-Forming Elimination from $ArCH_2CO_2C_6H_3$-2-X-4-NO_2[a,b] Promoted by $R_2NH/R_2NH_2^+$ in 70 mol % MeCN(aq)[c,d] at 25.0 °C

		$10^2 k_2^E$, $M^{-1} s^{-1}$[g,h]				
R_2NH[e]	pK_a[f]	X = H (**1a**)[i]	X = OMe (**1b**)[i]	X = Cl (**1c**)[i]	X = CF_3 (**1d**)	X = NO_2 (**1e**)
Bz(*i*-Pr)NH	16.8	0.235	0.202	46.0	186	478
i-Bu_2NH	18.2	1.27[j]	1.28	85.8	488	1020
i-Pr_2NH	18.5	4.48	2.22	282	587	1260
2,6-DMP[k]	18.9	4.40	3.85	446	1040	2490

[a] Ar = thienyl. [b] [Substrate] = 3.0×10^{-5} M. [c] $[R_2NH]/[R_2NH_2^+] = 1.0$ except as otherwise noted. [d] $\mu = 0.1$ ($Bu_4N^+Br^-$). [e] $[R_2NH] = 8.0 \times 10^{-4}$ to 5.0×10^{-2} M. [f] Reference 14. [g] Average of three or more rate constants. [h] Estimated uncertainty, ±5%. [i] Calculated from the k_{obs} by using eq 2. [j] $k_2^E = 0.0180$ $M^{-1} s^{-1}$ when $[R_2NH]/[R_2NH_2^+] = 2.0$. [k] *cis*-2,6-Dimethylpiperidine.

we have investigated the reactions of aryl thienylacetates (**1a**−**e**) promoted by $R_2NH/R_2NH_2^+$ in 70 mol % MeCN(aq) (eq 1). It is well-established that the reactions of 4-$YC_6H_4CH_2CO_2C_6H_3$-2-X-4-NO_2 [Y = H (**2**), NO_2 (**3**)] with R_2NH in MeCN and $R_2NH/R_2NH_2^+$ in 70 mol % MeCN(aq) proceed by the ketene-forming elimination followed by the addition.[2,3] Compared to the aminolysis of *p*-nitrophenyl- and 2,4-dinitrohphenyl acetates in water,[11] the aminolysis of **1a** and **1e** with $R_2NH/R_2NH_2^+$ in 70 mol % MeCN(aq) would be retarded because the zwitterionic tetrahedral intermediate would be destabilized by the less protic solvents and the elimination reaction would be facilitated by the increased acidity of the C_β−H bond and the increased basicity of the amine bases. Hence, the reactions of **1a**−**e** with $R_2NH/R_2NH_2^+$ in 70 mol % MeCN(aq) should proceed by the elimination reaction pathway. Comparison with the existing data for **2** and **3** reveals the influence of the *β*-aryl group on the ketene-forming eliminations.[2,5]



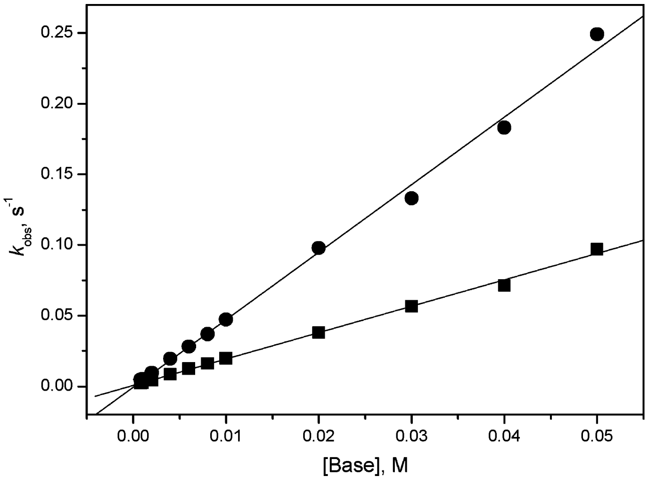


FIGURE 1. Plots of k_{obs} versus base concentration for eliminations from 2-trifluoromethyl-4-nitrophenyl thienylacetate (**1d**, ■) and 2,4-dinitrophenyl thienylacetate (**1e**, ●) promoted by *i*-Bu_2NH/*i*-$Bu_2NH_2^+$ in 70 mol % MeCN(aq) at 25.0 °C. [*i*-Bu_2NH]/[*i*-$Bu_2NH_2^+$] = 1.0, $\mu = 0.10$ M ($Bu_4N^+Br^-$).

Results

Aryl thienylacetates **1a**−**e** were synthesized by the reaction between 2-thiopheneacetic acid, substituted phenols, 2-chloro-1-methyl pyridinium, and Et_3N in CH_2Cl_2 as reported.[2,12] The spectral and analytical data for the compounds were consistent with the proposed structures.

The products of between **1a** and *i*-Bu_2NH/*i*-$BuNH_2^+$ in 70 mol % MeCN(aq) were identified by thin-layer chromatography (TLC) and gas chromatography (GC) as before.[2] The products were *N*,*N*-di(isobutyl)thenylamide and 4-nitrophenoxide. The yield of *N*,*N*-di(isobutyl)thenylamide determined by GC was 86%. For all reactions, the yields of aryloxides determined by comparing the infinity absorption of the samples from the kinetic studies with those of the authentic aryloxides were in the range of 96−99%.

The possibility of competition by the aminolysis reaction has been ruled out as before.[2,3] The k_2^E values for the reactions of **1a** and **1e** with 2,6-DMP/2,6-DMPH$^+$ in 70 mol % MeCN(aq) are 0.0440 and 24.9 $M^{-1} s^{-1}$, respectively (Table 1). The values are much larger (≥100-fold) than $k_2 = 0$ and 0.250 $M^{-1} s^{-1}$ reported for the aminolysis of 4-nitro- and 2,4-dinitrophenyl butyrates.[3] Because steric effects of the thenyl and butyl groups are expected to be similar,[13] the aminolysis of **1a** and **1e** should proceed at comparable rates to those of the former.[3] This would predict that the ketene-forming elimination should be the predominant reaction pathway under the condition employed in this study. In addition, all compounds were stable for at least 3 days in 70 mol % MeCN(aq), indicating that the solvolytic elimination is negligible.

The rates of elimination reactions were followed by monitoring the increase in the absorption at the λ_{max} for the aryloxides in the range of 400−426 nm. In all cases, clean isosbestic points were noted in the range of 290−352 nm. Excellent pseudo-first-order kinetic plots which covered at least three half-lives were obtained. The rate constants are summarized in Tables S1−S4 in the Supporting Information.

For the reactions of **1d** and **1e** with $R_2NH/R_2NH_2^+$ in 70 mol % MeCN(aq), the plots of k_{obs} versus base concentration were straight lines passing through the origin, indicating that the reactions are second-order, first-order to the substrate and first-order to the base (Figure 1 and Figures S1−S3). The slopes of the plots are the overall second-order rate constants k_2^E. Values of k_2^E for eliminations from **1d** and **1e** are summarized in Table 1. The rate increases as the leaving group ability and the pK_a value of the promoting base are increased. On the other hand, the corresponding plots for **1a**−**c** were curves at low base concentration and became straight lines at higher base concentration (Figures 2 and S4−S15). The data were analyzed by

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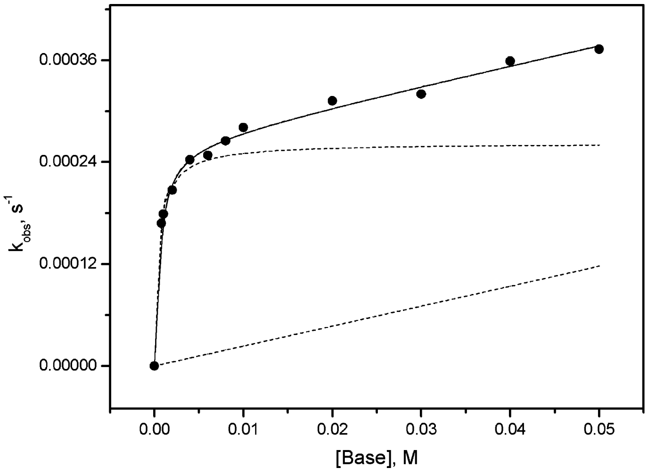


FIGURE 2. Plots of k_{obs} versus base concentration for eliminations from *p*-nitrophenyl thienylacetate (**1a**) promoted by Bz(*i*-Pr)NH/Bz(*i*-Pr)NH_2^+ in 70 mol % MeCN(aq) at 25.0 °C, Bz(*i*-Pr)NH/Bz(*i*-Pr)-NH_2^+ = 1.0, μ = 0.1 M ($Bu_4N^+Br^-$). The closed circles are the experimental data and the solid line shows the fitted curve by using eq 2 (see text). The curve is dissected into the E2 and E1cb reaction components (dashed lines).

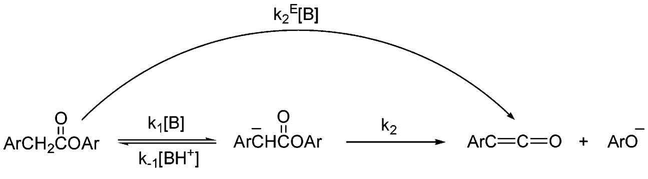
TABLE 2. The k_1 and k_{-1}/k_2 Values for Elimination from $ArCH_2CO_2C_6H_3$-2-X-4-NO_2[a,b] Promoted by $R_2NH/R_2NH_2^+$ in 70 mol % MeCN(aq)[c,d] at 25.0 °C

	k_1, M^{-1} s^{-1} [e,f]			$10^{-3}k_{-1}/k_2$, M^{-1} [e]		
R_2NH	**1a**	**1b**	**1c**	**1a**	**1b**	**1c**
Bz(*i*-Pr)NH	0.528	0.183	0.770	2.11	1.21	0.0606
i-Bu_2NH	1.14[g]	0.627	2.35	1.11[g]	1.26	0.0266
i-Pr_2NH	1.58	0.936	2.73	0.250	0.289	0.119
2,6-DMP[h]	2.36	1.45	3.47	0.369	0.480	0.0719

[a–d] See Table 1 for footnotes. [e] Calculated from k_{obs} by using eq 2. [f] The slopes of the plots of log k_1 versus pK_a of the bases for **1a**−**c** are 0.30 ± 0.04, 0.42 ± 0.02, and 0.32 ± 0.02, respectively. [g] $k_1 = 1.18$ M^{-1} s^{-1} and $k_{-1}/k_2 = 1.22 \times 10^3$ M^{-1}, respectively, when $[R_2NH]/[R_2NH_2^+] = 2.0$. [h] *cis*-2,6-Dimethylpiperidine.

assuming that the reaction proceeds by concurrent E2 and E1cb mechanisms (eq 2).[2,5]

The plots were dissected into the E2 and E1cb reaction components, and k_2^E, k_1, and k_{-1}/k_2 values that best fit with eq 2 were calculated. In all cases, the correlations between the calculated and the experimental data were excellent. Calculated values of k_2^E, k_1, and k_{-1}/k_2 for **1a**−**c** are summarized in Tables 1 and 2.



$$k_{obs} = k_2^E[B] + \frac{k_1k_2[B]}{k_{-1}[BH^+] + k_2} \qquad (2)$$

The possibility of the buffer association as the cause of the curvature was ruled out by the straight lines observed in the plots of k_{obs} versus [base] for the reactions of **1d** and **1e** (Figures 1 and S1−S3). Also, the possibility that the salt effect may have caused the steady increase in the k_{obs} at higher base concentration is negated because the ionic strength is maintained to be 0.10 M with $Bu_4N^+Br^-$. To assess the effect of buffer ratio, the k_{obs} values for the reaction of **1a** have been measured at $[R_2NH]/[R_2NH_2^+] = 2.0$. At a given base concentration, the k_{obs} is always larger at a higher buffer ratio, as expected from eq 2 (Table S2). In addition, the rate data showed excellent correlations with eq 2 (Figure S7). Moreover, the values of k_2^E, k_1, and k_{-1}/k_2 are nearly the same regardless of the buffer ratio (Tables 1 and 2).

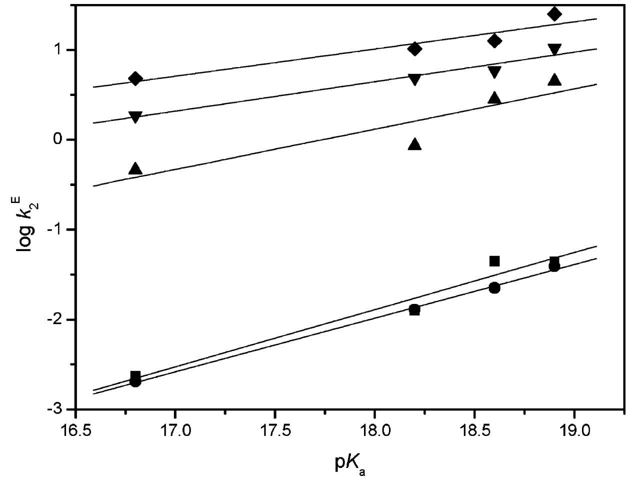


FIGURE 3. Brönsted plots for the k_2^E pathways for eliminations from $ArCH_2CO_2C_6H_3$-2-X-4-NO_2 (Ar = thienyl) promoted by $R_2NH/R_2NH_2^+$ in 70 mol % MeCN(aq) at 25.0 °C, $[R_2NH]/[R_2NH_2^+] = 1.0$, μ = 0.1($Bu_4N^+Br^-$). X = H (**1a**, ■), OMe (**1b**, ●), Cl (**1c**, ▲), CF_3 (**1d**, ▼), NO_2 (**1e**, □).

Brönsted plots for the k_2 pathways of **1a**−**e** are depicted in Figure 3. For all compounds, the plots are linear with good correlations. The β values are in the range of 0.30−0.64 and increase as the leaving group ability of the aryloxide decreases (Table 3). The k_1 increases and the k_{-1}/k_2 ratio decreases with a stronger base (Table 2). When the leaving group is changed to a better one, the k_1 scatters and the k_{-1}/k_2 ratio decreases gradually. The plots of log k_1 versus pK_a values of base are straight lines (Figures S16). The slopes of the plots for **1a**−**c** are 0.30 ± 0.04, 0.42 ± 0.02, and 0.32 ± 0.02, respectively (Table 2).

The plots of k_2^E values for **1a**−**e** against the pK_{lg} values of the leaving group are depicted in Figure 4. The rate data show good correlations with the straight lines, if the data for **1a** and **b** are excluded. Therefore, the β_{lg} values were calculated from the straight lines without the data for **1a** and **b**. The $|\beta_{lg}|$ values are in the range of 0.31−0.52 and show a decreasing trend with a stronger base (Table 4).

To provide additional evidence for a competing E1cb mechanism, an H−D exchange experiment was carried out by mixing **1a**−**c** with *i*-Bu_2NH/*i*-$Bu_2NH_2^+$ in 70 mol % MeCN−30% D_2O at 25.0 °C in an nuclear magnetic resonance (NMR) tube. The NMR spectrum taken immediately after mixing indicated complete H−D exchange at the β-carbon.

Discussion

Mechanism of Eliminations from 1. Results of kinetic investigations and product studies reveal that the reactions of **1d** and **1e** with $R_2NH-R_2NH_2^+$ in 70 mol % MeCN(aq) proceed by the E2 mechanism. The reactions produce elimination products and exhibit second-order kinetics, negating all but bimolecular pathways. In addition, an E1cb mechanism is ruled

TABLE 3. **Brönsted β Values for the k_2^E Pathways for Eliminations from $ArCH_2CO_2C_6H_3$-2-X-4-NO_2[a] Promoted by $R_2NH/R_2NH_2^+$ in 70 mol % MeCN(aq)[b,c] at 25.0 °C**

	X = H (**1a**)	X = OMe (**1b**)	X = Cl (**1c**)	X = CF_3 (**1d**)	X = NO_2 (**1e**)
pK_{lg}[d]	20.7	20.6	18.1	17.0	16.0
b	0.64 ± 0.09[e]	0.60 ± 0.02[e]	0.5 ± 0.1[e]	0.33 ± 0.05	0.30 ± 0.07

[a] Ar = thienyl. [b] $[R_2NH]/[R_2NH_2^+] = 1.0$. [c] $\mu = 0.1$ ($Bu_4N^+Br^-$). [d] Reference 15. [e] k_2^E values calculated from the k_{obs} by using eq 2 have been used.

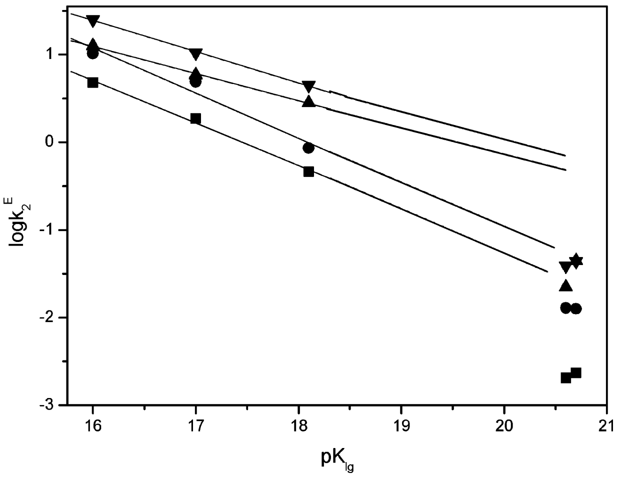


FIGURE 4. Plots log k_2^E versus pK_{lg} values of the leaving group for the k_2^E pathways for eliminations from $ArCH_2CO_2C_6H_3$-2-X-4-NO_2 (Ar = thienyl) promoted by $R_2NH/R_2NH_2^+$ in 70 mol % MeCN(aq) at 25.0 °C, $[R_2NH[/[R_2NH_2^+] = 1.0$, $\mu = 0.1(Bu_4N^+Br^-)$. R_2NH = Bz(*i*-Pr)NH(■), *i*-Bu_2NH(●), *i*-Pr_2NH(▲), 2,6-DMP(▼).

TABLE 4. **β_{lg} Values for the k_2^E Pathways for Eliminations from $ArCH_2COOC_6H_3$-2-X-4-NO_2[a] Promoted by $R_2NH/R_2NH_2^+$ in 70 mol % MeCN(aq)[b,c] at 25.0 °C**

R_2NH	Bz(*i*-Pr)NH	*i*-Bu_2NH	*i*-Pr_2NH	2,6-DMP[d]
pK_a	16.8	18.2	18.5	18.9
β_{lg}	−0.49 ± 0.04	−0.52 ± 0.11	−0.31 ± 0.01	−0.36 ± 0.01

[a] Ar = thienyl. [b] $[R_2NH]/[R_2NH_2^+] = 1.0$. [c] $\mu = 0.1$ ($Bu_4N^+Br^-$). [d] *cis*-2,6-Dimethylpiperidine.

out by the substantial values of β and $|\beta_{lg}|$.[16,17] Moreover, the β values of the k_2^E processes for **1a**−**e** increase with a poorer leaving group (Table 3). This effect corresponds to a positive p_{xy} interaction coefficient, $p_{xy} = \partial\beta/\partial pK_{lg}$, which describes the interaction between the base catalyst and the leaving group.[16,17] Furthermore, the observed increase in the $|\beta_{lg}|$ values with a weaker base is another manifestation of this effect, that is, $p_{xy} = \partial\beta_{lg}/\partial pK_{BH} > 0$ (Table 4). The positive interaction coefficients, that is, $p_{xy} = \partial\beta/\partial pK_{lg} = \partial\beta_{lg}/\partial pK_{BH} > 0$, provide additional evidence for the E2 mechanism (vide infra).[16,17]

On the other hand, the plots of k_{obs} versus the base concentration for the reactions of **1a**−**c** with $R_2NH-R_2NH_2^+$ in 70 mol % MeCN(aq) were curves at low buffer concentration and became straight lines at [buffer] > 0.008−0.05 M (Figures 2 and S4−S15). Similar results were observed for eliminations from **3** under the same condition and were ascribed to the concurrent E2 and E1cb mechanisms.[5,6] There is convincing evidence in support of this mechanistic duality. First, all rate data show excellent correlations with eq 2, that is, $k_{obs} = k_2^E[B] + k_1k_2[B]/(k_{-1}[BH^+] + k_2)$ (Figures 2 and S4−S15). The shapes of the dissected lines are typical for the E2 and E1cb mechanisms. In addition, the k_{obs} value for the reaction of **1a** with $[R_2NH]/[R_2NH_2^+]$ increases upon change of the buffer ratio from 1.0 to 2.0, as expected from eq 2 (Table S2). Furthermore, the calculated rate constants for the E2 and E1cb pathways provide additional evidence for this mechanistic duality. (1) The k_2^E values for **1a**−**c** nicely fit in the trend observed for **1d** and **1e**, that is, the k_2^E of **1a**−**e** increases with a stronger base and a better leaving group (Table 1). The only exception to this trend is the faster rate of **1a** than **1b**, which can be attributed to the smaller leaving group steric effect. (2) The increase in the k_1 value with a stronger base is consistent with what would be expected for the deprotonation step (Table 2). For a given base, the k_1 values of **1a**−**1c** are scattered as they should be independent for the leaving group variation. In addition, the slopes of the plots of log k_1 versus pK_a of the bases for **1a**−**c** are in the range of 0.30−0.42, which is again consistent because the transition state for this step should be reactant-like (see footnote in Table 2). (3) For *i*-Bu_2NH-promoted elimination from **1a**, the small decrease in k_2^E and k_1 values with the increase in the buffer ratio from 1 to 2 can be attributed to the modest decrease in the basicity because of the enhanced hydrogen bonding between the base and the excess conjugate acid (Tables 1 and 2). The decrease in the k_{-1}/k_2 value by the same variation of the buffer ratio is reasonable because *i*-$Bu_2NH_2^+$ would stabilize the carbanion intermediate to decrease k_{-1} more than k_2 because the second step involves a higher energy barrier. (4) The decrease in the k_{-1}/k_2 values in the order **1a** ≈ **1b** > **1c** is also consistent (Table 2). The k_{-1} should be relatively insensitive to the leaving group variation, whereas k_2 should increase in the order **1a** ≈ **1b** < **1c**. A combination of these factors would be to decrease the k_{-1}/k_2 values. (5) The increase in the k_{-1}/k_2 ratio with a weaker base can also be explained similarly. The k_{-1} value should increase with the acidity of $R_2NH_2^+$, although k_2 should be independent of the base strength. This predicts an increase in the k_{-1}/k_2 ratio with the weaker base. The smaller value of k_{-1}/k_2 for *i*-Pr_2NH/*i*-$Pr_2NH_2^+$ than expected from the pK_a value can be attributed to the base steric effect. Because *i*-$Pr_2NH_2^+$ is sterically more hindered than others, it should decrease k_{-1} without changing k_2 to decrease k_{-1}/k_2. Also, the scattered values of k_{-1}/k_2 for **1c** may be due to the experimental errors caused by the small contribution of the E1cb pathway (Figures S12−S15).

Finally, the NMR spectra taken immediately after mixing **1a**−**c** with *i*-Bu_2NH/*i*-$Bu_2NH_2^+$ in 70 mol %−30% D_2O at 25.0 °C indicated complete absence of the protons on the

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TABLE 5. Effect of β-Aryl Group on the Ketene-Forming Eliminations from $ArCH_2CO_2C_6H_4$-4-NO_2 Promoted by $R_2NH/R_2NH_2^+$ Buffers in 70 mol % MeCN(aq) at 25.0 °C

	Ar = thienyl (**1a**)	Ar = phenyl (**2**)[a]	Ar = *p*-nitrophenyl (**3**)[b]
rel. rate (k_2^E)[c]	1	0.7	70
b	0.64 ± 0.09	0.77 ± 0.03[c,d]	0.47 ± 0.01
β_{lg}	−0.49 ± 0.01	−0.43[e]	−0.21 ± 0.01
k_1	0.528		11.7
k_{-1}/k_2	2105		560

[a] Reference 2. [b] Reference 5. [c] R_2NH=Bz(*i*-Pr)NH. [d] Determined in the absence of $Bu_4N^+Br^-$. [e] Solvent was MeCN.

β-carbon. All of these results provide strong evidence that elimination from **1a**−**c** promoted by $R_2NH/R_2NH_2^+$ in 70 mol % MeCN(aq) proceeds by the concurrent E2 and E1cb mechanisms.

Interestingly, the k_2^E values for **1a** and **b** show large negative deviations in Figure 4. This could be because the extents of C_α−OAr bond cleavages are smaller than those of **1c**−**e**. The transition state would then be destabilized because of the difficulty of the charge transfer from the β- to the α-carbon, to decrease the degree of double bond character and the rate. In addition, the Brönsted β values increase by 2-fold from 0.30−0.33 to 0.60−0.64 by the same variation of the reactant structure, indicating a sharp increase in the proton transfer (Table 3). Hence, an abrupt change of the E2 transition state is indicated by the change from **1c**−**e** to **1a** and **b**. A similar result was observed for **2** under the same condition.[5] At present, the origin of this abrupt change is not clear. Nevertheless, this result indicates unusual sensitivity of the E2 transition state to the reactant structure in the borderline between the E2 and E1cb.

Effect of the β-Aryl Group on the Ketene-Forming Transition State. Table 5 shows that the rates, β and $|\beta_{lg}|$ values, for the E2 reactions of **1a** and **2** are similar, indicating similar transition-state structures. The most important finding in this study is that **1a** reacts by competing E2 and E1cb mechanisms, whereas **2** reacts by the E2 mechanism. Because the negative charge density at the β-carbon can be delocalized by the thienyl group, the E1cb intermediate seems to be stabilized and the E1cb mechanism competes. This indicates the stronger anion stabilizing ability of the thienyl group in comparison to the phenyl group. However, the electron-withdrawing ability of the thienyl group is much weaker than that of the *p*-nitrophenyl group. Hence, k_1 of **1a** is smaller than that of **3** by 70-fold, indicating the weaker acidity of the C_β−H bond in the former. In addition, the k_{-1}/k_2 of **1a** is larger than that of **3** by a factor of 4. Because the deprotonation from **1a** (k_1) proceeds at a slower rate than that from **3**, the k_{-1} step should be more exothermic and faster. On the other hand, the k_2 value should be independent of the energy of the intermediate because it involves a higher energy barrier (vide supra). This would predict a larger k_{-1}/k_2 value for **1a**.

In conclusion, we have investigated the ketene-forming eliminations from **1a**−**e** promoted by $R_2NH/R_2NH_2^+$ in 70 mol % MeCN(aq). The rates and the transition-state structures for the E2 pathways are similar to those for the corresponding eliminations from **2**. However, eliminations from **1a**−**c** proceed by the competing E2 and E1cb mechanisms, which were reported for **3** having a strongly electron-withdrawing *p*-nitrophenyl group. This result underlines the carbanion stabilizing ability of the thienyl group.

Experimental Section

Materials. Aryl thienylacetates **1** were synthesized by reacting 2-thiophenacetic acid, substituted phenols, 2-chloro-1-methylpyridinium iodide, and triethylamine in CH_2Cl_2 under nitrogen.[2,12] The yield (%), IR (KBr, C=O, cm^{-1}), ^1H NMR (400 MHz, $CDCl_3$, *J* values are in Hz), ^{13}C NMR (100 MHz), and mass spectral data for the new compounds are as follows.

***p*-Nitrophenyl Thienylacetate (1a).** Yield 62%; IR 1762; ^1H NMR δ 4.13 (s, 2H), 7.02 (dd, $J = 3.50, 5.12$, 1H), 7.05 (d, $J = 3.50$, 1H), 7.29 (m, 3H), 8.27 (d, $J = 9.12$, 2H); ^{13}C NMR δ 35.5, 122.3, 125.2, 25.7, 127.1, 127.5, 133.4, 145.5, 155.3, 167.9; HRMS-(EI); *m/z* calcd for $C_{12}H_9NO_4S$ 263.0252, found 263.0255.

2-Methoxy-4-nitrophenyl thienylacetate (1b). Yield 70%; IR 1772; ^1H NMR δ 3.89 (s, 3H), 4.14 (s, 2H), 7.01 (dd, $J = 3.48, 5.12$, 1H), 7.21 (d, $J = 8.60$, 1H), 7.28 (dd, $J = 5.12, 1.34$, 1H), 7.82 (d, $J = 2.42$, 1H), 7.87 (dd, $J = 2.42, 8.60$, 1H); ^{13}C NMR δ 35.0, 56.4, 107.7, 116.4, 123.1, 125.5, 127.0, 127.4, 133.7. 144.9, 146.4, 151.6, 167.6; HRMS (EI); *m/z* calcd for $C_{13}H_{11}NO_5S$ 293.0358, found 293.0359.

2-Chloro-4-nitrophenyl thienylacetate (1c). Yield 61%; IR 1782; ^1H NMR δ 4.18 (s, 2H), 7.02 (t, $J = 3.42$, 1H), 7.08 (d, $J = 3.42$, 1H), 7.29 (dd, $J = 1.32, 5.12$, 1H), 7.34 (d, $J = 8.88$, 1H), 8.17 (dd, $J = 2.72, 8.88$, 1H), 8.35 (d, $J = 2.72$, 1H); ^{13}C NMR δ 35.0, 123.1, 124.2, 125.7, 126.0, 127.0, 127.7, 128.3, 133.0, 145.8, 151.9, 167.1; HRMS(EI); *m/z* calcd for $C_{12}H_8ClNO_4S$ 296.9863, found 296.9861.

2-Trifluoromethyl-4-nitrophenyl Thienylacetate (1d). Yield 65%; IR 1782; ^1H NMR δ 4.17 (s, 2H), 7.02 (dd, $J = 3.24, 4.84$, 1H), 7.05 (d, $J = 3.76$, 1H), 7.29 (dd, $J = 1.08, 4.84$, 1H), 7.49 (d, $J = 9.12$, 1H), 8.45 (dd, $J = 2.68, 8.60$, 1H), 8.57 (d, $J = 2.68$, 1H); ^{13}C NMR δ 35.0, 120.2, 123.0, 125.5, 125.8, 127.2, 127.8, 128.2, 132.6, 145.0, 152.7, 167.4; LRMS (EI) *m/z* 331(20)[M]$^+$, 124(4), 97(100); HRMS (EI); *m/z* calcd for $C_{13}H_8F_3NO_4S$ 331.0126, found 331.0131.

2,4-Dinitrophenyl Thienylacetate (1e). Yield 45%; IR 1788; ^1H NMR δ 4.23 (s, 2H), 7.02 (dd, $J = 3.42, 5.14$, 1H), 7.08 (d, $J = 3.42$, 1H), 7.29 (dd, $J = 1.04, 5.14$, 1H), 7.48 (d, $J = 8.88$, 1H), 8.51 (dd, $J = 2.74, 8.88$, 1H), 8.97 (d, $J = 2.74$, 1H); ^{13}C NMR δ 35.0, 120.2, 123.0, 125.5, 125.8, 127.2, 127.8, 128.2, 132.6, 145.0, 152.7, 167.4; HRMS(EI); *m/z* calcd for $C_{12}H_8N_2O_6S$ 308.0126, found 308.0123.

Acetonitrile was purified as described before. The solutions of $R_2NH/R_2NH_2^+$ in 70 mol % MeCN(aq) were prepared by dissolving equivalent amount of R_2NH and $R_2NH_2^+$ in 70 mol % MeCN(aq). In all cases, the ionic strength was maintained to 0.1 M with $Bu_4N^+Br^-$.

Kinetic Studies. Reactions of **1** with $R_2NH/R_2NH_2^+$ in 70 mol % MeCN(aq) were followed by monitoring the increase in the absorbance of the aryloxides at 400−426 nm with a UV−vis spectrophotometer as described.[2−6]

Calculation of k_2^E, k_1, and k_{-1}/k_2 Values. Utilizing the k_{obs} values and the base concentration, k_2^E, k_1, and k_{-1}/k_2 values that best fit with eq 2 have been calculated as before.[2,5]

Product Studies. The products of the reactions between **1a** and *i*-Bu_2NH/*i*-$Bu_2NH_2^+$ in 70 mol % MeCN(aq) were identified as described.[2] From this reaction, *N*,*N*-diisobutylthenamide was obtained in 86% yield. For all reactions, the yields of aryloxides as determined by comparing the absorbance of the infinity absorbance of the samples from the kinetic studies with those of the authentic aryloxides were in the range of 96−99%.

H−D Exchange Experiment. To determine whether **1a**−**c** may undergo H−D exchange during the reaction, the reaction was performed in an NMR tube. The reactants (0.04 mmol) were added to a solution containing i-Bu_2NH/i-$Bu_2NH_2^+$ (0.05 M, 0.6 mL) in 70 mol % MeCN−30% D_2O at 25.0 °C. The NMR spectrum taken immediately after mixing indicated complete H−D exchange at the β-carbon.

Control Experiments. The stabilities of **1a**−**e** were determined as reported.[2−4] Solutions of aryl thienylacetates **1a**−**d** were stable for at least 1 week in 70 mol % MeCN(aq) solution at room temperature. However, the solution of **1e** was stable for only 3 days.

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Supporting Information Available: Synthesis, rate constants for eliminations from **1a**−**e** promoted by $R_2NH/R_2NH_2^+$ in 70 mol % MeCN(aq), and plots of k_{obs} versus base concentration. This information is available free of charge via the Internet at http://pubs.acs.org.

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