

Kinetic Analysis of Elementary Steps in Nucleophilic Vinylic Substitution Reactions of α -Nitro- β -X-stilbenes (X = OCH₂CF₃, OCH₃, NO₂) with Various Nucleophiles. Detection of the Intermediate in the Reaction of α -Nitro- β -(2,2,2-trifluoroethoxy)stilbene with HOCH₂CH₂S⁻ and of β -Methoxy- α -nitrostilbene with CF₃CH₂O⁻

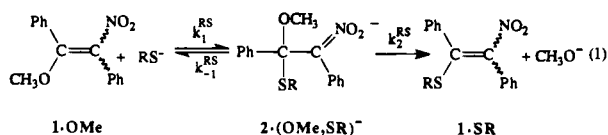
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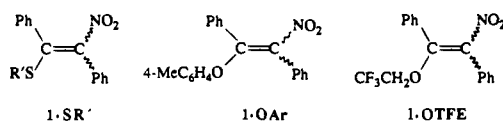
Abstract: Rate constants of elementary steps in the addition–elimination mechanism of nucleophilic vinylic substitutions (S_NV) were determined by studying the following reactions in 50% Me₂SO–50% water at 20 °C: (1) α -nitro- β -(2,2,2-trifluoroethoxy)stilbene (Ph(OCH₂CF₃)C=C(NO₂)Ph, 1-OTFE) and α,β -dinitrostilbene (Ph(NO₂)C=C(NO₂)Ph, 1-NO₂) with OH⁻, piperidine, and HOCH₂CH₂S⁻, which led to the expected substitution products 1-OH, 1-Pip, and 1-SCH₂CH₂OH, respectively, although 1-OH is rapidly converted into PhC(O)C(Ph)=NO₂⁻ (3⁻); (2) 1-OTFE with CF₃CH₂O⁻, which leads to the adduct Ph(OCH₂CF₃)₂CC(Ph)=NO₂⁻, (2-(OTFE)₂⁻); (3) 1-NO₂ with CF₃CH₂O⁻, which leads to 3⁻ by rapid hydrolysis of 1-OTFE formed as the immediate product of the reaction; (4) β -methoxy- α -nitrostilbene (1-OMe) with CF₃CH₂O⁻ which leads to the intermediate Ph(OCH₃)(OCH₂CF₃)CC(Ph)=NO₂⁻ (2-(OMe,OTFE)⁻); and (5) 1,2-diphenyl-2-nitroethanone 2,2,2-trifluoroethyl acetal (Ph(OCH₂CF₃)₂CCH(Ph)(NO₂)) with OH⁻, which leads to 3⁻ by rapid hydrolysis of 1-OTFE, formed as the immediate product by CF₃CH₂O⁻ loss from the deprotonated acetal. In the reactions of 1-OTFE with OH⁻ and piperidine, as well as the reactions of 1-NO₂ with OH⁻, CF₃CH₂O⁻, piperidine, and HOCH₂CH₂S⁻, the S_NV intermediate, whose formation is the rate-limiting step, does not accumulate to detectable levels. However, in the reaction of 1-OTFE with HOCH₂CH₂S⁻, the intermediate Ph(OCH₂CF₃)(SCH₂CH₂OH)CC(Ph)=NO₂⁻, (2-(OTFE,SR)⁻) is directly observable, which allows a kinetic determination of all steps in the reaction. The dependence of the various rate constants on structure can be understood as arising from an interplay of electronic, steric, resonance, and anomeric effects. An important result is that rates of alkoxide ion departure (CH₃O⁻ vs CF₃CH₂O⁻) from intermediates such as Ph(OR',SR)CC(Ph)=NO₂⁻ and Ph(OR',OR)CC(Ph)=NO₂⁻ show a strong dependence on the pK_a of the respective alkoxide ion (β_{1g} close to -1), suggesting a large amount of C–O bond cleavage in the transition state.

We recently initiated a research program aimed at finding systems that would allow the detection and kinetic characterization of the intermediate in nucleophilic vinylic substitution (S_NV) reactions that proceed by the addition–elimination mechanism.¹ The reaction of β -methoxy- α -nitrostilbene (1-OMe) with alkanethiolate ions provided the first example (eq 1) where



the intermediate could be observed spectrophotometrically and all three rate constants be determined directly.² For RS⁻ =

HOCH₂CH₂S⁻ in 50% Me₂SO–50% water (v/v) at 20 °C, $k_1^{\text{RS}} = 3.90 \times 10^2 \text{ M}^{-1} \text{ s}^{-1}$, $k_{-1}^{\text{RS}} = 5.10 \times 10^{-2} \text{ s}^{-1}$, $K_1^{\text{RS}} = k_1^{\text{RS}}/k_{-1}^{\text{RS}} = 7.65 \times 10^3 \text{ M}^{-1}$, and $k_2^{\text{RS}} = 9.6 \times 10^{-6} \text{ s}^{-1}$. These parameters show that for eq 1 the conditions necessary to detect the intermediate (high K_1^{RS} and high $k_1^{\text{RS}}/k_2^{\text{RS}}$ ratio) are so amply met that one would expect to observe the intermediate even if the methoxy group in 1-OMe were replaced by a better leaving group. This is indeed the case with 1-SR' (R' = HOCH₂CH₂, CH₃CH₂CH₂, and CH₃O₂CCH₂CH₂), while 1-OAr represents a borderline situation for which the evidence is inconclusive.^{2b} The difficulty in observing the intermediate in



the reaction of thiolate ions with 1-OAr arises from a combination of steric effects and the lower basicity of ArO⁻ (pK_a =

(2) (a) Bernasconi, C. F.; Killion, R. B., Jr.; Fassberg, J.; Rappoport, Z. *J. Am. Chem. Soc.* **1989**, *111*, 6862. (b) Bernasconi, C. F.; Fassberg, J.; Killion, R. B.; Rappoport, Z. *J. Am. Chem. Soc.* **1990**, *112*, 3169.

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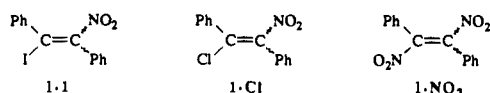
Ⓢ Abstract published in *Advance ACS Abstracts*, November 15, 1994.

(1) For reviews, see: (a) Rappoport, *Z. Adv. Phys. Org. Chem.* **1969**, *7*, 1. (b) Modena, G. *Acc. Chem. Res.* **1971**, *4*, 73. (c) Miller, S. I. *Tetrahedron* **1977**, *33*, 1211. (d) Rappoport, *Z. Acc. Chem. Res.* **1981**, *14*, 7. (e) Rappoport, *Z. Recl. Trav. Chim. Pays-Bas* **1985**, *104*, 309. (f) Shainyan, B. A. *Usp. Khim.* **1986**, *55*, 942. (g) Rappoport, *Z. Acc. Chem. Res.* **1992**, *25*, 474.

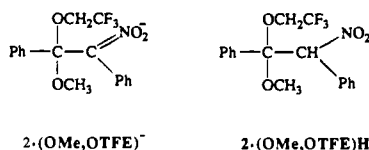
11.6)³ compared to that of MeO^- ($\text{p}K_a \approx 17.2$).³ Both the lower basicity and the increased crowding in the intermediate enhance β while the steric effect also lowers k_1 and K_1 .

A leaving group that falls between MeO^- and ArO^- in terms of basicity is $\text{CF}_3\text{CH}_2\text{O}^-$ ($\text{p}K_a 14.0$)³, and hence one would expect to be able to detect and kinetically characterize the intermediate in the reaction of 1-OTFE with thiolate ions and possibly with other nucleophiles.⁴ Such a study would provide important information about the sensitivity of nucleofugality to the leaving group basicity.

To our surprise we have not been able to synthesize 1-OTFE by nucleophilic substitution of 1-I, 1-Cl, or 1- NO_2 , despite investment of considerable effort.⁵ However, small quantities

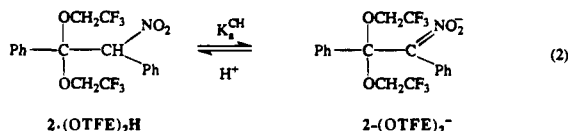


of 1-OTFE could be isolated after acidification of a solution of 2-(OMe,OTFE)⁻, which leads mainly to 1-OMe and 2-(OMe,OTFE)H, with 1-OTFE being a minor byproduct. Enough of



this material could be prepared to allow a limited number of kinetic experiments of the reaction of 1-OTFE with OH^- , $\text{CF}_3\text{CH}_2\text{O}^-$, $\text{HOCH}_2\text{CH}_2\text{S}^-$, and piperidine.

1-OTFE was also generated *in situ* as a steady state intermediate by the reactions of α,β -dinitrostilbene (1- NO_2) and β -methoxy- α -nitrostilbene (1-OMe) with $\text{CF}_3\text{CH}_2\text{O}^-$ and by deprotonation of the easily accessible acetal 2-(OTFE)₂H (eq 2) and subsequent loss of $\text{CF}_3\text{CH}_2\text{O}^-$ from 2-(OTFE)₂⁻. By



generating 1-OTFE in this fashion, rate constants for $\text{CF}_3\text{CH}_2\text{O}^-$ loss from 2-(OTFE)₂⁻ and 2-(OMe,OTFE)⁻ and relative rate constants for OH^- and $\text{CF}_3\text{CH}_2\text{O}^-$ addition to 1-OTFE could be determined. Finally, we also report rate constants for the reactions of α,β -dinitrostilbene with OH^- , $\text{CF}_3\text{CH}_2\text{O}^-$, $\text{HOCH}_2\text{CH}_2\text{S}^-$, and piperidine.

Results

General Conditions for the Kinetic and Spectroscopic Determinations. All reactions were run in 50% Me_2SO –50% water (v/v) at 20 °C. Pseudo-first-order conditions, with the nucleophile in excess, were used throughout, and the ionic strength was maintained at 0.5 M with KCl.

Isolation of 1-OTFE. About 5 mg of 1-OTFE was isolated by means of preparative HPLC from mixtures consisting of 1-OMe, 2-(OMe,OTFE)H, and small quantities of 1-OTFE. These mixtures were generated by the reaction of dilute HCl with solutions of 2-(OMe,OTFE)⁻, the latter being formed from reaction of 1-OMe with $\text{CF}_3\text{CH}_2\text{O}^-$. The identification of

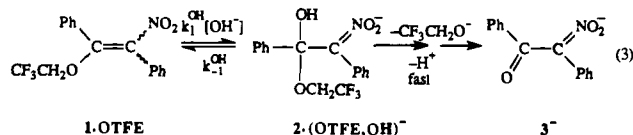
(3) In 50% Me_2SO –50% water at 20 °C.

(4) A further possible advantage of the $\text{CF}_3\text{CH}_2\text{O}$ group relative to the ArO group is that it may lead to less crowding in the intermediate, although that may depend on the conformation of nucleophile and leaving group.

(5) Weiss, M.; Rappoport, Z. Unpublished results.

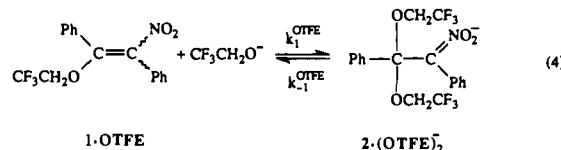
1-OTFE was based on its UV spectrum, which is virtually identical with that of 1-OMe, and its mass spectrum⁶ (for more details see the Experimental Section). On an analytical column, the 1-OTFE fraction could actually be resolved into two approximately equal components, presumably the *Z*- and *E*-isomer, but on the preparative column the two isomers could not be separated. It is noteworthy that our attempts at generating 1-OTFE by acidifying a solution of 2-(OTFE)₂⁻ yielded only traces of 1-OTFE, the main product being 2-(OTFE)₂H.

Reaction of 1-OTFE with OH^- , $\text{CF}_3\text{CH}_2\text{O}^-$, and Piperidine. 1-OTFE reacts with OH^- to form 3⁻ according to eq 3, in which 2-(OTFE,OH)⁻ is a steady state intermediate. k_{obsd} , the pseudo-first-order rate constant, is proportional to $[\text{KOH}]$ over a range of $[\text{KOH}]$ from 0.004 to 0.2 M (Table S1 of supplementary material).⁷ The rate data yield $k_1^{\text{OH}} = 0.41 \pm$



0.01 $\text{M}^{-1} \text{s}^{-1}$; note that all error limits given in this paper are standard deviations. The assumption that the loss of $\text{CF}_3\text{CH}_2\text{O}^-$ from the intermediate is fast and k_1^{OH} is rate limiting will be justified in the Discussion.

The reaction of 1-OTFE with $\text{CF}_3\text{CH}_2\text{O}^-$, eq 4, was studied in $\text{CF}_3\text{CH}_2\text{O}^-/\text{CF}_3\text{CH}_2\text{OH}$ buffers between pH 13.40 and 14.38; the $\text{CF}_3\text{CH}_2\text{O}^-$ concentration was varied from 0.014 to 0.187 M (Table S2).⁷ Under these conditions, the equilibrium strongly



favors the adduct side, i.e., $k_1^{\text{OTFE}}[\text{CF}_3\text{CH}_2\text{O}^-] \gg k_{-1}^{\text{OTFE}}$, as will be demonstrated below, and hence k_{obsd} should be given by $k_1^{\text{OTFE}}[\text{CF}_3\text{CH}_2\text{O}^-]$. However, the hydrolysis reaction, eq 3, competes with eq 4 so that k_{obsd} obeys eq 5, and $k_1^{\text{OTFE}} = 0.20$

$$k_{\text{obsd}} = k_1^{\text{OTFE}}[\text{CF}_3\text{CH}_2\text{O}^-] + k_1^{\text{OH}}a_{\text{OH}^-} \quad (5)$$

$\pm 0.01 \text{ M}^{-1} \text{ s}^{-1}$ was obtained as the slope of a plot of $(k_{\text{obsd}} - k_1^{\text{OH}}a_{\text{OH}^-})$ vs $[\text{CF}_3\text{CH}_2\text{O}^-]$ (Figure 1). It should be noted that the concentrations of $\text{CF}_3\text{CH}_2\text{O}^-$ were subject to a small correction because of association between $\text{CF}_3\text{CH}_2\text{O}^-$ and $\text{CF}_3\text{CH}_2\text{OH}$, as described in more detail below.

We also should point out that in eq 5 hydroxide ion activity rather than $[\text{OH}^-]$ is used because this is the quantity determined from pH measurements or calculated from the $\text{p}K_a$ of $\text{CF}_3\text{CH}_2\text{OH}$ (see Table S1).⁷ Inasmuch as $[\text{OH}^-]$ and a_{OH^-} may not be exactly equal and k_1^{OH} was determined from the slope of k_{obsd} vs $[\text{OH}^-]$, this may lead to minor inaccuracies in the $k_1^{\text{OH}}a_{\text{OH}^-}$ term of eq 5. However, the fact that the points in Figure 1 for which the $k_1^{\text{OH}}a_{\text{OH}^-}$ term is substantial lie on the same line as the points where the $k_1^{\text{OH}}a_{\text{OH}^-}$ term is quite small shows that this is not a serious problem.

The reaction of 1-OTFE with piperidine leads to the corresponding substitution product 1-Pip (eq 6) which was prepared and fully characterized previously.^{8,9} Rates were measured as

(6) Not enough material was available for NMR spectra.

(7) See paragraph concerning supplementary material at the end of this paper.

(8) Rappoport, Z.; Topol, A. *J. Org. Chem.* **1989**, *54*, 5967.

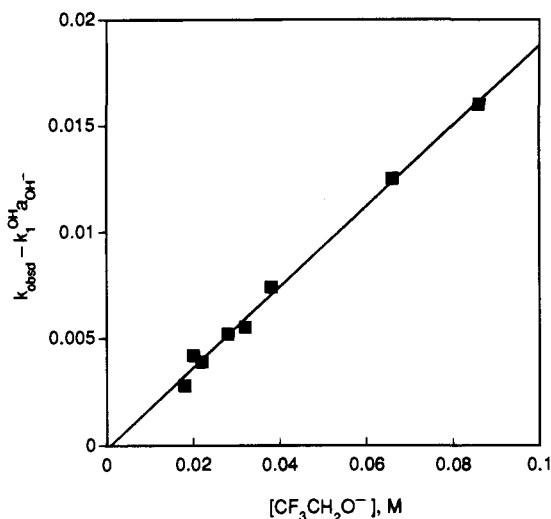
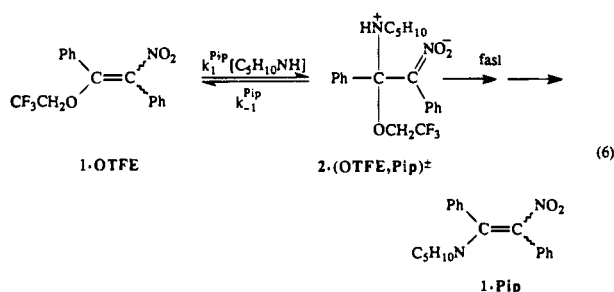


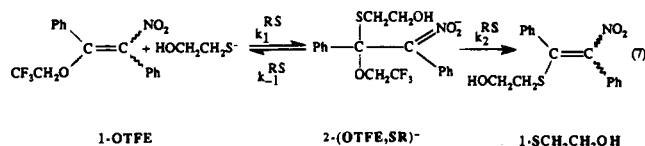
Figure 1. Reaction of 1-OTFE with $\text{CF}_3\text{CH}_2\text{O}^-$. Plot of $k_{\text{obsd}} - k_1^{\text{OH}} a_{\text{OH}^-}$ vs $[\text{CF}_3\text{CH}_2\text{O}^-]$ according to eq 5.



function of piperidine concentration at pH 12.13 (Table S3).⁷ A plot of k_{obsd} vs piperidine concentration (not shown) is linear; since at this pH the k_1^{Pip} step is undoubtedly rate limiting (see Discussion), the slope of the plot, $0.529 \pm 0.014 \text{ M}^{-1} \text{ s}^{-1}$, corresponds to k_1^{Pip} .

Reaction of 1-OTFE with $\text{HOCH}_2\text{CH}_2\text{S}^-$. This reaction is characterized by two kinetic processes. The faster one shows a strong dependence on nucleophile concentration and a decrease in absorbance above 330 nm, leading to spectrum II in Figure 2. The second process is relatively slow, independent of $[\text{HOCH}_2\text{CH}_2\text{S}^-]$, and shows the formation of a species which has a λ_{max} at 365 nm (spectrum III in Figure 2).

We attribute the first process to reversible formation of the intermediate $2-(\text{OTFE}, \text{SR})^-$, eq 7, by reaction of 1-OTFE with $\text{HOCH}_2\text{CH}_2\text{S}^-$. A plot of k_{obsd} vs $[\text{HOCH}_2\text{CH}_2\text{S}^-]$ is shown



in Figure 3 while the raw data are summarized in Table S4.⁷ From slope and intercept, according to eq 8, one obtains $k_1^{\text{RS}} = 176 \pm 4 \text{ M}^{-1} \text{ s}^{-1}$ and $k_{-1}^{\text{RS}} = 0.10 \pm 0.03 \text{ s}^{-1}$. The second

$$k_{\text{obsd}} = k_1^{\text{RS}} [\text{HOCH}_2\text{CH}_2\text{S}^-] + k_{-1}^{\text{RS}} \quad (8)$$

process corresponds to the conversion of the intermediate to 1-SCH₂CH₂OH, identified by comparison of its absorption

(9) Bernasconi, C. F.; Fassberg, J.; Killion, R. B.; Rappoport, Z. *J. Org. Chem.* **1990**, *55*, 4568.

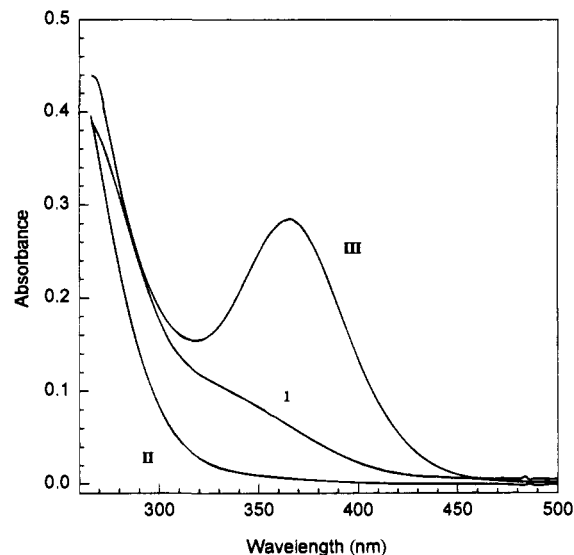


Figure 2. Absorption of 1-OTFE (I), $2-(\text{OTFE}, \text{SR})^-$ (II), and 1-SCH₂CH₂OH (III) in 50% Me₂SO–50% water at 20 °C. The spectra were generated from a $3.0 \times 10^{-5} \text{ M}$ solution of 1-OTFE in the presence of $5 \times 10^{-3} \text{ M}$ $\text{HOCH}_2\text{CH}_2\text{S}^-$, pH 9.56. Spectrum II was taken 4 s after mixing and spectrum III 400 s after mixing.

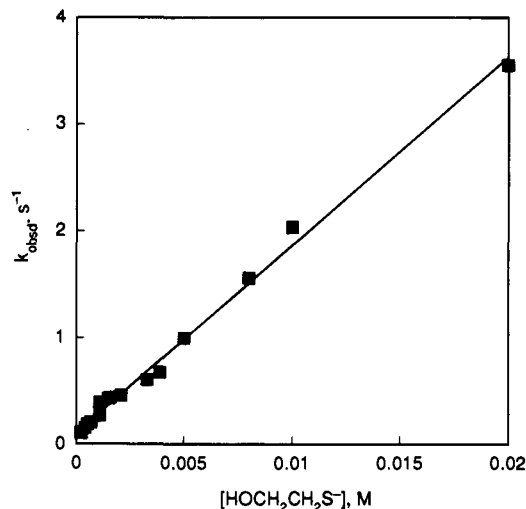


Figure 3. Reaction of 1-OTFE with $\text{HOCH}_2\text{CH}_2\text{S}^-$. Plot of k_{obsd} vs $[\text{HOCH}_2\text{CH}_2\text{S}^-]$ according to eq 8.

spectrum with an authentic sample of 1-SCH₂CH₂OH.^{2b} The average value of k_2^{RS} from five determinations at $[\text{HOCH}_2\text{CH}_2\text{S}^-]$ between 0.001 and 0.02 M (Table S4)⁷ is $0.0140 \pm 0.003 \text{ s}^{-1}$.

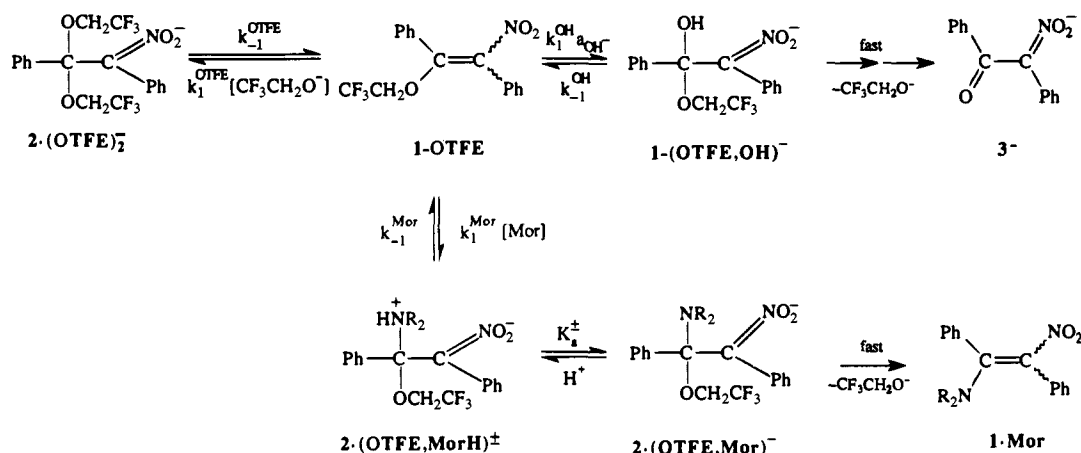
Hydrolysis of 1,2-Diphenyl-2-nitroethane 2,2,2-Trifluoroethyl Acetal, $2-(\text{OTFE})_2\text{H}$. $2-(\text{OTFE})_2\text{H}$ has a pK_a^{CH} of 7.79¹⁰ and hence is present as the anion $2-(\text{OTFE})_2^-$ in moderately basic solution. Such a solution slowly decomposes to form the 1,2-diphenyl-2-nitroethane anion, 3^- , as indicated by a close match between the UV/vis spectrum of an authentic sample of 3^- ¹¹ and that of the infinity spectrum of the reaction.¹² The rate of decomposition of $2-(\text{OTFE})_2^-$, which was measured at KOH concentrations between 0.001 and 0.1 M (Table 1), is independent of base concentration and yields an average $k_{\text{obsd}} = (1.65 \pm 0.15) \times 10^{-5} \text{ s}^{-1}$. A marginally higher k_{obsd} ($2.0-$

(10) Bernasconi, C. F.; Schuck, D. F.; Ketner, R.; Rappoport, Z. To be published.

(11) Bernasconi, C. F.; Fassberg, J.; Killion, R. B.; Schuck, D. F.; Rappoport, Z. *J. Am. Chem. Soc.* **1991**, *113*, 4937.

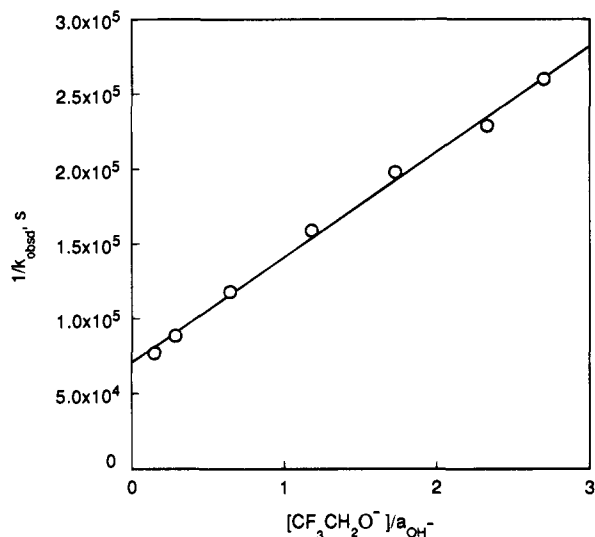
(12) The infinity spectrum was not stable, though, due to slow decomposition of 3^- .

Scheme 1

Table 1. Reaction of 2-(OTFE)_2^- in the Presence of KOH and Morpholine^a

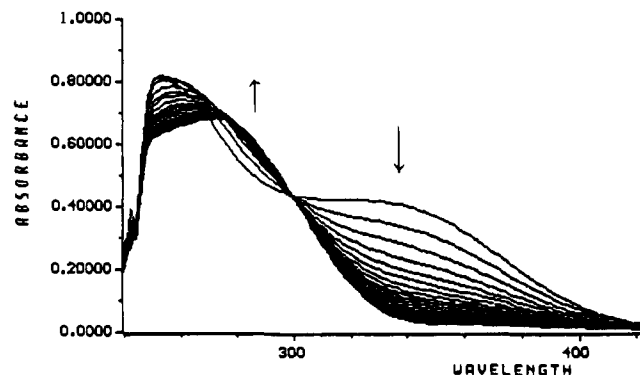
pH	[KOH] ^b (M)	[Mor] ^c (M)	k_{obsd} (s ⁻¹)
12.90	0.001		1.48×10^{-5}
13.44	0.005		1.77×10^{-5}
13.90	0.010		1.65×10^{-5}
14.90	0.10		1.69×10^{-5}
8.72		0.24	2.00×10^{-5} ^d
8.72		0.40	2.19×10^{-5} ^d

^a In 50% Me₂SO–50% water (v/v) at 20 °C, $\mu = 0.5$ M (KCl); [substrate]₀ = 8.33×10^{-5} M. ^b Kinetics monitored at 340 nm, corresponding to maximum absorbance difference between 2-(OTFE)_2^- and 3^- . ^c Free base. ^d Kinetics monitored at 422 nm (λ_{max} of 1-Mor).

Figure 4. Reaction of $2\text{-(OTFE)}_2\text{H}$ with $\text{CF}_3\text{CH}_2\text{O}^-/\text{CF}_3\text{CH}_2\text{OH}$ buffers. Plot according to eq 10.

$2.2) \times 10^{-5} \text{ s}^{-1}$) is obtained when 2-(OTFE)_2^- is placed into a morpholine buffer (Table 1). However, in this case the product is 1-Mor (Scheme 1) instead of 3^- , as shown by comparison with the UV/vis spectra of an authentic sample of 1-Mor ($\lambda_{\text{max}} = 422 \text{ nm}$).

These results are consistent with the mechanism of Scheme 1 in which 1-OTFE is a steady state intermediate. The fact that k_{obsd} is independent of [KOH] indicates k_{-1}^{OTFE} is rate limiting, i.e., $k_1^{\text{OH}} a_{\text{OH}^-} \gg k_1^{\text{OTFE}} [\text{CF}_3\text{CH}_2\text{O}^-]$ and $k_{\text{obsd}} = k_{-1}^{\text{OTFE}}$ in the KOH experiments. The same is true for the morpholine runs, i.e., $k_{\text{Mor}} [\text{Mor}] \gg k_1^{\text{OTFE}} [\text{CF}_3\text{CH}_2\text{O}^-]$; the slightly higher k_{obsd} in the morpholine experiments and the roughly linear dependence of k_{obsd} on the morpholine buffer concentration

Figure 5. Reaction of 1-NO₂ with a 0.08 M $\text{CF}_3\text{CH}_2\text{O}^-/0.8$ M $\text{CF}_3\text{CH}_2\text{OH}$ buffer, $[1\text{-NO}_2]_0 = 8.33 \times 10^{-5}$ M. Repetitive UV scans at 10 s intervals.

(Table 1) are most likely due to general acid catalysis of $\text{CF}_3\text{CH}_2\text{O}^-$ departure from 2-(OTFE)_2^- by the morpholinium ion.

A change in the rate-limiting step can be induced by running the reaction in trifluoroethanol buffers which enhance $k_1^{\text{OTFE}} [\text{CF}_3\text{CH}_2\text{O}^-]$. The results of such runs are summarized in Table 2.

They are consistent with eq 9 which, after inversion, leads to eq 10. Figure 4 shows an inversion plot according to eq 10

$$k_{\text{obsd}} = \frac{k_{-1}^{\text{OTFE}} k_1^{\text{OH}} a_{\text{OH}^-}}{k_1^{\text{OTFE}} [\text{CF}_3\text{CH}_2\text{O}^-] + k_1^{\text{OH}} a_{\text{OH}^-}} \quad (9)$$

$$\frac{1}{k_{\text{obsd}}} = \frac{1}{k_{-1}^{\text{OTFE}}} + \frac{k_1^{\text{OTFE}} [\text{CF}_3\text{CH}_2\text{O}^-]}{k_{-1}^{\text{OTFE}} k_1^{\text{OH}} a_{\text{OH}^-}} \quad (10)$$

from which $k_{-1}^{\text{OTFE}} = (1.42 \pm 0.07) \times 10^{-5} \text{ s}^{-1}$ and $k_1^{\text{OTFE}}/k_1^{\text{OH}} = 0.99 \pm 0.09$ is obtained. The agreement between k_{-1}^{OTFE} calculated from Figure 1 and that observed in the absence of $\text{CF}_3\text{CH}_2\text{O}^-$ ($1.65 \times 10^{-5} \text{ s}^{-1}$) is seen to be excellent. From $k_1^{\text{OH}} = 0.41 \pm 0.01 \text{ M}^{-1} \text{ s}^{-1}$ (see above) and $k_1^{\text{OTFE}}/k_1^{\text{OH}} = 0.99 \pm 0.09$, one obtains $k_1^{\text{OTFE}} = 0.41 \pm 0.05 \text{ M}^{-1} \text{ s}^{-1}$, which compares with $k_1^{\text{OTFE}} = 0.20 \pm 0.01 \text{ M}^{-1} \text{ s}^{-1}$ determined directly from Figure 1. Possible reasons for the discrepancy will be addressed in the Discussion.

Reaction of α,β -Dinitrostilbene with $\text{CF}_3\text{CH}_2\text{O}^-$. When (Z)- α,β -dinitrostilbene, 1-NO₂, is reacted with a $\text{CF}_3\text{CH}_2\text{O}^-/\text{CF}_3\text{CH}_2\text{OH}$ buffer, rapid conversion into 2-(OTFE)_2^- is observed. Figure 5 shows repetitive scans at 10 s intervals taken

Scheme 2

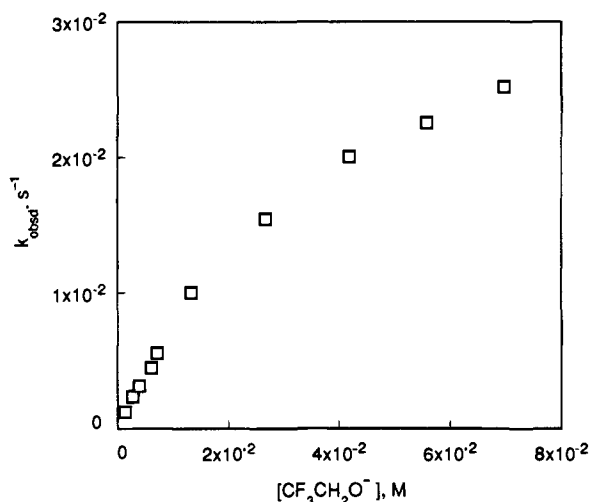
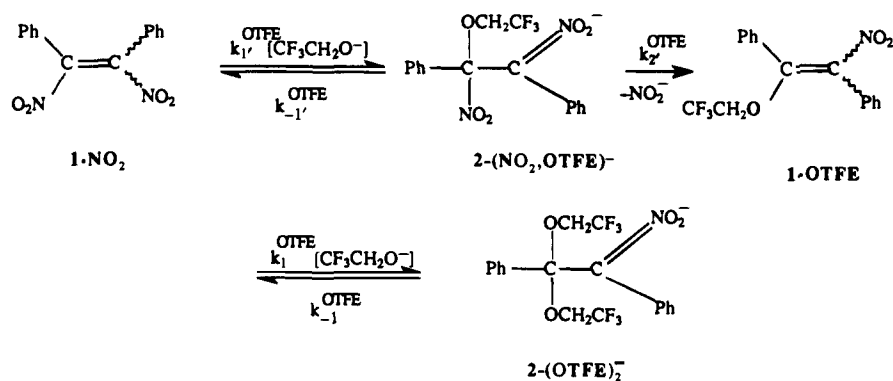


Figure 7. Reaction of 1-OMe with $\text{CF}_3\text{CH}_2\text{O}^-$. $[\text{CF}_3\text{CH}_2\text{O}^-/\text{CF}_3\text{CH}_2\text{OH}] = 0.067$, pH 12.83.

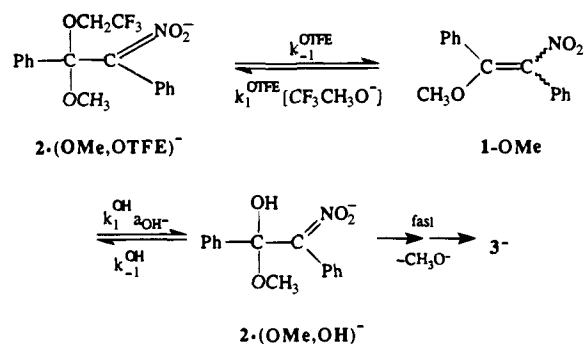
affords $k_1^{\text{OTFE}} = 0.73 \pm 0.05 \text{ M}^{-1} \text{ s}^{-1}$. The leveling off at high concentrations can again be attributed to the association equilibrium of eq 11; the best fit of the data with eq 12 (k_1^{OTFE} replaced by k_1^{OTFE}) affords $K_{\text{assoc}} = 2.0 \pm 0.7 \text{ M}^{-1}$, in excellent agreement with the value of $1.8 \pm 0.7 \text{ M}^{-1}$ obtained from the 1- NO_2 data.

Our interpretation of the reaction in terms of eq 13 is consistent with the spectral observations since 2-(OMe,OTFE)^- should have a spectrum that is very similar to that of 2-(OTFE)_2^- .¹³ An alternative explanation of our results, according to which the observed product is 2-(OTFE)_2^- , is unsatisfactory because it would require fast conversion of 2-(OMe,OTFE)^- to 2-(OTFE)_2^- through rapid loss of MeO^- from 2-(OMe,OTFE)^- to form 1-OTFE, followed by addition of $\text{CF}_3\text{CH}_2\text{O}^-$ to 1-OTFE. That MeO^- loss from 2-(OMe,OTFE)^- cannot be fast is seen from $k_{-1}^{\text{OTFE}} = 1.65 \times 10^{-5} \text{ s}^{-1}$ (Scheme 1) for $\text{CF}_3\text{CH}_2\text{O}^-$ loss from 2-(OTFE)_2^- : since MeO^- is a poorer leaving group than $\text{CF}_3\text{CH}_2\text{O}^-$, MeO^- loss from 2-(OMe,OTFE)^- should have a rate constant $< 1.65 \times 10^{-5} \text{ s}^{-1}$, which is much smaller than the k_{obsd} values (Table S6).⁷

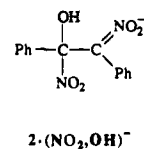
Just as is the case for 2-(OTFE)_2^- , 2-(OMe,OTFE)^- is slowly converted to 3^- as shown in Scheme 3, which is analogous to the upper part of Scheme 1. Rates of this process were determined as a function of the $[\text{CF}_3\text{CH}_2\text{O}^-]/a_{\text{OH}^-}$ ratio (Table 3). An inversion plot according to eq 10 is shown in Figure 8. It yields $k_{-1}^{\text{OTFE}} = (5.0 \pm 0.5) \times 10^{-5} \text{ s}^{-1}$ and $k_1^{\text{OTFE}}/k_1^{\text{OH}} = 0.8 \pm 0.1$. This ratio is in good agreement with $k_1^{\text{OTFE}}/k_1^{\text{OH}} = 1.06$ obtained from $k_1^{\text{OTFE}} = 0.73 \text{ M}^{-1} \text{ s}^{-1}$ determined above and $k_1^{\text{OH}} = 0.69 \text{ M}^{-1} \text{ s}^{-1}$ determined previously.¹¹

(13) The spectrum of 2-(OMe,OTFE)^- is also very similar to that of 2-(OMe)_2^- ; Bernasconi, C. F.; Fassberg, J. Unpublished results.

Scheme 3



Reaction of α,β -Dinitrostilbene with OH^- , Piperidine, and $\text{HOCH}_2\text{CH}_2\text{S}^-$. The reaction of α,β -dinitrostilbene (1- NO_2) with OH^- is analogous to the reaction of 1-OTFE with the same nucleophile (eq 3), i.e., it leads to 3^- via steady state intermediate $2\text{-(NO}_2,\text{OH})^-$. Both the *Z*- and *E*-isomer were studied.



Nucleophilic attack on the substrate is again assumed to be rate limiting. The rate data summarized in Table S7⁷ yield $k_1^{\text{OH}} = 0.229 \pm 0.003 \text{ M}^{-1} \text{ s}^{-1}$ for the *Z*-isomer and $k_1^{\text{OH}} = 0.332 \pm 0.006 \text{ M}^{-1} \text{ s}^{-1}$ for the *E*-isomer.

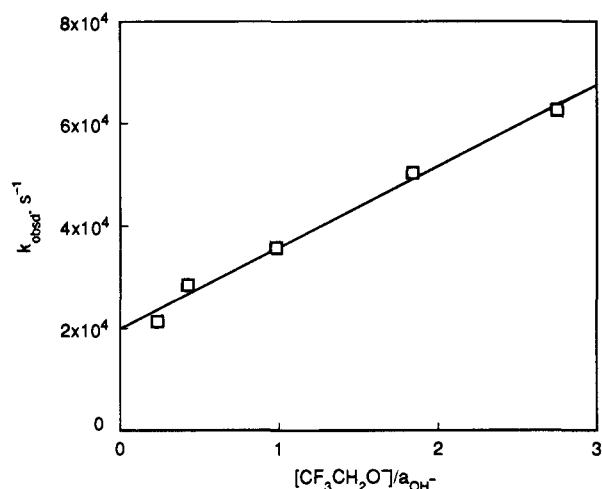
The reaction of 1- NO_2 (*Z*-isomer) with piperidine leads to 1-Pip and can be described in a similar way as the reaction of piperidine with 1-OTFE (eq 6). Plots (not shown) of k_{obsd} vs piperidine concentration over a range of $[\text{Pip}]$ from 5×10^{-3} to $2.5 \times 10^{-1} \text{ M}$ (Table S8)⁷ were linear with negligible intercepts and slopes of 42.9 ± 0.3 , 45.5 ± 0.6 , 46.7 ± 2.0 , and $43.5 \pm 0.9 \text{ M}^{-1} \text{ s}^{-1}$ at pH 11.02, 11.39, 12.0, and 13.9, respectively. The pH independence of the slopes indicates that nucleophilic attack is rate limiting; from the average of the slopes we obtain $k_1^{\text{Pip}} = 44.6 \text{ M}^{-1} \text{ s}^{-1}$.

The reaction of $\text{HOCH}_2\text{CH}_2\text{S}^-$ with 1- NO_2 yields 1- $\text{SCH}_2\text{CH}_2\text{OH}$ just as with 1-OTFE, but in contrast with this latter substrate, the corresponding intermediate, $2\text{-(NO}_2,\text{SCH}_2\text{CH}_2\text{OH})^-$, does not accumulate to detectable levels. This can be seen from the fact that k_{obsd} obtained at 300 nm (disappearance of 1- NO_2) and 366 nm (appearance of 1- $\text{SCH}_2\text{CH}_2\text{OH}$) are indistinguishable (Table S9).⁷ The rates were determined in Et_3N buffers at pH 10.53 and in DABCO buffers at pH 8.61 (Table S9).⁷ At pH 10.46–10.59 a $k_1^{\text{RS}} = (4.12 \pm 0.12) \times 10^3 \text{ M}^{-1} \text{ s}^{-1}$ and at pH 8.61 a $k_1^{\text{RS}} = (3.86 \pm 0.15) \times 10^3 \text{ M}^{-1} \text{ s}^{-1}$ were obtained;

Table 3. Reaction of 2-(OMe, OTFE)⁻ in CF₃CH₂OH/CF₃CH₂O⁻ Buffers^a

pH	[CF ₃ CH ₂ OH] (M)	[CF ₃ CH ₂ O ⁻] (M)	<i>a</i> _{OH⁻} ^b (M)	[CF ₃ CH ₂ O ⁻]	
				<i>a</i> _{OH⁻}	<i>k</i> _{obsd} (s ⁻¹)
13.48	3.46 × 10 ⁻²	1.04 × 10 ⁻²	3.80 × 10 ⁻³	2.75	1.60 × 10 ⁻⁵
13.47	2.32 × 10 ⁻²	6.84 × 10 ⁻³	3.72 × 10 ⁻³	1.84	1.99 × 10 ⁻⁵
13.33	1.24 × 10 ⁻²	2.64 × 10 ⁻³	2.69 × 10 ⁻³	0.982	2.80 × 10 ⁻⁵
13.09	5.34 × 10 ⁻³	6.57 × 10 ⁻⁴	1.55 × 10 ⁻³	0.424	3.52 × 10 ⁻⁵
12.19	2.95 × 10 ⁻³	4.58 × 10 ⁻⁵	1.95 × 10 ⁻⁴	0.235	4.70 × 10 ⁻⁵

^a In 50% Me₂SO–50% water (v/v) at 20 °C, μ = 0.5 M (KCl); [substrate]₀ = 8.33 × 10⁻⁵ M, monitored at 340 nm, corresponding to maximum absorbance difference between 2-(OTFE)₂⁻ and 3⁻. ^b Calculated on the basis of p*K*_w = 15.9.

**Figure 8.** Reaction of 2-(OMe,OTFE)⁻ with CF₃CH₂O⁻/CF₃CH₂OH buffers. Plot according to eq 10.

an average value of $(4.00 \pm 0.15) \times 10^3 \text{ M}^{-1} \text{ s}^{-1}$ will be adopted.

Decomposition of 2-(OMe)₂⁻. An approximate *k*₋₁ of $1.8 \times 10^{-8} \text{ s}^{-1}$ for the loss of CH₃O⁻ from 2-(OMe)₂ was reported previously based on an HPLC study.¹¹ We have reinvestigated this process in a 0.2 M KOH solution in 50% Me₂SO–50% water after generating 2-(OMe)₂ from 1-OMe and NaOMe in Me₂SO. A *k*₋₁ = $(4.0 \pm 0.4) \times 10^{-3} \text{ s}^{-1}$ was obtained by the method of initial rates as described in the Experimental Section.

Discussion

1-OTFE, the Elusive Substrate. The reason why 1-OTFE cannot be generated by reaction of any 1-X with CF₃CH₂O⁻ is that 1-OTFE is rapidly converted to 2-(OTFE)₂⁻ in the presence of a large enough concentration of CF₃CH₂O⁻ to avoid other competing reactions, e.g., hydrolysis. Our attempt at generating 1-OTFE in any meaningful quantities by acidification of 2-(OTFE)₂⁻ was also unsuccessful; apparently acid-catalyzed CF₃CH₂O⁻ departure from 2-(OTFE)₂⁻ is much slower than protonation to form 2-(OTFE)₂⁻. This contrasts with the behavior of 2-(OMe)₂⁻ which, in the presence of strong acid, leads exclusively to 1-OMe.¹¹

Observation of S_NV Intermediates. One of the major objectives of this work was to examine the possibility of directly observing the intermediate in the S_NV reaction of 1-OTFE with nucleophiles and determining the rate constants of the individual steps. In the reaction of 1-OTFE with HOCH₂CH₂S⁻ (eq 7), the intermediate does indeed accumulate to detectable levels; its absorption spectrum, which is virtually identical to that of 2-(OMe,SR)⁻ reported previously,² is shown in Figure 2.

The “intermediate” 2-(OTFE)₂⁻ in the reaction of 1-OTFE with CF₃CH₂O⁻ is also observable; it can be generated either as shown in eq 4 or by deprotonation of the acetal 2-(OTFE)₂H.

However, since eq 4 does not lead to “products” and hence 2-(OTFE)₂⁻ is not a “true” intermediate in the same sense as 2-(OTFE,SR)⁻, its detectability is not particularly noteworthy. This is because what makes “true” S_NV intermediates typically elusive is that the requirement for nucleophilic attack to be faster than leaving group departure (*k*₁[Nu]/*k*₂ > (>>) 1) is difficult to meet; the corollary requirement that *K*₁[Nu] > (>>) 1 is much more easily met, and for 2-(OTFE)₂⁻, it is the *only* requirement. Note that when discussing the S_NV mechanism in general rather than applied to a specific example, we shall use the generic symbols *k*₁, *k*₋₁, *k*₂, and *K*₁ rather than specific symbols such as *k*₁^{RS}, *k*₁^{OTFE}, *k*₂^{RS}, etc.

In the reactions of 1-OTFE with OH⁻ and piperidine, the respective intermediates do not accumulate to detectable levels. This finding is not surprising in view of the fact that the corresponding intermediates in the reactions of 1-OMe with the same nucleophiles could not be detected either,^{9,11} since CF₃CH₂O⁻ is a much better leaving group than CH₃O⁻ (more on this below), the requirement that *k*₁[Nu]/*k*₂ > (>>) 1 is even more difficult to meet with 1-OTFE than with 1-OMe.

One other “true” S_NV intermediate that was generated in measurable quantities is 2-(OMe,OTFE)⁻, as shown in eq 13. In this case methoxide ion departure is extremely slow so that the condition *k*₁[CF₃CH₂O⁻]/*k*₂ >> 1 is amply met. In fact, *k*₂ is so small that no decay of 2-(OMe,OTFE)⁻ could be observed over a period of weeks.

Identification of Rate-Limiting Steps. For the conversion of 1-OTFE into 3⁻ (eq 3 and Scheme 1), as well as for the reaction of 1-NO₂ with OH⁻, we have assumed that the *k*₁^{OH} step is rate limiting. For 1-OMe, the correctness of this assumption has recently been demonstrated directly.¹¹ Since CF₃CH₂O⁻ departure from 2-(OTFE,OH)⁻ should be even faster than CH₃O⁻ departure from 2-(OMe,OH)⁻, there can be no doubt that the *k*₁^{OH} step is also rate limiting in the reaction of 1-OTFE with OH⁻. This conclusion establishes the correctness of eqs 9 and 10 and the authenticity of the *k*₁^{OTFE}/*k*₁^{OH} ratios obtained by applying these equations.

Even though little is known about the nucleofugality of NO₂⁻, its low basicity strongly suggests that it should be a much better leaving group than CH₃O⁻ and even CF₃CH₂O⁻,¹⁴ thus making the *k*₁^{OH} step rate limiting in the reaction of OH⁻ with 1-NO₂. By the same argument, nucleophilic attack should also be rate limiting in the reaction of 1-NO₂ with CF₃CH₂O⁻ (Scheme 2) and HOCH₂CH₂S⁻. For the latter reaction, this assertion can be supported more directly as follows. The equilibrium constant for nucleophilic attack by HOCH₂CH₂S⁻ should be comparable to that for the reaction of HOCH₂CH₂S⁻ with 1-OMe and 1-OTFE, or possibly be even somewhat larger due to the strong

(14) In spite of the potential pitfalls of deducing relative nucleofugalities based on basicities, the p*K*_a values of CF₃CH₂OH (14.0)^{3,15} and HOCH₂CH₂SH (10.56)^{2b,3} are sufficiently different from that of HNO₂ (<(<)<)3.37 in water¹⁶ to allow the assumption that NO₂⁻ should be a better leaving group than CF₃CH₂O⁻ and HOCH₂CH₂S⁻.

Table 4. Summary of Rate Constants for Leaving Group Expulsions in 50% Me₂SO–50% Water (v/v) at 20 °C

no.	k_{-1} (s ⁻¹)	k_2 (s ⁻¹)
1	$1\text{-OTFE} + \text{HOCH}_2\text{CH}_2\text{S}^- \xleftarrow{0.10 \pm 0.03} 2\text{-(OTFE,SR)}^-$	$2\text{-(OTFE,SR)}^- \xrightarrow{0.014 \pm 0.003} 1\text{-SCH}_2\text{CH}_2\text{OH} + \text{CF}_3\text{CH}_2\text{O}^-$
2	$1\text{-OMe} + \text{HOCH}_2\text{CH}_2\text{S}^- \xleftarrow{5.10 \times 10^{-2}^a} 2\text{-(OMe,SR)}^-$	$2\text{-(OMe,SR)}^- \xrightarrow{9.6 \times 10^{-6}^a} 1\text{-SCH}_2\text{CH}_2\text{OH} + \text{CH}_3\text{O}^-$
3	$1\text{-OTFE} + \text{CF}_3\text{CH}_2\text{O}^- \xleftarrow{(1.65 \pm 0.15) \times 10^{-5}^b} 2\text{-(OTFE)}_2^-$	
4	$1\text{-OMe} + \text{CF}_3\text{CH}_2\text{O}^- \xleftarrow{(5.0 \pm 0.5) \times 10^{-5}} 2\text{-(OMe,OTFE)}^-$	
5	$1\text{-OMe} + \text{CH}_3\text{O}^- \xleftarrow{(4.0 \pm 0.4) \times 10^{-8}^b} 2\text{-(OMe)}_2^-$	

^a From reference 2. ^b Not statistically corrected.

electron-withdrawing inductive effect of the nitro group. This should make $2\text{-(NO}_2\text{,SR)}^-$ directly detectable if the k_2 step were not very rapid. The fact that no intermediate was detected demonstrates that $k_2^{\text{RS}} \gg k_{-1}^{\text{RS}}$ and $k_2^{\text{RS}} \gg k_1^{\text{RS}}[\text{HOCH}_2\text{CH}_2\text{S}^-]$ and hence that the k_1^{RS} step is rate limiting.

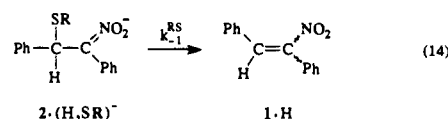
For the reaction of 1-NO₂ with piperidine, absence of base catalysis (pH independent slopes of plots of k_{obsd} vs piperidine concentration) demonstrates directly that the k_1 step is rate limiting. For the reaction of 1-OMe with piperidine it has been shown earlier⁹ that at pH >10.8 nucleophilic attack is rate limiting; hence it is safe to conclude that for the reaction of piperidine with 1-OTFE measured at pH 12.13 the same should be the case.

Structure–Reactivity Relationships. A. Rate Constants for Leaving Group Departure. Data for the dependence of leaving group departure rates on structure in S_NV reactions are scarce.¹⁸ Of particular interest is the dependence on the basicity of the leaving group. Our results are summarized in Table 4. Comparison of $k_2 = 0.014 \text{ s}^{-1}$ for loss of $\text{CF}_3\text{CH}_2\text{O}^-$ from 2-(OTFE,SR)^- with $k_2 = 9.6 \times 10^{-6} \text{ s}^{-1}$ for loss of CH_3O^- from 2-(OMe,SR)^- indicates a strong dependence on $\text{p}K_a^{\text{ROH}}$ ($\text{p}K_a^{\text{CF}_3\text{CH}_2\text{OH}} = 14.0^{3,15}$ and $\text{p}K_a^{\text{MeOH}} \approx 17.2^{3,19}$) which translates into a $\beta_{\text{lg}} = d \log k_2/d\text{p}K_a^{\text{ROH}} \approx -0.99$. The large β_{lg} value suggests a transition state with extensive or nearly complete C–O bond cleavage.²² It should be noted, though, that the β_{lg} value may somewhat overestimate the extent of bond cleavage because the larger size of the $\text{CF}_3\text{CH}_2\text{O}$ group compared to that of the CH_3O group^{26,27} probably leads to a steric acceleration of the k_2 step in the collapse of 2-(OTFE,SR)^- .

A similarly high β_{lg} (–1.06) is obtained when comparing $k_{-1} = 5.0 \times 10^{-5} \text{ s}^{-1}$ for $\text{CF}_3\text{CH}_2\text{O}^-$ loss from 2-(OMe,OTFE)^- with the statistically corrected $k_{-1} = 2.0 \times 10^{-8} \text{ s}^{-1}$ for CH_3O^-

expulsion from 2-(OMe)_2^- . Again, the “true” β_{lg} value is probably somewhat smaller than the above number suggests because of the potential steric enhancement of the loss of $\text{CF}_3\text{CH}_2\text{O}^-$ compared to that of the loss of CH_3O^- . Nevertheless, the fact remains that β_{lg} is large, as is the case for the k_2 steps. Thus, irrespective of the intermediate, C–O bond cleavage is well advanced in the transition state of alkoxide ion expulsion.²⁸

A previous study of k_{-1}^{RS} of reaction 1 as a function of RS^- ($\text{CH}_3\text{CH}_2\text{S}^-$, $\text{HOCH}_2\text{CH}_2\text{S}^-$, $\text{CH}_3\text{O}_2\text{CCH}_2\text{CH}_2\text{S}^-$, and $\text{CH}_3\text{O}_2\text{CCH}_2\text{S}^-$) yielded a $\beta_{\text{lg}} = -0.71$ (or $\beta_{\text{lg}}^n = -0.89$ with β_{lg}^n being the normalized β_{lg}) for the k_{-1} step,² while $\beta_{\text{lg}} = -0.68$ ($\beta_{\text{lg}}^n = -0.81$) was reported for k_{-1}^{RS} of reaction 14.³⁰ These results again suggest rather late transition states.



These findings are consistent with some earlier generalizations according to which the transition state for departure of sluggish leaving groups from highly delocalized carbanions tends to be product-like.^{31a} However, with good leaving groups (e.g., Cl or Br) departing from highly delocalized carbanions, the transition state is early,³¹ while for weakly delocalized carbanions the transition state is always early, irrespective of the nature of the leaving group.³²

The rate constants summarized in Table 4 reveal some other noteworthy features. For example, $k_{-1} = 5 \times 10^{-5} \text{ s}^{-1}$ for expulsion of $\text{CF}_3\text{CH}_2\text{O}^-$ from 2-(OMe,OTFE)^- is seen to be

(25) (a) Jencks, W. P. *Chem. Rev.* **1985**, *85*, 511. (b) Jencks, W. P. *Bull. Soc. Chim. Fr.* **1988**, 218.

(26) The ν parameters for CH_3O and $\text{CF}_3\text{CH}_2\text{O}$ are 0.36 and 0.65 (estimate), respectively.²⁷

(27) (a) Charton, M. The Quantitative Description of Steric Effects. *Stud. Org. Chem.* **1991**, *42*, 629. (b) Charton, M. Personal communication.

(28) A reviewer has suggested that the interpretation of β_{lg} in terms of C–O bond cleavage may be complicated by the fact that we are dealing with nitro-stabilized carbanions, just as the Brønsted α values for the deprotonation of nitroalkanes are distorted.²⁹ We do not believe this to be the case because β_{lg} is determined from a substituent effect in the leaving group rather than in the nitro-stabilized moiety from which the leaving group departs. In other words, with respect to the analogy to the deprotonation of nitroalkanes, β_{lg} should be compared to β determined by varying the substituent in the base (which does not show abnormal behavior) rather than α determined by varying the substituent in the nitroalkane.

(29) Bordwell, F. G.; Boyle, W. J., Jr. *J. Am. Chem. Soc.* **1972**, *94*, 3907.

(30) Bernasconi, C. F.; Killion, R. B. *J. Am. Chem. Soc.* **1988**, *110*, 7506.

(31) (a) Avramovitch, B.; Weyerstahl, P.; Rappoport, Z. *J. Am. Chem. Soc.* **1987**, *109*, 6687. (b) Grout, A.; McLennan, D. J.; Spackman, I. H. *J. Chem. Soc., Chem. Commun.* **1976**, 775.

(32) Stirling, C. J. M. *Acc. Chem. Res.* **1979**, *12*, 198.

(15) This work, see the Experimental Section.

(16) The value of 3.37¹⁷ refers to $\text{O}=\text{N}-\text{OH}$; the relevant acid in our situation is $\text{O}=\text{NH}^+-\text{O}^-$ whose $\text{p}K_a$ must be lower than that of $\text{O}=\text{N}-\text{OH}$.

(17) *CRC Handbook of Chemistry and Physics*, 52nd ed.; Weast, R. C., Ed.; Chemical Rubber Co.: Cleveland, OH, 1971–1972; p D–121.

(18) Bernasconi, C. F. *Tetrahedron* **1989**, *45*, 4017.

(19) Based on $\text{p}K_a = 15.5$ in water²⁰ and adding 1.7 units, which correspond to the increase of $\text{p}K_w$ from water to 50% Me₂SO–50% water.²¹

(20) Ballinger, P.; Long, F. *J. Am. Chem. Soc.* **1959**, *81*, 1050; **1960**, *82*, 795.

(21) Hallé, J.-C.; Gaboriaud, R.; Schaal, R. *Bull. Soc. Chim. Fr.* **1970**, 2047.

(22) This is the traditional interpretation of β_{lg} .²³ This view has been challenged²⁴ as well as defended.²⁵

(23) (a) Leffler, J. E.; Grunwald, E. *Rates and Equilibria of Organic Reactions*; Wiley: New York, 1963. (b) Kresge, A. J. *Acc. Chem. Res.* **1975**, *8*, 354.

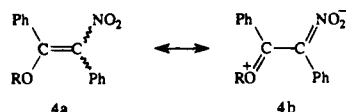
(24) (a) Pross, A. *J. Org. Chem.* **1984**, *49*, 1811. (b) Bordwell, F. G.; Hughes, D. L. *J. Am. Chem. Soc.* **1985**, *107*, 4737. (c) Pross, A.; Shaik, S. S. *New J. Chem.* **1989**, *13*, 427. (d) Hoz, S. *Acc. Chem. Res.* **1993**, *26*, 69.

Table 5. Summary of Rate and Equilibrium Constants for Nucleophilic Attachment of Various Nucleophiles to Vinylic Substrates of the Type 1-X in 50% Me₂SO–50% Water at 20°C^a

1-X	k_1^{OH} (M ⁻¹ s ⁻¹)	k_1^{OTFE} (M ⁻¹ s ⁻¹)	$K_1^{\text{OTFE } b}$ (M ⁻¹)	$k_1^{\text{HOCH}_2\text{CH}_2\text{S}^-}$ (M ⁻¹ s ⁻¹)	$K_1^{\text{HOCH}_2\text{CH}_2\text{S}^-}$ (M ⁻¹)	k_1^{Pip} (M ⁻¹ s ⁻¹)
1-H	0.219			5.81×10^4	8.28×10^6	1.17×10^2
1-OMe	0.691	<i>0.73 ± 0.05</i>	<i>(1.45 ± 0.24) × 10⁴</i>	3.9×10^2	7.65×10^3	1.01
1-OTFE	<i>0.41 ± 0.01</i>	<i>0.20 ± 0.01^d</i>	<i>(1.21 ± 0.17) × 10⁴</i>	<i>(1.76 ± 0.04) × 10²</i>	<i>(1.76 ± 0.56) × 10³</i>	<i>0.529 ± 0.014</i>
		<i>0.41 ± 0.01^e</i>	<i>(2.48 ± 0.29) × 10⁴</i>			
1-NO ₂ (Z) ^c	<i>0.229 ± 0.003</i>	<i>0.49 ± 0.01</i>		<i>(4.00 ± 0.15) × 10³</i>		<i>44.6 ± 1.7</i>
1-NO ₂ (E) ^c	<i>0.332 ± 0.006</i>					
1-Cl	2.53×10^{-3}			37.8		1.81×10^{-2}
1-I	2.01×10^{-4}			7.78		7.40×10^{-4}
1-SCH ₂ CH ₃	2.55×10^{-4}			≈4.74		9.08×10^{-5}

^a Numbers in italics: this work; other numbers from refs 11 and 30. ^b Calculated as k_1/k_{-1} with k_{-1} from Table 4. ^c Not statistically corrected. ^d k_1^{OTFE} obtained from slope of Figure 1. ^e From $k_1^{\text{OTFE}}/k_1^{\text{OH}} = 0.99$ obtained from Figure 4 and $k_1^{\text{OH}} = 0.41 \text{ M}^{-1} \text{ s}^{-1}$.

about 6-fold higher than the statistically corrected $k_{-1}^{\text{corr}} = k_{-1}/2 = 0.82 \times 10^{-5} \text{ s}^{-1}$ for CF₃CH₂O⁻ expulsion from 2-(OTFE)₂⁻. This is most plausibly attributed to a combination of two factors. One is the stronger electron-withdrawing inductive effect of the trifluoroethoxy group which stabilizes 2-(OTFE)₂⁻ more than 2-(OMe,OTFE)⁻ and hence decreases k_{-1} for 2-(OTFE)₂⁻. The other is the stronger push by the methoxy group which enhances k_{-1} for 2-(OMe,OTFE)⁻. This push arises from the developing resonance effect that stabilizes 1-OR (4b).² The observed rate



factor of about 6 actually underestimates the combined influence of the inductive effect and push because the expulsion of CF₃CH₂O⁻ from 2-(OTFE)₂⁻ is accelerated by a steric effect due to the larger size of the trifluoroethoxy group that is left behind. As shown below, this steric effect must be quite significant.

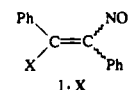
In contrast to the above, $k_{-1} = 5.10 \times 10^{-2} \text{ s}^{-1}$ for HOCH₂CH₂S⁻ expulsion from 2-(OMe,SR)⁻ is smaller than $k_{-1} = 0.10 \text{ s}^{-1}$ for expulsion of HOCH₂CH₂S⁻ from 2-(OTFE,SR)⁻. In this case the stronger push by the methoxy group and the stronger electron-withdrawing effect of the trifluoroethoxy group appear to be overcompensated by the steric acceleration of the reaction of 2-(OTFE,SR)⁻. In view of the large size of sulfur, this is a reasonable result because steric crowding in the intermediates derived from HOCH₂CH₂S⁻ is expected to be more severe than in those derived from CF₃CH₂O⁻.

The last comparison of interest is that between $k_{-1} = 0.10 \text{ s}^{-1}$ for the loss of HOCH₂CH₂S⁻ from 2-(OTFE,SR)⁻ and the statistically corrected $k_{-1}^{\text{corr}} = k_{-1}/2 = 0.82 \times 10^{-5} \text{ s}^{-1}$ for the loss of CF₃CH₂O⁻ from 2-(OTFE)₂⁻. On the basis of $\text{p}K_{\text{a}}^{\text{CF}_3\text{CH}_2\text{OH}} = 14.0$ and $\text{p}K_{\text{a}}^{\text{HOCH}_2\text{CH}_2\text{SH}} = 10.56$,² one calculates a $\beta_{\text{lg}} = -1.19$, although the "true" β_{lg} value should be somewhat smaller because the k_{-1} for HOCH₂CH₂S⁻ expulsion from 2-(OTFE,SR)⁻ is probably somewhat enhanced by a stronger steric effect than that in 2-(OTFE)₂⁻. The fact that this β_{lg} value is quite comparable to the β_{lg} values obtained from the comparison of CH₃O⁻ with CF₃CH₂O⁻ as nucleofuges is noteworthy since in general sulfur and oxygen nucleofuges are not expected to belong to the same Brønsted family.³² For example, PhO⁻ and PhS⁻ have approximately the same leaving group rank on Stirling's scale³² even though the difference in acidity between PhSH ($\text{p}K_{\text{a}} = 6.6$)³³ and PhOH ($\text{p}K_{\text{a}} = 10.0$)³³ is comparable to that between HOCH₂CH₂SH and CF₃CH₂OH.

(33) Serjeant, E. P.; Dempsey, B. *Ionization Constants of Organic Acids in Aqueous Solution*; Pergamon Press: Oxford, 1979.

A factor that may contribute to the large difference in the rate of departure of HOCH₂CH₂S⁻ compared to that of CF₃CH₂O⁻ is the anomeric effect^{34–37} (see below) which stabilizes 2-(OTFE)₂⁻ much more strongly than 2-(OTFE,SR)⁻ and hence slows down CF₃CH₂O⁻ departure from 2-(OTFE)₂⁻.

B. Rate Constants for Nucleophilic Attack on Various Substrates. Table 5 provides a summary of rate and equilibrium constants for nucleophilic attack by different nucleophiles on various substrates of the type 1-X determined in this study and in previous work.^{2,9,11,30} The new rate and equilibrium constants



are in italics. For the reaction of 1-OTFE with CF₃CH₂O⁻, two k_1^{OTFE} values are given which differ by a factor of 2. The first is based on the slope in Figure 1; the second is calculated from the $k_1^{\text{OTFE}}/k_1^{\text{OH}}$ ratio (0.99) obtained from Figure 4 and k_1^{OH} . The difference between the two k_1^{OTFE} values is too large to be accounted for by the combined experimental errors of k_1^{OH} , the $k_1^{\text{OTFE}}/k_1^{\text{OH}}$ ratio, and k_1^{OTFE} from Figure 1. However, since the error limits are based on standard deviations, they do not account for systematic errors that may be larger than the standard deviations. A potential source for the discrepancy is our equating [OH⁻] with a_{OH^-} as discussed under Results. Another is that the *E/Z*-isomer ratio in 1-OTFE generated from 2-(OMe,OTFE)⁻ (k_1^{OH} and k_1^{OTFE}) may differ from that in 1-OTFE produced *in situ* from 2-(OTFE)₂⁻ ($k_1^{\text{OTFE}}/k_1^{\text{OH}}$). Inasmuch as the reactivity of the two isomers is probably not identical (more on this below), the observed rate constants, which constitute weighted averages of the rate constants of the individual isomers,³⁸ could be somewhat different for the different 1-OTFE mixtures.

It is noteworthy that even though all substrates have the same skeleton and differ only in their leaving groups, there is no "universal" nucleophilicity order, i.e., the order of nucleophilic reactivity depends significantly on the leaving group, even though the departure of this group is not part of the k_1 step. Based primarily on the previously reported rate constants, four major factors affecting reactivity were identified.¹¹ (1) *Steric Effects*. These are best seen in the reactions with HOCH₂CH₂S⁻

(34) Kirby, A. G. *The Anomeric Effect and Related Stereoelectronic Effects of Oxygen*; Springer-Verlag: Berlin, 1983.

(35) Deslongchamps, P. *Stereoelectronic Effects in Organic Chemistry*; Pergamon: Oxford, 1983.

(36) Schleyer, P. v. R.; Jemmis, E. D.; Spitznagel, G. W. *J. Am. Chem. Soc.* **1985**, *107*, 6393.

(37) Harcourt, M. P.; More O'Ferrall, R. A. *Bull. Soc. Chim. Fr.* **1988**, 407.

(38) Bernasconi, C. F. *Relaxation Kinetics*; Academic Press: New York, 1976; p 144.

and piperidine ($1-H \gg 1-OMe \gg 1-Cl \gg 1-I > 1-SCH_2CH_3$) because here anomeric effects (see below) are negligible. (2) *Resonance in the Substrate.* With 1-OMe, resonance stabilization (**4b**) lowers its reactivity which contributes to the fact that $1-H \gg 1-OMe$ in the reactions with $HOCH_2CH_2S^-$ and piperidine. (3) *Anomeric Effect.*^{34–37} This effect is particularly pronounced when both the leaving group and the nucleophile are oxyanions. This serves to explain the high reactivity 1-OMe with OH^- which makes it even more reactive than 1-H. (4) *Symbiotic Effects.*³⁹ These effects may enhance hard (soft) nucleophile/hard (soft) leaving group interactions. They manifest themselves, e.g., in the higher k_F/k_{Cl} ratio for alkoxy vs thio nucleophiles in nucleophilic vinylic substitutions.⁴⁰

How well do the new results fit into the above framework? The fact that 1-NO₂ is less reactive than 1-H toward $HOCH_2CH_2S^-$ and piperidine, especially if a statistical correction is applied for 1-NO₂, illustrates again the strong sensitivity to steric effects of these reactions since on purely electronic grounds 1-NO₂ should be appreciably more reactive than 1-H. The electron-withdrawing effect of the nitro group does, however, manifest itself in the substantially higher $k_1^{HOCH_2CH_2S^-}$ and k_1^{Pip} values for 1-NO₂ compared to 1-OMe where the steric effects are apparently more equally matched. The much higher reactivity of 1-NO₂ than 1-Cl toward OH^- (ratio 90.9),⁴¹ $HOCH_2CH_2S^-$ (106),⁴¹ and piperidine (2460)⁴¹ illustrates the same phenomenon. These ratios are comparable to similar ratios in S_NAr reactions⁴² of 1-X-2,4-dinitrobenzene, e.g., $k_{NO_2}/k_{Cl} = 500$ for the methoxide ion in methanol and 1860 for PhS⁻ in methanol.⁴³ However, the similar $k_1(1-NO_2)/k_1(1-Cl)$ reactivity ratios toward the hard OH^- (90.9) and the soft $HOCH_2CH_2S^-$ (106), despite the presumably greater softness of 1-NO₂ compared to 1-Cl, indicate that the symbiotic effects are not playing a major role in our case.

In contrast to the much lower reactivity of 1-OMe and 1-OTFE than 1-NO₂ toward piperidine and $HOCH_2CH_2S^-$, the reactivity of 1-OMe and 1-OTFE toward OH^- and $CF_3CH_2O^-$ is quite comparable to that of 1-NO₂, again demonstrating the importance of the anomeric effect when both the nucleophile and the leaving group are oxyanions.

In comparing the reactivity of 1-OTFE with that of 1-OMe, one needs to consider the interplay of three factors. The first is the stronger inductive effect of the trifluoroethoxy group which should make k_1 and K_1 larger for 1-OTFE than for 1-OMe. The second is the stronger substrate resonance effect (**4b**) in 1-OMe which should reduce k_1 and K_1 for 1-OMe relative to that of 1-OTFE. The third effect, which opposes the first two, is the greater steric crowding in the intermediate and transition state in the reaction of 1-OTFE. The fact that k_1 for 1-OTFE is smaller than for 1-OMe with all nucleophiles shows that the steric effect outweighs the combined influence of the resonance and inductive effects. This finding supports our earlier contention that the steric effect is likely to attenuate the combined influence of the inductive effect and push on k_{-1} when comparing $CF_3CH_2O^-$ expulsion from $2-(OTFE)_2^-$ with $CF_3CH_2O^-$ expulsion from $2-(OMe,OTFE)^-$.

In view of the nearly identical reactivity of the *Z*- and *E*-isomers of 1-NO₂ toward OH^- , no further kinetic determina-

tions with the *E*-isomer were performed since this was a difficult compound to work with due to its low solubility. The difference in the k_1^{OH} values for the two isomers is too small to warrant an elaborate interpretation. Hence, the small difference in reactivity between the *Z*- and *E*-isomers suggests that the *Z*- and *E*-isomers of 1-OTFE and 1-OMe are probably also similar in reactivity.⁴⁴ This is consistent with the fact that all kinetic experiments displayed good first-order behavior, even though 1-OTFE and 1-OMe were present as a mixture of the *Z*- and *E*-isomers.

CF₃CH₂OH/CF₃CH₂O⁻ Association. The fact that the reaction of $CF_3CH_2O^-$ with both 1-NO₂ and 1-OCH₃ shows the same kind of curvilinear dependence of k_{obsd} on buffer concentration which leads to the same $K_{assoc} \approx 2.0 M^{-1}$ strongly supports our interpretation in terms of eq 5. Gandler and Jencks⁴⁵ reported similar observations when studying the kinetics of the $CF_3CH_2O^-$ -promoted E2 reaction of (2-arylethyl)-quinuclidinium ions. They found a $K_{assoc} = 0.8 M^{-1}$ in 60% Me₂SO–40% water at 40 °C; in view of the lower temperature (20 °C) in the present study, our somewhat higher K_{assoc} appears entirely consistent with Gandler and Jencks' value.

Conclusions

The reactions of 1-OTFE and 1-NO₂ with OH^- , $HOCH_2CH_2S^-$, and piperidine lead to the corresponding vinylic substitution products (**3**⁻, 1-SCH₂CH₂OH, and 1-Pip, respectively) and so does the reaction of 1-NO₂ with $CF_3CH_2O^-$, although the product, 1-OTFE, cannot be observed because it is immediately converted to $2-(OTFE)_2^-$. This rapid conversion of 1-OTFE in the presence of $CF_3CH_2O^-$ is the reason why 1-OTFE cannot be synthesized by reaction of any 1-X with $CF_3CH_2O^-$.

In the reaction of 1-OTFE with $HOCH_2CH_2S^-$ the intermediate, $2-(OTFE,SR)^-$, accumulates to detectable levels which allowed a determination of all relevant rate constants (k_1 , k_{-1} , and k_2); in the reaction of 1-OMe with $CF_3CH_2O^-$, the intermediate, $1-(OMe,OTFE)^-$, is also visible and, for all practical purposes, actually constitutes the "product" since loss of CH_3O^- to form 1-OTFE is too slow to be observed.

The observed structure–reactivity relationships can be summarized as follows.

(1) Departure of oxyanion leaving groups from the intermediates either in the k_2 direction or the k_{-1} direction is highly sensitive to leaving group basicity, with β_{lg} values close to -1 , suggesting transition states in which the C–O bond is largely extended.

(2) $CF_3CH_2O^-$ expulsion from $2-(OMe,OTFE)^-$ is appreciably faster than from $2-(OTFE)_2^-$, despite a steric effect favoring the latter. This is because of the combined influence of the stronger inductive effect of the CF_3CH_2O group (lowers k_{-1} for $2-(OTFE)_2^-$) and the stronger push by the MeO group (increases k_{-1} for $2-(OMe,OTFE)^-$).

(3) The structural effects on the k_1 step of the reactions reported in this study follow patterns observed previously in which there is a complex interplay between steric, electronic (inductive), anomeric, and substrate resonance effects.

Experimental Section

Materials. (*Z*)- α,β -Dinitrostilbene was obtained from Janssen Chimica Co., mp 110 °C, while the *E*-isomer was prepared according to the procedure of Campbell et al.,^{8,46} mp 187–188 °C. 1,2-Diphenyl-

(39) (a) Bunnett, J. F. *Annu. Rev. Phys. Chem.* **1963**, *14*, 271. (b) Pearson, R. G. In *Advances in Linear Free Energy Relationships*; Chapman, N. B., Shorter, J., Eds.; Plenum: New York, 1972; Chapter 6, pp 304–306.

(40) Rappoport, Z. In *Nucleophilicity*; Harris, J. M., McManus, E. P., Eds.; Advances Chemistry Series 215; American Chemical Society: Washington, DC, 1987; p 399.

(41) Without statistical correction.

(42) Terrier, F. *Nucleophilic Aromatic Displacement*; VCH Publishers: New York, 1991.

(43) Bartoli, G.; Todesco, P. E. *Acc. Chem. Res.* **1977**, *10*, 125.

(44) Note that for 1-I there is a substantially larger reactivity difference between the *E*- and *Z*-isomers, especially with the relatively bulky piperidine and morpholine nucleophiles.⁸

(45) Gandler, J. R.; Jencks, W. P. *J. Am. Chem. Soc.* **1982**, *104*, 1937.

(46) Campbell, K. N.; Shavel, J. S.; Campbell, B. K. *J. Am. Chem. Soc.* **1953**, *115*, 2400.

2-nitroethanone 2,2,2-trifluoroethyl acetal, **2**-(OTFE)₂H, was synthesized from **1**-I as follows. To a solution of sodium 2,2,2-trifluoroethoxide (24.4 g, 0.2 mmol, prepared from 2,2,2-trifluoroethanol and sodium in dry ether under nitrogen) in TFE (50 mL) was added a solution of α -iodo- β -nitrostilbene (**1**-I) (4.0 g, 11.4 mmol) in MeCN (150 mL). The slightly nonhomogeneous solution was stirred for 47 h (since the reaction was not complete after 24 h) under nitrogen at room temperature. TLC showed the formation of at least three compounds in addition to unreacted precursor. The solvent was evaporated, water and ether were added, the phases were separated, the organic phase was dried (MgSO₄), and the solvent was evaporated, leaving a yellow viscous oil which solidified after a few hours. Chromatography of the solid on a silica gel column with a 97:3 petroleum ether:ether eluent gave **2**-(OTFE)₂H as a white solid (1.54 g), mp 73 °C. A second fraction, slightly impure, mp 71–74 °C (850 mg, total yield 50%), was obtained. IR (Nujol)_{max}: ν 1550 (s, NO₂). ¹H NMR (200 MHz, CD₃CN): δ 3.85 (center of q, CH₂, J = 8.5 Hz), 4.32 (center of two overlapping q, CH₂, J = 8.5 Hz, J_{gem} = 2.5 Hz), 6.43 (1 H, s, CH), 7.10–7.51 (10 H, m, Ar). MS (70 eV, 100 °C) m/e (rel abundance, assignment): 377 (9, M – NO₂), 287 (100, M – CH(NO₂)Ph), 278 (44, M – NO₂ – OTFE), 167 (88, PhCOC=CF₂), 165 (54), 105 (86, PhCO), 77 (21, Ph). Anal. Calcd for C₁₈H₁₅F₆NO₄: C, 51.06; H, 3.55; N, 3.31. Found: C, 51.01; H, 3.55; N, 3.36.

α -Nitro- β -(2,2,2-trifluoroethoxy)stilbene (**1**-OTFE) was prepared from solutions of **2**-(OMe,OTFE)[–] that had been acidified with HCl. In a typical run, **2**-(OMe,OTFE)[–] was generated by adding 20 mg of **1**-OMe to 0.5 mL of a 2.0 M CF₃CH₂OH/0.5 M CF₃CH₂O[–] buffer in 50% Me₂SO–50% water at 20 °C and letting the reaction proceed for about 1 min. The major products of the reaction of **2**-(OMe,OTFE)[–] with 10 mL of 0.5 M HCl were **1**-OMe and **2**-(OMe,OTFE)H, while **1**-OTFE was formed in about 5% yield, as determined by HPLC analysis. The **1**-OTFE fraction was collected by HPLC using an Alltech 250 × 10 mm preparative column with Absorbosphere HS C₁₈ 7 μ m packing and a 2.5 mL/min flow rate in a Hewlett Packard 1090M chromatograph; mobile phase A, 30% CH₃CN–70% H₂O; solvent B, 80% CH₃CN–20% H₂O; 100% A for 2 min, 0–100% B in 20 min, 100% B for 8 min. The effluent was collected over KCl to separate the aqueous from the organic phase; this was repeated by adding more KCl. The aqueous layer was then extracted with ether and the ether extract combined with the organic layer, dried over MgSO₄, and filtered. After removing most of the solvent under vacuum, **1**-OTFE was identified by negative FAB MS m/e (rel abundance, assignment): 323 (100, M), 240 (15, M – CF₃CH₂), 224 (17, M – CF₃CH₂O).

The following compounds were available from previous studies: β -methoxy- α -nitrostilbene (**1**-OMe),² 1,2-diphenyl-2-nitroethanone (**3**H),¹¹ β -morpholino- α -nitrostilbene⁹ and β -(2-hydroxythioethoxy)- α -nitrostilbene (**1**-SCH₂CH₂OH),^{2b} β -Mercaptoethanol (Aldrich) and 2,2,2-trifluoroethanol (Aldrich; NMR grade) were distilled and stored under nitrogen. Piperidine, morpholine, and triethylamine were refluxed over CaH₂, distilled, and stored in the dark at 4 °C. DABCO (1,4-diazabicyclo[2.2.2]octane) was recrystallized from hexane. Me₂SO (Fisher Scientific) was dried over CaH₂ and distilled under vacuum before use. HCl and KOH solutions were Dilut-it (Baker) diluted to appropriate volumes with filtered deionized water.

Reaction Solutions and pH Determinations. Solutions in 50% DMSO–50% water (v/v) were prepared by adding appropriate amounts of aqueous stock solutions to a volumetric flask containing a measured amount of DMSO that would correspond to 50% of the final solution volume and then diluting to the mark with water. The ionic strength was maintained at 0.5 M with KCl. All pH measurements were performed on an Orion Research 611 digital pH meter with a Corning No. 476022 glass electrode and a Ross Sure Flow reference electrode. The pH meters were calibrated with standard buffer solutions in 50% DMSO–50% water (v/v) as described by Hallé et al.²¹ The pH of a reaction solution was determined using a mock mixing technique that simulates the stopped-flow experiment or UV/vis experiment.

Determination of the pK_a of Trifluoroethanol. The pK_a of CF₃CH₂OH was determined by potentiometric measurement. A series of 12 buffers at constant [CF₃CH₂O[–]] = 0.1 M but variable [CF₃CH₂OH] (0.04–0.50 M) was prepared in 50% Me₂SO–50% water at 20 °C, μ = 0.5 M (KCl). A plot of the pH of each solution vs log([CF₃CH₂O[–]]/[CF₃CH₂OH]) gave a slope of 1.07 ± 0.08 and an intercept of pK_a = 14.00 ± 0.05.

CH₂O[–]]/[CF₃CH₂OH]) gave a slope of 1.07 ± 0.08 and an intercept of pK_a = 14.00 ± 0.05.

Spectroscopic and Kinetic Measurements. Spectroscopic measurements were carried out in a Perkin Elmer lambda 2 spectrophotometer with thermostated cell blocks at 20 °C. Kinetic measurements were made using a Durrum–Gibson stopped-flow spectrophotometer or Applied Photophysics stopped-flow spectrophotometer, both equipped with computerized data acquisition and analysis. For those reactions that were slower than ca. 2.0 × 10^{–3} s^{–1}, conventional UV/vis methods were employed. The runs with k_{obsd} between 4 × 10^{–6} and 10^{–5} s^{–1} were followed for at least 2 half-lives, the faster runs for 3–4 half-lives. Rate constants for all reactions were determined by curve fitting the raw data with the commercially available nonlinear regression program Enzfitter.⁴⁷

The rate of the reaction of **2**-(OMe)₂[–] → **1**-OMe + CH₃O[–] was determined as follows. The reaction solution of **2**-(OMe)₂[–] was generated by adding a methanolic solution of NaOMe to **1**-OMe in DMSO and diluting with aqueous KOH to make a 0.2 M KOH reaction solution in 50% Me₂SO–50% water. Under these conditions, **1**-OMe is rapidly hydrolyzed to form **3**[–] which in turn may hydrolyze to PhCH=NO₂[–] and PhCOO[–]. Hence the reaction was monitored at 330 nm which corresponds to an isosbestic point between **3**[–] and PhCH=NO₂[–]. Due to the extreme slowness of the reaction (k_{-1} = 4.0 × 10^{–8} s^{–1}), the method of initial rates had to be used. The initial concentration of **2**-(OMe)₂[–] was such as to have yielded an absorbance of about 5 units if the reaction had gone to completion; the reaction was followed for 7 days by taking readings every 9 h.

Isolation of 1,2-Diphenyl-2-nitroethanone 2,2,2-Trifluoroethyl Acetal (2-(OTFE)₂H) from Reaction of (Z)- α,β -Dinitrostilbene with CF₃CH₂O[–]. In a 250 mL round bottom flask, 0.0675 g of (Z)- α,β -dinitrostilbene was added to the minimum amount of acetonitrile required to dissolve the solid (approximately 10 mL). To this stirred solution at room temperature was added 50 mL of a buffer of 0.1 M trifluoroethoxide/1 M trifluoroethanol prepared in a 50% DMSO–50% water solution, μ = 0.5 M (KCl). The ratio of trifluoroethoxide to substrate was 20:1 ([stilbene] = 5.0 × 10^{–3} M). The progress of the reaction was followed by monitoring the rate of disappearance of the yellow (Z)- α,β -dinitrostilbene by UV/vis spectroscopy. After approximately 10 min, the UV/vis spectrum showed no evidence for the presence of starting material; rather, a new spectrum was apparent with a maximum absorbance at 272 nm strongly resembling that of the 1,2-diphenyl-2-nitroethanone 2,2,2-trifluoroethyl acetal anion (**2**-(OTFE)₂[–]). After 20 min, the sample was poured into a saturated aqueous KCl solution and extracted with dichloromethane. The aqueous sample was neutralized with 1 M aqueous acetic acid solution to a pH ≈ 5. The resulting product was extracted several times with dichloromethane and dried with magnesium sulfate, and the solvent was removed. This produced an oil that was induced to crystallize by addition of petroleum ether followed by slow evaporation of the solvent over several days. Only a portion of the oil could be induced to crystallize. A white solid was isolated, mp 69–72 °C. An authentic sample of **2**-(OTFE)₂H has mp 73 °C.

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Supplementary Material Available: Tables S1–S9, kinetic data (9 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.