Thiolate Reduction of Sulfilimines. 2. Further Evidence for a Highly Coupled Concerted Transition State

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Received October 6, 1986

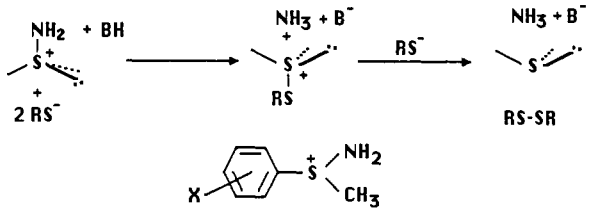
The reduction of *S*-methyl-*S*-(substituted phenyl)sulfilimmonium salts by 3-nitro-5-thiobenzoic acid (NTBA) and by 3-thiobenzoic acid (TBA) (aqueous solution, 25 °C, μ 1.0 with KCl) is first order in proton activity and thiolate concentration in the range pH 3.5–6.6. The solvent deuterium isotope effects for the reduction by NTBA are k_H/k_D = 7.62 and 6.50 for the *S*-phenyl- and *S*-(4-nitrophenyl)-substituted compounds, respectively; for TBA reduction of the same compounds, k_H/k_D = 2.89 and 1.66, respectively. Plots of third-order rate constants for the proton and acetic acid catalyzed reactions against the σ^n scale give sharply curved Hammett plots; approximate values for β_{nuc} vary in the range 1–1.4 for the proton-catalyzed reaction and 0.2–0.7 for the acetic acid catalyzed reaction and are also nonlinear when plotted against the σ^n scale. General-acid catalysis is observed and Brønsted α values of 0.61 and 0.49 are obtained for NTBA reduction of *S*-(4-methoxyphenyl)- and *S*-(4-nitrophenyl)-substituted compounds, respectively; the Brønsted α for the TBA reduction of the *S*-phenyl-substituted compounds is $\approx$0.7; $P_{xy} = \partial\alpha/\partial\sigma^n \approx 0.13$. The term $P_{xy} = \partial\beta_{nuc}/\partial pK_a^{HA} = \partial pK_a^{RSH} \approx 0.08$. The data are consistent with a mechanism in which S–S bond formation, S–N bond cleavage, and proton transfer all occur in a fully concerted transition state.

Sulfilimines react with thiolate anions to give the corresponding sulfide, the reductant disulfide, and the free amine[1,2] (Scheme I). Experimentally, the reaction is first order in thiol concentration,[1] and the reduction of the (presumed) thiasulfonium intermediate proceeds very rapidly under the assay conditions. The reaction is first order in proton concentration, and general-acid catalysis is observed.[2] Although an addition–elimination mechanism is possible for sulfilimine reduction,[3,4] previous work[2] on the reduction of *N*-(substituted benzyl)-*S*,*S*-dimethylsulfilimines was inconsistent with a stepwise reaction involving a sulfurane intermediate and suggested instead that S–S bond formation, S–N bond cleavage, and proton transfer were occurring in one *fully concerted* S_N2 transition state. It was suggested that this highly coupled transition state was favored over the stepwise reaction because of the presumed instability of the thiasulfurane intermediate.[2,5] In order to more fully characterize this unique example of a fully concerted, intermolecular, general catalyzed reaction we have examined the reduction of *S*-methyl-*S*-(substituted phenyl)sulfilimmonium salts (Scheme I; a structural change that should further destabilize possible sulfurane intermediates)[6] by 3-nitro-5-thiobenzoic acid (NTBA) and by 3-thiobenzoic acid (TBA). The data are consistent with a general catalyzed S_N2 reaction with the position of the transition state a delicate function of anti-Hammond forces exerted by the potential intermediates.

Experimental Section

Synthesis. *S*-Methyl-*S*-(substituted phenyl)sulfilimmonium salts were prepared from the corresponding thioanisole by amination with *O*-(mesitylenesulfonyl)hydroxylamine (MSH).[7] Substituted thiophenols and *S*-methyl thiophenols were obtained from either Aldrich, Fairfield, or Alpha and were used without further purification. *O*-(Mesitylenesulfonyl)hydroxylamine (MSH) was prepared by the method of Tamura,[7] stored frozen, and recrystallized from ether/hexane solution before each sulfilimine synthesis. Elemental analyses within acceptable error limits were obtained for all new compounds. The synthesis of the substituted sulfilimines used in this work from the appropriate *S*-methylthiophenols parallels the following example:

Scheme I



***S*-Methyl-*S*-phenylsulfilimine Mesitylenesulfonate.** A solution of *S*-methylthiophenol (80 mmol) in 10 mL of CH_2Cl_2 was slowly added to a cold (4 °C) solution of MSH (8.0 mmol in 15 mL of CH_2Cl_2) over a period of approximately 10 min. After being stirred at 4 °C for 45 min, 70 mL of diethyl ether was added and the resulting turbid solution was allowed to stand at 4 °C for 24 h. The colorless precipitate was collected by vacuum filtration and recrystallized from an ethanol/diethyl ether mixture to give 1.6 g of product (64%), mp 114 °C (lit.[7] mp 110–111 °C). ^1H NMR data for this and other compounds prepared appear in Table I.

Kinetic Studies. All kinetic runs were performed by following the disappearance of thiol anion at either 412 (NTBA) or 270 nm (TBA) with a Hitachi 100-60 UV–vis spectrophotometer equipped with an automatic cell changer and a thermostated cell compartment. Temperature was maintained at 25 °C, and the ionic strength was maintained at 1.0 with KCl. The pH of each cell was determined at the end of each run with a Corning pH meter equipped with a combined glass electrode. All kinetic determinations were run under conditions in which the sulfilimine (at (3.3–6.7) × 10^{-3} M) was 50–100-fold in excess of thiol concentration. First-order rate constants were obtained from semilogarithmic plots of $A_\infty - A_t$ against time. Such plots were typically linear for over 4 half-lives. Apparent constants for buffer catalysis were converted to third-order rate constants by dividing by the concentration of thiol anion,[1,2] calculated from the observed pH and the pK_a of the thiol used (4.25 for NTBA and 6.05 for TBA). Catalytic constants for each buffer were obtained by extrapolating linear replots of apparent third-order catalytic constants vs. fraction of the buffer in the acid form to 100% buffer acid; no general-base catalysis was evident. For strongly acidic buffers, catalytic constants were obtained from solutions that were >99% buffer base[2,4] with use of a dilute solution of acetate buffer to maintain the experimental pH; at least two pH values were ex-

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Table I. Physical Properties of *S*-Methyl-*S*-(substituted phenyl)sulfilimine Mesitylenesulfonates

substituent	% yield[a]	mp, °C	NMR,[b] ppm
p-OCH_3	45	120–121	2.2 (s, 3 H), 2.6 (s, 6 H), 3.4 (s, 3 H), 3.5 (s, 3 H); 6.8 (s, 2 H), ≈7.5 (m, 4 H)
p-CH_3	70	124	2.2 (s, 3 H), 2.4 (s, 3 H), 2.5 (s, 6 H), 3.3 (s, 3 H), 7.0 (s, 2 H), ≈7.5 (m, 4 H)
m-CH_3	68	105–107	2.2 (s, 3 H), 2.4 (s, 3 H), 2.6 (s, 6 H), 3.3 (s, 3 H), 7.1 (s, 2 H), ≈7.7 (m, 4 H)
unsubstituted	64	114[c]	2.2 (s, 3 H), 2.5 (s, 6 H), 3.5 (s, 3 H), 6.8 (s, 2 H), ≈7.8 (m, 4 H)
p-F	80	123	2.2 (s, 3 H), 2.6 (s, 6 H), 3.3 (s, 3 H), 6.9 (s, 2 H), ≈7.6 (m, 4 H)
m-OCH_3	70	102	2.2 (s, 3 H), 2.5 (s, 6 H), 3.3 (s, 3 H), 3.9 (s, 3 H), 7.0 (s, 2 H), ≈7.5 (m, 4 H)
p-Cl	55	118	2.3 (s, 3 H), 2.5 (s, 6 H), 3.3 (s, 3 H), 7.0 (s, 2 H), ≈7.6 (m, 4 H)
p-Br	38	124	2.2 (s, 3 H), 2.8 (s, 6 H), 3.3 (s, 3 H), 6.8 (s, 2 H), 7.9 (s, 4 H)
m-Cl	49	100	2.3 (s, 3 H), 2.6 (s, 6 H), 3.3 (s, 3 H), 7.1 (s, 2 H), ≈7.9 (m, 4 H)
p-NO_2	58	156	2.3 (s, 3 H), 2.6 (s, 6 H), 3.3 (s, 3 H), 6.9 (s, 2 H), ≈7.6 (m, 4 H)

[a] Recrystallized yields. [b] In $CDCl_3$. [c] Lit.[7] mp 110–117 °C.

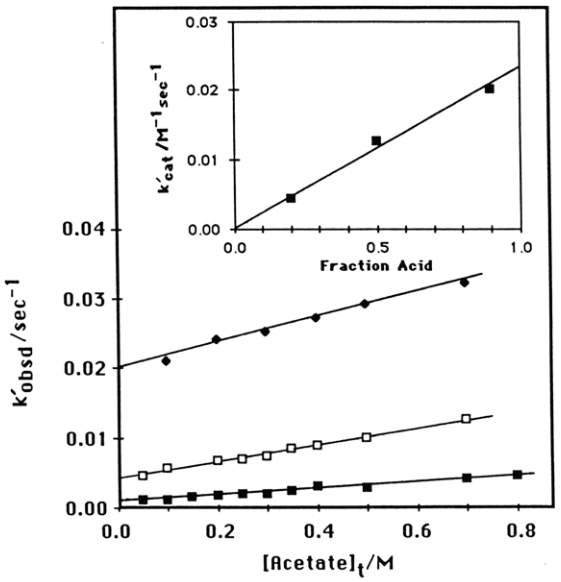

Figure 1. Plot of observed rate constants as a function of acetate buffer concentration for the NTBA reduction of *S*-methyl-*S*-(4-methoxyphenyl)sulfilimine for the following buffer ratios: 20% acid (♦), 50% acid (○), and 90% acid (■). Aqueous solution, 25 °C, ionic strength 1.0 with KCl. Inset: Plot of observed catalytic constants as a function of the fraction of the buffer in the acid form.

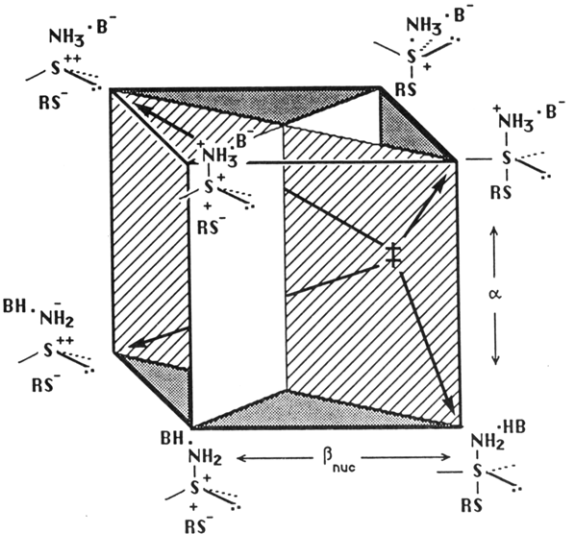

Figure 2. Multidimensional free energy reaction surface depicting the thiolate reduction of sulfilimines. Axes for proton transfer (Brønsted α) and S–S bond formation (β_{nuc}) are shown; S–N bond cleavage occurs in the "*z* axis", and possible intermediates are shown at the vertices. A suggested location for the transition state is shown (‡), and the arrows indicate those intermediates that would exert significant anti-Hammond forces on the position of the transition state; in general, the magnitude of these forces will be an inverse function of the distance between the intermediate and the transition state.

amined. Catalytic constants were calculated from the slopes of these plots and the calculated fraction of the buffer in the acidic form at that pH. Although acid catalysis being observed at >99% buffer base sounds odd, it is readily apparent[2,4,8] that under these conditions the ratio between the apparent catalytic constants (the slope) and the observe rate constants for the proton-catalyzed reaction (the intercept) approaches its upper limit. Errors that might arise from uncertainties in the buffer pK_a are essentially balanced out since the same pK_a value is also used in the Brønsted correlation.[8]

Solvent deuterium isotope effects were determined by parallel kinetic runs of samples prepared by dilution of a small amount of concentrated DCl solution into cells containing KCl, sulfilimine, thiol, and either H_2O or D_2O. Typically, five to seven concentrations of DCl were examined in the range pH 3.5–5, and isotope efects were determined from the slopes of linar plots of log k_{obsd} vs. [DCl]. The calculated proton activities were confirmed by pH measurements; pD was obtained from the observed pH meter reading by adding 0.42. Apparent pK_a values for NTBA and TBA in D_2O were determined by spectrophotometric titration.

Results and Discussion

Rate constants for the reduction of *S*-methyl-*S*-(substituted phenyl)sulfilimines are strictly first order with respect to proton and thiolate concentration in the range pH 4.5–6.6; third-order rate constants for the proton-catalyzed reaction are collected in Table I. The solvent deuterium isotope effect for the proton-catalyzed reduction of *S*-phenyl- and *S*-(4-nitrophenyl)-substituted compounds by NTBA are k_H/k_D = 7.62 and 6.5, respectively. This observed effect is unusually large for a solvent deuterium isotope effect[9] and suggests that a great deal of zero-point energy has been lost in the rate-limiting transition state. For reduction of these same compounds by TBA, the isotope effects are k_H/k_D = 2.89 and 1.66, respectively, suggesting a significant shift in transition state structure on going to the more powerful nucleophile.

Rate constants for the reduction reaction were also dependent upon the concentration of buffer acid (Figure 1), and the generalized rate law for the compounds investigated is shown in eq 1. As before,[1,2] the strict first-order dependence on thiol concentration means that attack by the first mole of thiol is entirely rate limiting and that the subsequent reduction reaction is very fast on the time scale of these experiments.

$$v/[RS^-][\text{sulfilimine}] = k_H[H^+] + k_{BH}[BH] \quad (1)$$

The dependence of the third-order rate constant for the proton and acetic acid catalyzed reduction by NTBA on the *S*-phenyl substituent is shown in Figure 3. It is unlikely that the deviations from linearity represent con-

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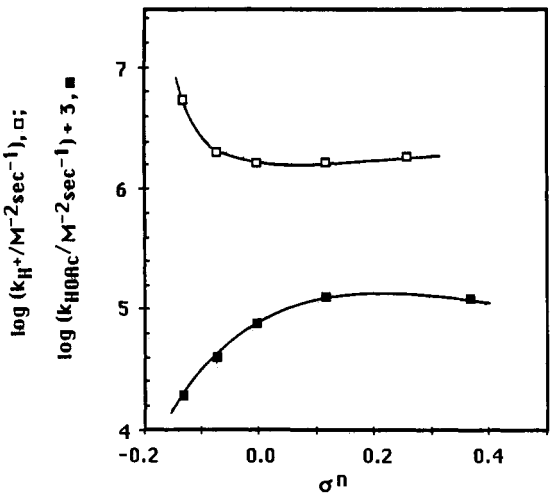

Figure 3. Plot of the logarithm of the third-order rate constant for the TBA reduction of *S*-methyl-*S*-(substituted phenyl)-sulfilimines as a function of the σ^n scale for the reaction catalyzed by proton (●) and by acetic acid (■). Aqueous solution, 25 °C, ionic strength 1.0 with KCl.

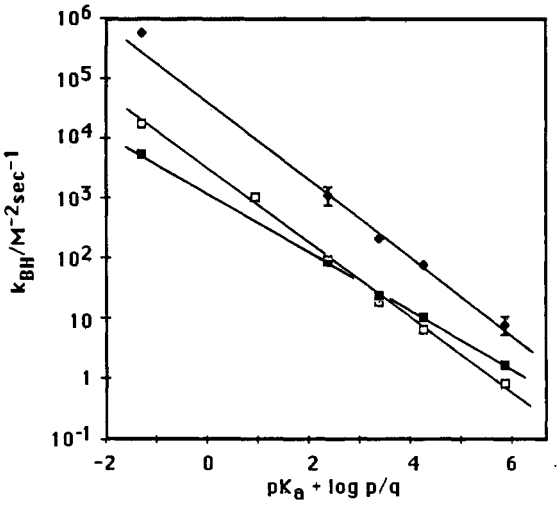

Figure 4. Brønsted plots for the general-acid-catalyzed thiolate reduction of *S*-methyl-*S*-(substituted phenyl)sulfilimines for the following phenyl substituents: 4-nitro, reduction by NTBA (■); 4-methoxy, reduction by NTBA (□); unsubstituted, reduction by TBA (●). Aqueous solution, 25 °C, ionic strength 1.0 with KCl. The slopes are 0.49, and 0.61, and ≈0.7, respectively.

tributions from resonance terms[10] since a very large r^+ value would be required to reconcile the nonlinearity. Further, resonance contributions through sulfur atoms are generally small due to poor overlap between the sulfur d orbitals and the aromatic π system.[11] It is most likely that the curvature is a simple result of systematic changes in transition-state structure in response to changes in the electropositivity of the central sulfur. The difference between the values shown in the figure, divided by the pK_a difference between the proton and acetate, gives a rough description of the behavior of the Brønsted α in response to substituent effects. In general, the data suggest that the α value *decreases* with electron-withdrawing groups in the phenyl substituent.

General-Acid-Catalyzed Reduction. As the concentration of buffer acid is increased at constant pH, the observed rate constants for the thiol reduction reactions increase linearly (figure 1). The catalytic constants for the buffers examined are collected in Table II, and the data appear in the Brønsted plots in Figure 4. The slopes of these plots, the Brønsted α values (Table III), decrease with electron-withdrawing groups in the sulfonium phenyl group; the change is shown numerically by the term $p_{xy} = \partial\alpha/\partial\sigma^n \approx 0.13$.[13] The presence of a large p_{xy} term such as this provides strong supportive evidence that the observed proton transfer is, in fact, *coupled*, to S–N bond breaking in the rate-limiting transition state. As is evident from the Hammett plots in Figure 3, the predicted structure/reactivity cross-correlation,[12] $\partial\alpha/\partial\sigma^n = \partial\rho/-\partial pK_a^{HA}$, is also observed. Increasing the pK_a of the reductant thiol (from NTBA to TBA) results in an increase in the Brønsted α to about 0.7 for the *S*-phenyl compound;

Table II. Rate Constants for the Thiolate Reduction of *S*-Methyl-*S*-(substituted phenyl)sulfilimmonium Salts[a]

substitutent	σ^n[b]	$10^4k_{H^+}$,[c] M^{-2} s^{-1}	k_{HOAc}, M^{-2} s^{-1}
Reduction by 2-Nitro-4-thiobenzoic Acid			
p-MeO	−0.13	5.05	6.36
p-Me	−0.12	3.3	7.78
m-Me	−0.07	3.28	8.08
unsubstituted	0	3.23	7.48
k_{H^+}/k_{D^+}[d]		7.62 ± 0.01	
m-MeO	0.12	1.77	10.1
p-F	0.15	1.91	7.58
p-Cl	0.26	1.40	6.67
p-Br	0.28	1.44	9.4
m-Cl	0.37	1.44	7.31
p-NO_2	0.78	1.52	10.1
k_{H^+}/k_{D^+}[d]		6.50 ± 0.01	
Reduction by 3-Thiobenzoic Acid			
p-MeO	−0.13	540	19
m-Me	−0.07	205	39
unsubstituted	0	163	76
k_{H^+}/k_{D^+}[d]		2.89 ± 0.01	
m-MeO	0.12	163	123
p-Cl	0.26	185	133
m-Cl	0.37	216	120
p-NO_2	0.78	220	
k_{H^+}/k_{D^+}[d]		1.66 ± 0.01	

[a] Reactions in aqueous solution, 25 °C, ionic strength 1.0 with KCl. [b] From: Hine, J. *Structural Effects of Equilibria in Organic Chemistry*; Wiley: New York, 1975; Chapter 3. [c] Third-order rate constant for reduction by thiolate anion. [d] Observed solvent deuterium isotope effect on the proton-catalyzed reaction.

Table III. Catalytic Constants for Buffer Catalysis of the Thiolate Reduction of *S*-Methyl-*S*-(substituted phenyl)sulfilimmonium Salts[a]

		k_{BH},[c] M^{-2} s^{-1}		
		NTBA		
buffer	pK_a[b]	*p*-OCH_3[d]	*p*-NO_2[d]	TBA, -H[d]
cacodylic acid	6.21	0.80	1.60	8 ± 3
acetic acid	4.60	6.36	10.1	75 ± 5
glycolic acid	3.82	17.9	22.6	200 ± 10
chloroacetic acid	2.70	80.0	80.0	
dichloroacetic acid	1008			
H_3O^+	−1.74	5.05×10^4	1.52×10^4	1.63×10^6
Brønsted α		0.61	0.49	0.7

[a] Reactions in aqueous solution, 25 °C, ionic strength 1.0 with KCl. [b] From: Jencks, W. P.; Regenstein, J. In *Handbook of Biochemistry and Molecular Biology*; Fasman, G. D., Ed.; CRC: Cleveland OH, 1975. Sayer, J. M.; Peskin, M.; Jencks, W. P. *J. Am. Chem. Soc.* **1973**, *95*, 4277–4287. [c] Second-order rate constant for general-acid-catalyzed reduction by thiolate anion. [d] Phenyl substituent.

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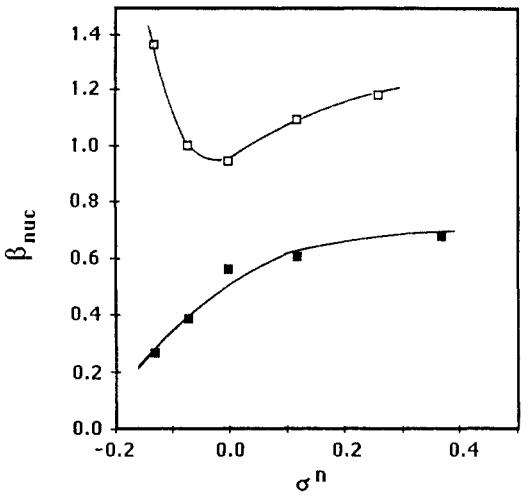

Figure 5. Plot of approximate β_{nuc} values for the thiolate reduction of *S*-methyl-*S*-(substituted phenyl)sulfilimines as a function of the σ^n scale for the reaction catalyzed by proton (●) and by acetic acid (■). Aqueous solution, 25 °C, ionic strength 1.0 with KCl.

the term $p_{xy} = \partial\beta_{nuc}/\partial pK_a^{HA} = \partial\alpha/\partial pK_a^{RSH} \approx 0.08$. The observed increase in the Brønsted α value is consistent with the *decrease* in the solvent deuterium isotope effect that is observed as the nucleophile is changed from NTBA to TBA. The *magnitude* of the decrease is surprisingly large, suggesting that a very sharp isotope effect maximum[13,14] may exist for proton transfer in the acid-catalyzed transition state. The data in Tables II and III can also be combined to give substituent effects on the approximate β_{nuc} values (Figure 5). Again, a nonlinear correlation is observed but, in general, increasing the acid strength increases the β_{nuc} value and, for most compounds, electron-withdrawing groups also tend to slightly increase β_{nuc}.

The parameters β_{nuc} and Brønsted α can be used as rough guides to locate the transition state on the surface of an expanded More O'Ferrell–Jencks reaction surface.[2-4,12] On the basis of these parameters, the transition state would appear to be in the upper right-hand, front sector of the multidimensional surface shown in Figure 2. In this reaction cube, each face represents a separate More O'Ferrell–Jencks reaction surface; such a cube is necessary in the present work since there are at least three modes of coupled motion available in the general catalyzed reaction. As before,[2] a stepwise reaction in which the protonated sulfurane is a distinct intermediate can be ruled out because the pK_a of such an intermediate (estimated previously[2] to be about 2 ± 1) would be *less than* the pK_a of many of the general acids used in this study,[14] making a reaction in which proton transfer was concerted with S–S bond formation thermodynamically unfavorable and henace disallowed.[15,16] A reaction coordinate involving general-acid-catalyzed breakdown of a sulfurane intermediate, formed at equilibrium, is also considered unlikely since there would be great difficulty in accounting for the observed (approximate) values of β_{nuc} (0.2–1.4) for a transition state in which complete S–S bond formation had occurred. Further, the term $(\partial\alpha/\partial pK_a^{RSH})$ would be predicted to be *positive* for a transition state involving general-acid-catalyzed breakdown of a sulfurane intermediate, inconsistent with the *negative* value that is observed (Table III).

If the transition state is, in fact, interior and in this sector of the cube, those intermediates that will have the largest effect on transition state movement will be those most similar in structure to the transition state itself. Thus, the movement of the transition state will be largely controlled by substituent effects on the two putative sulfurane–general acid encounter complexes on the right-front edge of the cube. The most significant forces in moving the transition state are likely to be *anti*-Hammond with respect to the stability of the two putative encounter complexes (arrows, Figure 2) since the angle between the transition state and the reactants and products is large.

Correlating the structure/reactivity parameters in Tables II and III with the intermediates opn the right-front edge of the diagram in Figure 2, increasing the acid strength of BH will *destabilize* the neutral sulfurane complex and *stabilize* the protonated sulfurane complex. The transition state will respond with *anti*-Hammond movements *away from* the bottom right corner and *toward* the upper right. Since the Brønsted α is ≥0.5, the largest movement will be toward the upper right, giving an *increase* in β_{nuc}, consistent with the data in Figure 5 and Table III. This same effect would predict an upward curvature to Brønsted plots since $\partial\alpha/\partial\text{-}pK_a^{HA}$ would be ≥0. This effect is (perhaps) slightly evident in the data for substituted acetate catalysis in the plots in Figure 4 and cannot be easily quantitated ($\partial\alpha/\partial\text{-}pK_a^{HA}$ is small).

Following similar arguments, increasing the pK_a of the thiol (adding electron-donating groups) will also stabilize the protonated sulfurane complex, leading to movement of the transition state up and to the right, giving an increase in the Brønsted α value, consistent with the data in Figure 4 and Tables II and III. Conversely, electron-withdrawing groups in the sulfonium phenyl should *stabilize* the neutral sulfurane complex and *destabilize* the protonated sulfurane. The movement now will be down and toward the neutral sulfurane leading to a *decrease* in the Brønsted α and an *increase* in the value of β_{nuc}, consistent with the data in Figures 4 and 5 and Tables II and III. The sign of the Hammett ρ and the curvature observed in the plots in Figure 3 ($\partial\rho/\partial\sigma^n \neq 0$) is more difficult to reconcile since very little is known that would allow equilibrium ρ values to be estimated for the intermediates shown in Figure 2. It is possible, however, that ρ may change sign on going from the sulfilimine encounter complex to the sulfurane intermediates since electron-withdrawing substituents would be expected to favor complex formation, but would *dis*favor sulfurane cation formation.

The present data are consistent with a fully concerted, general-acid-catalyzed S_N2 reaction. This general conclusion is based on the following arguments: general-acid catalysis is observed and there is a large isotope effect on the general catalyzed reaction, suggesting that proton transfer is involved in the rate-limiting transition state. Further, the Brønsted α changes considerably as the pK_a of the thiol is changed, indicating that the thiolate anion is having a direct effect on the extent and nature of the proton transfer and suggesting that thiolate is also present in the rate-limiting transition state. It seems unlikely that the thiolate is merely present as a "spectator" in the reaction complex since the value of β_{nuc} varies considerably as the nature of the sulfilimine or the pK_a of the catalyzing acid is changed, suggesting that bond formation to the attacking sulfur is actually occurring. Thus, the attack of

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(15) The pK_as for N-protonation of sulfilimines and sulfuranes derived from them are estimated to be about 16 and 7 units, respectively, below the pK_a of the parent amine.[3]
(16) Jencks, W. P. *Chem. Rev.* **1972**, *72*, 232–237.

thiolate on the sulfilimine seems to be concerted with proton transfer. The last requirement to make the reaction *fully* concerted (S–N cleavage) is inferred since (by the pK_a argument presented earlier) general catalysis is not expected to be thermodynamically favorable unless S–N bond breaking is also occurring (general catalysis of sulfurane formation is "disallowed" because the sulfilimine–NH_2^+ in the transition state would be a stronger acid than the acetate catalyst). Hence the conclusion that the reaction is behaving *as if* it was fully concerted. The observed structure/reactivity cross-correlations (p_{xy} coefficients)[12] for this coupled reaction are generally very large and, for Hammett data, the direct p_x coefficient is $\neq 0$. The sensitivity of the transition state to changes in reactant structure strongly suggests that the intrinsic Marcus barrier,[13,17] $\Delta G_0^{\ddagger}$, is very small and that a significant work (w_r) term contributes to $\Delta G_{obsd}^{\ddagger}$. The visualization of a multidimensional surface such as that in Figure 2 is not trivial, and it is difficult to intuitively grasp the physical meaning of a saddle point when it is described in (at least) four dimensions. Predictions, such as those given above, can often be obtained by separately visualizing each face as a three-dimensional surface and assuming that the resultant movement of the transition state will be the vector sum of each of those movements. While this approximation will give generalized indications of the direction of transition-state movements in response to structural changes, it would be very naive to suppose that changes in energies in one "face" were not iterated into the energies of all of the potential intermediates, resulting in complex, coupled movements. The reaction cube in the figure is, however, a useful tool for visualizing and appreciating the complexity of a highly coupled reaction such as this and for allowing qualitative explanations and predictions to be made. It should be noted that general catalysis is rarely seen in concerted displacement reactions, probably because of the entropic requirements of such a highly coupled transition states. In the present case, the high polarizability of the sulfur d orbitals may allow the formation of "unusually tight" encounter complexes, in effect, making the general catalyzed reaction "pseudo second order" and reducing the entropic requirements to attainable levels.

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Acknowledgment. This work was supported by a grant from the National Science Foundation, CHE 8511865.

Registry No. *p*-$MeOC_6H_4S(CH_3)NH_2^+ \cdot 2,4,6\text{-}Me_3C_6H_2SO_3^-$, 108297-57-0; *p*-$MeC_6H_4S(CH_3)NH_2^+ \cdot 2,4,6\text{-}Me_3C_6H_2SO_3^-$, 108297-58-1; *m*-$MeC_6H_4S(CH_3)NH_2^+ \cdot 2,4,6\text{-}Me_3C_6H_2SO_3^-$, 108297-60-5; $C_6H_5S(CH_3)NH_2^+ \cdot 2,4,6\text{-}Me_3C_6H_2SO_3^-$, 39149-52-5; *m*-$MeOC_6H_4S(CH_3)NH_2^+ \cdot 2,4,6\text{-}Me_3C_6H_2SO_3^-$, 108297-62-7; *p*-$FC_6H_4S(CH_3)NH_2^+ \cdot 2,4,6\text{-}Me_3C_6H_2SO_3^-$, 108297-64-9; *p*-$ClC_6H_4S(CH_3)NH_2^+ \cdot 2,4,6\text{-}Me_3C_6H_2SO_3^-$, 80723-63-3; *p*-$BrC_6H_4S(CH_3)NH_2^+ \cdot 2,4,6\text{-}Me_3C_6H_2SO_3^-$, 108297-66-1; *m*-$ClC_6H_4S(CH_3)NH_2^+ \cdot 2,4,6\text{-}Me_3C_6H_2SO_3^-$, 108297-68-3; *p*-$O_2NC_6H_4S(CH_3)NH_2^+ \cdot 2,4,6\text{-}Me_3C_6H_2SO_3^-$, 80723-54-2; *m*-$HSC_6H_4CO_2H$, 4869-59-4; D_2, 7782-39-0; MSH, 36016-40-7; *S*-methylthiophenol, 100-68-5; 2-nitro-4-thiobenzoic acid, 103840-07-9.

Nucleophilic Additions to Triazolinedione Ylides, Extremely Reactive Carbonyl Equivalents: A New Class of Condensation Reactions[1]

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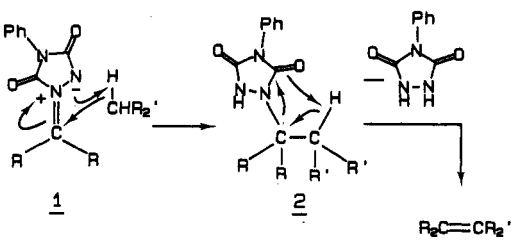
Received October 7, 1986

The ylides of *N*-phenyltriazolinedione (**10** and **13**) are readily prepared when the ylide carbon atom is substituted by phenyl or 3-methylindol-2-yl groups. In fact the indole-substituted ylide **10** is sufficiently stabile to be isolated in good yield when it is formed by the oxidation of the corresponding urazole **9** with *tert*-butyl hypochlorite followed by dehydrohalogenation with triethylamine. These triazolinedione ylides both undergo facile addition of nucleophiles at the ylide carbon atoms. In the case of nucleophilic addition by enolate species, the initial adducts undergo subsequent elimination of *N*-phenylurazole to form olefinic condensation products, while nucleophilic addition of pyrrole or *n*-butanethiol results in bis adducts in which two molecules of the nucleophile become attached to what had been the ylide carbon atom. The in situ generation of these triazolinedione ylides and subsequent transformations are operationally extremely simple procedures that frequently afford high product yields and as such would seem to offer considerable promise as synthetic methods.

Carbonyl condensation reactions are among the most important reactions in organic chemistry. It occurred to us that certain azomethine imine ylides might function as highly polar carbonyl analogues in this same capacity as outlined in Scheme I. In particular, triazolinedione ylides (**1**) have been generated by several methods[2] and are readily available through simple oxidation of appropriately substituted urazoles (vide infra). These ylides might be expected to offer several advantages in condensation reactions over the parent carbonyl compounds. The ylide itself might serve as the base to generate the requisite nucleophile when dealing with relatively acidic systems (Scheme I). The resulting protonated ylide, and possibly even the ylide itself, should be a substantially better electrophile than the parent carbonyl group. Finally, the resulting substituted urazole adduct (**2**) would be expected

Scheme I



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