of exchange of the α-methylene protons were followed by integrating the signals at 170 and 202 cps using the latter methoxy signal as internal standard. The methoxy group integral, divided by three, gave the value of the integral for one proton and from this the number of α-methylene protons as a function of time was determined. Pseudo-first-order rate constants were determined by multiplying the slopes of plots of log (hydrogen atoms remaining) *vs.* time by -2.303 (Table III).

Product Analysis. The courses of the reactions of 4-methoxy-2-butanone and of 4-methoxy-4-methyl-2-pentanone were scanned using a Beckman Model DBG spectrophotometer. Only increases in absorbance with time were observed at $\lambda_{\max}$ for 3-buten-2-one (213 mμ) and $\lambda_{\max}$ for 4-methyl-3-penten-2-one (244 mμ) for the respective reactions of the β-methoxy ketones.

To 3 ml of 0.1 *N* aqueous KOH solution contained in a cuvette was added 1.96×10^{-5} g (5×10^{-5} *M*) of 4-methoxy-4-methyl-2-pentanone in $^1/_{300}$ ml of methanol. After reaction the solution (5×10^{-5} *M* in product, mesityl oxide) had an absorbance of 0.553 OD. From the molar extinction coefficient for mesityl oxide, $1.11 \times 10^{-4,24}$ and the absorbance value 0.553, the concentration of mesityl oxide produced was 4.98×10^{-5} *M*, representing essentially quantitative conversion of 4-methoxy-4-methyl-2-pentanone to mesityl oxide.

For the reactions of **1** (9.4×10^{-5} *M*) in 0.02–0.10 *M* potassium hydroxide solutions (30°), the absorbance at 221 mμ at $t_{\max} = 0.145 \pm 0.002$ for five KOH concentrations. This absorbance corresponds to a 20% conversion of **1** to 3-buten-2-one ($\epsilon_{221} = 7.87 \times 10^3$) at $t_{\max}$. Conversion of **1** to 3-buten-2-one *via* an $A \rightarrow B \rightarrow C$ process alone requires 67% conversion to the α,β-unsaturated ketone at $t_{\max}$ (*vide supra*). Thus the elimination reaction of **1** proceeds to the extent of 30% and presumably most of **1** undergoes aldol-type condensation reactions. In an attempted product isolation experiment reaction of 0.5 g of **1** with potassium hydroxide solution yielded yellow, gumlike material which could not be characterized. This reaction is accompanied initially and transiently by the formation of the pungent, characteristic odor of 3-buten-2-one.

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Base-Catalyzed β-Elimination Reactions in Aqueous Solution. III. Elimination from *t*-Butyl 3-Acetoxythiol Esters[1]

Leo R. Fedor

Contribution from the Department of Medicinal Chemistry, School of Pharmacy, State University of New York at Buffalo, Buffalo, New York 14214.

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Abstract: The β elimination of acetate from *t*-butyl 3-acetoxyethiolpropionate (**1**), *t*-butyl 3-acetoxythiolbutyrate (**2**), and *t*-butyl 3-acetoxy-3-methylthiolbutyrate (**3**) to give the respective α,β-unsaturated thiol esters is general base catalyzed by tertiary amines and hydroxyl ion. The reactivities of the thiol esters are reasonably correlated by the Brønsted-type equations: $\log k_2(\mathbf{1}) = 0.25\text{p}K_a - 1.87$, $\log k_2(\mathbf{2}) = 0.37\text{p}K_a - 4.01$, and $\log k_2(\mathbf{3}) = 0.47\text{p}K_a - 6.10$.

The greater reactivity of thiol esters *vs.* oxygen esters in condensation reactions at the α-carbon atom is likely related to the stronger acidity of thiol esters as carbon acids.[2] This biologically important class of compounds possesses acidities comparable to ketones rather than to oxygen esters and accordingly thiol esters and ketones should possess similar reactivities with regard to reactions occurring at the α-methylene carbon atom. This investigation provides the basis for a comparison between the general base catalyzed elimination of acetate from *t*-butyl β-acetoxythiolcarboxylates (eq 1) and from β-acetoxy ketones.[3]

$$\begin{aligned} &R_1R_2C(OAc)CH_2COSC(CH_3)_3 + B \longrightarrow \\ &\qquad R_1R_2C{=}CHCOSC(CH_3)_3 + BH^+ + AcO^- \quad (1) \end{aligned}$$

Results

The reactions of *t*-butyl 3-acetoxythiolpropionate (**1**), *t*-butyl 3-acetoxythiolbutyrate (**2**), and *t*-butyl 3-acetoxy-3-methylthiolbutyrate (**3**) in aqueous solutions of tertiary amine buffers to give the appropriate α,β-unsaturated thiol esters (eq 1) are kinetically described by

$$dP/dt = (k_2[\text{amine}] + k_{\text{OH}}K_w/a_{\text{H}})[\text{thiol ester}] \quad (2)$$

eq 2. Under pseudo-first-order conditions at constant pH, $k_{\text{obsd}} = k_2'[\text{amine}]_{\text{total}} + k_{\text{OH}} + K_w/a_{\text{H}}$ and plots of k_{obsd} *vs.* $[\text{amine}]_{\text{total}}$ are linear with slope, k_2', and intercept, $k_{\text{OH}}K_w/a_{\text{H}}$ (Figure 1). The second-order rate constant k_2' may be evaluated by dividing k_2' by $K_a/(K_a + a_{\text{H}})$, the mole fraction of total amine present as free amine at a given pH (Table I). The value for k_2 was invariant within the limit of the experimental error for reactions carried out at several pH values for selected amines. No general acid catalysis was detected under the conditions of these experiments. The constant k_{OH} was evaluated from the slope of plots

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[1] Support for this investigation by the National Institutes of Health is gratefully acknowledged.

[2] T. C. Bruice and S. J. Benkovic, "Bioorganic Mechanisms," Vol. 1, W. A. Benjamin, Inc., New York, N. Y., 1966, Chapter 3 and references therein.

[3] L. R. Fedor, *J. Am. Chem. Soc.*, **89**, 4479 (1967).

Table I. Rate Constants for the Reaction of *t*-Butyl 3-Acetoxythiolpropionate (**1**), *t*-Butyl 3-Acetoxythiolbutyrate (**2**), and *t*-Butyl 3-Acetoxy-3-methylthiolbutyrate (**3**) with Tertiary Amines and Hydroxyl Ion (Solvent H_2O, t = 30°, μ = 1.0 *M* with KCl)

Ester	Base catalyst	pH (range)	k_2, M^{-1} min^{-1}	pK_a (pK_a^D)	Concn range	No. of k_{obsd} values
1	OH^- (A)		100			21
2			55			14
3			12			9
1	$(C_2H_5)_3N$ (B)	11.0	4.8		0.05–0.50	23
2			0.56	10.90	0.04–0.20	5
			0		0.04–0.10	4
1	t-$C_4H_9N(CH_3)_2$ (C)	10.8	6.4	10.80	0.02–0.20	13
2			0.47	10.80	0.02–0.20	6
3			0	10.74	0.04–0.20	5
1	i-$C_3H_7N(CH_3)_2$ (D)	10.58	8.4	10.54	0.05–0.50	5
2			0.98	10.52	0.05–0.50	6
3			0.082	10.58	0.02–0.10	5
1	$(C_2H_5)_2NCH_3$ (E)	10.58	6.8	10.60	0.02–0.32	10
2			0.84	10.55	0.04–0.40	6
3			0.046	10.58	0.02–0.10	5
1	$(CH_3)_2NC_2H_5$ (F)	10.36	7.2	10.35	0.02–0.10	5
			1.5	10.35	0.02–0.10	5
			0.093	10.01–10.36	0.02–0.10	10
1	n-$C_3H_7N(CH_3)_2$ (G)	10.24	7.7	10.24	0.02–0.20	6
			1.08	10.24	0.02–0.20	6
1	$(CH_3)_3N$ (H)	10.01	8.3	11.19	0.006–0.06	5
2			1.24	10.03	0.05–0.50	6
3			0.106	10.10	0.02–0.20	5
2	$(C_2H_5)_2NCH_2CH_2OH$ (I)	9.95	0.122	9.95	0.05–0.50	6
1	$(CH_3)_2NCH_2COO^-$ (J)	9.80	0.62	9.80	0.02–0.20	10
2			0.13	9.45	0.05–0.40	5
1	$(CH_3)_2NCH_2CH_2OH$ (K)	9.46	2.5	10.39	0.02–0.10	5
2			0.15	9.45	0.05–0.40	5
3			0.0062	10.08	0.10–0.50	5
2	$(CH_3)_2N(CH_2)_2N(CH_3)_2$ (L)	9.45	0.36	9.45	0.05–0.50	6
1	$N(CH_2CH_2)_3N$ (M)	9.15	2.4	10.60–10.90	0.02–0.10	10
2			0.35	9.03	0.04–0.10	5
3			0.02	9.55	0.04–0.20	5
1	$CH_3N(CH_2CH_2)_2O$ (N)	7.70	0.082	8.97	0.04–0.10	4
2			0.0073	8.75	0.05–0.50	5
1	OD^- [a]	11.02	165			
2		11.02	82.0			
3		11.02	18.1			
1	$(CH_3)_2NC_2H_5$ [b]	11.02	7.8	11.02		
2			1.58	11.02	0.02–0.08	5
3			0.089	11.02	0.02–0.08	3
1	$(CH_3)_2NC_2H_5$ [c]	9.46	0.83	9.46	0.06–0.10	3

[a] k_{obsd} extrapolated to zero buffer concentration in $(CH_3)_2NC_2H_5$–D_2O divided by a_{OD} (pD 11.02). [b] Solvent, D_2O. [c] Solvent, 50% aqueous dioxane; pH 9.46 = pK_a.

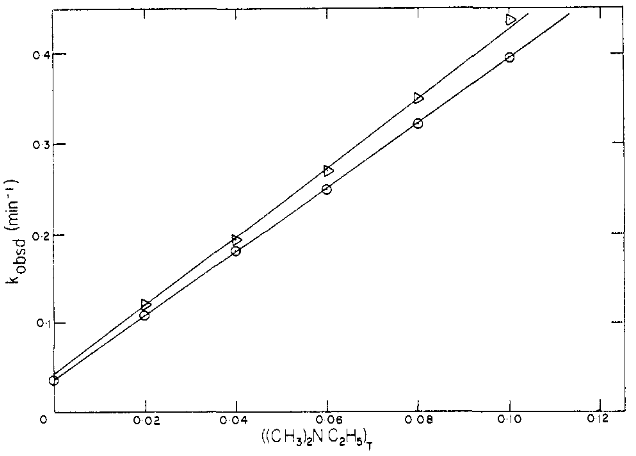

Figure 1. Plot of the pseudo-first-order rate constant, k_{obsd} (min^{-1}), *vs.* the total concentration (*M*) of dimethylethylamine for the reaction of *t*-butyl 3-acetoxythiolpropionate with the amine in water (○) and in deuterium oxide (△), t = 30°, μ = 1.0 *M* (KCl).

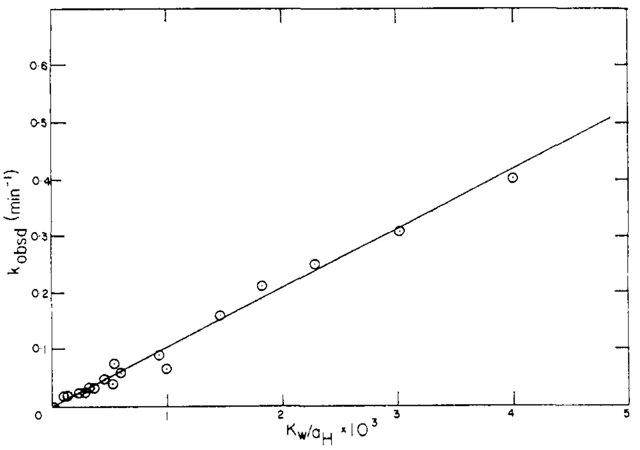

Figure 2. Plot of the pseudo-first-order rate constant, k_{obsd} (min^{-1}), determined by extrapolation of plots of k_{obsd} *vs.* buffer concentration to zero buffer concentration *vs.* the activity of hydroxyl ion, K_w/a_H, for reactions of *t*-butyl 3-acetoxythiolpropionate.

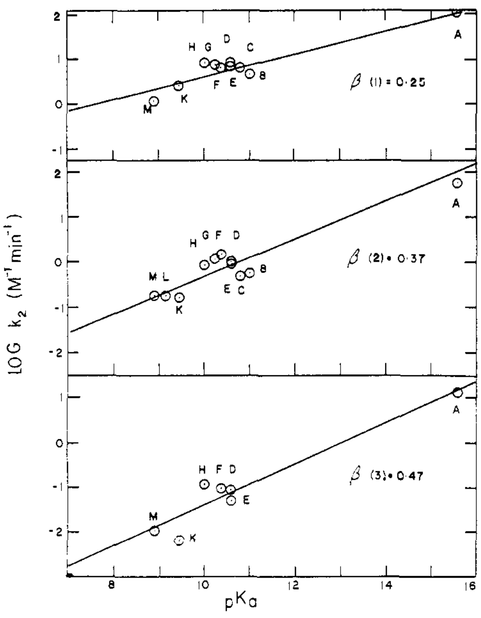

Figure 3. Brønsted-type plot of the logarithm of the second-order rate constant, k_2 (M^{-1} min^{-1}), *vs.* pK_a of the conjugate acid of the bases used. The equations of the lines are log $k_2(\mathbf{1}) = 0.25 \pm 0.03(r = 0.947)pK_a - 1.87$, log $k_2(\mathbf{2}) = 0.37 \pm 0.05(r = 0.930)pK_a - 4.01$, log $k_2(\mathbf{3}) = 0.47 \pm 0.06(r = 0.961)pK_a - 6.10$.

of k_{obsd}, determined by extrapolating plots of k_{obsd} *vs.* amine buffer concentration at constant pH to zero buffer concentration for several pH values *vs.* K_w/a_H (Figure 2). The deuterium solvent kinetic isotope effects, k_D/k_H, for the dimethylethylamine-catalyzed reactions of thiol esters are 1.08 for **1**, 0.95 for **2**, and 0.96 for **3** (Table I). A less reliable value for k_{OD} for the deuterioxide ion catalyzed reactions was determined by dividing the intercepts of plots of k_{obsd} *vs.* [$(CH_3)_2NC_2H_5$] in D_2O (Figure 1) by a_{OD} (Table I). From these values for k_{OD} the deuterium solvent kinetic isotope, k_D/k_H, for reactions with lyoxide species are 1.65 for **1**, 1.49 for **2**, and 1.51 for **3**.

Discussion

The β elimination of acetate from **1**, **2**, and **3** to give the respective α,β-unsaturated thiolesters (eq 1) is general base catalyzed by tertiary amines and by hydroxyl ion. The reactivities[4] of these compounds as well as their sensitivity to the strength of the base catalyst used are approximately given by the Bronsted-type equations, log $k_2(\mathbf{1}) = 0.25$p$K_a - 1.87$, log $k_2(\mathbf{2}) = 0.37$p$K_a - 4.01$, and log $k_2(\mathbf{3}) = 0.47$p$K_a - 6.10$ (Figure 3). Inspection of the equations reveals that the reactivities of **1**, **2**, and **3** decrease in this order and that the sensitivity of these thiol esters to the basicity of the catalyst decreases in the order $\mathbf{3} > \mathbf{2} > \mathbf{1}$, the order of decreasing β-methyl substitution. The variations in reactivity as well as in β suggest that steric factors and acidity factors are important determinants of the transition-state geometry for β elimination in thiol esters.

The most striking effect of steric hindrance to proton abstraction is seen in the failure of both triethylamine and N,N-dimethyl-*t*-butylamine to catalyze elimination of acetate from **3**. Similarly, triethylamine is weakly catalytic in the elimination of acetate from the structurally analogous 4-acetoxy-4-methyl-2-pentanone;[3] N,N-dimethyl-*t*-butylamine is not catalytic.[5] In contrast the Brønsted-type plot for **1** (Figure 3) shows that this thiol ester is practically insensitive to the bulk of the amine. Thus N,N-dimethyl-*t*-butylamine lies on the regression line and is presumed to be as effective as other tertiary amines catalyzing the elimination of acetate from **1**. In this connection Pearson and Williams[6] found that methylamine, $k_2 = 0.85$ M^{-1} min^{-1}, and *t*-butylamine, $k_2 = 1.13$ M^{-1} min^{-1}, Δp$K_a = 0.15$, are equally effective general base catalysts for the ionization of nitroethane. The effect on the rate of elimination of systematically increasing the bulk of the amine is evident in the reactions of **2**. Proceeding along the series trimethylamine ($k_2 = 1.24$ M^{-1} min^{-1}, p$K_a = 10.01$), dimethylethylamine ($k_2 = 1.5$ M^{-1} min^{-1}, p$K_a = 10.35$), dimethylisopropylamine ($k_2 = 0.98$ M^{-1} min^{-1}, p$K_a = 10.51$), dimethyl-*t*-butylamine ($k_2 = 0.47$ M^{-1} min^{-1}, p$K_a = 10.82$) the reactivity of the amines increases with increasing pK_a from trimethylamine to dimethylethylamine and then decreases with increasing pK_a and steric hindrance. The relative reactivities of **3**, **2**, and **1** toward hydroxyl ion are 1:4.6:8.35 (Table I). The ratio of the hydroxide rates for **3** and **1** may be compared with that for the reaction of hydroxyl ion with the structurally analogous ketones 4-acetoxy-4-methyl-2-pentanone and 4-acetoxy-2-butanone for which the ratio is 8.15.[3] A more striking example of the rate-retarding influence of β-methyl substitution in proton abstraction reactions is that of the base-catalyzed deuteration of 4,4-dimethyl-2-pentanone, 2-pentanone, and butanone for which the ratio of rate constants for α-methylene proton abstraction by deuterioxide ion is 1:43:100.[7] It can be concluded that steric hindrance within the series **1**, **2**, and **3** is a reflection of β-methyl substituion as well as increased bulk of the amine catalyst and the two factors are mutually inclusive in considerations of the nature of the transition-state geometry.

The sensitivity of **1**, **2**, and **3** toward general base catalysis increases in that order (β = 0.25, 0.37, 0.47). Assuming the Bronsted β coefficient provides a measure of the extent of proton transfer in the transition state[8] it may be concluded that there is successively more proton transfer in the transition state for elimination proceeding from **1** to **3** and that the transition state becomes successively more product like. The difference in the extent of proton transfer reasonably reflects a progressive decrease in acidity, $\mathbf{1} > \mathbf{2} > \mathbf{3}$, resulting from the inductive effects of the β-methyl substituents of **2** and **3** as well as from the different solvation capabilities of the incipient carbanion. Thus the presumed greater steric requirement of **3** suggests that it is more difficult to solvate the transition state for re-

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(4) The reactivity comparison is approximate because β varies throughout.

(5) The pseudo-first-order rate constants (min^{-1}) and concentrations of N,N-dimethyl-*t*-butylamine at pH 10.82 are 0.062, 0.04 *M*; 0.057, 0.10 *M*; 0.061, 0.16 *M*; 0.058, 0.20 *M*.

(6) R. G. Pearson and F. V. Williams, *J. Am. Chem. Soc.*, **76**, 258 (1954).

(7) C. Rappe and W. H. Sack, *J. Org. Chem.*, **32**, 4127 (1967).

(8) R. P. Bell, "The Proton in Chemistry," Cornell University Press, Ithaca, N. Y., 1959, Chapter 10.

actions of this thiol ester than for **1**.[9] The reactivities of **3** and of the structurally similar 4-acetoxy-4-methyl-2-pentanone are directly comparable since their Brønsted β coefficients are identical (0.47 *vs.* 0.46 *via* least squares). The approximately tenfold greater reactivity of the ketone over the thiol ester is likely a reflection of the presumed greater acidity of the ketone[2] although the difference in reactivity may be due to a difference in mechanism. Since the Brønsted-type relationship averages out deviations from the regression line, in cases where the relationship is imperfectly obeyed due to steric effects, the α effect, etc., it may be more meaningful to compare the reactivities of the thiol ester and ketone toward hydroxyl ion. For **1** and 4-acetoxy-2-butanone,[3] k_{co}/k_{cos} = 5.2; for **3** and 4-acetoxy-4-methyl-2-pentanone,[3] k_{co}/k_{cos} = 5.0. These rate ratios are comparable to that for proton transfer from the α-carbon atom of acetone and ethyl thiolacetate to hydroxyl ion for which $k_{co}/k_{cos} = 4.25$.[13]

General base catalysis in β elimination requires that proton abstraction be rate determining. Two mechanisms which accommodate this fact are (1) concerted proton transfer to the base accompanied by olefin bond formation and acetoxy bond breaking, (2) rate-determining enolization to give the enolate anion followed by rapid decomposition of this anion to give products. In accordance with these mechanisms, the deuterium solvent kinetic isotope effect predicts $k_D/k_H = 1$ for the amine-catalyzed reactions and 1.4–2.0 for the lyoxide ion catalyzed reactions.[14] Experimentally, k_D/k_H is 1.04–0.98 for the dimethylethylamine-catalyzed reactions of **1**, **2**, and **3**; 1.51–1.65 for the lyoxide ion catalyzed reactions of **1**, **2**, and **3**. Steffa and Thronton[15] have reported k_{OD}/k_{OH} ratios of 1.57–1.79 for β-elimination reactions of several β-phenylethyl derivatives and have taken this result as evidence of extensive proton transfer to lyoxide species in the transition state.

$$\mathrm{S} + \mathrm{B} \underset{k_2}{\overset{k_1}{\rightleftarrows}} \mathrm{S}^- + \mathrm{BH}^+ \quad \text{slow}$$

$$\mathrm{S}^- \xrightarrow{k_3} \text{products} \quad \text{fast}$$

In a recent study[16] evidence was offered in support of the ElcB mechanism for elimination of methoxide from 4-methoxy-2-butanone and from 4-methoxy-4-methyl-2-pentanone. Thus the rate of decomposition of these ketones to form the α,β-unsaturated ketones is independent of the concentration of amine buffer and dependent only on the pH of the solution which controls the concentration of enolate anion. Also, α-methylene proton exchange, as determined in D_2O by nuclear magnetic resonance spectroscopy, is rapid compared to the rate of elimination of methoxide ion and the exchange reaction is general base catalyzed. The change in mechanism from one of general base catalysis in the case of acetoxy ketones[3] to specific base catalysis in the case of methoxy ketones suggests that β elimination from ketones follows the above two-step sequence. In those cases involving good leaving groups (AcO^-), k_1 is rate determining; in those cases involving poor leaving groups (MeO^-), k_3 is rate determining.

As far as we are aware there is no direct evidence to indicate that thiol esters are capable of enolization. Thus there are no reported instances of O-alkylation of thiol esters or any evidence that they undergo imine formation.[17] This does not preclude the possibility that thiol esters are capable of undergoing enolization, however. In at least two other respects thiol esters behave like ketones: (1) thiol esters possess acidities comparable to ketones rather than to oxygen esters (*vida supra*), (2) thiol esters form addition products at the carbonyl bond.[19,20] These similarities as well as the similarity between β-acetoxy ketones and β-acetoxythiol esters in β-elimination reactions (general base catalysis and near-identity of β values) coupled with the probability that the ketones undergo elimination *via* rate-determining enolization suggests that the thiol esters may behave similarly. The evidence does not permit an unequivocal assignment of mechanism and additional experiments are in progress which hopefully will permit a distinction between a concerted mechanism and one involving rate-determining enolization.

Experimental Section

Apparatus. Gilford Model 2000 and Beckman DBG spectrophotometers were used for collection of rate data and for scanning reactions. Temperature was maintained in the cuvettes by circulating water of constant temperature from a Tamson T9 bath through thermospacers. pH was measured using a Radiometer PHM 22 pH meter with a PHA scale expander and a GK2021B combination electrode.

Reagents. Inorganic reagents were Fisher Certified ACS grade materials. Deuterium oxide, 99.8%, and deuterium chloride in deuterium oxide were purchased from Ciba Co. Tap distilled water was redistilled through a Corning AGla still before use. Organic reagents were purchased from Aldrich Chemical Co., Fisher Co., and Ames Laboratories and were redistilled or crystallized before use. Some of the tertiary amines used in this study were prepared by formic acid–formaldehyde methylation of the appropriate primary or secondary amine.[21] 3-Acetoxypropionic acid, bp 90-91° (0.5 mm) (lit.[22] 83-84° (0.4 mm)) was prepared from propiolactone and sodium acetate by the procedure of Gresham, *et al.*[22] 3-Acetoxybutyric acid was prepared from 3-hydroxybutyric acid and acetyl chloride in ether, bp 93-96° (0.8 mm) (lit.[23] 93-94° (0.5 mm)). 3-Hydroxy-3-methylbutyric acid was prepared from 4-hydroxy-4-methyl-2-pentanone by the haloform reaction.[24]

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[9] The solvation argument is analogous to that invoked to explain the acidity differences among the series ammonium ion, methylammonium ion, dimethylammonium ion, and trimethylammonium ion, to mention one example.[10-12]

[10] Reference 8, Chapter 5.

[11] A. G. Evans and S. D. Hamann, *Trans. Faraday Soc.*, **47**, 34 (1952).

[12] J. E. Leffler and E. Grunwald, "Rates and Equilibria of Organic Reactions," John Wiley & Sons, Inc., New York, N. Y., 1963, p 371, and references therein.

[13] G. E. Lienhard and F. C. Wang, *J. Am. Chem. Soc.*, **90**, 3781 (1968), and references therein.

[14] F. A. Long, *Ann. N. Y. Acad. Sci.*, **84**, 596 (1960).

[15] L. J. Steffa and E. R. Thornton, *J. Am. Chem. Soc.*, **89**, 6149 (1967).

[16] L. R. Fedor, *ibid.*, **91**, 908 (1969).

[17] Imino thiol esters are known[18] but they are not synthesized from thiol esters.

[18] Reference 13 and references therein.

[19] T. C. Bruice and L. R. Fedor, *J. Am. Chem. Soc.*, **86**, 4886 (1964).

[20] L. R. Fedor and T. C. Bruice, *ibid.*, **87**, 4138 (1965).

[21] H. T. Clarke, H. B. Gillespie, and S. Z. Weisshaus, *ibid.*, **55**, 4571 (1933).

[22] T. L. Gresham, J. E. Jansen, and F. W. Shaver, *ibid.*, **70**, 1003 (1948).

[23] R. Anschutz and O. Motschmann, *Ann.*, **392**, 100 (1912).

[24] D. D. Coffman, R. Cramer, and W. E. Mochel, *J. Am. Chem. Soc.*, **80**, 2882 (1958).

3-Acetoxy-3-methylbutyric acid, bp 90–93° (0.4 mm), was prepared from 3-hydroxy-3-methylbutyric acid and acetyl chloride in ether. Unless otherwise stated thiol esters were prepared *via* the mixed anhydride method as described. Equimolar quantities of the appropriate carboxylic acid and trifluoroacetic anhydride were mixed and allowed to stand for 20 min in a container fitted with a calcium chloride drying tube. To this mixed anhydride was added an equivalent amount of 2-methyl-2-propanethiol and the resulting solution, after standing 10–12 hr, was washed with sodium bicarbonate solution to remove the trifluoroacetic acid and extracted with ether. The ether extract was dried over magnesium sulfate, the ether was removed, and the residue was distilled to give the product. Prepared by this method were *t*-butyl 3-acetoxythiolpropionate, bp 59–60° (0.1 mm) (*Anal.* Calcd for $C_9H_{16}O_3S$: C, 52.91; H, 7.90; S, 15.70. Found: C, 52.77; H, 8.07; S, 16.08), *t*-butyl 3-acetoxythiolbutyrate, bp 60° (0.15 mm) (*Anal.* Calcd for $C_{10}H_{18}O_3S$: C, 55.01; H, 8.31; S, 14.69. Found: C, 55.29; H, 8.33; S, 14.90), *t*-butyl 3-acetoxy-3-methylthiolbutyrate, bp 60–64° (0.7 mm) (*Anal.* Calcd for $C_{11}H_{20}O_3S$: C, 56.86; H, 8.67; S, 13.80. Found: C, 56.45; H, 8.44; S, 13.70), *t*-butyl 3-bromothiolpropionate, bp 90–91° (6.5 mm), *t*-butyl 3-methylthiolcrotonate, bp 38° (0.6 mm) (*Anal.* Calcd for $C_9H_{16}OS$: C, 62.73; H, 9.36; S, 18.61. Found: C, 62.90; H, 9.47; S, 18.66). *t*-Butyl thiolacrylate, bp 46–47° (8 mm) (lit.[25] 44.5–45° (8 mm)) was prepared by the dehydrohalogenation of *t*-butyl 3-bromothiolpropionate with an equimolar amount of triethylamine in refluxing ether. *t*-Butyl thiolcrotonate, bp 37–41° (0.8 mm) (lit.[26] 99–101° (25 mm)) was prepared according to the method of Schleppnik and Zienty.[26]

Kinetics. Reactions were carried out under pseudo-first-order conditions at 30 ± 0.1° in aqueous solution $\mu = 1.0\ M$ (KCl), as previously described.[3] β elimination of acetate ion from β-acetoxythiol esters was monitored at 265 mμ, the OD increase with time providing a measure of the production of α,β-unsaturated thiol ester. Pseudo-first-order rate constants for reactions of *t*-butyl 3-acetoxythiolbutyrate and *t*-butyl 3-methylthiolbutyrate were determined from slopes of plots of log $(OD_\infty - OD_0)/(OD_\infty - OD_t)$ *vs.* time. Reactions of *t*-butyl 3-acetoxythiolpropionate are characterized by a rapid increase in absorbance at 265 mμ followed by a slower, but significant, decrease in absorbance. Kinetically this process is described as an A → B (k_1') → C (k_2') reaction.[27] The concentration of B, at any time is given by the expression $[B] = A_0k_1'/(k_2' - k_1')\{(e^{-k_1't} - e^{-k_2't})\}$. For large values of t, k_2' was determined by multiplying the slope of plots of log $(OD_t - OD_\infty)$ *vs.* t by 2.303.[16] The constant k_1' for elimination of acetate from *t*-butyl 3-acetoxythiolpropionate was determined by multiplying the slope of plots of log $\{e^{-k_2't} - [(OD_t - OD_\infty)/C]\}$ *vs.* t by 2.303.[16] The term C is a constant and is the intercept of those plots used to determine k_2'.

The reactions of relatively unhindered amines as trimethylamine with *t*-butyl 3-acetoxythiolpropionate is complicated by the tendency for these amines to rapidly react with the product, *t*-butyl thiolacrylate. The reaction is virtually instantaneous resulting in little or no absorbance increase at 265 mμ. The reaction is adequately described by the equation

$$CH_2{=}CHCOSC(CH_3)_3 + (CH_3)_3N + H^+ \rightleftharpoons (CH_3)_3\overset{+}{N}CH_2CH_2COSC(CH_3)_3$$

for which an equilibrium constant K may be written, K = (complex)/(thiolacrylate)($(CH_3)_3N$)(H^+) where (complex) = (total acrylate − free acrylate). For trimethylamine this constant has the value 1×10^{12} (Table II); for triethylenediamine, $K = 7 \pm 1 \times 10^{11}$ (data not shown). Because these interactions are hydrogen ion dependent complexation is disfavored by working with buffers of high pH and convenient absorbance changes at 265 mμ can be obtained.

Table II. Data for the Determination of K for the Interaction of *t*-Butyl Thiolacrylate with Trimethylamine

$((CH_3)_3N)_{total}$ M	pH	Absorbance[a]	(Complex) 10^5	$K \times 10^{-12}$
0.005	9.91	0.200	0.89	1.02
0.010	9.97	0.181	1.19	0.80
0.020	10.01	0.136	1.90	0.90
0.030	10.03	0.093	2.58	1.21
0.040	10.05	0.090	2.64	0.96
0.060	10.04	0.057	3.16	1.23
0.100	10.07	0.039	3.44	1.19
				1.04

[a] The absorbance due to *t*-butyl thiolacrylate in water = 0.256, $\epsilon = 6300\ cm^{-1}\ M^{-1}$ (263 mμ); therefore, the concentration of *t*-butyl thiolacrylate = $4.07 \times 10^{-5}\ M$.

pK_a values were determined by the method of half-neutralization. pD was determined from the equation of Fife and Bruice.[28] Hydroxyl ion activity was determined from K_w/a_H where $-\log K_w$ = 13.833 at 30°[29] and deuterioxide ion activity was determined from K_D/a_D where $-\log K_D$ = 14.65 at 30°.[30]

Products. The reactions of *t*-butyl 3-acetoxythiolpropionate, *t*-butyl 3-acetoxythiolbutyrate, and *t*-butyl 3-acetoxy-3-methylthiolbutyrate with tertiary amines were scanned from 325 to 200 mμ. The spectra are characterized by a decrease in absorbance at 233 mμ with a concomitant increase in absorbance at 265 mμ. These absorbances correspond to the saturated thiol esters and their respective α,β-unsaturated thiolesters.

In the pH range 10.18–11.00 (four pH values, 23 k_{obsd} values), the second-order rate constant for loss of absorbance at 265 mμ for the reaction of *t*-butyl 3-acetoxythiolpropionate with triethylamine is 0.31 M^{-1} min^{-1}; for loss of absorbance at 265 mμ for the reaction of *t*-butyl thiolacrylate with triethylamine (3 pH values, 17 k_{obsd} values), $k_2 = 0.33\ M^{-1}$ min^{-1}.

t-Butyl 3-acetoxythiolpropionate in 0.2 M N,N-dimethyl-*t*-butylamine buffer, pH 10.80, gave 92% *t*-butyl thiolacrylate; *t*-butyl 3-acetoxythiolbutyrate in 0.045 M trimethylamine buffer, pH 10.05, gave 86% *t*-butyl thiolcrotonate. Thus the rate of hydrolysis of the thiolesters is unimportant compared with the rate of β elimination.

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