

Study of the Alkaline Hydrolysis and Nuclear Magnetic Resonance Spectra of Some Thiol Esters¹

JOHN P. IDOUX*

Department of Chemistry, Florida Technological University, Orlando, Florida 32816

PHILIP T. R. HWANG² AND C. KINNEY HANCOCK

Department of Chemistry, Texas A & M University, College Station, Texas 77843

Received June 29, 1973

The alkaline hydrolysis rate constants at 35° in 40% aqueous *p*-dioxane and the nmr chemical shifts have been measured for nine thiolacetates, CH₂COSR', nine methyl thiol esters, RCOSCH₃, and seven disubstituted thiol esters, RCOSR'. Alkaline hydrolysis rate constants are controlled almost exclusively by steric effects of the R and R' groups. The nmr substituent chemical shifts (SCS) of thiol esters are controlled largely by steric and six-number effects of the R and R' groups. All of these correlations are discussed and compared with correlations previously reported for similar oxygen esters, RCOOR', on the basis of differences in various structural features of the two series. A contributing structure involving negative charge development at the sulfur atom is apparently not of importance for simple thiol esters.

In the alkaline hydrolysis of esters, RCOOR', the reaction site in the reactant state is trigonal and unsaturated while the reaction site in the intermediate is tetrahedral and saturated. Moreover, the rate-determining step in the mechanism³ for the reaction is the coordination of the hydroxyl ion with the carbonyl carbon. Consequently, in the absence of α,β unsaturation in the R group, the alkaline hydrolysis rate constant for RCOOR' is affected by polar and steric effects of the R' group.

For example, eq 1 has been found⁴ for the alkaline hydrolysis rate constants of nine methyl esters, RCO-

$$\log k = 1.25 + 1.75\sigma^* + 0.848 E_s^c - 0.383 (n - 3),$$

(100.0) (100.0) (100.0)

$$R = 0.998, s = 0.043 \quad (1)$$

OCH₃, in 40% aqueous *p*-dioxane at 35°. In eq 1, k is the second-order rate constant, σ^* is Taft's polar substituent constant,^{5a} E_s^c is Taft's steric substituent constant^{5b} corrected⁴ for hyperconjugative effects, n is the number of α hydrogens in the R group, R is the multiple correlation coefficient,^{6a} and s is the standard deviation from regression.^{6a} The numbers in parentheses below the three coefficients of eq 1 are the percentage confidence levels as determined by "Student's" t tests.^{6b} It is apparent from eq 1 that $\log k$ is an almost exact function of σ^* , E_s^c , and $(n - 3)$, with each of these three independent variables being highly significant.

Further, Newman⁷ has shown that, for the esterification of carboxylic acids and the hydrolysis of esters, the six number of a substituent (*i.e.*, the number of atoms in the six position from the carbonyl oxygen atom as atom one) makes a large contribution to the

total steric effect of that substituent. For example, eq 2 has been found⁸ for the alkaline hydrolysis rate

$$\log k = 1.35 + 0.688\sigma^* + 0.644 E_s^c + 0.0477 (\Delta 6),$$

(95.5) (100.0) (99.4)

$$R = 0.997, s = 0.070 \quad (2)$$

constants of nine acetate esters, CH₂COOR', in 40% aqueous *p*-dioxane at 35°. In eq 2, $\Delta 6$ is the change in the six number, *i.e.*, the difference of the six number of a substituent in the R part of the ester minus the six number of the same substituent in the R' part of the ester. It is evident that eq 2 provides a quantitative relationship that is almost as exact as that of eq 1.

For the nine acetate esters mentioned previously,⁸ in addition to nine others, Rosado and his coworkers⁹ have found eq 3 to apply to the measured substituent chemical shifts (SCS) of these acetates relative to methyl acetate. In eq 3, σ^* has the same meaning as

$$\text{SCS (Hz)} = 0.953 + 20.4\sigma^* + 1.11 (\text{C-6 no.}),$$

(100.0) (100.0)

$$R = 0.943, s = 0.659 \quad (3)$$

before and C-6 no. is the number of carbon atoms in the six position.⁷ Equation 3 indicates, as concluded by Kan,¹⁰ that the SCS values of acetate esters are governed largely by polar and six number effects of the R' group. Rosado and his coworkers⁹ have also measured the SCS of a series of methyl esters relative to methyl acetate and have found that eq 4 applies for this series.

$$\text{SCS (Hz)} = 0.446 + 18.4\sigma^* - 2.06 (n - 3),$$

(100.0) (100.0)

$$R = 0.863, s = 0.415 \quad (4)$$

In view of the differences and of the multitude of substituent effects exhibited by oxygen esters in alkaline hydrolysis and in substituent chemical shift correlations, we have made similar studies on the corresponding sulfur esters. The present paper is concerned with the results of these studies and with a

(1) Presented in part at the Florida Section American Chemical Society Meeting-in-Miniature, Key Biscayne, Fla., May 18-20, 1972.

(2) Abstracted in part from the Ph.D. Dissertation of P. T. R. Hwang, Texas A & M University, Aug 1965.

(3) M. L. Bender, *J. Amer. Chem. Soc.*, **73**, 1626 (1951).

(4) C. K. Hancock, E. A. Meyers, and B. J. Yager, *J. Amer. Chem. Soc.*, **83**, 4211 (1961).

(5) R. W. Taft, Jr., "Steric Effects in Organic Chemistry," M. S. Newman, Ed., Wiley, New York, N. Y., 1956: (a) p 619; (b) p 598.

(6) G. W. Snedecor, "Statistical Methods," 5th ed, The Iowa State College Press, Ames, Iowa, 1956: (a) Chapter 14; (b) pp 46, 418, and 441; (c) Chapter 6.

(7) M. S. Newman, *J. Amer. Chem. Soc.*, **72**, 4783 (1950).

(8) C. K. Hancock, B. J. Yager, C. P. Falls, and J. O. Schreck, *J. Amer. Chem. Soc.*, **85**, 1297 (1963).

(9) O. Rosado-Lojo, C. Kinney Hancock, and A. Danti, *J. Org. Chem.*, **31**, 1899 (1966).

(10) R. O. Kan, *J. Amer. Chem. Soc.*, **86**, 5180 (1964).

comparison of these results to those for the corresponding oxygen esters.

Results and Discussion

Alkaline Hydrolysis Rate Constants of Thiol Esters.—The alkaline hydrolysis rate constants at 35° in 40% aqueous *p*-dioxane for 24 thiol esters are shown in Table I and the various substituent parameters are shown in Table II.

TABLE I
ALKALINE HYDROLYSIS RATE CONSTANTS FOR 24 THIOL
ESTERS IN 40% AQUEOUS *p*-DIOXANE AT 35°

Registry no.	RCOSR'		<i>k</i> , l. mol ⁻¹ min ⁻¹ , av	
	No.	R'		
625-60-5	1	CH ₃	C ₂ H ₅	9.58
2307-10-0	2	CH ₃	<i>n</i> -C ₃ H ₇	7.40
926-73-8	3	CH ₃	<i>i</i> -C ₃ H ₇	5.74
928-47-2	4	CH ₃	<i>n</i> -C ₄ H ₉	6.30
2432-37-3	5	CH ₃	<i>i</i> -C ₄ H ₉	6.23
2432-39-5	6	CH ₃	<i>s</i> -C ₄ H ₉	4.14
999-90-6	7	CH ₃	<i>t</i> -C ₄ H ₉	2.52
32362-99-5	8	CH ₃	C ₆ H ₅ CH ₂	12.59
1534-08-3	9	CH ₃	CH ₃	17.42
5925-75-7	10	C ₂ H ₅	CH ₃	11.49
2432-51-1	11	<i>n</i> -C ₃ H ₇	CH ₃	5.32
42075-42-3	12	<i>i</i> -C ₃ H ₇	CH ₃	3.46
42075-43-4	13	<i>n</i> -C ₄ H ₉	CH ₃	4.66
23747-45-7	14	<i>i</i> -C ₄ H ₉	CH ₃	1.32
42075-45-6	15	<i>s</i> -C ₄ H ₉	CH ₃	1.02
42075-46-7	16	<i>t</i> -C ₄ H ₉	CH ₃	0.45
5925-74-6	17	C ₆ H ₅ CH ₂	CH ₃	10.70
2432-42-0	18	C ₂ H ₅	C ₂ H ₅	5.93
2432-92-0	19	<i>n</i> -C ₃ H ₇	C ₂ H ₅	2.56
6330-43-4	20	<i>n</i> -C ₃ H ₇	<i>t</i> -C ₄ H ₉	0.506
2432-91-9	21	<i>i</i> -C ₄ H ₉	<i>s</i> -C ₄ H ₉	0.278
42075-51-4	22	<i>s</i> -C ₄ H ₉	<i>t</i> -C ₄ H ₉	0.0756
28058-96-0	23	<i>t</i> -C ₄ H ₉	<i>t</i> -C ₄ H ₉	0.0390
42075-53-6	24	<i>n</i> -C ₄ H ₉	C ₆ H ₅ CH ₂	4.86

TABLE II
SUBSTITUENT PARAMETERS

No.	Substituent	σ^{*a}	E_s^b	E_s^{cc}	$(n-3)^d$	$\Delta\epsilon^e$	$6\#^f$
1	C ₂ H ₅	-0.100	-0.07	-0.38	-1	-3	0
2	<i>n</i> -C ₃ H ₇	-0.115	-0.36	-0.67	-1	0	3
3	<i>i</i> -C ₃ H ₇	-0.190	-0.47	-1.08	-2	-6	0
4	<i>n</i> -C ₄ H ₉	-0.130	-0.39	-0.70	-1	0	3
5	<i>i</i> -C ₄ H ₉	-0.125	-0.93	-1.24	-1	3	6
6	<i>s</i> -C ₄ H ₉	-0.210	-1.13	-1.74	-2	-3	3
7	<i>t</i> -C ₄ H ₉	-0.300	-1.54	-2.46	-3	-9	0
8	C ₆ H ₅ CH ₂	0.215	-0.38	-0.69	-1	2	4
9	CH ₃	0.000	0.00	0.00	0	0	0

^a Reference 5a. ^b Reference 5b. ^c Reference 4. ^d n is the number of α hydrogens. ^e Reference 8. ^f Reference 7.

A. Thiolacetates, CH₃COSR'.—Since eq 2 provides a good correlation *via* the extended Taft equation for the alkaline hydrolysis of the oxygen esters, CH₃COOR', a similar correlation has been attempted for the corresponding thiolacetates (No. 1–9 of Table I) to give eq 5. Rejecting the least significant variable, $\Delta\epsilon$, the $\log k = 1.14 + 0.675\sigma^* + 0.236E_s^c + 0.0032(\Delta\epsilon)$,
(95.9) (99.7) (26.6)

$$R = 0.977, s = 0.067 \quad (5)$$

correlation becomes eq 6. Rejecting the next least significant variable, $\Delta\epsilon$, the $\log k = 1.14 + 0.632\sigma^* + 0.232E_s^c$,
(98.1) (99.9)

$$R = 0.976, s = 0.062 \quad (6)$$

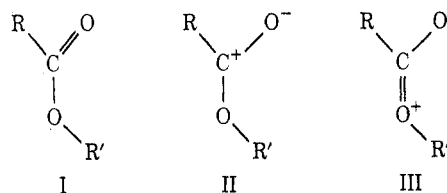
nificant variable, σ^* , the correlation becomes eq 7. Statistical consideration of eq 5–7 indicates that $\Delta\epsilon$

$$\log k = 1.15 + 0.314E_s^c, r = 0.936, s = 0.094 \quad (7)$$

(100.0)

is not significant, σ^* is significant, and E_s^c is highly significant. Of the total variance of $\log k$, 95.3% ($R^2 \times 100$) is accounted for by eq 6 and 87.6% is accounted for by eq 7. Thus, it appears that most of the variation in the $\log k$'s of the thiolacetates is due to steric effects. In contrast, for the corresponding acetates, CH₃COOR', $\log k$ is a good function of σ^* , E_s^c , and $\Delta\epsilon$, as shown previously by eq 2.

The nine thiolacetates (with the exception of R' = CH₃) used in the correlations to obtain eq 5–7 all undergo the alkaline hydrolysis reaction more rapidly than the corresponding acetates under the same experimental conditions. The greater reactivity of the thiolacetates is not due to mercaptide ion catalysis, since comparable rates were obtained between reactions run in the presence of initial concentrations of mercaptide ion of 0.006 *M* and reactions run in the absence of added mercaptide ion. These differences in reactivity as well as the predominant influence of steric effects over that of polar and six-number effects on the $\log k$ values of the thiolacetates compared to the importance of all three of these factors with regard to the acetates can be accounted for on the basis of differences in various structural features of the two series. That is, esters exist predominantly¹¹ in the *cis* conformation I and are resonance hybrids¹² with structures I, II, and III being the main contributors. While similar



contributors might be expected for thiol esters, a form such as III makes little contribution to the structure of a thiol ester relative to an oxygen ester, since the unshared electron pairs on the larger sulfur atom are not able to overlap as efficiently with the adjacent carbonyl group and form a double bond. At the same time, therefore, the relative importance of a form such as II should be more important for thiol esters than for the corresponding oxygen esters and should effectively render the carbonyl group of the thiol esters more polarizable. The observed greater reactivity of the thiolacetates toward alkaline hydrolysis relative to the acetates can be accounted for on this basis, since the rate-determining step in both reactions is coordination of the hydroxide ion with the carbonyl group. In addition to the relative importance of various contributing structures and on the basis of bond-angle data for sulfides and ethers^{13,14} and bond-distance data for thiol acids and carboxylic acids,^{15,16} one would

(11) J. M. O'Gorman, W. Shand, Jr., and V. Schomaker, *J. Amer. Chem. Soc.*, **72**, 4222 (1950).

(12) G. W. Wheland, "Resonance in Organic Chemistry," Wiley, New York, N. Y., 1955, p 236.

(13) L. O. Brockway and H. O. Jenkins, *J. Amer. Chem. Soc.*, **58**, 2036 (1936).

(14) L. Pauling and L. O. Brockway, *J. Amer. Chem. Soc.*, **58**, 2684 (1935).

(15) W. Gordy, *J. Chem. Phys.*, **14**, 560 (1946).

(16) I. L. Karle and J. Karle, *J. Chem. Phys.*, **22**, 43 (1954).

expect the C-S-C bond angle of a thiol ester to be smaller than the corresponding C-O-C bond angle in an oxygen ester and the carbonyl C-S bond in a thiol ester to be longer than the corresponding carbonyl C-O bond in the oxygen ester. Thus any polar effect from R' will have to be transmitted over a longer distance in the case of thiol esters. This fact, along with the decreased importance of a contributing form such as III for thiol esters compared to oxygen esters, indicates that polar effects from R' should be less important in thiol esters relative to oxygen esters. In essence, then, the sulfur atom in the thiol acetates appears to serve as an effective buffer of polar effects from R'.

The smaller C-S-C bond angle and the longer C-S bond in thiol esters relative to the corresponding C-O parameters in the oxygen esters have the effect of moving the R' group of the thiol ester closer to the carbonyl oxygen and farther from the carbonyl carbon where the rate-determining coordination with the hydroxyl ion occurs. The result is that the relative importance of steric effects for the thiolacetates should be less than for the acetates. This is indeed reflected in the smaller δ° values of eq 5-7 compared to that of 0.664 in eq 2. In addition, the bond-angle and bond-distance differences are probably responsible then for the insignificance of the effect of the changes in the six number, $\Delta 6$, in the case of the thiol esters since, as pointed out previously,⁸ the six number of a particular group often changes when that group's position in the acyl portion of an ester is compared to its position in the alkyl portion.

B. Methyl Thiol Esters, RCOSCH₃.—Since eq 1 provides an excellent correlation for the methyl esters, RCOOCH₃, under the same experimental conditions, a similar correlation for the corresponding methyl thiol esters (No. 9-17 of Table I) was carried out to give eq 8.

$$\log k = 1.14 + 0.947\sigma^* + 0.917 E_s^\circ - 0.323 (n - 3),$$

(98.2) (100.0) (98.4)

$$R = 0.002, s = 0.083 \quad (8)$$

Rejecting $(n - 3)$ the correlation becomes eq 9.

$$\log k = 1.23 + 0.719\sigma^* + 0.599 E_s^\circ,$$

(83.3) (99.9)

$$R = 0.973, s = 0.143 \quad (9)$$

Rejecting σ^* , the correlation becomes eq 10.

$$\log k = 1.25 + 0.691 E_s^\circ, r = 0.961, s = 0.157 \quad (10)$$

(100.0)

Equation 8 accounts for 98.5% ($R^2 \times 100$) of the variance of $\log k$ and indicates that σ^* and $(n - 3)$ are significant while E_s° is highly significant. Equation 10 accounts for 92.5% of the variance of $\log k$ and indicates that $\log k$ for the alkaline hydrolysis of RCO-SCH₃, as in the case of the thiolacetates (CH₃CO-SR'), is controlled largely by steric effects of the substituent alkyl group. However, in contrast to the thiolacetates, the methyl thiol esters all undergo the alkaline hydrolysis reaction more slowly than the corresponding methyl acetates under the same experimental conditions. This is probably due in part to the slightly greater influence of steric effects in the acyl portion of a methyl thiolacetate relative to that in a methyl acetate (*i.e.* δ° of eq 8 is 0.917 compared to 0.848 in eq 1.)

In general, steric effects are of preponderant influence in controlling the alkaline hydrolysis of any thiol ester (RCOSR'). This is confirmed by the correlation provided by eq 11, which is the multiple regression of $\log k$ for all the thiol esters of Table I on the appropriate steric substituent constants. Equation 11, with only two independent variables, accounts for

$$\log k = 1.24 + 0.704 E_{sr}^\circ + 0.410 E_{sr}^c,$$

$$R = 0.980, s = 0.144 \quad (11)$$

96.1% ($R^2 \times 100$) of the variance of $\log k$ and is as significant as the multiple regression of $\log k$ on $\sigma_{R'}^*$ ($n - 3$), $\sigma_{R'}^*$ ($\Delta 6$), E_{sr}° and E_{sr}^c .

Nuclear Magnetic Resonance Spectra of Thiol Esters.—The substituent chemical shifts (SCS) of 17 thiol esters relative to methyl thiolacetate are given in Table III. Inspection of these data shows that the

TABLE III
SUBSTITUENT CHEMICAL SHIFTS (SCS) FOR 17 THIOL ESTERS

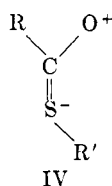
No.	—Thiol ester RCOSR'—		Shift of RCOSR' from CH ₃ CO-SCH ₃ , Hz, 37°, neat vs. TMS
	R	R'	
1	CH ₃	C ₂ H ₅	1.7
2	CH ₃	<i>n</i> -C ₃ H ₇	1.4
3	CH ₃	<i>i</i> -C ₃ H ₇	-0.5
4	CH ₃	<i>n</i> -C ₄ H ₉	0.3
5	CH ₃	<i>i</i> -C ₄ H ₉	0.7
6	CH ₃	<i>s</i> -C ₄ H ₉	-0.4
7	CH ₃	<i>t</i> -C ₄ H ₉	-5.1
8	CH ₃	C ₆ H ₅ CH ₂	-10.7
9	CH ₃	CH ₃	0.0
10	C ₂ H ₅	CH ₃	-0.4
11	<i>n</i> -C ₃ H ₇	CH ₃	0.1
12	<i>i</i> -C ₃ H ₇	CH ₃	-1.0
13	<i>n</i> -C ₄ H ₉	CH ₃	-0.4
14	<i>i</i> -C ₄ H ₉	CH ₃	-0.2
15	<i>s</i> -C ₄ H ₉	CH ₃	-0.9
16	<i>t</i> -C ₄ H ₉	CH ₃	-3.3
17	C ₆ H ₅ CH ₂	CH ₃	-12.5

SCS for benzyl thiolacetate (no. 8) and methyl phenylthiolacetate (no. 17) are markedly different from those of the other 15 thiol esters. These large differences are due to the magnetic anisotropy¹⁰ of the phenyl ring present in both of these thiol esters and absent in the other 15. Consequently, the data for these two thiol esters are omitted in all of the subsequent correlations involving the chemical shifts.

It is interesting to note that the acyl methyl hydrogens of the thiolacetates occur downfield relative to these hydrogens in the corresponding acetates. The greater importance of resonance forms such as II (positive charge development on the carbonyl carbon) and the decreased importance of forms such as III (multiple bond character of atoms between R and R') for the thiolacetates relative to the acetates have the effect of causing less shielding of the acyl methyl hydrogens in the thiolacetates. As a result, these hydrogens experience a greater downfield shift relative to those in the acetates. On the other hand, the alkyl methyl hydrogens of the methyl esters occur downfield relative to these hydrogens in the methyl thiol esters. In this case, the greater importance of a resonance form (III) involving positive charge development on the alkyl oxygen of a methyl ester relative to such positive

charge development on the sulfur atom of a methyl thiol ester tends to decrease the shielding of the alkyl methyl hydrogens in a methyl ester and thus shifts them downfield.

We would like to point out that the contributing structure IV has been suggested¹⁷ as being important



for thiol esters relative to oxygen esters and has been considered when explaining differences between thiol esters and other acyl compounds.^{18,19} Structure IV suggests negative charge development at the sulfur atom *via* electron donation from the carbonyl group into the sulfur 3d orbitals. The importance of such a structure could easily be invoked in explaining our reactivity and nmr data. However, we do not feel it necessary to do so but rather the fact that our data are explicable in terms of more conventional structures leads us to question the importance of IV as a significant factor in the ground-state stabilization of thiol esters. Wadsö²⁰ has reported heats of hydrolysis for thiol esters and oxygen esters which confirm this conclusion and more recently Collings²¹ and his co-workers have questioned the importance of structure IV based on infrared studies on thiol esters and other acyl compounds.

A. Thiolacetates, CH₃COSR'.—In view of the fairly good correlation provided by eq 3 for the acetates, the correlation of the SCS of the acyl methyl protons of eight of the thiolacetates (benzyl thiolacetate omitted) was also attempted. σ^* and H-6 no., where H-6 no. (see Table IV) is the number of hydrogen atoms in the

TABLE IV
CARBON SIX NUMBERS AND HYDROGEN SIX NUMBERS
FOR SUBSTITUENTS

Substituent	As R' of CH ₃ COSR'		As R of RCOSCH ₃	
	C-6 no. ^a	H-6 no. ^b	C-6 no. ^a	H-6 no. ^b
CH ₃	0	0	0	0
C ₂ H ₅	0	3	0	0
<i>n</i> -C ₃ H ₇	1	2	0	3
<i>i</i> -C ₃ H ₇	0	6	0	0
<i>n</i> -C ₄ H ₉	1	2	1	2
<i>i</i> -C ₄ H ₉	2	1	0	6
<i>s</i> -C ₄ H ₉	1	5	0	3
<i>t</i> -C ₄ H ₉	0	9	0	0

^a Carbon six number, *i.e.*, the number of carbon atoms in the six position from the carbonyl oxygen atom as atom number one.

^b Hydrogen six number, *i.e.*, the number of hydrogen atoms in the six position from the carbonyl oxygen atom as atom number one.

six position from the carbonyl oxygen atom as atom number one, were found to be insignificant variables.

(17) A. W. Baker and G. H. Harris, *J. Amer. Chem. Soc.*, **82**, 1923 (1960).

(18) I. Wallmark, M. H. Krackov, S. Chu, and H. G. Mautner, *J. Amer. Chem. Soc.*, **92**, 4447 (1970).

(19) W. P. Jencks, B. Schaffhausen, K. Tornheim, and H. White, *J. Amer. Chem. Soc.*, **93**, 3917 (1971).

(20) I. Wadsö, *Acta Chem. Scand.*, **16**, 487 (1962).

(21) A. J. Collings, P. F. Jackson, and K. J. Morgan, *J. Chem. Soc. B*, 581 (1970).

The relationship which best fits the data is shown in eq 12. This equation accounts for 79% of the variance

$$\begin{aligned}
 \text{SCS (Hz)} &= 1.30 + 2.23 E_s^c + 1.21 (\text{C-6 no.}), \\
 &\quad (99.0) \qquad (90.5) \\
 R &= 0.889, s = 1.15 \quad (12)
 \end{aligned}$$

in SCS and indicates that E_s^c is a significant variable while C-6 no. is almost significant. The significance of E_s^c for the chemical shifts of the thiolacetates is in agreement with its significance for the alkaline hydrolysis rate constants of the same compounds (see eq 7). The near significance of C-6 no. for the thiol esters is in agreement with its significance for the chemical shifts of the corresponding acetates (see eq 3). It is believed that C-6 no. would be a highly significant variable for a more extensive series of thiolacetates with a larger range of C-6 no. and SCS values. The data in the second column of Table IV show that there is very little variation of the C-6 no. values for the eight thiolacetates correlated by eq 12. Also, omitting the data for *tert*-butyl thiolacetate, the chemical shifts for the other seven thiolacetates given in the fourth column of Table III cover a range of only 2.3 Hz. The fact that σ^* is not a significant variable is expected and for the same reasons, as outlined previously, that it is not significant when considering the alkaline hydrolysis rate constants.

B. Methyl Thiol Esters, RCOSCH₃.—Correlation of the SCS of the alkyl methyl protons of eight methyl thiol esters relative to methyl thiolacetate (no. 9–16 of Table III) with σ^* , E_s^c , ($n - 3$), and 6# gave an equation which showed that σ^* was the least significant variable (83% confidence level). Eliminating σ^* and repeating the correlation gave an equation with ($n - 3$) as the next least significant variable (55% confidence level). Eliminating ($n - 3$), the new correlation gives eq 13, which provides a fairly good fit for the data.

$$\begin{aligned}
 \text{SCS (Hz)} &= 0.097 + 1.25 E_s^c + 0.237 (\text{C-6 no.}), \\
 &\quad (99.9) \qquad (99.1) \\
 R &= 0.966, s = 0.336 \quad (13)
 \end{aligned}$$

The standard deviation of 0.336 in eq 13 is only 10% of the range of 3.4 in hertz values involved. This range in hertz values is relatively small in comparison to the ranges in E_s^c and C-6 no. values. The reason for this is that the C-6 no. tends to become more positive as E_s^c becomes more negative, *i.e.*, the term 0.237 (C-6 no.) increases as the term 1.25 E_s^c decreases and these two effects tend to compensate for one another.

Thus, it appears that steric factors have the greatest influence on the chemical shifts of acyl or alkyl methyl hydrogens in thiol esters just as such factors are of most importance in controlling the alkaline hydrolysis of these compounds. These results are in marked contrast to similar studies on oxygen esters where polar effects were at least of equal importance.

Experimental Section

Materials.—Methyl and benzyl mercaptans (Distillation Products Industries) were purchased. The other seven mercaptans used in this study were donated by the Phillips Petroleum Co.

Methyl and ethyl thiolacetates (Waterloo Chemical Co.) were purchased. The other 22 thiol esters were prepared by refluxing

a mercaptan with an acyl chloride in pyridine solution.^{22a} All of the thiol esters were purified as described previously.⁴ The physical constants for nine of the esters agree with previously reported values and the constants for the other 13 previously unreported esters are given in Table V.

TABLE V
PHYSICAL CONSTANTS FOR 13 THIOL ESTERS, RCOSR'^a

RCOSR'		n_{D}^{20}	Bp °C (mm)
R	R'		
$n\text{-C}_3\text{H}_7$	CH_3	1.4595 ^b	142-142.5 (757)
$i\text{-C}_3\text{H}_7$	CH_3	1.4559	132-132.1 (757)
$n\text{-C}_4\text{H}_9$	CH_3	1.4614 ^c	165.2-165.4 (757)
$i\text{-C}_4\text{H}_9$	CH_3	1.4577	155.4-155.5 (756)
$s\text{-C}_4\text{H}_9$	CH_3	1.4585	153.8-154 (756)
$t\text{-C}_4\text{H}_9$	CH_3	1.4576	137-137.1 (756)
$\text{C}_6\text{H}_5\text{CH}_2$	CH_3	1.5592	112-112.2 (4)
$n\text{-C}_4\text{H}_9$	C_2H_5	1.4576	178-178.1 (757)
$n\text{-C}_6\text{H}_{13}$	$t\text{-C}_4\text{H}_9$	1.4505 ^d	49.5-50 (4.5)
$i\text{-C}_4\text{H}_9$	$s\text{-C}_4\text{H}_9$	1.4556	77.1-77.2 (6.5)
$s\text{-C}_4\text{H}_9$	$t\text{-C}_4\text{H}_9$	1.4507	62.5-63.0 (6.0)
$t\text{-C}_4\text{H}_9$	$t\text{-C}_4\text{H}_9$	1.4695 ^e	177.5-180 (757)
$n\text{-C}_6\text{H}_{13}$	$\text{C}_6\text{H}_5\text{CH}_2$	1.5347	159.1-159.5 (7.0)

^a Satisfactory combustion analytical data for C, H, and S ($\pm 0.3\%$) were reported for all of the compounds in this table: Ed. ^b At 26°. ^c At 24°. ^d At 27°. ^e At 23°.

Standard sodium hydroxide solution and 40% aqueous *p*-dioxane were prepared as described previously.⁴

Determination of Alkaline Hydrolysis Rate Constants.—The apparatus and method of determination of the rate constants were the same as described previously,⁴ except that (1) null points were obtained by a null indicator (Leeds and Northrup No. 8067), (2) the initial concentrations in the reaction mixture were 0.005 *M* thiol ester and 0.01 *M* sodium hydroxide.

(22) (a) P. N. Rylander and D. S. Tarbell, *J. Amer. Chem. Soc.*, **72**, 3021 (1950); (b) J. R. Schaefgen, *J. Amer. Chem. Soc.*, **70**, 1308 (1948).

Aromatic Nitration with Nitric Acid and Trifluoromethanesulfonic Acid

CLIFFORD L. COON,* WILLIAM G. BLUCHER, AND MARION E. HILL

Chemistry Laboratory, Stanford Research Institute, Menlo Park, California 94025

Received May 19, 1973

Nitration of aromatic compounds is accomplished by a nitrating reagent not previously reported. Two equivalents of trifluoromethanesulfonic acid (1) and one of HNO_3 combine to form a white, crystalline solid that has been identified as a mixture of nitronium trifluoromethanesulfonate (3) and the monohydrate of 1. 3 is an excellent nitrating reagent in inert organic solvents, H_2SO_4 , or $\text{CF}_3\text{SO}_3\text{H}$, and has been used to nitrate toluene, benzene, nitrobenzene, chlorobenzene, *m*-xylene, and benzotrifluoride. Nitrations with 3 have been carried out over a temperature range of -110 to 30° , yields are consistently $>98\%$, and exceptionally high positional selectivity has been demonstrated. For example, 3 reacts in 1 min with toluene in an inert organic solvent at -110 , -90 , or -60° to give quantitative yields of mononitrotoluene that contains only 0.23, 0.36, and 0.53% of the meta isomer, respectively. When the mononitration of toluene is carried out at -110 , -90 , -60 , -30 , and 0° followed by dinitration at 0° , the combined meta-isomer percentages are 0.33, 0.51, 0.75, 1.08, and 1.33, respectively.

In the course of work to find a method of reducing meta substitution in the mono- and dinitration of toluene, a study was made on the effect of various strong acids on isomer percentages. The recent availability of trifluoromethanesulfonic acid (1), prompted us to determine its effectiveness, relative to other acids, as a nitration solvent and catalyst. 1 is a strong monobasic acid and possesses an acid strength 427 times as great as that of nitric acid and 14 times as great as that of sulfuric acid.¹ This work resulted in

It can be shown from previous studies^{4,22b} that the integrated rate equation for this reaction is

$$(a/t)(1/R_0 - 1/R_t) = 2ak(1/R_t) - 2ak/R_\infty \quad (14)$$

where R_0 and R_t are the resistance readings at time zero and at time t , a is the initial concentration of the thiol ester, k is the second-order rate constant, and R_∞ is the resistance reading after complete reaction (R_∞ is not required in this treatment). An approximate value of R_0 was obtained by measuring the resistance in the same conductivity cell of 0.01 *M* sodium hydroxide in 40% aqueous *p*-dioxane. Using this value of R_0 , the initial plot of $(1/t)(1/R_0 - 1/R_t)$ vs. $1/R_t$ was always curved to some extent. If the curvature was concave upward, a slightly higher value of R_0 was then tried, and this procedure was repeated until linearity was obtained. If the initial plot was concave downward, slightly lower values of R_0 were tried until linearity resulted. The slope of the regression²⁰ of $(1/t)(1/R_0 - 1/R_t)$ on $1/R_t$ was divided by $2a$ to obtain k .

Two or three rate-constant determinations were made on each thiol ester and the average k values are given in Table I. For the 24 thiol esters, the maximum deviation from the mean of replicate k values exceeded 2.0% only in the following four cases: $(\text{CH}_3)_2\text{CHCOSCH}_3$, 2.2%; $\text{CH}_3(\text{CH}_2)_2\text{COSCH}_3$, 2.9%; $(\text{CH}_3)_3\text{CCO-SCH}_3$, 5.2%; and $\text{CH}_3(\text{CH}_2)_3\text{COSCH}_2\text{CH}_3$, 4.1%.

The following alkaline hydrolysis rate constants at 30° in 43 wt % aqueous acetone, determined by the titration method, have been reported previously: ethyl thiolacetate,^{22b} 4.39; isopropyl thiolacetate,^{22a} 2.42. Under the same conditions, except by the above-described conductivity method, k values of 4.49, 4.61, and 4.30 (av of 4.47) for ethyl thiolacetate and of 2.34 and 2.48 (av of 2.41) for isopropyl thiolacetate were found.

Nmr Spectral Measurements.—Using a Varian A-60 spectrometer, the chemical shifts of the thiol esters (neat), with respect to tetramethylsilane as internal standard, were measured at 37° at 250-Hz chart width and are accurate to about 0.2 Hz. The chemical shifts of methyl protons relative to those of methyl thiolacetate are shown in Table III.

Acknowledgments.—This study was supported in part by a research grant (C. K. H) from the Robert A. Welch Foundation.

the discovery of nitronium trifluoromethanesulfonate and its subsequent use as a reagent to effect aromatic nitration.

The use of nitronium salts for the nitration of aromatic compounds is well known and has recently been reviewed extensively in several articles concerned with the mechanism of aromatic nitration.²⁻⁵ It has long

(2) J. G. Hoggett, R. B. Moodie, J. R. Penton, and K. Scholfield, "Nitration Aromatic Reactivity," University Press, Cambridge, England, 1971.

(3) G. A. Olah and S. J. Kuhn in "Friedel-Crafts and Related Reactions," Vol. III, G. A. Olah, Ed., Interscience, New York, N. Y., 1964, Chapter XLIII.

(4) G. A. Olah, *Accounts Chem. Res.*, **4**, 248 (1971).

(5) J. H. Ridd, *Accounts Chem. Res.*, **4**, 248 (1971).

(1) T. Gramstad, *Tidsskr. Kjemii, Bergv. Met.*, **19**, 62 (1959); *Chem. Abstr.*, **54**, 12739 (1960).