Protiodesilylation of Substituted 2-Trimethylsilylthiophens

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First-order rate constants at 50 °C have been determined for cleavage of the thiophen compounds $XC_4H_2S{\cdot}SiMe_3$-2 in mixtures of (a) MeOH (5 vol.) with aqueous $HClO_4$ (2 vol.) and (b) CH_3CO_2H (4 vol.) with aqueous H_2SO_4 (3 vol.). Relative rates, k_{rel}, in the first medium are (X =) 5-OMe, 7 200; 5-Me, 36; H, 1.00; 5-Cl, 1.08×10^{-1}; 5-Br, 9.0×10^{-2}; 3-Br, 5.0×10^{-2}; 4-Br, 4.9×10^{-3}, and in the second medium, 5-Me, 36; H, 1.00; 5-Cl, 1.28×10^{-1}; 5-Br, 9.8×10^{-2}; 3-Br, 5.5×10^{-2}; 4-Br, 6.5×10^{-3}; 5-NO_2, 9.1×10^{-7}; 3-NO_2, 7.1×10^{-7}. Except for the nitro-compounds, the two sets of log k_{rel} values show excellent linear correlations with values for the corresponding $XC_6H_4{\cdot}SiMe_3$ compounds, with 3-, 4-, and 5-X in the thiophen ring being taken as equivalent to *o*-, *m*-, and *p*-X groups, respectively, in the benzene ring, the effects of substituents being a little larger in the thiophen than the benzene system; 3- and 5-$O_2NC_4H_2S{\cdot}SiMe_3$ are less reactive than would be expected from the correlations. Again with the exception of the data for the nitro-compound, the log k_{rel} values for the 4- and 5-substituted thiophens show very good correlation with σ_m^+ and σ_p^+ constants.

THERE has been much interest in comparisons of the effects of ring substituents in the reactions of corresponding derivatives of benzene and thiophen.[1-5] It is known that for a good number of reactions in side-chains attached to the 2-position of thiophen or 1-position of benzene, the effects of 4- and 5-substituents in the thiophen ring closely parallel those of *m*- and *p*-substituents, respectively, in the benzene ring, and that σ_m and σ_p (or, where appropriate, σ_m^+ and $\sigma_p^{+\,3}$) substituent constants can be used for the 4- and 5-groups.[1,2] Furthermore, σ_m^+ and σ_p^+ constants can be used for 4- and 5-substituents in electrophilic substitutions at the 2-position of the thiophen.[1,4] Additionally, in the base cleavage of phenyl- and 2-thienyl-trimethylsilanes, on which the rate-determining step is thought to be generation of the aryl carbanion, the effects of 4- and 5-substituents again closely parallel those of *m*- and *p*-substituents.[6]

One important aspect of the comparisons relates to the relative magnitudes of the effects in corresponding thiophen and benzene derivatives, which are usually regarded as a measure of the relative ease of transmission of substituent effects on the two systems. We recently briefly reviewed the literature on this topic, and showed that in the reduction of the ketones $XC_6H_4{\cdot}CO{\cdot}C_4H_2SY$ with sodium borohydride, in which the substituents in the benzene and thiophen rings are interacting with the same reaction centre, the effects of the 4- and 5- were markedly greater than those of the *m*- and *p*-substituents.[5] There is some theoretical interest in the relative magnitudes of the ρ^+ values for electrophilic substitutions in benzene and thiophen rings,[7,8] but unfortunately only for one such reaction, chlorination in acetic acid,[8-12] have substituted benzenes and thiophens been studied under precisely the same conditions, and even in this case different substituents were used in the two rings,[8] so that direct comparison cannot be made. In order to provide data for an electrophilic aromatic substitution in the two systems in the same medium we have examined the protiodesilylation of $XC_4H_2S{\cdot}SiMe_3$-2 compounds in $HClO_4$–MeOH–H_2O and H_2SO_4–CH_3CO_2H–H_2O, for which the corresponding data are available for $XC_6H_4{\cdot}SiMe_3$ compounds.[13-16]

RESULTS AND DISCUSSION

The rates of cleavage of $XC_4H_2S{\cdot}SiMe_3$-2 compounds in $HClO_4$–MeOH–H_2O or H_2SO_4–CH_3CO_2H–H_2O were determined spectrophotometrically as previously described for $XC_6H_4{\cdot}SiMe_3$ compounds,[13-16] and good first-order kinetics were observed. However, for 5-$MeOC_4H_2S{\cdot}SiMe_3$-2 in H_2SO_4–CH_3CO_2H–H_2O interference from another reaction, possibly involving attack by sulphonating species on the silicon compound or the cleavage product, prevented measurement of the rate of protiodesilylation. As for the benzene series, the spread of rates is such that a range of acid concentrations has to be employed, and since the rate is not proportional to the acid concentration an overlap procedure[13-16] has to be used to determine the value of k_{rel}, the rate relative to that for the parent $C_4H_3S{\cdot}SiMe_3$-2. To provide additional overlap data and also to permit direct comparison, some $XC_6H_4{\cdot}SiMe_3$ compounds were examined alongside the thiophen derivatives. The conditions used and the

TABLE 1

Cleavage of $XC_4H_2S{\cdot}SiMe_3$ compounds in $HClO_4$–MeOH–H_2O at 50.0 °C[a]

X	λ/nm[b]	[$HClO_4$]/M[a]	10^5k[c]	k_{rel}[d]
5-OMe	260	6.0×10^{-3}	1 150	7 200
5-Me	250	6.0×10^{-3}	5.7	
		6.0×10^{-1}	810	36
H	245	6.0×10^{-1}	22.7	1
		2.48	206	
		4.95	1 035	
5-Cl	260	4.95	112	1.08×10^{-1}
5-Br	261	4.95	92.5	9.0×10^{-2}
3-Br	260	4.95	52	5.0×10^{-2}
4-Br	260	4.95	5.1	4.9×10^{-3}

[a] Aqueous perchloric acid (2 vol.) of the concentration shown was mixed with a methanolic solution (5 vol.) of the organosilane. [b] Wavelength used to monitor reaction. [c] Observed first-order rate constant. [d] Rate relative to that for $C_4H_3S{\cdot}SiMe_3$-2.

results obtained are shown in Tables 1 and 2. In Table 3 are shown the k_{rel} values (used in correlations below) for the $XC_6H_4{\cdot}SiMe_3$ compounds relative to $C_6H_5SiMe_3$, some of the values being derived from data in Table 2 and others taken from the literature;[13-16] there is satisfactory agreement between previously k_{rel} values and those derived from the present work.

TABLE 2

Rates of cleavage of $XC_4H_2S{\cdot}SiMe_3$-2 and $YC_6H_4{\cdot}SiMe_3$ compounds in H_2SO_4–CH_3CO_2H–H_2O at 50.0 °C [a]

X	Y	λ/nm [b]	$[H_2SO_4]$/M [a]	10^5k/s^{-1} [c]	k_{rel} [d]
5-OMe					(5 900) [e]
5-Me		250	0.13	1 430	36
H		253	0.13	40.0	1.0
			1.30	630	
5-Cl		260	1.30	81	1.28×10^{-1}
5-Br		261	1.30	62	9.8×10^{-2}
			2.67	235	
3-Br		261	2.67	132	5.5×10^{-2}
4-Br		261	2.67	15.6	6.5×10^{-3}
			6.60	350	
	H	266	6.60	12.7	2.36×10^{-4}
			10.1	270	
	p-Cl	275	10.1	43.2	3.81×10^{-5}
			11.7	184	
	m-Cl	275	11.7	12.3	2.56×10^{-6}
			13.2	46.5	
5-NO_2		340	6.60	0.050	9.3×10^{-7}
			13.2	16.5	9.1×10^{-7}
			16.2	183	
3-NO_2		320	13.2	12.9	7.1×10^{-7}
	p-NO_2	340	16.2	3.62	1.8×10^{-8}

[a] Aqueous sulphuric acid (3 vol.) of the concentration shown was mixed with a solution (4 vol.) of the organosilane in anhydrous acetic acid. [b] Wavelength used to monitor reaction. [c] Observed first-order rate constant. [d] Rate relative to that of $C_4H_3S{\cdot}SiMe_3$-2. [e] Derived from results for $HClO_4$–MeOH–H_2O (see text).

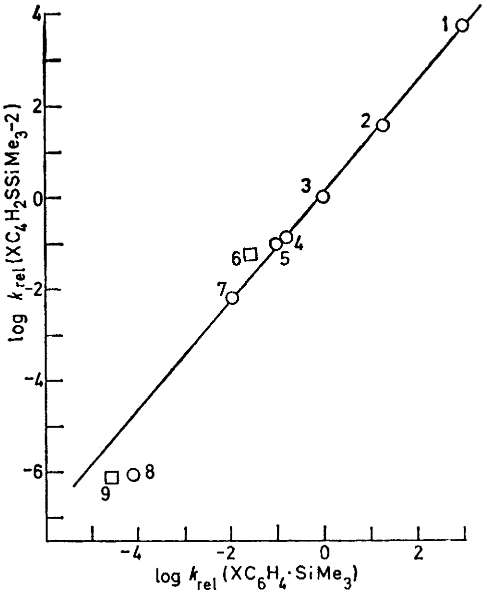
There is an excellent linear correlation between the log k_{rel} values in $HClO_4$–MeOH–H_2O and those in H_2SO_4–CH_3CO_2H–H_2O (*r* 1.000; slope 1.03; intercept, −0.03; 6 points); as with $XC_6H_4{\cdot}SiMe_3$ compounds the substituent effects are a little larger in the former medium. Use of this correlation enables a k_{rel} value of 5 900 to be derived for 5-$MeOC_4H_2S{\cdot}SiMe_3$-2 in H_2SO_4–CH_3CO_2H–H_2O.

TABLE 3

Values, k_{rel}, of the reactivities of $XC_6H_4{\cdot}SiMe_3$ compounds relative to that of $C_6H_5SiMe_3$ in H_2SO_4–CH_3CO_2H–H_2O at 50 °C

X	k_{rel}	X	k_{rel}	X	k_{rel}
p-OMe	1 010 [b]	*p*-Br	8.9×10^{-2} [d]	*o*-Br	2.5×10^{-2} [h]
p-Me	18 [b]	*m*-Cl	1.09×10^{-2} [a,e]	*o*-NO_2	3×10^{-5} [h,i]
H	1.0	*m*-Br	1.07×10^{-2} [f,g]	*p*-NO_2	7.6×10^{-5} [a,j]
p-Cl	1.6×10^{-1} [a,c]				

[a] Value from data in Table 2. [b] Ref. 14. [c] Lit.,[14] 1.9×10^{-1}. [d] Based on a value of 1.6×10^{-1} for *p*-Cl and the previously observed relative reactivities of the *p*-Cl and *p*-Br compounds.[14] [e] Lit.,[15] 1.19×10^{-2}. [f] Based on a value of 1.09×10^{-1} for the *m*-Cl and the previously observed relative reactivities of *m*-Cl and *m*-Br compounds.[15] [g] Lit.,[15] 1.17×10^{-2}. [h] Ref. 16. [i] Based on value of 7.6×10^{-5} for *p*-NO_2 and relative reactivities of *o*- and *p*-NO_2.[16] [j] Lit.,[14] 1.2×10^{-4}.



Plot of log k_{rel} for $XC_4H_2S{\cdot}SiMe_3$-2 against log k_{rel} for $XC_6H_4{\cdot}SiMe_3$ in H_2SO_4–CH_3CO_2H–H_2O; the squares denote 3- and *o*-groups. Numbering of points; 1, 5- and *p*-OMe; 2, 5- and *p*-Me; 3, H; 4, 5- and *p*-Cl; 5, 5- and *p*-Br; 6, 3- and *o*-Br; 7, 4- and *m*-Br; 8, 5- and *p*-NO_2; 9, 3- and *o*-NO_2

There is a remarkably exact linear correlation (*r* 1.000; slope, 1.18; intercept 0.06; 6 points) between the log k_{rel} values for the thiophen and benzene derivatives in $HClO_4$–MeOH–H_2O, 4- and 5- being regarded as equivalent to *m*- and *p*-substituents. The slope (1.18) of the line shows that the effects of the substituents are a little greater in the thiophen than in the benzene series. For the same range of substituents there is an almost equally good correlation for the cleavages in H_2SO_4–CH_3CO_2H–H_2O (*r* 0.999; slope, 1.19; intercept, 0.115; 6 points), but the point for the 5- and *p*-NO_2 group lies well below the line (see Figure); the deviation, of 1.24 log k_{rel} units, corresponds to a reactivity for the 5-nitro-compound *ca.* 17 times less than expected. [If the point for the NO_2 substituent is included in the correlation, the correlation coefficient is 0.994 (slope, 1.34; intercept 0.01; 7 points).] Because of this abnormally large deactivation, coupled with the greater spread of rates for the thiophen series, the 5-nitrothiophen is less than twice as reactive as the *p*-nitrophenyl compound, whereas the parent thienyl is *ca.* 4 250 times as reactive as the phenyl compound. It is difficult to account satisfactorily for the abnormal effect of the 5-NO_2 group. In reactions involving correlations with σ-constants the 5-NO_2 substituent seems to behave normally,[1] but only for one electrophilic substitution or other reaction which might be expected to involve correlations with σ^+ constants is information available for this substituent; this is for molecular chlorination in acetic acid, where the log k_{rel} value for the 5-NO_2 compound has been reported to lie on the plot against σ^+,[4] but the observation must be treated with reservations since the effect of the 5-NO_2 group was determined relative to that of the 5-CO_2H group in 85% acetic acid whereas the other data refer to 100% acetic acid (see the discussion below). In principle one could seek an explanation in terms of interaction of the NO_2 group with the strongly acid medium, *e.g.* a rather strong hydrogen bonding which would increase the electron-withdrawing ability of the substituent, but then a comparable effect would be expected for the NO_2 group attached to the benzene ring in this same medium, whereas, in fact, the data for *m*- and *p*-$O_2NC_6H_4{\cdot}SiMe_3$ correlate well with the usual σ^+ constants.[14] An explanation in terms of some kind of interaction between the 5-NO_2 group and the S atom also seems to be ruled out, since the 3-NO_2 group has a similarly abnormally large deactivating effect relative to that of the *o*-NO_2 group, and furthermore, as we have seen, 5-NO_2 seems to behave normally in other types of reaction. There could be some interaction between the medium and the S atom which is significant only at high acidities, but since the S atom bears a substantial degree of positive charge it is difficult to envisage any interaction which would increase this charge and lead to deactivation of the ring. This leaves the possibility that because of the different geometries of the ring systems there is less steric inhibition to coplanarity of the NO_2 group and the ring in the thiophen than in the benzene derivative, so that conjugative electron withdrawal by the group is greater.

Not surprisingly, in view of the corresponding correlations with σ^+ for the $XC_6H_4{\cdot}SiMe_3$ series, excellent linear plots of log k_{rel} against σ^+ are obtained for the $XC_4H_2S{\cdot}SiMe_3$ compounds in both media (in $HClO_4$–MeOH–H_2O, *r* 0.998; slope, −5.29; intercept, −0.19; 6 points; in H_2SO_4–MeOH–H_2O, *r* 0.998; slope, −5.13; intercept, −0.15; 6 points) provided the data for the 5-NO_2 group in the one medium are omitted; the point for the 5-nitro-compound lies 1.95 log k_{rel} units below the line, *i.e.* the compound is, by this measure, *ca.* 90 times less reactive than expected. [If the data for the NO_2 substituent are included in the overall correlation, the correlation coefficient is reduced to 0.983 (slope, −6.08; intercept, −0.38; 7 points).]

Comparison with Other Systems.—As far as comparison can be made, the ρ^+ values for thiophen compounds do not differ greatly from those for the corresponding reactions of benzene compounds, and only in one case, mercuriation, does the ρ^+ value seem to be higher for the thiophen system.[1] However, only for one reaction, molecular chlorination in acetic acid, were the medium and electrophilic reagent identical for the thiophen and benzene compounds, and so the data for that reaction have assumed a special significance. A ρ^+ value of −10, derived by Brown and Okamoto,[11] is usually accepted for the benzene system,[12,17] and a value of −6.5 was derived by Butler and Hendry for the thiophen system on the basis of data for thiophen and four 5-X substituents, *viz.*, Cl, Br, CO_2H, CO_2Et.[9] Later McDonald and Richmond using slightly modified k_{rel} values for these substituents, supplied by Butler, derived a ρ^+ of -9.39 ± 1.31, virtually identical with the ρ^+ value of -9.56 ± 0.55 which they derived for the benzene series for a range of very different substituents (*p*-OMe, -Ph, -Me, -Et, -Pr^i, -Bu^t, and *m*-Pr^i).[8] It is thus relevant to consider the reliability of their ρ^+ value for the thiophen. If the log k_{rel}/σ^+ ratio is derived for each of the substituents the values are (5-X=) Cl, 4.00; Br, 2.18; CO_2H, 9.4; CO_2Et, 8.00. A linear regression analysis for the 5 points does indeed, give a slope, ρ^+, of 9.38 (*r* 0.972; 5 points) but the correlation line misses the origin (*i.e.* the point for X = H) by 0.47 log k_{rel} units, *i.e.* by more than the log k_{rel} values for the 5-Cl or 5-Br compounds. Furthermore, the points for the *p*-Cl and *p*-Br compounds lie significantly away from the line of the log k_{rel}/σ^+ plot, for the benzene series,[10-12] and those for the 5-Cl and 5-Br compounds in the thiophen series may well show similar deviations. Overall it seems that there is no sound basis for the ρ^+ value of -9.39 ± 1.31 derived by McDonald and Richmond, although there is also no firm evidence that it is in error. A little more convincing is the value of −7.8 derived by Marino[4] from k_{rel} values for the -Cl, -Br; -I, -CO_2H, -CO_2Et, and -NO_2 compounds; * while the k_{rel} value used for the 5-NO_2 compound was based on the relative reactivities of the 5-NO_2 and 5-CO_2H compounds in 85% acetic acid, this would not be expected to give rise to a large error. Possibly all that can be concluded is that it is unlikely that in molecular chlorination the ρ^+ value for the thiophen series is larger than that for the benzene series, as it is, by a small amount, in protiodesilylation.

However, we must emphasize that we do not think that it would be in any way surprising to find the ρ^+ value for the thiophen compounds sometimes higher and sometimes lower than that for the benzene compounds over a range of electrophilic substitutions. The much higher reactivity of thiophen than of benzene would (for rate-determining formation of the Wheland intermediate) imply a transition state closer to the reactants for the thiophen than for benzene, and thus a smaller charge on the aromatic ring. If the interaction of the 4- and 5-X substituents in the thiophen ring with a given charge were identical with that for the *m*- and *p*-X substituents in the benzene ring, then one would expect the ρ^+ value always to be lower for the thiophen than for the benzene compounds, but if (as we found for a reaction involving a correlation with σ rather than σ^+ constants [5]) the interaction is greater for the thiophen ring then the ρ^+ values can be either larger or smaller for the thiophen compounds, or, by

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* Marino used the slightly incorrect k_{rel} values for 5-Cl and 5-Br originally reported by Butler and Hendry,[9] but use of the amended values [8] would make very little difference.

chance, equal in both sets. The difference between the positions of the transition states will, of course, depend on the reactivity of the electrophile and other factors (in desilylations the large stabilizing effect of the Me_3Si group on the developing charge will lead to a transition state closer to the reactants), and if it is small then the greater interaction between the substituents and the charge will give a higher ρ^+ value to the thiophen compound; this may well be the case in protiodesilylation.

EXPERIMENTAL

Thiophen Compounds.—The preparations of the $XC_4H_2S{\cdot}SiMe_3$-2 compounds have been described previously.[6]

Rate Measurements.—Rates were determined spectrophotometrically as previously described;[13-16] the wavelengths used are specified in Tables 1 and 2. In all the cases for which rate constants are reported, good first-order kinetics were observed and the spectrum of the solution after 10 half-lives was as expected for formation of $X{\cdot}C_4H_3S$.

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REFERENCES

[1] P. Tomasik and C. D. Johnson, *Adv. Heterocycl. Chem.*, 1976, **20**, 1.

[2] H. H. Jaffé and H. L. Jones, *Adv. Heterocycl. Chem.*, 1964, **3**, 209.

[3] D. S. Noyce, C. A. Lipinski, and R. W. Nichols, *J. Org. Chem.*, 1972, **37**, 2615.

[4] G. Marino, *Adv. Heterocycl. Chem.*, 1971, **13**, 235.

[5] M. Fiorenza, A. Ricci, G. Sbrana, G. Pirazzini, C. Eaborn, and J. G. Stamper, *J. Chem. Soc., Perkin Trans. 2*, 1978, 1232.

[6] G. Seconi, C. Eaborn, and J. G. Stamper, *J. Organomet. Chem.*, 1980, **204**, 153.

[7] C. D. Johnson and K. Schofield, *J. Am. Chem. Soc.*, 1973, **95**, 270; C. D. Johnson, 'The Hammett Equation,' Cambridge University Press, Cambridge, 1973, pp. 104—107.

[8] R. N. McDonald and J. M. Richmond, *J. Chem. Soc., Chem. Commun.*, 1974, 333.

[9] A. R. Butler and J. B. Hendry, *J. Chem. Soc. B*, 1970, 848.

[10] L. M. Stock and F. W. Baker, *J. Am. Chem. Soc.*, 1962, **84**, 1661.

[11] H. C. Brown and Y. Okamoto, *J. Am. Chem. Soc.*, 1958, **80**, 4979.

[12] L. M. Stock and H. C. Brown, *Adv. Phys. Org. Chem.*, 1963, 35.

[13] C. Eaborn, *J. Chem. Soc.*, 1956, 4853.

[14] F. B. Deans and C. Eaborn, *J. Chem. Soc.*, 1959, 2299.

[15] C. Eaborn and P. M. Jackson, *J. Chem. Soc. B*, 1969, 21.

[16] C. Eaborn, D. R. M. Walton, and D. J. Young, *J. Chem. Soc. B*, 1969, 15.

[17] R. O. C. Norman and R. Taylor, 'Electrophilic Substitution in Benzenoid Compounds,' Elsevier, Amsterdam, 1965, p. 288.