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NEIGHBOURING GROUP PARTICIPATION IN REACTIONS OF SULPHIDES WITH CHLORAMINE-T

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Abstract—Neighbouring group participation in reactions of chloramine-T with *ortho*-substituted aryl methyl sulphides and diaryl sulphides has been studied. The reaction is markedly hindered by the steric effect of the *ortho* substituent of the phenyl ring, but groups having a CO moiety show an anchimeric effect in the following order: $o\text{-}CH_2CO_2Me \sim o\text{-}CH_2CO_2H < o\text{-}CH_2CO_2^- < o\text{-}CO_2Me \sim o\text{-}CO_2H < o\text{-}CO_2^- \ll 2o\text{-}CO_2^-$. The participation of water in the rate-determining step may be ruled out on the basis of salt and isotope effect. Substituents with neighbouring group participation diminish the yield of sulphilimine in solvents containing water. The electrophilic chlorination of sulphides by TsNHCl may be assumed to be the rate-determining step with the positively charged sulphonium centre stabilized by the negatively polarized or charged carbonyl-oxygen in the transition state. This type of interaction hinders the nucleophilic attack of sulphonamidate ion at the sulphonium centre in the fast product-controlling steps, decreasing the yield of sulphilimine.

In a previous study on the reactions of sulphides with sodium salts of N-chloro-arenesulphonamides ("Mann–Pope reaction") a mechanism has been proposed on the basis of kinetic measurements and product analysis (Scheme 1, 1–6).[1]

Using buffered 1:1 (v/v) water–ethanol solvent, the rate eqn (7) proved to be valid in a wide pH range (pH 3–9). The pH-independent rate constants k_1' and k_d' have been calculated for the rate-determining steps (2) and (3) by eqns (8) and (9), respectively. [C] and [S] represent the stoicheiometric concentrations of $ArSO_2NCl^-Na^+$ and R^1R^2S:

$$-\frac{d[C]}{dt} = k_1[S][C] + k_d[C]^2 \quad (7)$$

$$k_1 = \frac{[H^+]}{K_a + [H^+]} \cdot k_1' \quad (8)$$

$$k_d = \frac{K_a[H^+]}{(K_a + [H^+])^2} \cdot k_d'. \quad (9)$$

The proportion of sulphilimines and sulphoxides produced in fast steps (5–6), was found to depend on the structure of sulphides and on the media.[1] It has also been established[2] that sulphides having a carboxyl group adjacent to the S atom yield only sulphoxides in media containing water, clearly pointing to the neighbouring group participation of the carboxyl substituent.

Investigations in this latter field of organic sulphur chemistry have shown that in many reactions the anchimeric effect is due to the rate-determining intramolecular nucleophilic attack of the carboxyl group at the sulphonium centre resulting in the formation of a cyclic acyloxysulphonium ion as reactive intermediate.[3–8] In other cases, however, either the *ortho* carboxyl group has been found to act as a general base catalyst promoting the nucleophilic attack of water at a sulphonium centre,[9] or the sulphinyl-O atom has been supposed to attack the carboxyl group which had been converted into a better electrophile in a preequilibrium reaction.[10a–c]

This paper reports a study of the neighbouring group participation occuring in the Mann–Pope reaction. The reactions of chloramine-T ($Ar = p\text{-}MeC_6H_4$) with aryl methyl sulphides and diaryl sulphides having various *ortho* substituents are investigated and compared with those of *para*-substituted and unsubstituted compounds.

$$ArSO_2NHCl + H_2O \underset{}{\overset{K_a}{\rightleftharpoons}} ArSO_2NCl^- + H_3O^+ \quad (1)$$

$$ArSO_2NHCl + R^1R^2S \xrightarrow{k_1,\ slow} \underset{\text{Intermediate}}{[ArSO_2NH^-, R^1R^2SCl^+]} \quad (2)$$

$$ArSO_2NHCl + ArSO_2NCl^- \underset{k_{-d},\ fast}{\overset{k_d,\ slow}{\rightleftharpoons}} ArSO_2NCl_2 + ArSO_2NH^- \quad (3)$$

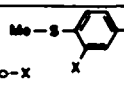
$$ArSO_2NCl_2 + R^1R^2S \xrightarrow{k_2,\ fast} \underset{\text{Intermediate}}{[ArSO_2NCl^-, R^1R^2SCl^+]} \quad (4)$$

$$[ArSO_2NQ^-, R^1R^2SCl^+] \xrightarrow{fast} \begin{cases} \xrightarrow{-Cl^-} ArSO_2N(Q)\overset{+}{S}R^1R^2 \xrightarrow[-QB]{B^-} ArSO_2NSR^1R^2 & (5) \\ \xrightarrow[-HCl]{H_2O} ArSO_2NHQ + R^1R^2SO & (6) \end{cases}$$

$Q = H$ or Cl

Scheme 1.

Table 1. Rate constants and yield of sulphilimine for reactions of chloramine-T with aryl methyl sulphides (20°; solvent 1:1 (v/v) H_2O–EtOH, 0.05 M K_2HPO_4–KH_2PO_4 or 0.05 M Britton–Robinson buffer)

	 o-X, X, p-Y	$pK_a^{s(a)}$	pH[b]	k_1 (l/mol.sec)	k_1'	$k_1'(o)/k_1'(p)$	k_d (l/mol.sec)	k_d'	Yield of sulphilimine % [c]
1a	OMe H	-	8.05	0.126	24.7	0.059	0.104	20.6	47
1b[d]	H OMe	-	8.05	2.12	416	-	0.1	19.9	50
2a	Cl H	-	3.25	0.064	0.064	0.025	0.063	20.5	44
2b[d]	H Cl	-	8.05	0.013	2.54	-	0.098	19.3	40
3a	NO_2 H	-	3.25	(e)	-	-	0.064	20.9	(f)
3b	H NO_2	-	3.25	(e)	-	-	0.062	20.2	(f)
4a	CO_2Me H	-	3.25	0.994	0.997	6.5	0.060	19.5	12[g]
4b	H CO_2Me	-	3.25	0.154	0.154	-	0.070	22.7	35
5a	CO_2H H	5.38	3.25	5.85	2.26	9.1	(h)	-	0[i]
5b	H CO_2H	5.53	3.25	0.288	0.249	-	0.060	19.5	28
6a	CO_2^- H	5.38	8.05	2.50	492	62.8	0.10	19.7	(j)
6b	H CO_2^-	5.53	8.05	0.040	7.84	-	0.091	17.9	(j)
7a	CH_2CO_2Me H	-	3.25	3.13	3.14	0.26	(h)	-	18
7b	H CH_2CO_2Me	-	8.05	0.062	12.2	-	0.095	18.7	32
8a	CH_2CO_2H H	5.68	3.25	6.50	5.77	0.62	(h)	-	7
8b	H CH_2CO_2H	5.48	3.25	9.66	9.32	-	(h)	-	(k)
9a	$CH_2CO_2^-$ H	5.68	8.05	1.05	207	2.9	0.10	19.7	(j)
9b	H $CH_2CO_2^-$	5.48	8.05	0.367	72.2	-	0.096	18.9	(j)
10	CO_2^- OMe	5.14	8.76	3.20	3200	-	(h)	-	-
11	CO_2^- Cl	4.90	8.05	0.477	93.7	-	0.115	22.7	-

[a] Acidity exponents for carboxy-sulphides in 1:1 (v/v) water-ethanol at 20°. [b] pH of the buffered reaction mixture. [c] Reactions were carried out in unbuffered 1:1 (v/v) water-ethanol at 20°; starting concentrations, $[S] = [C] = 10^{-3}$ mol/l. [d] Data taken from lit[1b]. [e] Since $k_1' \ll k_d'$, k_1 cannot be observed. [f] Products with NO_2 group cannot be measured by polarographic method. [g] Sulphoxide (88%) was also measured. [h] Since $k_d \ll k_1'$, k_d cannot be observed. [i] Sulphoxide (100%) was also measured. [j] See data for carboxylic acid. [k] Product is unstable.

RESULTS

Kinetic measurements. The rate constants of the reactions of chloramine-T with aryl methyl sulphides and diaryl sulphides, listed in Tables 1 and 2 were measured by iodometric and/or spectrophotometric methods published earlier.[1] Since the oxidation of sulphides with iodine is accelerated by the *ortho* carboxyl group,[9] only the second method was used to investigate substrates having this substituent.

Measurements were carried out at pH 8.05 and/or 3.25, with the extremely reactive methyl (4-methoxy-2-carboxyphenyl) sulphide investigated at pH 8.76. Under these conditions the reactivity of both the ionised and unionised forms of the carboxy-substituted sulphides can be studied (see pK_a^s data in Tables 1 and 2). The conversion of sluggishly reacting sulphides was investigated at pH 3.25, where a commensurability of k_1 with k_d could be expected for these compounds.[1]

Rate eqn (7) was found to be valid for the *ortho*-substituted sulphides. The pH independent rate constants of carboxy-substituted methyl aryl sulphides were calculated from eqn (10). For the evaluation of the $k_1'(CO_2^-)$ rate constant, the term containing the $k_1'(CO_2H)$ constant may be neglected, because its contribution is smaller than the experimental error. The $k_1'(CO_2^-)$ rate constants for the dianionic form of dicarboxy-substituted diaryl sulphides were calculated from eqn (11).

$$k_1 = \frac{[H^+]}{(K_a + [H^+])} \cdot \frac{[H^+]}{(K_a^s + [H^+])} \cdot k_1'(CO_2H) + \frac{[H^+]}{(K_a + [H^+])} \cdot \frac{K_a^s}{(K_a^s + [H^+])} \cdot k_1'(CO_2^-) \quad (10)$$

$$k_1 = \frac{[H^+]}{(K_a + [H^+])} \cdot \frac{K_{a,1}^s \cdot K_{a,2}^s}{(K_{a,1}^s \cdot K_{a,2}^s + [H^+]^2)} \cdot k_1'(CO_2^-). \quad (11)$$

Steric, anchimeric and substituent effects in the reactions of aryl methyl sulphides and diaryl sulphides. Since the electronic effects of a substituent in both *ortho* and

Table 2. Rate constants for reactions of chloramine-T with diaryl sulphides (20°; solvent 1:1 (v/v) H_2O–EtOH, 0.05 M K_2HPO_4–KH_2PO_4, pH 8.05)

	o-X	o-X'	p-Y	$pK_{a,1}^{a}$ [a]	$pK_{a,2}^{a}$ [a]	k_1	k_1' (l/mol.sec)	k_d	k_d'
12	CO_2^-	H	H	5.24	-	(b)	-	0.087	17.1
13	CO_2^-	CO_2^-	H	4.86	5.76	0.071	13.9	0.100	19.7
14 [d]	CO_2^-	CO_2^-	OMe	4.76	5.69	1.23	241	0.10	19.7
15 [d]	CO_2^-	CO_2^-	NHAc	4.68 [c]	5.63 [c]	0.221	43.4	0.109	21.5

[a] Acidity exponents for carboxy sulphides in 1:1 (v/v) H_2O–EtOH at 20°C. [b] Since $k_1 \ll k_d$, k_1 cannot be observed. [c] Calculated from pK_a^a values of 13 and 14 by the Hammett equation. [d] Preparation published in lit[17b].

para positions are assumed to be the same, the steric and neighbouring group effects of an *ortho* substituent can be estimated by calculating the ratio of the rate constants of the *ortho* and *para* substituted compounds.[11] The $k_1'(o)/k_1'(p)$ relative rate constants for the reactions of various aryl methyl sulphides are given in Table 1.

The small relative rate values for **1a** and **2a** sulphides reflect the steric effect of the *o*-OMe and *o*-Cl substituents. The steric and anchimeric effect of the strongly electron-withdrawing *o*-NO_2 group cannot be measured (though these effects have been observed in the reactions of organic sulphur compounds[12]), because the compounds **3a** and **3b** are not nucleophilic enough to undergo a reaction with TsNHCl. In these cases the conversion is controlled only by the rate of formation of $TsNCl_2$ ($k_d \gg k_1$ and $k_{-d} \ll k_2$; cf. 3 and 4) which is independent of the sulphide substrate.[1]

Relative rates greater than unity indicate that the unfavourable steric effect of *o*-CO_2Me, *o*-CO_2H and *o*-CO_2^- groups (**4a**, **5a**, **6a**) are overcompensated by their anchimeric assistance. The neighbouring group participation of the *ortho*-methoxycarbonyl substituent in the Mann–Pope reaction deserves special attention, because in other reactions of organic sulphur compounds this effect has not been detected (cf. nucleophilic displacements at a sulphonium centre[3,4,7]). The neighbouring group activity of CO_2Me and CO_2H groups in the sulphides **4a** and **5a** are strikingly similar and differ, on the other hand, from that of the CO_2^- group in the compound **6a** by not more than one order of magnitude ($CO_2Me \sim CO_2H < CO_2^-$). Although the steric factor is more effective in the case of the compounds **7a–9a** with bulkier *ortho* groups, a less efficient anchimeric assistance following a similar trend can be observed for the homologous substituents ($CH_2CO_2Me \sim CH_2CO_2H < CH_2CO_2^-$).

By comparing the k_1' rate constants for *p*-Y-*o*-CO_2^-–C_6H_3SMe sulphides (**10**, **6a**, **11**; see Table 1) with those found earlier[1b] for *p*-Y-C_6H_4SMe compounds, the relative rates $k_1'(o\text{-}CO_2^-)/k_1'(H) = 7.7$, 23.4 and 37.5 were calculated for compounds having Y = OMe, H, Cl substituents, respectively. This means that the anchimeric effect of the *o*-CO_2^- group decreases with the increase of the electron-donating ability of the *para* substituent. If the *o*-CO_2^- group is assumed to contribute to the stabilization of the positively polarized S atom in the transition state, this observation points to a saturation effect.

The electronic effect of the *p*-Y substituents in *p*-Y-*o*-CO_2^-–C_6H_3SMe sulphides can be evaluated by the Jaffe 4-parameter eqn (12),[13] where σ_s, ρ_s and σ_c, ρ_c are the substituent and reaction constants referring to the S atom and carboxylate group as reaction centre, respectively:

$$\log [k_1'(p\text{-Y})/k_1'(p\text{-H})] = \sigma_s\rho_s + \sigma_c\rho_c. \qquad (12)$$

For the reactions of TsNHCl with *p*-Y-*o*-CO_2^-–C_6H_3SMe compounds (Y = OMe, H, Cl) $\rho_s = -3.06$ and $\rho_c = -0.07$ were calculated, while $\rho_s = -4.25$ had earlier been found[1b] for *m*-Y- and *p*-Y-substituted sulphides without *o*-CO_2^- group. The decrease of ρ_s absolute value may be attributed to the interaction of the *o*-CO_2^- group with the positive sulphonium centre in the transition state, reducing the electronic effect of the *p*-Y substituent. On the other hand, ρ_c near to 0 indicates that the effectiveness of the *o*-CO_2^- group is practically not influenced by the substituent effect.

Diphenyl sulphide and its derivatives with electron-withdrawing groups have been shown[1b] not to react with TsNHCl at any measurable rate, because of $k_1 \ll k_d$ in the whole pH region. Although the neighbouring group participation of one *o*-CO_2^- group in the compound **12** is not sufficient in itself to render the k_1 value measurable, yet k_1 becomes commensurable with k_d in the conversion of the sulphide **13** having two *o*-CO_2^- groups (Table 2). The high neighbouring group activity of two *ortho*-carboxylate groups, which is not compensated by the increased steric effect, is well indicated by the conversion of (*p*-MeO-*o*-CO_2^-–C_6H_3)$_2$S (**14**) reacting with TsNHCl 513-times faster than (*p*-MeO–C_6H_4)$_2$S (cf. Table 2 and lit.[1b]).

Salt effect. The k_1 rate constant for the reaction of *o*-CO_2H–C_6H_4SMe with TsNHCl proved to be practically independent of the buffer concentration either in basic or in acidic solution (Table 3), in the same way as for the reaction of C_6H_5SMe.[1b]

Isotope effect. The rate of the reactions of TsNHCl or TsNDCl with $TsNCl^-$, C_6H_5SMe, *o*-MeO–C_6H_4SMe and *o*-CO_2^-–C_6H_4SMe were determined in 1:1 (v/v) EtOH–

Table 3. Rate constants k_1 for the reaction of chloramine-T with 2-methylthiobenzoic acid in 1:1 (v/v) H_2O–EtOH containing K_2HPO_4–KH_2PO_4 buffer (a), or Britton–Robinson buffer (b), in various concentrations (20°)

Buffer concentration (M)	k_1 (l/mol.sec) pH 8.05[a]	pH 3.25[b]
0.2	2.51	-
0.1	2.40	5.81
0.05	2.50	5.85
0.025	2.38	5.93

H_2O and 1:1 (v/v) EtOD–D_2O solvents containing 0.04 M K_2HPO_4–0.01 M KH_2PO_4 buffer (Table 4).

For the explanation of the observed data, the solvent isotope effect, the primary and the secondary isotope effects are to be taken into account. (a) TsNHCl is presumably a stronger acid than TsNDCl (cf. lit.[14]), so that the concentration of the deuterated species can be higher than that of TsNHCl even if the deuterium and hydrogen ion activities of the two solvents are equivalent.† Therefore the reactions must proceed faster in EtOD–D_2O solution, thus a simple comparison of the observed $k_1(H)/k_1(D)$ values is only reasonable. (b) If water as a nucleophile or a proton-transfer agent is considered as taking part in the rate-determining step, a decrease of the rate constant should be expected in deuterated solvent.[9,15] (c) A secondary isotope effect smaller than the primary effect pertains to reactions involving a rate-determining electrophilic attack by TsNHCl or TsNDCl chlorinating agents. In this case, however, the isotope effects presumably do not differ significantly.[16]

Data in Table 4 show that nearly the same isotope effect was observed for all of the studied reactions. As water obviously does not take part in the rate-determining reaction of TsNHCl with $TsNCl^-$, the participation of water as a nucleophile or a proton-transfer agent in the rate-controlling step of the reactions between TsNHCl and sulphides may also be precluded.

Product analysis. Reactions between chloramine-T and aryl methyl sulphides with various *ortho* and *para* substituents were carried out in unbuffered 1:1 (v/v) water–ethanol solvent containing the reactants in 10^{-3} mol/l concentrations.‡ The yield of sulphilimines as well as that of sulphoxides formed from the sulphides 4a and 5a were measured polarographically[1] (Table 1).

Data for 7a, 4a, 8a and 5a show that sulphilimine formation is markedly hindered, i.e. sulphoxide formation is decisively promoted if a CO moiety is incorporated in the *ortho* neighbouring group of the sulphide substrate ($CH_2CO_2Me < CO_2Me < CH_2CO_2H < CO_2H$). 100% sulphoxide and no sulphilimine is formed from the sulphide 5a containing *o*-CO_2H group. This observation is consistent with the result of earlier preparative studies.[2]

The sulphilimine–sulphoxide product distribution, however, is known to be controlled by the concentration of the reactants and by the water-content of the solvent, as well.[16] While 4a was converted into sulphilimine only in a yield of 12% in diluted solution, a conversion of 60% was found when the usual preparative method had been applied.[7b]§ In dry solvents sulphilimine can also be prepared from 5a.[7] Finally, bis(*o*-carboxyaryl) sulphides 13–15 react with chloramine-T to produce sulphoxide or sulphurane depending on whether or not the solvent contains water.[2,17]

MECHANISM

Rate-determining steps. The above experimental data seem to provide sufficient information to clarify the mechanism of the Mann–Pope reaction with neighbouring group participation. All reaction pathways with a *rapid* pre-equilibrium reaction resulting in the formation of chlorosulphonium intermediate, and followed by a *rate-determining* step, like (a) the intramolecular/intermolecular general base catalyzed nucleophilic attack of water on the sulphonium ion, or (b) the intramolecular nucleophilic attack of the carbonyl–oxygen at the sulphonium centre, can be neglected, because they are not consistent with the results obtained experimentally (Scheme 2). For, in case of the rate-determining nucleophilic attack of water, the rate of reaction should have decreased on isotopic substitution. Furthermore, the rate of S_Ni reactions between the sulphonium centre and the carbonyl–oxygen of the neighbouring groups should have decreased in the order $CO_2^- > CO_2H > CO_2Me$,

†The problem of measuring deuterium ion activity in 1:1 (v/v) EtOD–D_2O system has not been solved.

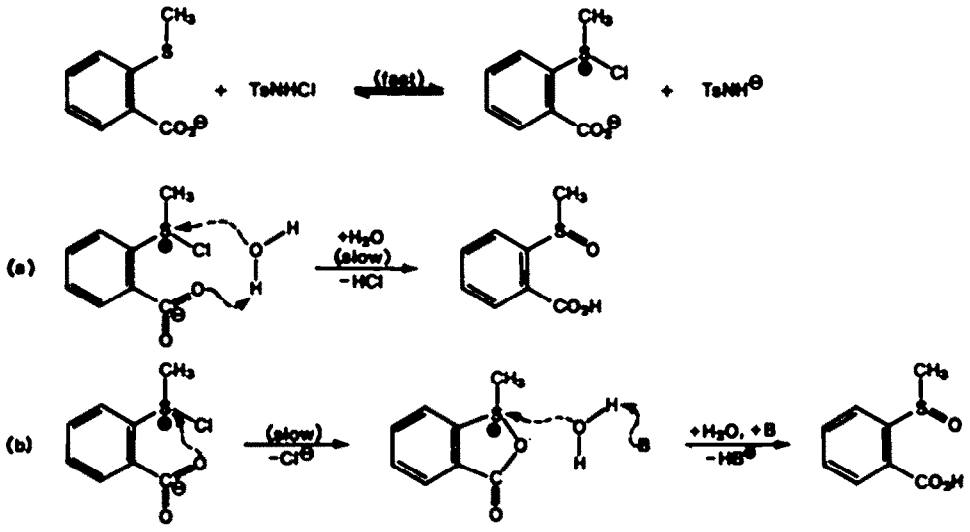
‡Under these conditions the different effects of *ortho* and *para* substituents on sulphilimine–sulphoxide product distribution can be well observed, while in buffered solutions the formation of sulphoxide is predominant (salt effect[1]).

§Since a higher concentration of the reactants favours the formation of sulphilimines,[1] the neighbouring group effect of *o*-CO_2Me substituent cannot be ruled out on the basis of preparative experiments (cf. Bohman and Allenmark[7b]).

Table 4. Rate constants and isotope effects in reactions of chloramine-T with aryl methyl sulphides (20°; solvent 1:1 (v/v) H_2O–EtOH (a) or 1:1 (v/v) D_2O–EtOD (b), 0.04 M K_2HPO_4–0.01 M KH_2PO_4)

Sulphide	$k_1(H)^{(a,c)}$	$k_d(H)^{(a,c)}$	$k_1(D)^{(b)}$	$k_d(D)^{(b)}$	$k_1(H)/k_1(D)$	$k_d(H)/k_d(D)$
	(l/mol.sec)					
C_6H_5SMe	0.0397	0.0351	0.0760	0.0680	0.522	0.516
o-CO_2H-C_6H_4SMe (5a)	0.903	(d)	1.88	(d)	0.480	-
o-MeO-C_6H_4SMe (4a)	0.0448	0.0373	0.0865	0.0710	0.519	0.525

[c]At pH 8.50. [d]Since $k_d \ll k_1$, k_d cannot be observed.

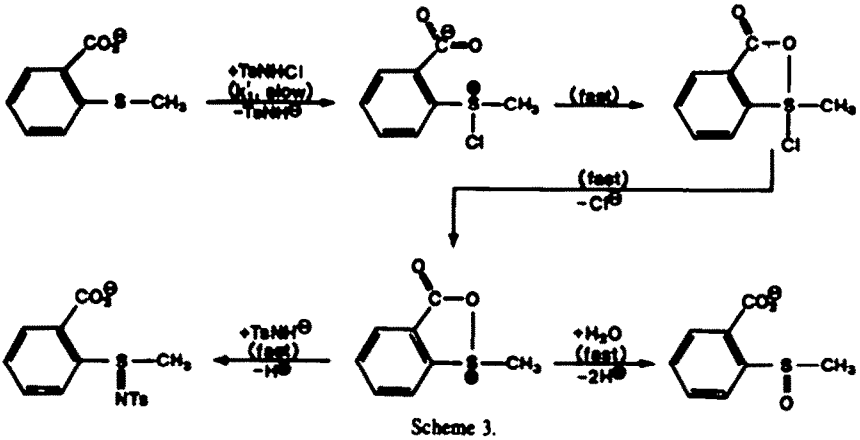


Scheme 2.

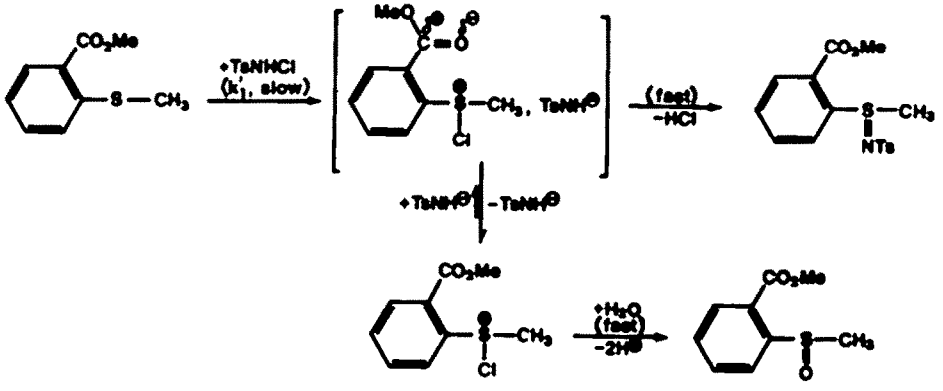
$CH_2CO_2^-$, CH_2CO_2H, CH_2CO_2Me, without any indications of neighbouring group participation for the latter *ortho* substituents (cf. data from the literature for nucleophilic displacement at a sulphonium centre[3,4,5a,7]).

The striking order of reactivity observed for sulphides having different *ortho* substituents with a CO moiety, $(CO_2^-)_2 \gg CO_2^- > CO_2H \sim CO_2Me > CH_2CO_2^- > CH_2CO_2H \sim CH_2CO_2Me$, suggests that the formation of a chlorosulphonium intermediate can be regarded as rate-determining even in these cases. The anchimeric assistance may be attributed to the electrostatic stabilization of the positive sulphonium centre by the negatively charged or polarized carbonyl-oxygen of the neighbouring group (see "slow steps" in Schemes 3 and 4).

Some support for this view comes from X-ray data[18] indicating a nonbonded interaction between the carbonyl-oxygen and adjacent S atom bearing a fractional positive charge. This type of stabilization is particularly effective when a sterically favourable 5-



Scheme 3.



Scheme 4.

membered ring is performed with the contribution of o-CO_2^-, o-CO_2H or o-CO_2Me neighbouring groups, while in case of homologous groups (o-$CH_2CO_2^-$, etc.) the preformation of a relatively unfavourable, non-planar 6-membered ring[11,19] can only be taken into consideration. Moreover, the significant decrease in absolute value of the ρ constant found for reactions assisted anchimerically by o-CO_2^- group provides strong indications that the electrostatic field effect is decisive for the stabilization of the transition state of sulphonium type.

Product-controlling steps. Sulphilimines and sulphoxides are known to be produced from chlorosulphonium-sulphonamidate ion-pair intermediates by the fast nucleophilic attack of sulphonamidate anion or water molecule at the sulphonium centre (5 and 6 in Scheme 1).[1] Product analysis data for the compounds **1a–b** and **2a–b** show that the product-controlling steps are not markedly affected by the *ortho* or *para* position of OMe and Cl substituents.

In case of the sulphides **5a** and **6a** with o-CO_2H or o-CO_2^- group, respectively, the attack of the neighbouring *ortho* group at the sulphonium centre seems to be faster than that of the N-nucleophile. The reaction is proposed, therefore, to occur through a cyclic chlorosulphurane intermediate producing cyclic acyloxysulphonium ion intermediate with loss of chloride ion.[20] Since chlorosulphonium cation and sulphonamidate anion get separated in this reaction, and the concentration of N-nucleophile is relatively small, sulphilimine can be subsequently produced only if the solvent is free from water.[7b,c] In solvents containing water the hydrolysis of the acyloxysulphonium ion is very rapid resulting in the exclusive formation of sulphoxide (Scheme 3).

In reactions assisted by less effective neighbouring groups (CO_2Me, CH_2CO_2H, CH_2CO_2Me) sulphoxide formation is not so selective. This means that the production of sulphilimine is not excluded, although the yields are rather poor. It seems very likely that in these cases cyclic acyloxysulphonium ion intermediates cannot be formed through chlorosulphuranes, because of unfavourable electronic and steric factors. For this reason the corresponding sulphides are converted in the usual way, as shown in Scheme 4. The decrease in the yield of sulphilimine may be attributed to the electrostatic interaction between the sulphonium centre and the adjacent carbonyl–oxygen. The field effect favours the separation of the chlorosulphonium–sulphonamidate ion-pair, diminishing the chances of direct coordination.

EXPERIMENTAL

Materials. The majority of compounds was prepared by known methods. The purity was checked by m.p./b.p. determination, analysis and spectroscopic methods.

4-Methylthio-phenylacetic acid (**8b**). The mixture of 4-iodophenylacetic acid[21] (2.62 g, 10 mmol), copper(I) methylthiolate (1.18 g, 12 mmol) and quinoline (5 ml) was heated at 200° for 1 hr. After cooling, the mixture was diluted with a soln of NaOH (1.2 g, 30 mmol) in water (45 ml), then distilled in a current of steam. The residue was cooled, filtered and acidified with 20% HCl aq. The ppt was filtered and crystallized from EtOH–H_2O; yield 1.1 g (60%), m.p. 92–4°.[22]

Methyl 2-methylthio-phenylacetate (**7a**) *and methyl 4-methylthio-phenylacetate* (**7b**). The corresponding phenylacetic acids were methylated with diazomethane.[7c] The crude esters were purified by distillation.[22,23] The yields were almost quantitative.

S - Methyl - S - (4 - methoxycarbonylmethyl - phenyl) - N - p - tolylsulphonyl - sulphilimine. This compound was prepared from **7b** and chloramine-T in MeOH by the usual method,[24] and recrystallized from MeOH; yield 50%; m.p. 130–1°; characteristic bands of IR spectrum (in KBr pellet): ν_{CO}: 1731 cm^{-1}, ν_{SO_2}: 1281, 1142 cm^{-1}; ν_{RNS}: 950, 767 cm^{-1} (cf. lit.[25]). (Found: C, 56.2; H, 5.1; N, 4.1; S, 17.2. Calc. for $C_{17}H_{19}NO_5S_2$ [365.5]: C, 55.9; H, 5.2; N, 3.8; S, 17.5%.)

2-Methylthio-5-methoxybenzoic acid (**10**). To a soln of 5-methoxythiosalicylic acid[17b] (1.84 g, 10 mmol) and NaOH (0.84 g, 21 mmol) in water (25 ml) was dropwise added dimethyl sulphate (2.77 g, 22 mmol) under N_2, and it was allowed to stand at room temp. for 1 hr. A soln of NaOH (1.6 g, 40 mmol) in water (9 ml) was poured into the mixture and its temp. was raised to 80°. After cooling the soln was acidified with 20% HCl aq, the ppt was filtered off and crystallized from EtOH (0.84 g, 42%), m.p. 149–50°. (Found: C, 54.6; H, 5.4; S, 16.1. Calc. for $C_9H_{10}O_3S$ [198.2]: C, 54.5; H, 5.1; S, 16.2%.)

2-Methylthio-5-nitrobenzoic acid. Methanthiol (10 g, 0.2 mol) and methyl 2-chloro-5-nitrobenzoate[26] (43 g, 0.2 mol) were dissolved in a soln of NaOH (8 g, 0.2 mol) in water (30 ml) and EtOH (300 ml) at −20°. The soln was boiled for 1 hr, then 20% NaOH aq (100 ml) was added and refluxed for an additional 1 hr. The mixture was poured into water and acidified with HCl aq. Without cooling (at 50–60°) the ppt was filtered off and crystallized from EtOH–H_2O (24.1 g, 57%), m.p. 220–3°. (Found: C, 45.8; H, 3.6; N, 7.1; S, 14.4. Calc. for $C_8H_7NO_4S$ [213.2]: C, 45.1; H, 3.3; N, 6.6; S, 15.0%.)

2-Methylthio-5-aminobenzoic acid. The mixture of 2-methylthio-5-nitrobeazoic acid (21.3 g, 0.1 mol) Fe dust (39 g, 0.7 g atom), $FeCl_3$ (1 g) and water (200 ml) was heated and shaken frequently at 100° for 4 hr. To the mud-like mixture concentrated NH_4OH aq (100 ml) was added and then allowed to cool, and the insoluble Fe salts were filtered off. The filtrate was evaporated under reduced pressure, the residue was dissolved in water (100 ml) and acidified to pH 5 with 20% HCl aq. The precipitated amino compound was filtered off and dried *in vacuo* over KOH; yield 3.9 g (21%), m.p. 240–50° (dec).

The insoluble Fe salts separated earlier by filtration were suspended in EtOH (300 ml) and concentrated NH_4OH aq (200 ml), then filtered. The filtrate was evaporated under reduced pressure, the residue was mixed with EtOH (100 ml) and concentrated HCl aq (500 ml), and kept at 0° overnight. 2-Methylthio-5-aminobenzoic acid hydrochloride separated in white crystals; yield 8.6 g (39%), m.p. 231–4° (dec). (Found: C, 44.0; H, 4.9; Cl, 16.7; N, 6.6; S, 13.9. Calc. for $C_8H_{10}ClNO_2S$ [219.7]: C, 43.7; H, 4.6; Cl, 16.1; N, 6.4; S, 14.6%.)

2-Methylthio-5-chlorobenzoic acid (**11**). Into a hot (100°) soln of 2-methylthio-5-aminobenzoic acid hydrochloride (6.6 g, 30 mmol) and copper(I) oxide (15 g, 105 mmol) in 20% HCl aq (200 ml) was dropped a soln of $NaNO_2$ (10 g, 144 mmol) in water (50 ml). The mixture was allowed to cool to room temp., the crystals were filtered off, dried and recrystallized from EtOH–H_2O; yield 4.8 g (79%), m.p. 184°. (Found: C, 48.0; H, 3.5; Cl, 17.9; S, 15.5. Calc. for $C_8H_7ClO_2S$ [202.7]: C, 47.4; H, 3.5; Cl, 17.5; S, 15.8%.)

Kinetics.† Kinetic measurements were carried out in 1:1 (v/v) water–ethanol solvent, containing 0.05 M K_2HPO_4–KH_2PO_4 or Britton–Robinson buffer, at constant pH and 20.00 ± 0.05°C. The concentrations of the reactants varied between 5×10^{-3}–5×10^{-4} M. The reactions of *ortho*-carboxy-substituted sulphides were followed spectrophotometrically. The absorbances of the reactants and the products differ significantly at 260–330 nm. The conversion of the other sulphides were followed by using iodometric method.

Product analysis.† The yields of sulphilimines and sulphoxides produced in the reactions were determined polarographically.

pK_a^* measurements. Dissociation exponents for the majority of carboxy-substituted sulphides were determined in 1:1 (v/v) water–ethanol solvent at 20° by UV spectrophotometric method. Since the absorbances of the ionized and unionized forms of **8a** were found not to differ significantly, the pK_a^* of this compound was measured by potentiometric titration. pK_a^* values of sulphide dicarboxylic acids were also calculated from the poten-

†See details in lit.[18]

tiometric titration curves. Because of the poor solubility of 15 the dissociation exponents could not be measured by potentiometric method but were calculated by using the Hammett equation. pH measurements in EtOH–H_2O solvent were carried out by applying the method of Bates *et al.*[27]

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REFERENCES

[1a]F. Ruff and Á. Kucsman, *Acta Chim. Acad. Sci. Hung.* **62**, 437 (1969); **65**, 107 (1970); [b]F. Ruff and Á. Kucsman, *J. Chem. Soc.* Perkin II. 509 (1975); [c]F. Ruff, K. Komoto, N. Furukawa and S. Oae, *Tetrahedron* **32**, 2763 (1976).

[2]Á. Kucsman, I. Kapovits and B. Tanács, *Ibid.* **18**, 79 (1962).

[3a]S. Allenmark, *Int. J. Sulfur Chem.* **8**, 127 (1973); and Refs. therein; [b]C.-E. Hagberg and S. Allenmark, *Chem. Scripta* **5**, 13 (1974); [c]H. Johnsson and S. Allenmark, *Ibid.* **8**, 216, 223 (1975).

[4a]D. Landini and G. Torre, *Boll. Sci. Fac. Chim. ind. Bologna* **27**, 227 (1969); [b]D. Landini and F. Rolla, *J. Chem. Soc.* Perkin II, 1317 (1972); [c]D. Landini, F. Rolla and G. Torre, *Int. J. Sulfur Chem.* **A2**, 43 (1972); [d]D. Landini, A. M. Maia and F. Rolla, *J. Chem. Soc.* Perkin II, 1288 (1976).

[5a]T. Numata, K. Sakai, N. Kise, N. Kunieda and S. Oae, *Chem. & Ind.* 576 (1971); [b]T. Numata, K. Sakai, N. Kise, N. Kunieda and S. Oae, *Int. J. Sulfur Chem.* **A1**, 1 (1971).

[6]R. Annunziata, M. Cinquini and S. Colonna, *J. Chem. Soc.* Perkin I. 282 (1975).

[7a]O. Bohman and S. Allenmark, *Tetrahedron Letters* 405 (1973); [b]O. Bohman and S. Allenmark, *Chem. Scripta* **4**, 202 (1973); [c]I. Kapovits, F. Ruff, J. Gulyás and Á. Kucsman, *Tetrahedron* **32**, 1811 (1976).

[8]T. Durst, K.-C. Tin and M. J. V. Marcil, *Can. J. Chem.* **51**, 1704 (1973).

[9]W. Tagaki, M. Ochiai and S. Oae, *Tetrahedron Letters* 6131 (1968).

[10a]T. Numata and S. Oae, *Chem. & Ind.* 726 (1972); [b]S. Oae and T. Numata, *Tetrahedron* **30**, 2641 (1974); [c]T. Numata and S. Oae, *Ibid.* **32**, 2699 (1976); [d]B. Stridberg and S. Allenmark, *Acta Chem. Scand.* **B28**, 591 (1974); **B30**, 219 (1976).

[11]B. Capon, *Quart. Rev.* **18**, 45 (1964).

[12a]E. N. Givens and H. Kwart, *J. Am. Chem. Soc.* **90**, 378, 386 (1968); [b]H. Kwart and H. Omura, *Ibid.* **93**, 7250 (1971).

[13]H. H. Jaffe, *Ibid.* **76**, 4261 (1954).

[14]K. B. Wiberg, *Chem. Rev.* **55**, 713 (1955).

[15]S. S. Minor and R. L. Schowen, *J. Am. Chem. Soc.* **95**, 2279 (1973).

[16]E. Halevi, *Progr. Phys. Org. Chem.* **1**, 109 (1963).

[17a]I. Kapovits and A. Kálmán, *Chem. Comm.* 649 (1971); [b]I. Kapovits, J. Rábai, F. Ruff and Á. Kucsman, to be published.

[18a]B. Dahlén, *Acta Cryst.* **B29**, 595 (1973); [b]S. Abrahamsson and H. M. Zacharis, *Acta Chem. Scand.* **A30**, 375 (1976); and Refs. therein.

[19]L. J. Andrews, L. J. Spears and R. M. Keefer, *J. Am. Chem. Soc.* **86**, 687 (1964).

[20a]K. Mislow, T. Simmons, J. T. Melillo and A. L. Ternay, *Ibid.* **86**, 1452 (1964); [b]C. R. Johnson and J. J. Rigau, *Ibid.* **91**, 5398 (1969); [c]N. E. Hester, *Int. J. Sulphur Chem.* **8**, 119 (1973); [d]J. C. Martin and E. F. Perozzi, *J. Am. Chem. Soc.* **96**, 3155 (1974).

[21]C. F. Maberry and C. L. Jackson *Ber. Dtsch. Chem. Ges.* **11**, 55 (1878).

[22]J. W. Corse, R. G. Jones, Q. F. Soper, C. W. Whitehead and O. K. Behrens, *J. Am. Chem. Soc.* **70**, 2837 (1948).

[23]J. Casanova, Jr., N. D. Werner and H. R. Kiefer, *Ibid.* **89**, 2411 (1967).

[24]I. Kapovits, F. Ruff and Á. Kucsman, *Tetrahedron* **28**, 4413 (1972).

[25]Á. Kucsman, F. Ruff and B. Tanács, *Int. J. Sulfur Chem.* **8**, 505 (1976).

[26]B. B. Dey and Y. G. Doraiswami, *J. Indian Chem. Soc.* **10**, 309 (1933).

[27]R. G. Bates, M. Paabo and R. A. Robinson, *J. Phys. Chem.* **67**, 1833 (1963).