

Kinetics of Anilinodechlorination of 3-Bromo- and 3-Methoxy-2-thenoyl Chlorides in Benzene

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The susceptibility constants measured for the reaction of 3-bromo- (Ia) and 3-methoxy-2-thenoyl (Ic) chlorides with some *meta*- and *para*-substituted anilines in benzene at 25 °C have confirmed the occurrence of two different mechanisms for the anilinodechlorination of 3-substituted 2-thenoyl chlorides: (i) the classical AE mechanism and (ii) the IP mechanism (unusual for reactions with anilines in non-polar aprotic solvents) which can operate when electron-releasing substituents are present in the thiophen ring.

The study of substituent effects in the solvolysis of aromatic acyl chlorides has revealed that electron-attracting substituents, which increase the positive charge on the carbon atom site of the reaction, favour the occurrence of a bimolecular mechanism (AE mechanism).¹ On the other hand, in polar solvents, the electron-releasing substituents (*e.g.* *p*-methoxy), which disfavour the AE mechanism, promote a unimolecular mechanism: therefore, the Hammett plot appears as a non-linear concave upward curve with a minimum indicating a change of mechanism as a function of the substituent present.¹

The reactions with amines usually follow a different pattern: † it has been assumed that irrespective of the nucleophilic reagent the mechanism is bimolecular and the intermediate existence of an acylium ion is usually considered as improbable.^{1b} For example, the anilinodechlorination reactions of 3- or 4-substituted benzoyl chlorides³ and of 2-thenoyl chloride^{4a} in benzene give good linear Hammett plots in a wide range of substituents (*e.g.* from *p*-methoxy to *p*-nitro as electron-donating and -withdrawing substituents, respectively).

Recently we have studied the anilinodechlorination reaction of some 3-substituted 2-thenoyl chlorides⁵ in benzene, which represents the first interesting example of non-linear Hammett plot in this kind of reactions. In this reaction, in fact, we found a minimum of reactivity with the 3-SMe substituent and an increase of reactivity on going to either more electron-attracting or -releasing substituents.

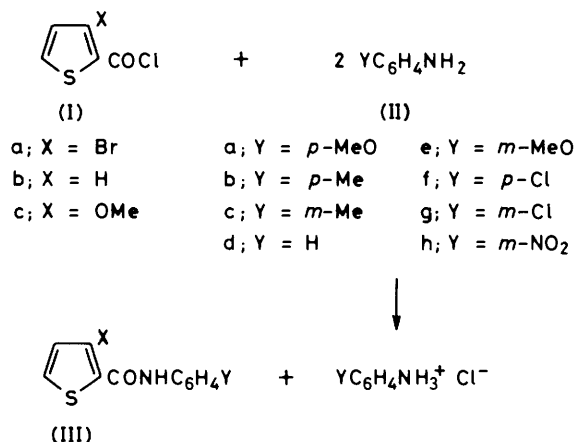
In order to gain evidence for a change of mechanism and to exclude the possibility of a unique linear free energy (l.f.e.) correlation with scattered points, we have now measured the reactivity of some thenoyl chlorides with a series of *meta*- and *para*-substituted anilines and calculated the various susceptibility constants involved. These Brønsted-like correlations can give information about the reaction mechanism: the AE mechanism is much more sensitive than the IP mechanism to the effects of substituents present in the aniline moiety. ‡

Results and Discussion

The reactions of 2-thenoyl chloride (Ib) with anilines (IIa–g) in benzene have already been studied.^{4a} In order to extend the

† The IP mechanism (the Sreen ion pair mechanism) has been shown to occur in the aminodechlorination of some diarylimidoyl chlorides in benzene.²

‡ In a solvent such as benzene the Ingold free carbonium ion mechanism⁶ (dissociative pre-equilibrium followed by a slow reaction with the aniline) appears quite improbable.



range of substituents to a strong electron-withdrawing group we have measured the reactivity of (Ib) with *m*-nitroaniline (IIh) confirming that good Hammett ($\rho -3.30 \pm 0.19$, $i 0.11 \pm 0.06$, $r 0.990$, $n 8$) and Brønsted-like ($\beta 1.13 \pm 0.07$, $i 0.13 \pm 0.06$, $r 0.990$, $n 8$) plots can be obtained.

We have now collected data concerning the reactions of 3-bromo- (Ia) and 3-methoxy-2-thenoyl (Ic) chlorides with anilines (IIa–h): chloride (Ia) contains a substituent which falls (see above) in the range of electron-attracting substituents (positive Hammett susceptibility constant) and (Ic) a substituent which falls in the range of electron-releasing substituents (negative Hammett susceptibility constant).⁵

The kinetic data collected (see Table 1) give good linear free energy relationships with high susceptibility constants for (Ia) ($\rho -3.48 \pm 0.11$, $i -0.08 \pm 0.04$, $r 0.997$, $n 8$; $\beta 1.19 \pm 0.03$, $i -0.07 \pm 0.03$, $r 0.997$, $n 8$), which well compare with previous data for (Ib),^{4a} and low susceptibility constants for (Ic) ($\rho -0.98 \pm 0.06$, $i 0.02 \pm 0.02$, $r 0.990$, $n 8$; $\beta 0.34 \pm 0.02$, $i 0.02 \pm 0.02$, $r 0.991$, $n 8$, respectively). The literature values of susceptibility constants for anilinodechlorination reactions in benzene (AE mechanism) are in the range $\rho 3.5 \pm 0.2$ and $\beta 1.1 \pm 0.2$.^{3,4} Therefore, the values calculated for (Ia and b) fit well with expectations for the AE mechanism; on the other hand, the values calculated for (Ic)

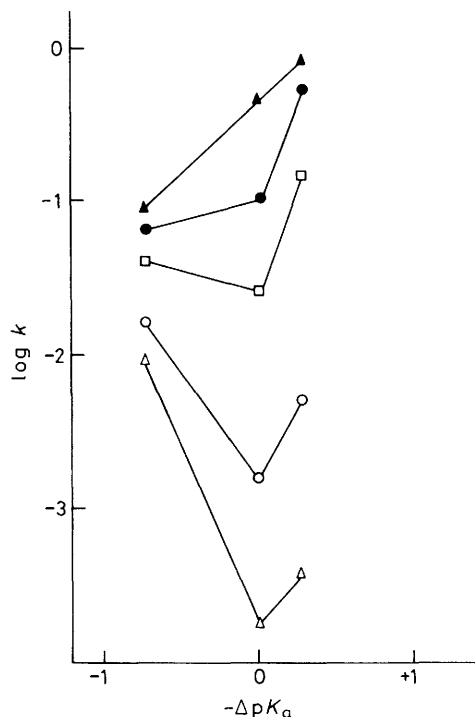
§ A single value of β measured in a solvent like benzene should be handled with caution as a mechanistic probe, but the value calculated for (Ib) can be safely used for comparison with those of (Ia and c) (see later).

are very low, especially if one considers that the reactions have been carried out in a non-polar aprotic solvent. These values clearly indicate the formation of a transition state with low carbon-nitrogen bond formation (which is made easy by electron-attracting substituents in the acyl chloride and by electron-releasing substituents in the aniline) and therefore they constitute a proof for the IP mechanism.² Acylium-chloride ion pair formation is favoured by electron-releasing substituents in the acyl chloride and the combination of the acylium ion with aniline is only moderately affected by the substituents present in the aniline moiety.

Thus, all the data collected in this and in previous papers agree with the operation of two different reaction mechanisms for the anilinodechlorination of 3-substituted 2-thenoyl chlorides: the first (AE mechanism) promoted by electron-attracting, the second (IP mechanism) by electron-releasing substituents in the 2-thenoyl chloride, respectively. It is worth noting that the trend of susceptibility constants observed by us cannot be connected with the reactivity-selectivity principle:⁷ in fact chlorides (Ia and b) (both characterized by high susceptibility constants) are both more [(Ia)] and less [(Ib)] reactive, with aniline, than (Ic) (characterized by low susceptibility constants).

A logarithmic plot of the reactivity of the single substituted aniline as a function of the effects of the substituent (*e.g.* the pK_a of the corresponding acid) present in the acyl chloride can give useful information. The Figure shows that for four anilines (IIb, d, g, and h) there is no l.f.e.r. and curved plots are observed; on the other hand for *p*-methoxyaniline (IIa)

there is an excellent l.f.e.r. (s 1.19, r 0.9999, n 3). Taking as a reference the reactivity with aniline (IIId), for which the sequence (Ia) > (Ic) > (Ib) has been shown, one can observe that the introduction of an electron-repelling substituent [*e.g.* X = *p*-MeO or *p*-Me, in (IIa or b)], favouring the AE mechan-



Logarithmic plot of the kinetic constants for the reaction of 3-substituted 2-thenoyl chlorides (Ia–c) with anilines [(IIa) (▲), (IIb) (●), (IIc) (□), (IIg) (○), and (IIh) (△)] in benzene at 25 °C versus $-\Delta pK_a$ of the corresponding acids

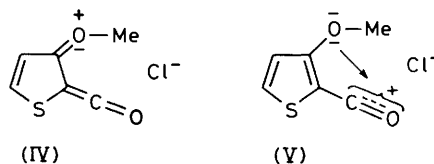


Table 1. Rate constants ^a for the reaction of 3-substituted 2-thenoyl chlorides (I) with substituted anilines (II) in benzene at 25 °C

Y	$10^3 k / \text{l mol}^{-1} \text{s}^{-1}$		
	X = 3-Br	3-H ^b	3-MeO
H	14.3	2.58	4.00
<i>m</i> -Me	19.9	3.58	4.18
<i>p</i> -Me	52.3	10.3	6.42
<i>m</i> -MeO	3.98	1.91	2.95
<i>p</i> -MeO	78.8	44.6	8.63
<i>m</i> -Cl	0.501	0.156	1.61
<i>p</i> -Cl	2.65	0.608	2.78
<i>m</i> -NO ₂	0.0375	0.0181 ^c	0.893

^a Rate constants are accurate to $\pm 3\%$. ^b Values calculated from activation parameters: see A. Arcoria, S. Fisichella, G. Scarlata, and D. Sciotto, *J. Org. Chem.*, 1973, **38**, 82. ^c This work.

Table 2. Physical and analytical data for 3-bromo- and 3-methoxy-thiophen-2-carbanilides (III) ^a

X	Y	M.p. (°C)	Found (%)			Formula	Required (%)		
			C	H	N		C	H	N
Br	<i>m</i> -Me	90	48.6	3.5	4.6	C ₁₂ H ₁₀ BrNOS	48.7	3.4	4.7
	<i>p</i> -Me	92	48.8	3.6	4.6	C ₁₂ H ₁₀ BrNOS	48.7	3.4	4.7
	<i>m</i> -MeO	70	46.1	3.2	4.4	C ₁₂ H ₁₀ BrNO ₂ S	46.2	3.2	4.5
	<i>p</i> -MeO	117	46.3	3.1	4.5	C ₁₂ H ₁₀ BrNO ₂ S	46.2	3.2	4.5
	<i>m</i> -Cl	86	41.7	2.1	4.5	C ₁₁ H ₇ ClBrNOS	41.7	2.2	4.4
	<i>p</i> -Cl	112	41.8	2.1	4.5	C ₁₁ H ₇ ClBrNOS	41.7	2.2	4.4
	<i>m</i> -NO ₂	160	40.5	2.3	8.7	C ₁₁ H ₇ BrN ₂ O ₃ S	40.4	2.2	8.6
	MeO	<i>m</i> -Me	98	63.0	5.2	5.7	C ₁₃ H ₁₃ NO ₂ S	63.1	5.3
<i>p</i> -Me		102	63.0	5.3	5.6	C ₁₃ H ₁₃ NO ₂ S	63.1	5.3	5.7
<i>m</i> -MeO		79	59.2	5.0	5.2	C ₁₃ H ₁₃ NO ₃ S	59.3	5.0	5.3
<i>p</i> -MeO		92	59.2	5.1	5.3	C ₁₃ H ₁₃ NO ₃ S	59.3	5.0	5.3
<i>m</i> -Cl		119	53.9	3.8	5.1	C ₁₂ H ₁₀ ClNO ₂ S	53.8	3.8	5.2
<i>p</i> -Cl		114	53.8	3.9	5.3	C ₁₂ H ₁₀ ClNO ₂ S	53.8	3.8	5.2
<i>m</i> -NO ₂		112	51.9	3.7	10.0	C ₁₂ H ₁₀ N ₂ O ₄ S	51.8	3.6	10.1

^a Crystallized from aqueous ethanol.

ism, changes the reactivity sequence to (Ia) > (Ib) > (Ic); on the other hand the introduction of an electron-withdrawing substituent [$X = m\text{-Cl}$ or $m\text{-NO}_2$ in (IIg or h)] causes the sequence to be (Ic) > (Ia) > (Ib). This clearly indicates the different weight of the AE and the IP mechanisms as a function of the substituents present in the thenoyl chlorides and in the anilines. The occurrence of an l.f.e.r. with *p*-methoxyaniline seems to indicate that only the AE mechanism operates for this aniline.

The peculiar behaviour of 3-substituted 2-thenoyl chlorides seems linked to the special opportunity for a dissociative mechanism related to the nature of the 2,3-relation in five-membered ring derivatives [which favours the acylium ion-chloride ion pair formation by through-resonance (IV)] or to a field effect (V).

The first kind of interaction (hyper-*ortho* interaction) has already been demonstrated by other studies of reactivity⁸ as well as by studies of ground state interactions⁹ (¹³C and ¹H n.m.r.).

Experimental

Synthesis and Purification of Compounds.—The 3-substituted thiophen-2-carbanilides (III) were prepared by well known procedures:⁴ physical and analytical data of the unknown terms are collected in Table 2. 3-Substituted 2-thenoyl chlorides (I), anilines (II), and benzene were prepared and/or purified as previously reported.⁵

Kinetic Measurements.—The reaction was followed kinetically, as previously reported.⁴ The initial concentrations of the reactants after mixing were thenoyl chloride 0.005M and

aniline 0.01M. For the reaction of 3-bromo-2-thenoyl chloride with *p*-methoxyaniline the initial concentrations were acid chloride 0.0025M and aniline 0.005M.

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