

## Sulphinyl, Sulphonyl, and Sulphonium Groups as Leaving Groups in Aromatic Nucleophilic Substitutions

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The kinetics of hydrolysis of mononitrophenyl sulphoxides, sulphones, and sulphonium methylsulphate by sodium hydroxide have been measured in 25% aqueous dioxan. The mobility order of the leaving groups ( $\ddot{S}Me_2 \geq SO \approx SO_2$  for *p*-nitro-derivatives, and  $SO > SO_2$  for *o*-nitro-derivatives) are discussed in terms of electronic and steric effects.

SULPHINYL, sulphonyl, and sulphonium groups are effective substituents for the activation of nucleophilic reactions of halogenated aromatic compounds.<sup>1</sup> Quantitative effects have been measured and discussed by comparison with those of other substituents,<sup>2</sup> but little attention has been devoted to nucleophilic substitutions where these groups behave as leaving groups. We have been interested in the kinetics of nitration of aromatic sulphoxides<sup>3</sup> and sulphonium ion<sup>4</sup> as a means of evaluating orientation in electrophilic substitutions. In this paper we report an investigation of the nucleophilic substitutions of aromatic sulphoxides, sulphones, and sulphonium salts.

The remarkable mobility of the positive pole  $\ddot{S}R_2$  has been pointed out in the reactions by methoxide<sup>5</sup> and hydroxide<sup>6</sup> ions as nucleophiles. Bunnett and his co-workers first observed the reactivity sequence  $SOPh > SO_2Ph$  in the reaction of dinitrophenyl derivatives with piperidine in methanol.<sup>7</sup> Recently, the nucleofugicity of sulphonyl halides,<sup>8</sup> sulphonamide,<sup>8</sup> and sulphones<sup>9</sup> has been determined for a variety of experimental conditions.

The lack of comparable data concerning the mobility of  $SOR$ ,  $SO_2R$ , and  $\ddot{S}R_2$  groups stimulated a kinetic study of the alkaline hydrolysis of *ortho*- and *para*-X-substituted nitrobenzenes, where X is  $SOMe$ ,  $SOPh$ ,  $SO_2Me$ ,  $SO_2Ph$ , and  $\ddot{S}Me_2$ .

### RESULTS AND DISCUSSION

The reactions of *ortho*- and *para*-nitrophenyl sulphoxides and sulphones, and of the *para*-nitrophenyldimethylsulphonium ion, with an excess of sodium hydroxide at 35–75 °C in 25% aqueous dioxan yield the corresponding nitrophenols quantitatively. No by-products arising from competitive reactions have been found. It was also checked that the sulphonium salt does not form the sulphur ylid.<sup>10</sup> In these experimental conditions, *m*-nitrophenyl sulphoxides and sulphones are not hydrolysed. *m*-Nitrophenyldimethylsulphonium ion undergoes dealkylation to *m*-nitrophenyl methyl sulphide.

The kinetics of hydrolysis have been followed by monitoring the absorption of the sodium nitrophenolate formed (see Experimental section). The reactions are pseudo-first-order with respect to the sulphur compound

to at least 75% completion. Kinetic runs carried out at various concentrations of sodium hydroxide (excess) indicate that reaction is also first-order with respect to the nucleophilic reagent. The overall second-order rate constants ( $k_2$ ) were calculated from the slope of the plot of  $k_{obs}$  against the nucleophile concentration. The zero-intercept indicates the absence of neutral hydrolysis, according to the simple rate law (1).

$$k_{obs} = k_2[NaOH] \quad (1)$$

Table 1 reports the values of  $k_{obs}$  on varying  $[NaOH]$  for the hydrolysis of *p*-nitrophenyldimethylsulphonium ion at 50 °C. Table 2 reports the  $k_2$  values at various temperatures, together with the activation parameters.

TABLE 1

Pseudo-first-order and second-order rate constants for the reactions of *p*-nitrophenyldimethylsulphonium methylsulphate with sodium hydroxide in 25% aqueous dioxan at 50 °C

[NaOH]/M	$10^4 k_{obs}/s^{-1}$	$10^4 k_2^a/l \text{ mol}^{-1} s^{-1}$
0.2	0.485	2.43
0.4	1.01	2.52
0.6	1.50	2.50
0.8	1.88	2.35
1.0	2.55	2.55
1.2	2.97	2.48

<sup>a</sup>  $k_2 = k_{obs}/[NaOH]$ . The slope of the plot of  $k_{obs}$  against  $[NaOH]$  is  $k_2 2.49 \times 10^{-4} l \text{ mol}^{-1} s^{-1}$  (intercept  $-1 \times 10^{-6}$ ; correlation coefficient 0.998).

While the hydrolysis rates of the sulphoxides and sulphones are of the same order of magnitude, that of the sulphonium ion is noticeably higher. This can be ascribed to the strong electronegativity of the positive pole, in agreement with the extended theoretical order of mobility:  $X^+ > X^+-X^- > X^0 > X^-$ .<sup>5,11</sup>

On this basis, the reactivity order  $SO_2 > SO$  might be expected, because the sulphonyl group has a stronger dipole than sulphinyl in line with the Hammett-constant values ( $\sigma_{p-SO_2Me}$  0.72,  $\sigma_{p-SOMe}$  0.49).<sup>12</sup> Actually, the following sequences have been observed:  $SO \approx SO_2$  for *para*-derivatives,  $SO > SO_2$  for *ortho*-derivatives.

The mobility of the leaving groups depends on the polar and steric effects relative to the substituent and on the nucleophilic power of the attacking reagent. In our case the comparable reactivities observed for *para*-derivatives could originate from a balance of electronic

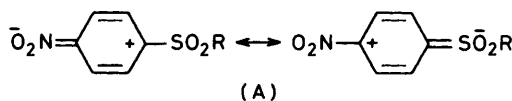
TABLE 2

Second-order rate constants ( $k_2$ ) and activation parameters for the reactions of X-substituted nitrobenzenes with sodium hydroxide in 25% aqueous dioxan

X	$10^5 k_2 / \text{l mol}^{-1} \text{s}^{-1} \text{ }^a$				$\Delta H^\ddagger / \text{kcal mol}^{-1} \text{ }^b$	$-\Delta S^\ddagger / \text{cal mol}^{-1} \text{K}^{-1} \text{ }^b$
	35 °C	50 °C	65 °C	75 °C		
<i>o</i> -SOMe	0.217	1.35	6.37		22.7	10.8
<i>o</i> -SOPh		1.56	6.64	17.8	21.1	15.5
<i>o</i> -SO <sub>2</sub> Me		0.728	3.38	8.30	21.2	16.6
<i>o</i> -SO <sub>2</sub> Ph		0.586	2.65	6.02	20.3	19.7
<i>p</i> -SOMe		1.38	7.14	14.2	20.5	17.4
<i>p</i> -SOPh		1.06	4.93	10.4	20.0	19.6
<i>p</i> -SO <sub>2</sub> Me		1.44	7.13	18.4	22.2	12.2
<i>p</i> -SO <sub>2</sub> Ph		0.941	4.61	11.5	21.8	14.0
<i>p</i> -SMe <sub>2</sub> <sup>+</sup>	5.80	24.9	111		19.7	14.0

<sup>a</sup> Maximum error  $\pm 7\%$ . <sup>b</sup> Calculated at 50 °C. Maximum error  $\pm 0.6 \text{ kcal mol}^{-1}$  for  $\Delta H^\ddagger$  and  $\pm 3 \text{ cal mol}^{-1} \text{K}^{-1}$  for  $\Delta S^\ddagger$ .

effects in the ground state. In fact, although the greater polarity of the sulphonyl group would increase the reactivity, the interaction of  $\pi$ - $d$  orbitals<sup>13</sup> decreases it, diminishing the effectiveness of the nucleophilic attack on the adjacent aromatic carbon atom as in (A).



On the other hand the reduced conjugability of the aromatic sulfoxides has been demonstrated by i.r.<sup>14</sup> and u.v.<sup>15</sup> spectroscopic studies, as well as by  $pK_a$ <sup>16</sup> and kinetic<sup>17</sup> measurements.

The further decrease of the reactivity of *ortho*-substituted sulfoxides can be ascribed to primary steric effects which partly hinder the reagent approach. In fact, the *ortho*:*para* ratio, which is  $\geq 1$  for the sulfoxides, becomes  $< 1$  for the more bulky sulfoxides. Moreover, diphenyl derivatives are always less reactive than the corresponding methyl phenyl derivatives, owing to the additional steric hindrance.

The values of the activation parameters are close to those in the literature for compounds where X = Cl, Br, and I.<sup>1</sup> This may be regarded as an indication of a common two-step (addition-elimination) mechanism. Moreover, the absence of significant leaving group effects is indicative of a reaction pathway in which the first step is rate limiting.

#### EXPERIMENTAL

**Materials.**—Peroxide-free 1,4-dioxan was purified by the literature method,<sup>18</sup> kept over sodium, and distilled before use. Deionized water was used to prepare 25% (v/v) aqueous dioxan.

Sulfoxides were synthesized by oxidation of the corresponding sulphides with an equimolar amount of H<sub>2</sub>O<sub>2</sub> in ethanol, in the presence of perchloric acid at 70 °C for 3 h.<sup>19</sup> The mixture was neutralized with sodium hydrogen carbonate. After evaporation of ethanol and addition of an aqueous solution of sodium chloride, the solution was extracted by chloroform. By evaporation, the crude sulfoxide was obtained. Chromatography on an Al<sub>2</sub>O<sub>3</sub>

column (eluants: ligroin, benzene, chloroform) provides the sulfoxide with  $> 99.5\%$  purity.

Sulfoxides were synthesized by oxidation of the corresponding sulphides with an excess of H<sub>2</sub>O<sub>2</sub> in acetic acid at 90 °C for 2 h. On addition of water the sulfoxide precipitates from the solution.

*p*-Nitrophenyldimethylsulphonium methylsulphate was obtained by methylation of the corresponding sulphide with dimethyl sulphate in slight excess at 90 °C for 2 h. The crude salt was triturated over acetone and then filtered off.<sup>20</sup>

The identification and purity of the synthesized compounds were performed by m.p., u.v. spectra, and t.l.c. and g.l.c.: [X, m.p. (°C), solvent of crystallization]: *o*-SOMe, 101–102, benzene;<sup>21</sup> *o*-SOPh, 104–105, ethanol;<sup>22</sup> *o*-SO<sub>2</sub>Me, 94, ligroin;<sup>15</sup> *o*-SO<sub>2</sub>Ph, 145, ethanol;<sup>23</sup> *p*-SOMe, 151–152, ethanol;<sup>15</sup> *p*-SOPh, 141, ethanol;<sup>15</sup> *p*-SO<sub>2</sub>Me, 107–108, ethanol;<sup>15</sup> *p*-SO<sub>2</sub>Ph, 140, aqueous ethanol;<sup>23</sup> *p*-SMe<sub>2</sub><sup>+</sup>, 157–158, methanol.<sup>24</sup>

**Kinetic Measurements.**—The reactions have been followed by u.v.-visible spectrophotometry by measuring the absorbance at 421 nm for the hydrolysis of *para*-derivatives and at 407 nm for that of *ortho*-derivatives. The selected wavelengths correspond to the absorption maximum of *p*- and *o*-nitrophenolates in 25% aqueous dioxan.

Portions of thermostatted standard solutions of the sulphur compound and sodium hydroxide were mixed in the thermostatted cell, and the absorbance of the nitrophenolate formed was measured at various intervals. No interference due to the reagents was found. The initial concentrations were  $0.5\text{--}1.0 \times 10^{-4} \text{M}$  for sulphur compounds and  $0.2\text{--}1.2 \text{M}$  for sodium hydroxide.

Pseudo-first-order rate constants have been calculated from the first-order rate law, using the absorbances [equation (2) where  $A_t$  is the absorbance at time  $t$  and  $A_\infty$  is that at

$$k_{\text{obs}} = \frac{2.303}{t} \log \frac{A_\infty}{A_\infty - A_t} \quad (2)$$

infinite time].  $A_\infty$  was also calculated from the molar extinction coefficients of the nitrophenolates in 25% aqueous dioxan: *o*-nitrophenolate,  $\epsilon$  5 120 at 407 nm; *p*-nitrophenolate,  $\epsilon$  20 300 at 421 nm.

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