

## Sulphur–Oxygen Cleavage in the Reaction of Four- and Five-membered Sultones with Hydroxide: Evidence for a Stereoelectronic Effect in Sulphonyl Reactions

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Hydroxide ion cleaves the simple 4- and 5-ring sultones (**1a**) and (**1b**) chiefly by S–O rather than the C–O bond breakage normally found with unhindered sulphonic esters; we infer that electron donation to the sulphonyl group by an attached donor atom X is a function of the C–S–X–C dihedral angle such that the electron delocalization is least with the smallest dihedral angle.

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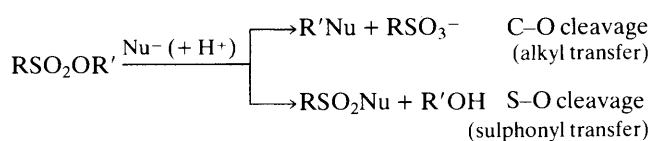
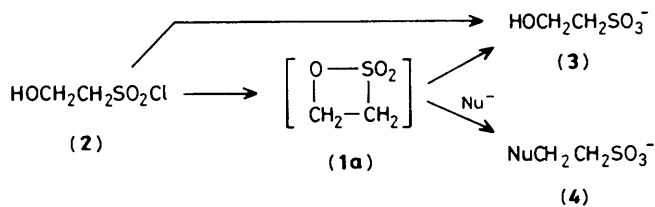
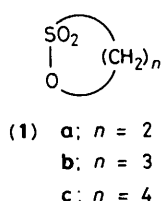
Reaction of a nucleophile with sulphonic esters commonly takes place with carbon–oxygen bond cleavage,<sup>1</sup> the alternative sulphur–oxygen cleavage being confined to aryl esters<sup>2</sup> and others with structural features clearly disavouring C–O cleavage (Scheme 1).<sup>3</sup> We now report that reaction of

hydroxide proceeds mainly by S–O cleavage in two substrates in which one would expect no inhibition of C–O cleavage, namely the sultones (**1a**) and (**1b**), and offer a rationale invoking a stereoelectronic effect involving the sulphonyl group.

**Table 1.**  $^{18}\text{O}$ -Labelling experiments: S-O vs. C-O cleavage.<sup>a</sup>

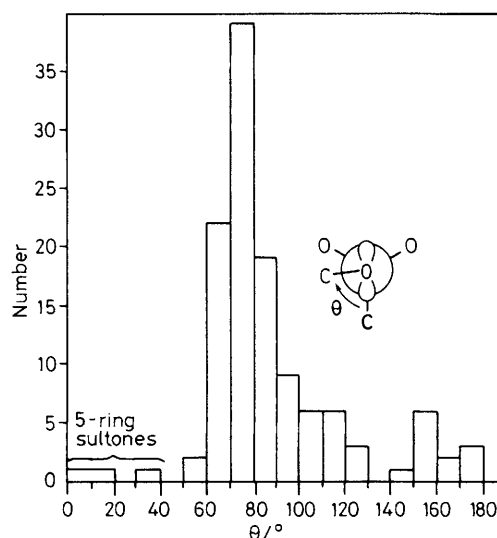
Substrate	pH	Nucleophile <sup>b</sup>	Label distribution <sup>c</sup>		Sultone cleavage (%)	
			$\text{H}^{18}\text{O}$ -	$-\text{S}^{18}\text{O}^{16}\text{O}_2^-$	C-O	S-O
$\text{H}^{18}\text{OCH}_2\text{CH}_2\text{SO}_2\text{Cl}$	6.0	$\text{H}_2\text{O}$	10	90	97	3
$\text{H}^{18}\text{OCH}_2\text{CH}_2\text{SO}_2\text{Cl}$	13.0	$\text{OH}^-$	94	6	6	94
$\text{H}^{18}\text{OCH}_2\text{CH}_2\text{SO}_2\text{Cl}$	13.0	$\text{OH}^-$	88	12	13	87
$\text{H}^{18}\text{OCH}_2\text{CH}_2\text{SO}_2\text{Cl}$	13.5	$\text{OH}^-$	92	8	8	92
$^{18}\text{O}-\text{SO}_2(\text{CH}_2)_2\text{CH}_2$	7.0	$\text{H}_2\text{O}$	4	96	96	4
$^{18}\text{O}-\text{SO}_2(\text{CH}_2)_2\text{CH}_2$	13.0	$\text{OH}^-$	55	45	45	55
$^{18}\text{O}-\text{SO}_2(\text{CH}_2)_3\text{CH}_2$	13.0	$\text{OH}^-$	<4	>96	>96	<4

<sup>a</sup> In water at 25°C, pH maintained by pH-stat. <sup>b</sup> Deduced from product composition experiments with  $\text{Cl}^-$ : the ratio  $[\text{HO}(\text{CH}_2)_n\text{SO}_3^-]/[\text{Cl}(\text{CH}_2)_n\text{SO}_3^-]$  is pH independent in the pH range 4–10 and increases linearly with  $[\text{OH}^-]$  above pH 11. <sup>c</sup> In  $\text{HO}(\text{CH}_2)_n\text{SO}_3^- \text{Na}^+$  as a percentage of the original label in the substrate, determined from the relative integrals of the  $^{16}\text{O}-^{13}\text{C}$  and  $^{18}\text{O}-^{13}\text{C}$  n.m.r. signals in substrates and products; estimated error *ca.*  $\pm 5\%$ .

**Scheme 1****Scheme 2**

Recent investigation<sup>4</sup> of the hydrolysis of 2-hydroxyethanesulphonyl chloride (2) is consistent with the mechanism shown in Scheme 2, in which the path by way of  $\beta$ -sultone (1a) accounts for about 90% of the product in the pH range 6–13.

In accord with this mechanism, the label in 2- $^{18}\text{O}$ hydroxyethanesulphonyl chloride migrated almost entirely to the sulphur atom at pH 6 (and 25°C) (see Table 1). At pH 13, however, a quite different labelling pattern was observed with most of the original label staying on the hydroxy group. Assuming that the mechanism at pH >12 is the same as that at pH 5–10 except that the  $\beta$ -sultone (1a) is cleaved by hydroxide rather than water,<sup>†</sup> then this means that  $\beta$ -sultone



**Figure 1.** Population distribution of the C-S-O-C dihedral angle ( $\theta$ ) in sulphonic esters, as obtained from the Cambridge Datafile. In each of the three examples with  $\theta < 50^\circ$  the C-S-O-C system is part of a five-membered ring.

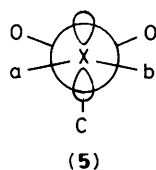
reacts almost entirely ( $\sim 90\%$  or more) by S-O rather than C-O cleavage.

The behaviour of  $[1-^{18}\text{O}]$ -(1b) was qualitatively similar, reacting with water (pH 7) with exclusive attack at carbon, but with hydroxide (pH 13) with more S-O than C-O cleavage.  $[1-^{18}\text{O}]$ -(1c), however, showed only C-O cleavage at pH 13 (see Table 1).

Some (14%) S-O cleavage<sup>5</sup> of ethylene sulphate and (1a), along with rate accelerations of up to  $10^7$ -fold in certain related 5-ring esters,<sup>5a</sup> has been reported and largely attributed<sup>5a</sup> to relief of ring strain in the transition state. On this basis one might expect a similar acceleration of C-O cleavage of five-membered rings, but the effects reported<sup>6</sup> in such reactions of (1b) are, in fact, very much smaller ( $< 50$ -fold at 37°C), suggesting to us that another factor in addition to strain relief is important in these reactions.

We propose that the delocalization  $\text{C}-\text{SO}_2-\text{X}-\text{C} \leftrightarrow \text{C}=\text{SO}_2=\text{X}-\text{C}$  varies with the C-S-X-C dihedral angle, and that the delocalization is greatest with  $\theta$  around  $75^\circ$  and least with  $\theta = 0^\circ$ ; such a suggestion has, in fact, been made to account for  $^{13}\text{C}$  n.m.r. shifts in 5- and 6-membered sultones.<sup>7</sup> Reduced

<sup>†</sup> In accord with this we have found that at pH 13 addition of aniline gave (4, Nu = PhNH<sub>2</sub>) (in 44% yield with 0.3 M PhNH<sub>2</sub>).



delocalization in the sultones (**1a**) and (**1b**) would lead to (a) lowering of the S–O bond order, (b) decrease in the magnitude of the partial positive charge on carbon, and (c) increase in the partial positive charge on the sulphur, thereby facilitating nucleophilic attack at sulphur.

Such a stereoelectronic effect should appear in the conformational preferences of sulphonic esters. Search of the Cambridge Crystallographic Data Centre Files (1986) yielded 121 C–S–O–C dihedral angles ( $\theta$ ) distributed as shown in Figure 1. Most angles are in the range 60–90° (in accord with dipole moment and electron diffraction studies<sup>8</sup>) and except for three five-membered ring sultones (in which a small value of  $\theta$  is enforced), no sulphonic esters have  $\theta$  less than 50°; since there is no similar avoidance of C–O eclipsing (at  $\theta \approx 115^\circ$ ), this is probably not primarily due to C–C eclipsing. A similar study of the dihedral angles about the C–S–N–C bond of *N,N*-dialkylsulphonamides and the C–S–C<sub>ipso</sub>–C<sub>ortho</sub> bond in aryl sulphones showed the same pattern with dihedral angles in the range 60–120° in 88% of the sulphonamides and in 94% of the sulphones. These results and recent *X*-ray crystallographic and theoretical studies<sup>9</sup> are in full accord with the generalised picture that (5) is the most stable conformation when X = carbon (carbanion, aryl, or alkenyl carbon), nitrogen, and oxygen (each with its appropriate attachments).

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