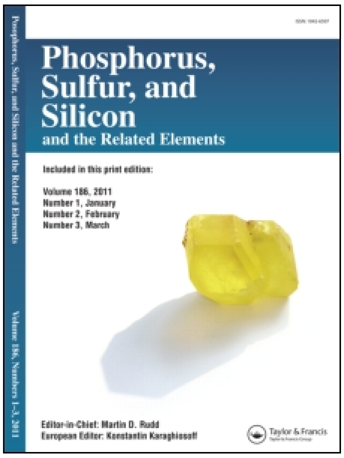

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ω-HYDROXY-1-ALKANESULFONYL CHLORIDES[1]

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The general synthesis of hydroxyalkanesulfonyl chlorides is illustrated by the preparation of 6-hydroxy-1-butanesulfonyl chloride (**2e**) and 5-hydroxy-1-pentanesulfonyl chloride (**2d**) as fairly stable, oily liquids (of ~95% purity) characterized by ^{1}Hmr, ^{13}Cmr and infrared spectra, and by conversion both to the corresponding sultones (**3**) and to crystalline acetoxy-piperidides (**6**); **2d** and **2e** form apparent polymers, very slowly on standing at room temperature and more rapidly on heating, but on reaction with triethylamine yield the sultones (**3d** and **3e**). A sample consisting mostly (>70%) of 4-hydroxy-1-butanesulfonyl chloride (**2c**), prepared and characterized similarly, was found to form the sultone (**3c**) slowly in non-polar solvents, much more readily in polar media ($t_{1/2}$ ~20 min in water), and very rapidly in the presence of triethylamine. Effective concentrations for the spontaneous cyclization of 4-hydroxy-1-butanesulfonyl chlorides (**2c**) and the tertiary-amine induced cyclizations of **2d** and **2e** are estimated at roughly 3×10^2, 0.1, and 0.05 M, respectively. The mechanism of the chlorination reaction and the origins of the different products with different substrates and reaction conditions are discussed.

Hydroxyalkanesulfonyl chlorides (**2**) are bifunctional compounds with two related features of interest: (i) reaction of one function with the other leads to coupling, either of separate molecules with ultimate production of a polymer, or within the same molecule with formation of a ring, and (ii) the reaction may be expected to occur quite readily. Species with these general properties prompt a number of questions, e.g. (i) can they really be made, or, more precisely, under what conditions (if any) can they be generated, or even isolated? (ii) what factors of structure and conditions control whether they form cyclic or polymeric products? (iii) are they, in fact, precursors for the synthesis of useful polymers?

A few years ago we noted that chlorination of an aqueous solution of 2-mercaptoethanol (**1a**) gave 2-hydroxyethanesulfonyl chloride (**2a**), thereby providing the first proved example of a hydroxyalkanesulfonyl chloride.[2,3] More recently[4] we were led from oxygen-labeling studies to conclude that the analogous reaction of 3-mercapto-1-propanol (**1b**) proceeds by way of 3-hydroxy-1-propanesulfonyl chloride (**2b**) which immediately cyclizes to 1,2-oxathiolane 2,2-dioxide (propane sultone) (**3b**).

The typical behavior of a class of bifunctional molecules is not to be expected, however, in the simplest members of the series, and we have therefore taken up the question of the isolability and properties of the higher ω-hydroxy-1-alkanesulfonyl chlorides. We now report the observation of three such species, 4-hydroxy-1-butanesulfonyl chloride (**2c**), 5-hydroxy-1-pentanesulfonyl chloride (**2d**) and 6-hydroxy-1-hexanesulfonyl chloride (**2e**); the first of these was found to

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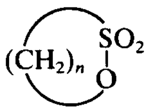
† On leave from the Technical University of Gdańsk, Poland.

$HO(CH_2)_nSH$ 1

$HO(CH_2)_nSO_2Cl$ 2



3

$HO(CH_2)_n—S—C(NH_2)_2^+Cl^-$ 2

$Cl(CH_2)_nSO_2Cl$ 5

a) $n = 2$ b) $n = 3$ c) $n = 4$ d) $n = 5$ e) $n = 6$

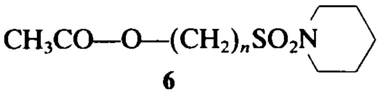
cyclize readily to the corresponding sultone (**3c**), while the other two were comparatively stable. In this paper we report the preparation and some of the properties of these ω-hydroxy-1-alkanesulfonyl chlorides (**2**), along with some conclusions on the mechanism and general applicability of the aqueous chlorination route to such compounds.

RESULTS AND DISCUSSION

The Five- and Six-Carbon ω-Hydroxy-1-alkanesulfonyl Chlorides (**2d** *and* **2e**)

ω-Hydroxy-1-alkylthiouronium salts (**4**) were prepared by reaction of the corresponding α,ω-chlorohydrins with thiourea.[5] Aqueous chlorination of the six-carbon thiouronium salt (**4e**) gave an oily product which showed infrared, ^{1}Hmr and ^{13}Cmr spectra appropriate to a reasonably clean specimen of 6-hydroxy-1-hexanesulfonyl chloride (**2e**). The sulfonyl chloride was further characterized by acetylation followed by reaction with piperidine to give the crystalline piperidide (**6**, $n = 6$), with elemental analyses and spectra in full agreement with expectation.

Similar treatment of 5-hydroxy-1-pentylthiouronium chloride (**4d**) gave 5-hydroxy-1-pentanesulfonyl chloride (**2d**), also as an oil showing the expected spectra; **2d** was also further similarly characterized by conversion to the crystalline acetoxy-piperidide (**6**, $n = 5$).



6

The sulfonyl chlorides (**2d** and **2e**) gradually decomposed on standing under various conditions, with similar approximate half-lives, as estimated from ^{1}Hmr spectra, of (a) for a neat sample, one week at room temperature and one month at −20°C, (b) for a solution 0·1 M in $CDCl_3$, 20 days at room temperature, and 3 days at reflux temperature; the products of these reactions were amorphous, rather insoluble materials showing ^{1}Hmr peaks consistent with the presence of a $—CH_2SO_2O—CH_2—$ grouping, and therefore probably polymeric materials of the general formula $—[SO_2(CH_2)_nO]_m—$ (where $n = 5$ or 6, respectively). Under more vigorous conditions, as, for example, on attempted distillation, **2d** or **2e** gave only products of general decomposition.

Reaction of **2d** and **2e** with triethylamine in CH_2Cl_2 solution gave the corresponding sultones **3d** and **3e**; with dilute solutions (e.g. 0.02 M) there was little or no sign of polymer formation, but at higher concentrations minor signals assigned to the polymer appeared in the ^{1}Hmr spectra. The structures of the sultones followed from mode of synthesis, spectra, elemental analyses, and, in the case of **3e**, osmometric determination of molecular weight; in addition, **3e** was found to react with trimethylamine and ammonia to form the zwitterions, $Me_3N^+(CH_2)_6SO_3^-$ and $NH_3^+(CH_2)_6SO_3^-$, respectively.

Preparation of the simple alkyl esters of 5-hydroxy-1-pentane- and 6-hydroxy-1-hexanesulfonic acids was found to be feasible provided a high concentration of the alcohol was used; with ethanol or 1-pentanol as the solvent, for example, only the acyclic ester (**7**) with no sign of the sultone was observed; with intermediate concentrations of the alcohol, e.g. 0.1 M in CH_2Cl_2, a mixture of the ester (**7**) and the sultone (**3**) was formed.

$$HO(CH_2)_nSO_2OR$$

7

The competition between the intramolecular reaction to form the sultone (**3**) and the intermolecular reaction with the simple alcohol to give **7** is conveniently discussed in terms of effective concentrations, C_{eff} (also called effective molarities, EM),[6] which is defined by $C_{eff} = k_1/k_2$, where k_1 refers to the first order rate constant of an intramolecular reaction and k_2 to the second order rate constant of the closest equivalent intermolecular reaction under the same conditions. When products of both inter- and intramolecular reactions are observed, then the effective concentration is easily obtained from the product ratio taken with the concentration of the competing reagent; for the present case the appropriate expression is $C_{eff} = [ROH] \times$ (ratio of **3** to **7**). From this we found the C_{eff} values for the triethylamine promoted formation of the seven- and eight-membered sultones (**3d** and **3e**) to be approximately 0.1 and 0.05 M, respectively. In the presence of deuterated alcohol (ROD) or other deuterated active hydrogen source, the ester and sultone so obtained were found to be largely α-monodeuterated (i.e, —$CHDSO_2O$—), indicating that most, and perhaps all, of the products (**3** and **7**) arise from the sulfene,[7] $HO(CH_2)_{n-1}CH{=}SO_2$ (**8**).

This behavior is to be contrasted with that in the absence of added base, where no sultones (**3**) and only apparently polymeric products were observed. Under these conditions sulfenes are not formed[7] and esters are believed to be generated by a direct displacement at the sulfur atom of Cl^- by ROH. On the assumption that 10% or more of the sultone (**3**) in the product would be visible in the nmr spectra, we may conclude that C_{eff} for formation of **3d** or **3e** by the direct displacement route must be $<0{\cdot}01$ M. Since the corresponding values for the cyclization of the sulfene to **3d** or **3e** are distinctly higher, this implies that there is greater strain in the transition states for the direct, spontaneous cyclization to form **3d** and **3e** than in the sulfene cyclizations. This is not unreasonable when one notes (a) that the transition state for the direct displacement cyclization would be expected to have a C—S—O bond angle of close to 90°, whereas that for the sulfene cyclization (if it is like that for nucleophilic attack on a carbonyl group[8]) is probably closer to 120°, and (b) that numerous investigations are consistent with the picture that reactions with seven- and eight-membered cyclic transition states are facilitated by bond angle increase and slowed by bond angle decrease.[9]

4-Hydroxy-1-butanesulfonyl Chloride (**3c**)

The thiouronium salt (**4c**), prepared as described above, was obtained as a syrup showing appropriate peaks in the ^{1}Hmr and ^{13}Cmr spectra, but also containing about 20% of another product which was largely removed by crystallization from the mixture; the crystalline by-product was identified as 1,4-butanebisthiouronium dichloride by (a) the simplicity of its ^{1}H and ^{13}C nmr spectra, and (b) conversion to 1,4-butanedisulfonyl chloride[10,11] on aqueous chlorination. Alternatively, reaction of 4-chloro-1-butyl acetate with thiourea gave mostly **4c**, along with about 15% of the corresponding acetoxy derivative. Alkaline hydrolysis of crude **4c** from either source gave the mercapto-alcohol (**1c**), which was purified by distillation and converted to the crystalline mono- and bis-carbamates.

Chlorination of an aqueous solution of **4c** gave, on workup, a mixture (in about 50% yield) the nmr spectra of which showed the presence of roughly 50% 4-hydroxy-1-butanesulfonyl chloride (**2c**), 25% 4-chloro-1-butanesulfonyl chloride (**5c**), and 30% butane sultone (**3c**) (with small amounts of either 1,4-butanedisulfonyl chloride or 4-acetoxy-1-butanesulfonyl chloride, depending on the impurities present in the **4c**); the proportions of the major products varied somewhat with reaction conditions. Chlorination of an aqueous solution of the mercaptan (**1c**) gave a similar mixture of **2c**, **3c**, and **5c**. It was found that the cleanest specimen of **2c** was obtained by washing the aqueous reaction mixture with a small amount of chloroform to remove some of the sultone (**3c**) and most of the chloro-sulfonyl chloride (**5c**), followed by a thorough extraction with dichloromethane; this gave a product consisting largely (~70%) of the hydroxysulfonyl chloride (**4c**) plus the sultone (~25%) and a little **5c** (~5%); the structure of **2c** follows from (a) its infrared, ^{1}Hmr and ^{13}Cmr spectra and (b) conversion of both to the sultone (**3c**)[12] and to the crystalline piperidide (**6**, $n = 4$).

Part of the difficulty in obtaining a pure sample of **2c** was due to its conversion to the sultone (**3c**) during workup. This was shown by an experiment in which the crude aqueous product (after the chloroform wash) was divided into a number of aliquots; immediate extraction of the first portion gave a product with **2c** and **3c** in a 70:30 ratio, with that extracted after 15 min showing a 40:60 ratio, that after 30 min a 15:85 ratio, and that after 1 h only traces of **2c**. The half-life of **2c** in water at room temperature is estimated to be about 20 min; in accord with this a solution containing **2c** in D_2O showed only signals due to **3c** after 1 h. The spontaneous cyclization of **2c** to **3c** is evidently quite a bit slower in non-polar solvents, with a half-life of about 15 h being found for a $CDCl_3$ solution.*

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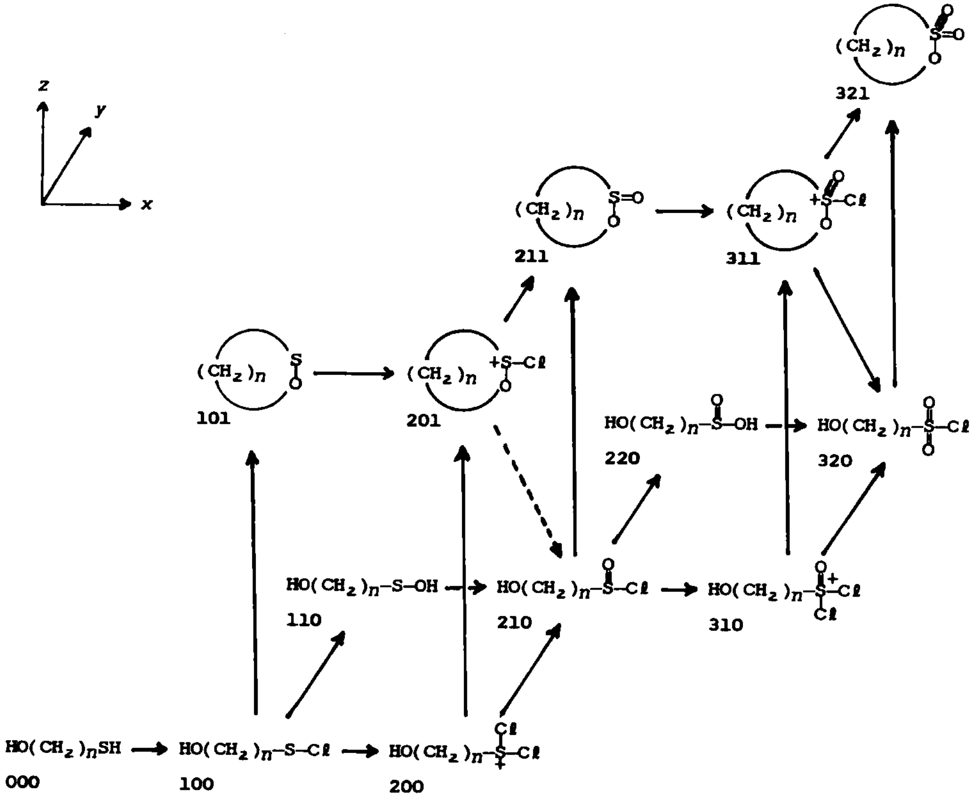
* *Note added in proof:* In very recent experiments with **2c** prepared in the absence of water, we find a distinctly longer half-life for the cyclization, **2c**→**3c**, strongly suggesting that the reaction is catalyzed even by small amounts of water.

These results recall earlier experiments on the chlorination of 3-mercapto-1-propanol,[3,4] in which we showed that the products were propane sultone (**3b**) and 3-chloro-1-propanesulfonyl chloride (**5b**), with the former (**3b**) being formed by very rapid cyclization of the hydroxy-sulfonyl chloride (**2b**). The only real difference with the four-carbon system is that the cyclization of the sulfonyl chloride (**2c**) to form the six-membered ring sultone (**3c**) is distinctly slower than the analogous formation of the five-membered homologue (**3b**), thereby allowing **2c** to be (a) observed by nmr spectra as the major component of the reaction mixture, and (b) at least partly separated from the other products and its cyclization observed separately; this, of course, is in full accord with the usual pattern of reactivity in five- vs six-membered ring formation.[6]

As with the cyclizations leading to **2d** and **2e**, above, we describe the ease of formation of **3c** in terms of the effective concentration of the reaction; by comparing the rate of cyclization of **2c** with that of the reaction of butanesulfonyl chloride with 1-butanol under the same conditions, we obtained a rough value of C_{eff} for **2c**→**3c** of 3×10^2 M (in $CDCl_3$, 0.9 M in 1-butanol, at 20°C); as expected, no sign of any polymer from **2c** was seen. Similarly in the reaction of **2c** with triethylamine with ethanol as the solvent, the product was largely **3c** with little or no ethyl ester (**7**, $n = 4$, $R = Et$) in evidence. At this point it was decided that further study of **2c** should be deferred until procedures for obtaining purer specimens of **2c** were developed.

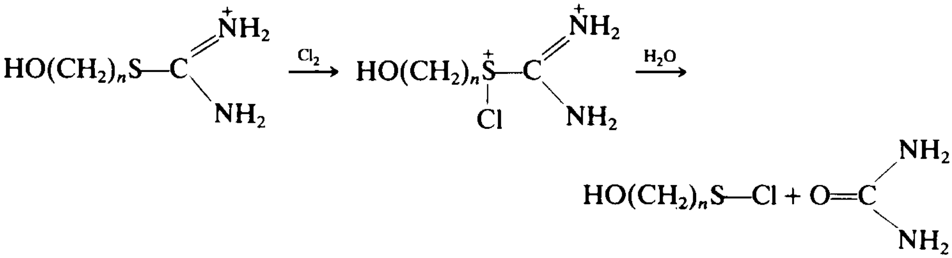


SCHEME 1

The Mechanism of the Aqueous Chlorination

Scheme 1 presents in a three-dimensional grid pattern most of the reactions which we regard as likely contributors to the general conversion of ω-mercapto-1-alkanols (**1**) to the ω-hydroxy-1-alkanesulfonyl chlorides (**2**) by chlorination in an aqueous medium. In this representation we place the starting material at the origin and depict successive reactions with each reagent as progressive movements along a particular axis; i.e. each chlorination leads to the species one position farther along the x-axis, each hydrolysis to the position one unit farther on the y-axis, and cyclization to the species one unit up the z-axis. Starting with the coordinates of the starting material (0,0,0), which we write simply as **000**, and representing each reaction by an integral change in the appropriate coordinate, we obtain designations for each of the various species as shown. Note that for two species connected by a "coordinate step" (i.e. one shown by an arrow parallel to one of the coordinates), two of the coordinates stay the same while that corresponding to the reaction changes by one unit; e.g. the cyclization of the hydroxy-sulfonyl chloride, **320**→**321**, alters only the final digit (the z-value). A convenient feature of this notation is that the coordinates for any species gives the number of "coordinate steps" of the shortest pathway from the starting material to that species. E.g. the hydroxy-sulfonyl chloride (**320**) is obtained from the starting material in three chlorination and two hydrolysis steps; the sum of the coordinates obviously gives the total number of "coordinate steps" in the shortest route.

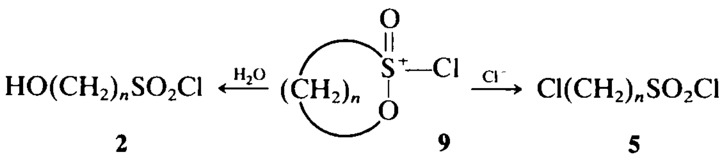
For reactions starting with a thiouronium salt a slightly modified path to the sulfenyl chloride (**100**) is required:



Although, in the above schemes, we represent the product of the chlorination of dicoordinated sulfur as a chlorosulfonium ion (e.g. **200**), we are not attempting to draw any distinction between these species and the corresponding sulfurane, $HO(CH_2)_nSCl_3$, or molecular complex structures, $HO(CH_2)_nS—Cl—Cl$, for which there is precedent,[13] and which may well be present as components of the equilibrium or even the important reacting species in these transformations; the same disclaimer holds also for the other cationic species in Scheme 1, i.e. **201**, **310**, and **311**.

Chlorination of the five- and six-carbon thiouronium salts (**4d** and **4e**) in the presence of a large excess of water, as in the present experiments, evidently occurs by a mechanism confined to the xy-plane of Scheme 1. We have no evidence for distinguishing among the four pathways from **100** to **320**, but since both the chlorination and hydrolysis steps are bimolecular the relative rates can presumably be altered simply by changing relative concentrations; with a low concentration of chlorine, for example, the sequence **100**→**110**→**210**→**220**→**320** may be the important mechanism, whereas at a higher chlorine concentration the route **100**→**200**→**210**→**310**→**320** may supervene, and at an intermediate concentration ratio all four pathways could perhaps be significant. In this context we point out that the grid pattern picture used in Scheme 1 has the advantage of displaying clearly both the number of possible routes and the potential for variation with reaction conditions, and, though at first glance it may appear rather elaborate, it may well be the least complicated way of representing an intrinsically complex system.

The aqueous chlorination of the three- and four-carbon substrates (**1b**, **1c**, and **4c**) clearly involves, in addition to the chlorination and hydrolysis processes, reaction in the *z*-axis to form cyclic species, as might be expected from the high effective concentrations commonly found in five- and six-membered ring-formation reactions.[6] The available evidence from product composition and oxygen-labeling[4] studies is consistent with formation of both the ω-chloro- and the ω-hydroxy-1-sulfonyl chlorides (**5b** and **5c**, and **2b** and **2c**) by nucleophilic attack on the ω-carbon of the oxochlorosulfoxonium species (**9** ≡ **311** in Scheme 1) with C—O bond cleavage:



The C—O cleavage mechanism shown here (and in Scheme 1 by the solid diagonal arrow, or, less probably,[14] by the dotted diagonal arrow between **201** and **210**) is obviously not the only possible route to the hydroxy-sulfonyl chlorides (**2** ≡ **320**). The oxygen-labeling experiments[4] show, however, that within the experimental uncertainty of the method all of the propane sultone (**2b**) is formed by a route involving C—O cleavage of **9** ($n = 3$). The corresponding labeling studies have not been done with the four-carbon system, but the formation of 4-chloro-1-butanesulfonyl chloride (**5c**) is also most simply accounted for on the basis of a similar C—O cleavage pathway. The likely intermediate (**9**, $n = 4$) might be expected to give much the same ratio of **5** to **2** (or **3**) as that from the three-carbon analogue (**9**, $n = 3$) under similar conditions; that similar product ratios are in fact observed strongly suggests that most, and perhaps all, of the 4-hydroxy-1-butanesulfonyl chloride arises from the cyclic species (**311** ≡ **9**, $n = 4$).

Scheme 1 shows six possible routes to the oxychlorosulfoxonium ion (**311**). In the light of (a) the excess of chlorine used (thereby favouring **100**→**200** over the alternatives), and (b) the high C_{eff} values usually found with six-membered ring formation reactions (leading to formation of **201** rather than **210**), it seems likely that the predominant pathway for the formation of **2c**(≡**320**, $n = 4$) from **1c** follows the sequence **000**→**100**→**200**→**201**→**211**→**311**→**320**.

Factors Controlling the Synthesis of ω-Hydroxy-1-alkanesulfonyl Chlorides (**2**)

One factor affecting the nature of the products of aqueous chlorination of **1** and (or) **4** is the reaction medium. Goethals and Verzele[5] have reported that chlorination of aqueous *suspensions* of **1b** to **1e** gave the chloro-sulfonyl chlorides (**5b** to **5e**) in yields varying from 31 to 78%; specifically, **1c** gave a 70% yield of **5c** described as containing 5% of the sultone (**3c**). In our hands chlorination of an aqueous *solution* of either **1c** or **4c** gave a mixture of approximately equal amounts of **2c** and **5c**. This experiment suggests that the key difference between our results and those of the Belgian workers[5] is not the fact that they used the thiol and most of our chlorinations were performed on thiouronium salts, but that their reactions took place in an organic phase and ours in water. In the latter medium there is a competition between water and Cl^- for cleavage of the cation **9**(≡ **311**), whereas in the organic phase the concentration of water is low and hence the rate of hydrolysis of **9** slow relative to Cl^- attack. With the five- and six-carbon systems the reaction in aqueous solution presumably leads to rapid hydrolyses (e.g. **200**→**210**) and thence to the hydroxy-sulfonyl chlorides (**2**). In the organic phase reactions, hydrolysis is slow relative to either cyclization (when C_{eff} is higher than the concentration) or the corresponding intermolecular reaction; (the latter process, which was omitted from Scheme 1 for simplicity, would yield acyclic intermediates such as $HO(CH_2)_nSO—O(CH_2)_nSO—Cl$ when C_{eff} is lower than the concentration. Both the cyclic or acyclic species would be expected to lead ultimately to **5** rather than **2**, since under these conditions the chloride concentration would be high relative to that of water, and C—O cleavage of **311** or its acyclic analogue by attack of chloride would be the favoured reaction.

In agreement with this picture we found that chlorination of **1e** in a mixture of CH_2Cl_2 and water gave a mixture in which **5e** predominated over the small amount of **2e**. Though in our view thiols and thiouronium salts react by essentially the same pathway, the latter, by virtue of their ionic character, are much more water-soluble than the thiols and their reaction is much more likely to take place entirely in the aqueous phase. This simple practical consideration favors the use of the thiouronium salts (**5**) over the thiols (**1**) (wherever this is feasible) for the synthesis of hydroxy-sulfonyl chlorides.

Also crucial to determining the course of aqueous chlorination reactions is the structure of the starting material—and hence of the possible products. The polymerization of the five- and six-carbon hydroxy-sulfonyl chlorides (**2d** and **2e**) is sufficiently slow that, although this reaction evidently limits the storage of these compounds, it does not interfere significantly with their preparation. Experience with the three- and four-carbon sulfonyl chlorides (**2b** and **2c**) shows cyclization to the sultone (**3**) to be the key reaction determining if **2** can be isolated. We may expect as a general rule that when C_{eff} for **2**→**3** is ≤ 100 the hydroxy-sulfonyl chloride (**2**) can be expected to be easily prepared; with increasing C_{eff} values, however, isolation of **2** (instead of **3**) would become more and more difficult and ultimately impossible.

EXPERIMENTAL

Magnetic resonance spectra were obtained using Varian T60, XL100, XL200, and XL300 instruments, with all reported chemical shift values (relative to tetramethylsilane for organic solutions and sodium 3-(trimethylsilyl)propionate for aqueous solutions) from the high field instruments unless otherwise noted. Infrared (ir) spectra were recorded with a Beckman 4250 spectrometer calibrated with a polystyrene film. Melting points were obtained with a Kofler Hot Stage apparatus and are uncorrected. Where not otherwise indicated reagents and solvents were reagent or other good commerical grade and were used without further purification.

Thiouronium salts (**4**). (a) *6-Hydroxy-1-hexylthiouronium chloride* (**4e**). A solution of 6-chloro-1-hexanol[18] (9.17 g, 67.1 mmol) and thiourea (5.59 g, 73.4 mmol) in ethanol (4 mL) and water (15 mL) was refluxed for 15 h; the mixture was then washed with CH_2Cl_2, and the aqueous layer evaporated to dryness under reduced pressure (below 50°C) to give a white solid (14.5 g, ~100%). Recrystallization from absolute ethanol–ether gave white needles melting at 127–128°C; ir (KBr) ν_{max}: 3300 (v br), 1638 (vs), 1447 (s), 1288 (m), 1068 (m), 1050 (s), 1033 (s), 982 (m), 686 (m), 610 (m), 490 (m) cm^{-1}; ^{1}Hmr (D_2O) δ: 1.12–1.92 (m, 8H), 3.16 (t, 2H), 3.62 (t, 2H); ^{13}Cmr (D_2O) δ: 31.1, 33.9, 34.3, 37.3, 37.7, 68.3, 178.3. Anal. Calcd. for $C_7H_{14}N_2OSCl$: C, 39.52; H, 8.05; N, 13.17; S, 15.07; Cl, 16.68. Found: C, 39.62; H, 8.22; N, 13.26; S, 15.01; Cl, 16.81.

(b) *5-Hydroxy-1-pentylthiouronium chloride* (**4d**). 5-Chloro-1-pentyl acetate[19] (10.0 g) was refluxed with a mixture of conc. H_2SO_4 (30 mL), H_2O, (75 mL), and methanol (100 mL) for 2.5 h; workup followed by distillation gave 5-chloro-1-pentanol (4.17 g, 54%); the chloropentanol (4.17 g, 34 mmol) and thiourea (2.53 g, 33 mmol) in water (8 mL) and ethanol (2 mL) after refluxing for 18 h and workup as above, gave a colorless oil (6.37 g, 94%) which solidified on standing in the cold; recrystallization from absolute ethanol–ether gave white crystals, mp 91.5–92°C; ir (KBr) ν_{max}: 3300 (v br), 1660 (vs), 1428 (m), 1400 (br m), 1295 (m), 1235 (m), 1060 (m), 1035 (m), 684 (m) cm^{-1}; ^{1}Hmr (D_2O) δ: 1.22–1.96 (m, 6H), 3.16 (t, 2H), 3.63 (t, 2H); ^{13}Cmr (D_2O) δ: 26.6, 30.2, 33.3 (double intensity), 64.0, 174.2. Anal. Calcd. for $C_6H_{15}N_2OSCl$: C, 36.20; H, 7.60; N, 14.07; S, 16.11; Cl, 17.81. Found: C, 36.43; H, 7.73; N, 13.91; S, 15.88; Cl, 18.22.

(c) *4-Hydroxy-1-butylthiouronium chloride* (**4c**). 4-Chloro-1-butanol (1.08 g, 10 mmol), thiourea (0.741 g, 9.5 mmol), water (6 mL), and ethanol (2 mL) upon refluxing for 22 h and workup as above gave a colorless viscous liquid (1.64 g) which partly crystallized on standing. The liquid component was dissolved in abs. EtOH and the solid product removed by filtration. This crystalline material (0.295 g, 18%) was shown to be 1,4-butylbisthiouronium chloride: recrystallization from EtOH-water gave white crystals, mp 223–225°C; ir (KBr) ν_{max}: 3100 (v br), 1625, 1430, 1320, 1210, 700 cm^{-1}; ^{1}Hmr (D_2O) δ: 1.86–1.92 (m, 4H), 3.15–3.22 (m, 4H); ^{13}Cmr (D_2O) δ: 29.3, 32.8, 173.8; aqueous chlorination yielded 1,4-butanedisulfonyl chloride, which on recrystallization from light petroleum gave white needles, mp 83–84°C (reported mp 82.5°C[10], 83–84°C[11]; ^{1}Hmr ($CDCl_3$) δ: 2.26–2.33 (m, 4H), 3.73–3.81 (m, 4H); ^{13}Cmr ($CDCl_3$) δ: 22.5, 63.9. Evaporation of the alcohol from the filtrate left **4c** as a viscous liquid (1.35 g, 78%); ^{1}Hmr (D_2O) δ: 1.67–1.88 (m, 2H), 3.16 (t, 2H), 3.62 (t, 2H); signals appropriate to a small amount (5–10%) of the 1,4-bisthiouronium salt were also visible in the nmr spectra; the major peaks in the ^{13}Cmr spectrum were identical to those of the sample from the acetate (below). 4-Chloro-1-butyl acetate[20] (3.65 g, 24.3 mmol) and thiourea (1.89 g, 24.25 mmol), when refluxed in water (5 mL) and ethanol (5 mL) for 22 h, gave, after workup, a viscous liquid (5.5 g, ~100%), which from its ^{1}Hmr spectrum consisted of **4c** with about 15% of its O-acetate derivative (with a singlet at 2.10 and a triplet at 4.12 ppm); ^{13}Cmr (D_2O) δ: 25.6, 31.2, 31.7, 62.0, 172.4.

6-Hydroxy-1-hexanesulfonyl chloride (**2e**). Chlorine was bubbled into water (850 mL) cooled in an ice-salt bath until the solution turned yellow-green; an aqueous solution of **4e** (897 mg, 4.22 mmol) in water (150 mL) was added dropwise over 10 min and the mixture stirred a further 40 min. Thorough extraction with CH_2Cl_2 (6 × 100 mL), followed by washing of the organic layer with small amounts of aqueous $NaHSO_3$ to remove excess Cl_2, and evaporation of the solvent gave **2e** as a colorless viscous oil (716 mg, 3.57 mmol, 85%) (attempted distillation gave only decomposition); ir (neat) ν_{max}: 3600–3020 (br m), 2936 (s), 2855 (s), 1683 (m), 1453 (m), 1360 (vs), 1156 (vs), 1142 (m), 948 (m), 908 (m) cm^{-1}; ^{1}Hmr ($CDCl_3$) δ: 1.3–1.8 (m, 6H), 1.8–2.3 (m, 2H), 3.6–3.84 (m, 4H), 5.13 (var s, 1H); ^{13}Cmr ($CDCl_3$) δ: 24.2, 25.1, 27.2, 32.0, 62.3, 65.3; the nmr spectra typically showed small extra peaks ascribable to ~5% impurity.

The sulfonyl chloride was further characterized by conversion to 6-acetoxy-1-hexanesulfonpiperidide (**6**, $n = 6$), as follows. To the sulfonyl chloride in dry CH_2Cl_2 was added a seven-fold excess of acetyl chloride and the mixture allowed to stand for 22 h; after washing with aqueous $NaHCO_3$ and evaporation of the solvent the acetoxy-sulfonyl chloride was obtained as pale yellow oil; ir (neat) ν_{max}: 2950 (s), 2870 (m), 1720 (vs), 1360 (vs), 1240 (vs), 1150 (vs), 1040 (m) cm^{-1}; ^{1}Hmr ($CDCl_3$, T60) δ: 1.15–2.25 (m, 8H), 2.03 (s, 3H), 3.67 (t, 3H), 4.03 (t, 2H). Reaction for 1.5 h with excess piperidine in CH_2Cl_2 followed by conventional workup, yielded a yellowish oil which, on recrystallization from cold pentane, gave **6** ($n = 6$) as white needles, mp 41.5–43.0°C; ir ($CHCl_3$) ν_{max}: 2940 (m), 2850 (m), 1730 (vs), 1334 (vs), 1320 (s), 1200–1278 (s, br), 1159 (s), 1134 (s), 1050 (m), 935 (m) cm^{-1}; ^{1}Hmr ($CDCl_3$) δ: 1.35–2.05 (m, 14H), 2.15 (s, 3H), 2.98 (t, 2H), 3.33 (m, 4H), 4.16 (t, 2H). Anal. Calcd. for $C_{13}H_{25}NO_4S$: C, 53.58; H, 8.65; N, 4.81; S, 11.00. Found: C, 53.72; H, 8.50; N, 4.63; S, 11.12. Calcd. exact mass: 291.1504. Found: 291.1500.

Chlorination of a more concentrated solution of the thiouronium chloride (48 mg in a total of 5 mL of water) gave in addition to the ^{1}Hmr peaks ascribed to the hydroxy-sulfonyl chloride, a triplet at δ4.2 possibly assignable to a —CH_2OSO_2— of a polymeric by-product; a white, insoluble, apparently polymeric material was also observed in a number of runs. No sign of any 6-chlorohexanesulfonyl chloride was visible in the ^{13}Cmr spectra of any of these chlorination products of the thiouronium salt even in the presence of considerable amounts of NaCl (e.g. 4 M).

A refluxing solution of **2e** (0.1 M in $CDCl_3$) gradually showed the development of ^{1}Hmr triplets at δ 3.1 and 4.2 believed to be due to polymer; after 4 to 5 days the area of each of these signals was about the same as that of multiplet (4H) around δ 3.7, indicating that the solution contained a roughly 2:1 mixture of polymer to **2e**; the presumed polymer signals also appear on refluxing in benzene or on long standing (20 da) in $CDCl_3$. No sign of **3e** was seen in the spectra; control experiments showed **3e** to be stable to these conditions, but was decomposed to a black intractable material on heating at 130°C for 24 h.

5-Hydroxy-1-pentanesulfonyl chloride (**2d**). The thiouronium chloride (**4d**) (750 mg, 3.7 mmol) in water (200 mL) was added dropwise with stirring to an ice-cold solution of Cl_2 in water (1 L) prepared as above, and the mixture stirred for a further 45 min. Workup as above gave **2d** (651 mg, 92%) as a clear, slightly yellowish oil; best yields and highest purity seemed to be favored by using a large excess of Cl_2 and high dilution; ir ($CHCl_3$) ν_{max}: 3620 (m), 3520–3330 (br m), 2940 (s), 2865 (m), 1456 (m), 1370 (vs), 1264 (s), 1160 (vs), 1065 (m) cm^{-1}; ^{1}Hmr ($CDCl_3$) δ: 1.18–2.56 (m, 6H), 2.86 (s, 1H), 3.46–3.88 (m, 4H); ^{13}Cmr ($CDCl_3$) δ: 23.9, 24.1, 31.7, 62.1, 65.3.

The acetyl derivative, prepared as above, was a clear slightly yellow oil; ir ($CHCl_3$) ν_{max}: 2950 (br m), 1730 (s), 1460 (br m), 1370 (s), 1245 (br s), 1160 (vs), 1060 (w) cm^{-1}; ^{1}Hmr ($CDCl_3$) δ: 1.40–2.34 (m, 6H), 2.06 (s, 3H), 3.72 (t, 2H), 4.12 (t, 2H). The piperidide (**6**, $n = 5$) formed white crystals from cold pentane, mp 30.5–31°C; ir ($CHCl_3$) ν_{max}: 2896 (m), 1731 (s), 01361 (m), 1336 (s), 1236 (br s), 1156 (s), 1136 (s), 1041 (m), 936 (m), 636 (m) cm^{-1}; ^{1}Hmr ($CDCl_3$, T-60) δ: 1.3–1.9 (br "s", 12H), 2.10 (s, 3H), 2.66–3.05 ("t", 2H), 3.1–3.36 (m, 4H), 4.02 (t, 2H). Anal. Calcd. for $C_{12}H_{23}NO_4S$: C, 51.97: H, 8.36; N, 5.05; S, 11.54. Found: C, 52.01; H, 8.36; N, 4.89; S, 11.87.

4-Mercapto-1-butanol (**1c**). A solution of crude **4c** (5.5 g, 30 mmol) (made from 4-chloro-1-butyl acetate and containing ~15% acetate ester), in aqueous 10% NaOH was allowed to react for 5 h at room temperature; workup gave 4-mercapto-1-butanol (**1c**) (2.03 g, ~65%), bp 105–106°C (30 torr); ^{1}Hmr ($CDCl_3$) δ: 1.32 (t, 1H), 1.57–1.65 (m, 4H), 2.27 (s, 1H), 2.5 (q, 2H), 3.57 (t, 2H); ^{13}Cmr ($CDCl_3$) δ: 24.5, 30.3, 31.3, 62.0. Heating **1c** with phenyl isocyanate gave a roughly 2:1 mixture of the phenylurethane-thiol ($PhNHCOOCH_2CH_2CH_2CH_2SH$) (mp 124–125°C; ^{1}Hmr ($CDCl_3$) δ: 1.36 (t, 1H), 1.6–1.86 (m, 4H), 2.56 (q, 2H), 4.17 (m, 2H), 6.82 (br s, 1H), 7.0–7.4 (m, 5H); ^{13}Cmr ($CDCl_3$) δ: 24.2, 27.7, 30.3, 64.6, 118.7, 123.4, 129.0, 137.9, 153.5), and the bisphenylcarbamate ($PhNHCOOCH_2CH_2CH_2CH_2SCONHPh$) (mp 126–128°C, reported[21] mp 128°C; ^{1}Hmr ($CDCl_3$) δ: 1.74–1.86 (sym m, 4H), 3.04 ("t", 2H), 4.19 ("t", 2H), 6.56 (br s, 1H), 7.0–7.45 (m, 11H); ^{13}Cmr ($CDCl_3$) δ: 27.0, 27.8, 29.9, 64.7, 118.6, 119.8, 123.4, 124.5, 129.0, 129.1, 137.7, 137.9, 153.5, 180.6) separated by recrystallization from benzene.

4-Hydroxy-1-butanesulfonyl chloride (**2c**). Chlorine was bubbled into water (100 mL) cooled in an ice bath until the solution turned yellow (about 1 min), and an aqueous solution of **4c** (100 mg) in water (5 mL) added quickly. The reaction mixture was extracted immediately with a small portion (3 mL) of chloroform (to remove the **5c** and, where formed, the 1,4-disulfonyl chloride or the acetoxysulfonyl chloride), and then further extracted thoroughly, and as quickly as possible, with CH_2Cl_2 (3 × 50 mL); drying of the extract ($NaSO_4$) and evaporation of the solvent gave impure (~70%) **2c** as an oil (54 mg, 51%); ^{1}Hmr ($CDCl_3$) δ: 1.70–1.89 (m, 2H), 2.15–2.26 (m, 2H), 3.71–3.82 (m, 4H); ^{13}Cmr ($CDCl_3$) δ: 21.6, 30.1, 61.8, 65.4, plus small signals at 23.0, 23.7, 48.4, 74.1 assigned to **3c**.

4-Mercapto-1-butanol (**1c**) (200 mg, 1.89 mmol) on similar chlorination gave (a) in the $CHCl_3$ wash, a 24:76 mixture (40 mg) of **3c** and **5c**, and (b) in the CH_2Cl_2 extract, a 65:28:7 mixture of **2c**, **3c**, and **5c**; estimated overall yields: **2c**, 89 mg, 27%; **3c**, 37 mg, 14%; **5c**, 44 mg, 12%. Spectra of authentic specimens: (a) butane sultone[12] (**3c**) ^{1}Hmr ($CDCl_3$) δ: 1.72–1.79 (m, 2H), 2.10–2.17 (m, 2H), 3.06 (t, 2H), 4.45 (t, 2H); ^{13}Cmr ($CDCl_3$) δ: 22.8, 23.5, 48.3, 74.1; (b) 4-chloro-1-butanesulfonyl chloride (**5c**) (prepared[22] by refluxing a solution of **3c** in $SOCl_2$ containing a little dimethylformamide for 22 h) ^{1}Hmr ($CDCl_3$) δ: 1.93–2.07 (m, 2H), 2.16–2.31 (m, 2H), 3.62 (t, 2H), 3.74 (t, 2H); ^{13}Cmr ($CDCl_3$) δ: 21.9, 30.0, 43.7, 64.5.

The acetyl derivative, prepared as above, was a clear oil; ^{1}Hmr ($CDCl_3$) δ: 1.83–1.90, (m, 2H), 2.07 (s, 3H), 2.07–2.14 (m, 2H), 3.77 (t, 2H), 4.13 (t, 2H); ^{13}Cmr ($CDCl_3$) δ: 20.6, 21.1, 26.3, 62.8, 64.5, 170.6. The piperidide (**6**, $n = 4$) formed white crystals, mp 44–45°C, from cold hexane; ir (CCl_4) ν_{max}: 2950 (s), 2870 (m), 1745 (vs), 1450 (m), 1365 (s), 1340 (vs), 1240 (vs), 1165 (s), 1145 (s), 1055 (s), 940 (s) cm^{-1}; ^{1}Hmr ($CDCl_3$) δ: 1.46–1.69 (m, 10H), 1.90 (s, 3H), 2.77 (t, 2H), 3.05–3.10 (m, 4H), 3.94 (t, 2H); ^{13}Cmr ($CDCl_3$) δ: 20.0, 20.9, 23.8, 25.7, 27.5, 46.6, 48.5, 63.4, 171.0. Calcd. exact mass for $C_{11}H_{21}O_4SN$: 263.1191. Found: 263.1191.

In one chlorination of **4c** the aqueous product (after the initial $CHCl_3$ wash) was split into five aliquots which were separately extracted with CH_2Cl_2: (i) which was extracted immediately showed the ^{1}Hmr spectrum of a 74:26 ratio of **2c** to **3c**, (ii) extracted after 15 min, 55:45, (iii) 30 min, 23:77, (iv) 45 min, ~15:85, (v) 60 min, <10:90, indicating $t_{1/2}$ around 20 ± 5 min; a solution of **2c** (with about 25% **3c**) in D_2O showed no protons signals due to **2c** after 1 h at room temperature. In $CDCl_3$ the following ratios of **2c** to **3c** were estimated from the ^{1}Hmr spectrum: start 76:24, 20 h 36:64; 27 h 17:83, 44 h 9:91, corresponding $t_{1/2}$ ~15 ± 3 h at room temperature*. (Shown on p. 164).

1,2-Oxathiocane 2,2-dioxide (*1,6-hexane sultone*) (**3e**). A solution of 6-hydroxy-1-hexanesulfonyl chloride (**2e**) (999 mg, 5.0 mmol) in dry CH_2Cl_2 (35 mL) was added slowly over 2 h (syringe pump) to a solution of triethylamine (1.4 mL, 10 mmol) in CH_2Cl_2 (250 mL) and the mixture stirred a further 0.5 h. Workup gave a yellow-brown oil (500 mg, 61%) which on filtration of a benzene solution through Kiesegel 60, followed by recrystallization from petroleum ether (bp 35–55°C), yielded **3e** as white flakes melting at 37.0–37.5°C; ir ($CHCl_3$) ν_{max}: 2930 (m), 1350 (vs), 1160 (vs), 940 (s), 925 (s) cm^{-1}; ^{1}Hmr ($CDCl_3$) δ: 1.58–2.19 (m, 8H), 3.27 (t, 2H), 4.46 (t, 2H); ^{13}Cmr ($CDCl_3$) δ: 22.9, 25.5, 25.8, 28.7, 50.1, 73.1. Anal. Calcd. for $C_6H_{12}O_3S$: C, 43.88; H, 7.37; S, 19.52; molecular weight, 164. Found: C, 43.72; H, 7.51; S, 19.39; molecular weight (vapor phase osmometry, CH_3OH solvent, (−)-borneol reference), 159.

Tertiary amines other than triethylamine gave the following results on reaction with **2e** in CH_2Cl_2 (conditions as noted): pyridine (112 h reflux) no sign of **3e**,

~10% of presumed polymer (δ 3.1 and 4.2); 2,6-lutidine (22 h reflux) no **3e**, ~30% "polymer"; dimethylbenzylamine (18 h reflux) roughly 60% **3e**, 10% "polymer", and 30% unreacted **2c**; N,N-diisopropylethylamine (16 h at room temperature) essentially complete conversion to **3e**, no "polymer".

The sultone (**3e**) (30 mg, 0.18 mmol) on reaction with excess trimethylamine (0.2 mL) in $CHCl_3$ (1 mL) for 48 h yielded 6-(*N,N,N*-trimethylammonio)-1-hexanesulfonate, $Me_3N^+(CH_2)_6SO_3^-$, as white crystals (38 mg, 95%); upon recrystallization from ethanol these melted at 345°C (with decomp.) (reported[23] 367°C). With NH_3 in $CHCl_3$ for 7 days at 60°C, **3e** gave $NH_3^+(CH_2)_6SO_3^-$, mp (recryst. ether-ethanol) 294–298°C; lit[24]. mp 303–305°C.

1,2-Oxathiepane 2,2-dioxide (*1,5-pentane sultone*) (**3d**). A solution of 5-hydroxy-1-pentanesulfonyl chloride (**2d**) (250 mg, 1.34 mmol) in dry CH_2Cl_2 (12 mL) was added dropwise over 10 min to a solution of triethylamine (1 mL) in CH_2Cl_2 (80 mL) cooled in an ice-salt bath and the mixture stirred a further 40 min. Workup gave a yellowish oil (171 mg, 85%); distillation under reduced pressure gave **3d** as a colorless oil; ir ($CHCl_3$) ν_{max}: 1355 (s), 1170 (s), 1155 (m), 985 (m), 950 (m), 895 (m), 720 (s) cm^{-1} (Sharma *et al.*[25] report 1138, 1150, and 895 cm^{-1}); ^{1}Hmr ($CDCl_3$) δ: 1.55–2.48 (m, 6H), 3.30 (t, 2H), 4.28 (t, 2H); ^{13}Cmr ($CDCl_3$) δ: 22.7, 25.3, 28.8, 52.9, 70.4. Anal. Calcd. for $C_5H_{10}O_3S$: C, 40.00; H, 6.71; S, 21.32. Found: C, 40.09; H, 6.71; S, 21.23.

Chlorination of 6-hydroxy-1-hexanethiol (**1e**). Chlorine was bubbled into a vigorously stirred solution of 6-hydroxyhexane-1-thiol (128 mg, 0.94 mmol, prepared by NaOH hydrolysis of the thiouronium chloride[5]) in a mixture of CH_2Cl_2 (1 mL) and water (0.1 mL) until Cl_2 absorption ceased. Workup gave a clear oil, which from the following spectra is believed to be mainly 6-chloro-1-hexanesulfonyl chloride plus some **2e**: ir (neat) ν_{max}: 2940 (s), 2930 (s), 2860 (m), 1460 (m), 1370 (vs), 1160 (vs) cm^{-1}; ^{1}Hmr ($CDCl_3$) δ: 1.46–2.25 (m, 8H), 3.56 (t, 2H), 3.69 (t, 2H); ^{13}Cmr ($CDCl_3$) δ: 24.2, 26.2, 26.9, 32.0, 44.6, 65.2 (plus small peaks at 24.3, 25.2, 27.4, 32.1, 62.5, 65.3 ascribable to ~20% of **2e**); Krebes *et al.*[26] report δ values of 65.5 and 44.7 for C-1 and C-6, respectively, of 6-chloro-1-hexanesulfonyl chloride.

Reaction of the ω-Hydroxy-1-alkanesulfonyl chlorides (**2d** *and* **2e**) *with alcohols*. (a) *Ethyl 6-hydroxy-1-hexanesulfonate*. Triethylamine (94 mg, 0.93 mmol) in ethanol (25 mL) was added dropwise with stirring over 10 min to an ice-cooled solution of **2e** (124 mg, 0.62 mmol) in ethanol (50 mL) and stirred a further 95 min. Removal of the ethanol followed by workup with CH_2Cl_2 and water gave ethyl 6-hydroxy-1-hexanesulfonate as a clear oil (49 mg, 37%); ir (neat) ν_{max}: 3560 (s), 3420 (s), 2940 (vs), 2860 (s), 1470 (s), 1350 (br vs), 1160 (vs), 1000 (vs), 920 (vs) cm^{-1}; ^{1}Hmr ($CDCl_3$) δ: 1.26–2.07 (m, 12H), 3.11 (t, 2H), 3.66 (t, 2H), 4.31 (q, 2H); ^{13}Cmr ($CDCl_3$) δ: 15.2, 23.4, 25.2, 27.9, 32.3, 50.4, 62.6, 65.9.

(b) *1-Pentyl 6-hydroxy-1-hexanesulfonate*. Reaction of **2e** (108 mg, 0.54 mmol) with triethylamine (64 mg, 0.63 mmol) in cold 1-pentanol (5 mL) for 105 min followed by workup with CH_2Cl_2 and water gave the 1-pentyl ester as a yellow oil; ir (neat) ν_{max}: 3540 (m), 3400 (s), 2940 (vs), 2870 (s), 1470 (s), 1350 (vs), 1165 (vs), 1050 (s), 960 (vs), 910 (vs) cm^{-1}; ^{1}Hmr ($CDCl_3$) δ: 0.92 (t, 3H), 1.18–2.06 (m, 15H), 3.10 (t, 2H), 3.65 (t, 2H), 4.22 (t, 2H); ^{13}Cmr ($CDCl_3$) δ: 13.9, 22.1, 23.4, 25.2, 27.6, 27.9, 28.1, 32.3, 50.2, 62.5, 69.8.

(c) *Ethyl 5-hydroxy-1-pentanesulfonate.* Triethylamine (0.5 mL), **2d** (110 mg) and cold absolute ethanol (30 mL) gave, on workup after 1 h, a yellowish oil (64 mg, 55%); ^{1}Hmr ($CDCl_3$) δ: 1.42 (t, ~3H), 1.5–2.5 (m, ~7H), 3.12 (t, 2H), 3.66 ("t", 2H), 4.32 (q, 2H).

(d) *Deuterium labeling experiments.* 6-Hydroxy-1-hexanesulfonyl chloride (**2e**) (97 mg, 0.5 mmol) was shaken briefly with a mixture of D_2O and CH_2Cl_2 followed by separation and then by evaporation of the organic phase; the $DO(CH_2)_6SO_2Cl$ so obtained was allowed to react with butanol-*d* (750 mg, 10.0 mmol, 0.2 M) and triethylamine (100 mg, 1 mmol) in dry CH_2Cl_2 (50 mL) for 100 min. The ^{1}Hmr spectrum showed the product to consist of sultone (**3e**) and the butyl ester in the ratio of about 1:4, with each component substantially monodeuterated at the α-position, i.e. ~80% —$CHDSO_2O$— and ~20% —CH_2SO_2O— (±20% in each case), from the integrals of the δ3.10 and 3.26 signals (due to $CHDSO_2$ and CH_2SO_2 groups) relative to those at lower field. Further similar experiments using (a) **2d** and butanol-*d* and gave a similar mixture of sultone (**3e**) and butyl ester both largely α-monodeuterated, and (b) **2e** without added alcohol and using Et_3ND^+ Cl^- as the deuterium source and giving partly α-monodeuterated sultone (**3e**).

Estimation of the effective concentrations of the sultone-forming reactions. 6-Hydroxy-1-hexanesulfonyl chloride (**2e**) (100 mg, 0.50 mmol), absolute ethanol (460 mg, 10.0 mmol, 0.10 M), and triethylamine (80 mg, 0.8 mmol) in dry CH_2Cl_2 (100 mL) after 115 min, followed by workup yielded a product (60 mg) shown by ^{1}Hmr integration to consist of the sultone (**3e**) and the ethyl ester in the ratio 35:65; $C_{eff} = [ROH] \times [sultone]/[ester] = 0.098 \times 35/65 = 0.053$. Other experiments with 0.05 M ethanol, and 0.05 and 0.10 M pentanol gave C_{eff} values of 0.047, 0.043, and 0.058, respectively; mean C_{eff} for formation of **3e**, 0.048 M.

5-Hydroxy-1-pentanesulfonyl chloride (**2d**) (108 mg, 0.58 mmol), absolute ethanol (230 mg, 5.0 mmol, 0.05 M), and triethylamine (0.5 mL) in CH_2Cl_2 (100 mL) yielded an oil judged from integration of the signals at δ3.5–3.8 and 3.0–3.4 (or 4.0–4.4) to consist of sultone (**3d**) and ethyl ester in the ratio 15:7, corresponding to $C_{eff} = 0.11$.

^{1}Hmr spectra of a solution (at room temperature) of a sample of the crude reaction product (50 mg) containing **2c** (65%, 34 mg, plus **3c** 28%, and **5c** 7%) in $CDCl_3$ (1 mL) plus 1-butanol-*d* (75 mg, 0.9 M) were run at intervals and the extent of conversion of the **2c** to **3c** determined by comparison of the integral of the signals at 3.06 and 4.45 (due to **3c**) with the total integral of the 3.0 to 4.5 region; 42 min, 17% reaction; 81 min, 32%; 111 min, 44%; $k_1 = (8.7 \pm 0.7) \times 10^{-5} s^{-1}$. A solution of butanesulfonyl chloride and 1-butanol (initially 0.2 and 0.9 M, respectively) in $CDCl_3$ was kept at room temperature and ^{1}Hmr spectra run at 5 to 8 day intervals; $k_2 = (3.1 \pm 0.2) \times 10^{-7} M^{-1} s^{-1}$ (mean of five values over 34 da, 54% reaction); C_{eff} 2.8×10^2 M.

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