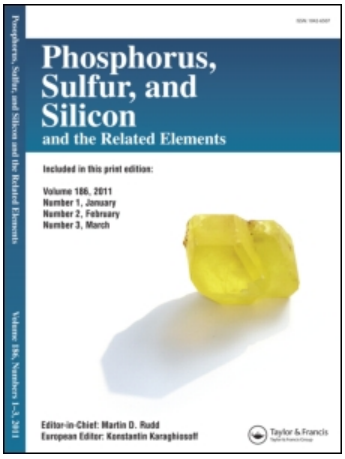

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THE CHEMISTRY OF 1,1'-THIOBIS-(2-CHLOROETHANE) (SULPHUR MUSTARD) PART I. SOME SIMPLE DERIVATIVES

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THE CHEMISTRY OF 1,1′-THIOBIS-(2-CHLOROETHANE) (SULPHUR MUSTARD) PART I. SOME SIMPLE DERIVATIVES

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Some derivatives of 1,1′-thiobis(2-chloroethane) (sulphur mustard) have been synthesised for use as reference compounds in a wide range of studies embracing analysis, metabolism, environmental degradation and decontamination. Compounds include products formed by hydrolysis, substitution and elimination reactions and their oxidised sulphoxide and sulphone analogues. A comprehensive series of methylthio, methylsulphinyl and methylsulphonyl derivatives has been synthesised in support of metabolic studies.

Key words: Thiobis(2-chloroethane) and derivatives; analysis; metabolism; environmental degradation; decontamination.

INTRODUCTION

Sulphur mustard, 1,1′-thiobis(2-chloroethane), is a potent vesicant and carcinogen. It was first used as a chemical warfare agent during the 1914–1918 war and has been stockpiled by several countries since that time. Most recently it was used on several occasions during the Iran-Iraq conflict[1,2,3] which has resulted in renewed prominance and interest.

The degradation of sulphur mustard in the environment and in biological systems is complex. To allow the development of protocols for the analysis and retrospective identification of sulphur mustard in a variety of matrices, it is desirable to have a detailed knowledge of the chemistry and biochemistry involved in degradation and metabolism, and to have available, where possible, a range of known and putative breakdown products for use as reference compounds.

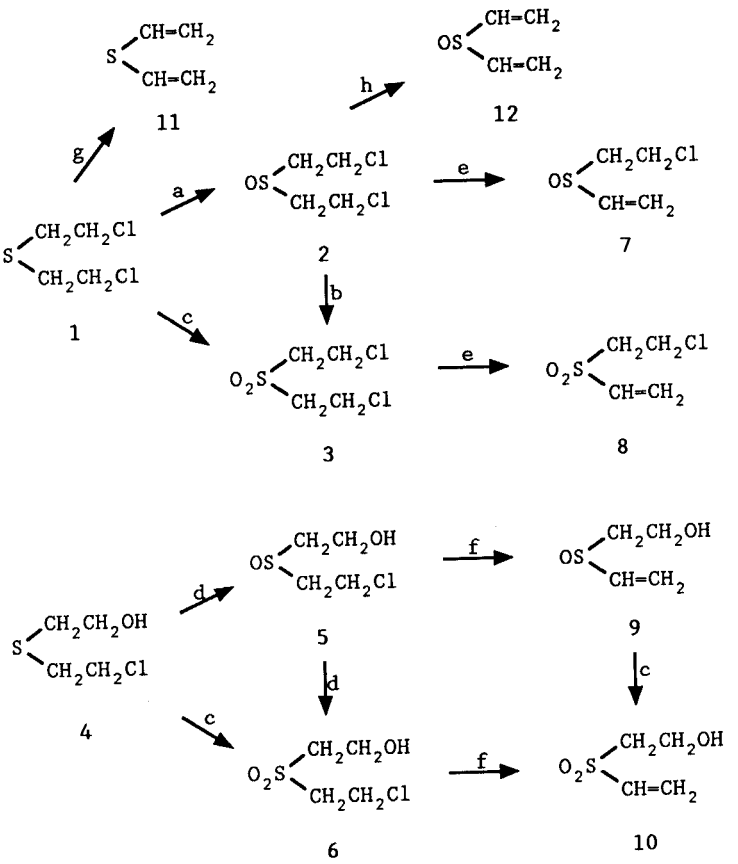
Sulphur mustard reacts with nucleophilic reagents at the β-carbon atom,[4] and with electrophilic reagents at sulphur[5] under relatively mild conditions. Together with other β-chloroethyl sulphides, sulphur mustard shows extraordinary reactivity towards nucleophiles, including water, when compared with analogous alkyl halides. This is a consequence of the anchiomeric assistance afforded by sulphur to the cleavage of the carbon-chlorine bond and results in the facile formation of a reactive cyclic thiiranium species. The latter process has been shown to occur by an S_N1 reaction mechanism whereas subsequent reaction of the intermediate with nucleophiles to give products occurs by an S_N2 mechanism. The ready formation of a thiiranium ion is an intramolecular manifestation of the ability of sulphur to interact with an electrophilic centre (the carbon-chlorine bond). On an intermolecular level, the ready interaction via the sulphur atom with electrophiles has two major consequences. Firstly, mustard (or a suitable derivative) can self-condense[4,6]

to afford initially a sulphonium ion species and ultimately a variety of products. Secondly, oxidation readily occurs to give sulphoxide and sulphone analogues, depending on conditions, in both chemical and biological systems. After oxidation, neighbouring group participation by sulphur is no longer available and formation of a thiiranium ion is precluded. The loss of chloride ion from β-chloroethyl sulphoxides and sulphones now occurs by a β-elimination mechanism, and the substitution of chlorine by nucleophiles occurs by a base-catalysed multi-step elimination-addition pathway.[7]

The potential complexity of any investigation into the analytical, environmental or biological chemistry of sulphur mustard necessitates a substantial synthetic programme to provide standards for use in analytical procedures and for the unequivocal identification of products and intermediates. Reaction products derived from hydrolysis, oxidation and elimination are of particular importance to the environmental fate of sulphur mustard; reactions with nucleophiles, particularly with glutathione, predominate in the metabolic fate of sulphur mustard in animals.[8] The chemistry and biological properties of sulphur mustard have been investigated intermittently for over 100 years for a variety of reasons, and have been reviewed in a recent book.[9] Methods for the preparation of numerous mustard-related derivatives have been reported in the older literature but in many instances these procedures give products that are of dubious purity, or are inadequately described and characterised since they were prepared without the benefit of modern chromatographic and spectroscopic techniques. This paper (Part I) describes the syntheses of a number of compounds derived formally from simple oxidation, hydrolysis and elimination reactions, incorporating full experimental details and spectroscopic data. Also described are the syntheses of some methylthio, methylsulphinyl and methylsulphonyl derivatives, required in support of metabolic studies of sulphur mustard.[9] A second paper (Part II)[10] will cover the synthesis of some conjugates of sulphur mustard, mustard sulphoxide and mustard sulphone with cysteine, *N*-acetylcysteine and *N*-acetylcysteine methyl ester.

RESULTS AND DISCUSSION

The series of compounds described in Scheme I were synthesised by a sequence of simple manipulations from mustard **1** and half-mustard **4** and represent convenient methods for the preparation of compounds shown, which are formally derived from simple hydrolysis, oxidation and elimination reactions. Half-mustard **4**, as prepared by the method of Seligman and Rutenberg,[11] was stored in ether solution, used without further purification and was satisfactory for our purposes. The reported method of Grant and Kinsey[12] for the synthesis of **4** proved to be unsatisfactory in our hands. Mustard sulphoxide **2** is readily prepared by oxidation of **1** with conc. nitric acid at room temperature.[13,14] For mustard sulphone **3**, more forcing conditions at elevated temperatures were required (hydrogen peroxide-acetic acid at 100°C). Published procedures using chromium trioxide[13,14] were equally effective. The half-mustard sulphoxide **5** was readily prepared from **4** by oxidation with 3-chloroperbenzoic acid at 0–5°C. The use of longer reaction times at room temperature gave the sulphone **6** which could also be prepared directly from **5** using hydrogen peroxide in acetic acid. The preparation of **6** has been reported



SCHEME I Reagents: a. HNO_3; b. $KMnO_4$; c. H_2O_2/AcOH; d. 3-CPBA; e. Et_3N; f. K_2CO_3; g. NaOMe; h. Na_2CO_3.

(with little detail) via the oxidative chlorination of thiodiglycol **37** [together with the subsequent elimination of the product using anhydrous sodium carbonate[15] to give **10**].

Preparations of vinyl compounds **7**, **8**, **9** and **10** were all achieved in good yields. Under carefully controlled conditions, treatment of mustard sulphoxide **2** with aqueous potassium carbonate at 50°C resulted in the selective elimination of only one mole of hydrogen chloride to afford the vinylsulphoxide **7**. Similarly, as first reported by Alexander and Chrombie,[17] reaction of **3** with one mole equivalent of triethylamine in benzene at room temperature overnight gave the vinylsulphone **8**. Treatment of **5** with aqueous potassium carbonate at 50°C gave **9**, in high yield, which was smoothly oxidised to sulphone **10** with hydrogen peroxide-acetic acid.

The reaction of sulphur mustard with a variety of oxidizing agents and the subsequent dehydrohalogenation and hydrolysis of the products in basic aqueous solution was investigated by Price and Bullitt[16] with a view to establishing methods for the treatment of water contaminated with mustard.

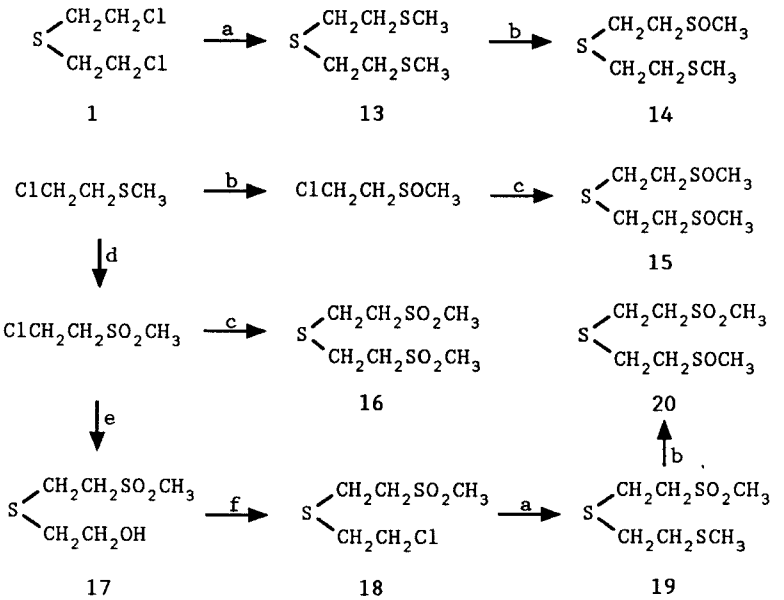
Divinyl sulphide **11** is an unstable mobile liquid that readily polymerizes at room temperature.[18] Treatment of mustard with sodium methoxide in methanol produced a complex array of products from which **11** was isolated in poor yield. A literature

procedure[19] to prepare **11** for polymer and spectroscopic studies utilised thiodiglycol **37** and potassium hydroxide to produce a complex mixture from which **11** was isolated in 36% yield with the advantage of using a non-toxic starting material. The preparation of divinyl sulphoxide **12** from **2** and boiling aqueous sodium carbonate in virtually quantitative yield[20] compared favourably with literature procedures[17] that used di-iodo derivatives and triethylamine as base.

The preparation of **7**, **8**, **9**, **10** and **12** in good yields using weak bases under mild reaction conditions from the corresponding β-chloro derivative is indicative of the ease with which the β-elimination reaction occurs in the sulphoxide and sulphone series.

Schemes II, III and IV summarise the syntheses of some methylthio, methylsulphinyl and methylsulphonyl derivatives of sulphur mustard and their oxidation products. It is recognised that those sulphoxide derivatives that are asymmetrically substituted exist as racemates whilst those with two sulphoxide groups additionally contain a pair of diastereoisomers. No attempt has been made to resolve any of these mixtures of isomers into optically pure components. The effect of the presence of optical isomers on the interpretation and complexity of NMR spectra is discussed briefly later in the paper.

The method used for the synthesis of tri-thiane **13** was in principle that of Meade and Moggridge.[21] Treatment of **13** with one mole equivalent of sodium periodate resulted in the selective oxidation of one of the two terminal methylthio groups to give **14** in preference to oxidation of the central sulphur atom (to give **21**). The isolated ratio of **14:21** was *ca.* 4:1. Bis-sulphoxide **15** was readily synthesised from sodium sulphide and two moles of 1-chloro-2-(methylsulphinyl)ethane in 91% yield. A similar procedure with 1-chloro-2-(methylsulphonyl)ethane gave the bis-sulphone **16**[24] in high yield.

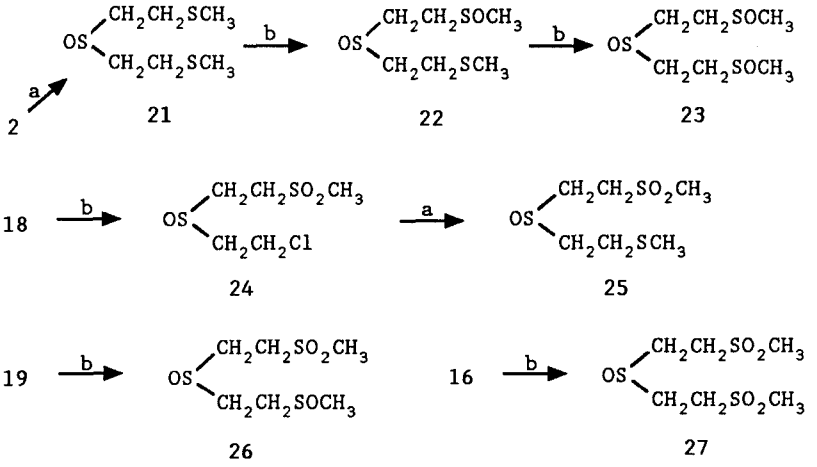


SCHEME II Reagents: a. MeSH/NaOMe; b. $NaIO_4$; c. Na_2S; d. H_2O_2/AcOH; e. $HSCH_2CH_2OH$/MeOH; f. $SOCl_2$.

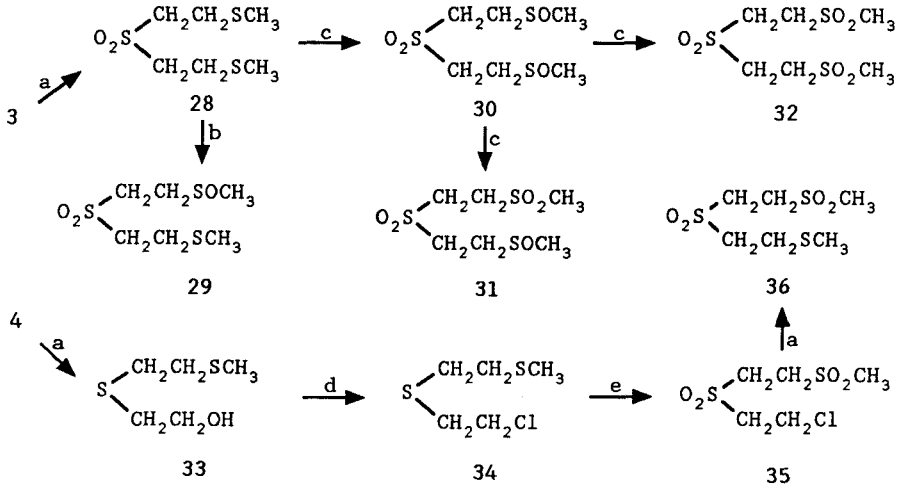
The required mixed oxidation states at sulphur in sulphone **19** could only be obtained using a multistep sequence. Alkylation of 2-mercaptoethanol with 1-chloro-2-(methylsulphonyl)ethane gave hydroxysulphone **17** which with thionyl chloride gave the half-mustard derivative **18** in 92% yield. Reaction with methanethiol gave the sulphone **19** in good yield.

Sodium periodate proved to be a convenient and effective oxidising agent[22] for the preparation of sulphoxides such as **14** and **20** from sulphides under very mild conditions where the starting material is soluble in water or aqueous alcohol, with no concommitant sulphone formation.

Sulphoxide **21** was readily synthesised by the base-catalysed addition of methanethiol to mustard sulphoxide **2** presumably *via* an elimination-addition pathway. Sequential selective oxidations of **21** with sodium periodate gave the bis and tris-sulphoxides, **22** and **23** respectively in good yields. A synthesis of **23** has been



SCHEME III Reagents: a. MeSH/NaOMe; b. $NaIO_4$.



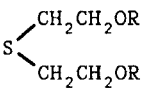
SCHEME IV Reagents: a. MeSH/NaOMe; b. $NaIO_4$; c. H_2O_2; d. $SOCl_2$; e. H_2O_2/AcOH.

reported by the nitric acid oxidation of tri-thiane **13**[23]. Periodate oxidation of **18** constituted a simple synthesis of **24** as did oxidations of **19** and **16** to give **26** and **27** respectively.

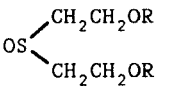
Compounds **28** to **32** in this Scheme were made by successively selectively oxidising each member of the group starting from sulphone **28**. It was evident proceeding up the series, that as oxidation states at sulphur increased, more forcing oxidation conditions were required. Products also became increasingly sparingly soluble in all solvents. The fully oxidised tris-sulphone **32** has been previously prepared in a one-step procedure by oxidation of tri-thiane **13**[21] or from sodium methanesulphonate and mustard sulphone **3**[24]. Compounds **29** and **30** have been isolated and identified as metabolites of sulphur mustard in the rat.[8] A sensitive analytical method for these metabolites has been developed, using gas chromatography-mass spectrometry, in which they are both reduced with titanium trichloride to the common analyte **28**.[25]

As noted above, the synthesis of compounds such as **36**, with very dissimilar oxidation states at sulphur, cannot be synthesised by a series of sequential oxidations from a suitable starting material. Consequently, **36** was synthesised by a 4 step reaction sequence as shown. Treatment of half-mustard 4 with methanethiol in methanolic sodium methoxide gave the 1,2-disulphide **33**[24] which was smoothly chlorinated with thionyl chloride to give **34** and then oxidised by hydrogen peroxide in acetic acid to give the bis-sulphone half-mustard **35**[24] as a white stable crystalline solid in virtually quantitative yield. With additional methanethiol, **35** gave the required bis-sulphone **36**.

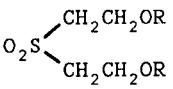
The dihydroxy sulphoxide **38** was readily prepared by hydrogen peroxide oxidation of thiodiglycol **37**[26]; this is one of many procedures for the synthesis of this compound.[16] The corresponding sulphone **39** requires stronger oxidising agents and is difficult to prepare as a pure compound. Levin[26] used perbenzoic acid to prepare pure **39** (using m.p. ad criterion of purity). In this present work 3-chloroperbenzoic acid was used to give **39** in 54% yield after purification by chromatography and recrystallisation. The method reported by Gilman and Beaber,[27] using hydrogen peroxide in glacial acetic acid, was not successful in these laboratories, as was also noted by Price and Bullitt.[16] Bis-acetates **40**,[13] **41** and **42**[16] were prepared conven-



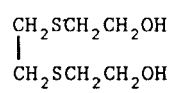
37 R = H
40 R = Ac
43 R = CH_3



38 R = H
41 R = Ac
44 R = CH_3



39 R = H
42 R = Ac
45 R = CH_3



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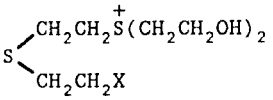

47 X = Cl, OH

SCHEME V

tionally from the corresponding diols using acetic anhydride in pyridine. The dimethoxy sulphide **43** was prepared in satisfactory yield by condensation of 1-chloro-2-methoxyethane with sodium sulphide. The sulphoxide and sulphone analogues **44** and **45** were prepared from mustard sulphoxide **2** and sulphone **3** respectively using sodium hydroxide in methanol, proceeding *via* conjugate addition to the intermediate unsaturated divinyl compound as originally demonstrated by Alexander and Chrombie.[17]

The formation of bis-sulphide **46** as a by-product from reactions of half-mustard **4** or mustard **1** carried out in the presence of water has long been recognised.[6,31] The precise course of the reaction depends on reaction conditions and can be extremely complex. Intermolecular attack of sulphide substrate on an ethylene-sulphonium ion intermediate gives sulphonium species such as **47** which can then decompose to **46**. A recent study[4] has confirmed and extended these findings and established a complex hydrolysis mechanism for 2-chloroethyl sulphides involving a number of reversible transformations in which sulphonium species such as **47** are considered to be important. Compound **46** was readily prepared by condensing 2 moles of 2-chloroethanol with ethanedithiol under basic conditions. The literature method employs dibromoethane and mercaptoethanol.[29]

NMR Data

The analysis of the NMR spectra of the compounds described in this paper is (with the exception of vinyl compounds **7**, **8**, **9** and **10**) essentially that of two pairs of adjacent methylene groups separated by a central sulphur atom. For those compounds in which the chemical shift difference between adjacent methylene groups is >0.2 ppm, a first order analysis of the vicinal proton couplings can be made. Where the geminal protons within each adjacent methylene group are magnetically equivalent, then a set of triplets is observed with J = *ca.* 7 Hz (eg **3**, **40**). In certain cases, the triplet is significantly distorted suggesting restricted rotation about C—S and C—C bonds (eg **1**). The presence of a sulphoxide group in the molecule renders pairs of protons in adjacent methylene groups nonequivalent with the result that spectra are much more complicated. However, second order analysis of geminal couplings enables a full analysis of these spectra as ABXY systems assuming adjacent methylene groups retain first-order vicinal couplings (eg **2**). Where the sulphoxide is asymmetrically substituted, then the situation is even more complex and each "arm" of the molecule must be assessed separately (eg **25**). These compounds exist as racemic mixtures but as each enantiomer has the same spectrum, no effect is observed. Compounds with two asymmetrically substituted sulphoxide groups are a mixture of four optical isomers comprising an enantiomeric pair and a diastereoisomeric pair. The latter pair will each have different NMR spectra which in turn will be different from that of the enantiomeric pair resulting in a spectrum made up of apparently three components resulting in extremely complex spectra (eg **22**, **26**).

Where the difference in chemical shift between adjacent methylene groups is small, wholly second-order spectra are obtained comprising complex broad multiplets in which few if any features can be interpreted (eg **5**, **13**, **14**, **44**).

CONCLUSION

This paper describes the synthesis of a large number of compounds that may be relevant to investigations into the chemistry and biochemistry associated with sulphur mustard. Practical syntheses leading to pure compounds are described incorporating full experimental details and chromatographic procedures, updating where necessary those previously published in earlier studies. Full spectroscopic details (^{1}H and ^{13}C NMR, IR and MS) are included.

EXPERIMENTAL

General Procedures. TLC was performed by upward irrigation of microscope slides coated with Merck silica gel 60 G and column chromatography with Merck silica gel, particle size 0.063-0.200 mm, in the same solvent as used for TLC; the plates were developed with iodine vapour. All solvents, with the exception of diethyl ether, were routinely distilled prior to use. The identity and homogeneity of all products was established by full spectroscopic analysis. NMR spectra were determined on a Jeol GSX 400 instrument in deuteriochloroform solution unless otherwise stated. Chemical shifts (δ) are reported in ppm downfield from TMS. Resonances are identified by underlining the atom(s) concerned in the appropriate part structure. Coupling constants (J) between protons of methylene groups are described by labelling protons α to the middle sulphur atom as "1" and "1'" (where non-equivalent) and those β as "2" and "2'". Thus, geminal couplings are shown as J_{11}, or J_{22}, and vicinal couplings as J_{12}, J_{21}, etc. All coupling constants are reported in Hz. IR spectra were measured on a Perkin Elmer FT 1750 instrument using a KBr disc for solids and KBr plates for liquid samples and are measured in cm^{-1}. Mass spectra were obtained using a VG 7070EQ magnetic sector mass spectrometer. Electron impact (EI) ionisation at 70 eV was used for those very simple compounds which gave molecular ions using EI. Most of the compounds described, especially methyltio, methylsulphinyl and methylsulphonyl derivatives fragmented extensively using EI and were also thermally labile. For those compounds desorption chemical ionisation (DCI) was routinely used employing ammonia as reagent gas. This method generally gave strong quasi-molecular ions, $[M + NH_4]^+$ and/or $[MH]^+$, plus a few structurally indicative fragment ions. Molecular ions and those of relative abundance above 10% (except for clusters of low mass ions) are quoted for EI spectra; structurally indicative ions above 2–4% are quoted for DCI spectra.

Caution. 1,1'-Thiobis(2-chloroethane) (sulphur mustard) is a potent vesicant and carcinogen and should be handled only by suitably qualified and protected individuals using a well ventilated fume cupboard. 1,1'-Sulphonylbis(2-chloroethane) **4** (mustard sulphone) also has pronounced vesicant properties and should be handled accordingly. The potential of any compound that contains the 2-chloroethylthio functionality to act as a biological alkylating agent should be recognised and appropriate handling precautions taken.

Compounds in Scheme I.

1,1'-Sulphinylbis(2-chloroethane) (**2**). Mustard **1** (7 ml, 10 g, 0.063 mole) was added dropwise with stirring to conc. nitric acid, cooled in an ice-water bath. The mixture was stirred at 0–5°C for an additional 30 min, allowed to warm to room temperature and then diluted with water (50 ml). The white solid was filtered off and recrystallised from water to afford colourless crystals of 1,1'-sulphinylbis(2-chloroethane) **2** (9.3 g, 84%), m.p. 111°C, lit[12] 109.5°C. NMR: ^{1}H: δ 3.12 (4H, overlapping A and B parts of ABXY system, $J_{11'} = 13.6$, $J_{12} = 4.6$, $J_{12'} = 6.2$, $J_{1'2} = 6.8$ and $J_{1'2'} = 8.8$, $SOC\underline{H}_2$) and 3.93 (4H, overlapping X and Y parts of ABXY system, $J_{22'} = 11.8$, $J_{21} = 4.6$, $J_{2'1} = 6.2$, $J_{21'} = 6.8$ and $J_{2'1'} = 8.8$, $C\underline{H}_2Cl$); ^{13}C: δ 36.67 ($\underline{C}H_2Cl$) and 55.05 ($SO\underline{C}H_2$). IR: ν_{max} 1410, 1020, 935, 890, 665 and 640. MS (EI): m/z 178, 176, 174 ($\overline{M}^+$, 9%), 114, 112 (M^+—C_2H_3Cl, 12), 76 ($SOC_2H_4^+$, 26), 65 (28), 63 ($C_2H_4Cl^+$, 100).

1.1'-Sulphonylbis(2-chloroethane) (**3**).

(i) Starting from 1,1'-sulphinylbis(2-chloroethane) (**2**). The sulphoxide **2** (10.0 g, 0.057 mole) was added to a solution of potassium permanganate (7.5 g) in water (70 ml) containing conc. sulphuric acid (8.0 ml). The mixture was boiled under reflux for 7 h, cooled and extracted with chloroform. The extract was dried and concentrated. Recrystallisation of the crude product from carbon tetrachloride gave 1,1'-sulphonylbis(2-chloroethane) **3** as a white solid, (8.6 g, 79%), m.p. 54–55°C, lit.[13] 55°C. NMR: ^{1}H: δ 3.60 (4H, t, $J_{12} = 6.83$, $SO_2C\underline{H}_2$, and 3.98 (4H, t, $J_{21} = 6.83$, $C\underline{H}_2Cl$); ^{13}C: δ 35.61 ($\underline{C}H_2Cl$) and 56.58

(SO_2CH_2). IR: ν_{max} 1290, 1120, 860, 790, 540 and 490. MS (EI): m/z 195, 193, 191 (MH^+, 2%), 65 (32), 63 ($C_2H_4Cl^+$, 100).

(ii) Starting from mustard (**1**). Mustard **1** was added dropwise to a stirred mixture of glacial acetic acid (10 ml) and hydrogen peroxide (30%, 100 vol) which was then stirred and boiled for 1 h. After cooling, the volume of the solution was reduced by half, the resulting solid filtered, dried and recrystallised from carbon tetrachloride to afford the sulphone **3** as white crystals (6.4 g, 59%), m.p. 55°C, lit.[13] 55°C.

2-(2-Chloreothylthio)ethanol (**4**). Sodium hydride (100%, 5.5 g) was added to a stirred solution of 2-mercaptoethanol (18 ml, 19.8 g, 0.25 mole) in methanol (150 ml). Stirring was continued for an additional 30 min when dichloromethane (150 ml) was added. The mixture was allowed to stand at *ca.* 5°C (refrigerator) for 5 days. The precipitated sodium chloride was filtered off, the solvent removed and the residue washed with water. The crude half-mustard **4** was not purified further and was taken up in a known volume of ether and stored over anhydrous magnesium sulphate at −20°C (freezer) until required. An aliquot of the ethereal solution was evaporated to dryness for spectroscopic analysis. NMR: ^{1}H: δ 2.25 (1H, very broad, OH), 2.7 (2H, t, J_{12} = 6.2, SCH_2CH_2Cl), 2.84 (2H, t, J_{12} = 9.4, SCH_2CH_2OH), 3.61 (2H, t, J_{21} = 9.4, CH_2OH), 3.69 (2H, t, J_{21} = 6.2, CH_2Cl); ^{13}C: δ 34.1 (SCH_2CH_2OH), 35.43 (SCH_2CH_2Cl), 43.22 (CH_2Cl) and 60.92 (CH_2OH). IR: ν_{max} 3330, 1430, 1410, 1300, 1275, 1220, 1060, 1045, 1020 and 695. MS (EI): m/z 142 (10), 140 (M^+, 27%), 111 (39), 109 (M^+—CH_2OH, 100), 104 (M^+—HCl, 51), 91 ($C_3H_7OS^+$, 29), 73 (31), 63 (54), 61 (67), 47 (56), 45 (54).

The method is that of Seligman and Rutenberg.[11]

2-(2-Chloroethylsulphinyl)ethanol (**5**). A solution of sulphide **4** (0.5 g, 0.0036 mole) in dichloromethane (20 ml) was stirred and cooled in an ice-water bath whilst 3-chloroperbenzoic acid (0.9 g, 0.0045 mole) was added in small portions. The mixture was stirred at 0–5°C for an additional 2 h and then allowed to warm to room temperature. The solid formed was filtered off, the residue evaporated to dryness and extracted with water (2 × 10 ml). The water was removed and the residue chromatographed with chloroform-methanol, 19 : 1, to give the major component (rf 0.4), 2-(2-chloroethylsulphinyl)ethanol **5** (0.37 g, 67%), as an oil that crystallised slowly on standing. This solid was recrystallised with difficulty from ethyl acetate to give material with m.p. 60–61°C. $C_4H_9SO_2Cl$: Calcd: C, 30.67; H, 5.79. Found: C, 30.28; H, 5.91. NMR: ^{1}H: δ (D_2O) 3.1 (2H, m, $SOCH_2CH_2Cl$), 3.2 (2H, m, $SOCH_2CH_2OH$), 4.0 (2H, m, CH_2OH) and 4.1 (2H, m, CH_2Cl); ^{13}C: δ 37.39 (CH_2Cl), 54.85, 54.98 and 55.3 (remaining C). IR: ν_{max} 3335, 1450, 1400, 1310 1030 and 665. MS (EI): m/z 158 (3), 156 (M^+, 7%), 114 (10), 112 (M^+—C_2H_4O, 29), 76 ($C_2H_4SO^+$, 50), 65 (17) 63, (92), 45 (100).

2-(2-Chloroethylsulphonyl)ethanol (**6**).

(i) Starting from sulphoxide **5**. A mixture of sulphoxide **5** (0.4 g. 0.0026 mole) and 3-chloroperbenzoic acid (1.0 g, excess) in dichloromethane was stirred at room temperature for 5 h. The solid formed was filtered off, the solvent evaporated and the residue taken up in hot water (10 ml). The solid that formed on cooling was again filtered, the water removed and the residue chromatographed with chloroform-methanol 19 : 1 (rf 0.2) to give 2-(2-chloroethylsulphonyl)ethanol **6** as a colourless oil (0.31 g, 70%). NMR: ^{1}H δ 3.35 (2H, t, J = 7.0, CH_2CH_2OH), 3.6 (2H, t, J = 7.5, CH_2CH_2Cl), 3.9 (2H, t, J = 7.0, CH_2OH) and 4.1 (2H, t, J = 7.5, CH_2Cl); ^{13}C: δ 35.73 (CH_2Cl), 55.82, 56.34 and 56.35 (remaining C). IR: ν_{max} 3510, 3390, 1325, 1290, 1125 and 1070. MS (NH_3 DCI): m/z 192 (12), 190 ($M + NH_4^+$, 32%), 154 ($M + NH_4^+$—HCl, 100), 136 (9), 119 (2), 87 (2), 44 (4).

(ii) Starting from sulphide **4**. A solution of hydrogen peroxide (30%, 100 vol, excess) in acetic acid (1.0 ml) was added to a solution of 2-(2-chloroethylthio)ethanol **4** (0.25 g, 0.0018 mole) in acetic acid (5 ml) stirred and heated at 60°. After 2.5 h, the solvent was removed and the residue chromatographed (chloroform-methanol 19:1) to give 2-(2-chloroethylsulphonyl)ethanol **6** (0.17 g, 61%) as an oil.

1-(2-Chloroethylsulphinyl)ethene (**7**).[28] The sulphoxide **2** (0.8 g, 0.0046 mole) was boiled under reflux with triethylamine (0.5 g, 0.0048 mole) in benzene solution (20 ml) for 24 h. On cooling, the reaction mixture was washed with a small volume of water, dried, concentrated and chromatographed (petrol-acetone 7:3, rf 0.4) to give the vinyl sulphoxide **7** as a colourless oil (0.39 g., 61%). NMR: ^{1}H: δ (D_2O) 3.27 (1H, A part of ABXY system, ddd, $J_{11'}$ = 14, J_{12} = 5.6, $J_{12'}$ = 5.6, CH_2CH_2Cl) and 3.42 (1H, B part of ABXY system, ddd, $J_{1'1}$ = 14, $J_{1'2}$ = 7.4, $J_{1'2'}$ = 7.4, $SOCH_2$) and 3.82 (1H, X part of ABXY system, ddd, $J_{22'}$ = 11.2, J_{21} = 5.6, $J_{21'}$ = 7.4, CH_2Cl) and 3.94 (1H, Y part of ABXY system, ddd, $J_{2'2}$ = 11.2, $J_{2'1}$ = 5.6, $J_{2'1'}$ = 7.4, CH_2Cl), 6.10 (1H, d, J_{21cis} = 9.8, $J_{22'}$ = 0, $CH{=}CH_2$), 6.20 (1H, d, $J_{21trans}$ = 16.45, $J_{22'}$ = 0, $CH{=}CH_2$) and 6.85 (1H, dd, J_{12cis} = 9.8 and $J_{12trans}$ = 16.45, $CH{=}CH_2$); ^{13}C: δ 36.27 (CH_2Cl), 55.26 ($SOCH_2$), 122.90 ($CH{=}CH_2$), and 139.62 ($CH{=}CH_2$). IR: ν_{max} 1370, 1300, 1050, 960 and 670. MS (EI): m/z 140 (11), 138 (M^+, 28%), 76 ($C_2H_4SO^+$, 77), 65 (30), 63 ($C_2H_4Cl^+$, 100), 59 (22), 58 (15), 47 (27), 45 (19).

1-(2-Chloroethylsulphonyl)ethene (**8**). A mixture of sulphone **3** (0.8 g, 0.0042 mole) and triethylamine (0.5 g, 0.005 mole) in benzene solution (5 ml) was stored at room temperature overnight. The solution was washed with water, dried and concentrated. The residue was chromatographed firstly with chloroform-methanol 76 : 1 and then with petrol-acetone 7 : 3 to give the vinyl sulphone **8** as a colourless oil (0.57 g, 88%). NMR: ^{1}H: δ 3.46 (1H, t, J = 7.26 $SO_2C\underline{H}_2$), 3.84 (1H, t, J = 7.26, $C\underline{H}_2Cl$), 6.25 (1H, d, J_{12cis} = 9.83, $J_{22'}$ = 0, CH=C$\underline{H}_2$), 6.49 (1H, d, $J_{12trans}$ = 16.67, $J_{22'}$ = 0, CH=C$\underline{H}_2$) and 6.73 (1H, dd, J_{12cis} = 9.83 and $J_{12trans}$ = 16.67, C$\underline{H}$=CH$_2$); ^{13}C: δ 35.57 ($\underline{C}H_2Cl$), 56.27 ($SO_2\underline{C}H_2$), 131.38 (CH=$\underline{C}H_2$) and 136.23 ($\underline{C}H$=CH$_2$). IR: ν_{max} 1390, 1330, 1310, 1140, 1120, 980, 810 and 760. MS (EI): m/z 157 (2) 155 (MH^+, 8%), 127 (MH^+—C_2H_4, 17), 91 ($C_2H_3SO_2^+$, 12), 75 (41), 66 (21), 65 (31), 63 ($C_2H_4Cl^+$, 100), 48 (16), 43 (32).

The method is that of Alexander and Chrombie.[17]

2-(Ethenylsulphinyl)ethanol (**9**). The sulphoxide **5** (0.2 g, 0.0012 mole) was stirred in aqueous potassium carbonate solution (2.5 ml, 50% saturated) at 50°C for 5 h when TLC (chloroform-methanol 9:1) showed that little starting material remained. The mixture was evaporated to dryness and th residue chromatographed over silica to give vinylsulphoxide **9** (136 mg, 89%) as a colourless oil. NMR: ^{1}H: δ 2.73 (1H, A part of ABXY system, ddd, $J_{11'}$ = 13.8, J_{12} = 5.0, $J_{12'}$ = 8.9, $C\underline{H}_2CH_2OH$) and 2.98 (1H, B part of ABXY system, ddd, $J_{1'1}$ = 13.8, $J_{1'2}$ = 3.8, $J_{1'2'}$ = 5.0, $C\underline{H}_2CH_2OH$), 3.91 and 4.20 (both 1H, X and Y parts of ABXY system, both m, $CH_2\underline{O}H$), 4.25 (1H, br s, O$\underline{H}$), 5.90 (1H, d, J_{21cis} = 10.0, $J_{22'}$ = 0, CH=C$\underline{H}_2$), 6.03 (1H, d, $J_{21trans}$ = 17.0, $J_{22'}$ = 0, CH=C$\underline{H}_2$) and 6.63 (1H, dd, J_{12cis} = 10.0 and $J_{12trans}$ = 17.0, C$\underline{H}$=CH$_2$); ^{13}C: δ 55.11 and 55.73 ($\underline{C}H_2CH_2OH$), 122.28 (CH=$\underline{C}H_2$) and 139.90 ($\underline{C}H$=CH$_2$). IR: ν_{max} 3330, 1380, 1050, 960 and 930. MS (EI): m/z 120 (M^+, 15%), 92 (M^+—C_2H_4, 30), 77 (18), 76 ($C_2H_4SO^+$, 100), 63 (21), 59 (38), 58 (28), 47 (48), 45 (77), 43 (63).

2-(Ethenylsulphonyl)ethanol (**10**). The vinylsulphoxide **9** (0.5 g, 0.0042 mole) was stored at room temperature in acetic acid (5 ml) containing hydrogen peroxide (30%, 100 vol, 1.0 ml) for 8 h. The solvent was removed *in vacuo* and the residue chromatographed with chloroform-methanol 9:1 to give the vinylsulphone **10** as a homogeneous oil (0.38 g, 67%). NMR: ^{1}H: δ 2.72 (1H, s, O$\underline{H}$), 3.33 (2H, t, J = 5.8, CH_2CH_2OH), 4.04 (2H, t, J = 5.8, $CH_2\underline{O}H$), 6.17 (1H, d, J_{21cis} = 10.0, $J_{22'}$ = 0, CH=C$\underline{H}_2$), 6.45 (1H, d, $J_{21trans}$ = 17.0, $J_{22'}$ = 0, CH=C$\underline{H}_2$) and 6.70 (1H, dd, J_{12cis} = 10.0 and $J_{12trans}$ = 17.0, C$\underline{H}$=CH$_2$); ^{13}C: δ 56.23 and 56.46 ($\underline{C}H_2CH_2OH$), 130.39 (CH=$\underline{C}H_2$) and 136.64 ($\underline{C}H$=CH$_2$). IR: ν_{max} 3450, 1390, 1320, 1300, 1130, 1060, 990 and 765. MS (EI): m/z 137 (MH^+, 69%), 119 (MH^+—H_2O, 23), 93 (MH^+—C_2H_4O, 34), 91 ($C_2H_3SO_2^+$, 26), 75 (16), 63 (13), 45 (100), 43 (41), 39 (22).

1,1'-Thiobis-ethene (**11**).[19] Mustard (1.0 g, 0.0063 mole) was treated with a solution of sodium methoxide (0.7 g, 0.013 mole) in methanol (20 ml) and the mixture heated at 60°C for 6 h. Some of the methanol was removed under reduced pressure, water added and the product extracted into ether. The ether solution was dried and concentrated and the residue chromatographed with petrol-acetone 38 : 1 (rf 0.5), to give the divinylsulphide **11** (0.09 g, 17%) as a colourless mobile liquid which polymerised readily on standing at room temperature. NMR: ^{1}H: δ 5.22 (2H, d, J_{12cis} = 9.8, CH=C$\underline{H}_2$), 5.23 (2H, d, $J_{12trans}$ = 16.67, CH=C$\underline{H}_2$) and 6.31 (2H, dd, J_{12cis} = 9.8 and $J_{12\ trans}$ = 16.67, C$\underline{H}$=CH$_2$); ^{13}C: δ 114.7 (CH=$\underline{C}H_2$) and 129.7 ($\underline{C}H$=CH$_2$). IR: ν_{max} 1590, 1390, 1265, 955, 880, 735 and 730. MS (EI): m/z 86 (M^+, 67%), 85 (M^+—H, 100), 60 (18), 59 (53), 58 (46), 57 (20), 45 (50).

1,1'-Sulphinylbis-ethene (**12**). A solution of sulphoxide **2** (13.0 g, 0.074 mole) in water (50 ml) containing sodium carbonate (24 g) was boiled under reflux for 2.5 h. On cooling, the solution was extracted with chloroform. The extract was dried, evaporated and the residue distilled under reduced pressure to afford **12** (7.5 g, 99%), b.p. 81–84°C/16 mm (lit[20] 87°C/18 mm) as a colourless homogeneous liquid. NMR: ^{1}H: δ 5.45 (2H, d, J_{12cis} = 9.8, CH=C$\underline{H}_2$), 5.60 (2H, d, $J_{12trans}$ = 16.5, CH=C$\underline{H}_2$) and 6.30 (2H, dd, J_{12cis} = 9.8 and $J_{12\ trans}$ = 16.5, C$\underline{H}$=CH$_2$); ^{13}C: δ 119.64 (CH=$\underline{C}H_2$) and 139.92 ($\underline{C}H$=CH$_2$). IR: ν_{max} 1590, 1360, 1230, 1050, 950, 750 and 690. MS (EI): m/z 102 (M^+, 32%), 85 (18), 76 (18), 73 (24), 59 (100), 58 (40), 54 (17), 47 (31), 45 (42).

The method is due to Ford-Moore.[20]

Compounds in Scheme II.

1,1'-Thiobis[2-(methylthio)ethane] (**13**). Methanethiol was passed into a solution of sodium methoxide in methanol (25 ml) until the gain in weight was *ca.* 1.8 g. Mustard **1** (1.0 g, 0.0063 mole) was added to the stirred solution, the mixture maintained at room temperature for 30 min and then boiled for 1 h. The solvent was removed and the mixture taken up in water, extracted into ether, dried and evaporated to give a colourless oil. The oil was chromatographed using petrolethyl acetate 19 : 1 (rf 0.5) to give **13** (0.96 g, 64%). NMR: ^{1}H: δ 2.17 (6H, s, 2 × S$\underline{C}H_3$) and 2.75 (8H, m, remaining H); ^{13}C: δ 15.34 (S$\underline{C}H_3$), 31.5 and 34.0 (remaining C). IR: ν_{max} 2940, 1430, 1265, 1205, 730 and 685. MS (EI): m/z 182 (M^+, 10%), 134 (M^+—CH_3SH, 15), 108 (M^+—$CH_3SC_2H_3$, 34), 75 ($CH_3SC_2H_4^+$) 74 (44), 61 (28), 47 (16), 45 (15), 41 (13).

The method is that of Meade and Moggridge.[21]

1-Methylsulphinyl-2-[2-(methylthio)ethylthio]ethane (**14**). A solution of sodium periodate (0.21 g, 0.001 mole) in water (2.5 ml) was added to a stirred solution of **13** (0.25 g, 0.0014 water) in ethanol (2.5 ml). After 2 h, water was added and the product extracted into chloroform. The extract was dried, concentrated and the residue chromatographed with petrol-acetone 7 : 3, to give firstly sulphoxide **21** (30 mg, 11%) (*vide infra*) and secondly the major product (rf 0.4), sulphoxide 14 (130 mg, 48%) as a colourless oil. NMR: ^{1}H: δ 2.2 (3H, s, SC$\underline{H}_3$), 2.6 (3H, s, SOC$\underline{H}_3$), 2.68 and 2.75 (each 2H, each m, SC$\underline{H}_2$C$\underline{H}_2$S) and 2.91 and 2.96 (each 2H, each m, SC$\underline{H}_2$C$\underline{H}_2$SO); ^{13}C: δ 15.43 (S$\underline{C}$H$_3$), 23.44 (S$\underline{C}$H$_2$CH$_2$SO), 31.88 and 33.84 (S$\underline{C}$H$_2$CH$_2$S), 38.48 (SO$\underline{C}$H$_3$) and 54.23 ($\underline{C}$H$_2$SOCH$_3$). IR: ν_{max} 3435, 2915, 1425, 1295, 1260, 1225, 1150, 1135, 1110 and 530. MS (NH$_3$ DCI): m/z 216 (M + NH$_4^+$, 44%), 199 (MH$^+$, 100), 135 (MH$^+$—Ch$_3$SOH, 19), 75 (CH$_3$SC$_2$H$_4^+$, 20).

1-Chloro-2-(methylsulphinyl)ethane. A solution of sodium periodate (2.25 g) in water (15 ml) was added dropwise to a solution of 1-chloro-2-(methylthio)ethane (2.0 g, 0.018 mole) in methanol (15 ml). The mixture was stirred at room temperature for 1 h, filtered and concentrated. The residue was chromatographed (chloroform-methanol 38:1, rf 0.4) to give the sulphoxide as an oil (1.82 g, 80%).

1,1'-Thiobis[2-(methylsulphinyl)ethane] (**15**). A mixture of finely ground sodium sulphide nonahydrate (0.5 g, 0.0021 mole) and 1-chloro-2-(methylsulphinyl)ethane (0.5 g, 0.004 mole) was stirred together at 40–45°C for 1.5 h. The reaction mixture was extracted with chloroform, dried and concentrated. Chromatography (chloroform-methanol 38:1) gave the bis-sulphoxide **15** (0.41 g, 91%) as a white hygroscopic solid, m.p., 65–67°C. NMR: ^{1}H: δ 2.58 (6H, s, 2 × SOC$\underline{H}_3$), 2.91 and 2.96 (both 4H, m, remaining H); ^{13}C: δ 24.80 (S$\underline{C}$H$_2$), 38.54 (SO$\underline{C}$H$_3$) and 53.92 (SO$\underline{C}$H$_2$). IR: ν_{max} 3450, 1650, 1430, 1020 and 700. MS (NH$_3$ DCI): m/z 215 (MH$^+$, 100%), 199 (MH$^+$—0), 151 (MH$^+$—CH$_3$SOH, 11), 108 (14), 91 (13), 75 (8).

1-Chloro-2-(methylsulphonyl)ethane. A solution of 1-chloro-2-(methylsulphinyl)ethane (3.0 g, 0.027 mole) in glacial acetic acid (5.0 ml) containing hydrogen peroxide (60%, 5.0 ml) was heated at 60–65°C for 6 h. Most of the solvent was removed *in vacuo* and the residue taken up in ether, washed with water, dried and concentrated. The crude product was essentially homogeneous but was chromatographed over silica using benzene (rf 0.4) to give 1-chloro-2-(methylsulphonyl)ethane as a colourless oil (2.42 g, 63%).

1,1'-Thiobis[2-(methylsulphonyl)ethane] (**16**). A mixture of 1-chloro-2-(methylsulphonyl)ethane (0.2 g, 0.0014 mole) and finely ground sodium sulphide nonahydrate (0.2 g, 0.00083 mole) were stirred together at room temperature (mixture became hot). When cool, the solid residue was extracted with hot methanol. The extract was concentrated and the residual white solid recrystallised from isopropanol and then methanol to give the bis-sulphone (**16**) (0.14 g, 78%), as white crystals, m.p. 127–129°C, lit[24] 127°C. NMR: ^{1}H: δ (D$_2$O) 3.08 (4H, t, J = 8.0, SC$\underline{H}_2$), 3.16 (6H, s, 2 × SO$_2$C$\underline{H}_3$) and 3.60 (4H, t, J = 8.0, SO$_2$C$\underline{H}_2$); ^{13}C: δ 24.5 (S$\underline{C}$H$_2$), 42.8 (S$\underline{C}$H$_3$) and 53.1 (SO$_2\underline{C}$H$_2$). IR: ν_{max} 1430, 1280, 1265, 1235, 1160, 1190, 975 and 800. MS (NH$_3$ DCI): m/z 264 (M + NH$_4^+$, 100%), 167 (MH$^+$—CH$_3$SO$_2$H, 3), 124 (3), 86 (5).

The method is that of Brown and Moggridge.[24]

2-[2-(Methylsulphonyl)ethylthio]ethanol (**17**). A solution of 2-mercaptoethanol (0.15 g, 0.0019 mole) in methanol (5.0 ml) was treated with sodium hydride (100%, 50 mg). The mixture was stirred at room temperature for 0.5 h when 1-chloro-2-(methylsulphonyl)ethane (0.25 g, 0.0018 mole) in methanol (5.0 ml) was added. The reaction mixture was stirred at 50–55°C for 3 h when no starting material remained. After conventional processing, chromatography (chloroform-methanol 38 : 1, rf, 0.5) gave **17** as an oil (0.2 g, 61%). NMR: ^{1}H: δ 2.61 (1H, s, O$\underline{H}$), 2.68 (2H, t, J_{12} = 6.04, SC$\underline{H}_2$CH$_2$OH), 2.95 (3H, s, SO$_2$C$\underline{H}_3$), 2.96 (2H, m, SC$\underline{H}_2$CH$_2$SO$_2$), 3.38 (2H, m, SO$_2$C$\underline{H}_2$) and 3.72 (2H, t, J_{21} = 6.04, C$\underline{H}_2$OH); ^{13}C: δ 24.57 (S$\underline{C}$H$_2$CH$_2$SO$_2$), 35.38 (S$\underline{C}$H$_2$CH$_2$OH), 41.57 (SO$_2\underline{C}$H$_3$), 55.14 ($\underline{C}$H$_2$SO$_2$) and 61.52 ($\underline{C}$H$_2$OH). IR: ν_{max} 3400, 2920, 2875, 1400, 1290, 1220, 1145, 1050, 1010 and 940.

1-Chloro-2-[2-(methylsulphonyl)]ethylthio]ethane (**18**). Thionyl chloride (1.1 g) was added dropwise to a solution of hydroxysulphone **17** (1.0 g, 0.0054 mole) in benzene (15 ml). The solution was boiled under reflux for 1 h, cooled and the solvent removed under reduced pressure. The residue was chromatographed (petrol-acetone 9 : 1, rf 0.4) to give **18** as a white solid (0.93 g, 92%), m.p. 56–57°C. NMR: ^{1}H: δ 2.98 (2H, t, J_{12} = 7.24, SC$\underline{H}_2$CH$_2$Cl), 3.08 (3H, s, SO$_2$C$\underline{H}_3$), 3.12 (2H, m, SC$\underline{H}_2$CH$_2$SO$_2$), 3.41 (2H, m, S$\underline{H}_2$SO$_2$) and 3.82 (2H, t, J_{21} = 7.24, C$\underline{H}_2$Cl); ^{13}C: δ 24.46 (S$\underline{C}$H$_2$CH$_2$Cl), 34.54 (SCH$_2\underline{C}$H$_2$SO$_2$), 41.40 (SO$_2\underline{C}$H$_3$), 42.87 ($\underline{C}$H$_2$Cl) and 54.77 ($\underline{C}$H$_2$SO$_2$). IR: ν_{max} 1290, 1230, 1150, 1135, 1110, 1045, 995, 930, 740, 690, 680.

1-Methylsulphonyl-2-[2-(methylthio)ethylthio]ethane (**19**). Sodium hydride was added to methanol (35 ml) and the solution saturated with methanethiol. The chlorosulphone **18** (0.5 g, 0.0025 mole) was added to this mixture which was maintained at room temperature for 1 h and then warmed to 50°C for 1 h. The reaction mixture was processed in the usual way and the residue chromatographed (cyclohexane-

ether-methanol 5:4:1, rf 0.3) and then recrystallised from petrol-ethyl acetate to give **19** (0.38 g, 72%), m.p. 72–73°C. NMR: ^{1}H: δ 2.15 (3H, s, SCH_3), 2.72 and 2.76 (both 2H, both m, SCH_2CH_2S), 3.04 (3H, s, So_2CH_3), 3.09 (2H, t, J_{12} = 8.1, CH_2S) and 3.49 (2H, t, J_{21} = 8.1, CH_2SO_2); ^{13}C: δ 15.91 (SCH_3), 24.59 (SCH_2), 32.29 and 34.24 ($SCH_2CH_2SCH_3$), 41.68 (SO_2CH_3) and 55.16 (CH_2SO_2). IR: ν_{max} 2930, 2915, 1430, 1330, 1300, 1240, 1230, 1205, 1150, 1110, 940 and 795. MS (NH_3 DCI): m/z 232 ($M + NH_4^+$, 16%), 215 (MH^+, 22), 167 (MH^+—CH_3SH, 8), 134 (9), 75 ($CH_3SC_2H_4^+$, 100), 61 (9).

1-Methylsulphinyl-2-[2-(methylsulphonyl)ethylthio]ethane (**20**). A solution of **19** (0.1 g, 0.00047 mole) in methanol (3 ml) was treated with sodium periodate (0.1 g, 0.00047 mole) in water (3 ml). After 4 h, TLC (chloroform-methanol 9 : 1) showed two product spots and a trace of starting material. The solvent was removed under reduced pressure and the solid residue chromatographed directly to give firstly (rf 0.5) the title compound **20** (0.062 g, 58%), m.p. 80°C. $C_6H_{14}O_3S_2$: Calcd: C, 31.28; H, 6.13. Found: C, 31.55; H, 6.42. NMR: ^{1}H: δ 2.62 (3H, s, $SOCH_3$), 3.02, 3.04 and 3.08 (each 2H, each m, $CH_2SCH_2CH_2SOCH_3$), 3.09 (3H, s, SO_2CH_3) and 3.48 (2H, m, $CH_2SO_2CH_3$); ^{13}C δ 24.7 and 25.2 (CH_2SCH_2), 39.0 ($SOCH_3$), 41.7 (SO_2CH_3), 54.2 and 54.8 (CH_2SO and CH_2SO_2). IR: ν_{max} 3455, 1300, 1270, 1150, 1135, 1120, 1030, 970, 510. MS (NH_3 DCI): m/z 231 (MH^+, 100%), 167 (MH^+—CH_3SOH, 27), 91 (28), 75 (19). Further elution gave the tetra-oxide **26** (rf 0.2), (0.032 g, 28%), m.p. 158°C.

Compounds in Scheme III.

1,1'-Sulphinylbis[2-(methylthio)ethane] (**21**). Methanethiol was passed through a solution of sodium methoxide in methanol (25 ml) until the gain in weight was *ca.* 1.25 g. Sulphoxide **26** (1.4 g, 0.008 mole) was added to this solution which was stirred at room temperature for 0.5 h and then boiled for 1 h. The mixture was cooled, extracted with dichloromethane, dried and evaporated to give a low melting solid. The solid (rf 0.55) was chromatographed using chloroform-methanol 38:1, to give **21** (1.0 g, 63%), m.p. 37–38°C from petrol-diethyl ether. $C_6H_{14}OS_3$: Calcd: C, 36.31; H, 7.12. Found: C, 36.76; H, 7.11. NMR: ^{1}H: δ 2.20 (6H, s, 2 × SCH_3), 2.95 and 3.0 (each 4H, each m, remaining H); ^{13}C: δ 15.61 (SCH_3), 26.77 (CH_2S) and 51.98 ($SOCH_2$). IR: ν_{max} 2940, 1430 and 1040. MS (NH_3 DCI): m/z 199 (MH^+, 82%), 183 (MH^+—0, 3), 107 (9), 75 ($CH_3SC_2H_4^+$, 100).

1-Methylsulphinyl-2-[2-(methylthio)ethylsulphinyl]ethane (**22**). Sodium periodate (0.22 g, 0.001 mole) in water (2.5 ml) was added to a stirred solution of **21** (0.2 g, 0.001 mole) in methanol (2.5 ml). The mixture was stirred at room temperature and monitored by TLC (chloroform-methanol 19:1). After *ca.* 15 min, the majority of the starting material (rf 0.9) had been replaced by the product spot (rf 0.4). The mixture was evaporated to dryness (cold water-bath) and the residual solid slurried with chloroform and chromatographed directly (flash silica) with chloroform-methanol 19:1. The major fraction was isolated as a white crystalline solid which was recrystallised from isopropanol to give **22** (0.16 g, 75%), m.p. 137°C. $C_6H_{14}O_2S_3$: Calcd: C, 33.62, H, 6.58. Found: C, 33.48; H, 6.75. NMR: ^{1}H: δ 2.35 (3H, s, SCH_3), 2.85 (3H, s, $SOCH_3$), 3.05 (2H, m, CH_2SCH_3), 3.3 and 3.4 (6H, m, $SOCH_2CH_2SOCH_2$); ^{13}C: δ 15.29 (SCH_3), 27.57 (CH_2S), 38.37 ($SOCH_3$), 44.75 and 46.96 ($SOCH_2CH_2SO$), 52.77 ($SOCH_2$). IR: ν_{max} 1430, 1015 and 700. MS (NH_3 DCI): m/z 215 (MH^+, 96%), 151 (MH^+—CH_3SOH, 17), 107 (16), 91 (27), 75 ($CH_3SC_2H_4^+$, 100).

1,1'-Sulphinylbis[2-(methylsulphinyl)ethane] (**23**). A solution of sodium periodate (0.4 g, 0.002 mole) in water (5 ml) was added to a stirred solution of **21** (0.2 g, 0.0011 mole) in methanol (5 ml). The progress of the reaction was monitored by TLC (chloroform-methanol 19:1). After 8 h, both starting material **21** and intermediate **22** had disappeared. The mixture was filtered, concentrated and the residue extracted twice with hot methanol. The extract was again concentrated and the residue chromatographed (chloroform-methanol 9:1, rf 0.4). The homogeneous white solid was recrystallised for isopropanol to afford tri-sulphoxide **23** (0.19 g, 74%), m.p. 155–156°C, lit[23] 155–160°C dec. $C_6H_{14}O_3S_3$: Calcd: C, 31.28; H, 6.13. Found: C, 31.00; H, 6.07. NMR: ^{1}H: δ (D_2O) 2.65 (6H, s, 2 × $SOCH_3$) and 3.2 (8H, m, remaining H); ^{13}C: δ 39.5 ($SOCH_3$), 46.5 and 47.8 (remaining C); IR: ν_{max} 1430, 1120, 1020 and 700. MS (NH_3 DCI): m/z 248 ($M + NH_4^+$, 22%), 231 (MH^+, 60), 215 (MH^+—0, 6), 184 ($M + NH_4^+$—CH_3SOH, 22), 167 (MH^+—CH_3SOH), 108 (16), 91 (34).

1-Methylsulphonyl-2-[2-(methylthio)ethylsulphinyl]ethane (**25**). A solution of sodium periodate (0.8 g, 0.0037 mole) in water (5 ml) was added to a stirred solution of **18** (0.3 g, 0.0015 mole) in methanol (5 ml). The mixture was stirred at room temperature for 4 h when TLC (chloroform-methanol 19:1) indicated an absence of starting material. The solvent was removed under reduced pressure and the solid residue chromatographed to give 1-chloro-2-[2-(methylsulphonyl)ethylsulphinyl]ethane **24** (rf 0.25) as a white crystalline solid, (0.28 g, 84%, m.p. 130°C). This product was taken up in methanol (10 ml) and added to a mixture of sodium hydride (0.036 g, 0.0015 mole) in methanol (10 ml) saturated with methanethiol. After 3 h, when TLC (chloroform-methanol 19:1) showed no starting material, the solvent was removed and the residue recrystallised twice from propan-2-ol to give **25** (0.2 g, 58% overall from **18**), m.p. 126°C. $C_6H_{14}O_3S_3$: Calcd: C, 31.28; H, 6.15. Found: C, 31.28; H, 6.02. NMR: ^{1}H: δ 2.16

(3H, s, SCH_3), 2.96 (2H, A and B part of ABXY system, d of t, $J_{2'2}$ = 14.2, $J_{2'1}$ = 8.1, $J_{2'1'}$ = 8.1 overlapping ddd, $J_{22'}$ = 14.2, J_{21} = 5.2, $J_{21'}$ = 8.2 CH_2SCH_3), 3.19 (3H, s, SO_2CH_3), 3.40 (2H, X and Y part of ABXY system, ddd, $J_{11'}$ = 16.4, J_{12} = 5.2, $J_{12'}$ = 8.1 overlapping d of t, $J_{1'1}$ eq 16.4, $J_{1'2}$ = 8.2, $SOCH_2CH_2S$), 3.45 (1H, ddd, A part of ABXY system, $J_{11'}$ = 14.1, J_{12} = 7.2, $J_{12'}$ = 9.8) overlapping 3.52 (1H, ddd, B part of ABXY system, $J_{1'1}$ = 14.1, $J_{1'2}$ = 9.8, $J_{1'2'}$ = 5.8 $SOCH_2CH_2SO_2$) and 3.72 (2H, two overlayed ddd, AB part of ABXY system, $J_{22'}$ = 4.2, J_{21} = 7.2, $J_{21'}$ = 9.8, $J_{2'1}$ = 9.8, $J_{2'1'}$ = 5.8, $SOCH_2CH_2SO_2$); ^{13}C: δ 16.92 (SCH_3), 28.78 (CH_2SCH_3), 43.00 and 45.13 (CH_2SCH_3), 49.83 ($SOCH_2CH_2S$) and 53.42 ($SOCH_2CH_2SO_2$). IR: ν_{max} 2980, 2915, 1320, 1295, 1270, 1145, 1130, 1115, 1020, 990, 950, 820 and 515. MS (NH_3 DCI): m/z 248 ($M + NH_4^+$, 21%), 231 (MH^+, 34), 215 (MH^+—0, 6), 151 (MH^+—CH_3SO_2H, 10), 124 ($CH_3SC_2H_4SOH^+$, 32), 107 ($CH_3SO_2C_2H_4^+$, 40), 75 ($CH_3SC_2H_4^+$, 100).

1-Methylsulphinyl-2-[2-(methylsulphonyl)ethylsulphinyl]ethane (**26**). A solution of sodium periodate (0.15 g, 0.0007 mole) in water (2.5 ml) was added to a solution of **19** (0.050 g, 0.0026 mole) in methanol (2.0 ml) and the mixture stored at room temperature overnight. The solvent was removed and the whole residue chromatographed directly (chloroform-methanol 9 : 1, rf 0.25) to give **26** as white crystals (0.052 g, 89%), m.p. 158°C from ethanol. NMR: ^1H: δ 2.68 (3H, s, $SOCH_3$), 3.14 (3H, s, SO_2CH_3), 3.20, 3.25, 3.30 and 3.56 (m, remaining H); ^{13}C: δ 39.1 ($SOCH_3$), 41.2 (SO_2CH_3), 43.8 (CH_2SO_2), 46.2 (CH_2SOCH_3), 47.5 and 47.9 (CH_2SOCH_2). IR: ν_{max} 3510, 2970, 2920, 1430, 1385, 1300, 1270, 1135, 1025, 970, 775, 700, 520. MS (NH_3 DCI): m/z 247 (MH^+, 39%), 183 (MH^+—CH_3SOH, 30), 124 (42), 91 ($CH_3SOC_2H_4^+$, 100).

1,1'-Sulphinylbis[(2-methylsulphonyl)ethane] (**27**). A solution of sodium periodate (0.3 g, 0.0014 mole) in water (3.0 ml) was added to a solution of bis-sulphone **16** (0.2 g, 0.008 mole) in methanol (2.5 ml). The mixture was stored overnight at room temperature, the solvent removed and the solid residue extracted with boiling methanol (3 × 10 ml). The solvent was removed and the white residue was recrystallised from methanol to give the **27** (0.19 g, 88%), m.p. 162°C, $C_6H_{14}O_5S_3$: Calcd: C, 26.46; H, 5.18. Found: C, 26.58; H, 4.93. This compound was insufficiently soluble to purify by column chromatography). NMR: ^1H: δ (D_2O) 3.20 (6H, s, 2 × SO_2CH_3), 3.30 (2H, A part of ABXY system, ddd, $J_{11'}$ = 13.4, J_{12} = 7.1, $J_{12'}$ = 8.5, $SOCH_2$), 3.45 (2H, B part of ABXY system, m, $SOCH_2$), 3.73 and 3.75 (each 2H, X and Y part of ABXY system, each m, CH_2SO_2); ^{13}C: δ 41.29 (SO_2CH_3), 43.82 (CH_2SO_2) and 47.51 (CH_2SO). IR: ν_{max} 1430, 1280, 1265, 1135, 1115, 1040, 1030, 775. MS (NH_3 DCI): m/z 280 ($M + NH_4^+$, 5%), 263 (MH^+, 8), 200 ($M + NH_4^+$—CH_3SO_2H, 9), 183 (4), 174 (6), 158 (13), 124 (100).

Compounds in Scheme IV.

1,1'-Sulphonylbis[(2-methylthio)ethane] (**28**). As described above, mustard sulphone **3** (2.9 g, 0.0152 mole) was treated with methanethiol (2.25 g, 0.047 mole) in sodium methoxide in methanol (50 ml) at room temperature for 1 h. The mixture was poured into water and the resulting crystals filtered off, dried and recrystallised from isopropanol to give **28**, m.p. 79–80°C (0.98 g, 30%). $C_6H_{14}O_2S_3$: Calcd: C, 33.63; H, 6.58. Found: C, 33.68; H, 6.45. NMR: ^1H, δ 2.20 (6H, s, 2 × SCH_3), 2.96 (4H, m, CH_2SCH_3) and 3.33 (4H, m, CH_2SO_2); ^{13}C: δ 15.96 (SCH_3), 26.27 (CH_2S) and 53.5 (CH_2SO_2). IR: ν_{max} 1430, 1300, 1260, 1150, 1110 and 810. MS (NH_3 DCI): m/z 232 ($M + NH_4^+$, 100%), 215 (MH^+, 2), 184 ($M + NH_4^+$—CH_3SH, 3).

1-Methylsulphinyl-2-[2-(methylthio)ethylsulphonyl]ethane (**29**). A mixture of **28** (0.1 g, 0.0047 mole) and sodium periodate (0.12 g, 0.00056 mole) in aqueous methanol (1:1, 5 ml) was stirred at room temperature for 4 h. when nearly all the starting material had disappeared. The mixture was filtered, concentrated and the solid residue extracted with warm methanol (x3). The extract was concentrated and the residue chromatographed (chloroform-methanol 19:1) to afford **29** as a white crystalline solid (0.061 g, 56%), m.p. 114°C. $C_6H_{14}O_3S_3$: Calcd: C, 31.28; H, 6.13. Found: C, 31.07; H, 6.23. NMR: ^1H: δ (D_2O) 2.04 (3H, s, SCH_3), 2.64 (3H, s, $SOCH_3$), 2.85 (2H, m, CH_2SCH_3), 3.13 and 3.31 (both 1H, m, CH_2SOCH_3), 3.50 (2H, m, $SO_2CH_2CH_2S$) and 3.59 (2H, m, $SO_2CH_2CH_2SO$); ^{13}C: δ 16.98 (SCH_3), 27.63 (CH_2S), 39.56 ($SOCH_3$), 46.30 and 46.40 ($SO_2CH_2CH_2SO$) and 54.93 ($SO_2CH_2CH_2SCH_3$). IR: ν_{max} 1430, 1230, 1270, 1110, 1030 and 810. MS (NH_3 DCI): m/z 248 ($M + NH_4^+$, 4%), 231 (MH^+, 6), 184 ($M + NH_4^+$—CH_3SOH, 100), 136 (6), 108 (8), 91 (11), 75 (13), 74 (17).

1,1'-Sulphonylbis[2-(methylsulphinyl)ethane] (**30**). A solution of **28** (0.2 g, 0.00093 mole) in water was treated with 30% hydrogen peroxide (100 vol, 2 equivs) at room temperature until little starting material remained (TLC chloroform-methanol 9:1). The mixture was evaporated to dryness, the crude product absorbed onto silica and chromatographed over silica to afford the bis-methylsulphinyl derivative **30** as a white solid (68%), m.p. 163–165°C. $C_6H_{14}O_4S_3$: Calcd: C, 29.24; H, 5.73. Found: C, 29.11; H, 5.72. NMR: ^1H: δ (D_2O) 2.65 (6H, s, 2 × $SOCH_3$), 3.15 (2H, X part of A_2XY system, d of t, $J_{22'}$ = 14.0 and J_{21} = 9.0, CH_2SOCH_3), 3.35 (2H, Y part of A_2XY system, d of t, $J_{2'2}$ = 1.40 and $J_{2'1}$ = 9.0

(CH_2SOCH_3) and 3.65 (4H, t, J_{12} = 9.0 and $J_{12'}$ = 9.0, SO_2CH_2); ^{13}C: δ 36.77 ($SOCH_3$), 43.65 (CH_2SOCH_3) and 45.83 (CH_2SO_2). IR: ν_{max} 1430, 1300, 1260, 1200, 1180, 1030 and 810. MS (NH_3 DCI): m/z 248 ($M + NH_4^+$, 8%), 231 (MH^+, 27), 184 ($M + NH_4^+$—CH_3SOH, 25), 167 (MH^+—CH_3SOH, 100), 108 (29), 91 (42).

1-Methylsulphinyl-2-[2-(methylsulphonyl)ethylsulphonyl]ethane (**31**). The bis-methylsulphinyl derivative **30** (0.1 g, 0.00041 mole) was boiled under reflux with hydrogen peroxide (30%, 1.5 ml) for 8 h. when no starting material remained. The solution was evaporated to dryness and the residue recrystallised from hot water to give the bis-sulphone **31** (76 mg. 75%) as a white solid, m.p. 165–166°C. $C_6H_{14}O_5S_3$: Calcd: C, 26.46; H, 5.18. Found: C, 26.78; H, 5.04. NMR: ^1H: δ (CD_3OD) 2.83 (3H, s, $SOCH_3$), 3.25 (3H, s, SO_2CH_3), 3.33 (1H, X part of A_2XY system, t, $J_{22'}$ = 13.5 and J_{21} = 8.7, CH_2SO), 3.52 (1H, Y part of A_2XY system, t, $J_{2'2}$ = 13.5 and $J_{2'1}$ = 6.8, CH_2SO) and 3.85 (6H, m, remaining H); ^{13}C: δ 39.85 ($SOCH_3$), 43.30 (SO_2CH_3), 46.61 (CH_2SOCH_3), 48.56, 48.87 and 49.06 (remaining C). IR: ν_{max} 3450, 1350, 1325, 1150, 1120, 1035, 805 and 500. MS (NH_3 DCI): m/z 280 ($M + NH_4^+$, 18%), 263 ($M + H^+$, 15), 216 ($M + NH_4^+$—CH_3SOH, 56), 200 ($M + NH_4^+$—CH_3SO_2H, 17), 184 (19), 183 (16), 136 (71), 124 (100), 108 (44), 91 (50).

1,1'-Sulphonylbis[(2-methylsulphonyl)ethane] (**32**).[21,24] The bis-methylsulphinyl derivative **30** (0.1 g, 0.00041 mole) was stirred and boiled under reflux with hydrogen peroxide (30%, 1.5 ml) for 24 h. The solution was concentrated and the residue recrystallised twice from water to afford the tris-sulphone **32** (54 mg, 49%) as white crystals, m.p. 266°C, lit[21] 265°C. $C_6H_{14}O_6S_3$: Calcd: C, 25.89; H, 5.07. Found: C, 25.55; H, 4.85. MS: (NH_3 DCI) m/z 296 ($M + NH_4^+$, 53%), 279 (MH^+, 3), 216 ($M + NH_4^+$—CH_3SO_2H, 100), 136 (9), 124 (37). NMR data could not be obtained on this compound due to its extreme insolubility.

2-[2-(Methylthio)ethylthio]ethanol (**33**). Sodium hydride (0.25 g, 0.01 mole) was added with stirring to methanol (40 ml). This solution was saturated with methanethiol and then **4** (1.1 g, 0.0078 mole) was added. The mixture was stirred at room temperature for 1 h then boiled under reflux for 1 h. On cooling, most of the methanol was removed, water (25 ml) added, and the product extracted into ether. Chromatography (chloroform-methanol 76 : 1) gave **33** (0.98 g, 82%) as an oil. NMR: ^1H: δ 2.1 (3H, s, SCH_3), 2.3 (1H, s, OH), 2.62 (2H, ddd, cannot define J, CH_2SCH_3) overlapping 2.64 (2H, ddd, cannot define J, $SCH_2CH_2SCH_3$) overlapping 2.64 (2H, t, J_{21} = 5.92, SCH_2CH_2OH) and 3.7 (2H, t, J_{12} = 5.92, CH_2OH); ^{13}C: δ 15.67 (SCH_3), 31.40 and 34.35 (SCH_2CH_2S), 35.39 (SCH_2CH_2OH) 60.67 (CH_2OH). IR: ν_{max} 3410, 2915, 2870, 1430, 1205, 1050, 1010, 960, 755, 730 and 690. MS (NH_3 DCI): m/z 170 ($M + NH_4^+$, 100%), 153 (MH^+, 77), 135 (MH^+—H_2O, 9), 105 (MH^+—CH_3SH, 30), 75 (77), 44 (13).

1-Chloro-2-[2-(methylthio)ethylthio]ethane (**34**). Thionyl chloride (2.5 g, 0.021 mole) in benzene (10 ml) was added to a solution of sulphide **33** (1.5 g, 0.01 mole) in benzene (20 ml). The mixture was allowed to stand at room temperature for 30 min and then boiled under reflux for 2 h. The solvent was removed and the residue chromatographed (petrol-ether 38 : 1) to give the half-mustard derivative **34** as an oil (1.23 g, 73%). NMR: ^1H: δ 2.2 (3H, s, SCH_3), 2.72 and 2.74 (both 2H, m, $SCH_2CH_2SCH_3$), 2.89 (2H, t, J_{12} = 7.3, SCH_2CH_2Cl), 3.62 (2H, t, J_{21} = 7.3, CH_2Cl); ^{13}C: δ 15.57 (SCH_3), 31.43 ($SCH_2CH_2SCH_3$), 34.23 and 34.27 (SCH_2CH_2Cl and CH_2SCH_3) and 43.18 (CH_2Cl). IR: ν_{max} 2965, 2915, 2850, 1430, 1290, 1270, 1215, 1200, 1040, 960, 850, 695 and 650. MS (EI): m/z 172 (6), 170 (M^+, 17), 134 (M^+—HCl, 29), 125 (7), 123 (M^+—CH_3S, 16), 111 (7), 109 ($CH_2SC_2H_4Cl^+$, 24), 79 (16), 75 (80), 63 (35), 61 (CH_2Ch_2Cl, 100), 60 (24), 58 (26), 47 (38), 46 (31), 45 (74).

1-Chloro-2-[2-(methylsulphonyl)ethylsulphonyl]ethane (**35**). A solution of **34** in hydrogen peroxide (60%, 4.0 ml) and glacial acetic acid was maintained at 60–65°C for 6 h. The mixture was allowed to cool and on standing overnight deposited **35** as white crystals (1.38 g, 64%), m.p. 162°C, lit.[24] 162°C. NMR: ^1H: δ 3.25 (3H, s, SCH_3), 3.52 (2H, t, J_{12} = 6.47, $SO_2CH_2CH_2Cl$), 3.56 and 3.64 (both 2H, both m, $SO_2CH_2CH_2SO_2$) 3.98 (2H, t, J_{21} = 6.47, CH_2Cl); ^{13}C: δ 35.7 (CH_2Cl), 42.6 (SO_2CH_3), 48.8 and 49.2 ($SO_2CH_2CH_2SO_2$) and 56.8 ($SO_2CH_2CH_2Cl$). IR: ν_{max} 3430, 2990, 1330, 1290, 1235, 1150, 1110, 800 and 510. MS (NH_3 DCI): 254 (28), 252 ($M + NH_4^+$, 65), 216 ($M + NH_4^+$—HCl, 100), 136 (13), 124 (17).

1-Methylsulphonyl-2-[2-(methylthio)ethylsulphonyl]ethane (**36**). Sodium hydride (0.02 g, 0.0008 mole) was added to methanol (15 ml) and the solution saturated with methanethiol. This solution was added dropwise to a solution of **35** (0.15 g, 0.00064 mole) in methanol at 30°C and the mixture stored at room temperature until TLC (chloroform-methanol 9 : 1) showed an absence of starting material. The solvent was removed and the residue recrystallised (twice) from methanol to give **36** (0.12 g, 76%) as white crystals with m.p. 174–176°C. $C_6H_{14}O_4S_3$: Calcd: C, 29.24; H, 5.73. Found: C, 29.21; H, 5.50. NMR: ^1H: δ 2.17 (3H, s, SCH_3), 2.98 (2H, m, CH_2SCH_3), 3.19 (3H, s, SO_2CH_3) and 3.63 and 3.79 (6H, overlapping m, $CH_2SO_2CH_2CH_2SO_2$); ^{13}C: δ 16.3 (SCH_3), 26.8 (SCH_2), 42.2 (SO_2CH_3), 46.6 and 47.4 ($SO_2CH_2CH_2SO_2$) and 54.4 ($SO_2CH_2CH_2SCH_3$); IR: ν_{max} 2990, 2915, 2845, 1645, 1540, 1515, 1280,

1230, 1140, 1110, 790 and 660. MS (NH_3 DCI): m/z 264 ($M + NH_4^+$, 100%), 184 ($M + NH_4^+ — CH_3SO_2H$, 27), 136 (3), 124 (10), 75 (43), 74 (35).

Compounds in Scheme V.

2,2'-Sulphinylbis-ethanol (**38**).[26] A solution of hydrogen peroxide (5.0 ml, 30%) was added over 10 min to a stirred solution o thiodiglycol **37** (5.0 g, 0.041 mole) in water (5 ml) cooled in an ice-water bath. The mixture was maintained at this temperature for 30 min and then concentrated to a small volume under reduced pressure. The solid that precipitated was filtered of and recrystallised from isopropanol to give the sulphoxide **38** (3.7 g, 65%), m.p. 113–115°C, lit[26] 111–112°C. NMR: ^1H: δ (D_2O) 3.06 (2H, d of t, $J_{1'1'} = 13.89$, $J_{12} = 4.47$, $J_{12'} = 4.47$, $SOC\underline{H}_2$), 3.14 (2H, ddd, $J_{1'1} = 13.89$, $J_{1'2} = 5.77$, $J_{1'2} = 8.12$, $SOC\underline{H}_2$) and 4.00 (4H, m, $C\underline{H}_2OH$); ^{13}C: δ 56.8 and 57.37 (all C). IR: ν_{max} 3330, 1330, 1075, 990, 960 and 880. MS (EI): m/z 138 (M^+, 3%), 120 ($M^+ — H_2O$, 2), 94 ($M^+ — C_2H_4O$, 49), 74 ($C_2H_4SO^+$, 100), 63 (41), 45 (80).

2,2'-Sulphonylbis-ethanol (**39**).[26] A solution of sulphoxide **38** (1.3 g, 0.0094 mole) and 3-chloroperbenzoic acid (1.7 g, *ca* 0.01 mole) in chloroform (20 ml) was stirred at room temperature until no starting material remained (*ca* 4h). The mixture was evaporated to dryness and the residue chromatographed over silica with chloroform-methanol 9:1. The product (rf 0.65) was collected and the solvent removed to afford a semi-solid that was washed with chloroform (in which the product is sparingly soluble) and then recrystallised twice from isopropanol-methanol to give the sulphone **39** as a low melting solid (0.78 g, 54%), m.p. 55–56°C, lit.[16] 54–55°C. $C_4H_{10}O_4S$: Calcd: C, 31.45; H, 6.44. Found: C, 31.16; H, 6.54. NMR: ^1H: δ (D_2O) 3.4 (4H, t, $J_{12} = 7.0$ $SO_2C\underline{H}_2$) and 3.95 (4H, t, $J_{21} = 7.0$, $C\underline{H}_2OH$); ^{13}C: δ 54.72 and 55.96 (all C). IR: ν_{max} 3390, 2940, 1400, 1315, 1280, 1190 and 1125. MS (EI): m/z 155 (MH^+, 2%), 111 ($MH^+ — C_2H_4O$, 10), 93 (21), 81 (13), 63 (12), 45 (100), 43 (33).

1,1'-Thiobis(2-acetoxyethane) (**40**).[13] A solution of thiodiglycol **37** (5.0 g, 0.041 mole) in pyridine (5 ml) was added to a stirred solution of acetic anhydride (6 ml) in pyridine (6 ml) cooled in an ice-water bath. The mixture was stirred at 0–5°C for 1 h, allowed to warm to room temperature and stirred for an additional 1 h. After dilution with water, the product was extracted into chloroform, dried and concentrated and the residue distilled under reduced pressure to give the di-acetate **40** as a colourless liquid (6.1 g, 72%), b.p. 100–101°C/0.5 mm, lit.[13] 155–6°C/20mm. NMR: ^1H: δ 2.05 (6H, s, $COC\underline{H}_3$), 2.8 (4H, t, $J_{12} = 7.0$, $SC\underline{H}_2$) and 4.2 (4H, t, $J_{21} = 7.0$, $C\underline{H}_2O$); ^{13}C: δ 20.95 ($CO\underline{C}H_3$), 30.77 ($S\underline{C}H_2$), 63.54 ($\underline{C}H_2O$) and 170.77 ($\underline{C}OCH_3$). IR: ν_{max} 1755, 1390, 1370, 1235 and 1030. MS (NH_3 DCI): m/z 224 ($M + NH_4^+$, 37), 147 ($MH^+ — CH_3CO_2H$, 100), 146 (18), 87 ($MH^+ — 2CH_3CO_2H$, 49), 86 (48).

1,1'-Sulphinylbis(2-acetoxyethane) (**41**). A mixture of sulphoxide **38** (2.0 g, 0.0114 mole), acetic anhydride (4.0 ml) and pyridine (4.0 ml) was stored at room temperature for 3 h when no starting material remained. Water was added and the mixture extracted with chloroform. Conventional processing gave an oil that was chromatographed with petrol-acetone 7:3 (rf 0.2) to afford the bis-acetate **40** (2.33 g, 92%) as a colourless oil. NMR: ^1H: δ 2.05 (6H, s, $COC\underline{H}_3$), 3.1 (4H, t, $J_{12} = 7.0$, $SOC\underline{H}_2$) and 4.5 (4H, t, $J_{12} = 7.0$, $C\underline{H}_2O$); ^{13}C: δ 20.92 ($CO\underline{C}H_3$), 51.81 ($SO\underline{C}H_2$), 57.24 ($\underline{C}H_2O$) and 170.66 ($\underline{C}OCH_3$). IR: ν_{max} 1725, 1370, 1351, 1230 and 1040. MS (NH_3 DCI): m/z 240 ($M + NH_4^+$, 3%), 223 (MH^+, 63), 180 (7), 163 ($MH^+ — CH_3CO_2H$, 100), 147 (18), 121 (6), 103 (8), 87 (64), 86 (64).

1,1'-Sulphonylbis(2-acetoxyethane) (**42**).[17] As described above, the sulphone **39** (2.0 g, 0.018 mole) with acetic anhydride (4.0 ml) and pyridine (4.0 ml) gave, after chromatography with chloroform-methanol 38 : 1 (rf 0.6), the bis-acetate **42** (1.22 g, 40%) as a colourless viscous liquid. NMR: ^1H: δ 2.05 (6H, s, $COC\underline{H}_3$), 3.45 (4H, t, $J_{12} = 7.0$, $SO_2C\underline{H}_2$) and 4.50 (4H, t, $J_{21} = 7.0$, $C\underline{H}_2O$); ^{13}C: δ 20.62 ($CO\underline{C}H_3$), 53.30 ($SO_2\underline{C}H_2$), 57.57 ($\underline{C}H_2O$) and 170.11 ($\underline{C}OCH_3$). IR: ν_{max} 1740, 1380, 1360, 1315, 1280, 1235, 1065 and 1030. MS (NH_3 DCI): m/z 256 ($M + NH_4^+$, 62%), 196 ($M + NH_4^+ — CH_3CO_2H$, 100), 136 (10), 87 (23).

1,1'-Thiobis(2-methoxyethane) (**43**).[30] Sodium sulphide (1.5 g, 0.0063 mole) was added to a solution of 1-chloro-2-methoxyethane (2.5 g, 0.026 mole) in methanol (5 ml). After stirring for 4 h, most of the methanol was removed under reduced pressure, water (10 ml) was added and the reaction product extracted into ether. The extract was processed in the usual way and chromatographed with petrol-ether 9:1 to afford the dimethoxy sulphide **43** as an oil (1.06 g, 54%). NMR: ^1H: δ 2.7 (4H, t, $J_{12} = 7.0$ $SC\underline{H}_2$), 3.30 (6H, s, $OC\underline{H}_3$) and 3.50 (4H, t, $J_{21} = 7.0$, $C\underline{H}_2O$); ^{13}C: δ 31.84 ($S\underline{C}H_2$), 58.7 ($O\underline{C}H_3$) and 72.2 ($\underline{C}H_2O$). IR: ν_{max} 2940, 2860, 1490, 1390, 1190, 1125 and 955. MS (EI): 150 (M^+, 4%), 118 ($M^+ — CH_3OH$, 37), 75 (72), 72 (18), 59 (50), 58 (73), 45 (100).

1,1'-Sulphinylbis(2-methoxyethane) (**44**).[17] A solution of sulphoxide **23** (1.5 g, 0.0086 mole) in methanol (40 ml) containing sodium hydroxide (1.5 g) was stored at room temperature overnight. Most of the methanol was removed under reduced pressure. The mixture was diluted with water and the product was extracted into ether. After conventional processing, the residual oil was chromatographed with

chloroform-methanol 19:1 (rf 0.4) to afford the dimethoxy sulphoxide **44** (0.99 g, 70%) as a colourless oil. NMR: ^{1}H: δ 2.90 and 3.10 (both 2H, both m, $SOCH_2$), 3.4 (6H, s, OCH_3) and 3.8 (4H, m, CH_2O); ^{13}C: δ 52.63 ($SOCH_2$), 58.44 (OCH_3) and 64.49 (CH_2O). IR: ν_{max} 2900, 1470, 1390, 1120, 1040 and 980. MS (EI): m/z 167 (MH^+, 2%), 149 (12), 108 (14), 86 (23) 84 (37), 80 (14), 76 (10) 59 (100), 45 (45).

1,1'-Sulphonylbis(2-methoxyethane) (**45**).[17] As described above, sulphone **3** (1.5 g, 0.0079 mole) with sodium hydroxide in methanol gave after chromatography (chloroform-methanol 19:1, rf 0.65) the dimethoxy sulphone **45** (0.98 g, 69%) as a colourless oil. NMR: ^{1}H: δ 3.35 (4H, t, J_{12} = 6.5, SO_2CH_2), 3.4 (6H, s, OCH_3) and 3.80 (4H, t, J_{21} = 6.5, CH_2O); ^{13}C: δ 54.80 (SO_2CH_2), 58.94 (OCH_3) and 66.87 (CH_2O). IR: ν_{max} 2940, 1470, 1390, 1315, 1300, 1110, 985 and 970. MS (NH_3 DCI): m/z 200 ($M + NH_4^+$, 85%), 183 (MH^+, 100), 168 ($M + NH_4^+ - CH_3OH$, 34), 151 ($MH^+ - CH_3OH$, 23), 136 (10), 119 (11), 59 (57), 58 (70), 45 (23).

1,2-Bis(2-hydroxyethylthio)ethane (**46**).[29] Sodium metal (2.0 g, 0.087 mole) was added in small pieces to a solution of ethanedithiol (3.5 g, 0.037 mole) in ethanol (25 ml). After 1 h, 2-chloroethanol (6.4 g, 0.8 mole) was added dropwise and the mixture was boiled under reflux for 3 h. When cool, the mixture was filtered (to remove sodium chloride) and evaporated to dryness. The residue was taken up in boiling ethyl acetate and again filtered. On cooling, the diol **47** was deposited as white crystals (4.93 g, 72%), m.p. 62°C, lit[29] 64°C. NMR: ^{1}H: δ 2.50 (2H, broad s, OH), 2.74 (4H, t, J_{12} = 6.0, SCH_2CH_2OH) 2.75 (4H, s, SCH_2CH_2S) and 3.72 (4H, t, J_{21} = 6.0, CH_2OH); ^{13}C: δ 32.28 (SCH_2CH_2S), 35.61 (SCH_2CH_2OH) and 61.00 (CH_2OH). IR: ν_{max} 4000, 2940, 1430, 1350, 1205, 1135, 1050 and 960. MS (NH_3 DCI): m/z 200 ($M + NH_4^+$, 27%), 183 (MH^+, 24), 182 (2), 165 (20), 137 (6), 105 ($C_2H_4SC_2H_4OH^+$, 100).

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