Carbohydrate Research, 102 (1982) 69–81
Elsevier Scientific Publishing Company, Amsterdam – Printed in The Netherlands

SYNTHESIS AND STRUCTURES OF SOME DIGLYCOLALDEHYDE THIOACETALS*

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(Received January 21st, 1981; accepted for publication, September 14th, 1981)

ABSTRACT

Diglycolaldehyde (2,2′-oxybisacetaldehyde, **1a**) reacts with thiols under conditions similar to those for monosaccharides. The nature of the reaction products depends on the degree of α-substitution of the thiol. The acyclic dithioacetal **2a** was the only product isolated when methanethiol was used, but mixtures of acyclic dithioacetals, *cis*-2,6-bis(alkylthio)-1,4-dioxanes, and *trans*-2,6-bis(alkylthio)-1,4-dioxanes were obtained when ethanethiol, 1-propanethiol, and 2-propanethiol were used. From **1a** and 2-methylpropane-2-thiol, the acyclic dithioacetal **2e** and the *cis* (**7**) and *trans* (**8**) stereoisomers of 3,5-bis(*tert*-butylthio)-1,4-oxathiane were isolated. On the other hand, when diglycolaldehyde bis(dialkyl acetals) (**9a–d**) or 2,6-di-isopropoxy-1,4-dioxane (**10**) were treated with primary or secondary thiols in acid media, the acyclic dithioacetals were isolated as the only products. The acyclic dithioacetal **2e** and the oxathiane derivatives **7** and **8** were obtained when **9a–d** or **10** were treated with 2-methylpropane-2-thiol under the above conditions.

INTRODUCTION

No systematic study of the reactions between 1,5-dialdehydes and thiols in acid media has been reported. Some experimental results have been reported showing that several types of products can be obtained. Thus, the sulfonyldiacetaldehyde bis(hemithioacetal) **11** was obtained from sulfonyldiacetaldehyde and thiophenol[1], and 1,1,2-tris(benzylthio)ethane was isolated when **12** was treated with α-toluenethiol in acid media[2]. Some monosaccharide dialdehydes have been also studied. 1,2-*O*-Isopropylidene-D-*xylo*-pentodialdose reacted with 1,2-ethanedithiol, to give *xylo*-pentodialdose bis(ethylene dithioacetal), and D-*manno*-[3] and D-*gluco*-hexodialdoses[4] were transformed into their bis(diethyl dithioacetals). On the other hand, **13** was obtained from the appropriate dialdehyde and ethanethiol in the presence of dry hydrogen chloride[5]. In all cases, the dialdose bis(dithioacetal) was isolated as a solid and no attempt was made to isolate other possible products.

We have studied the reactions of dialdehydes, for example, glutaraldehyde (**1b**),

*Derivatives of Diglycolaldehyde, Part XIV. For Part XIII, see ref. 12.

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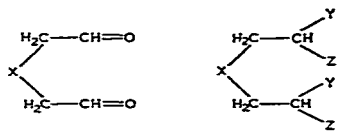
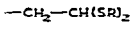
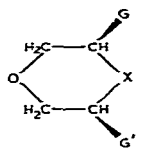


1a X = O
1b X = CH_2
1c X = S
1d X = NH

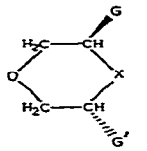
2a-f X = O, Y = Z = S—R
11 X = SO_2, Y = S—Ph, Z = OH
15 X = O, Y = Z = OH
17 X = O, Y = S—R, Z = OH



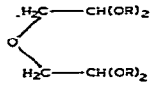
3 X = S—R
4 X = OH



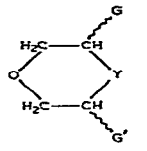
5b-d X = O, G = G' = S—R
7 X = S, G = G' = S-Bu^t
24 X = SO, G = G' = SO_2Bu^t
25 X = SO_2, G = G' = SO_2Bu^t



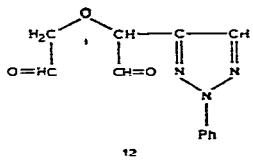
6b-d X = O, G = G' = S—R
8 X = S, G = G' = S-Bu^t



9a R = Me
9b R = Et
9c R = Pr^n
9d R = Pr^i



10 Y = O, G = G' = O-Pr^i
14 Y = O, G = G' = OH
16 Y = O, G = OH, G' = S—R



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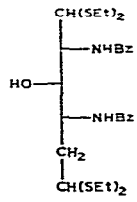

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thiodiglycolaldehyde (**1c**), iminodiglycolaldehyde (**1d**), and *xylo*-pentodialdose, with thiols, in order to establish the influence of the nature of the dialdehyde on the structure of the products.

We now report on the reactions of diglycolaldehyde (**1a**) and some thiols in aqueous, acid media, and on the reactions of diglycolaldehyde acetals and the same thiols in anhydrous, acid media.

RESULTS AND DISCUSSION

Diglycolaldehyde[6] (**1a**), which can be prepared in a polymeric state from its bis(dimethyl acetal) by acid hydrolysis, was dissolved in concentrated hydrochloric acid before treatment with each thiol, and therefore **1a** and the hydrated forms **14** and **15** may be intermediates in the reaction. The hydration–dehydration process is a very rapid reaction and has been studied[6-8] for both diglycolaldehyde (**1a**) and thiodiglycolaldehyde (**1c**) in D_2O solutions by ^{1}H-n.m.r. spectroscopy. When aqueous solutions of diglycolaldehyde are treated with thiols, two types of hemithioacetals (**16** and **17**) can presumably be formed. Although we have not isolated any diglycolaldehyde hemithioacetal, **11**, which is structurally related to **17**, has been reported.

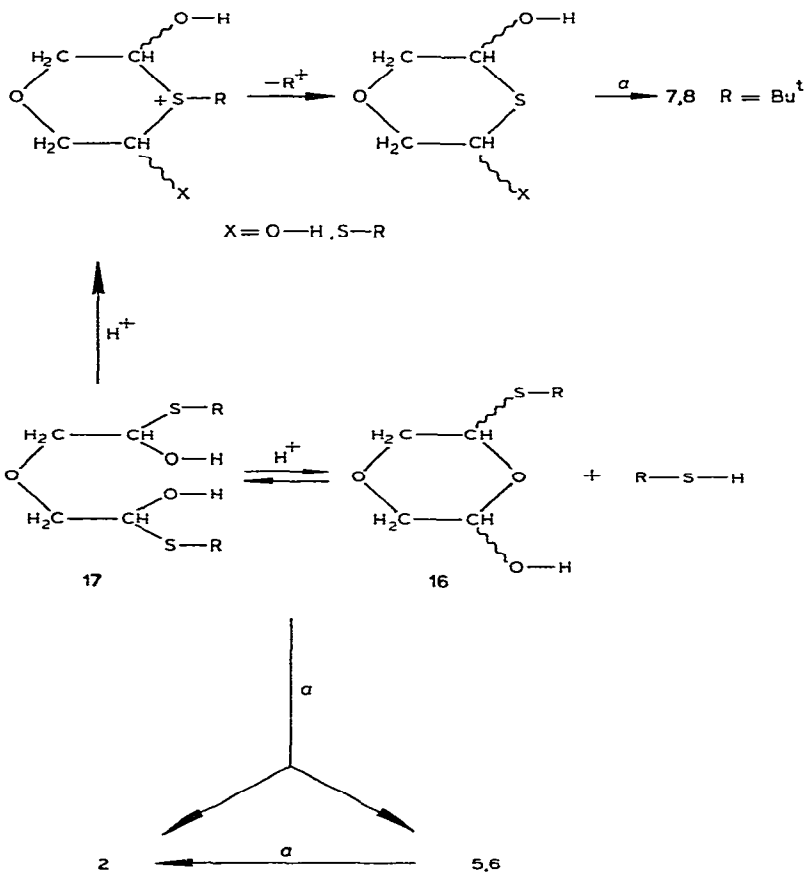
Methanethiol, and primary, secondary, and tertiary thiols were treated with diglycolaldehyde and the yields of products are given in Table I. As expected on

TABLE I

REACTION PRODUCTS FROM DIGLYCOLALDEHYDE (1a) AND SOME THIOLS IN ACID MEDIA

Thiol	*Products (%)*[a]			
MeSH	2a (74)	3a (traces)		
EtSH	2b (75)	3b (0.2)	4b (0.2)	5b,6b (1.15)[b]
PrSH	2c (70)	3c (0.3)	4c (1.5)	5c,6c (4.0)[b]
Pr^{i}SH	2d (43.8)	3d (1.9)	4d (5.5)	5d,6d (3.75)[b]
Bu^{t}SH	2e (12)[c]	3e (9.0)	4e (15.0)	7,8 (54.7)[b]
$HSCH_2CH_2SH$	2f (77.4)			

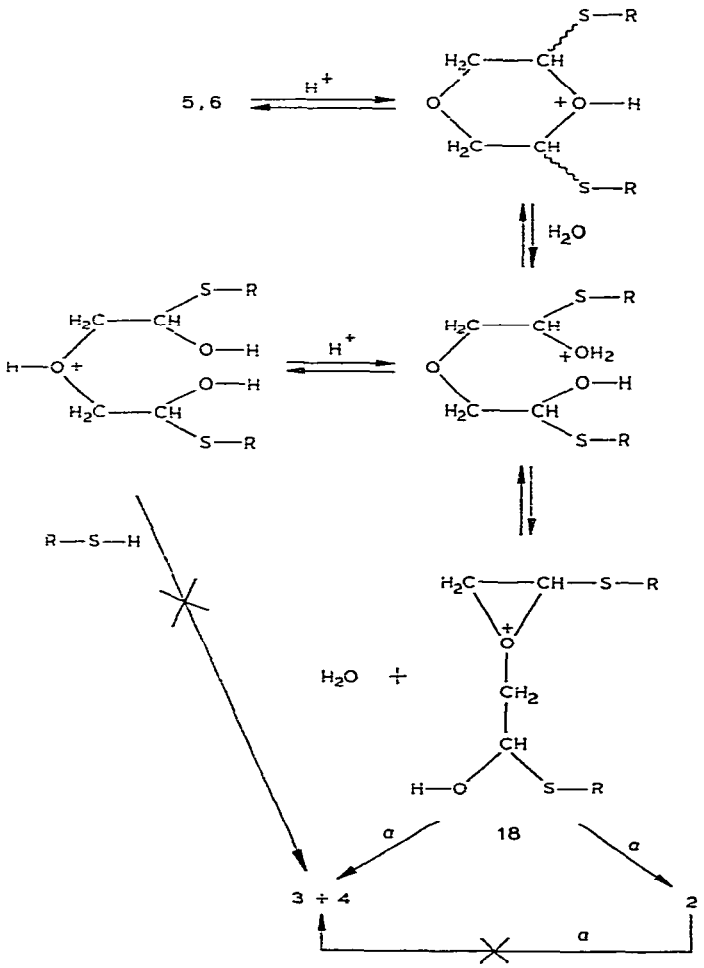
[a]Yields referred to starting dialdehyde. [b]For the mixture of stereoisomers. [c]A small proportion of di-(*tert*-butyl) sulfide was also obtained.



Scheme 1. Reactions *a* involve R-S-H/H$^+$

steric considerations the acyclic (**2**)–cyclic (**5,6**) product ratio decreased when substitution at the α-position in the thiols increased. Methanethiol gave no cyclic products, and 2-methylpropane-2-thiol gave mainly, and unexpectedly, a mixture of stereoisomers **7** and **8**.

Compounds **2**, **5**, and **6** appear to be formed from diglycolaldehyde hemithioacetals through competitive processes, as illustrated in Scheme 1. Thus, **2b** and **2d** were obtained from the corresponding mixture **5,6** and the appropriate thiol in acid media, but these reactions were slower than for diglycolaldehyde (**1a**) under similar conditions. These results indicate that **5,6** are not intermediates in the main route for the transformation of **1a** into **2a–e**. On the other hand, the reaction of **1a** with ethanethiol (1:2 molar ratio) yielded **2b** as the only product, and the mixture **5b,6b** was not detected by t.l.c. The transformations of acyclic dithioacetals **2** into the cyclic compounds **5,6** did not occur in the presence or absence of the appropriate

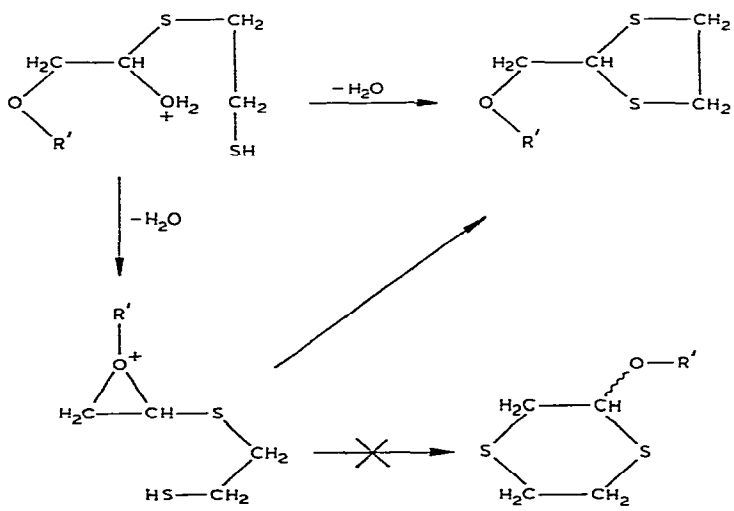


Scheme 2. Reaction *a* involves R-S-H/H+

thiol in acid media. Therefore, **5,6** are not the products of thermodynamic control in these reactions and the results do not resemble those reported in the carbohydrate field, where acyclic dithioacetals of monosaccharides are the products of kinetic control and 1-thioglycosides those of thermodynamic control[9-11].

In the reaction of diglycolaldehyde (**1a**) and 2-methylpropane-2-thiol in hydrochloric acid, the acyclic dithioacetal **2e** was a minor product and the mixture of *cis*- and *trans*-3,5-bis(*tert*-butylthio)-1,4-oxathianes were the only cyclic products; 2,6-bis(*tert*-butylthio)-1,4-dioxanes were not detected (see Scheme 1). This behaviour of the *tert*-butyl compounds has been ascribed to the easy formation of the *tert*-butyl cation and to release of steric strain in the molecule when the *tert*-butyl cation is lost[12]. The acyclic dithioacetal **2e** and 2-methylpropane-2-thiol did not react under the above conditions. However, when **2e** was left at room temperature in concentrated hydrochloric acid for 2 days, **3e** and a mixture of **7** and **8** were formed. The reaction was slower (t.l.c.) than the formation of **7** and **8** from **1a**. On the other hand, the mixture of **7** and **8** did not react with 2-methylpropane-2-thiol in acid media to give **2e**. These data show that **2e** and both **7** and **8** were probably formed from **1a** through competitive processes.

The formation of **3** and **4** and the fact that their relative yields increased with increase in the size of R is in accordance with Scheme 2, which is based on the following data. Compounds **3** and **4** were not detected when acyclic dithioacetals (**2**) were treated for prolonged periods with the appropriate thiol in acid media. Thus, compounds **2** are not intermediates in the formation of **3** and **4**. When the mixture of stereoisomers **5d,6d** was treated with 2-propanethiol, **3d** and **4d** were formed, but more slowly than from **1a** under the same conditions. Hence, **5d,6d** are probably not intermediates in the main route for the formation of **3d** and **4d**. On the other



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Scheme 3. R′ = CH_2 — CH=O or other equivalent group.

hand, when **5b,6b** were treated in a similar manner, **3b** and **4b** were not detected by t.l.c. Formation of **3** and **4** cannot be explained by an S_N2 process (see Scheme 2) because the less-hindered thiols would then produce yields of **3** and **4** higher than those found. To explain this fact and the failure of 1,2-ethanedithiol to give **3** and **4**, the oxonium ion **18** has been postulated as an intermediate. The higher yields of **3e** and **4e** from the reaction of **1a** and 2-methylpropane-2-thiol can be ascribed to the relatively high steric release when the acyclic intermediate is transformed into **18** (see Scheme 2). With 1,2-ethanedithiol, the formation of **18** competes with attack of sulfur from the free thiol group and, although the oxonium ion can be formed, the rate of formation for a five-membered ring is higher than for a six-membered one. Compound **19** or any derivative thereof was not detected (see Scheme 3).

When the diglycolaldehyde bis(dialkylacetals) (**9a–d**)[13,14] were treated with ethanethiol in the presence of small amounts of concentrated sulfuric acid, **2b** was the only product isolated; the formation of 2,6-bis(ethylthio)-1,4-dioxanes (**5b,6b**) was not observed (t.l.c.). However, in the reaction of diglycolaldehyde bis(dimethyl acetal) (**9a**) and 2-methylpropane-2-thiol in the presence of boron trifluoride, the acyclic dithioacetal **2e** and a mixture of **7** and **8** were isolated. Attempts to obtain **5b,6b** from 2,6-di-isopropoxy-1,4-dioxane[13,14] (**10**) and ethanethiol in acid media gave only **2b**, even when a 1:2 molar ratio was used. However, under similar conditions, 2-methylpropane-2-thiol and **10** yielded **2e**, **7**, and **8**.

Compounds **3a–e**[12] and **4b–e**[14] were identified by comparisons with authentic specimens. Compounds **2a–e** showed a typical i.r. absorption at 1114 $\pm$10 cm^{-1} (see Table II). The values for ν decreased with increase in the size of the alkylthio groups. However, the position of this band differs somewhat from that for **2f**, and can be ascribed to the presence of the 1,3-dithiolane rings. The ^{1}H-n.m.r. spectra showed AB_2 coupling systems, except for **2f** where there was an AX_2 system.

The i.r. spectra for *cis*-2,6-bis(alkylthio)-1,4-dioxanes (**5b–d**) were more complex than those for the acyclic compounds (**2a–e**) (Table III). The same effect was observed when the spectra of the diglycolaldehyde dialkyl acetals were compared

TABLE II

I.R. AND ^{1}H-N.M.R.[a] DATA FOR **2a–f**

Compound	ν *(cm^{-1})*	δ *Ha*	δ *Hb*	J_{ab} *(Hz)*
2a	1124	3.75	3.65	6.6
2b	1117	3.91	3.72	7.0
2c	1110	3.84	3.66	6.9
2d	1108	3.82	3.59	6.7
2e	1105	3.80	3.51	7.0
2f	1097	4.51 (t)	3.53 (d)	7.0

[a]Recorded for solutions in CCl_4; $CDCl_3$ was used for **2f**. The values for δ Hb are approximate, because of the overlapping of the 5th and 6th signals in the AB_2 systems.

TABLE III

TYPICAL I.R. ABSORPTION BANDS FOR **5b–d** AND **6b–e**

R	*Compound*	*ν (cm⁻¹)*	*Compound*	*ν (cm⁻¹)*
Et	**5b**	1020, 780	**6b**	1094, 982, 870, 844
Pr	**5c**	1030, 780	**6c**	1095, 982, 870, 844
Pr^i	**5d**	1030, 776	**6d**	1091, 990, 877, 851
Bu^t	—	— —	**6e**	1088, 980, 867, 838[14]

TABLE IV

^{1}H-N.M.R. DATA[a] FOR **5b–d** AND **6b–e**

Compound	*δ Hx*	*δ Hb*	*δ Ha*
5b	4.66	3.75	3.28
6b	5.26	3.88	3.55
5c	4.66	3.75	3.28
6c	5.28	3.82	3.50
5d	4.75	3.72	3.25
6d	5.26	3.82	3.50
6e[14]	5.35	3.96	3.60

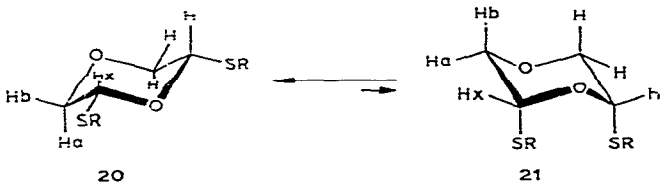
[a]For solutions in $CDCl_3$ (internal Me_4Si).

with those of *cis*-2,6-dialkoxy-1,4-dioxanes[15]. The *trans* isomers **6b–e** had the highest number of typical bands in the same spectral zone.

The ^{1}H-n.m.r. spectra for the *cis*-2,6-bis(alkylthio)-1,4-dioxanes (**5b–d**) showed ABX systems for the hydrogens bonded at the ring carbon atoms, in agreement with the conformational equilibria between two C_s conformers **20** and **21** (see Table IV). The values for J_{ax}, J_{bx}, and J_{ab} were 10.4, 2.9, and 11.2 Hz, respectively, and $J_{ax} + J_{bx}$ was 13.4 Hz in all cases. The values for $J_{ax} + J_{bx}$ in *cis*-2,6-dialkoxy-1,4-dioxanes[13,15] showed a gradual change from 10.2 to 11.5 Hz with increase in the degree of substitution at the carbon directly bonded to oxygen in the alkoxy radicals. This behaviour accords with operation of the "hockey-stick" effect[16] between the sulfur atoms and the oxygen at position 4 and it stabilises the diequatorial disposition for alkylthio groups in conformer **20**. The population ratio for **20** and **21** at equilibrium appears to be independent of the nature of R.

In the *trans*-isomers **6b–e**, the chair conformers **22** and **23** form a degenerate system and only one ABX coupling can be observed. The $J_{ax} + J_{bx}$ values are higher for *cis* than for *trans* stereoisomers. Compounds **6b**, **6c**, and **6d** showed $J_{ax} + J_{bx}$ 8.7 Hz, whereas the value for **6e**[14] was 9.6 Hz. The values for chemical shifts are also in agreement with configurational assignments (Table IV).

The stereoisomers of 3,5-bis(*tert*-butylthio)-1,4-oxathiane were isolated and



20 21

22 23

one was crystalline (m.p. 67–68°). The ^{1}H-n.m.r. spectra did not allow the relative configuration for those stereoisomers to be established, because a first-order interpretation could not be applied. Also, the X-ray diffraction method was unsuccessful when applied to the crystalline stereoisomer. When each of the stereoisomers was oxidised with hydrogen peroxide–acetic acid, the same product **24** was obtained. Compound **24** was oxidised to the sulfone **25**.

EXPERIMENTAL

General methods. — Organic solutions were dried over anhydrous Na_2SO_4. Solvents were evaporated under diminished pressure at <40°. Column chromatography was carried out on Silica gel 60 (Merck, 70–230 mesh, ASTM). Melting points (uncorrected) were obtained with an Electrothermal Melting Point apparatus. I.r. spectra were recorded for films on NaCl or KBr discs with a Pye–Unicam SP 1000 spectrometer. ^{1}H-N.m.r. spectra were recorded for solutions in various solvents (internal Me_4Si) with a Perkin–Elmer–Hitachi R-20 B spectrometer. Chemical shifts are given on the δ scale and couplings in Hz.

Diglycolaldehyde[6] (**1a**) was prepared in a polymeric state from its bis(dimethyl acetal) (**9a**; 11.5 g, 59.27 mmol) in an almost quantitative yield by acid hydrolysis. Diglycolaldehyde bis(dialkyl acetals) (**9a–d**) and 2,6-di-isopropoxy-1,4-dioxane (**10**) were obtained as previously described[13].

Reactions between diglycolaldehyde (**1a**) *and thiols in concentrated hydrochloric acid.* — The aldehyde (**1a**, 59.27 mmol) in ice-cooled, concentrated hydrochloric acid (30 ml) was treated with the appropriate thiol. A solid CO_2–acetone mixture was used as external coolant when methanethiol was used. The mixture was stirred at room temperature, basified with aqueous 40% KOH, and extracted with ether

(3 × 50 ml), and the combined extracts were dried and concentrated, to give a crude oil.

The following thiols and reaction times were used:

	MeSH	*EtSH*	*PrSH*	*Pr^{i}SH*	*Bu^{t}SH*	*HSCH$_2$CH$_2$SH*
Vol. (ml)	20	28	38	38	30	15
Time (min)	25	30	60	75	120	15

Compounds **3a–e**[12], **4b–e**[14], and di-(*tert*-butyl) sulphide[17] were identified by comparisons with authentic samples.

(*a*) *With methanethiol.* Distillation of the crude product yielded, first, a mixture (0.3 g) of **2a** and **3a**, b.p. up to ~130°/0.5 mmHg, and then diglycolaldehyde bis(dimethyl dithioacetal) (**2a**, 11.5 g), which was purified by column chromatography (benzene), yielding material (11.3 g, 74%) having b.p. 140–142°/0.5 mmHg; ν_{max} 1351, 1282, 1234, 1124, 1070, and 961 cm^{-1}. ^{1}H-N.m.r. ($CDCl_3$) data: δ 3.68 (m, 3 H) and 2.10 (s, 6 H) (Found: C, 36.9; H, 6.8; S, 49.9. $C_8H_{18}OS_4$ calc.: C, 37.1; H, 7.0; S, 49.6%).

(*b*) *With ethanethiol.* Distillation of the crude product yielded, first, a mixture (0.25 g) of several compounds, b.p. 94–95°/0.5 mmHg, and then diglycolaldehyde bis(diethyl dithioacetal) (**2b**; 13.94 g, 75%), b.p. 158–160°/0.5 mmHg, which was identified by comparison with authentic material[15]. Column chromatography (5:1 hexane–ether) of the mixture gave 1,1,2-tris(ethylthio)ethane (**3b**, 0.021 g); **2b** (0.065 g); a mixture (0.062 g) of **2b**, *cis*-2,6-bis(ethylthio)-1,4-dioxane (**5b**), and *trans*-2,6-bis(ethylthio)-1,4-dioxane (**6b**); a mixture (0.08 g) of **5b** and **6b**; and glycolaldehyde diethyl dithioacetal (**4b**, 0.019 g), ν_{max} 3365, 1373, 1072, 1050, 1010, and 972 cm^{-1}. ^{1}H-N.m.r. (CCl_4) data: δ 3.84–3.30 (m, 3 H), 2.60 (m, 5 H, J 7.2 Hz, one proton exchangeable with D_2O), and 1.20 (t, 6 H, J 7.2 Hz). The mixture of **5b** and **6b** was rechromatographed (50:1 hexane–ether), to give **5b**; ν_{max} 1378, 1295, 1230, 1114, 1020, 970, 900, and 780 cm^{-1}; ^{1}H-n.m.r. ($CDCl_3$) data: δ 4.66 (dd, 1 H, J 10.4 and 2.9 Hz), 3.75 (dd, 1 H, J 11.2 and 2.9 Hz), 3.28 (dd, 1 H, J 11.2 and 10.4 Hz), 2.70 (m, 2 H, J 7.0 Hz), and 1.25 (t, 3 H, J 7.0 Hz); and **6b**; ν_{max} 1375, 1312, 1270, 1212, 1094, 982, 870, and 844 cm^{-1}; ^{1}H-n.m.r. ($CDCl_3$) data: δ 5.26 (dd, 1 H, J 5.4 and 3.3 Hz), 3.88 (dd, 1 H, J 11.8 and 3.3 Hz), 3.55 (dd, 1 H, J 11.8 and 5.4 Hz), 2.66 (m, 2 H, J 7.0 Hz), and 1.30 (t, 3 H, J 7.0 Hz) (Found for **5b** + **6b**: C, 45.9; H, 7.6; S, 30.6. $C_8H_{16}O_2S_2$ calc.: C, 46.1; H, 7.7; S, 30.7%).

(*c*) *With propanethiol.* Distillation of the crude product yielded, first, a mixture (1.78 g), b.p. 90–105°/0.4 mmHg, and then diglycolaldehyde bis(dipropyl dithioacetal) (**2c**; 15.3 g, 70%), b.p. 160–162°/0.4 mmHg; ν_{max} 1360, 1225, 1100, and 885 cm^{-1}. ^{1}H-N.m.r. (CCl_4) data: δ 3.70 (m, 3 H), 2.64 (m, 4 H), 1.55 (m, 4 H), and 1.00 (t, 6 H, J 6.7 Hz) (Found: C, 51.5; H, 8.7; S, 34.2. $C_{16}H_{34}OS_4$ calc.: C, 51.8; H, 9.2; S, 34.5%).

Chromatography of the mixture (50:1 hexane–ether) gave 1,1,2-tris(propylthio)ethane (**3c**, 0.041 g), **2c** (0.068 g), **5c** (0.137 g), a mixture (0.205 g) of **5c** and **6c**, **6c** (0.219 g), and glycolaldehyde dipropyl dithioacetal (**4c**, 0.178 g); ν_{max} 3420, 1465, 1378, 1296, 1242, 1055, 1020, and 780 cm^{-1}. ^{1}H-N.m.r. (CCl_4) data: δ 3.90–3.40 (m, 3 H), 2.60 (m, 4 H), 2.30 (bs, 1 H, proton exchangeable with D_2O), 1.62 (m, 4 H), and 1.00 (t, 6 H). *cis*-2,6-Bis(propylthio)-1,4-dioxane (**5c**) had ν_{max} 1376, 1294, 1204, 1030, 902, and 780 cm^{-1}. ^{1}H-N.m.r. ($CDCl_3$) data: δ 4.66 (dd, 1 H, J 10.4 and 2.9 Hz), 3.75 (dd, 1 H, J 11.2 and 2.9 Hz), 3.28 (dd, 1 H, J 11.2 and 10.4 Hz), 2.65 (m, 2 H), 1.53 (m, 2 H), and 0.96 (t, 3 H, J 7.0 Hz). *trans*-2,6-Bis(propylthio)-1,4-dioxane (**6c**) had ν_{max} 1376, 1320, 1240, 1120, 1095, 982, 870, and 844 cm^{-1}. ^{1}H-N.m.r. ($CDCl_3$) data: δ 5.28 (dd, 1 H, J 5.4 and 3.3 Hz), 3.82 (dd, 1 H, J 11.8 and 3.3 Hz), 3.50 (dd, 1 H, J 11.8 and 5.4 Hz), 2.58 (m, 2 H), 1.55 (m, 2 H), and 0.96 (t, 3 H, J 7.0 Hz) (Found for **5c** + **6c**: C, 50.8; H, 8.4; S, 27.2. $C_{10}H_{20}O_2S_2$ calc.: C, 50.8; H, 8.5; S, 27.1%).

(*d*) *With 2-propanethiol.* Distillation of the crude product yielded a mixture (2.1 g), b.p. 85–100°/0.5 mmHg, and then diglycolaldehyde bis(di-isopropyl dithioacetal) (**2d**; 9.6 g, 43.8%), b.p. 148–150°/0.4 mmHg; ν_{max} 1365, 1152, 1108, 1050, and 925 cm^{-1}. ^{1}H-N.m.r. (CCl_4) data: δ 3.65 (m, 3 H), 3.15 (m, 2 H, J 6.2 Hz), and 1.28 (d, 12 H, J 6.2 Hz) (Found: C, 51.6; H, 9.2; S, 34.7. $C_{16}H_{34}OS_4$ calc.: C, 51.8; H, 9.2; S, 34.6%).

Chromatography (50:1 benzene–methanol) of the mixture gave 1,1,2-tris(isopropylthio)ethane (**3d**, 0.21 g); a mixture (0.84 g) of **3d**, **5d**, and **6d**; a mixture (0.052 g) of **5d** and **6d**; and glycolaldehyde di-isopropyl dithioacetal (**4d**, 0.63 g); ν_{max} 3410, 1378, 1363, 1238, 1150, 1047, 1010, and 760 cm^{-1}. ^{1}H-N.m.r. (CCl_4) data: δ 4.00–3.50 (m, 3 H), 3.11 (m, 2 H, J 7 Hz), 2.90 (bs, 1 H, proton exchangeable with D_2O), and 1.30 (d, 12 H, J 7 Hz). Rechromatography (50:1 hexane–ether) of the second fraction gave **3d** (0.073 g), **5d** (0.052 g), a mixture (0.105 g) of **5d** and **6d**, and **6d** (0.315 g). *cis*-2,6-Bis(isopropylthio)-1,4-dioxane (**5d**) had ν_{max} 1368, 1295, 1230, 1160, 1111, 1030, and 776 cm^{-1}. ^{1}H-N.m.r. ($CDCl_3$) data: δ 4.76 (dd, 1 H, J 10.4 and 2.9 Hz), 3.72 (dd, 1 H, J 11.2 and 2.9 Hz), 3.25 (dd, 1 H, J 11.2 and 10.4 Hz), 3.12 (m, 1 H, J 6.2 Hz), and 1.30 (d, 6 H, J 6.2 Hz). *trans*-2,6-Bis(isopropylthio)-1,4-dioxane (**6d**) had ν_{max} 1366, 1290, 1214, 1128, 1091, 990, 877, and 851 cm^{-1}. ^{1}H-N.m.r. ($CDCl_3$) data: δ 5.26 (dd, 1 H, J 5.4 and 3.3 Hz), 3.82 (dd, 1 H, J 11.8 and 3.3 Hz), 3.50 (dd, 1 H, J 11.8 and 5.4 Hz), 3.04 (m, 1 H, J 6.2 Hz), and 1.32 (d, 6 H, J 6.2 Hz) (Found for **5d** + **6d**: C, 50.7; H, 8.3; S, 26.9. $C_{10}H_{20}O_2S_2$ calc.: C, 50.8; H, 8.5, S, 27.1%).

(*e*) *With 2-methylpropane-2-thiol.* Distillation of the crude product yielded a mixture (12.96 g), b.p. 94°/0.1 mmHg, and then diglycolaldehyde bis(di-*tert*-butyl dithioacetal) (**2e**; 3.0 g, 12%), b.p. 140–145°/0.1 mmHg; ν_{max} 1364, 1162, 1105, 1047, and 970 cm^{-1}. ^{1}H-N.m.r. (CCl_4) data: δ 3.62 (m, 3 H) and 1.32 (s, 18 H) (Found: C, 56.1; H, 10.1; S, 29.7. $C_{20}H_{42}OS_4$ calc.: C, 56.3; H, 9.9; S, 30.0%).

Redistillation of the mixture gave a fraction (3.72 g), b.p. 75–85°/0.1 mmHg, that was resolved by column chromatography (30:1 hexane–ether) into di-(*tert*-butyl) sulfide[17] (0.207 g); 1,1,2-tris(*tert*-butylthio)ethane (**3e**, 1.56 g), m.p. 79–80°

(from ethanol–water); and glycolaldehyde di-*tert*-butyl dithioacetal (**4e**, 1.95 g); ν_{max} 3450, 1380, 1360, 1154, 1045, 1020, and 765 cm^{-1}. ^{1}H-N.m.r. (CCl_4) data: τ 4.00–3.40 (m, 3 H), 2.48 (t, 1 H, proton exchangeable with D_2O), and 1.38 (s, 18 H). A second fraction (9.13 g, 54.7%), b.p. 93–97°/0.1 mmHg, which contained **7**, **8**, and traces of **3e**, was crystallised from ethanol, to give *cis*-3,5-bis(*tert*-butylthio)-1,4-oxathiane (**7**) or *trans*-3,5-bis(*tert*-butylthio)-1,4-oxathiane (**8**) (4 g), m.p. 67–68°; ν_{max} 1368, 1270, 1180, 1158, 1090, 1050, 970, and 920 cm^{-1}. ^{1}H-N.m.r. ($CDCl_3$) data: δ 3.97 (m, 2 H), 3.16 (m, 1 H), and 1.32 (s, 9 H) (Found: C, 51.4; H, 8.8; S, 34.0. $C_{12}H_{24}OS_3$ calc.: C, 51.3; H, 8.6; S, 34.3%).

The mixture (5 g) of **3e**, **7**, and **8** in the mother liquor was partially resolved by column chromatography (30:1 hexane–ether), to give **3e** (0.15 g), and a mixture (4.6 g) of **7** and **8** (Found: C, 51.5; H, 8.4; S, 34.1. $C_{12}H_{24}OS_3$ calc.: C, 51.3; H, 8.6; S, 34.3%). This mixture was partially resolved by column chromatography (100:1 hexane–ether), to give a mixture (3.06 g) of **7** and **8**, and **8** or **7** (1.53 g) as a liquid; ν_{max} 1360, 1260, 1152, 1090, 1038, 970, and 878 cm^{-1}. ^{1}H-N.m.r. ($CDCl_3$) data: δ 4.20–3.41 (m, 3 H) and 1.38 (s, 9 H).

Di-(*tert*-butyl) sulfide[17], obtained from 2-methylpropane-2-thiol and 2-methylpropan-2-ol in acid media (87–88%), had b.p. 148–149°.

(*f*) *With 1,2-ethanedithiol.* Distillation of the crude product gave diglycolaldehyde bis(ethylene dithioacetal) (**2f**; 11.2 g, 77.4%), b.p. 155–162°/0.1 mmHg, m.p. 58–59° (from ether); ν_{max} 1420, 1276, 1150, 1097, 996, 972, and 850 cm^{-1}. ^{1}H-N.m.r. ($CDCl_3$) data: δ 4.51 (t, 1 H, *J* 7 Hz), 3.52 (d, 2 H, *J* 7 Hz), and 3.12 (s, 4 H) (Found: C, 37.9; H, 5.6; S, 50.1. $C_8H_{14}OS_4$ calc.: C, 37.7; H, 5.5; S, 50.4%).

Solutions of **2b**, **2d**, or **2e** in concentrated hydrochloric acid were stirred, basified with aqueous 50% KOH, and extracted with ether (2 × 50 ml), and the combined extracts were dried, filtered, and concentrated; the starting material was recovered.

Starting product (g)	*Acid (ml)*	*RSH (ml)*	*Time (h)*	*Yield (%)*[a]
2b (1.30)	1	—	14	57
2b (1.15)	1	EtSH (0.4)	24	87
2d (1.90)	5	—	24	86
2d (2.00)	5	Pr^iSH (6.0)	15	100
2e (0.46)	1.5	—	48	30.4[b]
2e (0.50)	1	Bu^tSH (2.0)	20	96

[a]Yields of recovered starting-material. [b]Compounds **3e** (0.07 g) and a mixture (0.1 g) of **7** and **8** were also isolated by column chromatography.

Reactions between **5,6** and **7,8** *with thiols in acid media.* (*a*) A mixture of **5b,6b** (0.22 g), ethanethiol (1.2 ml), and concentrated hydrochloric acid (1 ml) was stirred for 30 min, basified, and extracted with ether. The crude product (0.203 g) contained (t.l.c., 10:1 hexane–ether) mainly **5b,6b**, but traces of **2b**.

(*b*) A mixture of **5d**,**6d** (0.03 g), 2-propanethiol (1 ml), and concentrated hydrochloric acid (1 ml) was stirred for 75 min. The crude product contained (t.l.c., 9 : 1 hexane–ether) **5d**,**6d** together with small proportions of **3d**, **2d**, and **4d**. All of the products were identified by comparisons with authentic specimens.

(*c*) A mixture of **7**,**8** (0.2 g), 2-methylpropane-2-thiol (1 ml), and concentrated hydrochloric acid (1 ml) was stirred for 2 h, basified, and extracted with ether, to give crude **7**,**8** (~100%).

Reactions of diglycolaldehyde bis(dialkyl acetals) (**9a–d**) *and 2,6-di-isopropoxy-1,4-dioxane* (**10**) *with thiols in anhydrous acid media. — General method.* To a solution of **9a–d** or **10** in the thiol was added the acid. The mixture was stirred at room temperature and the crude product was isolated by extraction with ether. The following results were obtained.

Starting compound (g)	*RSH (ml)*	*Time (h)*	*Acid (g)*	*Products*[a] *(g)*
9a (5)	EtSH (15)	24	H_2SO_4 (1)	**2b** (6.7, 83%)
9b (7.5)	EtSH (100)	24	H_2SO_4 (1)	**2b** (8.1, 89.5%)
9c (11)	EtSH (35)	24	H_2SO_4 (1)	**2b** (9, 78.3%)
9d (1.54)	EtSH (10)	24	H_2SO_4 (0.5)	**2b** (1.16, 73.4%)
9a (5)	Bu^{t}SH (20)	336	1.5 ml[b]	**7**,**8** (3.32, 46.1%)
				2e (3.40, 31%)
10 (3.4)	EtSH (50)	24	H_2SO_4 (1)	**2b** (3.9, 74.5%)[c]
10 (3)	EtSH (5)	336	1.5 ml[b]	**2b** (3.2, 69.3%)[d]
10 (3)	Bu^{t}SH (18)	336	1.5 ml[b]	**7**,**8** (3.2, 77.7%)
				2e (0.85, 13.6%)

[a]Identified by comparisons with authentic specimens. [b]$BF_3 \cdot (Et_2O)_2$ was used. [c]When the acetal–thiol molar ratio was 1 : 2, the yield of **2b** was 29.7%. [d]When the acetal–thiol molar ratio was 1 : 2, the yield of **2b** was 37.0%, and 20% of **10** was recovered.

Oxidation of cis- *and* trans-*3,5-bis*(tert-*butylthio*)-*1,4-oxathiane* (**7** *and* **8**). — A solution of the stereoisomer (0.95 g), m.p. 67–68°, in acetic anhydride (5 ml) and acetic acid (14 ml) was cooled in an ice-bath, aqueous 30% H_2O_2 (8 ml) was added, and the mixture was stored in the refrigerator for 1 day and then at room temperature for 7 days. Chloroform (75 ml) was added and the solution was washed with saturated, aqueous $NaHCO_3$ (3 × 25 ml) and water (25 ml), dried, filtered, and concentrated to dryness. Recrystallisation of the residue from ethanol (10 ml) gave *cis*-3,5-bis(*tert*-butylsulfonyl)-1,4-oxathiane 4-oxide (**24**; 0.854 g, 70%), m.p. 204–205° with softening at 196–198°; ν_{max} 1300, 1115, 1070, 1052, and 902 cm^{-1}. ^{1}H-N.m.r. ($CDCl_3$) data: δ 5.05 (dd, 1 H, *J* 9.7 and 4.7 Hz), 4.3 (m, 2 H), and 1.4 (s, 9 H) (Found: C, 40.0; H, 6.4. $C_{12}H_{24}O_6S_3$ calc.: C, 40.0; H, 6.7%).

Treatment of the liquid stereoisomer in the same way gave **24** (76.9%).

To a solution of **24** (0.22 g) in acetic anhydride (2 ml) and acetic acid (4 ml) was added aqueous 30% H_2O_2 (3 ml), and the mixture was left at room temperature for 18 days. The product was isolated as described above, purified by column chro-

matography (ether), and recrystallised from ethanol, to give *cis*-3,5-bis(*tert*-butylsulfonyl)-1,4-oxathiane 4,4-dioxide (**25**; 0.11 g, 47.9%), m.p. 132–134°; ν_{max} 1353, 1313, 1295, 1172, 1150, 1112, and 772 cm^{-1}. ^{1}H-N.m.r. ($CDCl_3$) data: δ 4.9 (m, 1 H), 4.4 (m, 2 H), and 1.4 (s, 9 H) (Found: C, 38.5; H, 6.6, $C_{12}H_{24}O_7S_3$ calc.: C, 38.3; H, 6.4%).

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