Thio-sugars. Part VI.[1] Syntheses of Episulphides by Reaction of Methyl 2,3- and 3,4-Anhydroglycopyranosides with Potassium Thiocyanate or Thiourea

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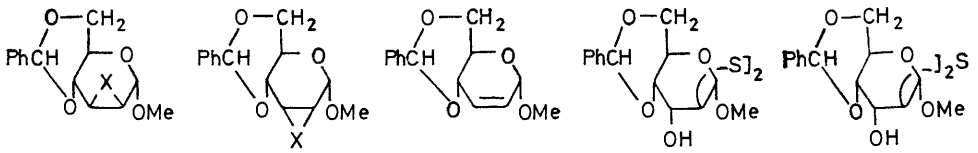
Episulphides, in which the thiiran ring is of opposite configuration to that of the epoxide, have been prepared by reaction of potassium thiocyanate or thiourea with methyl 2,3-anhydro-4,6-*O*-benzylidene-α-D-taloside, -β-D-taloside, -α-D-guloside, and -β-D-guloside, methyl 2,3-anhydro-4,6-di-*O*-methyl-α-D-alloside and -mannoside, methyl 3,4-anhydro-6-deoxy-α-L-taloside, and methyl 3,4-anhydro-6-deoxy-2-*O*-methyl-α-L-taloside. Some of the episulphides were obtained in high yield, but other products, including unsaturated glycosides (shown to be formed from episulphides), were also identified, and predominated in the reactions of the β-D-glycosides. Prolonged treatment of several of the episulphides with potassium thiocyanate resulted in partial stereomutation of the thiiran ring, whilst prolonged treatment with thiourea led to desulphurisation. Considerable differences in the reactivities of the epoxides, and of the episulphides, are explained by steric and conformational effects.

The ^{1}H n.m.r. parameters for the epoxides and episulphides are tabulated.

THE direct conversion of aliphatic or alicyclic epoxides into episulphides by treatment with thiocyanate salts or thiourea is well known,[2,3] but attempts to effect similar reactions with sugar epoxides have usually been disappointing, and multi-stage processes have been used instead;[4,5] the direct method appears to have been satisfactory only when the epoxide is external to the sugar ring.[6] Guthrie and Murphy [7] obtained small yields of the epithio-alloside (4) by reaction of methyl 2,3-anhydro-4,6-*O*-benzylidene-α-D-mannoside (1) with thiocyanate or thiourea, but reaction of the *allo*-epoxide (3) with thiourea was said to give the epithio-mannoside (2) (63%) together with methyl 4,6-*O*-benzylidene-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (5). It was subsequently shown, however,[8] that the supposed episulphide (2) is 2,2′-dithiobis(methyl 4,6-*O*-benzylidene-2-deoxy-α-D-altroside) (6), from which the genuine episulphide (2) can be obtained almost quantitatively by conversion into the methanesulphonate, followed by reduction with borohydride. The Japanese workers [8] also obtained the episulphide (2) in very low yield by reaction of the *allo*-epoxide (3) with ammonium thiocyanate; with potassium thiocyanate the epoxide gave mainly the monosulphide (7). Guthrie and Murphy's deduction (from the stability of their supposed *manno*-episulphide towards thiourea), that the unsaturated product (5) was not formed through an episulphide, is thus unsubstantiated.



Although criticism has been expressed [7] of the view [4] that the difficulty in effecting the direct conversion of an epoxide such as (1) into an episulphide is a consequence of the rigidity imposed on the pyranose ring by the presence of the benzylidene group, conformational

[1] Part V, J. M. Heap and L. N. Owen, *J. Chem. Soc.* (*C*), 1970, 712.

[2] C. C. J. Culvenor, W. Davies, and K. H. Pausacker, *J. Chem. Soc.*, 1946, 1050; C. C. J. Culvenor, W. Davies, and N. S. Heath, *ibid.*, 1949, 278; F. G. Bordwell and H. M. Andersen, *J. Amer. Chem. Soc.*, 1953, **75**, 4959; L. Goodman and B. R. Baker, *ibid.*, 1959, **81**, 4924.

[3] M. G. Ettlinger, *J. Amer. Chem. Soc.*, 1950, **72**, 4792; E. E. van Tamelen, *ibid.*, 1951, **73**, 3444; C. C. Price and P. F. Kirk, *ibid.*, 1953, **75**, 2396.

[4] J. E. Christensen and L. Goodman, *J. Amer. Chem. Soc.*, 1961, **83**, 3827.

[5] L. Goodman, *Chem. Comm.*, 1968, 219; K. J. Ryan, E. M. Acton, and L. Goodman, *J. Org. Chem.*, 1968, **33**, 3727.

[6] L. D. Hall, L. Hough, and R. A. Pritchard, *J. Chem. Soc.*, 1961, 1537; U. G. Nayak and R. L. Whistler, *J. Org. Chem.*, 1969, **34**, 97.

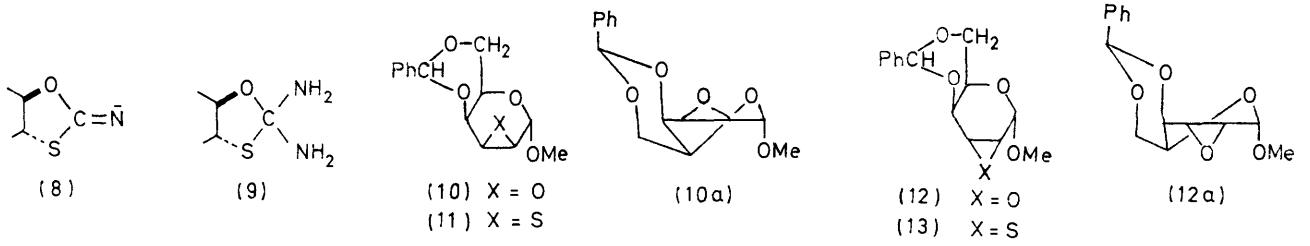
[7] R. D. Guthrie and D. Murphy, *J. Chem. Soc.*, 1965, 6666.

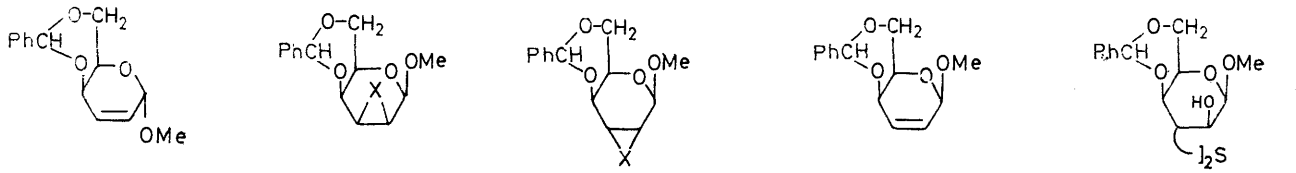
[8] M. Kojima, M. Watanabe, and T. Taguchi, *Tetrahedron Letters*, 1968, 839.

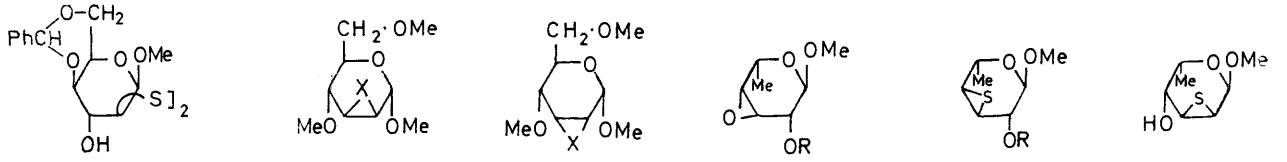
mobility, whilst not completely inhibited, is certainly severely restricted in this carbohydrate analogue of *trans*-decalin, and this could hinder the formation of the *trans*-fused five-membered ring in the necessary intermediate of type (8) (from thiocyanate) [3] or type (9) (from thiourea).[9] If the configuration at C-4 is inverted, the system becomes analogous to the much more flexible *cis*-decalin, and we have therefore studied the reactivity, towards thiocyanate and thiourea, of 2,3-epoxides containing a *cis*-fused 4,6-*O*-benzylidene ring, in the expectation that episulphides would be formed more readily than from the 2,3-epoxides (1) and (3).

gulo-epoxide (12) reacted slowly to give methyl 4,6-*O*-benzylidene-2,3-dideoxy-α-D-*threo*-hex-2-enopyranoside (14) (42%), a similar quantity of epoxide being recovered; no episulphide was detected.

The β-glycosides corresponding to the epoxides (10) and (12) reacted less smoothly. The *talo*-compound (15) with thiocyanate gave the *gulo*-episulphide (18) (33%), methyl 4,6-*O*-benzylidene-2,3-dideoxy-β-D-*threo*-hex-2-enopyranoside (19) (20%), and 3,3′-thiobis(methyl 4,6-*O*-benzylidene-3-deoxy-β-D-idoside) (20) (40%); with thiourea, the same products were obtained in yields of 9, 22, and 25%, respectively. When the reaction with





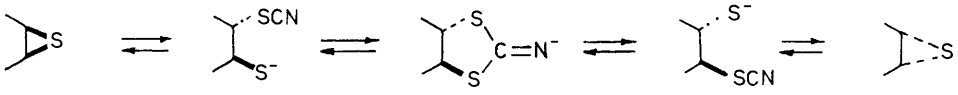


Reaction of methyl 2,3-anhydro-4,6-*O*-benzylidene-α-D-taloside (10) with potassium thiocyanate gave, in 89% yield, the *gulo*-episulphide (13); when thiourea was used the yield was only 12% (or 40%, allowing for recovered epoxide). Methyl 2,3-anhydro-4,6-*O*-benzylidene-α-D-guloside (12), although requiring a longer reaction time, with thiocyanate gave the *talo*-episulphide (11) (74%), and, surprisingly, the *gulo*-episulphide (13) (20%); the formation of the latter is discussed later. In the preferred $^{O}H_{5}$ conformations, rear approach of the nucleophile to open the oxiran ring is more hindered in the *gulo*- (12a) than in the *talo*-epoxide (10a), thus accounting for the difference in reactivity. With thiourea, the thiocyanate was prolonged, no episulphide was isolated and the yield of the unsaturated product (19) rose to 50%, clearly demonstrating that the latter compound is derived from the episulphide. The *gulo*-epoxide (17) with thiocyanate also gave compound (19) (9%), together with 2,2′-dithiobis(methyl 4,6-*O*-benzylidene-2-deoxy-β-D-idoside) (21) (31%), but, in remarkable contrast, with thiourea this epoxide gave 59% of the *talo*-episulphide (16) with 17% of the unsaturated glycoside (19); the reason why the use of thiourea is more effective in this instance than with the other epoxides is probably that the desired product (16) is particularly resistant to further attack by this reagent (see below).

In their ring-opening reactions with nucleophiles, the epoxides (15) and (17) normally give products which are formed from the $^{O}H_{5}$ conformation by diaxial fission,[10]

[9] C. C. J. Culvenor, W. Davies, and W. E. Savige, *J. Chem. Soc.*, 1952, 4480.
[10] N. R. Williams, *Adv. Carbohydrate Chem.*, 1970, **25**, 109.

and the constitutions of the monosulphide (20) and the disulphide (21) are assigned on this basis. Diaxial opening by thiocyanate ion would give the 3-thiocyanato-idoside from (15) and the 2-thiocyanato-idoside from (17), both in the $^4C_1$ conformation, which must change to enable the cyclic intermediate [*cf.* (8)] to be formed. The hydroxy- and thiocyanato-groups could become diequatorial by a change to the $^1C_4$ conformation, but this is unlikely because it would result in C-6 and the phenyl group becoming axial. The $^4C_1$ conformation could, however, change to a boat ($B_{2,5}$), which would permit cyclisation, but such a change in the β-series (not in the α-series) involves a passing interaction between the methoxy-group and the substituent at C-2; with the β-glycosides, therefore, solvolysis to the hydroxy-thiol competes significantly with the formation of the cyclic intermediate necessary for production of the episulphide.



SCHEME

The monosulphide (20) is then derived by further reaction of the 3-mercapto-compound with the epoxide (15), whilst the more hindered 2-mercapto-compound fails to attack the more hindered epoxide (17) and merely undergoes aerial oxidation to give the disulphide (21).

As examples of systems in which no acetal bridge is present, methyl 2,3-anhydro-4,6-di-*O*-methyl-α-D-alloside (24), methyl 2,3-anhydro-4,6-di-*O*-methyl-α-D-mannoside (22), methyl 3,4-anhydro-6-deoxy-α-L-taloside (26), and methyl 3,4-anhydro-6-deoxy-2-*O*-methyl-α-L-taloside (27) were treated with potassium thiocyanate. The episulphides (23), (25), (28), and (29) were isolated in yields of 46, 35, 22, and 15%, respectively, no other products being identified. Yields of 16 and 35%, respectively, of the episulphides (23) and (25) were obtained when thiourea was used instead of thiocyanate.

The structure of the episulphide (28), unlike those of the other three, is not self-evident, because if thiocyanate ion attacked the epoxide (26) at C-3 the thiocyanato-group would be *trans* with respect to the hydroxy-functions at both C-2 and C-4. The cyclic intermediate, and consequently the episulphide, could therefore be a 2,3-compound. That this was not so was shown by the ^{1}H n.m.r. spectrum of the episulphide. A two-proton multiplet at τ 5·9—6·3 was assigned to H-2 and H-5, because INDOR and spin-decoupling techniques established coupling to the anomeric proton (doublet at τ 5·54) and to the methyl protons (doublet at τ 8·52); this multiplet also showed coupling to the hydroxy-proton, which therefore is at C-2. The relative magnitudes of $J_{2,3}$ (2·5) and $J_{3,4}$ (7·0 Hz) also support the formulation as the 3,4-*altro*-episulphide (28) rather than the 2,3-*gulo*-isomer (30). Another product, which could not be purified, was obtained from the reaction of the epoxide (26); this may have been the 2,3-episulphide (30), because evidence is presented in the following paper that both a 2,3- and a 3,4-trithiocarbonate are formed by reaction of this epoxide with sodium methyl xanthate.

Lightner and Djerassi [11] observed that steroid episulphides, prepared from epoxides by reaction with thiocyanate, were sometimes contaminated with epimers, and 2α,3α-epoxy-9β-methyl-*trans*-decalin was reported to give a 4 : 1 mixture of the 2β,3β- and the 2α,3α-episulphide. They suggested that the isomerisation occurred by interaction of the first-formed episulphide with thiocyanate ion, implying the operation of the illustrated mechanism (see Scheme). Jankowski and Harvey,[12] who did not mention this earlier work, have recently shown that some cyclohexane episulphides can be isomerised by heating with thiocyanate. We accordingly studied the effect of treating the various sugar episulphides with thiocyanate or thiourea for longer times than had been used in their preparation. In the description which follows, total recoveries of chromatographically separated materials were generally *ca.* 95%, including original episulphide (which accounted for almost all the balance of the yields of transformation products quoted).

The α-*talo*-episulphide (11), after reaction with potassium thiocyanate in boiling aqueous ethanol for 3 days, was partly converted into the *gulo*-isomer (13) (38%), thus explaining the isolation of the two episulphides (11) and (13) from the reaction of the epoxide (12). With thiourea, under similar conditions, the episulphide (11) was totally destroyed in 24 h; no isomer was detected, but a 97% yield of the olefinic product (14) was isolated, in complete accord with the reaction of the epoxide (12) with thiourea. There is therefore no doubt that the unsaturated glycosides encountered by ourselves, and by others [7,8] are derived by desulphurisation of an intermediate episulphide. The formation of olefins by nucleophilic attack on the sulphur atom of a thiiran ring has been effected by a variety of reagents, including trivalent phosphorus compounds,[4,13,14] alkyl- or aryl-lithium,[14,15] sodium toluene-α-thiolate,[16] and sodium alkyl xanthates.[8,17]

Prolonged reaction of the α-*gulo*-episulphide (13) with thiocyanate gave 6% of the isomer (11) (attack at C-2

[11] D. A. Lightner and C. Djerassi, *Tetrahedron*, 1965, **21**, 583.
[12] K. Jankowski and R. Harvey, *Canad. J. Chem.*, 1972, **50**, 3930.
[13] R. E. Davis, *J. Org. Chem.*, 1958, **23**, 1767; R. D. Schuetz and R. L. Jacobs, *ibid.*, p. 1799; 1961, **26**, 3467; D. B. Denney and M. J. Boskin, *J. Amer. Chem. Soc.*, 1960, **82**, 4736.
[14] N. P. Neureiter and F. G. Bordwell, *J. Amer. Chem. Soc.*, 1959, **81**, 578.
[15] F. G. Bordwell, H. M. Andersen, and B. M. Pitt, *J. Amer. Chem. Soc.*, 1954, **76**, 1082; M. Morton and R. F. Kammereck, *ibid.*, 1970, **92**, 3217.
[16] J. F. McGhie, W. A. Ross, F. J. Julietti, B. E. Grimwood, G. Usher, and N. M. Waldron, *Chem. and Ind.*, 1962, 1980.
[17] J. F. McGhie, W. A. Ross, F. J. Julietti, G. Swift, G. Usher, N. M. Waldron, and B. E. Grimwood, *Chem. and Ind.*, 1964, 460.

in the original episulphide is hindered) and 20% of the olefinic glycoside (14), whilst with thiourea the sole transformation product was again this olefin (79%).

The corresponding β-glycosides showed interesting differences from their α-counterparts. The *talo*-episulphide (16) with thiocyanate gave the *gulo*-compound (18) (20%) with some olefin (19) (6%), but although thiourea again gave no isomer, but only olefin, the conversion was merely 15%, perhaps because attack on the sulphur atom in the episulphide (16) is more hindered than in the α-isomer (11). On the other hand, the *gulo*-episulphide (18), in which attack on carbon is hindered, on treatment with thiocyanate gave no isomer, but only the olefin (19) (20%), whilst thiourea likewise gave only the olefin, but the conversion was 89%, attack on the sulphur atom now being subject to minimal steric hindrance. A striking feature, noted with all four episulphides, is that thiourea is a much more effective desulphurising agent than thiocyanate, and consequently is best avoided in the preparation of an episulphide unless the latter is protected by steric hindrance against attack on the sulphur atom.

Interconversion of the 4,6-di-*O*-methyl compounds (23) and (25) with potassium thiocyanate was also demonstrated, the *allo*-episulphide yielding 20% of the *manno*-compound, whilst the latter was isomerised under the same conditions to the extent of 8%.

Studies of the ^{1}H n.m.r. spectra of several 2,3-epoxy-sugars [18-20] and of the 2,3-episulphide (4) [18] have shown that the coupling constants between the epoxide-ring (or epithio-ring) protons and their neighbours at C-1 and C-4 are very small (<1 Hz; often zero) when the relationship is *trans*, and rather small (1·5—5·5 Hz) when the relationship is *cis*. Parameters for H-1 and $J_{1,2}$ for the 2,3-epoxides and 2,3-episulphides prepared in the present work are shown in the Table. Data for compounds (10), (11), (17), (18), (22), and (23), in which H-1 and H-2 are *trans*, and compounds (12), (13), (16), (24), and (25), in which H-1 and H-2 are *cis*, agree with this generalisation, as also do the values of $J_{3,4}$ for compounds (18), (23), and (25) (the only three of these eleven for which this coupling could be measured). The zero value for the *cis*-1,2-coupling in the 2,3-anhydro-β-taloside (15) is clearly anomalous, but it may be significant that the corresponding 2,3-episulphide (16) shows an appreciably smaller *cis*-1,2-coupling than those observed for the episulphides (13) and (25).

^{1}H N.m.r. data on 3,4-epoxides are sparse, but in the few examples where $J_{2,3}$ and $J_{4,5}$ have been measurable [19] the values accord with the generalisation for $J_{1,2}$ and $J_{3,4}$ in 2,3-epoxides. However, the two 3,4-episulphides (28) and (29) showed $J_{2,3}$ 2·5 and 3·5 Hz, respectively, and $J_{4,5}$ 4·0 and 6·0 Hz, respectively, though both couplings are *trans*.

In deuteriochloroform, the resonance for H-1 in the 2,3-epithio-α-D-alloside (25) appeared as a triplet, presumably because of virtual coupling between this proton and the thiiran protons, as reported for the spectrum of methyl 4,6-*O*-benzylidene-2,3-dideoxy-2,3-epithio-α-D-alloside,[18] but in hexadeuteriobenzene the expected doublet was observed. The value for $J_{4,5}$ (9·0 Hz) for compound (25) is consistent with the $^{O}H_5$ conformation, which indeed would be expected for all the 2,3-epoxides and 2,3-episulphides of the α-configuration. The same conformation is likely to be preferred also for the β-glycosides (15)—(18), in spite of the unfavourable anomeric effect, because the alternative $^{5}H_{O}$ conformation would result in axial orientations for both C-6 and the benzylidene phenyl group.[10] For the 3,4-epoxides and episulphides (26)—(29), the $^{L}{}^{1}H_{O}$ conformation is sterically favoured; furthermore, the alternative $^{L}{}^{O}H_{1}$ conformation, with a diaxial relationship between H-1 and H-2, could not be reconciled with the values of $J_{1,2}$.

^{1}H N.m.r. parameters for solutions in $CDCl_3$ (τ values; J in Hz)

Compound	H-1	H-2	H-3	$J_{1,2}$	$J_{2,3}$	$J_{3,4}$
(10)	4·90 (s)	6·88 (d)	6·4 (m)	0·0	3·5	
(11)	4·83 (s)	6·95 (d)		0·0	6·0	
(12)	4·88 (d)	6·55 (m)		2·5		
(13)	4·68 (d)	6·65 (m)		3·2		
(15)	5·29 (s)	6·8 (m)		0·0		
(16)	5·11 (d)	6·8 (m)		2·0	6·0	
(17)	5·20 (s)	6·7 (m)		0·0		
(18)	5·00 (d)	6·77 (q)		0·3	6·5	0·5
(22)	5·10 (s)	6·81 (q)		0·0		
(23)	5·02 (s)	6·94 (q)		0·0	6·8	0·0
(24)	5·07 (d)			2·0		
(25) [a]	5·25 (d)	7·0 (m) [b]		4·4		3·2
(26)	5·54 (s)			0·0		
(27)	5·50 (d)			1·0		
(28)	5·54 (d)	6·1 (m) [c]		5·0	2·5	7·0
(29) [a]	5·45 (d)	6·52 (q)	7·24 (q) [d]	5·0	3·5	7·0

[a] In C_6D_6. [b] Also 6·42 (q, H-4), 6·06 (m, H-5), 6·56 (m, H-6); $J_{4,5}$ 9·0, $J_{5,6}$ 3·0, $J_{5,6'}$ 4·0. [c] Also 7·05 (m, H-3 and H-4), 6·1 (m, H-5), 8·52 (d, H-6); $J_{4,5}$ 4·0, $J_{5,6}$ 7·0. [d] Also 7·44 (q, H-4), 6·42 (m, H-5), 8·85 (d, H-6); $J_{4,5}$ 6·0, $J_{5,6}$ 6·0.

Further evidence for the constitutions of the new episulphides is provided by their conversion into the trithiocarbonates described in the following paper.

EXPERIMENTAL

^{1}H N.m.r. spectra were recorded for solutions in deuteriochloroform (unless otherwise stated) on Varian A-60 or HA-100 instruments, and the important parameters are given in the Table; resonances for aromatic, benzylic, *O*-methyl protons, *etc.*, were in accord with the constitutions of the compounds. I.r. spectra were recorded for all products, and were used to assist in identifications and comparisons, but the absorptions, which were unexceptional, are not given. Optical rotations were measured, for solutions in chloroform, with a Perkin-Elmer 141 polarimeter. Kieselgel GF_{254} (Merck) was used for t.l.c., and silica M.F.C. (Hopkin and Williams) for column chromatography. Extracts were dried over magnesium sulphate, and solvents were removed under reduced pressure below 50°. Petroleum refers to the fraction of b.p. 40—60°.

Methyl 2,3-Anhydro-4,6-di-O-methyl-α-D-mannoside.— A solution of methyl 2,3-anhydro-4,6-*O*-benzylidene-α-D-man-

[18] D. H. Buss, L. Hough, L. D. Hall, and J. F. Manville, *Tetrahedron*, 1965, **21**, 69; *cf.* F. Sweet and R. K. Brown, *Canad. J. Chem.*, 1968, **46**, 1481.

[19] J. G. Buchanan, R. Fletcher, K. Parry, and W. A. Thomas, *J. Chem. Soc.* (*B*), 1969, 377.

[20] R. J. Ferrier and N. Prasad, *J. Chem. Soc.* (*C*), 1969, 575; L. Hough, P. A. Munroe, and A. C. Richardson, *ibid.*, 1971, 1090.

noside [21] (3·4 g) and oxalic acid (10 g) in acetone (325 ml) and water (40 ml) was boiled under reflux for 16 h, and then neutralised with barium carbonate. The salts were filtered off and washed with acetone, and the combined filtrate and washings were evaporated to remove the acetone. The aqueous residue was extracted once with ether to remove benzaldehyde, and it was then evaporated to dryness. Extraction of the residue with acetone gave an oil (2·1 g) which was methylated four times with methyl iodide–silver oxide. Distillation of the product gave the *4,6-di-O-methyl compound* (1·7 g), b.p. 51—52° at 10^{-3} mmHg, $[\alpha]_D^{23}$ +142° (*c* 1·6), τ 5·1 (1H, s, H-1) (Found: C, 52·75; H, 7·7. $C_9H_{16}O_5$ requires C, 52·9; H, 7·9%).

Methyl 2,3-Anhydro-4,6-O-benzylidene-α-D-guloside and -taloside.—The mixture of epoxides, prepared by Reichstein's method,[22-24] was separated by preparative t.l.c. (chloroform). The *gulo*-epoxide had m.p. 175—176° (lit.,[22] 178—179°; lit.,[24] 174—175°), and the *talo*-epoxide, m.p. 231—237° (lit.,[22] 241—242°).

Reactions of Epoxides.—Except where further details are given, the proportions of reagents, and the reaction conditions, were based on the following general methods.

(i) A solution of the epoxide (1 mmol) and potassium thiocyanate (0·5 g) in ethanol (*ca.* 25 ml for the 4,6-*O*-benzylidene compounds; *ca.* 10 ml for the 4,6-di-*O*-methyl compounds) and water (2—3 ml) was boiled gently under reflux for the period specified, then cooled, diluted with water, and extracted with chloroform. The product isolated from these extracts was purified by preparative t.l.c. (chloroform, unless otherwise specified).

(ii) A solution of the epoxide (1 mmol) and thiourea (0·4 g) in ethanol (*ca.* 30 ml for the 4,6-*O*-benzylidene compounds; *ca.* 10 ml for the 4,6-di-*O*-methyl compounds) was boiled under reflux, and worked up as described above.

With potassium thiocyanate. (*a*) Methyl 2,3-anhydro-4,6-*O*-benzylidene-α-D-taloside (210 mg) after 30 h gave *methyl 4,6-O-benzylidene-2,3-dideoxy-2,3-epithio-α-D-guloside* (13) (198 mg), m.p. 114—115° (from ether–petroleum), $[\alpha]_D^{22}$ +23·2° (*c* 0·8) (Found: C, 59·8; H, 6·0; S, 11·6. $C_{14}H_{16}O_4S$ requires C, 60·0; H, 5·75; S, 11·4%).

(*b*) Methyl 2,3-anhydro-4,6-*O*-benzylidene-α-D-guloside (120 mg) after 170 h gave *methyl 4,6-O-benzylidene-2,3-dideoxy-2,3-epithio-α-D-taloside* (11) (94 mg), m.p. 170—173° (from chloroform–ether), $[\alpha]_D^{21}$ −56·3° (*c* 0·5) (Found: C, 60·3; H, 5·8; S, 11·3%), and the isomeric *gulo*-episulphide (25 mg), m.p. and mixed m.p. 110—113°.

(*c*) Methyl 2,3-anhydro-4,6-*O*-benzylidene-β-D-taloside [22] (100 mg), potassium thiocyanate (200 mg), ethanol (5 ml), and water (1 ml) after 18 h gave *methyl 4,6-O-benzylidene-2,3-dideoxy-2,3-epithio-β-D-guloside* (18) (35 mg), m.p. 115—116° (from ether), $[\alpha]_D^{22}$ −72·0° (*c* 0·2) (Found: C, 60·1; H, 5·2; S, 11·3%), methyl 4,6-*O*-benzylidene-2,3-dideoxy-β-D-*threo*-hex-2-enopyranoside (19 mg), m.p. 124—127° (from chloroform–ether), $[\alpha]_D^{22}$ −168° (*c* 0·8) (lit.,[25] m.p. 122—123°, $[\alpha]_D^{25}$ −172°), and *3,3'-thiobis(methyl 4,6-O-benzylidene-3-deoxy-β-D-idoside)* (20) (42 mg), m.p. 139—141° (from chloroform–ether), $[\alpha]_D^{22}$ −50·4° (*c* 0·8) (Found: M^+, 562. $C_{28}H_{34}O_{10}S$ requires *M*, 562), which with acetic anhydride–pyridine gave the *bis-2-O-acetate*, m.p. 258—263°, $[\alpha]_D$ +11·2° (*c* 0·25) (Found: C, 59·2; H, 5·9; S, 5·0. $C_{32}H_{38}O_{12}S$ requires C, 59·4; H, 5·9; S, 4·95%). The ^1H n.m.r. spectrum of the hexenoside agreed with that reported.[25]

(*d*) Methyl 2,3-anhydro-4,6-*O*-benzylidene-β-D-guloside [22] (120 mg) after 3 days gave unchanged epoxide (8 mg), methyl 4,6-*O*-benzylidene-2,3-dideoxy-β-D-*threo*-hex-2-enoside (10 mg), and *2,2'-dithiobis(methyl 4,6-O-benzylidene-2-deoxy-β-D-idoside)* (21) (39 mg), m.p. 200—202° (from chloroform–ether), $[\alpha]_D^{23}$ +46·8° (*c* 0·4) (Found: C, 56·9; H, 5·2; S, 11·0. $C_{28}H_{34}O_{10}S_2$ requires C, 56·55; H, 5·7; S, 10·8%).

(*e*) Methyl 2,3-anhydro-4,6-di-*O*-methyl-α-D-alloside [26] (220 mg) after 12 h gave (t.l.c. in ether) *methyl 2,3-dideoxy-2,3-epithio-4,6-di-O-methyl-α-D-mannoside* (23) (111 mg), b.p. 70° at 10^{-5} mmHg, $[\alpha]_D^{23}$ +126° (*c* 0·9) (Found: C, 48·9; H, 7·25; S, 14·85. $C_9H_{16}O_4S$ requires C, 49·1; H, 7·3; S, 14·55%).

(*f*) Methyl 2,3-anhydro-4,6-di-*O*-methyl-α-D-mannoside (250 mg) after 18 h gave a crude product which was directly crystallised from petroleum to give *methyl 2,3-dideoxy-2,3-epithio-4,6-di-O-methyl-α-D-alloside* (25) (95 mg), m.p. 52—55°, $[\alpha]_D^{25}$ +249° (*c* 0·6) (Found: C, 48·9; H, 7·2; S, 14·55%).

(*g*) Methyl 3,4-anhydro-6-deoxy-α-L-taloside [27] (539 mg), potassium thiocyanate (720 mg), ethanol (15 ml), and water (10 ml) were stirred together at 80° for 16 h. Dilution with water and extraction with ether gave a crude product which was purified by column chromatography (ether) to give *methyl 3,4,6-trideoxy-3,4-epithio-α-L-altroside* (28) (130 mg), m.p. 62—72° (solidified oil) $[\alpha]_D^{23}$ −97° (*c* 0·3) (Found: C, 47·9; H, 6·8; S, 18·1. $C_7H_{12}O_3S$ requires C, 47·7; H, 6·9; S, 18·2%).

(*h*) Methyl 3,4-anhydro-6-deoxy-2-*O*-methyl-α-L-taloside [28] (250 mg), potassium thiocyanate (310 mg), ethanol (15 ml), and water (5 ml) after 18 h gave *methyl 3,4,6-trideoxy-3,4-epithio-2-O-methyl-α-L-altroside* (29) (40 mg), m.p. 30°, $[\alpha]_D^{25}$ −91° (*c* 0·6) (Found: C, 50·4; H, 7·2; S, 16·6. $C_8H_{14}O_3S$ requires C, 50·5; H, 7·4; S, 16·85%).

With thiourea. (*a*) Methyl 2,3-anhydro-4,6-*O*-benzylidene-α-D-taloside (120 mg) after 23 h gave unchanged epoxide (83 mg) and methyl 4,6-O-benzylidene-2,3-dideoxy-2,3-epithio-α-D-guloside (13) (16 mg), m.p. and mixed m.p. 113—115°.

(*b*) Methyl 2,3-anhydro-4,6-*O*-benzylidene-α-D-guloside (100 mg) after 42 h gave (t.l.c. with ether–chloroform) unchanged epoxide (42 mg) and methyl 4,6-*O*-benzylidene-2,3-dideoxy-α-D-*threo*-hex-2-enopyranoside (14) (39 mg), m.p. 159—161° (from chloroform–ether), $[\alpha]_D^{21}$ −133° (*c* 0·5) (lit.,[25] m.p. 163—164°, $[\alpha]_D^{25}$ −130°).

(*c*) Methyl 2,3-anhydro-4,6-*O*-benzylidene-β-D-taloside (200 mg) after 48 h gave methyl 4,6-*O*-benzylidene-2,3-dideoxy-2,3-epithio-β-D-guloside (18) (24 mg), methyl 4,6-*O*-benzylidene-2,3-dideoxy-β-D-*threo*-hex-2-enopyranoside (19) (42 mg), 3,3'-thiobis(methyl 4,6-*O*-benzylidene-3-deoxy-β-D-idoside) (20) (75 mg), and unchanged epoxide (36 mg), all identified by comparison (m.p., i.r. spectra, and R_F) with authentic compounds.

(*d*) Methyl 2,3-anhydro-4,6-*O*-benzylidene-β-D-guloside (120 mg) after 48 h gave (t.l.c. with ether) unchanged epoxide (14 mg), methyl 4,6-*O*-benzylidene-2,3-dideoxy-β-D-*threo*-hex-2-enopyranoside (19 mg), and *methyl* 4,6-*O*-*benzylidene*-2,3-*dideoxy*-2,3-*epithio*-β-D-*taloside* (16) (75 mg),

[21] 'Methods in Carbohydrate Chemistry,' eds. R. L. Whistler and M. L. Wolfrom, Academic Press, New York and London, 1963, vol. 2, p. 189.
[22] E. Sorkin and T. Reichstein, *Helv. Chim. Acta*, 1945, **28**, 1.
[23] M. Gyr and T. Reichstein, *Helv. Chim. Acta*, 1945, **28**, 226.
[24] H. Huber and T. Reichstein, *Helv. Chim. Acta*, 1948, **31**, 1645.
[25] R. U. Lemieux, E. Fraga, and K. A. Watanabe, *Canad. J. Chem.*, 1968, **46**, 61.
[26] G. J. Robertson and H. G. Dunlop, *J. Chem. Soc.*, 1938, 472.
[27] J. Jary, K. Čapek, and J. Kováč, *Coll. Czech. Chem. Comm.*, 1963, **28**, 2171.
[28] G. Charalambous and E. E. Percival, *J. Chem. Soc.*, 1954, 2443.

m.p. 221—224° (subl.) (from chloroform–ether), $[\alpha]_D^{20}$ −158° (*c* 0·6) (Found: C, 59·9; H, 5·8; S, 11·2. $C_{14}H_{16}O_4S$ requires C, 60·0; H, 5·75; S, 11·4%).

(*e*) Methyl 2,3-anhydro-4,6-di-*O*-methyl-α-D-alloside (100 mg) after 18 h gave (t.l.c. with ether) methyl 2,3-dideoxy-2,3-epithio-4,6-di-*O*-methyl-α-D-mannoside (17 mg), identical with that obtained by the use of thiocyanate.

(*f*) Methyl 2,3-anhydro-4,6-di-*O*-methyl-α-D-mannoside (265 mg) after 18 h gave methyl 2,3-dideoxy-2,3-epithio-4,6-di-*O*-methyl-α-D-alloside (101 mg), m.p. and mixed m.p. 52—55°.

Reactions of Episulphides.—Except where further details are given, the proportions of reagents and reaction conditions were as follows.

(i) A solution of the episulphide (1 part) and potassium thiocyanate (2 parts, by weight) in ethanol (60 parts) and water (10 parts) was boiled under reflux for 72 h, then cooled, diluted with water, and extracted with chloroform. The product was separated into its components by preparative t.l.c. (ether), and these were identified by comparison with authentic compounds described in the preceding sections.

(ii) A solution of the episulphide (1 part) and thiourea (1·5 parts) in ethanol (100 parts) was boiled under reflux for 24 h, then treated in the same way.

With potassium thiocyanate. (*a*) Methyl 4,6-*O*-benzylidene-2,3-dideoxy-2,3-epithio-α-D-taloside (60 mg) gave methyl 4,6-*O*-benzylidene-2,3-dideoxy-2,3-epithio-α-D-guloside (23 mg) and starting material (34 mg).

(*b*) Methyl 4,6-*O*-benzylidene-2,3-dideoxy-2,3-epithio-α-D-guloside (60 mg) gave methyl 4,6-*O*-benzylidene-2,3-dideoxy-2,3-epithio-α-D-taloside (3·5 mg), methyl 4,6-*O*-benzylidene-2,3-dideoxy-α-D-*threo*-hex-2-enopyranoside (11 mg), and starting material (43 mg).

(*c*) Methyl 4,6-*O*-benzylidene-2,3-dideoxy-2,3-epithio-β-D-taloside (60 mg) gave methyl 4,6-*O*-benzylidene-2,3-dideoxy-2,3-epithio-β-D-guloside (12 mg), methyl 4,6-*O*-benzylidene-2,3-dideoxy-β-D-*threo*-hex-2-enopyranoside (3 mg), and starting material (44 mg).

(*d*) Methyl 4,6-*O*-benzylidene-2,3-dideoxy-2,3-epithio-β-D-guloside (60 mg) gave methyl 4,6-*O*-benzylidene-2,3-dideoxy-β-D-*threo*-hex-2-enopyranoside (11 mg) and starting material (47 mg).

(*e*) Methyl 2,3-dideoxy-2,3-epithio-4,6-di-*O*-methyl-α-D-alloside (112 mg) after 48 h gave methyl 2,3-dideoxy-2,3-epithio-4,6-di-*O*-methyl-α-D-mannoside (23 mg) and starting material (82 mg).

(f) Methyl 2,3-dideoxy-2,3-epithio-4,6-di-*O*-methyl-α-D-mannoside (82 mg) after 48 h gave methyl 2,3-dideoxy-2,3-epithio-4,6-di-*O*-methyl-α-D-alloside (7 mg) and starting material (63 mg).

With thiourea. (*a*) Methyl 4,6-*O*-benzylidene-2,3-dideoxy-2,3-epithio-α-D-taloside (50 mg) gave methyl 4,6-*O*-benzylidene-2,3-dideoxy-α-D-*threo*-hex-2-enopyranoside (43 mg).

(*b*) Methyl 4,6-*O*-benzylidene-2,3-dideoxy-2,3-epithio-α-D-guloside (60 mg) gave the same hex-2-enoside (43 mg) and starting material (9 mg).

(*c*) Methyl 4,6-*O*-benzylidene-2,3-dideoxy-2,3-epithio-β-D-taloside (60 mg) gave methyl 4,6-*O*-benzylidene-2,3-dideoxy-β-D-*threo*-hex-2-enopyranoside (8 mg) and starting material (44 mg).

(*d*) Methyl 4,6-*O*-benzylidene-2,3-dideoxy-2,3-epithio-β-D-guloside (60 mg) gave the same β-D-hex-2-enoside (45 mg).

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