Dithiols. Part 28.[1] Conversion of 1,3-Dithiolan-2-ones, 1,3-Oxathiolan-2-ones, and 1,3-Oxathiolan-2-thiones into 1,3-Dithiolan-2-thiones

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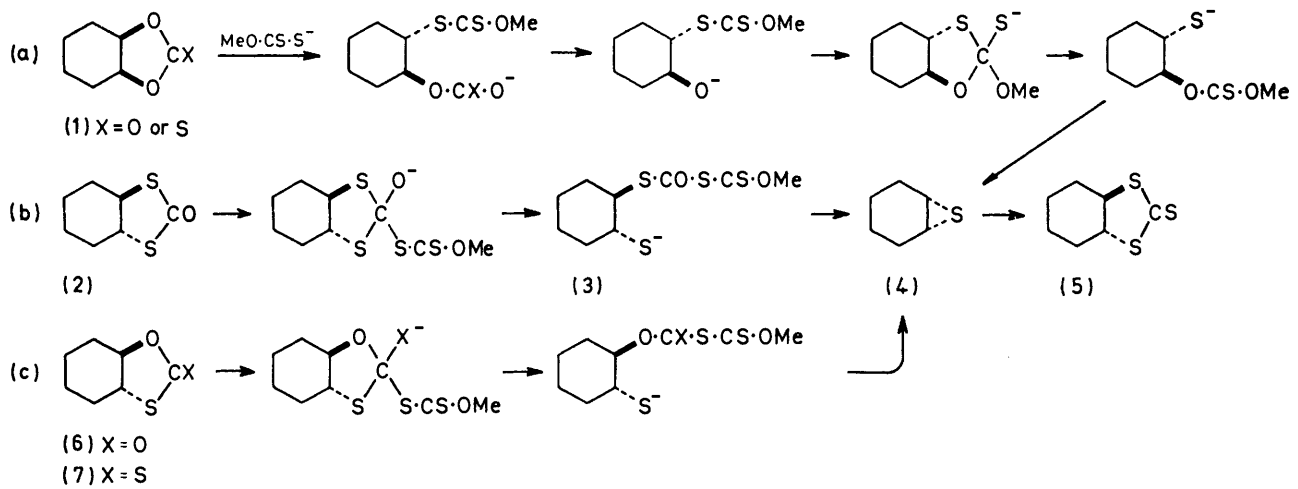
Reaction of *cis*-perhydro-1,3-benzodithiol-2-one with potassium *O*-methyl dithiocarbonate gives *cis*-perhydro-1,3-benzodithiole-2-thione; a mechanism involving cyclohexane-*cis*-1,2-dithiol as an intermediate is proposed. Similar reactions on the *cis*- and on the *trans*-forms of 4,5-dimethyl-1,3-oxathiolan-2-one, 4,5-dimethyl-1,3-oxathiolan-2-thione, 4,5-bis(benzyloxymethyl)-1,3-oxathiolan-2-one, and 4,5-bis(benzyloxymethyl)-1,3-oxathiolan-2-thione likewise give high yields of the corresponding trithiocarbonates with retention of configuration; the suggested mechanism requires attack on the carbonyl or thiocarbonyl group, and the formation of an intermediate episulphide, a proposal supported by the finding that *cis*-perhydro-1,3-benzoxathiole-2-thione, which for steric reasons cannot form an episulphide by such a mechanism, gives no *cis*-perhydro-1,3-benzodithiole-2-thione.

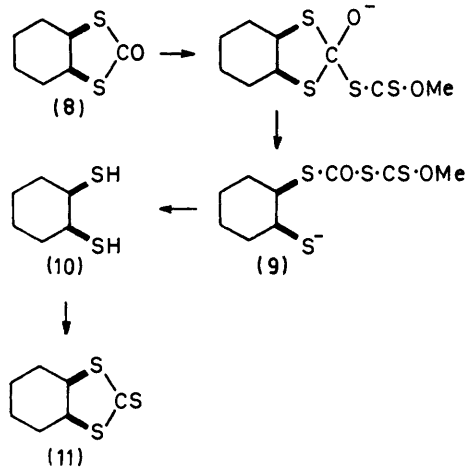
In Part 27,[1] it was shown that the reaction of a sodium (or potassium) *O*-alkyl dithiocarbonate with the cyclic carbonates or thioncarbonates derived from *meso*-butane-2,3-, DL-butane-2,3-, and cyclohexane-*cis*-1,2-diol gave the corresponding trithiocarbonates with DL-, *meso*-, or *trans*-configuration (5), respectively, better yields being obtained from the thioncarbonates than from the carbonates. The suggested mechanism involved attack by the thiolate anion of the dithiocarbonate on an 'alkyl' carbon atom, and the formation of an inter-



Scheme 1

[1] Part 27, N. G. Kardouche and L. N. Owen, *J.C.S. Perkin I*, 1975, 754.

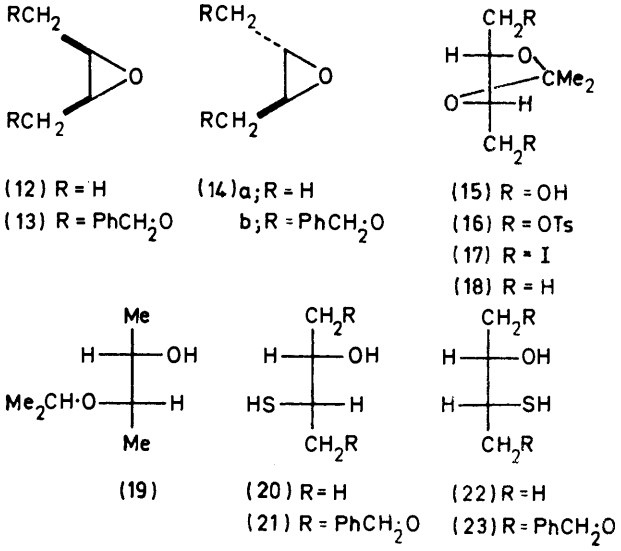
mediate episulphide with *meso*-, DL-, or *cis*-configuration respectively, as illustrated (Scheme 1a) for the cyclohexane compounds (1). This mechanism was supported by the observation that the carbonate and thioncarbonate of cyclohexane-*trans*-1,2-diol reacted with overall *retention* of configuration, evidently by a pathway not involving the unlikely intermediacy of *trans*-cyclohexene sulphide; a mechanism involving initial attack on the carbonyl or thiocarbonyl group was proposed. The *trans*-dithiolcarbonate (2) gave the *trans*-trithiocarbonate (5), and reactions on the *meso*- and the DL-butane analogues likewise resulted in retention of configuration; the proposed mechanism, illustrated for the cyclohexane compound (2) (Scheme 1b), also involved attack on the carbonyl group and led to an intermediate episulphide. It was, therefore, of interest to examine the behaviour of the *cis*-dithiolcarbonate (8), which was unlikely to react by a route which would necessitate the formation of *trans*-cyclohexene sulphide.



SCHEME 2

The compound (8) was prepared by treatment of the *cis*-trithiocarbonate (11) [2] with mercury(II) acetate; it reacted with potassium *O*-methyl dithiocarbonate to regenerate the trithiocarbonate (11) in 48% yield. This retention of configuration cannot be explained by the alternative attack on an ' alkyl ' position, and the initial stages leading to the mixed anhydride (9) (Scheme 2) are similar to those giving the mixed anhydride (3) from the *trans*-isomer (2). Because, however, the mixed anhydride (9) cannot give an episulphide, it is solvolysed to the *cis*-dithiol (10), which in common with other dithiols [3] reacts with the dithiocarbonate reagent to form a trithiocarbonate with retention of configuration; a general mechanism suggested [3] for the dithiol → trithiocarbonate transformation does not involve any sterically unacceptable intermediates when applied to the *cis*-dithiol (10). This modified mechanism *via* the dithiol would of course be valid for the dithiolcarbonates studied earlier, but the very high yields of trithiocarbonates then obtained [compared with the moderate yield from the dithiolcarbonate (8)] suggests that a route through a sterically acceptable episulphide (Scheme 1b) is normally preferred; the question could no doubt be resolved by isotopic labelling.

It then became of interest to examine the behaviour of carbonyl and thiocarbonyl derivatives of vicinal hydroxythiols towards the dithiocarbonate reagent. Reduction of 3-bromobutan-2-one with potassium borohydride, and treatment of the bromohydrin with base, gave *cis*-2,3-epoxybutane (12), samples from several preparations of which were shown by g.l.c. to contain significant amounts of *trans*-epoxide, which was removed by fractional distillation. The bromohydrin, therefore, was not stereochemically pure and the reduction of the bromo-ketone is evidently not stereospecific under the conditions used.[4] An authentic sample of the *trans*-epoxide (14a) was prepared from DL-butane-2,3-diol by Lucas and Garner's method,[5] but, because the DL-diol could not be isolated in adequate quantity from a commercial mixture of stereoisomers, for further work the L-diol was prepared from dimethyl 2,3-*O*-isopropylidene-L-tartrate *via* 2,3-*O*-isopropylidene-L-threitol (15), the bistoluene-*p*-sulphonate (16), and the di-iodide (17). When the di-iodide was hydrogenated in methanol buffered with potassium acetate over Raney nickel, the acidity developed was sufficient to remove the isopropylidene group, and the required diol was isolated directly. An attempt to reduce the bistoluene-*p*-sulphonate (16) to the dideoxy-compound (18) with lithium aluminium hydride resulted in cleavage of a CMe_2–O bond, the main product

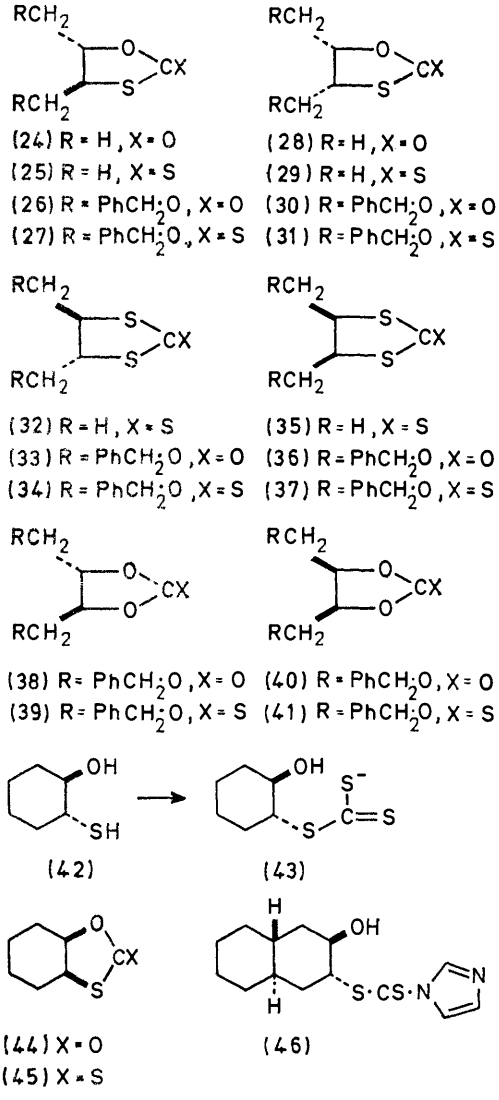


being the isopropyl ether (19). Conversion of the L-butane-2,3-diol into the L-epoxide (14a) was effected,

[2] H. Böhme and O. Müller, *Chem. Ber.*, 1965, **98**, 1455; *cf.* L. Bateman, R. W. Glazebrook, C. G. Moore, M. Porter, G. W. Ross, and R. W. Saville, *J. Chem. Soc.*, 1958, 2838.
[3] M. Kyaw and L. N. Owen, *J. Chem. Soc.*, 1965, 1298.
[4] *Cf.* S. M. Iqbal and L. N. Owen, *J. Chem. Soc.*, 1960, 1030.
[5] H. J. Lucas and H. K. Garner, *J. Amer. Chem. Soc.*, 1948, **70**, 990.

through the 2,3-*O*-benzylidene derivative, by Seeley and McElwee's method.[6]

Fission of the epoxides (12) and (14a) with potassium hydrogen sulphide gave the *threo*- and *erythro*-mercapto-alcohols (20) and (22), respectively, from which the cyclic thiolthioncarbonates (25) and (29) were obtained by reaction with *NN'*-thiocarbonyldi-imidazole; this is a much more satisfactory reagent [7,8] than thiocarbonyl chloride. Treatment of the products (25) and (29) with mercury(II) acetate gave the thiolcarbonates (24) and (28).



Reactions of these four cyclic thiocarbonates with potassium *O*-methyl dithiocarbonate in methanol were carried out in sealed tubes at *ca.* 65 °C, a technique which gave much better yields than reaction under reflux. The *erythro*-compounds (28) and (29) gave the *cis*-trithiocarbonate (35), whilst the *threo*-compounds (24) and (25) gave the *trans*-trithiocarbonate (32), the products (which have almost identical m.p.s) [9] being identified by comparison with authentic specimens. The retention of configuration in all four cases, and in similar reactions on the *trans*-cyclohexane derivatives (6) [10] and (7), can be explained by attack on the carbonyl or thiocarbonyl group, leading to an intermediate episulphide by the mechanistic pathway illustrated (Scheme 1c) for the conversion of the cyclohexane compounds (6) and (7) into the *trans*-trithiocarbonate (5). Such a pathway is sterically prohibited for the *cis*-cyclohexane derivatives (44) and (45); the former was reported [10] to give the *trans*-trithiocarbonate (5) in very low yield, and we find that the thiolthioncarbonate (45) behaves similarly. Compounds (44) and (45) were both prepared from *cis*-2-mercaptocyclohexanol, obtained by a method involving the supposed stereospecific addition of thioacetic acid to cyclohexenyl acetate,[11] but, in view of reports that the addition of thioacetic acid to 1-methylcyclohexene [12] and to *S*-cyclohexenyl thioacetate [13] is stereoselective but not stereospecific, it is possible that the 2-mercaptocyclohexanol was not entirely the *cis*-form. Although there are slight spectroscopic differences between the stereoisomeric mercapto-alcohols, unfortunately these are not sufficient to enable the presence of a small amount of *trans*-isomer to be detected with certainty in a mixture of both. Consequently, it is doubtful whether the small amount of *trans*-trithiocarbonate is a genuine product from the *cis*-compounds; if it is, the mechanism must involve attack at the *O*-alkyl position.

Reaction of *trans*-2-mercaptocyclohexanol (42) with potassium *O*-methyl dithiocarbonate gave a 64% yield of the *trans*-trithiocarbonate (5). From analogy with the mechanism for the similar reaction of cyclohexane-*trans*-1,2-dithiol,[3] cyclisation of the intermediate (43), with loss of sulphide ion, would lead to the *trans*-thiolthioncarbonate (7) as an actual intermediate in this process. The yield of trithiocarbonate obtained experimentally from this thiolthioncarbonate was almost quantitative, and the possibility that the *trans*-mercapto-alcohol itself might be an intermediate in that reaction is thereby excluded. *cis*-2-Mercaptocyclohexanol also gave the *trans*-trithiocarbonate, but in very low yield, and for the reason already mentioned this is of uncertain significance.

To study some analogous reactions of erythritol and DL-threitol derivatives, the *erythro*- (13) and the *threo*-epoxide (14b) were prepared by treatment of *cis*- and *trans*-1,4-bisbenzyloxybut-2-ene, respectively, with 3-chloroperbenzoic acid. Fission of the epoxides with potassium hydrogen sulphide afforded the *threo*- (21) and the *erythro*-mercapto-alcohol (23) from which the thiol-

[6] D. A. Seeley and J. McElwee, *J. Org. Chem.*, 1973, **38**, 1691.
[7] H. A. Staab and G. Walther, *Annalen*, 1962, **657**, 98.
[8] E. J. Corey and R. A. E. Winter, *J. Amer. Chem. Soc.*, 1963, **85**, 2677.
[9] C. G. Overberger and A. Drucker, *J. Org. Chem.*, 1964, **29**, 360.
[10] C. R. Meloy, *Trans. Illinois State Acad. Sci.*, 1963, **56**, 146; and personal communication.
[11] H. Behringer and W. Kley, *Annalen*, 1955, **595**, 160.
[12] F. G. Bordwell and W. A. Hewett, *J. Amer. Chem. Soc.*, 1957, **79**, 3493.
[13] J. D. Willett, J. R. Grunwell, and G. A. Berchtold, *J. Org. Chem.*, 1968, **33**, 2297.

thioncarbonates (27) and (31) were prepared. The thioncarbonates (39) and (41) were made from 1,4-di-*O*-benzyl-DL-threitol and -erythritol respectively (obtained by hydroxylation of *trans*-1,4-bisbenzyloxybut-2-ene under conditions appropriate for stereospecificity).

The *erythro*-epoxide (13) reacted with potassium *O*-methyl dithiocarbonate in methanol to give the *trans*-trithiocarbonate (34) but the yield was very dependent on the conditions, being 76% at 45 °C and 3% at reflux temperature in an open flask but 79% in a sealed tube at *ca.* 65 °C. The *threo*-epoxide (14b) gave the *cis*-trithiocarbonate (37) in yields of 11 (20 °C), 34 (31 °C), 51 (40 °C), 50 (49 °C), and 0% (reflux) in an open flask but 52% in a sealed tube at *ca.* 63 °C. Furthermore, the trithiocarbonate (37) was completely destroyed by being heated under reflux with the dithiocarbonate reagent. This instability is in contrast with the behaviour of the cyclohexane trithiocarbonate (5) which was recovered almost quantitatively after such treatment.

Treatment of the six thioncarbonates, (27), (31), (34), (37), (39), and (41), with mercury(II) acetate gave the carbonyl compounds (26), (30), (33), (36), (38), and (40); all except the two trithiocarbonates were then treated with the dithiocarbonate reagent by the sealed tube technique. In contrast to the behaviour of the carbonates and thioncarbonates derived from *meso*- and DL-butane-2,3-diols, the two carbonates (38) and (40) gave no trithiocarbonate, and even the thioncarbonates (39) and (41) gave only traces, the products being the corresponding diols; attack at the ' alkyl ' position is evidently sterically inhibited by the bulky benzyloxy groups, so that the reaction can proceed only by attack on the carbonyl or thiocarbonyl group, leading, by eventual solvolysis, to the diol. On the other hand, the six compounds (26), (27), (30), (31), (33), and (36) gave high yields of trithiocarbonates with retention of configuration, evidently also by attack on the carbonyl or thiocarbonyl function in the manner already depicted (*cf.* Schemes 1b and 1c). It might be thought that an analogous mechanism should apply to the four compounds (38—41), but the intermediate would then be an epoxide, which is less readily formed (intramolecular attack by alkoxide anion) than an episulphide (intramolecular attack by thiolate anion) and there was no evidence for the participation of an epoxide (leading to retention of configuration) in the reactions of the butane-2,3-diol derivatives studied earlier;[1] the proposal of such a mechanism to explain the reactions of the carbonate and the thioncarbonate of cyclohexane-*trans*-1,2-diol [1] is not inconsistent, because the entropy factor for ring closure is more favourable in the alicyclic system.

A cyclic thiolthioncarbonate could not be obtained by reaction of 3α-mercapto-*trans*-decalin-2β-ol with *NN'*-thiocarbonyldi-imidazole. The only recognisable product was the imidazolyl derivative (46) of the mercapto-alcohol; cyclisation of this diaxial type of intermediate to give the required product would be expected to be more difficult in the *trans*-decalin system than with the analogous cyclohexane derivative.[1]

EXPERIMENTAL

I.r. spectra were recorded with solutions in chloroform, and ^{1}H n.m.r. spectra for solutions in deuteriochloroform (Varian T60 instrument). Optical rotations (in chloroform unless otherwise stated) were measured with a Perkin-Elmer 141 polarimeter. The adsorbent for t.l.c. was Kieselgel GF_{254} (Merck), the developing solvent being dichloromethane where not otherwise specified. For g.l.c. a 2 m column of 15% Carbowax on Chromosorb W was used (Perkin-Elmer F11 instrument). Extracts were dried over magnesium sulphate and solvents were removed under reduced pressure below 50 °C. Petroleum refers to the solvent of b.p. 40—60 °C.

General Conditions.—Reactions with mercury(II) *acetate.* A mixture of the thione, mercury(II) acetate, and acetic acid, in the quantities specified, was stirred at 40—50 °C for *ca.* 45 min, then cooled, diluted with dichloromethane, filtered, and evaporated. The residue was partitioned between water and dichloromethane, and the organic portion was washed with aqueous sodium hydrogen carbonate, then dried and concentrated. The product was normally purified by t.l.c.

Reactions with NN'-*thiocarbonyldi-imidazole.* When the reaction was complete, the mixture was washed with water (and, when pyridine was present, with 2M-hydrochloric acid, and again with water) and the solution was then dried and evaporated to a residuewhich was purified by t.l.c.

Reactions with xanthate. The product was isolated by diluting the cooled mixture with water and extracting with dichloromethane. The extract was washed with water, then dried and evaporated, and the residue was purified by t.l.c.

Xanthate reagent A. Carbon disulphide (1 ml) was added to a solution of potassium hydroxide (0.6 g) in dry methanol (10 ml).

Xanthate reagent B. Carbon disulphide (0.8 ml) was added to a solution prepared from sodium (0.2 g) and dry methanol (25 ml).

Cyclohexane-cis-1,2-*dithiol.*—Cyclohexene (102 g) and sulphur (14 g) were heated in an autoclave at 120—150 °C for 5 h. When cold, the mixture was then diluted with tetrahydrofuran (100 ml), filtered, and added slowly (4 h) to lithium aluminium hydride (10 g) in tetrahydrofuran (250 ml). This mixture was then stirred overnight, boiled under reflux for 4 h, cooled, treated with ethyl acetate and with water, and worked up to give the dithiol (5.6 g), b.p. 48—51° at 0.2 mmHg, n_D^{18} 1.5540 (lit.,[2] 99—100° at 0.9 mmHg, n_D^{20} 1.5550).

cis-*Perhydro*-1,3-*benzodithiole*-2-*thione* (11).—(i) A solution of *NN'*-thiocarbonyldi-imidazole [7] (0.8 g) in dry dichloromethane (12 ml) was added to a solution of cyclohexane-*cis*-1,2-dithiol (0.26 g) and pyridine (4 ml) in dry dichloromethane (8 ml). The mixture was stirred overnight and worked up by the general method to give the *cis*-trithiocarbonate (11) (0.27 g), m.p. 100—101° (from ether–petroleum) (lit.,[2] 98—99°).

(ii) A solution of cyclohexane-*cis*-1,2-dithiol (0.24 g) in xanthate reagent A (10 ml) was boiled under reflux for 4 d, then worked up by the standard procedure to give the *cis*-trithiocarbonate (0.23 g, 81%), m.p. 100—101°.

cis-*Perhydro*-1,3-*benzodithiol*-2-*one* (8).—A solution of the *cis*-trithiocarbonate (11) (0.375 g) and mercury(II) acetate (2.9 g) in acetic acid (29 ml) was treated by the general procedure to give the cis-*dithiolcarbonate* (8) (0.28 g) as an oil, $\nu_{max.}$ (film) 1 716, 1 641, 1 283, 1 003, 874, and 755 cm^{-1}, τ 5.75 (2 H, m,) and 7.4—8.9 (8 H, m) (Found: C, 48.5;

H, 5.95; S, 36.6. $C_7H_{10}OS_2$ requires C, 48.2; H, 5.8; S, 36.8%).

Reaction of this product (0.28 g) with xanthate reagent A (7 ml) at the reflux temperature for 4 d gave the *cis*-trithiocarbonate (11) (0.15 g, 48%), m.p. 102—103° (from dichloromethane–petroleum).

Reduction of 3-*Bromobutan*-2-*one*.—Potassium borohydride (28.8 g) in water (400 ml) was added slowly to a stirred solution of the bromo-ketone [14] (196 g) in methanol (400 ml), the temperature of the mixture being kept below 20 °C. When the addition was complete the solution was left for 30 min and then neutralised with dilute sulphuric acid. Saturation with sodium chloride and extraction with ether gave 3-bromobutan-2-ol (126 g), b.p. 56—58° at 14 mmHg; this was mainly the DL-*threo*-compound (see below) but g.l.c. (180 °C) showed the presence of the stereoisomer.

cis-2,3-*Epoxybutane*.—The 3-bromobutan-2-ol (126 g) was added dropwise to a stirred solution of potassium hydroxide (202 g) in water (95 ml) at 90—95 °C. The crude epoxide (57 g) was allowed to distil over and was collected in a cooled receiver. Redistillation gave a product which, in various preparations, contained 20—40% of *trans*-epoxide, an authentic sample of which was prepared from DL-butane-2,3-diol by Lucas and Garner's method.[5] G.l.c. at 100 °C showed the following retention times: *cis*, 63; *trans*, 57 s.

Very slow fractional distillation of the mixed epoxide through a 30 cm column packed with Fenske helices, employing a high reflux ratio, gave early fractions rich in *trans*-epoxide and left a residue of pure *cis*-epoxide.

Dimethyl 2,3-O-*Isopropylidene*-L-*tartrate*.—This was prepared from dimethyl L-tartrate by the method described for the diethyl ester;[15] yield 94%, b.p. 100° at 0.5 mmHg, $[\alpha]_D^{21}$ −44.2° (*c* 5) {lit.,[15] 82—90° at 0.02 mmHg, $[\alpha]_D^{20}$ −49.4 (neat)}.

2,3-O-*Isopropylidene*-L-*threitol* (15).—Prepared by the method used [16] for reduction of the diethyl ester, the product (82%) had b.p. 96—98° at 0.3 mmHg, $[\alpha]_D^{23}$ +5.2° (*c* 5) (lit.,[16] 96—96.5° at 0.5 mmHg, $[\alpha]_D^{20}$ +4.1°). The 1,4-bistoluene-*p*-sulphonate (16) had m.p. 90—91°, $[\alpha]_D^{23}$ −10.6° (*c* 5) (lit.,[17] 91—92°, $[\alpha]_D^{24}$ −12.4°).

L-*Butane*-2,3-*diol*.— 1,4-Di-iodo-2,3-*O*-isopropylidene-L-butane-2,3-diol (17) was prepared in 73% yield from the bistoluene-*p*-sulphonate (16) by the reported method,[17] except that the reaction with sodium iodide was carried out in boiling acetone under reflux for 6 h. It had b.p. 108° at 0.8 mmHg, $[\alpha]_D^{24}$ −16.9° (*c* 8 in methanol) (lit.,[17] for D-isomer, 80—82° at 0.05 mmHg, $[\alpha]_D$ +17.5° in methanol).

A solution of this di-iodide (22.4 g) and potassium acetate (16.0 g) in dry methanol (200 ml) containing Raney nickel (*ca.* 7 g) was hydrogenated at atmospheric pressure. When absorption of hydrogen ceased, the solution was filtered and most of the methanol was removed by distillation through a 40 cm Vigreux column. The residue was diluted with dry ether (150 ml), molecular sieve (B.D.H., type 4A; 150 g) was added, and the mixture was set aside for 7 d. The molecular sieve was removed by filtration and washed with ether, and the combined ethereal solutions were evaporated to give L-butane-2,3-diol (2.5 g), b.p. 84—86° at 15 mmHg, $[\alpha]_D^{23}$ +19.8° (*c* 4) {lit.,[17] $[\alpha]_D$ +12.4° (neat)}.

L-threo-3-*Isopropoxybutan*-2-*ol* (19).—Lithium aluminium hydride (5.2 g) was added to a solution of 2,3-*O*-isopropylidene-1,4-di-*O*-tosyl-L-threitol (16) (30 g) in benzene (35 ml) and ether (120 ml). The mixture was boiled under reflux overnight, then more lithium aluminium hydride (2.5 g) was added, and the heating was continued for a further 24 h. Ethyl acetate was added to the cooled mixture, followed by water, and the mixture was then treated with an excess of aqueous sodium hydroxide. The ethereal layer was separated, washed with water, dried, and distilled to give the isopropyl ether as a fraction (4.5 g), b.p. 140—141°, n_D^{22} 1.4129, $[\alpha]_D^{24}$ +68.9° (*c* 5), τ 6.0—7.0 (3 H, m), 6.27br (1 H, s, exchanged by D_2O, OH), and 8.9 (12 H, m, 4Me).

2,3-O-*Benzylidene*-L-*butane*-2,3-*diol*.—A mixture of the L-diol (2.2 g), benzaldehyde (5 g), and sulphuric acid (10 mg) was stirred at *ca.* 95 °C for 16 h, then cooled, diluted with ether, and washed successively with aqueous sodium hydrogen carbonate, aqueous sodium hydrogen sulphite, and water. The aqueous portions were extracted with ether, and the combined ethereal solutions were dried and evaporated to give the benzylidene derivative (3.7 g), b.p. 55—56° at 0.13 mmHg, $[\alpha]_D^{25}$ +32° (*c* 5), τ 2.6 (5 H, m, Ph), 4.02 (1 H, s, PhC*H*), 6.18 (2 H, m), and 8.62 (6 H, dd, 2Me) (lit.,[18] b.p. 119° at 19 mmHg for DL-compound).

(4R,5S)-4,5-*Dimethyl*-1,3-*oxathiolan*-2-*thione* (29).—2,3-*O*-Benzylidene-L-butane-2,3-diol (3.5 g) was added to a slurry of *N*-bromosuccinimide (3.6 g) in carbon tetrachloride at 0 °C. The mixture was stirred in the dark for 24 h at ambient temperature. It was then filtered, and the filtrate was washed with aqueous sodium hydrogen carbonate, dried, and evaporated. The residual D-*erythro*-2-benzoyloxy-3-bromobutane (5.1 g) was added to sodium hydroxide (1.9 g) and ethylene glycol (14 ml), and the mixture was slowly heated to 140 °C. The volatile product (0.54 g), collected in a cooled receiver, was essentially L-*trans*-2,3-epoxybutane (g.l.c. at 100°), which was converted by Price and Kirk's method [19] into D-*erythro*-3-mercaptobutan-2-ol (22). This crude thiol (124 mg) was treated in the usual way with *NN'*-thiocarbonyldi-imidazole (250 mg) and pyridine (760 mg) in dichloromethane (7 ml) for 12 h to give the *thione* (29) (116 mg), an oil, τ 4.5—5.1 (1 H, m,) 5.7—6.3 (1 H, m), 8.43 and 8.58 (6 H, 2 t, 2Me) (Found: C, 40.6; H, 5.2; S, 43.4. $C_5H_8OS_2$ requires C, 40.5; H, 5.4; S, 43.3%).

(4R,5S)-4,5-*Dimethyl*-1,3-*oxathiolan*-2-*one* (28).—The preceding thione (29) (57 mg) was treated in the usual way with mercury(II) acetate (245 mg) in acetic acid (2.5 ml) to give the *thiolcarbonate* (28) (29 mg), an oil, $\nu_{max.}$ (film) 1 730 cm^{-1}, τ 4.8—5.4 (1 H, m), 5.7—6.5 (1 H, m), and 8.57 (6 H, dd, 2Me) (Found: C, 45.8; H, 6.1; S, 22.8. $C_5H_8O_2S$ requires C, 45.4; H, 6.1; S, 24.3%).

trans-4,5-*Dimethyl*-1,3-*oxathiolan*-2-*thione* (25).—*cis*-2,3-Epoxybutane (6.0 g) was converted by Price and Kirk's procedure [19] into DL-*threo*-3-mercaptobutan-2-ol (2.7 g), b.p. 67° at 24 mmHg. Reaction of this thiol (1.0 g) with *NN'*-thiocarbonyldi-imidazole (2.1 g) and pyridine (6.2 g) in dichloromethane (57 ml) for 12 h gave the *thione* (25) (1.3 g), an oil, τ 4.8—5.5 (1 H, m), 5.8—6.5 (1 H, m), and 8.45 (6 H, t, 2Me) (Found: C, 40.8; H, 5.6; S, 43.4. $C_5H_8OS_2$ requires C, 40.5; H, 5.4; S, 43.3%).

trans-4,5-*Dimethyl*-1,3-*oxathiolan*-2-*one* (24).—Treatment of the preceding thione (25) (0.34 g) with mercury(II) acetate (1.8 g) in acetic acid (18 ml) gave the *thiolcarbonate*

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(24) (0.20 g), an oil, purified by t.l.c. (ether–petroleum, 1 : 4), $\nu_{max.}$ (film) 1 723 cm^{-1}, τ 5.3—5.9 (1 H, m), 5.9—6.6 (1 H, m), and 8.52 (6 H, d, 2Me) (Found: C, 45.6; H, 6.1; S, 24.2. $C_5H_8O_2S$ requires C, 45.4; H, 6.1; S, 24.3%).

cis-4,5-*Dimethyl*-1,3-*dithiolan*-2-*thione* (35).—(i) A solution of (4*R*,5*S*)4,5-dimethyl-1,3-oxathiolan-2-thione (11.3 mg) in xanthate reagent A (0.6 ml) was heated in a sealed tube at 64—66 °C for 4 d to give the *cis*-trithiocarbonate (35) (5.7 mg, 46%), m.p. 41—42° (from ether–petroleum), which liquefied on admixture with the *trans*-isomer (m.p. 41—42°).

(ii) Under the same conditions, (4*R*,5*S*)-4,5-dimethyl-1,3-oxathiolan-2-one (5.0 mg) in reagent A (0.3 ml) gave the *cis*-trithiocarbonate (4.8 mg, 87%), m.p. 40.5—42° (from petroleum); ^1H n.m.r. spectrum identical with that of authentic material.[1]

trans-4,5-*Dimethyl*-1,3-*dithiolan*-2-*thione* (32).—(i) A solution of *trans*-4,5-dimethyl-1,3-oxathiolan-2-thione (23.5 mg) in reagent A (0.9 ml) was heated in a sealed tube at 64—66 °C for 4 d and gave the *trans*-trithiocarbonate (32) (21 mg, 81%), m.p. 39—41° (from petroleum), not depressed on admixture with an authentic sample.[1] The ^1H n.m.r. spectrum also identified it as the *trans*-compound.

(ii) Similarly, *trans*-4,5-dimethyl-1,3-oxathiolan-2-one (9.0 mg) in reagent A (0.6 ml) gave the *trans*-trithiocarbonate (10.2 mg, 76%) (^1H n.m.r. spectrum), m.p. and mixed m.p. 40.5—42°.

cis-2-*Mercaptocyclohexanol*.— *cis*-2-Acetylthiocyclohexyl acetate [11] (9.0 g) was dissolved in methanol (80 ml) containing 8% hydrogen chloride. After 6 d the solution was evaporated to give *cis*-2-mercaptocyclohexanol (4.2 g), b.p. 42—43.5° at 0.13 mmHg (lit.,[10] 89—91° at 8 mmHg).

cis-*Perhydro*-1,3-*benzoxathiole*-2-*thione* (45).—Treatment of *cis*-2-mercaptocyclohexanol (2.0 g) in the usual way with *NN'*-thiocarbonyldi-imidazole (3.1 g) and pyridine (10 ml) in dichloromethane (60 ml) gave the *thione* (45) (2.6 g), which was purified by t.l.c. (first in petroleum; then in ether–petroleum, 1 : 1). It was an oil, τ 4.9 (1 H, m), 6.1 (1 H, m), and 7.2—9.3 (8 H, m) (Found: C, 48.4; H, 5.7; S, 36.5. $C_7H_{10}OS_2$ requires C, 48.2; H, 5.8; S, 36.8%).

cis-*Perhydro*-1,3-*benzoxathiol*-2-*one* (44).—The preceding thione (45) (0.30 g) was treated in the usual way with mercury(II) acetate (0.54 g) in acetic acid (6 ml) to give the thiolcarbonate (44) (53 mg), purified by t.l.c. (dichloromethane–petroleum, 1 : 1). It was an oil, $\nu_{max.}$ 1 750 and 1 715 cm^{-1} (lit.,[10] $\nu_{max.}$ 1 754 and 1 715 cm^{-1}).

trans-*Perhydro*-1,3-*benzoxathiole*-2-*thione* (7).—*trans*-2-Mercaptocyclohexanol (0.10 g), *NN'*-thiocarbonyldi-imidazole (0.25 g), and pyridine (0.6 ml) gave the thione (7) (0.13 g), m.p. 58.5—60.5° (from petroleum) (lit.,[20] 58—59°).

trans-*Perhydro*-1,3-*benzodithiole*-2-*thione* (5).—(i) A solution of *cis*-perhydro-1,3-benzozathiole-2-thione (0.4 g) in reagent A (4 ml) was boiled under reflux for 12 h to give the *trans*-trithiocarbonate (5) (40 mg, 9%), m.p. 170—171° (from dichloromethane) (lit.,[1] 169—170°).

(ii) (with N. G. Kardouche). *trans*-Perhydro-1,3-benzoxathiole-2-thione (82 mg) was added to a solution prepared from carbon disulphide (1 g), ethanol (20 ml), and sodium (115 mg). The mixture was boiled under reflux for 24 h. When cooled, it deposited yellow crystals, which were collected. The residual solution was diluted with water and extracted with chloroform to give a further quantity of the *trans*-trithiocarbonate (total 89 mg, 99%), m.p. 168—170°.

(iii) A solution of *cis*-2-mercaptocyclohexanol (150 mg) in reagent A (10 ml) was boiled under reflux for 5 d. The product, purified by t.l.c. (ether–petroleum, 1 : 1) and then by recrystallisation from chloroform–petroleum, was the *trans*-trithiocarbonate (12 mg, 6%), m.p. 168—169°.

(iv) Similar treatment of *trans*-2-mercaptocyclohexanol (342 mg) with reagent A (22 ml) gave the *trans*-trithiocarbonate (314 mg, 64%), m.p. 168—170°.

cis-4,5-*Bis*(*benzyloxymethyl*)-1,3-*oxathiolan*-2-*thione* (31).—A solution of *trans*-1,4-bisbenzyloxybut-2-ene [21] (5.0 g) and 3-chloroperbenzoic acid (5.0 g) in dry ether was kept at *ca.* — 7 °C for 14 d and then at ambient temperature for 10 d. Excess of peracid was removed by shaking the mixture with aqueous sodium sulphite, and the ethereal layer was then washed with aqueous sodium hydrogen carbonate and with water. Evaporation of the dried solution gave the *trans*-epoxide (14b) (4.3 g), b.p. 160—170° at 0.1 mmHg (lit.,[21] 236—238° at 2 mmHg), which was treated in the usual way [19] with aqueous potassium hydrogen sulphide to give crude 1,4-di-*O*-benzyl-2-thioerythritol (23) (76%, based on thiol value). This thiol (1.3 g) was treated with pyridine (13 ml) and *NN'*-thiocarbonyldi-imidazole (1.96 g) in chloroform for 12 h to give the *thione* (31) (0.64 g), m.p. 53—55° (from ether–petroleum), τ 2.68 (10 H, s, Ar), 4.83 (1 H, q), 5.57 (4 H, d), and 5.6—6.5 (5 H, m) (Found: C, 63.3; H, 5.6; S, 17.3. $C_{19}H_{20}O_3S_2$ requires C, 63.3; H, 5.6; S, 17.8%).

cis-4,5-*Bis*(*benzyloxymethyl*)-1,3-*oxathiolan*-2-*one* (30).—Reaction of the preceding thione (31) (354 mg) with mercury(II) acetate (1.0 g) in acetic acid (10 ml) by the general procedure gave the *thiolcarbonate* (30) (274 mg), m.p. 51—54°, $\nu_{max.}$ 1 737 cm^{-1}, τ 2.63 (10 H, s, Ar), 5.15 (1 H, q), 5.47 (4 H, d), and 5.7—6.5 (5 H, m) (Found: C, 66.4; H, 5.9; S, 9.3. $C_{19}H_{20}O_4S$ requires C, 66.3; H, 5.85; S, 9.3%).

cis-1,4-*Bisbenzyloxybut*-2-*ene*.—A mixture of *cis*-but-2-ene-1,4-diol (8.0 g), benzyl bromide (60 g), powdered potassium hydroxide (17 g), and benzene (100 ml) was stirred at ambient temperature for 5 d. It was then diluted with benzene (100 ml) and washed successively with water and aqueous sodium hydrogen carbonate. Distillation of the dried solution gave the dibenzyl ether (19. 0 g), b.p. 146° at 0.1 mmHg (lit.,[22] b.p. 137—138° at 1 mmHg).

trans-4,5-*Bis*(*benzyloxymethyl*)-1,3-*oxathiolan*-2-*thione* (27).—A solution of *cis*-1,4-bisbenzyloxybut-2-ene (1.5 g) and 3-chloroperbenzoic acid (1.6 g) in dry ether was boiled under reflux for 27 h and then worked up as described for the *trans*-isomer to give the *cis*-epoxide (13) (1.4 g), which was treated with aqueous potassium hydrogen sulphide [19] to give crude 1,4-di-*O*-benzyl-2-thiothreitol (21) (32%, based on thiol value). Reaction of this thiol (1.0 g) with *NN'*-thiocarbonyldi-imidazole (0.8 g) in dichloromethane (30 ml) gave the *thione* (27) (0.17 g), an oil, τ 2.62 (10 H, s, Ar), 4.83 (1 H, m), 5.42 (4 H, t), 5.87 (1 H, m), and 6.1—6.5 (4 H, m) (Found: C, 63.3; H, 5.55; S, 17.7. $C_{19}H_{20}O_3S_2$ requires C, 63.3; H, 5.6; S, 17.8%).

trans-4,5-*Bis*(*benzyloxymethyl*)-1,3-*oxathiolan*-2-*one* (26).—Treatment of the preceding thione (27) (69 mg) with mercury(II) acetate (194 mg) in acetic acid (2.5 ml) gave the *thiolcarbonate* (26) (46 mg), an oil, $\nu_{max.}$ 1 742 cm^{-1}, τ 2.62 (10 H, s, Ar), 4.9—5.4 (1 H, m), 5.38 (4 H, s), 5.92 (1 H, m), and 6.33 (4 H, m) (Found: C, 66.2; H, 5.8; S, 9.0. $C_{19}H_{20}O_4S$ requires C, 66.3; H, 5.85; S, 9.3%).

1,4-*Di*-O-*benzylerythritol*.— *trans*-1,4-Bisbenzyloxybut-2-ene (8.0 g) was added to a mixture of 30% hydrogen peroxide (4.3 ml) and 90% formic acid (18.4 ml). The emul-

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[21] J. Kiss and F. Sirokmán, *Helv. Chim. Acta*, 1960, **43**, 334.

[22] W. Reppe und Mitarbeiter, *Annalen*, 1955, **596**, 131.

sion was stirred at 40 °C overnight, and was then cooled, treated with sufficient aqueous sodium hydrogen sulphite to destroy remaining peroxide, and concentrated. The residue was mixed with a solution of sodium hydroxide (2.7 g) in water (5.3 ml), and when the exothermic reaction had subsided the solution was diluted with water and extracted with dichloromethane. The extract was washed successively with dilute hydrochloric acid and with aqueous sodium hydrogen carbonate, and was then dried and evaporated to give the *meso*-diol (6.75 g), m.p. 57—58° (from ether–petroleum) (lit.,[23] 56—57°).

cis-4,5-*Bis*(*benzyloxymethyl*)-1,3-*dioxolan*-2-*thione* (41).—Reaction of 1,4-di-*O*-benzylerythritol (322 mg) with *NN'*-thiocarbonyldi-imidazole (0.39 g) in dichloromethane (16 ml) gave the *thione* (41) (326 mg), m.p. 107—108° (from ether–dichloromethane), τ 2.67 (10 H, s, Ar), 5.00 (2 H, m), 5.48 (4 H, s), and 6.2 (4 H, m) (Found: C, 66.5; H, 5.8; S, 9.3. $C_{19}H_{20}O_4S$ requires C, 66.3; H, 5.85; S, 9.3%).

cis-4,5-*Bis*(*benzyloxymethyl*)1,3-*dioxolan*-2-*one* (40).—The preceding thione (41) (500 mg) was treated with mercury(II) acetate (140 mg) in acetic acid (5.3 ml) to give the carbonate (40) (110 mg), m.p. 70—72°, $\nu_{max.}$ 1 805 cm^{-1}, τ 2.68 (10 H, s, Ar), 5.20 (2 H, m), 5.52 (4 H, s), and 6.25 (4 H, m) (Found: C, 69.5; H, 6.3. $C_{19}H_{20}O_5$ requires C, 69.5; H, 6.1%).

1,4-*Di*-O-*benzyl*-DL-*threitol*.—A solution of potassium permanganate (0.52 g) and magnesium sulphate (0.4 g) in water (10 ml) was slowly added (2 h) to a solution of *trans*-1,4-bisbenzyloxybut-2-ene (1.1 g) in ethanol (8 ml), the temperature being kept below −10 °C. After addition of sufficient sodium hydrogen sulphite to destroy the precipitate of manganese dioxide, the solution was extracted with dichloromethane to give an oil which was purified by t.l.c. (successively in dichloromethane, methanol, and ether) to furnish the DL-diol (0.32 g), m.p. 61.5—62.5° (from ether–petroleum) (lit.,[23] 61.5—62.5°).

trans-4,5-*Bis*(*benzyloxymethyl*)-1,3-*dioxolan*-2-*thione* (39).—Prepared by reaction of 1,4-di-*O*-benzyl-DL-threitol (42 mg) with *NN'*-thiocarbonyldi-imidazole (160 mg) in dichloromethane (8 ml) overnight, the *thione* (39) (47 mg) had m.p. 69—70° (from dichloromethane–petroleum), τ 2.67 (10 H, s, Ar), 5.08 (2 H, m), 5.42 (4 H, s), and 6.32 (4 H, m) (Found: C, 66.1; H, 5.6; S, 9.2. $C_{19}H_{20}O_4S$ requires C, 66.3; H, 5.85; S, 9.3%).

trans-4,5-*Bis*(*benzyloxymethyl*)-1,3-*dioxolan*-2-*one* (38).—Treatment of the preceding thione (39) (39 mg) with mercury(II) acetate in acetic acid (1.5 ml) gave the *carbonate* (38) (32 mg), m.p. 88—90° (from ether–petroleum), $\nu_{max.}$ 1 797 cm^{-1}, τ 2.63 (10 H, s, Ar), 5.1—5.5 (2 H, m), 5.38 (4 H, s), and 6.32 (4 H, m) (Found: C, 69.5; H, 6.35. $C_{19}H_{20}O_5$ requires C, 69.5; H, 6.1%).

cis-4,5-*Bis*(*benzyloxymethyl*)-1,3-*dithiolan*-2-*thione* (37).—(i) A solution of *trans*-1,4-bisbenzyloxy-2,3-epoxybutane (14b) (150 mg) in xanthate reagent B (10 ml) was stirred at 40 °C for 4 d, and gave the cis-*trithiocarbonate* (37) (102 mg, 51%), m.p. 67—68° (from dichloromethane–petroleum), τ 2.63 (10 H, s, Ar), 5.1—5.6 (2 H, m), 5.43 (4 H, s), and 5.7—6.6 (4 H, m) (Found: C, 60.4; H, 5.6; S, 25.7. $C_{19}H_{20}O_2S_3$ requires C, 60.6; H, 5.35; S, 25.55%). For yields obtained under different conditions, see main text.

(ii) A solution of *cis*-4,5-bis(benzyloxymethyl)-1,3-oxathiolan-2-thione (31) (32 mg) in reagent A (0.9 ml) was heated in a sealed tube at 64—66 °C for 4 d. The product was the *cis*-trithiocarbonate (25 mg, 77%), m.p. 68—70°, spectroscopically identical with the authentic material.

(iii) Under the conditions described in the preceding paragraph, *cis*-4,5-bis(benzyloxymethyl)-1,3-oxathiolan-2-(30) (22 mg) with reagent A (0.7 ml) gave the *cis*-trit carbonate (21 mg, 87%), m.p. 68—69.5°.

(iv) Also under the same conditions, *cis*-4,5-bis(benzylo methyl)-1,3-dithiolan-2-one (36) (35 mg) and reagent (1.0 ml) gave the *cis*-trithiocarbonate (30 mg, 76%), m 68—70°.

cis-4,5-*Bis*(*benzyloxymethyl*)-1,3-*dithiolan*-2-*one* (36) Reaction of the *cis*-trithiocarbonate (37) (131 mg) w mercury(II) acetate (500 mg) in acetic acid (5.3 ml) by general procedure gave the cis-*dithiolcarbonate* (36) (108 m m.p. 69—70°, $\nu_{max.}$ 1 729 cm^{-1}, τ 2.65 (10 H, s, Ar), 5.4— (2 H, m), 5.48 (4 H, s), and 6.0—6.4 (4 H, m) (Found: 63.4; H, 5.65; S, 17.9. $C_{19}H_{20}O_3S_2$ requires C, 63.3; 5.6; S, 17.8%).

trans-4,5-*Bis*(*benzyloxymethyl*)-1,3-*dithiolan*-2-*thione* (3 —(i) A solution of *cis*-1,4-bisbenzyloxy-2,3-epoxybut (13) (211 mg) in reagent B (13 ml) was stirred at 45 °C 4 d to give the trans-*trithiocarbonate* (34) (213 mg, 73% an oil, τ 2.58 (10 H, s, Ar), 5.3—5.7 (2 H, m), 5.40 (4 H, and 6.0—6.5 (4 H, m) (Found: C, 60.6; H, 5.2; 25.7. $C_{19}H_{20}O_2S_3$ requires C, 60.6; H, 5.35; S, 25.55% For yields obtained under different conditions, see ma text.

(ii) A solution of *trans*-4,5-bis(benzyloxymethyl)-1 oxathiolan-2-thione (27) (40 mg) in reagent A (1.1 m heated for 4 d in a sealed tube at 64—66 °C, gave the *tra* trithiocarbonate (39 mg, 90%), spectroscopically identic with the authentic sample.

(iii) Reaction of *trans*-4,5-bis(benzyloxymethyl)-1, oxathiolan-2-one (26) (9.3 mg) with reagent A (0.3 ml) und the same conditions gave the *trans*-trithiocarbonate (9.6 m 94%), identified spectroscopically.

(iv) *trans*-4,5-Bis(benzyloxymethyl)-1,3-dithiolan-2-o (33) (19 mg) with reagent A (0.5 ml) likewise gave the *tran* trithiocarbonate (14 mg, 71%).

trans-4,5-*Bis*(*benzyloxymethyl*)-1,3-*dithiolan*-2-*one* (33).- The *trans*-trithiocarbonate (34) (232 mg) was treated wit mercury(II) acetate (912 mg) in acetic acid (9 ml) to giv the trans-*dithiolcarbonate* (33) (97 mg), an oil, $\nu_{max.}$ 1 711 cm τ 2.65 (10 H, s, Ar), 5.43 (4 H, s), 5.4—6.0 (2 H, m), and 6.1-6.5 (4 H, m) (Found: C, 63.0; H, 5.6; S, 18.0. $C_{19}H_{20}O_3$ requires C, 63.3; H, 5.6; S, 17.8%).

Reactions of 4,5-*Bis*(*benzyloxymethyl*)-1,3-*dioxolan*-2 *thiones with Dithiocarbonate Salts*.—(i) The *cis*-compoun (41) (14.5 mg), heated with reagent A (0.4 ml) for 4 d at *ca* 65 °C in a sealed tube, gave a trace of a yellow produc presumably a trithiocarbonate.

(ii) The *trans*-compound (39) (33 mg) with reagent A (ml) under the same conditions likewise gave only a trace c yellow material. Some 1,4-di-*O*-benzyl-DL-threitol (3 mg) m.p. and mixed m.p. 61—62.5°, was isolated.

Reactions of 4,5-*Bis*(*benzyloxymethyl*)-1,3-*dioxolan*-2-*one with Dithiocarbonate Salts*.—(i) The *cis*-compound (40 (8 mg) with reagent A (0.3 ml) in a sealed tube at *ca*. 65 °C for 4 d gave no trithiocarbonate; some 1,4-di-*O*-benzyl erythritol (3 mg), m.p. and mixed m.p. 57—58.5°, wa isolated.

(ii) The *trans*-compound (38) (10 mg) with reagent A (0.3 ml) under the same conditions gave 1,4-di-*O*-benzyl-DL threitol (2 mg), m.p. and mixed m.p. 55—57°.

3α-(*Imidazol*-1-*ylthiocarbonylthio*)-trans-(4aαH,8aβH)-*decalin*-2β-*ol* (46).—A mixture of 3α-mercapto-*trans*-

[23] P. W. Feit and D. T. Nielsen, *J. Medicin. Chem.*, 1967, **10** 927.

decalin-2β-ol [24] (0.5 g), *NN'*-thiocarbonyldi-imidazole (0.64 g), pyridine (19 g), and dichloromethane (25 ml) was stirred for 12 h and worked up in the usual way. T.l.c. (dichloromethane–ether, 1 : 1) showed that the product contained at least four components, one of which was isolated as a solid. Recrystallisation from dichloromethane gave the *imidazolyl derivative* (46) (70 mg), m.p. 150—151°, $\nu_{max.}$ (mull) 3 250 cm^{-1}, τ 1.43 (1 H, s), 2.13 (1 H, s), 2.83 (1 H, s), 5.77 (1 H, m), 7.35 (1 H, s, OH; exchanged by D_2O), and 7.2—8.8 (14 H, m) (Found: C, 56.6; H, 6.7; N, 9.4; S, 21.4. $C_{14}H_{20}N_2OS_2$ requires C, 56.7; H, 6.8; N, 9.45; S, 21.2%).

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[24] M. E. Ali, N. G. Kardouche, and L. N. Owen, *J.C.S. Perkin I*, 1975, 748.