A New Method for the Deoxygenation of Secondary Alcohols

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On reaction with tributylstannane, *O*-cycloalkyl thiobenzoates and *O*-cycloalkyl *S*-methyl dithiocarbonates, derived from secondary alcohols, give good yields of the corresponding hydrocarbons. The mechanism of this planned reaction is radical in character and thus rearrangements common in carbocation reactions are avoided. The particular applicability of this procedure in sugar chemistry is illustrated. The reaction takes place under neutral conditions compatible with the presence of the functional groups which normally occur in aminoglycoside antibiotics.

A convenient general synthesis of *O*-cycloalkyl thioesters has been developed which gives access to *O*-cycloalkyl thioformates and thioacetates. An extension of this method affords the hitherto unknown *O*-cycloalkyl selenoformates and selenobenzoates. An attempted extension of the method to the synthesis of *O*-cholesteryl tellurobenzoate gave, unexpectedly, a good yield of benzyl cholesteryl ether.

In many areas of natural product chemistry, especially sugars and aminoglycoside antibiotics, there is need for a reaction in which secondary OH is replaced by H without the possibility of rearrangement. In general, primary alcohols are easily converted into toluene-*p*-sulphonates, mesylates, *etc.*, and equally easily reduced either directly, or *via* an appropriate halide or sulphur displacement followed by reduction, to the corresponding methyl compounds. The method can be extended to secondary alcohols where the oxygen is attached to a carbon atom at which S_N2 processes take place readily.[1,2]

Tertiary alcohols can also be dehydrated readily and the resultant olefin can be hydrogenated so that this transformation also is not a serious problem.

The major difficulty lies in the deoxygenation of secondary hydroxy-groups attached to carbon atoms at which S_N2 processes are hindered. Many of the secondary hydroxy-groups met in sugar chemistry are of this category. Since the selective removal of secondary hydroxy-groups may well confer enhanced biological activity on many polyhydroxylated antibiotics, we have sought to provide a method which involves use of neutral conditions and which avoids ionic processes of any type. In practice this means that the carbon–oxygen bond must be cleaved homolytically to give carbon radicals which must be quenched by hydrogen atom transfer from a suitable donor. Such a process is probably involved in the reduction of phenol phosphate esters and of amides [3] by sodium–ethylamine and similar reagents. We hoped, however, to avoid such vigorous reducing conditions and to develop a method which would be compatible with the presence of carbonyl, ester, lactone, and polyene functions.

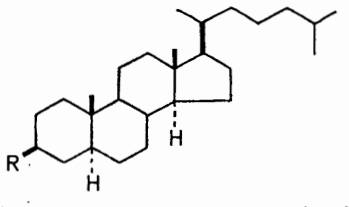
Initially, we considered the possibility of decarboxylation of an alkoxycarbonyl radical ($ROC\dot{O} \longrightarrow R\cdot + CO_2$)

[1] I. T. Harrison and S. Harrison, 'Compendium of Organic Synthetic Methods,' Wiley–Interscience, New York, 1971.

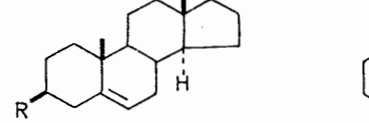
[2] S. Masamune, G. S. Bates, and P. A. Rossy, *J. Amer. Chem. Soc.*, 1973, **95**, 6452; S. Masamune, G. S. Bates, and P. E. Geoghiou, *ibid.*, 1974, **96**, 3686; and references cited therein.

[3] G. W. Kenner and N. R. Williams, *J. Chem. Soc.*, 1955, 522; R. E. Ireland, D. C. Muchmore, and U. Hengartner, *J. Amer. Chem. Soc.*, 1972, **94**, 5098.

but the literature suggests that such radicals are thermally stable unless the derived carbon radical is especially stabilised. Thus in the reduction of ethyl, benzyl, and cyclohexyl chloroformates by tributylstannane [4] the



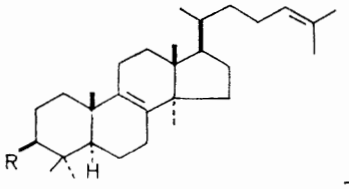
(1) R = OH
(2) R = O·COCl
(3) R = O·CO·NH·NH_2
(4) R = O·CO·NH·NH·CPh_3
(5) R = O·CO·N:N·CPh_3
(6) R = O·CO·CPh_3
(9) R = O·CS·N

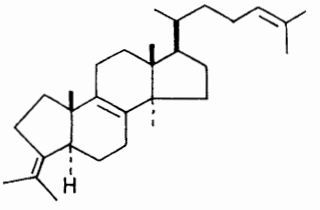


(10) R = O·CS·N, =NEt BF_4^-
(19) R = O·CSH
(26) R = O·CSPh
(27) R = H
(39) R = O·CS·N, O

desired fragmentation is seen only with the benzyl compound. In order to examine a photochemically generated alkoxycarbonyl radical, the model alcohol 5α-cholestan-3β-ol (1) was converted *via* the chloroformate (2) into the carbazate (3). Treatment with triphenylmethyl chloride–pyridine gave the ester (4), which was oxidised by t-butyl hypochlorite–pyridine to the azo-ester (5) in good overall yield from (1). On heating above the m.p. (105°), this gave a complex mixture, but photolysis (cyclohexane; Pyrex) gave a single compound, readily shown to be the triphenylacetate (6) by comparison with an authentic sample. There was no evidence for loss of carbon dioxide from the intermediate alkoxycarbonyl radical.

Free-radical conversion of an alcohol into an iodo-compound would also be acceptable, as reduction under mild





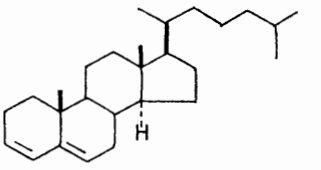
(7) R = O·COCl
(11) R = O·CS·N, =N
(12) R = O·CS·N, =NEt BF_4^-
(28) R = H
(30) R = O·CS·SMe

(8)

Bu^n_3Sn·S·COPh
(33)

conditions would give overall deoxygenation. However, there is no evidence to suggest bond homolysis in the reaction of chloroformates with iodide ion (RO·COI ⟶ $\dot{R} + CO_2 + \dot{I}$); instead, ionic displacement and elimination processes take place.[5] In confirmation of this, we found that the reaction of lanosterol chloroformate (7) with sodium or lithium iodide gave mainly isolanostatriene (8), the normal product of concerted rearrangement through a carbocation-like intermediate.[6]

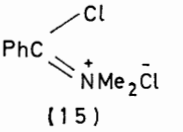
The analogous reaction sequence in the thiocarbonyl series was also examined. Treatment of cholestan-3β-ol (1) with an excess of *NN'*-thiocarbonyldi-imidazole [7]



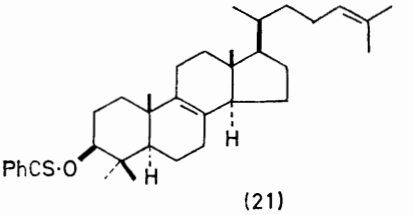
(13) R = O·CS·N, =N

(14)

(16) R = O·CPh(:$\overset{+}{N}Me_2$) $\bar{C}l$
(17) R = O·CSPh
(18) R = O·CSH
(20) R = O·CSMe
(22) R = O·CS·C_6H_4·OMe-*p*
(23) R = O·CS·C_6H_4·NO_2-*p*
(24) R = O·CS·C_6H_4·SO_2Me-*p*
(25) R = O·CS·C_6H_3(OMe)$_2$-2,4
(29) R = O·CS·SMe
(40) R = O·CS·CH=CHPh
(41) R = O·CS·CH_2·CH_2Ph
(61) R = O·CSePh
(62) R = O·CSeH
(63) R = O·CH_2Ph



(15)



(21)

gave (9) in high yield. Further reaction with triethyloxonium fluoroborate gave a salt which was assigned the *N*-alkylated structure (10) in view of its ready hydrolysis to regenerate (1). On reaction with an excess of iodide ion, this salt gave a mixture of 3β-iodocholestane and cholest-2-ene identical with that obtained from (2) and iodide ion. When lanosterol was subjected to the same sequence of reactions, proceeding through (11) and (12), the major product was again the rearranged olefin (8).

When the homoallylic thioimidazolide (13), prepared from thiocarbonyldi-imidazole and cholesterol, was

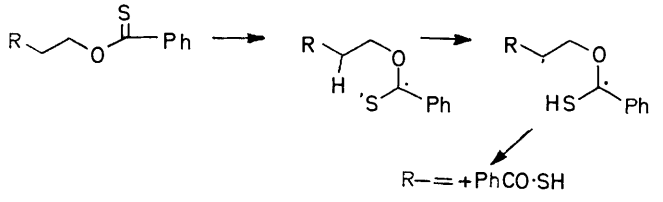
[4] H. G. Kuivila and E. J. Walsh, jun., *J. Amer. Chem. Soc.*, 1966, **88**, 571, 577; P. Beak and S. W. Mojé, *J. Org. Chem.*, 1974, **39**, 1320.

[5] D. N. Kevill and F. L. Weitl, *J. Org. Chem.*, 1967, **32**, 2633; Prof. A. Goosen, personal communication.

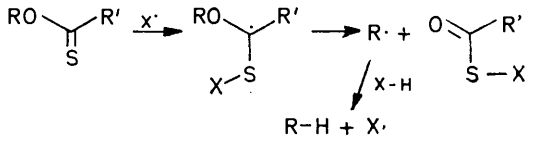
[6] L. Ruzicka, M. Montavon, and O. Jeger, *Helv. Chim. Acta*, 1948, **31**, 818; C. Dorée, J. F. McGhie, and F. Kurzer, *J. Chem. Soc.*, 1949, S167; Y. M. Y. Haddad and G. H. R. Summers, *ibid.*, 1959, 769.

[7] W. Ried and B. M. Beck, *Annalen*, 1961, **646**, 96.

photolysed (cyclohexane; silica), a high yield of cholesta-3,5-diene (14) was obtained. This is analogous to the known photoelimination of thiobenzoic acid from homoallylic and *O*-(2-phenylethyl) thiobenzoates.[8] Consideration of the mechanism of thiobenzoate photolysis[9] (Scheme 1) suggested a possible mechanism for deoxygenation (Scheme 2), brought about by the driving force

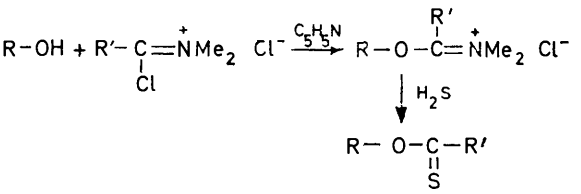


SCHEME 1



SCHEME 2

obtained in going from thiocarbonyl to carbonyl. The realisation of such a process necessitated the preparation of a variety of *O*-alkyl thioesters, mostly thiobenzoates. Earlier work[10] showed that these compounds may be prepared in high yield by treatment of the alcohol with (thiobenzoylthio)acetic acid and sodium imidazolide, but these strongly basic conditions are incompatible with many functional groups. From initial observations by Eilingsfeld[11] we have developed a general synthesis of *O*-alkyl thioesters under essentially neutral conditions. Condensation of an alcohol with an imidoyl chloride methochloride (prepared from phosgene and a tertiary amide) gives an intermediate salt, which is converted into a thioester by reaction with hydrogen sulphide–pyridine (Scheme 3). Thus, treatment of *NN*-dimethylbenzamide with phosgene gave the imidoyl chloride methochloride (**15**). Reaction with cholesterol at room temperature gave the salt (**16**), which could be isolated as a crystalline solid. Treatment *in situ* with hydrogen sulphide–pyridine gave *O*-cholesteryl thiobenzoate (**17**) in excellent yield. Similar conditions were used for a wide variety of *O*-alkyl thioester preparations.



SCHEME 3

By operating at low temperatures, the reactive imidoyl chlorides derived from dimethylformamide and dimethylacetamide could be used, and the intermediate salt could be thiolysed before the well known conversion into chlorohydrocarbon could take place. In this way, little known *O*-esters of thioformic and thioacetic acid could be obtained in high yield. The Table summarises the steroidal thioesters prepared by this method; other examples are described later.

Steric retardation of both the condensation and the thiolysis step was observed for *O*-lanosteryl thiobenzoate and *O*-cholesteryl 2,4-dimethoxythiobenzoate. An attempted preparation of *O*-cholesteryl thio-*o*-toluate failed at the second stage. Although condensation of the imidoyl chloride from *NN*-dimethyl-*o*-toluamide with cholesterol proceeded normally, subsequent reaction with hydrogen sulphide gave only a small amount of thioster with alcohol, cholesteryl chloride, and other, unidentified by-products.

Preparation of thioesters by the imidoyl chloride route*

Compound	Molar ratio [ROH : pyridine : chloride]	*T* (°C) [*t*/h] (for 1st step)	Yield (%)
O-Cholesteryl thioformate (18)	1 : 3 : 1.5	−10 [0.5]	82
O-Cholestanyl thioformate (19)	1 : 3 : 1.5	−10 [0.5]	88
O-Cholesteryl thioacetate (20)	1 : 3 : 1.5	15 [0.25]	84
O-Cholesteryl thiobenzoate (17)	1 : 2.5 : 1.2	15 [0.5]	90
O-Lanosteryl thiobenzoate (21)	1 : 4 : 1.75	15 [5]	92
O-Cholesteryl *p*-methoxythiobenzoate (22)	1 : 2.5 : 1.2	15 [1]	91
O-Cholesteryl *p*-nitrothiobenzoate (23)	1 : 2.5 : 1.2	0 [0.25]	84
O-Cholesteryl *p*-methylsulphonylthiobenzoate (24)	1 : 3 : 1.4	15 [0.5]	82
O-Cholesteryl 2,4-dimethoxythiobenzoate (25)	1 : 2.5 : 1.2	15 [3]	86

* The solvent was normally tetrahydrofuran–chloroform.

A variety of *O*-alkyl *S*-methyl dithiocarbonates were also prepared under essentially standard conditions. The alcohol was heated in tetrahydrofuran with an excess of sodium hydride containing a trace of imidazole as catalyst for alkoxide formation. An excess of carbon disulphide was added and, after further heating under reflux, the dithiocarbonate salt was alkylated with an excess of iodomethane or dimethyl sulphate.

In order to effect reaction according to Scheme 2, a reagent is required which affords radicals X capable of forming a strong S–X bond and which can also act as a hydrogen atom donor. In this way the carbon radical

[8] S. Achmatowicz, D. H. R. Barton, P. D. Magnus, G. A. Poulton, and P. J. West, *J.C.S. Perkin I*, 1973, 1567.

[9] D. H. R. Barton, M. Bolton, P. D. Magnus, P. J. West, G. Porter, and J. Wirz, *J.C.S. Chem. Comm.*, 1972, 632; J. Wirz, *J.C.S. Perkin II*, 1973, 1307.

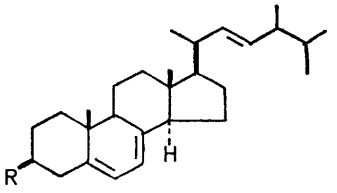
[10] D. H. R. Barton, C. Chavis, M. K. Kaloustian, P. D. Magnus, G. A. Poulton, and P. J. West, *J.C.S. Perkin I*, 1973, 1571.

[11] H. Eilingsfeld, M. Seefelder, and H. Weidinger, *Chem. Ber.*, 1963, **96**. 2899.

would be quenched in the desired manner and the radical X regenerated. Consideration of thermochemical data suggested that tributylstannane might be expected to possess the desired properties.

In the event, treatment of *O*-cholestanyl thiobenzoate (26) with an excess of tributylstannane in refluxing toluene gave the deoxygenation product, cholestane (27), in yields which increased with increasing dilution. For optimum conversion, a solution of the thioester was added gradually to a refluxing solution of tributylstannane under argon. After chromatography and crystallisation, the hydrocarbon was obtained (70—75%).

Reduction through inverse addition of the tin hydride to the thioester gave a similar result. The previously described alkoxythiocarbonylimidazoles were suitable substrates for reduction, and an 82% yield of cholestane was obtained from (9). However, reduction of the analogous lanosteryl compound (11) proceeded slowly, and required very large amounts of tributylstannane. The work-up was complicated by the presence of large amounts of a non-polar, non-volatile tin compound, and the desired product (28) was obtained in rather low yield. It is probable that imidazole was produced during the reaction, and behaved as a typical secondary amine in catalysing decomposition of the tin hydride to hexabutyldistannane.[12] *O*-Cholesteryl *S*-methyl dithiocarbonate (29) was also readily reduced under the standard conditions to give cholest-5-ene in high yield. Conversion of lanosterol into the dithiocarbonate (30) followed by reduction also gave (28) efficiently without the complications encountered with the imidazole derivative. The contrast between the ionic-type reactions of lanosterol (see above) giving rearrangement and the radical-type reaction giving no rearrangement confirms the radical nature of our reduction process. Similarly, *O*-ergosteryl *S*-methyl dithiocarbonate (31) was reduced in good yield to give the hydrocarbon (32). This preparation would be difficult to accomplish



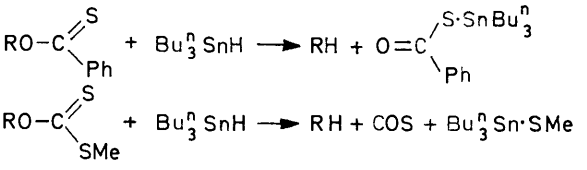
(31) R = O·CS·SMe
(32) R = H

$CH_3 \cdot [CH_2]_{16} \cdot CH_2R$

(34) R = O·CSPh
(35) R = O·CS·N(=N)(=)
(36) R = O·CS·SMe
(37) R = O·$SnBu^n_3$
(38) R = O·CH_2·S·$SnBu^n_3$

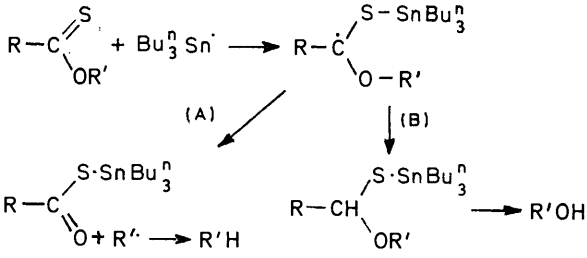
by ionic-type reactions, owing to the *i*-steroid rearrangement.

In the reduction of *O*-cholesteryl thiobenzoate, a strongly u.v.-active by-product was isolated by preparative t.l.c. as an oil whose spectroscopic properties were consistent with formulation as *S*-tributylstannyl thiobenzoate (33). In the dithiocarbonate reductions, carbonyl sulphide was evolved. The crude product retained the *S*-methyl group but was substantially free from carbonyl i.r. absorption. This suggests the stoicheiometry for the two reductions shown in Scheme 4.



SCHEME 4

When the aliphatic *O*-alkyl thioesters (18)—(20) were treated with tributylstannane, the major product was the corresponding alcohol, with little deoxygenation. This is in agreement with a two-step process in which the primary step, addition of the tributylstannyl radical to sulphur, is not necessarily followed by C–O fragmentation but by hydrogen capture and further reaction to give finally the alcohol. The inverse concentration dependence observed for the yield of deoxy-compound is a reflection of the need to retain a low concentration of the adduct radical in order to favour fragmentation over hydrogen capture. These considerations are summarized in Scheme 5.



SCHEME 5

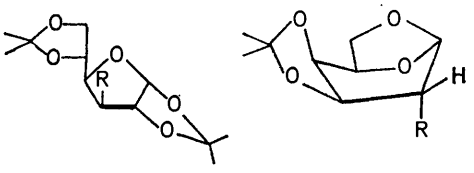
The delicate balance between pathways (A) and (B) in Scheme 5 is illustrated by reactions of the primary derivatives (34)—(36) prepared from octadecan-1-ol by the standard processes described earlier. Reduction of the thiobenzoate (34) gave predominantly a single new compound (t.l.c.) which was hydrolysed to octadecan-1-ol on attempted isolation or on treatment of the reaction mixture with a trace of acid. This was presumably the alkoxide (37) or a similar compound. No octadecane was present, showing that the slightly lower stability of primary relative to secondary radicals prevents fragmentation of the adduct radical. From the imidazolide (35), a new product was obtained as an oil which was identified spectroscopically as the hemithioacetal (38).

The primary dithiocarbonate (36) reacted sluggishly with tributylstannane, giving the corresponding alcohol as the major product.

Other secondary alcohol thiocarbonyl derivatives were examined with a view to improving yields. Reaction of

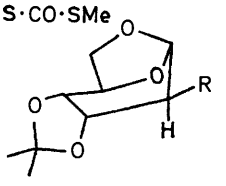
[12] R. Sommer, H. Neumann, and B. Schneider, *Tetrahedron Letters*, 1964, 3875.

the previously described salt (10) with morpholine gave the simple thiocarbamate (39), but this was completely unreactive towards tributylstannane. Several ring-substituted *O*-cholesteryl thiobenzoates were prepared



(42) R = OH
(43) R = O·CS·SMe
(44) R = H
(45) R = S·CO·SMe

(46) R = OH
(47) R = H



(48) R = OH
(49) R = H

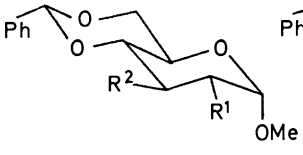
(Table) and compared with the unsubstituted compound under standard reduction conditions. The *p*-nitro-compound was unsuitable as a substrate, owing to attack of the reagent on the nitro-group, but all the other compounds gave good yields of deoxygenation product. However, they offered no real advantage over the unsubstituted compound. *O*-Cholesteryl thiocinnamate (40) * was reduced in the usual way, but no cholest-5-ene was formed. The major product was *O*-cholesteryl (2-phenyl)thiopropionate (41), presumably formed by free radical conjugate addition of the stannane, followed by hydrolysis during work-up of the resulting keten hemithioacetal derivative.

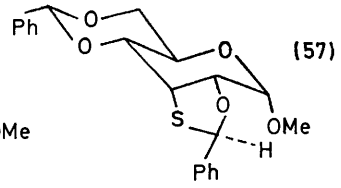
The deoxygenation process was extended into the field of carbohydrates by using simple model compounds. Treatement of the *S*-methyl dithiocarbonate (43) from di-*O*-isopropylideneglucofuranose [13] (42) with tributylstannane in refluxing toluene or xylene gave 3-deoxy-1,2 : 5,6-di-*O*-isopropylidene-α-glucofuranose (44) in 80—90% yield. In non-aromatic solvents of comparable b.p. such as dioxan or light petroleum, the reaction gave additional products and the yield of (44) was considerably diminished. The deoxy-compound (44) has been prepared previously by reduction with Raney nickel of the rearranged dithiocarbonate (45), produced in moderate yields by pyrolysis of (43).[14] The dithiocarbonate reduction process is clearly a superior preparative method for compound (44).

In these reductions, purification by chromatography of the *S*-methyl dithiocarbonate was not necessary. The following examples are illustrative. Conversion of 1,6-anhydro-3,4-*O*-isopropylidene-β-D-galactose [15] (46) into the crude dithiocarbonate, followed by reduction with tributylstannane, gave the deoxy-compound (47) in high yield. A similar result was obtained in the conversion of the corresponding altrose derivative [16] (48) into (49).

Application of the usual imidoyl chloride procedure to methyl 4,6-*O*-benzylidene-α-D-glucopyranoside (50) gave a mixture of monothiobenzoates, from which the major isomer could be isolated by crystallisation (70%). The minor isomer was isolable from the mother liquors by column chromatography and crystallisation. The two isomers were identified by the multiplicity of the n.m.r. signal due to the proton adjacent to the thiobenzoylated oxygen. This was distinct from other signals in the spectra of both isomers. The major isomer gave a broad triplet (*J ca.* 10 Hz) for this signal, and is thus the 3-isomer (51), and the minor isomer gave the expected doublet of doublets (*J ca.* 10 and 3.5 Hz). This 3 > 2 isomer distribution is the reverse of that observed for this carbohydrate derivative in acylation and sulphonylation.[17]

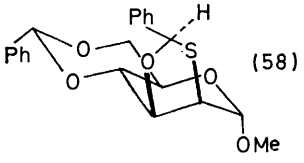
Deoxygenation of the 3-thiobenzoate (51) proceeded normally to give (53), also available through reduction with lithium aluminium hydride of the di-*O*-*p*-tolyl sulphonyl derivative [18] of (50).



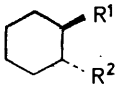


(57)

(50) $R^1 = R^2 = OH$
(51) $R^1 = OH, R^2 = O{\cdot}CSPh$
(52) $R^1 = O{\cdot}CSPh, R^2 = OH$
(53) $R^1 = OH, R^2 = H$
(56) $R^1 = R^2 = O{\cdot}CSPh$
(59) $R^1 = OCHS, R^2 = O{\cdot}CSPh$



(58)



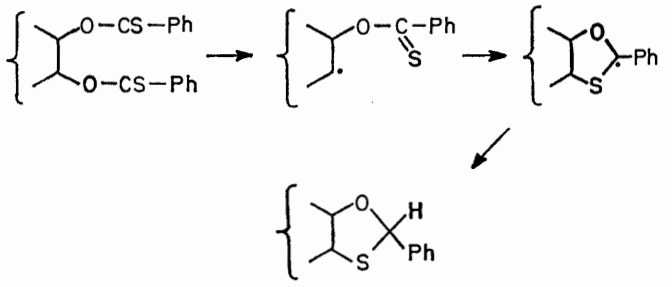
(54) $R^1 = OH, R^2 = O{\cdot}CSPh$
(55) $R^1 = R^2 = O{\cdot}CSPh$
(60) $R^1 = O{\cdot}COPh, R^2 = O{\cdot}CSPh$

Cyclohexane-1,2-diol was also converted into the mono-*O*-thiobenzoate (54) in high yield. Repetition of the process gave the bis-derivative (55). However, no pure compound could be isolated from the mixture obtained

* This compound, which was prepared by Mr. P. Hansen, will be described fully in a later publication.

[13] K. Freudenberg, *Ber.*, 1927, **60**, 232.
[14] E. J. Hedgeley, W. G. Overend, and R. A. C. Rennie, *J. Chem. Soc.*, 1963, 4701 and references cited therein.
[15] F. Micheel, *Ber.*, 1929, **62**, 687.
[16] F. H. Newth and L. F. Wiggins, *J. Chem. Soc.*, 1950, 1734.
[17] G. J. Robertson and C. F. Griffith, *J. Chem. Soc.*, 1935, 1193; H. R. Bolliger and D. A. Prins, *Helv. Chim. Acta*, 1945, **28**, 465.
[18] E. Vis and P. Karrer, *Helv. Chim. Acta*, 1954, **37**, 378.

on reaction of the derivative (55) with tributylstannane. The reaction was reinvestigated with the carbohydrate analogue (56), prepared in the usual way. Reaction with tributylstannane gave a mixture (t.l.c.) which was largely composed of two sulphur-containing compounds of very similar polarity. These could be isolated from the crude mixture by direct crystallisation. The n.m.r. spectra suggested the presence of a mixture of isomers. One pure isomer was obtained after repeated crystallisation and was fully characterised in the usual way as one of the isomers (57) and (58), in which the phenyl group has been placed in the more stable configuration. The isomers presumably arise through cyclisation of the intermediate carbon radical onto thiocarbonyl as shown in Scheme 6.



SCHEME 6

By the standard imidoyl chloride procedure, the 3-*O*-thiobenzoate (51) was converted into the 2-*O*-thioformate (59). Reaction of this ' mixed ' thioester with tributylstannane did not give a tractable product.

Benzoylation of (54) gave the cyclohexanediol benzoate *O*-thiobenzoate (60). This was deoxygenated smoothly in the normal way to cyclohexyl benzoate, without any intramolecular participation of the benzoate function.

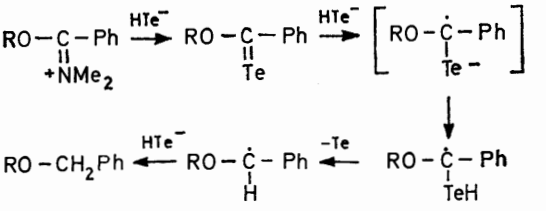
During these studies a report on a new method for preparing solutions of sodium hydroselenide appeared.[19] Reaction of elemental selenium with sodium borohydride in ethanol proceeds smoothly at room temperature according to equation (i). By reaction of such a solution with the previously described salt (16) we obtained

$$Se + NaBH_4 \xrightarrow{EtOH} (EtO)_3B + 3H_2 + NaHSe \quad (i)$$

a high yield of *O*-cholesteryl selenobenzoate (61), as a deep red, stable, crystalline substance. The corresponding ethyl selenobenzoate could be prepared similarly in excellent yield. Previous preparations of methyl selenobenzoate have utilised the action of hydrogen selenide–pyridine on the imidate ester hydrochloride, and gave only moderate yields.[20] The cholesteryl ester (61) reacted rapidly with tributylstannane under the usual conditions, but the amount of cholesterol formed was always greater than observed for the sulphur analogue. At best, a 60% conversion into the deoxygenation product was obtained. Presumably, the initial addition of the tin radical to the C=Se bond takes place more readily than in the sulphur case, and the resulting higher concentration of adduct radical produces more by-product.

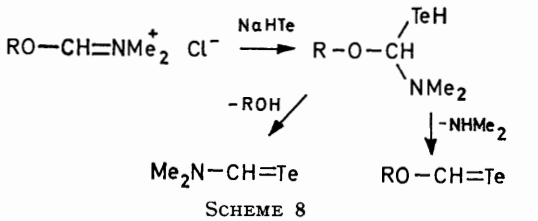
Aliphatic selenoesters have not been reported to date; by using the imidoyl chloride procedure we have prepared the first example, *O*-cholesteryl selenoformate (62) as a yellow, rather unstable solid. Other aspects of the chemistry of these selenoesters are under investigation.

Preparation of solutions of sodium hydrotelluride by the sodium borohydride process was also possible. On heating the powdered element with an excess of ethanolic borohydride with rigorous exclusion of oxygen, a rapid reaction sets in after a short induction period. Some of the borohydride is also hydrolysed, but the solution can be safely buffered with acetic acid to give a neutral solution of NaHTe. In an attempt to prepare *O*-cholesteryl tellurobenzoate, the salt (16) was treated with an excess of the telluride solution at −20 °C. However, immediate formation of elemental tellurium took place, and the single product isolated in high yield was benzyl cholesteryl ether (63). By use of inverse addition and an excess of the salt (16), the same result was obtained, (63) and unchanged (16) being the sole products. A reasonable mechanism would involve fast electron transfer to a tellurobenzoate, followed by loss of tellurium after hydrogen capture as in Scheme 7. The highly stabilised nature



SCHEME 7

of the intermediate carbon radical would assist the loss of tellurium. In keeping with this proposal, we found that treatment of the analogous aliphatic salt from cholesterol and the Vilsmeier salt gave no cholesteryl methyl ether. Instead, cholesterol and a highly unstable, orange, steroidal compound were produced. On attempted chromatographic isolation, the latter decomposed with formation of tellurium. It was probably the corresponding telluroformate. An unstable yellow non-steroidal compound was also formed, and was possibly dimethyltelluroformamide, produced



SCHEME 8

through partitioning of the tetrahedral intermediate in two ways as in Scheme 8. Further experiments may

[19] ' Organic Selenium Compounds: their Chemistry and Biochemistry,' eds. D. L. Klayman and W. H. Gunther, Wiley–Interscience, New York, 1973, p. 41.

[20] R. Mayer, S. Scheithauer, and D. Kunz, *Chem. Ber.*, 1966, **99**, 1393.

allow isolation of these interesting telluroesters from more hindered substrates. It is, however, already clear that an efficient and selective new synthesis of benzyl ethers is to hand.

EXPERIMENTAL

M.p.s were determined with a Kofler hot-stage apparatus. N.m.r. spectra were determined for solutions in [^{2}H]chloroform with tetramethylsilane as internal standard. Visible absorption spectra were determined for solutions in dichloromethane, and optical rotations for solutions in chloroform. All solvents were purified and dried by standard techniques.

The ' usual work-up ' refers to dilution with water, extraction with dichloromethane, washing with dilute acid, sodium hydrogen carbonate solution, and water, and drying ($MgSO_4$).

Cholestan-3β-yl Carbazate (3).—Cholestanol (3.00 g) was stirred for 2 h with ether (30 ml) containing phosgene (3 g), and the mixture was then evaporated *in vacuo*. The residue was stirred in tetrahydrofuran (30 ml) and a solution of hydrazine hydrate (2 ml) in methanol (20 ml) was added. After 2 min the reaction was worked up with water–dichloromethane; the organic solution was washed with water, dried, and evaporated. Recrystallisation gave the *carbazate* (3) (3.05 g; 92%), m.p. 208—209° (from dichloromethane–methanol), $\nu_{max.}$ (Nujol) 3420, 1725, 1205, and 1075 cm^{-1}, $[\alpha]_D^{20}$ +12.7 (*c* 3), τ 6.40 (2 H, s, exchanged with D_2O), 5.45 (1 H, m), and 3.92 (s, 1 H, exchanged with D_2O) (Found: C, 75.0; H, 11.1; N, 6.1. $C_{28}H_{50}N_2O_2$ requires C, 75.3; H, 11.3; N, 6.3%).

Cholestan-3β-yl Triphenylmethylazoformate (5).—The foregoing carbazate (3) (2.0 g) in dichloromethane (40 ml) and dry pyridine (2 ml) was stirred at 0 °C for 0.5 h with triphenylmethyl chloride (2.0 g). Stirring was continued at room temperature for 0.5 h, the solution was washed with water, dried, and evaporated, and the residue was chromatographed on alumina (Brockmann grade III). Gradient elution with petroleum (b.p. 60—80°) containing increasing amounts of benzene gave (4) (88%) slightly contaminated with triphenylmethanol. This product (1.65 g) in ether (70 ml) was stirred for 5 min at room temperature with pyridine (0.4 ml) and t-butyl hypochlorite (0.4 ml). After washing with water and drying, the solution was evaporated at 30 °C *in vacuo*. Recrystallisation with cooling from petroleum (b.p. 40—60°) gave the *azo-ester* (5) (1.35 g, 84%) as yellow prisms, m.p. 102—103° (decomp.), $[\alpha]_D^{20}$ +18.5 (*c* 2), $\nu_{max.}$ (Nujol) 1755, 1605, 1510, 1260, 1065, and 710 cm^{-1}, $\lambda_{max.}$ 239 nm (ε 47,300), τ 5.15 (1 H, m) and 2.78 (15 H, s) (Found: C, 82.1; H, 8.9; N, 4.0. $C_{47}H_{62}N_2O_2$ requires C, 82.2; H, 9.1; N, 4.1%).

Photolysis of the Azo-ester (5.)—The foregoing ester (205 mg) in cyclohexane (350 ml) was irradiated under argon with a 125 W high-pressure lamp and Pyrex apparatus, with water cooling. After 0.75 h, the solution was evaporated and the residue recrystallised twice from acetone–methanol to give the triphenylacetate (6) (163 mg, 78%) as needles, m.p. and mixed m.p. 126—129°.

Cholestan-3β-yl Triphenylacetate (6).—A mixture of cholestanol (388 mg), triphenylacetyl chloride (310 mg), and pyridine (0.25 ml) was stirred for 2 days with tetrahydrofuran (2 ml). After the usual work-up, the *ester* (6) was isolated by preparative t.l.c. on silica gel (35%); m.p. 127—129° (from acetone–methanol), $[\alpha]_D^{20}$ +6.1° (*c* 2), $\nu_{max.}$ (Nujol) 1725, 1605, 1210, 1010, 740, and 700 cm^{-1}, τ 5.13 (1 H, m) and 2.78 (15 H, s) (Found: C, 85.55; H, 9.35. $C_{47}H_{62}O_2$ requires C, 85.7; H, 9.5%).

Lanosteryl Chloroformate (7).—Lanosterol (1.00 g) was stirred for 6 h at room temperature in tetrahydrofuran (10 ml) with phosgene (12.5% w/v solution in toluene; 5 ml). Evaporation *in vacuo* gave the *chloroformate* (7) (95%) as large prisms, m.p. 112—113° (from acetone), $[\alpha]_D^{22}$ +45.0 (*c* 4.5), $\nu_{max.}$ (Nujol) 1770, 1380, 1160, 965, and 695 cm^{-1} (Found: C, 76.2; H, 9.9; Cl, 7.0. $C_{31}H_{49}ClO_2$ requires C, 76.25; H, 10.1; Cl, 7.3%).

Treatment of Cholestanyl Chloroformate with Iodine Ion.—The chloroformate (0.45 g) was refluxed for 16 h in dry acetone (15 ml) with anhydrous sodium iodide (1.5 g). After the usual work-up, the product was chromatographed on a silica plate [60 × 20 × 0.2 cm; elution with petroleum (b.p.60—80°)]. The crude iodo-compound (80% yield) was recrystallised twice from acetone to give pure 3β-iodocholestane, m.p. and mixed m.p. 103—105°.

Treatment of Lanosteryl Chloroformate with Iodide Ion.—The chloroformate (0.40 g) and anhydrous lithium iodide (0.75 g) were heated under reflux for 5 h in dry tetrahydrofuran (10 ml). After the usual work-up, the product was subjected to preparative t.l.c. as in the foregoing preparation. Removal, extraction, and recrystallisation of the least polar band gave isolanostatriene, m.p. and mixed m.p.[6] 134—136°. The slightly more polar band afforded an iodo-compound (74 mg, 17%) which crystallised from acetone–methanol as silky needles, m.p. 140—142°. A satisfactory elemental analysis was not obtained, but the n.m.r. spectrum exhibited a broad, one-proton signal at τ 5.68 and the mass spectrum exhibited *m/e* 536 (M^+) and 409 (M − 127, base peak).

N-(*Cholestan-3β-yloxythiocarbonyl*)*imidazole* (9).—Cholestanol (2.50 g) and *NN'*-thiocarbonyldi-imidazole (2.0 g) were refluxed in 1,2- dichloroethane (25 ml) for 3 h. The mixture was evaporated and the residue worked up in the usual way and recrystallised from ether–methanol to give the *imidazolide* (9) (2.92 g, 90%) as white needles, m.p. 151—152°, $[\alpha]_D^{20}$ −57.2° (*c* 0.8), $\nu_{max.}$ (Nujol) 1410, 1305, 1265, 1125, and 1010 cm^{-1}, $\lambda_{max.}$ 278 nm (ε 9600), τ 4.58 (1 H, m), 2.98 (1 H, s), 2.38 (1 H, s), and 1.67 (1 H, s) (Found: C, 74.6; H, 9.9; N, 5.65; S, 6.4. $C_{31}H_{50}N_2OS$ requires C, 74.65; H, 10.1; N, 5.6; S, 6.4%).

N-(*Cholesteryloxythiocarbonyl*)*imidazole* (13).—Cholesterol (1.0 g) and *NN'*-thiocarbonyldi-imidazole (1.0 g) were refluxed for 4 h in tetrahydrofuran (7 ml). Work-up as usual and recrystallisation gave the *derivative* (13) (1.15 g, 87%) as plates, m.p. 144—145° (from ether–ethanol), $[\alpha]_D^{20}$ −32.6° (*c* 3), $\nu_{max.}$ (Nujol) 1410, 1310, 1265, 1125, and 1020 cm^{-1}, $\lambda_{max.}$ 278 (ε 9600), τ 4.59 (1 H, m), 4.50br (1 H, d), 2.94 (1 H, s), 2.33 (1 H, s), and 1.63 (1 H, s) (Found: C, 75.2; H, 9.5; N, 5.5; S, 6.3. $C_{31}H_{48}N_2OS$ requires C, 75.0; H, 9.7; N, 5.6; S, 6.4%).

N-(*Lanosteryloxythiocarbonyl*)*imidazole* (11).—The previously described method was followed, using lanosterol (0.50 g) and *NN'*-thiocarbonyldi-imidazole (0.35 g) in 1,2-dichloroethane (5 ml). The *derivative* (11) (0.49 g, 82%) was obtained as tiny needles, m.p. 162—164° (from acetone–ethanol), $[\alpha]_D^{20}$ +11.1° (*c* 3), $\nu_{max.}$ (Nujol) 3120, 1295, 1250, 1125, and 985 cm^{-1}, $\lambda_{max.}$ 279 (ε 9400), τ 4.97 (1 H, m), 3.04 (1 H, s), 2.45 (1 H, s), and 1.17 (1 H, s) (Found: C, 75.9; H, 9.8; N, 5.1; S, 5.8. $C_{34}H_{52}N_2OS$ requires C, 76.1; H, 9.8; N, 5.7; S, 6.0%).

Alkylation and Hydrolysis of the Imidazole Derivative (9).—The imidazolide (100 mg) and triethyloxonium fluoroborate

(60 mg) were refluxed in dichloromethane (5 ml) for 0.5 h. Evaporation gave a gel, which was dissolved in tetrahydrofuran (5 ml) containing water (0.25 ml). After heating at 50—60 °C for 0.5 h, the mixture was worked up and the product recrystallised to give cholestan-3β-ol (45 mg).

Alkylation and Iodolysis of the Imidazole Derivative (9).—The foregoing procedure was followed to obtain the salt (10) as a gel. This was refluxed for 6 h with tetrahydrofuran (5 ml) and tetrabutylammonium iodide (0.35 g), and the resulting mixture was examined by t.l.c. Comparison with standards revealed the presence of 3β-iodocholestane and cholest-2-ene in a *ca.* 3 : 1 ratio.

Alkylation and Iodolysis of the Imidazole Derivative (11).—*N*-(Lanosteryloxythiocarbonyl)imidazole (200 mg) and triethyloxonium fluoroborate (110 mg) were refluxed in dry dichloromethane (10 ml) for 0.54 h. The mixture was evaporated and the residue was refluxed overnight in tetrahydrofuran (10 ml) with tetrabutylammonium iodide (0.80 g). T.l.c. indicated the presence of lanosterol and an olefin, with no significant amount of iodo-compound. Isolation (t.l.c.) and crystallisation gave isolanostatriene, m.p. and mixed m.p. 135—137° (from acetone–methanol).

Photolysis of the Imidazole Derivative (13).—The imidazolide (300 mg) in cyclohexane (300 ml) was irradiated under argon in Pyrex apparatus at room temperature, with a 125 W high-pressure lamp. After 3.5 h the solution was evaporated and the residue chromatographed on alumina (grade III). Elution with petroleum (b.p. 60—80°) gave cholesta-3,5-diene (154 mg, 69%).

O-*Cholestanyl Thioformate* (19).—*NN*-Dimethylformamide (2.2 g) was added to a solution of phosgene in dichloromethane (10% w/v; 40 ml) with stirring. After 0.5 h at room temperature, the solvent was evaporated off *in vacuo* and the residue stirred with dichloromethane (40 ml) and cooled to −15 to −20 °C. A solution of cholestanol (7.75 g) in dichloromethane (30 ml) and tetrahydrofuran (30 ml) was added during 15 min, and stirring was continued while the temperature was raised to 0 °C during 15 min. Dry pyridine (3 ml) was added, and a stream of dry hydrogen sulphide was passed through the solution for 5 min. After the usual work-up, evaporation gave the crude thioester, which was dried at 0.1 mmHg, dissolved in 2 : 1 petroleum (b.p. 60—80°)–dichloromethane, and filtered down a short column of silica gel (elution with the same solvent mixture). Evaporation and recrystallisation gave the *thioformate* (19) (7.75 g, 88%), m.p. 104—105° (from ether–methanol), $[\alpha]_D^{22}$ −69.6° (*C* 5), $\nu_{max.}$ (Nujol) 1245 cm^{-1}, $\lambda_{max.}$ 381 and 247 nm (ε 12.5 and 11,100), τ 4.57 (1 H, m) and 0.27 (1 H, s) (Found: C, 77.6; H, 11.1; S, 7.5. $C_{28}H_{48}OS$ requires C, 77.7; H, 11.2; S, 7.4%).

O-*Cholesteryl Thioformate* (18).—The method described in the foregoing preparation was followed, the cholestanol being replaced by cholesterol (7.72 g). Recrystallisation from ethanol gave the *thioformate* (18) (7.2 g, 82%) as long, pale yellow needles, m.p. 124—126°, $[\alpha]_D^{20}$ −74.8° (*c* 3), $\nu_{max.}$ (Nujol) 1240 cm^{-1}, $\lambda_{max.}$ 382 and 247 nm (ε 13 and 8700), τ 4.73 (1 H, m), 4.70br (1 H, d), and 0.29 (1 H, s) (Found: C, 77.9; H, 10.6; S, 7.5. $C_{28}H_{46}OS$ requires C, 78.1; H, 10.8; S, 7.4%).

O-*Cholesteryl Thioacetate* (20).—This preparation differs slightly from the other thioester preparations, in that the imidoyl chloride has to be kept in suspension until treatment with the alcohol, in order to prevent self-condensation. *NN*-Dimethylacetamide (4.2 g) was stirred in dichloromethane (25 ml) and a solution of phosgene in toluene (20% w/v; 25 ml) was added during 5 min. The semisolid mixture was diluted with 1 : 1 dichloromethane–toluene (25 ml) and stirred at room temperature for 0.5 h, and a solution of cholesterol (4.83 g) in dichloromethane (50 ml) was added. After stirring for 10 min, the mixture was cooled to 0 °C and treated with a stream of dry hydrogen sulphide during dropwise addition (5 min) of pyridine (15 ml). After 10 min, the mixture was worked up in the usual way and chromatographed on silica gel [elution with 2 : 1 light petroleum (b.p. 60—80°)–dichloromethane] to give the crude *thioester* (20) (95%), obtained as plates (4.68 g, 84%), m.p. 140—142° (from ether-ethanol), $[\alpha]_D^{22}$ +10.2° (*c* 3), $\nu_{max.}$ (Nujol) 1285, 1230, and 1045 cm^{-1}, $\lambda_{max.}$ 250 nm (ε 8600), τ 4.72 (1 H, m), 4.63br (1 H, d), and 7.48 (3 H, s) (Found: C, 78.4; H, 10.6; S, 7.2. $C_{29}H_{48}OS$ requires C, 78.3; H, 10.9; S, 7.2%).

O-*Cholesteryl Thiobenzoate* (17).—*NN*-Dimethylbenzamide (4.5 g) was kept for 17 h at room temperature in dichloromethane (40 ml) containing phosgene (5 g). The mixture was evaporated and the residue in dichloromethane (40 ml) was added to cholesterol (7.72 g) in tetrahydrofuran (50 ml) with stirring. The intermediate condensation product (16) crystallised, and after stirring for a further 10 min was converted into thioester by addition of pyridine (7 ml) and treatment for 5 min with hydrogen sulphide. After the usual work-up, the solution was evaporated and the residue recrystallised from dichloromethane–ethanol to give yellow prisms of the thiobenzoate (17) (9.1 g, 90%), identical with samples prepared by the older procedures.

Cholesteryl N-*Methylbenzimidate Methochloride* (16).—*NN*-Dimethylbenzamide (3.1 g) was kept overnight in phosgene–dichloromethane (10% w/v; 40 ml); then the solution was evaporated *in vacuo* and the residue stirred in dichloromethane (30 ml) during addition of cholesterol (7.7 g) in tetrahydrofuran (40 ml). Dry ether (60 ml) was added, and after 0.5 h the salt (16) was filtered off, washed with ether and dried *in vacuo* at 40 °C. The resulting fine white prisms (10.2 g, 94%) had m.p. 120—125° (decomp.), $[\alpha]_D^{20}$ −21° (*c* 2), $\nu_{max.}$ (Nujol) 1670, 1605, 1505, 1260, 900, and 680 cm^{-1}, τ 6.67 (3 H, 2), 6.38 (3 H, s), and 5.87 (1 H, m). Owing to its hygroscopic nature and thermal instability, a satisfactory analysis of the salt could not be obtained.

O-*Lanosteryl Thiobenzoate* (21).—(*a*) (Thiobenzoylthio)-acetic acid (2.12 g) in tetrahydrofuran (50 ml) was stirred with sodium hydride (60% dispersion; 1.0 g) and imidazole (1.3 g). The solution was heated to reflux for 1 min, a solution of lanosterol (4.0 g) in tetrahydrofuran (50 ml) was added, and refluxing was continued for 2 h. (Thiobenzoylthio)acetic acid (1.0 g) and sodium hydride (0.25 g) in tetrahydrofuran (20 ml) were added, and the refluxing was continued for a further 2 h. After cooling, glacial acetic acid was added gradually, and the mixture was worked up in the usual way. The crude product was chromatographed on silica gel [elution with 3 : 1 light petroleum (b.p. 60—80°)–benzene]. The thioester (21) (1.87 g, 35%) was obtained as yellow prisms, m.p. 187—189° (from benzene–methanol).

(*b*) *NN*-Dimethylbenzamide (1.5 g) was converted into the imidoyl chloride as described under cholesteryl thiobenzoate. The product (after evaporation) was stirred for 5 h with lanosterol (2.56 g) in tetrahydrofuran (12.5 ml) and dichloromethane (5 ml). The suspension was diluted with dichloromethane (40 ml), treated with pyridine (3 ml), and saturated with dry hydrogen sulphide. After passage of the gas for 10 min, the mixture was left at room temperature for 1 h, then worked up in the usual way. Evaporation gave a yellow solid, which was boiled with methanol (50 ml);

the mixture was cooled, then filtered, and the product washed with methanol. The resulting *thioester* (21) (2.87 g, 92%) had m.p. 188—190°, $[\alpha]_D^{20}$ −49.9 (*c* 2), $\nu_{max.}$ (Nujol) 1250, 1120, and 700 cm^{-1}, $\lambda_{max.}$ 418, 294, and 255 nm (ε 150, 11,700, and 11,500), τ 4.88 (1 H, m) (Found: C, 80.5; H, 10.1; S, 5.9. $C_{36}H_{54}OS$ requires C, 80.4; H, 10.4; S, 6.1%).

O-*Cholesteryl* p-*Methoxythiobenzoate* (21).— By the usual procedure (see cholesteryl thiobenzoate), *N*-(*p*-methoxybenzoyl)piperidine (2.65 g) was treated with an excess of phosgene in dichloromethane during 3 h at room temperature. The mixture was evaporated and the residue was stirred for 0.5 h at room temperature with cholesterol (3.86 g) in dichloromethane (20 ml) and tetrahydrofuran (20 ml). After addition of pyridine (3 ml) the solution was saturated with hydrogen sulphide (10 min) and worked up in the usual way. The thioester (22) (4.85 g, 91%) was obtained as needles, m.p. 190—192° (from dichloromethane–ethanol), identical with a sample prepared *via* the (thiobenzoylthio)-acetic acid route.[8]

O-*Cholesteryl* p-*Nitrothiobenzoate* (23).—*NN*-Dimethyl-*p*-nitrobenzamide (2.9 g) was converted into the imidoyl chloride in the usual way (24 h at room temperature). After evaporation, the solid was suspended with stirring in dichloromethane (30 ml) and cooled to 0 °C, and cholesterol (3.5 g) in tetrahydrofuran (25 ml) was added. After stirring at 0 °C for 15 min, the mixture was treated with pyridine (4 ml) and hydrogen sulphide, then worked up in the usual way. Recrystallisation of the crude product gave the *thioester* (23) as deep yellow plates, m.p. 179.5—181° (from chloroform—ethanol) (84%), $[\alpha]_D^{22}$ −30.6° (*c* 2.5), $\nu_{max.}$ 1605, 1530, 1355, 1260, and 865 cm^{-1}, $\lambda_{max.}$ 430, 303, and 280 nm (ε 240, 11,200, and 10,500), τ 4.50 (1 H, m) and 4.53br (1 H, d) (Found: C, 73.8; H, 8.9; N, 2.4; S, 6.1. $C_{34}H_{49}O_3NS$ requires C, 74.0; H, 8.95; N, 2.5; S, 5.8%).

O-*Cholesteryl* 2,4-*Dimethoxythiobenzoate* (25).—This was prepared as described for the *p*-methoxy-compound, from 2,4-dimethoxy-*NN*-dimethylbenzamide (2.8 g). Imidoyl chloride formation was allowed to proceed for 20 h and condensation with cholesterol for 3 h. After addition of pyridine (3 ml), the solution was treated for 15 min with hydrogen sulphide, and left at room temperature for 15 h. The usual work-up and chromatography gave the *thioester* (25) (4.8 g, 86%) as pale yellow needles (from ethanol), m.p. 144—146°, $[\alpha]_D^{20}$ −27.8 (*c* 5), $\nu_{max.}$ (Nujol) 1625, 1570, 1285, 1265, 1230, 1035, 835, and 805 cm^{-1}, $\lambda_{max.}$ 400, 329, 267, and 243 nm (ε 830, 10,400, 7500, and 11,500), τ 6.14 (6 H, s), 4.34 (2 H, m), 3.5—3.3 (2 H, m), and 2.15 (1 H, d, *J* 10 Hz) (Found: C, 76.4; H, 9.3; S, 5.7. $C_{36}H_{54}O_3S$ requires C, 76.3; H, 9.6; S, 5.7%).

O-*Cholesteryl* p-*Methylsulphonylthiobenzoate* (24).—*NN*-Dimethyl-*p*-methylsulphonylbenzamide (2.4 g) was kept at room temperature for 2 days in dichloromethane (20 ml) containing phosgene (4 g). The mixture was evaporated, and the residue stirred for 15 min with cholesterol (3.0 g), dichloromethane (35 ml), and hexamethylphosphoramide (5 ml). Pyridine (3.5 ml) was added, and after a further 15 min the mixture was treated for 10 min with hydrogen sulphide and worked up in the usual way. Recrystallisation from benzene–ethanol gave the *thioester* (24) (82%) as needles, m.p. 235–237°, $[\alpha]_D^{23}$ −32.3° (*c* 3.6), $\nu_{max.}$ (Nujol) 1400, 1250, 1235, 1155, 955, and 780 cm^{-1}, $\lambda_{max.}$ 426, 306, and 235 nm (ε 220, 6900, and 9400), τ 6.95 (3H, s), 4.2—4.8 (2 H, m) and 1.88 (ABq, *J ca.* 9 Hz) (Found: C, 71.7; H, 8.9; S, 10.7. $C_{35}H_{52}O_3S_2$ requires C, 71.9; H, 9.0; S, 11.0%).

O-*Cholesteryl* S-*Methyl Dithiocarbonate* (29).—Cholesterol (3.86 g), sodium hydride dispersion (80%; 0.5 g), and imidazole (20 mg) were stirred and refluxed for 3 h under nitrogen in tetrahydrofuran (50 ml). Carbon disulphide (3 ml) was added, and after refluxing for a further 0.5 h, methyl iodide (3 ml) was added, and refluxing was continued for 0.5 h. After addition of acetic acid (3 ml), the reaction was worked up in the usual way. The crude product was filtered in light petroleum (b.p. 40—60°)–benzene (1 : 1) down a small silica gel column, and recrystallised to give the dithiocarbonate (29) (92%), 126—128° (from ether–ethanol) (lit.,[21] 126—127°).

O-*Lanosteryl* S-*Methyl Dithiocarbonate* (30).—Lanosterol (4.0 g) was heated under reflux for 20 h with a mixture of sodium hydride (80%; 0.75 g) imidazole (0.2 g), tetrahydrofuran (40 ml), carbon disulphide (5 ml), and hexamethylphosphoramide (5 ml). Dimethyl sulphate (2 ml) was added, and, after refluxing for 0.5 h, the mixture was treated with acetic acid (2 ml) and worked up in the usual way. After chromatography as in the foregoing preparation, the product was recrystallised twice from dichloromethane–methanol to give the *dithiocarbonate* (30) as prisms (3.9 g, 85%), m.p. 124—126°, $[\alpha]_D^{20}$ +129° (*c* 3), $\nu_{max.}$ (Nujol) 1245, 1185, and 1030 cm^{-1}, $\lambda_{max.}$ 354, 284, and 233 nm (ε 77, 10,900, and 8500), τ 7.42 (3 H, s) and 4.82 (1 H, m) (Found: C, 74.2; H, 10.0; S, 12.25. $C_{32}H_{52}OS_2$ requires C, 74.4; H, 10.1; S, 12.4%).

N-(*Octadecyloxythiocarbonyl*)*imidazole* (35).—Octadecan-1-ol (2.70 g) and *NN'*-thiocarbonyldi-imidazole (2.40 g) were refluxed for 1 h in tetrahydrofuran (15 ml). After the usual work-up, evaporation gave an oil which was dissolved in light petroleum (25 ml); the solution was filtered and evaporated. Recrystallisation at room temperature by slow evaporation of a solution in ether–methanol gave the *imidazolide* (35) (3.15 g, 85%), m.p. 38.4—40°, $\nu_{max.}$ (Nujol) 1315, 1295, 1245, 1110, and 1010 cm^{-1}, $\lambda_{max.}$ 275.5 nm (ε 9700), τ 5.36 (2 H, t, *J* 7 Hz), 2.97 (1 H, s), 2.38, (1 H, s), and 1.67 (1 H, s) (Found: C, 69.6; H, 10.5; N, 7.3; S, 8.2. $C_{22}H_{40}N_2OS$ requires C, 69.4; H, 10.5; N, 7.4; S, 8.4%).

O-*Octadecyl Thiobenzoate* (34).—Octadecan-1-ol (2.70 g), imidazole (1.35 g), sodium hydride (80%; 0.85 g) and (thiobenzoylthio)acetic acid (2.5 g) were refluxed for 2 h in dry tetrahydrofuran (50 ml). After the usual work-up, the product was chromatographed on alumina (grade III), with light petroleum (b.p. 60—80°) as eluant, to give the *thiobenzoate* (34) (2.79 g, 74%), m.p. 48.5—49.5° (from ether–methanol), $\nu_{max.}$ (Nujol) 1600, 1275, 1240, 1090, and 700 cm^{-1}, $\lambda_{max.}$ 412, 295, and 249 nm (ε 140, 12,300, and 7300) (Found: C, 76.95; H, 10.9; S, 8.3. $C_{25}H_{42}OS$ requires C, 76.9; H, 10.8; S, 8.2%).

O-*Ergosteryl* S-*Methyl Dithiocarbonate* (31).—This was prepared from ergosterol (4.1 g) as described for the cholesteryl compound. Recrystallisation of the chromatographed product from ether–ethanol gave the *dithiocarbonate* (31) as plates (88%), m.p. 140—145° (decomp.), $[\alpha]_D^{20}$ −52.1° (*c* 5), $\nu_{max.}$ (Nujol) 1590, 1245, 1100, and 1020 cm^{-1}, $\lambda_{max.}$ (cyclohexane) 292sh, 281, and 273 nm (ε 6500, 14,800, and 14,800) τ 7.43 (3 H, s) and 4.3—4.9 (5 H, m) (Found: C, 74.2; H, 9.3; S, 13.2. $C_{30}H_{46}OS_2$ requires C, 74.0; H, 9.5; S, 13.2%).

5α-*Cholestane from the Thiobenzoate* (26).—*O*-Cholestan-3β-yl thiobenzoate (510 mg) in toluene (25 ml) was added during 0.5 h to a solution of tributylstannane (450 mg) in toluene (20 ml) with refluxing under argon. After reflux-

[21] G. L. O'Connor and H. R. Nace, *J. Amer. Chem. Soc.*, 1953, **75**, 2118.

ing till colourless (1.5 h) the solvent was removed *in vacuo* and the residue chromatographed on alumina (grade I), with light petroleum (b.p. 60—80°) as eluant. Evaporation of the eluates gave cholestane (from acetone–methanol) (270 mg, 73%), m.p. and mixed m.p. 78.5—79.5°.

5α-Cholestane from the Thioimidazolide (9).—The procedure described above was followed, with cholestanyloxythiocarbonylimidazole (510 mg). The yield of recrystallised hydrocarbon was 79%.

Cholest-5-ene from the Thioimidazolide (13).—Reduction of cholesteryloxythiocarbonylimidazole (505 mg) as in the previous preparation gave cholest-5-ene (278 mg, 74%) as needles, m.p. 92—93.5° (from ethanol), identical with a sample prepared by reduction of cholesteryl chloride with sodium–liquid ammonia.

Cholest-5-ene from the Dithiocarbonate (28).—The foregoing procedure was followed; *O*-cholesteryl *S*-methyl dithiocarbonate (1.0 g) in toluene (30 ml) was added to tributylstannane (800 mg) under reflux in toluene (30 ml) during 1 h. The refluxing was continued for 6 h, and the solution was evaporated and the residue chromatographed as usual and recrystallised to give cholest-5-ene, m.p. 90—92° (78%).

Lanosta-8,24-diene (28) *from the Dithiocarbonate* (30).—*O*-Lanosteryl *S*-methyl dithiocarbonate (1.40 g) in xylene (40 ml) was added during 0.5 h to tributylstannane (1.20 g) in xylene (30 ml) with refluxing and stirring under argon. After refluxing for a further 2 h, the solution was evaporated and the residue chromatographed in the usual way. Recrystallisation from acetone gave the hydrocarbon (83%), m.p. and mixed m.p.[22] 79—80°.

Ergosta-5,7,22-triene (32).—By the foregoing procedure, *O*-ergosteryl *S*-methyl dithiocarbonate (31) (0.95 g) was reduced with tributylstannane (0.65 g) in toluene (total volume 60 ml). After chromatography, the *ergosta-5,7,22-triene* was recrystallised from ethanol as needles (0.52 g, 67%), m.p. 111—112.5°, $[\alpha]_D^{22}$ −95.5° (*c* 2) (Found, C, 88.1; H, 11.4. $C_{28}H_{44}$ requires C, 88.35; H, 11.65%).

S-Tributylstannyl Thiobenzoate from Reduction of O-Cholestanyl Thiobenzoate (26).—*O*-Cholestanyl thiobenzoate (26) (510 mg) was reduced as described earlier. After evaporation, the product was chromatographed on a silica plate (60 × 20 × 0.3 cm), with light petroleum (b.p. 60—80°) containing 10% benzene as eluant. The strongly u.v.-active band (R_F *ca* 0.3) was removed and eluted with ether. Evaporation at 50 °C and 0.1 mmHg left the thiobenzoate as an oil, $\nu_{max.}$ (film) 3050, 2850, 1665, 1600, 1120, and 760 cm^{-1}, τ 2.8—2.4 (3 H, m) and 1.85 (2 H, m).

Reduction of Octadecyloxythiocarbonylimidazole (35).—By the usual procedure *N*-(octadecyloxythiocarbonyl)imidazole (1.0 g) in toluene (30 ml) was added over 1 h to tributylstannane (1.5 g) reflexing in toluene (30 ml). After refluxing for a further 4 h, the cooled solution was washed with dilute hydrochloric acid and water, dried, and evaporated to give an oil which was chromatographed on alumina (grade III), with light petroleum as eluant. Evaporation of the eluates gave the tin derivative (38) as an oil which decomposed on attempted volatilisation at 0.1 mmHg; $\nu_{max.}$ (film) 2850, 1460, 1373, and 1020 cm^{-1}, τ 6.52 (2 H, t, *J* 6 Hz) and 5.31 (2 H, s).

N-Cholestan-3β-yloxythiocarbonyl)morpholine (39).—Cholestanyloxythiocarbonylimidazole (3.0 g) and triethyloxonium fluoborate (1.3 g) were stirred for 2 h at room temperature in dichloromethane (20 ml). Morpholine (3 g) was then added, and after a further 1 h the mixture was diluted with dichloromethane and worked up in the usual way. Evaporation *in vacuo* gave the *thiocarbamate* (39) (95%) as plates, m.p. 175—177° from ethanol, $[\alpha]_D^{22}$ +10.6° (*c* 3), $\nu_{max.}$ (Nujol) 1290, 1250, 1235, 1170, 1115, and 895 cm^{-1}, τ 6.35br (6 H, s), 3.99 (2 H, m), and 4.73 (1 H, m) (Found: C, 74.2; H, 10.7; N, 2.5; S, 6.6. $C_{32}H_{55}NO_2S$ requires C, 74.2; H, 10.7; N, 2.7; S, 6.2%).

Reduction of Substituted O-Cholesteryl Thiobenzoates.—The appropriate *O*-thioester (2 mmol) in toluene (35 ml) was added over 1 h to tributylstannane (3 mmol) refluxing under argon in toluene (30 ml) and refluxing was continued until decolourisation was complete. The mixture was evaporated and the product examined by t.l.c. The cholest-5-ene was isolated by chromatography on alumina (grade I) and recrystallised from acetone–methanol.

O-Cholesteryl (2-Phenyl)thiopropionate (41).—*O*-cholesteryl thiocinnamate (kindly supplied by Mr. P. Hansen) (1.06 g) in toluene (40 ml) was added over 0.5 h to tributylstannane (0.85 g) in toluene (40 ml) under reflux under argon. After refluxing for a further 1.5 h, the solution was evaporated and the product chromatographed on alumina (grade III). Elution with light petroleum (b.p. 60—80°) followed by light petroleum (b.p. 60—80°)–benzene (5 : 1) gave the *thioester* (41) (0.86 g, 84%) as needles, m.p. 135—137° (from dichloromethane–ethanol), $[\alpha]_D^{22}$ −52.4° (*c* 2.6), $\nu_{max.}$ (Nujol) 1605, 1250, 1080, and 710 cm^{-1}, $\lambda_{max.}$ 249.5 (ε 7600), τ 7.00 (4 H, s), 4.73 (1 H, m), 4.62 (1 H, m), and 2.76 (5 H, s) (Found: C, 80.7; H, 9.95; S, 5.9. $C_{36}H_{54}O_5$ requires C, 80.8; H, 10.2; S, 6.0%).

3-Deoxy-1,2 : 5,6-di-O-isopropylidene-α-D-glucofuranose (44).—The *S*-methyl dithiocarbonate (43) (1.75 g) in toluene (40 ml) was added over 1 h to tributylstannane (2.1 g) in toluene (30 ml) under reflux under argon. Refluxing was continued overnight, and the solvent was then removed at 50 °C and 15 mmHg. The product was chromatographed on silica gel [elution with light petroleum (b.p. 40—60°) containing an increasing proportion of ether (5% increments)]. After elution of tin compounds followed by a minor by-product carbohydrate derivative also containing a tributyltin residue, the desired deoxy-compound (44) was obtained as an oil (1.04 g, 85%), $[\alpha]_D^{20}$ −7.5° (*c* 10) [lit.,[14] −5.8 (in EtOH, *c* 4)]. Hydrolysis with 0.02N-hydrochloric acid gave the 1,2-*O*-isopropylidene compound, m.p. 82—83° (from ether–petroleum) (lit.,[14] 84°). The deoxy-compound (44) was also converted into 3-deoxy-β-D-glucose tetra-acetate of correct m.p. by established procedures.

1,6-Anhydro-2-deoxy-3,4-O-isopropylidene-D-galactose (47).—A mixture of 1,6-anhydro-3,4-*O*-isopropylidene-β-D-galactose (4b) (900 mg), sodium hydride dispersion (80%; 270 mg), imidazole (5 mg), and dry tetrahydrofuran (12 ml) was stirred for 0.5 h at room temperature. Carbon disulphide (2 ml) was added and the stirring continued for 1 h. Methylation [MeI (0.5 ml)] and the usual work up gave a yellow oil which was heated under reflux in toluene (40 ml) in argon during addition over 1 h of a solution of tributylstannane (1.6 g) in toluene (30 ml). Refluxing was continued for 16 h, then the mixture was evaporated and worked up by silica chromatography as described for the analogous glucose derivative. Evaporation of t.l.c.-pure fractions gave the *deoxy-compound* (47) (780 mg, 94%). Distillation gave a sample of b.p. 75° at 2 mmHg, $[\alpha]_D^{22}$ −141° (*c* 3.5), τ 8.67 (3 H, s), 8.45 (3 H, s), 7.90 (2 H, m), 6.42 (1 H, m),

[22] J. F. McGhie, M. K. Pradhan, and J. F. Cavalla, *J. Chem. Soc.*, 1952, 3176.

5.4—5.9 (4 H, m), and 4.53 (1 H, t, *J* 2 Hz) (Found: C, 57.9; H, 7.5. $C_9H_{14}O_4$ requires C, 58.05; H, 7.6%).

1,6-*Anhydro*-2-*deoxy*-3,4-O-*isopropylidene*-D-*altrose* (49).—This was prepared and isolated exactly as in the foregoing preparation, starting from 1,6-anhydro-3,4-*O*-isopropylidene-β-D-altrose (48) (900 mg). The pure *deoxy-compound* (49) (710 mg, 86%) was obtained as an oil, b.p. 83° at 4 mmHg, $[\alpha]_D^{22}$ −123° (*c* 5), τ 8.67 (3 H, s), 8.45 (3 H, s), 8.5—7.5 (2 H, m), 6.4—5.1 (5 H, m), and 4.43 (1 H, m) (Found: C, 57.8; H, 7.5. $C_9H_{14}O_4$ requires C, 58.05; H, 7.6%).

Mono-O-*thiobenzoates* (51) *and* (52) *from Methyl* 4,6-O-*Benzylidene*-α-D-*glucopyranoside* (50).—*NN*-Dimethylbenzamide (3.7 g) was stirred overnight in dichloromethane (20 ml) containing phosgene (4 g), then the mixture was evaporated *in vacuo*. The residue was stirred in dichloromethane (20 ml) and a solution of pyridine (3.8 g) and methyl 4,6-*O*-benzylidene-α-D-glucopyranoside (5.3 g) in dry tetrahydrofuran (15 ml) was added. After 0.5 h at room temperature, the mixture was treated with dichloromethane (80 ml) and pyridine (2.5 g) and hydrogen sulphide was passed through for 10 min. After a further 1 h at room temperature, the mixture was worked up in the usual way, and evaporated to give a yellow solid. Recrystallisation from dichloromethane–petroleum gave in the first crop the pure 3-O-*thiobenzoate* (51) (3.7 g).

The mother liquors were chromatographed on silica gel, with benzene–ethyl acetate (20 : 1) as eluant to afford partial separation. Recrystallisation of enriched fractions gave more 3-thioester (0.9 g; total yield 4.6 g, 62%) which formed deep yellow needles, m.p. 186—187°, $[\alpha]_D^{22}$ +28.3° (*c* 2), $\nu_{max.}$ (Nujol) 3360, 1320, 1245, 1225, 1080, 995, 750, 700, and 690 cm^{-1}, $\lambda_{max.}$ 411, 293, and 253, nm (ε 170, 11,400, and 8000), τ 7.72br (1 H, s, exchanges with D_2O), 6.52 (3 H, s), 5.5—6.4 (5 H, m), 5.15 (1 H, d, *J* 4Hz), 4.48 (1 H, s), 3.47 (1 H, t, *J* 10 Hz), 2.5—2.9 (8 H, m), and 1.80 (2 H, m) (Found: C, 62.5; H, 5.5; S, 8.1. $C_{21}H_{22}O_6S$ requires C, 62.7; H, 5.5; S, 8.0%).

Recrystallisation of fractions containing mainly the less polar 2-O-*thiobenzoate* (52) gave pale yellow needles, m.p. 163—164°, $[\alpha]_D^{22}$ +127° (*c* 4.5), $\nu_{max.}$ (Nujol) 3480, 1595, 1230, 1040, 985, 775, 765, and 700 cm^{-1}, $\lambda_{max.}$ 412, 294, and 252 nm (ε 160, 10,800, and 8200), τ 7.35 (1 H, d, *J* 4 Hz, exchanges with D_2O), 6.63 (3 H, s), 5.4—6.8 (5 H, m), 4.78 (1 H, d, *J* 4 Hz), 4.45 (1 H, s), 4.23 (1 H, d, *J* 4 and 9.5 Hz), 2.78 (8 H, m), and 1.77 (2 H, m) (Found: C, 62.8; H, 5.3; S, 7.8. $C_{21}H_{22}O_6S$ requires C, 62.7; H, 5.5; S, 8.0%).

Methyl 4,6-O-*Benzylidene*-3-*deoxy*-α-D-*glucopyranoside* (53).—The foregoing 3-*O*-thiobenzoate (51) (0.80 g) in toluene (50 ml) was added during 1 h to tributylstannane (0.65 g) in toluene (30 ml) under argon under reflux in the usual way. When decolourised (2.5 g) the mixture was evaporated and the crude product chromatographed on alumina (grade III) with benzene, then ethyl acetate–benzene as eluants. The product was eluted in 10—30% ethyl acetate–benzene, and was crystallised to give the 3-deoxy-compound (53) as needles (70%) [from chloroform–light petroleum (b.p. 60—80°)], m.p. 184—186°, $[\alpha]_D^{20}$ +123° {lit.,[18] m.p. 186—188°, $[\alpha]_D^{20}$ +126°}.

Methyl 4,6-O-*Benzylidene*-2,3-*di*-O-*thiobenzoyl*-α-D-*glucopyranoside* (56).—*NN*-Dimethylbenzamide (2,3 g) was converted into the imidoyl chloride in the usual way and the product in dichloromethane (20 ml) was stirred at room temperature for 0.5 h with a solution of methyl 4,6-O-benzylidene-α-D-glucopyranoside (3.5 g) and pyridine (1.7 g) in tetrahydrofuran (20 ml). The mixture was then diluted with dichloromethane (100 ml) and pyridine (3 g) and treated for 15 min with dry hydrogen sulphide. After a further ½ h at room temperature the product was isolated by the usual work-up. Evaporation of the dried solution gave a yellow solid, which was dissolved in dry tetrahydrofuran (20 ml) and dichloromethane (15 ml), and a solution of the imidoyl chloride (prepared as before from 2.3 g of dimethylbenzamide) in dichloromethane (15 ml) was added. After addition of pyridine (2 g), the solution was refluxed for 1.5 h, cooled, and treated as before with pyridine, dichloromethane, and hydrogen sulphide. After the usual work-up, the product was chromatographed on alumina (grade III) with benzene as eluant. The pure bis-thiobenzoate (56) was obtained as a deep yellow foam (4.89 g, 75%), τ 6.63 (3 H, s), 5.4—6.3 (4 H, m), 4.73 (1 H, d, *J* 3.5 Hz), 4.50 (1 H, s), 3.86 (1 H, d, *J* 3.5 and 9 Hz), 2.7br (12 H, s), and 7.8—8.2 (4 H, m). This material was identical with a sample prepared by Dr. S. Prabhakar by the (thiobenzoylthio)acetic acid procedure.

Reduction of the Bis-thiobenzoate (56).—The foregoing compound (1.57 g) in toluene (30 ml) was added during 1 h to a refluxing solution of tributylstannane (1.9 g) in toluene (35 ml) under argon. After refluxing for 6 h, the solution was still yellow; more stannane (1 g) was added, and refluxing was continued for 15 h. Evaporation gave a semisolid which was dissolved in dichloromethane–light petroleum (b.p. 60—80°); the solution was evaporated to incipient crystallisation and cooled. This gave a mixture (0.45 g, 39%) of isomers (57) and (58). After several recrystallisations, one pure *isomer* was obtained as silky needles (from dichloromethane–light petroleum), m.p. 197—199°, $[\alpha]_D^{22}$ −44.4° (*c* 3), $\nu_{max.}$ (Nujol) 1155, 1090, 1050, 985, 975, 755, and 700 cm^{-1}, τ 6.48 (3 H, s), 5.5—6.2 (6 H, m), 4.90 (1 H, d, *J* 2.5 Hz), 4.43 (1 H, s), 3.77 (1 H, s), and 2.7br (10 H, s) (Found: C, 65.2; H, 5.7; S, 8.4. $C_{21}H_{21}O_5S$ requires C, 65.4; H, 5.5; S, 8.3%).

trans-*Cyclohexane*-1,2-*diol Monothiobenzoate* (54) *and the Derived* O-*Thiobenzoate* (55) *and Benzoate* (60).—*NN*-Dimethylbenzamide (11.0 g) was converted into the imidoyl chloride in the usual way. After evaporation, the product in dichloromethane (75 ml) was added to a stirred solution of *trans*-cyclohexane-1,2-diol (7.5 g) in tetrahydrofuran (30 ml) and dichloromethane (30 ml). Pyridine (15 ml) was then added dropwise, and after 0.5 h at room temperature the mixture was diluted with dichloromethane (100 ml) and treated for 5 min with hydrogen sulphide. After 2 h it was worked up in the usual way, and the crude product crystallised from dichloromethane–petroleum to give the O-*thioester* (54) (12.1 g, 80%) as needles, m.p. 104—106°, $\nu_{max.}$ (Nujol) 3160, 3060, 1595, 1320, 1245, 1075, 1055, 780, and 695 cm^{-1}, $\lambda_{max.}$ 410, 286, and 235 nm (ε 170, 10,200, and 7100), τ 6.1 (1 H, m) and 4.4 (1 H, m) (Found: C, 65.9; H, 6.9; S, 13.4. $C_{13}H_{16}O_2S$ requires C, 66.1; H, 6.8; S, 13.6%).

Benzoylation in the usual way gave the *benzoate* (60) as yellow prisms (from methanol), m.p. 71—73°, $\nu_{max.}$ (Nujol) 1715, 1280, 1240, 1125, 1030, and 715 cm^{-1}, $\lambda_{max.}$ 412, 291, 281sh, 249infl, and 230.5 nm (ε 170, 14,400, 13,600, 11,200, and 19,900), τ 4.5 (1 H, m) and 4.1 (1 H, m) (Found: C, 70.5; H, 6.0; S, 9.45. $C_{20}H_{20}O_3S$ requires C, 70.6; H, 5.9, S, 9.4%).

Treatment of the monothiobenzoate with 1.2 equiv. of the imidoyl chloride followed by hydrogen sulphide–pyridine in the usual manner gave *OO*-trans-*cyclohexane*-1,2-*diyl bisthiobenzoate* (55) as yellow prisms (from methanol) (78%), m.p. 137.5—139°, $\nu_{max.}$ (Nujol) 1280, 1255, 1245, 1240, 1125, 1030.

775, 715, and 690 cm^{-1}, $\lambda_{max.}$ 412. 288, and 237 nm (ε 300, 21,500, and 13,200), τ 3.7—4.0 (2 H, m) (Found: C, 67.5; H, 5.9; S, 18.05. $C_{20}H_{20}O_2S_2$ requires C, 67.4; H, 5.65; S, 18.0%).

Methyl 4,6-O-*Benzylidene*-3-O-*thiobenzoyl*-2-O-*thioformyl*-α-D-*glucopyranoside* (59).—Dimethylformamide (0.75 g) was added to an excess of phosgene in dichloromethane. After 0.5 h the mixture was evaporated and the solid stirred in dry dichloromethane (10 ml) during addition of the 3-*O*-thiobenzoate (2.4 g) in tetrahydrofuran (15 ml) and dichloromethane (15 ml) with ice cooling. Pyridine (2 ml) was added, and after stirring for 10 min at room temperature the mixture was treated with hydrogen sulphide for 10 min, then worked up in the usual way. Chromatography on silica gel, with benzene–ethyl acetate mixtures as eluant, gave the *thioformate* (59) (1.96 g) as a deep yellow foam, followed by starting material (0.52 g). A sample of the foam was subjected to preparative t.l.c. (silica; benzene); the purified product crystallised slowly from light petroleum (b.p. 60—80°) as large yellow prisms, m.p. 143—144°, $[\alpha]_D^{22}$ −112° (*c* 2), $\nu_{max.}$ (Nujol) 1240, 1220, 1055, 775, 765, and 690 cm^{-1}, τ 6.58 (3H, m), 4.88 (1 H, d, *J* 3.5 Hz), 4.52 (1 H, s), 3.87 (1 H, d), 3.05 (1 H, t, *J* 9 Hz), and 0.67 (1 H, s) (Found: C, 59.0; H, 4.9; S, 14.0. $C_{22}H_{22}O_6S_2$ requires C, 59.2; H, 5.0; S, 14.4%).

Cyclohexyl Benzoate from the O-*Thiobenzoate* (60).—The cyclohexanediol benzoate *O*-thiobenzoate (0.95 g) in toluene (30 ml) was added in the usual way to tributylstannane (1.2 g) refluxing in toluene (30 ml). After refluxing till the solution was decolourised (2.5 h), the toluene was evaporated off *in vacuo* and the residue chromatographed on silica gel. Elution with light petroleum (b.p. 60—80°)–benzene (5 : 1) gave tributylstannyl thiobenzoate; elution with the same solvents (1 : 1) gave cyclohexyl benzoate, which was distilled (Kugelrohr) at 120 °C and 0.5 mmHg to yield the pure ester (280 mg, 51%), identical with an authentic sample.

O-*Cholesteryl Selenobenzoate* (61).—Selenium powder (0.80 g) and sodium borohydride (0.50 g) were stirred in an inert atmosphere with ethanol (40 ml). When a clear, almost colourless solution had formed (more borohydride added if necessary), acetic acid (0.4 ml) was added, and the solution cooled to 0°. A solution of the salt (16) (5.5 g) in dichloromethane (40 ml) and ethanol (10 ml) was then added. After stirring at room temperature for 0.5 h, the mixture was diluted with dichloromethane (100 ml) and worked up in the usual way. Recrystallisation from dichloromethane–ethanol gave the *selenobenzoate* (61) (4.3 g, 78%) as deep red needles, m.p. 160—162°, $\nu_{max.}$ (Nujol) 1250, 1205, 1010, 920, and 765 cm^{-1}, $\lambda_{max.}$ 489, 337, and 257 nm. (ε 190, 8800, and 9400), τ 4.25 (1 H, m), 4.5 (1 H, m), 2.93 (3 H, m), and 1.72 (2 H, m) (Found: C, 73.3; H, 9.2; $C_{34}H_{50}OSe$ requires C, 73.2; H, 9.3%).

O-*Ethyl Selenobenzoate*.—*NN*-Dimethylbenzamide (4.5 g) was converted into the imidoyl chloride in the usual way, and, after evaporation, the product in dichloromethane (80 ml) was treated with ethanol (10 ml) followed by dry pyridine (5 ml). This solution was added to a solution of sodium hydroselenide, prepared as described in the foregoing preparation from selenium (2.4 g), ethanol (50 ml), sodium borohydride (1.5 g) with subsequent addition of acetic acid (1 ml). The deep red mixture was stirred for 10 min, then worked up in the usual way. Evaporation gave the selenoester contaminated with a small amount of dimethylbenzamide. The pure O-*ethyl selenobenzoate* was obtained by chromatography on alumina (grade V) with light petroleum (b.p. 40—60°) as eluant as a deep red oil (5.6 g, 97%), $\nu_{max.}$ (film) 1595, 1265, 1230, 1215, 1030, 720, and 690 cm^{-1}, $\lambda_{max.}$ 498, 338, and 257 nm (ε 200, 8900, and 9600) τ 8.38 (3H, t, *J* 7 Hz) and 5.16 (2 H, q, *J* 7 Hz) (Found: C, 50.95; H, 4.7. $C_9H_{10}OSe$ requires C, 50.7; H, 4.7%).

O-*Cholesteryl Selenoformate* (62.)—Dimethylformamide (0.9 g) was added to phosgene (2 g) in dichloromethane (20 ml). After 0.5 h, the solvent was evaporated off with exclusion of moisture and a solution of cholesterol (3.8 g) in dichloromethane (20 ml) and tetrahydrofuran (15 ml), precooled to −10 °C, was added to the solid imidoyl chloride. The mixture was stirred with ice cooling, pyridine (2 g) was added, and stirring was continued for 10 min at 0 °C. The resulting mixture was added at −20 °C to a solution of sodium hydroselenide prepared exactly as described previously from selenium (0.9 g) and sodium borohydride (0.6 g) in ethanol (30 ml), with subsequent addition of acetic acid (0.5 g). The yellow mixture was left without cooling for 10 min, then worked up in the usual way. After evaporation, the crude product was rapidly chromatographed on silica gel [elution with 1 : 1 dichloromethane–light petroleum (b.p. 40—60°)]. The yellow eluates were evaporated and the residue was dissolved in a small amount of dichloromethane and precipitated with ice-cold methanol (100 ml). The *selenoformate* (62) was dried *in vacuo* to give a pale yellow-orange solid (2.0 g, 44%). A sample recrystallised from dry acetonitrile formed orange needles, m.p. 126—128°, $\nu_{max.}$ (Nujol) 1365, 1250, and 1235 cm^{-1}, $\lambda_{max.}$ 277 and 448 nm (ε 8200 and 60), τ 4.5 (2 H, m) and −2.15 (1 H, s) (Found: C, 70.2; H, 9.65. $C_{28}H_{46}OSe$ requires C, 70.4; H, 9.7%). This compound should not be heated in hydroxylic solvents owing to its ready solvolysis.

Benzyl Cholesteryl Ether (63).—A mixture of powdered tellurium (1.30 g), ethanol (20 ml), and sodium borohydride (0.90 g) was heated and stirred under argon. After several minutes, vigorous effervescence set in, and the solution became pale purple in colour. After refluxing for about 15 min, most of the tellurium had dissolved. The mixture was cooled to −20 °C and a deoxygenated solution of acetic acid (1.2 ml) in ethanol (5 ml) was added. After 5 min, a solution of the salt (16) (2.0 g) in ethanol (25 ml) and dichloromethane (25 ml) was added, resulting in immediate precipitation of black tellurium. After stirring to room temperature, the mixture was filtered through Celite (washing with dichloromethane) and worked up in the usual way. Chromatography on alumina (grade I) [elution with light petroleum (b.p. 40—60°)–benzene] gave benzyl cholesteryl ether (1.4 g, 82%) as needles, m.p. 118—121° (from ethanol), $[\alpha]_D^{20}$ −25.2° {lit.,[23] m.p. 118–119°, $[\alpha]_D^{20}$ −26°}.

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