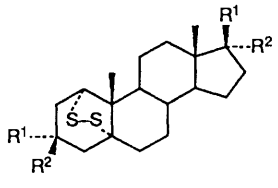
Investigation into the Reaction between 1α,5α-Epidithio Steroids and Electrophilic Halogenating Reagents:[1] Aspects of the Chemistry of Thiosulphenyl Chlorides and Thiiranium Ions

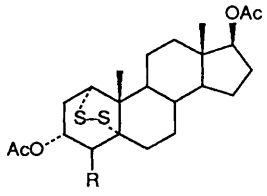
Derek H. R. Barton, Robert H. Hesse,* Stephen D. Lindell and Maurice M. Pechet
Research Institute for Medicine and Chemistry, 49 Amherst Street, Cambridge, MA 02142, USA

The reaction of sulphuryl dichloride with 1α,5α-epidithioandrostane-3α,17β-diol diacetate afforded a *ca.* 1:1 mixture of 1α-(chlorodithio)androst-5-ene-3α,17β-diol diacetate and 4β-chloro-1α,5α-epidithioandrostane-3α,17β-diol diacetate. These labile intermediates reacted with various nucleophiles to give a variety of products, many of which represent new or little known classes of thiosteroidal compounds. A number of these appear to arise from an unusual thiiranium ion intermediate. Possible explanations for the differing regioselectivity in the ring opening of the thiiranium ion are advanced.

As part of our continuing programme of investigations into novel steroid chemistry[2] we became interested in the properties of 1α,5α-epidithiosteroids. These unusual steroidal disulphides, most simply exemplified by the androstadienone derivatives **1** and **2**, were first described in 1959.[3] However, since that time their chemistry has received scant attention.[4] In particular, it occurred to us that the reaction of such compounds with halogenating reagents offered the potential for preparing a number of new thiosteroidal structures *via* sulphenyl halide chemistry. Although ultimately we sought to prepare compounds containing the more sensitive corticoid side-chain, initial studies were performed on the androstadienone-derived diacetate **3**.



1 R^1R^2 = O
2 R^1 = OH, R^2 = H



3 R = H
4 R = β-OH
5 R = β-OAc
6 R = =O
7 R = β-Cl

Results and Discussion

The reactions between the disulphide **3** and chlorine, bromine, sulphuryl dichloride, (dichloroiodo)benzene and *N*-bromosuccinimide (NBS) were investigated under a variety of conditions. In all cases the products of these reactions were consistent with the initial opening of the disulphide ring *via* electrophilic cleavage of the tertiary carbon–sulphur bond. This reaction was particularly clean and convenient when chlorinating reagents were employed as electrophiles.

This paper describes a variety of new thiosteroidal products formed by the reaction of substrate **3** with sulphuryl dichloride in tetrachloromethane or trichloro(fluoro)methane, followed by 'quenching' with a nucleophile. The nature of the products depended on the nucleophile used to 'quench' the reaction, as detailed in Table 1. The structure of the products was assigned on the basis of composition, molecular weight, spectral data, and chemical transformations as described below. The ^{1}H NMR and IR spectra and the elemental analyses were entirely consistent with the proposed structures.

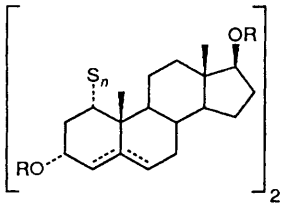
The dimeric nature of compounds **8**–**10** obtained by 'quenching' with potassium iodide (Table 1, entries 1 and 2) was apparent from the molecular weight, and the tetrasulphide link was suggested by composition and UV spectra (the UV absorption spectra of polysulphides are greatly influenced by the number of sulphur atoms in the chains).[5] Confirmation of structure was provided by the observation that the individual tetrasulphides **8**, **9** and **10** were reduced by sodium borohydride to give, respectively, the Δ^5-thiol **13**, the Δ^4-thiol **19** and a mixture of thiols **13** and **19**. Alternatively, hydrolysis of the Δ^5-tetrasulphide **8** in methanolic aq. potassium hydroxide[6] gave the dimeric tetrahydroxy disulphide **12** (88% yield), which was readily acetylated to give the tetraacetate **11**. Oxidation of the tetraol **12** with activated dimethyl sulphoxide,[7] followed by a base-catalysed β-elimination, yielded the known androsta-1,4-diene-3,17-dione[8] in 52% overall yield. Similarly, reduction (sodium borohydride) of the trisulphide **14**, obtained by 'quenching' with thiophenol (Table 1, entries 3 and 4), also yielded the 1α-thiol **13**. Oxidation of this thiol with iodine in the presence of sodium hydrogencarbonate[6] yielded the dimeric disulphide **11**.

Table 1 Reaction of the 1α,5α-disulphide **3** with sulphuryl dichloride

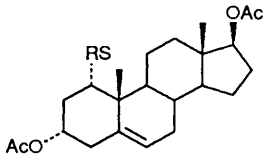
Entry	Nucleophile	Conditions[a]	Products (isolated yield %)
1	KI[b]	A	**8** (22), **9** (24), **10** (34), **26** (16)
2	KI[b]	B	**8** (18), **9** (32), **10** (36)
3	PhSH[c]	A	**14** (38), **22** (47)
4	PhSH[b]	B	**14** (33), **22** (50)
5	Bu^{t}SH[c]	B	**15** (35), **23** (42)
6	Bu_4NOAc[d]	B	**5** (34), **8** (14), **25** (5)
7	Water[b]	B	**4** (15), **8** (19), **10** (12), **25** (14)
8	aq. $AgClO_4$[b]	B	**4** (35), **8** (15), **13** (8)
9	aq. K_2CO_3[b]	C	**4** (18), **24** (13), **25** (9)

[a] Procedure A involved the direct addition of the 'quenching' nucleophile to the reaction mixture. Procedure B involved removal of the solvent under reduced pressure, redissolution in dry benzene, and then addition of a 'quenching' nucleophile. Procedure C involved adding the nucleophile to a solution of pure substrate **7**. [b] Nucleophile added as an aq. acetone solution. [c] Nucleophile added neat. [d] Nucleophile added as an acetone solution.

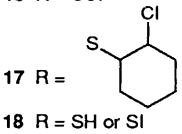
The UV absorption maximum of disulphides has been found to be quite dependent upon the CSSC dihedral angle,[9] an angle of 0° (as enforced by a five-membered ring) being associated with an extremely large bathochromic shift (λ_{max} ~370 nm). This phenomenon was helpful in assigning structure to the cyclic disulphides encountered in this study. Thus the 1,5-disulphides **3**, **4** and **5** and the 1,3-disulphides **26** all showed this bathochromic shift, while the 1,4-disulphides **23** and **24** in



8 Δ^5,Δ^5; R = Ac; n = 2
9 Δ^4,Δ^4; R = Ac; n = 2
10 Δ^4,Δ^5; R = Ac; n = 2
11 Δ^5,Δ^5; R = Ac; n = 1
12 Δ^5,Δ^5; R = H; n = 1



13 R = H
14 R = SSPh
15 R = $SSCMe_3$
16 R = SCl

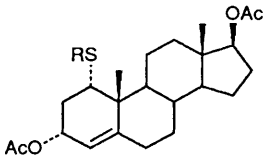


17 R =

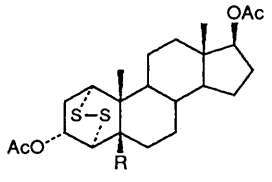
18 R = SH or Sl
18a R = SO_2H

which the CSSC dihedral angle can expand to more than 45° had UV maxima similar to open-chain analogues (λ_{max} ~260 nm). It is interesting to note that compound **25**, in which the trigonal centres at C-5 and -6 enforce an untwisting of the boat conformation with concomitant eclipsing of the CS bonds, shows the long-wavelength UV absorption characteristic of a CSSC dihedral near to 0°.

Compound **4**, formed by 'quenching' with water (Table 1, entries 7 and 8) was acetylated to the triacetate **5**, which was identical with material isolated when the reaction was quenched with acetate ion (entry 6). The composition of compound **4** suggested a hydroxylated analogue of compound **3**, the UV suggested a cyclic disulphide with a dihedral angle near 0°, and the ^{1}H NMR spectrum indicated the presence of a secondary, axial hydroxy group located adjacent to the acetoxy group at C-3. Oxidation of compound **4** with activated dimethyl sulphoxide (DMSO)[7] yielded the expected 4-keto compound **6** (59% yield), which exhibited the expected downfield shift of the 3β-proton when compared with compound **3**. The Δ^4-methyl trisulphide **20** was also formed during this oxidation (32% yield).* These data led to assignment of the 4β-hydroxy-1α,5α-epidithio structure to compound **4**.

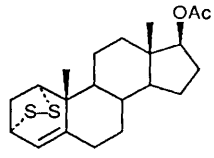


19 R = H
20 R = SSMe
21 R = SCl

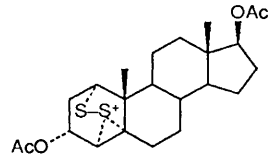


22 R = SPh
23 R = $SCMe_3$
24 R = OH
25 R = Δ^5–alkene

The similarity of the ^{1}H NMR spectra of compounds **22**, **23** and **24** suggested a common substitution pattern with a variable substituent. None of these compounds showed the long-wavelength UV absorption associated with the 1,5-epidithio link, but compounds **23** and **24** showed an absorption at ~260 nm characteristic of a disulphide with a CSSC dihedral angle ≫0°. Strong evidence for the substitution pattern and stereochemistry of the new 1α,4α-epidithio-5β-substituted system (**22**, **23** and **24**) stems ^{13}C NMR spectroscopic analysis of the 5β-phenylthio-1,4-disulphide **22**, formed by 'quenching' with thiophenol (Table 1, entries 3 and 4). The observation of a singlet at δ_C 60.8 established the presence of a tertiary carbon–sulphur linkage. The 9.0 ppm and 6.7 ppm downfield shifts of the C-19 carbon resonance (δ_C 20.4), when compared with those of 5α-androstane-3α,17β-diol diacetate (δ_C 11.4) and the disulphide **3** (δ_C 13.7), respectively, are consistent only with a *cis*-decalin-type structure as shown.[10]



26



27

Treatment of compound **22** with phosphoric acid[11] in refluxing chloroform effected clean conversion into the Δ^5-disulphide **25** (65% yield). This material was identical with that obtained from 'quenching' with acetate (Table 1, entry 6) or water (entry 7). Reductive desulphurization of compound **25** with nickel boride[12] yielded the known androst-5-ene-3α,17β-diol 3,17-diacetate[13] (16% yield). Finally, treatment of the 5β-substituted-1α,4α-disulphides **22** or **24** with perchloric acid and/or silver perchlorate yielded the 4β-hydroxy-1,5-disulphide **4**. This completes the correlations and suggests that the 5β-substituted-1,4-disulphides are of higher energy than the 4β-substituted-1,5-disulphides (in which the A-ring exists as a chair rather than a twist-boat).

The 1α,3α-disulphide **26**, obtained by 'quenching' with iodide (Table 1, entry 1), is not a primary product of the 'quenching' reaction but rather was shown to arise from further reaction of the Δ^4-tetrasulphides **9** and **10** catalysed by hydrogen iodide (produced, presumably, in the HCl-catalysed iodination of the acetone used to add the 'quenching' nucleophile). Compound **26** showed λ_{max} 371 nm, indicative of disulphide with a CSSC dihedral angle near 0°. The ^{13}C NMR spectrum had resonances characteristic of a trisubstituted double bond [δ_C 120.1(d), 143.1(s)]. The ^{1}H NMR spectrum showed a resonance for a vinyl hydrogen coupled to a single adjacent proton (similar to that observed in other 3α-substituted Δ^4-compounds but quite distinct from the more highly coupled proton observed in Δ^5-compounds, for instance compounds **13**–**15** or **25**) and a 2 H multiplet at δ 4.0 confirming attachment of *both* sulphurs to secondary carbons. These data led to assignment of structure **26** to this product, the formation of which from tetrasulphides **9** and **10** may be viewed as proceeding *via* intramolecular displacement of a protonated allylic acetate or of an allylic iodide intermediate by sulphur, followed by fragmentation of the resulting charged sulphur species to yield the epidisulphide **26**.

As briefly mentioned above, with the exception of the disulphide **26**, the thiosteroidal products shown in Table 1 were rationalized as arising *via* initial electrophilic cleavage of the tertiary carbon–sulphur bond in the disulphide **3**. Loss of a proton from C-6 or C-4 would then give the thiosulphenyl chlorides **16** and **21** respectively. Although sulphur–sulphur bond cleavage is generally observed upon chlorination of disulphides at room temperature or above,[6,11] di-*tert*-butyl disulphide has been reported to undergo a C–S bond cleavage upon reaction with chlorine at low temperatures.[14] The Δ^4-thiosulphenyl chloride **21** is proposed only as a transitory intermediate, which rapidly undergoes intramolecular *trans*, anti Markownikoff addition of the S–Cl bond to the 4,5-double bond,[15] giving the 4β-chloro-1α,5α-disulphide **7**. Conformational restraints appear to prevent the Δ^5-thiosulphenyl

* The trisulphide **20** can be rationalized as arising *via* loss of the 'activated' 4-hydroxy group to give a thiiranium ion **27**. Reaction of intermediate **27** with triethylamine during work-up might then give a thiolsulphenamide-type intermediate. This, in turn, would react with methanethiol, obtained in a Pummerer-type decomposition of dimethyl sulphoxide, to give compound **20**.

chloride **16** from undergoing a similar intramolecular addition reaction.

The initial formation of compounds **7** and **16** in the reaction between the disulphide **3** and sulphuryl dichloride was confirmed by isolation. The UV spectrum of compound **7** (λ_{max} 370 nm) was consistent with the presence of a 1,4-disulphide bridge,[9] while that for compound **16** (λ_{max} 286 nm) together with the presence of an olefinic signal in the ^{1}H NMR spectrum suggested the presence of the thiosulphenyl chloride. Further support for the proposed structures was provided by the observation that compound **16** formed the expected addition product **17** with cyclohexene, whereas compound **7** did not.

Thiosteroidal products **13**, **14** and **15** can clearly be seen to arise from the reaction of the 'quenching' nucleophiles with the Δ^5-thiosulphenyl chloride **16**, while products **8**, **9** and **10** equally obviously arise through condensation of the electrophiles **16** and **21** (or **7**) with a nucleophilic dithiolate such as **18** or its Δ^4-isomer. While the formation of the required nucleophilic component is readily rationalized in the case of work-up with a potentially *reducing* nucleophile such as iodide (Table 1, entries 1 and 2), the origin of species **18** or its anionic equivalent following 'quench' with acetate or with water (entries 6–8) requires comment. We propose that in these cases the dithiolate **18** arises through disproportionation of a thiosulphenic acid (Scheme 1). This proposal is supported by the observation that the thiol **13** (expected from hydrolysis of the thiosulphite **18a**) is formed along with tetrasulphide **8** under these conditions (Table 1, entry 8) and that the ratio of products **8**:**13** is ~2:1 as required by Scheme 1.

$$\mathbf{16} \xrightarrow{i} RSSOH \xrightarrow{ii} RSSH + RSS(O)X \quad (1)$$

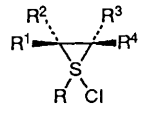
$$RSS(O)X \xrightarrow{i} RSH + SO_2 \quad (2)$$

X = Cl or OH

Scheme 1 *Reagents:* i, water; ii, RSSCl or RSSOH

That the 4-chloro compound **7** is the intermediate leading to products **4**, **5** and **22**–**25** was confirmed by treatment of pure compound **7** with thiophenol to yield compound **22** and with hydroxide to yield species **4**, **24** and **25** (Table 1, entry 9). The *trans*-diaxial configuration of the 4β-chlorine and 5α-sulphur atoms disposes compound **7** toward ready loss of chloride ion facilitated by sulphur participation to afford the thiiranium ion **27**. In this case it is of interest to note that nucleophiles appear to attack the thiiranium ion **27** at three sites. Namely, at sulphur to give the Δ^4-polysulphide **9**, at C-4 to give the 4β,5α-diaxially substituted products **4** and **5**, and at C-5 to give the 4α,5β-pseudodiaxially substituted products **22**, **23** and **24**. The attack upon compound **27** at sulphur by iodide ion (Table 1, entries 1 and 2) is not unexpected, since attack at either C-4 or C-5 would yield highly labile adducts, which analogously to compound **7** might be thought of as being in equilibrium with thiiranium ion **27**. Under these circumstances, attack at sulphur to yield a Δ^4-thiosulphenyl iodide, and subsequently the tetrasulphides **9** and **10**,[6] would provide the only irreversible product-forming reactions.

By analogy with the reactions of authenticated thiiranium ions, one might expect all nucleophiles which attack compound **27** at carbon to attack at C-5 to give the Markownikoff addition product.[16] While this is true for powerful nucleophiles such as thiol and hydroxide (Table 1, entries 3, 4, 5 and 9), poorer nucleophiles such as acetate ion or water (entries 6–8) appear to attack at C-4 to give the anti Markownikoff products. This is contrary to expectation, but is similar to the regioselectivity which has been reported for the reaction of nucleophiles with olefin–dimethyl(methylthio)sulphonium fluoroborate complexes.[17]



28

While thiiranium ions react with nucleophiles to give predominantly *trans*, Markownikoff adducts,[16] sulphenyl chlorides add to carbon–carbon double bonds under non-polar conditions in a predominantly *trans*, anti Markownikoff fashion.[15] To account for this difference it has been proposed that the latter reaction proceeds *via* a covalent cyclic sulphurane **28**.[16] The putative involvement of intermediate **28** in such additions is supported by ^{1}H NMR spectral data,[18a] by kinetic data,[18b] and by MO calculations.[18c] In addition numerous examples of other tetracovalent sulphur compounds bearing two carbon and two heteroatomic ligands are known,[19a] and the selenium analogue of the sulphurane **28** has been isolated.[18d] Most recently, Ruano and co-workers have reported the synthesis and isolation of two stable episulphuranes.[19b] The covalent intermediate **28** is thought to collapse internally *via* a tight ion pair to yield the observed *trans*, anti Markownikoff adducts.[16,18]

A similar covalent intermediate could account for the anti Markownikoff products, **4** and **5**. Hence, while powerful nucleophiles (thiol, hydroxide) attack the thiiranium ion **27** at C-5, if poorer nucleophiles (acetate, water) were to attack at sulphur to yield a cyclic sulphuranyl intermediate analogous to **28**, this might then collapse to give the 4β-substituted products. In support of a mechanism of this type, we have demonstrated that when attack at the tertiary carbon of a thiiranium ion is highly disfavoured by conformational factors, then a thiol will attack at sulphur rather than at the secondary carbon.[20]

An alternative and less exotic explanation is that both 4β and 5β products arise from attack at carbon, the site of attack being determined by the degree of development of the transition state. By this reasoning the transition state for attack by strong nucleophiles would be early, reactant-like, and the regioselectivity would be dominated by the greater charge density at the tertiary carbon leading to attack at C-5. With weaker nucleophiles the transition state would be later and more product-like. In this case the regioselectivity could be dominated by differences in stability (steric) of ring A and the SS bridge in the two types of product rather than charge distribution in the reacting ion. This would favour attack at C-4 which leads to the more stable product, *vide supra*.

What is clear from this work is that the little known analogues of thia compounds in which the C–S– link has been homologated by additional sulphur atoms are surprisingly well behaved, both as reactive intermediates and as products, and that the behaviour of these compounds is strikingly similar to that of the simpler and better known analogues. Application of this chemistry to the rational preparation of novel thiocorticosteroids is the subject of our companion paper.[20]

Experimental

M.p.s were determined with a Kofler hot-stage apparatus or in glass capillaries and are uncorrected. Optical rotations were determined with a Rudolph 70 photoelectric polarimeter. UV and IR spectra were recorded with Cary 11 and Perkin-Elmer 137 Infracord spectrophotometers, respectively. ^{1}H NMR spectra were recorded at 60 MHz on a Varian T60 spectrometer, unless otherwise stated. 250 MHz ^{1}H NMR spectra were run on

a Comeca 250 spectrometer. *J* Values are given in Hz. ^{13}C NMR spectra were recorded at 15.08 MHz on a Bruker WP 60 spectrometer, and are reported in order of assignment of resonances to carbons 1–19. NMR chemical shifts are related to Me_4Si (δ 0). Mass spectra were recorded using an AEI M59 spectrometer, and are reported in order of decreasing peak intensity. Rast molecular-weight determinations[21] were performed by grinding weighed amounts of steroid (~5 mg) and (+)-camphor together, and then recording the m.p. of three separate samples. Results thus obtained were accurate to within ±10%. Preparative TLC (PLC) was carried out on Analtech 1 mm silica gel GF-254 'Uniplates'. HPLC was carried out using Waters Associates 'Porasil A' silica gel packed in two 1 cm × 60 cm stainless steel columns, and a Waters Associates ALC-201 liquid chromatograph. Developing and eluting solvents are given in parentheses, and compounds are listed in order of increasing polarity. Aq. work-up refers to sequential washing of the reaction mixture with 5% aq. $NaHCO_3$ and saturated aq. NaCl, followed by drying over anhydrous $MgSO_4$ and evaporation of the solvent under reduced pressure. Acid and thiosulphate work-ups were performed as above, but with initial washing with 4% aq. HCl or 5% aq. $Na_2S_2O_3$, respectively.

1α,5α-*Epidithioandrostane*-3α,17β-*diol Diacetate* **3**.—4-(Dimethylamino)pyridine (DMAP) (100 mg, 0.82 mmol) was added to a stirred suspension of the diol **2**[3] (3.0 g, 8.5 mmol) in acetic anhydride (10 cm^3, 106 mmol) and triethylamine (20 cm^3). The remaining solid quickly dissolved, and then a few minutes later a pale yellow solid was precipitated. After 16 h the reaction mixture was poured onto crushed ice (100 g) and the precipitated solid was washed with water, redissolved in CH_2Cl_2 (200 cm^3), and dried ($MgSO_4$). Evaporation and crystallization from CH_2Cl_2–acetone yielded 1α,5α-*epidithioandrostane*-3α,17β-*diol diacetate* **3** (3.02 g, 81%), m.p. 245–247 °C (decomp.); $[\alpha]_D^{21}$ −60° (*c* 1.1, $CHCl_3$); λ_{max}(MeOH)/nm 372 (ε 60) and 293 (25); ν_{max}(KBr)/cm^{-1} 2980, 1735 and 1240; δ_H($CDCl_3$) 0.78 (3 H, s, 18-H_3), 1.10 (3 H, s, 19-H_3), 2.02 and 2.08 (6 H, 2 s, 17- and 3-OAc), 3.54 (1 H, t, *J* 2.54, 1β-H), 4.60 (1 H, br t, *J* 7.5, 17α-H) and 5.02 (1 H, br t, *J* 5.5, 3β-H); δ_C($CDCl_3$) 54.9, 30.2, 66.3, 43.5, 64.1, 35.5, 26.2, 35.2, 43.4, 51.0, 20.7, 36.7, 42.6, 50.5, 23.5, 27.7, 82.7, 12.2 and 13.7; *m/z* 253 [M − (HS_2 + 2 AcOH)], 313 [M − (HS_2 + AcOH)], 438 (M^+) and 271 [M − (HS_2 + AcOH + CH_2CO)] (Found: C, 62.85; H, 7.9; S, 14.6. $C_{23}H_{34}O_4S_2$ requires C, 63.0; H, 7.8; S, 14.6%).

Reaction of 1α,5α-*Epidithioandrostane*-3α,17β-*diol Diacetate* **3** *with Sulphuryl Dichloride.—Procedure A*. Sulphuryl dichloride (19 mm^3, 0.24 mmol) was added dropwise during a few seconds to a stirred solution of the disulphide **3** (100 mg, 0.23 mmol) in dry trichloro(fluoro)methane (60 cm^3) at room temperature. After 60 min, the reaction mixture was 'quenched' with various nucleophiles as described below.

(*a*) Potassium iodide (40 mg, 0.24 mmol) in water–acetone (2:98) (5 cm^3) was added, causing the reaction mixture quickly to turn red (I_2). After 30 min the reaction mixture was given a thiosulphate work-up. HPLC [EtOAc–cyclohexane (20:80)] yielded four products: (i) 1α,3α-*epidithioandrost*-4-*en*-17β-*yl acetate* **26** (14 mg, 16%) as a crystalline solid, which was recrystallized as yellow needles from CH_2Cl_2–hexane, m.p. 168–170 °C; $[\alpha]_D^{19}$ +75° (*c* 0.4, $CHCl_3$); λ_{max}(MeOH)/nm 370 (ε 95) and 301 (310); ν_{max}(KBr)/cm^{-1} 2990, 1740 and 1250; δ_H($CDCl_3$) 0.78 (3 H, s, 18-H_3), 1.16 (3 H, s, 19-H_3), 2.03 (6 H, s, 3- and 17-OAc), 3.95 (2 H, m, $w_{\frac{1}{2}}$ 12, 1β- and 3β-H), 4.63 (1 H, br t, *J* 8, 17α-H) and 5.48 (1 H, br d, *J* 6, 4-H); δ_C($CDCl_3$) 57.1, 40.8, 48.3, 120.1, 143.1, 31.5, 31.5, 35.4, 48.8, 44.3, 20.9, 36.4, 42.6, 50.1, 23.6, 27.5, 82.7, 21.2 and 12.0; *m/z* 253, 378 (M^+), 271 and 313 (Found: C, 66.35; H, 7.9; S, 17.0. $C_{21}H_{30}O_2S_2$ requires C, 66.6; H, 8.0; S, 16.95%).

(ii) *bis*-(3α,17β-*diacetoxyandrost*-4-*en*-1α-*yl*) *tetrasulphide* **9** (24 mg, 24%) as a glass, which was obtained as an oil from CH_2Cl_2, and was solidified and filtered at −78 °C to yield an amorphous solid, m.p. 121–125 °C, viscous melt; $[\alpha]_D^{26}$ +768° (*c* 0.6, $CHCl_3$); λ_{max}(MeOH)/nm 300sh (ε 2480); ν_{max}($CHCl_3$)/cm^{-1} 2980, 1735 and 1250; δ_H($CDCl_3$) 0.8 (6 H, s, 2 × 18-H_3), 1.17 (6 H, s, 2 × 19-H_3), 2.03 (12 H, s, 2 × 3- and 2 × 17-OAc), 3.27 (2 H, t, *J* 2.5, 2 × 1β-H), 4.63 (2 H, br t, *J* 8, 2 × 17α-H), 5.28 (2 H, br t, *J* 5, 2 × 3β-H) and 5.42 (2 H, br d, *J* 4.5, 2 × 4-H); *m/z* 312, 253, 313, 346, 271 and 438; 770 (Rast) (Found: C, 63.0; H, 7.8; S, 14.55. $C_{46}H_{66}O_8S_4$ requires C, 63.1; H, 7.6; S, 14.65%).

(iii) 3α,17β-*diacetoxyandrost*-4-*en*-1α-*yl* 3′α,17′β-*diacetoxyandrost*-5′-*en*-1′α-*yl tetrasulphide* **10** (34 mg, 34%) as a glass, which was solidified as described above for compound **9**, m.p. 117–121 °C, viscous melt; $[\alpha]_D^{26}$ +324° (*c* 0.9, $CHCl_3$); λ_{max}/nm 300sh (ε 2570); ν_{max}($CHCl_3$)/cm^{-1} 2980, 1735 and 1255; δ_H($CDCl_3$) 0.81 (6 H, s, 18- and 18′-H_3), 1.17 (6 H, s, 19- and 19′-H_3), 2.03 (12 H, s, 3-, 3′-, 17- and 17′-OAc), 3.40 (2 H, br s, $w_{\frac{1}{2}}$ 8, 1β- and 1′β-H), 4.63 (2 H, br t, *J* 7, 17α- and 17′α-H), 5.00 (1 H, br s, $w_{\frac{1}{2}}$ 10, 3′β-H) and 5.37 (3 H, m, $w_{\frac{1}{2}}$ 12, 3β-, 4- and 6′-H); *m/z* 312, 253, 346, 313, 271 and 438; M 850 (Rast) (Found: C, 63.0; H, 7.7; S, 14.6. $C_{46}H_{66}O_8S_4$ requires C, 63.1; H, 7.6; S, 14.65%).

(iv) *bis*-(3α,17β-*diacetoxyandrost*-5-*en*-1α-*yl*) *tetrasulphide* **8** (22 mg, 22%), as an oil, which was solidified as described above for compound **9**, m.p. 126–128 °C; $[\alpha]_D^{26}$ −69° (*c* 0.5, $CHCl_3$); λ_{max}(MeOH)/nm 300sh (ε 2560); ν_{max}(KBr)/cm^{-1} 2990, 1740 and 1240; δ_H($CDCl_3$) 0.82 (6 H, s, 2 × 18-H_3), 1.20 (6 H, s, 2 × 19-H_3), 2.02 and 2.05 (12 H, 2 s, 2 × 3- and 2 × 17-OAc), 3.45 (2 H, b_5, $w_{\frac{1}{2}}$ 8, 2 × 1β-H), 4.65 (2 H, br t, *J* 7.5, 2 × 17α-H), 5.02 (2 H, br s, $w_{\frac{1}{2}}$ 8, 2 × 3β-H) and 5.52 (2 H, br s, $w_{\frac{1}{2}}$ 9, 2 × 6-H); *m/z* 313, 346, 253, 312, 271, 438 and 436; M 900 (Rast) (Found: C, 62.9; H, 7.55; S, 14.05. $C_{46}H_{66}O_8S_4$ requires C, 63.1; H, 7.6; S, 14.65%).

(*b*) *Thiophenol* (24 mm^3, 0.23 mmol) was added. Aq. work-up and HPLC [EtOAc–cyclohexane (10:90)] yielded two products: (i) 1α-*phenyltrithioandrost*-5-*ene*-3α,17β-*diol diacetate* **14** (48 mg, 38%) as a glass, which was obtained as an oil from CH_2Cl_2–hexane. This was solidified and filtered off at −78 °C to yield a sticky solid, which gave a foam after being dried *in vacuo*, m.p. 42–45 °C; $[\alpha]_D^{27}$ −33° (*c* 0.7, $CHCl_3$); λ_{max}(MeOH)/nm 290sh (ε 2580) and 225 (13 390); ν_{max}($CHCl_3$)/cm^{-1} 2995, 1735, 1580, 1480 and 1255; δ_H($CDCl_3$) 0.81 (3 H, s, 18-H_3), 1.12 (3 H, s, 19-H_3), 1.93 (3 H, s, 3-OAc), 2.06 (3 H, s, 17-OAc), 3.28 (1 H, br s, $w_{\frac{1}{2}}$ 9, 1β-H), 4.63 (1 H, br t, *J* 7.5, 17α-H), 5.02 (1 H, br s, $w_{\frac{1}{2}}$ 9, 3β-H), 5.50 (1 H, br s, $w_{\frac{1}{2}}$ 9.5, 6-H), 7.35 (3 H, m, ArH) and 7.54 (2 H, m, ArH); *m/z* 313, 253, 241, 346, 546 (M^+), 405 (M − S_2Ph) and 514 (M − S); M 510 (Rast) (Found: C, 63.8; H, 7.1; S, 17.35. $C_{29}H_{38}O_4S_3$ requires C, 63.7; H, 7.0; S, 17.6%).

(ii) 1α,4α-*epidithio*-5β-*phenylthioandrostane*-3α,17β-*diol diacetate* **22** (59 mg, 47%) as a glass, which was crystallized as prisms from CH_2Cl_2–hexane; m.p. 132–134 °C; $[\alpha]_D^{25}$ −111° (*c* 0.6, $CHCl_3$); λ_{max}(MeOH)/nm 235 (ε 14 510); ν_{max}(KBr)/cm^{-1} 2990, 1740, 1570, 1480, 1240 and 750; δ_H($CDCl_3$; 250 MHz) 0.79 (3 H, s, 18-H_3), 1.17 (3 H, s, 19-H_3), 1.94 (1 H, ddd, *J* 1.5, 3.5 and 17, 2α-H), 2.06 (3 H, s, 17-OAc), 2.14 (3 H, s, 3-OAc), 2.40 (1 H, m, 16-H), 2.57 (1 H, ddd, *J* 7, 9 and 17, 2β-H), 2.96 (1 H, dd, *J* 1.5 and 7, 1β-H), 3.29 (1 H, d, *J* 4.5, 4β-H), 4.64 (1 H, dd, *J* 8 and 8, 17α-H), 5.48 (1 H, ddd, *J* 3.5, 4.5 and 9, 3β-H), 7.28 (3 H, m, ArH) and 7.52 (2 H, m, ArH); δ_C($CDCl_3$) 48.8, 33.2, 66.5, 63.3, 60.8, 36.5, 29.8, 35.1, 45.5, 43.5, 20.6, 36.2, 42.9, 50.1, 23.5, 27.6, 82.7, 12.3 and 20.4; *m/z* 437 (M − PhS), 253, 404, 271, 312 and 313; M 580 (Rast) (Found: C, 63.85; H, 7.1; S, 17.4. $C_{29}H_{38}O_4S_3$ requires C, 63.7; H, 7.0; S, 17.6%).

Procedure B. Sulphuryl dichloride (19 mm^3, 0.24 mmol) was added to a stirred solution of the disulphide **3** (100 mg, 0.23 mmol) in dry $CFCl_3$ (60 cm^3) at room temperature. After 60

min, the solvent was evaporated off under reduced pressure at ~27 °C. and the residue was immediately redissolved in dry benzene (5 cm^3) and placed under argon. This reaction mixture was then 'quenched' with various nucleophiles as described below. The mixture was stirred at room temperature for 30 min before dilution with ethyl acetate (40 cm^3) and work-up.

(a) *Potassium iodide* (40 mg, 0.24 mmol), added in water–acetone (2:98) (5 cm^3), followed by thiosulphate work-up and HPLC [EtOAc–cyclohexane (20:80)] afforded (i) bis-(3α,17β-diacetoxyandrost-4-en-1α-yl) tetrasulphide **9** (32 mg, 32%) as a glass which had HPLC, IR and ^1H NMR data identical with those of the sample described above.

(ii) 3α,17β-diacetoxyandrost-4-en-1α-yl 3′α,17′β-diacetoxyandrost-5′-en-1′α-yl tetrasulphide **10** (36 mg, 36%) as a glass which had HPLC, IR and ^1H NMR properties identical with those described above.

(iii) bis-(3α,17β-diacetoxyandrost-5-en-1α-yl) tetrasulphide **8** (18 mg, 18%) as a glass which had HPLC, IR and ^1H NMR properties identical with those described above.

(b) Thiophenol (47 mm^3, 0.46 mmol), added in a mixture of water (1 cm^3) and acetone (10 cm^3), followed by aq. work-up and HPLC [EtOH–cyclohexane (10:90)] afforded (i) 1α-phenyltrithioandrost-5-ene-3α,17β-diol diacetate **14** (41 mmg, 33%) as a glass which had HPLC, IR and ^1H NMR properties identical with those described above.

(ii) 1α,4α-epidithio-5β-phenylthioandrostane-3α,17β-diol diacetate **22** (63 mg, 50%), which was crystallized from CH_2Cl_2–hexane, m.p. 129.5–134 C; mixed m.p. with sample from above experiment undepressed; ^1H NMR spectrum identical with that described above.

(c) 2-Methylpropane-2-thiol (52 mm^3, 0.46 mmol), added in acetone (10 cm^3), followed by aq. work-up and HPLC [EtOAc–cyclohexane (10:90)] afforded (i) 1α-*tert*-butyltrithioandrost-5-ene-3α,17β-diol diacetate **15** (42 mg, 35%) as a glass: $[\alpha]_D^{17}$ +13° (*c* 0.8, $CHCl_3$); λ_{max}(MeOH)/nm 255 (ε 1970); $\nu_{max}(CHCl_3)/cm^{-1}$ 2980, 1735 and 1255; $\delta_H(CDCl_3)$ 0.82 (3 H, s, 18-H_3), 1.18 (3 H, s, 19-H_3), 1.37 (9 H, s, CMe_3), 2.03 (6 H, s, 3- and 17-OAc), 3.30 (1 H, br s, $w_{\frac{1}{2}}$ 10, 1β-H), 4.60 (1 H, br t, *J* 7, 17α-H), 4.98 (1 H, br s, $w_{\frac{1}{2}}$ 10, 3β-H) and 5.48 (1 H, br s, $w_{\frac{1}{2}}$ 10, 6-H); *m/z* 253, 313, 345, 344, 410, 470 (M − Bu′OH), 405 (M − Bu′S_2) and 526 (M^+).

(ii) 5β-tert-*butylthio*-1α,4α-*epidithioandrostane*-3α,17β-*diol diacetate* **23** (50 mg, 42%) as a glass; $[\alpha]_D^{17}$ −90° (*c* 0.9, $CHCl_3$); λ_{max}(MeOH)/nm 259 (ε 710); $\nu_{max}(CHCl_3)/cm^{-1}$ 2980, 1735 and 1250; $\delta_H(CDCl_3)$ 0.82 (3 H, s, 18-H_3), 1.20 (3 H, s, 19-H_3), 1.32 (9 H, s, Bu′S), 2.03 (3 H, s, 17-OAc), 2.11 (3 H, s, 3-OAc), 2.89 (1 H, br d, *J* 7, 1β-H), 3.15 (1 H, d, *J* 4, 4β-H), 4.65 (1 H, br t, *J* 7.5, 17α-H) and 5.52 (1 H, m, $w_{\frac{1}{2}}$ 16, 3β-H); *m/z* 437 (M − Bu′S), 405, 253, 312, 313 and 271.

(d) Tetrabutylammonium acetate (302 mg, 0.10 mmol), added in acetone (10 cm^3), followed by aq. work-up and HPLC [EtOAc–cyclohexane (20:80)] afforded (i) 1α,4α-*epidithioandrost*-5-*ene*-3α,17β-*diol diacetate* **25** (5 mg, 5%), which was crystallized from CH_2Cl_2–acetone, m.p. 208–211 °C; mixed m.p. with sample from experiment described below was undepressed; ^1H NMR spectrum identical with that described below.

(ii) bis-(3α,17β-diacetoxyandrost-5-en-1α-yl) tetrasulphide **8** (14 mg, 14%) as a glass which had HPLC and ^1H NMR properties identical with those described above.

(iii) 1α,5α-*epidithioandrostane*-3α,4β,17β-*triol triacetate* **5** (38 mg, 34%) as a crystalline solid, which was recrystallized as yellow plates from CH_2Cl_2–acetone, m.p. 217–219.5 °C; $[\alpha]_D^{26}$ −41 (*c* 1.2, $CHCl_3$); λ_{max}(MeOH)/nm 370 (ε 60) and 285 (35); $\nu_{max}(CHCl_3)$ cm^{-1} 2990, 1735 and 1250; $\delta_H(CDCl_3)$ 0.79 (3 H, s, 18-H_3), 1.12 (3 H, s, 19-H_3), 2.02, 2.08 and 2.12 (9 H, 3 s, 3-, 4- and 17-OAc), 3.62 (1 H, t, *J* 3, 1β-H), 4.67 (1 H, br t, *J* 7.5, 17α-H), 4.87 (1 H, br t, *J* 6.5, 3β-H) and 5.25 (1 H, s, $w_{\frac{1}{2}}$ 4, 4α-H); *m/z* 311, 269, 329, 496 (M^+) and 251 (Found: C, 60.5; H, 7.25; S, 13.0. $C_{25}H_{36}O_6S_2$ requires C, 60.45; H, 7.3; S, 12.9%).

(e) Water (1.0 cm^3, 56 mmol), added in acetone (10 cm^3), followed by aq. work-up and HPLC [EtOAc–cyclohexane (20:80)] afforded (i) 1α,4α-*epidithioandrost*-5-*ene*-3α,17β-*diol diacetate* **25** (14 mg, 14%), obtained as a crystalline solid, which was crystallized from CH_2Cl_2–acetone as yellow needles, m.p. 209–212 °C; $[\alpha]_D^{26}$ −97° (*c* 0.9, $CHCl_3$); λ_{max}(MeOH)/nm 350 (ε 75) and 308 (ε 160); ν_{max}(KBr)/cm^{-1} 2980, 1740, 1730 and 1245; $\delta_H(CDCl_3)$ 0.83 (3 H, s, 18-H_3), 1.13 (3 H, s, 19-H_3), 2.03 and 2.10 (6 H, 2 s, 17- and 3-OAc), 2.97 (1 H, br s, $w_{\frac{1}{2}}$ 8, 1β-H), 3.63 (1 H, d, *J* 2.5, 4β-H), 4.62 (1 H, br t, *J* 8, 17α-H), 5.38 (1 H, br t, *J* 6.5, 3β-H) and 5.75 (1 H, t, *J* 3, 6-H); *m/z* 361, 329, 404, 436 (M^+), 269, 311, 344 and 251; M 450 (Rast) (Found: C, 63.25; H, 7.35; S, 14.5. $C_{23}H_{32}O_4S_2$ requires C, 63.25; H, 7.4; S, 14.7%).

(ii) 3α,17β-diacetoxyandrost-4-en-1α-yl 3′α,17′β-diacetoxyandrost-5′-en-1′α-yl tetrasulphide **10** (12 mg, 12%) as a glass which had HPLC and ^1H NMR properties identical with those described above.

(iii) bis-(3α,17β-diacetoxyandrost-5-en-1α-yl) tetrasulphide **8** (19 mg, 19%) as a glass which had HPLC and ^1H NMR properties identical with those described above.

(iv) 1α,5α-epidithioandrostane-3α,4β,17β-triol 3,17-diacetate **4** (16 mg, 15%), which was crystallized from CH_2Cl_2–acetone, m.p. 218–221 °C; mixed m.p. with a sample from the experiment below was undepressed; ^1H NMR spectrum identical with that described below.

(f) Silver perchlorate (100 mg, 0.48 mmol) was added in a mixture of water (1.0 cm^3, 56 mmol) and acetone (10 cm^3). After 30 min, a solution of NaCl (50 mg, 0.85 mmol) in water (1 cm^3) was added, and the precipitated solid was removed by filtration. Aq. work-up and HPLC [EtOAc–cyclohexane (20:80)] afforded (i) 1α-mercaptoandrost-5-ene-3α,17β-diol 3,17-diacetate 13 (7 mg, 8%) as a glass. Material from a similar but larger scale experiment (54 mg) was crystallized from CH_2Cl_2–hexane (prisms), m.p. 149–152 °C; $[\alpha]_D^{23}$ −6° (*c* 0.7, $CHCl_3$); mixed m.p. with a sample obtained by reduction of compound **8** was undepressed; ^1H NMR spectrum identical with that described below.

(ii) bis-(3α,17β-diacetoxyandrost-5-en-1α-yl) tetrasulphide **8** (15 mg, 15%) as a glass. Material from a similar but larger scale experiment (110 mg) was obtained as an oil from CH_2Cl_2–hexane, which was solidified and filtered at −78 °C to give a solid, m.p. 125–126.5 °C, viscous melt; $[\alpha]_D^{26}$ −71° (*c* 0.5, $CHCl_3$); λ_{max}(MeOH)/nm 300sh (ε 2620); IR and ^1H NMR spectra identical with those given above.

(iii) 1α,5α-*epidithioandrostane*-3α,4β,17β-*triol* 3,17-*diacetate* **4** (36 mg, 35%) as a crystalline solid, which was recrystallized as yellow needles from CH_2Cl_2–acetone, m.p. 218.5–221 °C; $[\alpha]_D^{25}$ −42° (*c* 0.9, $CHCl_3$); λ_{max}(MeOH)/nm 370 (ε 60) and 292 (45); ν_{max}(KBr)/cm^{-1} 3600, 2990, 1735 and 1265; $\delta_H(CDCl_3)$ 0.77 (3 H, s, 18-H_3), 1.31 (3 H, s, 19-H_3), 2.03 and 2.10 (6 H, 2 s, 17- and 3-OAc), 3.57 (1 H, t, *J* 3, 1β-H), 3.92 (1 H, br s, $w_{\frac{1}{2}}$ 8, 4α-H), 4.62 (1 H, br t, *J* 7, 17α-H) and 4.83 (1 H, d, *J* 7, 3β-H); *m/z* 269 [M − (S_2H + 2 AcOH)], 287, 329, 454, (M^+), 251, 394, 361 and 436 (Found: C, 60.6; H, 7.45; S, 14.15. $C_{23}H_{34}O_5S_2$ requires C, 60.75; H, 7.55; S, 14.1%).

Procedure C. Reaction of 4β-*chloro*-1α,5α-*epidithioandrostane*-3α,17β-*diol diacetate* **7** *with aq. potassium carbonate.* The steroid **7** (see below) (120 mg, 0.25 mmol) was dissolved in dry tetrahydrofuran (THF) (10 cm^3), and then *immediately* afterwards a solution of potassium carbonate (100 mg, 0.72 mmol) in a mixture of water (15 cm^3) and acetone (10 cm^3) was added. The carbonate solution contained one drop of phenolphthalein, and the reaction mixture remained pink throughout the reaction, indicating pH ≥ 8.2. After the mixture had been stirred at room temperature for 30 min, EtOAc (100 cm^3) and saturated aq. NaCl (50 cm^3) were added, and the separated organic

layer was dried over Na_2SO_4. HPLC [EtOAc–cyclohexane (20:80)] yielded eight fractions, of which four were present in sufficient amounts for characterization (56 mg).

(i) (10 mg); a mixture of three or more compounds (^{1}H NMR) containing both acetate groups and a double bond (δ 5.70).

(ii) 1α,4α-epidithioandrost-5-ene-3α,17β-diol diacetate **25** (10 mg, 9%), crystallized from CH_2Cl_2–acetone, m.p. 209–211 °C; ^{1}H NMR spectrum identical with that described above.

(iii) 1α,5α-epidithioandrostane-3α,4β,17β-triol 3,17-diacetate **4** (21 mg, 18%) was crystallized from CH_2Cl_2–acetone, m.p. 217.5–220 °C; ^{1}H NMR spectrum identical with that described above.

(iv) 1α,4α-epidithioandrostane-3α,5β,17β-triol 3,17-diacetate **24** (15 mg, 13%) as a glass, which was obtained as an amorphous solid from CH_2Cl_2–hexane, m.p. 162–165 °C; $[\alpha]_D^{19}$ −92° (*c* 0.1, $CHCl_3$); λ_{max}(MeOH)/nm 264 (ε 770); ν_{max}(KBr)/cm^{-1} 3550, 2980, 1735, 1240 and 1040; δ_H($CDCl_3$) 0.80 (3 H, s, 18-H_3), 1.17 (3 H, s, 19-H_3), 2.03 (3 H, s, 17-OAc), 2.10 (3 H, s, 3-OAc), 2.90 (1 H, br d, *J* 7, 1β-H), 3.13 (1 H, d, *J* 4, 4β-H), 4.61 (1 H, br t, *J* 7, 17α-H) and 5.50 (1 H, m, $w_{\frac{1}{2}}$ 17, 3β-H); *m/z* 313, 253, 312, 405, 271 and 437 (M − OH).

Reduction of Steroidal Polysulphides with Sodium Borohydride.—(a) *Reduction of bis-*(3α,17β-*diacetoxyandrost-5-en-*1α-*yl*) *tetrasulphide* **8**. $NaBH_4$ (130 mg, 3.4 mmol) was added to a stirred solution of the tetrasulphide **8** (130 mg, 0.15 mmol) in THF (5 cm^3)–ethanol (5 cm^3). After the mixture had been stirred at room temperature for 4 h a further portion of $NaBH_4$ (100 mg, 2.6 mmol) was added and the reaction mixture was stirred for a further 2.5 h. Aq. 4% HCl (30 cm^3) was added (slowly), the reaction mixture was stirred for 5 min, and then EtAOc (40 cm^3) was added. The layers were separated and the organic phase was given an aq. work-up. PLC [EtOAc–cyclohexane (25:75)] yielded 1α-*mercaptoandrost-5-ene-*3α,17β-*diol* 3,17-*diacetate* **13** (104 mg, 86%), m.p. 139–148 °C, recrystallized as prisms from CH_2Cl_2–hexane (55 mg), m.p. 152.5–154 °C; $[\alpha]_D^{25}$ −7.5° (*c* 2.7, $CHCl_3$); ν_{max}(KBr)/cm^{-1} 2990, 2630 (SH str.), 1735 and 1240; δ_H($CDCl_3$; D_2O) 0.79 (3 H, s, 18-H_3), 1.17 (3 H, s, 19-H_3), 2.03 (6 H, s, 3- and 17-OAc), 3.13 (1 H, br s, $w_{\frac{1}{2}}$ 9, 1β-H), 4.60 (1 H, br t, *J* 8, 17α-H), 5.02 (1 H, br s, $w_{\frac{1}{2}}$ 9, 3β-H) and 5.54 (1 H, br s, $w_{\frac{1}{2}}$ 9, 6-H); *m/z* 346 (M − AcOH), 312, 253, 271 and 406 (M$^+$); 440 (Rast) (Found: C, 68.1; H, 8.45; S, 7.8. $C_{23}H_{34}O_4S$ requires C, 67.95; H, 8.45; S, 7.9%).

(b) *Reduction of bis-*(3α,17β-*diacetoxyandrost-4-en-*1α-*yl tetrasulphide* **9**. A solution of the tetrasulphide **9** (24 mg, 0.03 mmol) in THF (2 cm^3)–ethanol (2 cm^3) was stirred at room temperature in the presence of $NaBH_4$ (24 mg, 0.63 mmol) for 4.5 h. Work-up and PLC as described above yielded 1α-*mercaptoandrost-4-en-*3α,17β-*diol* 3,17-*diacetate* **19** (13 mg, 59%), crystallized from CH_2Cl_2–hexane (needles), m.p. 153–154 °C; $[\alpha]_D^{28}$ +166° (*c* 0.3, $CHCl_3$); ν_{max}(KBr)/cm^{-1} 2980, 2630 (SH str.), 1735, 1655 (Δ^4) and 1240; δ_H($CDCl_3$; D_2O) 0.82 (3 H, s, 18-H_3), 1.13 (3 H, s, 19-H_3), 2.02 and 2.05 (6 H, s, 17- and 3-OAc), 3.03 (1 H, br s, $w_{\frac{1}{2}}$ 10, 1β-H), 4.62 (1 H, br t, *J* 7, 17α-H), 5.26 (1 H, br t, *J* 4.5, 3β-H) and 5.43 (1 H, br d, *J* 4.5, 4-H); *m/z* 312, 253, 271, 346 and 406 (M) (Found: C, 68.05; H, 8.45; S, 7.8. $C_{23}H_{34}O_4S$ requires C, 67.95; H, 8.45; S, 7.9%).

(c) *Reduction of* 3α,17β-*diacetoxyandrost-4-en-*1α-*yl* 3α,17′β-*diacetoxyandrost-5′-en-*1α′-*yl tetrasulphide* **10**. The tetrasulphide **10** (38 mg, 0.04 mmol), dissolved in THF (2 cm^3)–ethanol (2 cm^3), was reduced with $NaBH_4$ (38 mg, 1.0 mmol) over a period of 4.5 h. Work-up and PLC as described above yielded a mixture of the Δ^4-1α-thiol **19** and the Δ^5-1α-thiol **13** (18 mg, 51%). This material was combined with a similar mixture (11 mg) obtained from another reduction of compound **10**, and the resulting product (29 mg) was separated by HPLC [EtOAc–cyclohexane (10:90)] to yield (i) 1α-mercaptoandrost-4-ene-3α,17β-diol diacetate **19** (8 mg), crystallized from CH_2Cl_2–hexane, m.p. 153–154 °C, mixed m.p. with a sample from (b) was undepressed; ^{1}H NMR spectrum identical with that described above.

(ii) 1α-mercaptoandrost-5-ene-3α,17β-diol diacetate **13** (16 gm), crystallized from CH_2Cl_2–hexane, m.p. 152–154 °C, mixed m.p. with a sample from (a) was undepressed; ^{1}H NMR spectrum identical with that described above.

(d) *Reduction of* 3α,17β-*diacetoxyandrost-5-en-*1α-*yl phenyl trisulphide* **14**. The trisulphide **14** (220 mg, 0.40 mmol) was dissolved in THF (10 cm^3) and reduced with $NaBH_4$ in a similar manner to that described above for compound **8**, to yield 1α-mercaptoandrost-5-ene-3α,17β-diol diacetate **13** (165 mg, 99%), which was crystallized from CH_2Cl_2–hexane (116 mg), m.p. 150–152 °C; IR and ^{1}H NMR spectra identical with those described above.

Iodine Oxidation of 1α-*Mercaptoandrost-5-ene-*3α,17β-*diol Diacetate* **13**.—Iodine (22 mg, 0.08 mmol) was added to a stirred solution of the thiol **13** (65 mg, 0.16 mmol) in dry THF (4 cm^3) containing solid $NaHCO_3$ (70 mg, 0.8 mmol). After 21 h the reaction mixture was diluted with EtOAc (50 cm^3) and given a thiosulphate work-up. PLC [EtOAc–cyclohexane (30:70)] yielded *bis-*(3α,17β-*diacetoxyandrost-5-en-*1α-*yl*) *disulphide* **11** (50 mg, 77%) as a crystalline solid, which was recrystallized as prisms (39 mg) from CH_2Cl_2–hexane, m.p. 247–240 °C; $[\alpha]_D^{24}$ −40° (*c* 1.0, $CHCl_3$); λ_{max}(MeOH)/nm 252sh (ε 330); ν_{max}(KBr)/cm^{-1} 2995, 1745 and 1240; δ_H($CDCl_3$) 0.80 (3 H, s, 18-H_3), 1.13 (3 H, s, 19-H_3), 2.00 and 2.03 (6 H, 2 s, 17- and 3-OAc), 3.00 (1 H, br s, $w_{\frac{1}{2}}$ 9, 1β-H), 4.62 (1 H, br t, *J* 7.5, 17α-H), 4.97 (1 H, br s, $w_{\frac{1}{2}}$ 9, 3β-H) and 5.45 (1 H, br s, $w_{\frac{1}{2}}$ 9.5, 6-H); *m/z* 253, 313, 312, 271, 346, 810 (M$^+$), 750 (M − AcOH), 690 (M − 2 AcOH) and 658 [M − (S + 2 AcOH)] (Found: C, 68.05; H, 8.2; S, 7.8. $C_{46}H_{66}O_8S_2$ requires C, 68.1; H, 8.2; S, 7.9%).

Hydrolysis of Bis-(3α,17β-*diacetoxyandrost-5-en-*1α-*yl*) *Tetrasulphide* **8**.—A solution of the steroid **8** (88 mg, 0.10 mmol) in benzene (5 cm^3) was stirred with a 2% solution of KOH in MeOH–water (95:5) (20 cm^3) at room temperature. After 21 h CH_2Cl_2 (100 cm^3) was added, and the mixture was washed successively with water, 4% HCl, 5% aq. $NaHCO_3$ and water, then dried ($MgSO_4$) and evaporated to give *bis-*(3α,17β-*dihydroxyandrost-5-en-*1α-*yl*) *disulphide* **12** (57 mg, 88%) as a solid, m.p. 172–177 °C. Crystallization from CH_2Cl_2–EtOAc–benzene afforded the tetraol **12** as plates [m.p. begins heating at 140 °C; some melting at 180–183 °C to give a viscous, glassy melt; recrystallizes 187–220 °C; final melting 238.5–241.5 °C (decomp.) to brown, mobile melt]; $[\alpha]_D^{23}$ +83° (*c* 1.0, $CHCl_3$); λ_{max}/nm 245 (infl.) (ε 470); ν_{max}(KBr)/cm^{-1} 3600 and 2990; δ_H($CDCl_3$) 0.77 (3 H, s, 18-H_3) 1.18 (3 H, s, 19-H_3) 3.07 (1 H, br s, $w_{\frac{1}{2}}$ 9.5, 1β-H), 3.70 (1 H, br t, *J* 7, 17α-H), 4.04 (1 H, br s, $w_{\frac{1}{2}}$ 11, 3β-H) and 5.63 (1 H, br s, $w_{\frac{1}{2}}$ 9, 6-H); *m/z* 253, 271, 289, 304, 320, 642 (M$^+$) and 624 (M − 18); M 620 (Rast) (Found: C, 70.5; H, 9.1; S, 9.85. $C_{38}H_{58}O_4S_2$ requires C, 71.0; H, 9.1S, 9.95%).

Acetylation of Bis-(3α,17β-*dihydroxyandrost-5-en-*1α-*yl*) *Disulphide* **12**.—DMAP (2 mg, 0.02 mmol) was added to a stirred suspension of the steroid **12** (48 mg, 0.08 mmol) in a mixture of benzene (4 cm^3), triethylamine (1 cm^3, 7.2 mmol) and acetic anhydride (0.5 cm^3, 5.3 mmol), causing the steroid to dissolve quickly. The mixture was stirred for 18.5 h. Water (10 cm^3) was added and the mixture was stirred for a further 5 min, when CH_2Cl_2 (50 cm^3) was added and the reaction mixture was given an aq. work-up. The crude bis-(3α,17β-diacetoxyandrost-5-en-1α-yl) disulphide **11** (56 mg, 92%), m.p. 224–231 °C, thus obtained was recrystallized from CH_2Cl_2–hexane (prisms), m.p. 248–250 °C; IR and ^{1}H NMR spectra identical with those described above.

Oxidation and Base Treatment of Bis-(3α,17β-dihydroxyandrost-5-en-1α-yl) Disulphide **12**.—Dry DMSO (200 mm^3, 2.4 mmol) in dry CH_2Cl_2 (5 cm^3) was added to a stirred solution of oxalyl dichloride (130 mm^3, 1.5 mmol) in dry CH_2Cl_2 (20 cm^3) at −60 °C over a period of 4 min. After another 2 min a solution of the steroid **12** (61 mg, 0.1 mmol) in dry CH_2Cl_2 (5 cm^3) was added during 4 min, and the mixture was stirred for a further 10 min, then dry triethylamine (1.0 cm^3, 7.2 mmol) was added during 2 min. After a further 5 min at −60 °C the solution was allowed to warm to room temperature (55 min), then was diluted with CH_2Cl_2 (50 cm^3), and given an acid work-up to afford crude Δ^5-3,17-dione [$\nu_{max}(CHCl_3)$ 1740 cm^{-1}]. The crude product mixture was redissolved in a mixture of benzene (10 cm^3) and 2% KOH in MeOH–water (95:5) (20 cm^3), the mixture was stirred at room temperature for 30 min. The volume was reduced to ~5 cm^3 under reduced pressure, CH_2Cl_2 (50 cm^3) was added, and the mixture was given an acid work-up. PLC [EtOAc–cyclohexane (90:10)] afforded androsta-1,4-diene-3,17-dione (25 mg, 52%), which was crystallized from hexane, m.p. 139–141.5 °C; mixed m.p. with authentic material was undepressed; IR and ^1H NMR spectra were identical with those obtained for authentic material.

Acetylation of 1α,5α-Epidithioandrostane-3α,4β,17β-triol 3,17-Diacetate **4**.—A solution of the steroid **4** (50 mg, 0.11 mmol) and DMAP (2 mg, 0.02 mmol) in a mixture of benzene (1 cm^3), triethylamine (1 cm^3, 7.2 mmol) and acetic anhydride (0.5 cm^3, 5.3 mmol) was stirred at room temperature for 1 h. Water (5 cm^3) was added, and the reaction mixture was stirred for a further 10 min. EtOAc (50 cm^3) was added, and the mixture was given an aq. work-up. Crystallization from CH_2Cl_2–acetone yielded 1α,5α-epidithioandrostane-3α,4β,17β-triol triacetate **5** as yellow plates (36 mg, 65%), m.p. 217–219 °C; mixed m.p. with material from the above experiment was undepressed; ^1H NMR spectrum identical with that described above.

Oxidation of 1α,5α-Epidithioandrostane-3α,4β,17β-triol 3,17-Diacetate **4**.—The 4β-hydroxy steroid **4** (59 mg, 0.13 mmol) was oxidized with DMSO (260 mm^3, 3.6 mmol)–oxalyl dichloride (160 mm^3, 1.8 mmol) according to the procedure described above for compound **12**. PLC [EtOAc–cyclohexane (25:75)] yielded two products: (i) 3α,17β-*diacetoxyandrost-4-en-1α-yl methyl trisulphide* **20** (20 mg, 32%) as a glass, which was crystallized from CH_2Cl_2–hexane–MeOH as needles, m.p. 127–129 °C; $[\alpha]_D^{21}$ +418° (*c* 0.3, $CHCl_3$); λ_{max}/nm (MeOH) 247 (infl.) (ε 1750); $\nu_{max}(CHCl_3)/cm^{-1}$ 2990, 1730, 1655 (Δ^4) and 1245; $\delta_H(CDCl_3)$ 0.83 (3 H, s, 18-H_3), 1.18 (3 H, s, 19-H_3), 2.05 (6 H, s, 3- and 17-OAc), 2.54 (3 H, s, SMe), 3.3 (1 H, t, *J* 3, 1β-H), 4.68 (1 H, br t, *J* 7.5, 17α-H), 5.33 (1 H, br t, *J* 5, 3β-H) and 5.48 (1 H, br d, *J* 4.5, 4-H); *m/z* 405 ($M - S_2CH_3$), 329, 345, 253, 313 and 271 (Found: C, 59.15; H, 7.55; S, 19.55. $C_{24}H_{36}O_4S_3$ requires C, 59.45; H, 7.5; S, 19.85%).

(ii) 1α,5α-*epidithio-4-oxoandrostane-3α,17β-diol diacetate* **6** (35 mg, 59%) as a pale yellow glass, which was crystallized as pale yellow prisms from CH_2Cl_2–hexane, m.p. 202–207 °C; $[\alpha]_D^{24}$ +245 (*c* 0.5, $CHCl_3$); λ_{max}(MeOH)/nm 355 (infl.) (ε 470), 340 (630) and 255 (840); $\nu_{max}(CHCl_3)/cm^{-1}$ 2995, 1735 and 1245; $\delta_H(CDCl_3)$ 0.79 (3 H, s, 18-H_3), 1.07 (3 H, s, 19-H_3), 2.05 (3 H, s, 17-OAc), 2.15 (3 H, s, 3-OAc), 3.70 (1 H, t, *J* 3, 1β-H), 4.65 (1 H, br t, *J* 7.5, 17α-H) and 5.28 (1 H, dd, J_{aa} 8.8, J_{ae} 1.8, 3β-H); *m/z* 452 (M^+), 267, 285 and 327 (Found: C, 60.6; H, 7.1; S, 14.0. $C_{23}H_{32}O_5S_2$ requires C, 61.05; H, 7.15; S, 14.15%).

Elimination of Thiophenol from 1α,4α-Epidithio-5β-phenylthioandrostane-3α,17β-diol Diacetate **22**.—85% Phosphoric acid (5 mm^3) was added to a solution of the steroid **22** (25 mg, 0.05 mmol) in chloroform (10 cm^3; containing 0.7% ethanol as preservative) and the mixture was refluxed under argon for 40 h. The mixture was diluted with CH_2Cl_2 (20 cm^3) and given an aq. work-up. PLC [EtOAc–cyclohexane (25:75)] afforded 1α,4α-epidithioandrost-5-ene-3α,17β-diol diacetate **25** (13 mg, 65%) as a crystalline solid, which was recrystallized as pale yellow needles from CH_2Cl_2–acetone (6 mg), m.p. 210–212 °C; mixed m.p. with a sample from the above experiment was undepressed; IR and ^1H NMR spectra were identical with those described above.

Desulphurization of 1α,4α-Epidithioandrost-5-ene-3α,17β-diol Diacetate **25** *with Nickel Boride*.—A solution of $NaBH_4$ (0.9 g, 24 mmol) in water (10 cm^3) was added dropwise over a period of 3 min to a solution of the steroid **25** (90 mg, 0.21 mmol), nickel(II) chloride (2.7 g, 11 mmol) and boric acid (2.8 g, 45 mmol) in ethanol (150 cm^3) at room temperature. A black suspension of nickel boride[20] was formed upon addition of the first drop of $NaBH_4$ solution. The mixture was stirred at room temperature for a total of 12 min, after which time TLC showed complete disappearance of starting material. The mixture was filtered through Celite, and the filter-cake was washed with ethanol. The combined filtrates were evaporated to 5 cm^3, water (100 cm^3) was added, and the mixture was extracted thrice with diethyl ether. The combined extracts were dried ($MgSO_4$) and evaporated. PLC [EtOAc–cyclohexane (25:75)] yielded two mixed fractions. The less polar fraction (24 mg) was a ~1:1 mixture of two A-ring acetate-eliminated products. The more polar fraction (31 mg) was a ~3:2 mixture of androst-5-ene-3α,17β-diol diacetate and one other compound still containing the A-ring acetoxy group. These were separated by HPLC [EtOAc–cyclohexane (10:90)] to give pure androst-5-ene-3α,17β-diol diacetate (12 mg, 16%) as a crystalline solid, m.p. 150–153 °C, which was recrystallized as needles (5 mg) from CH_2Cl_2–hexane, m.p. 156–157 °C (lit.,[21] 155–155.5 °C); $[\alpha]_D^{26}$ −7° (*c* 0.5, $CHCl_3$); ν_{max}(KBr)/cm^{-1} 2990, 1740, 1660 (Δ^5) and 1245; $\delta_H(CDCl_3)$ 0.80 (3 H, s, 18-H_3), 1.00 (3 H, s, 19-H_3), 2.03 (6 H, s, 3- and 17-OAc), 4.60 (1 H, br t, *J* 7, 17α-H), 4.99 (1 H, br s, $w_{\frac{1}{2}}$ 8, 3β-H) and 5.27 (1 H, br s, $w_{\frac{1}{2}}$ 10, 6-H).

Isomerization of 1α,4α-Epidithioandrostane-3α,5β,17β-triol 3,17-Diacetate **24** to 1α,5α-*Epidithioandrostane-3α,4β,17β-triol 3,17-Diacetate* **4**.—A solution of the 5β-alcohol **24** (10 mg, 0.022 mmol) in benzene (0.5 cm^3) was treated first with a solution of silver perchlorate (10 mg, 0.048 mmol) in 10% aq. acetone (1 cm^3), and then with aq. 4% HCl (25 mm^3, 0.027 mmol HCl). TLC [EtOAc–cyclohexane (20:80)] monitoring of the reaction showed a gradual conversion into isomer **4** over a period of *ca.* 1.5 h. The reaction mixture was then diluted with EtOAc (50 cm^3) and given an aq. work-up to yield 1α,5α-epidithioandrostane-3α,4β,17β-triol 3,17-diacetate **4** (10 mg, 99%) as a crystalline solid. Purification by HPLC [EtOAc–cyclohexane (20:80)] and crystallization from CH_2Cl_2–acetone yielded yellow needles, m.p. 217–220 °C; mixed m.p. with a sample from the above experiment was undepressed; ^1H NMR spectrum was identical with that described above.

Treatment of the 1α,4α-Epidithio-5β-phenylthioandrostane-3α,17β-diol Diacetate **22** *with Silver Perchlorate*.—A solution of $AgClO_4$ (40 mg, 0.19 mmol) in water (0.5 cm^3)–acetone (4 cm^3) was added to a solution of the steroid **22** (50 mg, 0.09 mmol) in benzene (2 cm^3). The reaction mixture was stirred at room temperature for 10 min, then was treated with saturated aq. NaCl (1 cm^3), and stirred for a further 5 min. The precipitated solids were then filtered off and EtOAc (50 cm^3) was added. Aq. work-up yielded 1α,5α-epidithioandrostane-3α,4β,17β-triol 3,17-diacetate **4** as a solid, which was crystallized from CH_2Cl_2–acetone as yellow needles (25 mg, 60%), m.p. 214–219 °C; ^1H NMR spectrum was identical with that described above.

Treatment of Bis-(3α,17β-diacetoxyandrost-4-en-1α-yl Tetrasulphide **9** *with Hydriodic Acid.*—57% Hydriodic acid (9 mm^3, 0.068 mmol HI) was added to a solution of the tetrasulphide **9** (30 mg, 0.034 mmol) in a mixture of CCl_4 (20 cm^3)–acetone (2 cm^3). TLC after 30 min showed complete conversion into a less polar compound and the solution was given a thiosulphate work-up. PLC [EtOAc–cyclohexane (25:75)] yielded 1α,3α-epidithioandrost-4-en-17β-yl acetate **26** (20 mg, 58%), which was crystallized as yellow needles from CH_2Cl_2–hexane, m.p. 168–171 °C; mixed m.p. with a sample from the above experiment was undepressed; ^1H NMR spectrum was identical with that described above.

4β-*Chloro*-1α,5α-*epidithioandrostane*-3α,17β-*diol Diacetate* **7** *and* 1α-*Chlorodithioandrost*-5-*ene*-3α,17β-*diol Diacetate* **16**.—A solution of the disulphide **3** (200 mg, 0.46 mmol) and sulphuryl dichloride (38 mm^3, 0.47 mmol) in dry $CFCl_3$ (100 cm^3) was stirred at room temperature for 1 h. The solvent was evaporated off to ~3–4 cm^3 under reduced pressure at 27 °C. Transfer of the solution to a dry Craig tube and further reduction of the solvent volume to ~1 cm^3 with a stream of dry argon led to spontaneous crystallization of 4β-*chloro*-1α,5α-*epidithioandrostane*-3α,17β-*diol diacetate* **7** as yellow prisms, which were centrifuged off, washed with dry $CFCl_3$, and dried under a stream of argon (102 mg, 47%), m.p. 93–94 °C [decomp. with vigorous evolution of gas (closed tube)]. Recrystallization from dry $CFCl_3$ (50 cm^3) as detailed above yielded an analytical sample, m.p. 98–100 °C [decomp. with vigorous evolution of gas (closed tube)]; $[\alpha]_D^{27}$ −40° (*c* 0.6, CCl_4); λ_{max}(cyclohexane)/nm 370 (ε 55) and 300 (130); ($[\alpha]_D$- and ε-values corrected for the presence of 0.35 mol equiv. $CFCl_3$ are −44°, 60 and 140, respectively); $\nu_{max}(CCl_4)/cm^{-1}$ 2980, 1740 and 1240; $\delta_H(CCl_4)$ 0.73 (3 H, s, 18-H_3), 1.40 (3 H, s, 19-H_3), 1.94 and 2.03 (6 H, 2 s, 3- and 17-OAc), 3.53 (1 H, t, *J* 3, 1β-H), 4.36 (1 H, s, $w_{\frac{1}{2}}$ 4.5, 4α-H), 4.60 (1 H, br t, *J* 7, 17α-H) and 5.13 (1 H, br d, *J* 6, 3β-H); *m/z* 329, 269, 436 (M − HCl), 287, 311, 312, 251, 371 and 472 (M^+) (Found: C, 53.9; H, 6.45; Cl, 13.75; F, 1.55; S, 12.15. $C_{23}H_{33}ClS_2O_4$·0.35 $CFCl_3$ requires C, 53.8; H, 6.4; Cl, 13.95; F, 1.3; S, 12.3%).

Crystallization of residual 4β-chloro steroid **7** from the mother liquors obtained above, followed by removal of the solvent, afforded pure 1α-chlorodithioandrost-5-ene-3α,17β-diol diacetate **16** as a yellow foam after evaporation of the solvent, m.p. 58–64 °C; $[\alpha]_D^{27}$ 0° (*c* 1.6, $CHCl_3$); λ_{max}(cyclohexane/nm 286 (ε 2910); $\nu_{max}(CHCl_3)/cm^{-1}$ 2980, 1740 and 1240; $\delta_H(CDCl_3)$ 0.80 (3 H, s, 18-H_3), 1.20 (3 H, s, 19-H_3), 2.05 (6 H, s, 3- and 17-OAc), 3.51 (1 H, br s, $w_{\frac{1}{2}}$ 9, 1β-H), 4.63 (1 H, br t, *J* 7.5, 17α-H), 5.06 (1 H, br s, $w_{\frac{1}{2}}$ 9, 3β-H) and 5.54 (1 H, br s, $w_{\frac{1}{2}}$ 10, 6-H); *m/z* 329, 269, 311, 312, 251, 287, 436 (M − HCl), 373 (M − S_2Cl), 371 and 472 (M^+).

Reaction of 1α-*Chlorodithioandrost*-5-*ene*-3α,17β-*diol Diacetate* **16** *with Cyclohexene.*—Cyclohexene (46 mm^3, 0.45 mmol) was added to an NMR tube containing a solution of the thiosulphenyl chloride **16** (106 mg, 0.22 mmol) (contaminated with ~10% of **26**) in dry CCl_4 (1 cm^3). The course of the reaction was monitored by measuring the integral of the δ 3.98 ^1H NMR signal, assigned to the proton geminal to chlorine in the adduct **17**. After 20 h this signal integrated for one proton, and the reaction mixture was diluted with EtOAc (100 cm^3) and given an aq. work-up. PLC [EtOAc–cyclohexane (25:75)] yielded 1α-[(1′RS,2′S,R-2′-*chlorocyclohexyldithio*]*androst*-5-*ene*-3α,17β-*diol diacetate* **17** (68 mg, 55%) as a glass. Further purification by HPLC [EtOAc–cyclohexane (10:90)] and crystallization initially from hexane, and subsequently from CH_2Cl_2/hexane, yielded prisms, m.p. 144–149 °C; $[\alpha]_D^{27}$ −90° (*c* 0.9, $CHCl_3$); λ_{max}(MeOH)/nm 247sh (ε 420); $\nu_{max}(CHCl_3)/cm^{-1}$ 2980, 1730 and 1245; $\delta_H(CDCl_3)$ 0.81 (3 H, s, 18-H_3), 1.31 (3 H, s, 19-H_3), 2.04 (6 H, s, 3- and 17-OAc), 3.18 (1 H, br s, $w_{\frac{1}{2}}$ 11, 1β-H), 3.98 (1 H, m, $w_{\frac{1}{2}}$ 24, 2′-H), 4.63 (1 H, br t, *J* 7, 17α-H), 4.98 (1 H, br s, $w_{\frac{1}{2}}$ 8, 3β-H) and 5.51 (1 H, br s, $w_{\frac{1}{2}}$ 9, 6-H); *m/z* 313, 253, 271, 554 (M^+), 495 and 518 (M − HCl) (Found: C, 62.55; H, 7.8; Cl, 6.7; S, 11.85. $C_{29}H_{43}ClO_4S_2$ requires C, 62.75; H, 7.8; Cl, 6.4; S, 11.55%).

Reaction of 4β-*Chloro*-1α,5α-*epidithioandrostane*-3α,17β-*diol Diacetate* **7** *with Cyclohexene.*—Cyclohexene (46 mm^3, 0.45 mmol) was added to an NMR tube containing a solution of the 4β-chlorosteroid **7** (105 mg, 0.22 mmol) in dry CCl_4 (1 cm^3). The ^1H NMR spectrum recorded after 30 h indicated that although some decomposition had occurred, substrate **7** was still present, and no signals were present at δ 4.0 PhSH (47 nm^3, 0.46 mmol) was added and the reaction mixture was given an aq. work-up. PLC [EtOAc–cyclohexane (25:75)] afforded 1α,4α-epidithio-5β-phenylthioandrostane-3α,17β-diol diacetate **22** (61 mg, 50%) as a glass, which was crystallized from CH_2Cl_2–hexane, m.p. 131–134 °C; mixed m.p. with a sample from the above experiment was undepressed; ^1H NMR spectrum was identical with that described above.

Acknowledgements

We would like to thank Dr. M. Vuilhorgne (ICSN, CNRS, Gif-sur-Yvette, France) for running ^{13}C NMR and 250 MHz ^1H NMR spectra.

References

1 Taken in part from the Ph.D. Thesis of S. D. Lindell, University of London, 1982.
2 D. H. R. Barton, J. Lister-James, R. H. Hesse, M. M. Pechet and S. Rozen, *J. Chem. Soc., Perkin Trans 1*, 1982, 1105; D. H. R. Barton, L. S. L. Choi, J. Lister-James, R. H. Hesse and M. M. Pechet, *J. Chem. Soc., Perkin Trans. 1*, 1982, 2599.
3 R. C. Tweit and R.M. Dodson, *J. Am. Chem. Soc.*, 1959, **81**, 4409; L. A. Neubert, M. Carmack and J. D. Huffman, *Acta Crystallogr., Sect B*, 1977, **33**, 962.
4 D. N. Harp and J. G. Gleason, *J. Org. Chem.*, 1970, **35**, 3259.
5 J. Tsurugi and T. Nakababayashi, *J. Org. Chem.*, 1959, **24**, 807; 1961, **26**, 2482.
6 E. E. Reid, *Organic Chemistry of Bivalent Sulfur*, Chemical Publishing Company, New York, 1960, vol. p. 362; L. Field, in *Organic Chemistry of Sulfur*, S. Oae, Plenum, London and New York, 1977, p. 303.
7 A. J. Mancuso, S.-L. Huang and D. Swern, *J. Org. Chem.*, 1978, **43**, 2480; A. J. Mancuso, D. S. Brownfain and D. Swern, *J. Org. Chem.*, 1979, **44**, 4148.
8 H. H. Inhoffen, G. Zuhlsdorff and Huang-Minlon, *Chem. Ber.*, 1940, **73**, 451.
9 G. Bergson, G. Claeson and L. Schotte, *Acta Chem. Scand.*, 1962, **16**, 1159; K. H. Bork and K. Brueckner, U.S.P. 3 164 584 (*Chem. Abstr.*, 1965, **62**, 7836a).
10 B. Balogh, D. M. Wilson and A. L. Burtingame, *Nature*, 1971, **233**, 261; W. A. Ayer, L. M. Browne, S. Fung and J. B. Stothers, *Can. J. Chem.*, 1976, **54**, 3272; *Org. Magn. Reson.*, 1978, **11**, 73; H. L. Holland and E. M. Thomas, *Can. J. Chem.*, 1979, **57**, 3069.
11 H. J. Boonstra, L. Brandsma, A. M. Wiegman and J. F. Arens, *Recl. Trav. Chim. Pays-Bas*, 1959, **78**, 252.
12 D. H. R. Barton, R. B. Boar, D. W. Hawkins and J. F. McGhie, *J. Chem. Soc., Perkin Trans. 1*, 1973, 654.
13 L. Ruzicka, M. W. Goldberg and W. Bosshard, *Helv. Chim. Acta*, 1937, **20**, 541; T. F. Gallagher and T. H. Kritchevsky, *J. Am. Chem. Soc.*, 1950, **72**, 882.
14 W. A. Schulze. G. H. Short and W. W. Crouch. *Ind. Engl. Chem.*, 1950, **42**, 916.
15 E. Kuhle, *Synthesis*, 1971, 563; G. H. Schmid, C. L. Dean and D. G. Garratt, *Can. J. Chem.*, 1976, **54**, 1253; A. S. Gybin. V. S. Bogdanor. M. Z. Krimer, W. A. Smit, L. A. Novgorodtseva, R. Sh. Achmedova, N. K. Sadovaya and N. S. Zefirov, *Zh. Org. Khim.*, 1979, **15**, 1361.
16 W. A. Smit, A. S. Gybin, V. S. Bogdanov, M. Z. Krimer and E. A. Vorobieva, *Tetrahedron Lett.*, 1978, 1085; W. A. Smit, N. S. Zefirov, I. V. Bodrikov and M. Z. Krimer, *Acc. Chem. Res.*, 1979, **12**, 282; W. A. Smit. N. S. Zefirov and I. V. Bodrikov, in *Organic Sulfur Chemistry*.

Invited Lectures. 9th Symposium 1980, eds. R. K. Freidlina and A. E. Skorva, Pergamon, Oxford and New York, 1981, p. 159.
17 B. M. Trost and T. Shibata, *J. Am. Chem. Soc.*, 1982, **104**, 3225; B. M. Trost, T. Shibata and S. J. Martin, *J. Am. Chem. Soc.*, 1982, **104**, 3228.
18 (*a*) D. O. Owsley, G. K. Helmkamp and M. F. Rettig, *J. Am. Chem. Soc.*, 1969, **91**, 5239; (*b*) I. V. Bodrikov, A. V. Borisov, L. V. Chumakov, N. S. Zefirov and W. A. Smit, *Tetrahedron Lett.*, 1980, **21**, 115; (*c*) V. M. Csizmadia, G. H. Schmid, P. Mezey and I. G. Csizmadia, *J. Chem. Soc., Perkin Trans. 2*, 1977, 1019; (*d*) D. G. Garratt and G. H. Schmid, *Can. J. Chem.*, 1974, **52**, 1027.
19 (*a*) N. C. Baenziger, R. E. Buckles, R. J. Maner and T. D. Simpson, *J. Am. Chem. Soc.*, 1969, **91**, 5749; G. E. Wilson, Jr., and M. M. Y. Chang, *J. Am. Chem. Soc.*, 1974, **96**, 7533; L. J. Adzima, E. N. Duesler and J. C. Martin, *J. Org. Chem.*, 1977, **42**, 4001; J. C. Martin and T. M. Balthazor, *J. Am. Chem. Soc.*, 1977, **99**, 152; L. J. Adziana, C. C. Chiang, I. C. Paul and J. C. Martin, *J. Am. Chem. Soc.*, 1978, **100**, 953; W. Y. Lam, E. N. Duesler and J. C. Martin, *J. Am. Chem. Soc.*, 1981, **103**, 127; (*b*) J. C. Carretero, J. L. G. Ruano and J. H. Rodriguez, *Tetrahedron Lett.*, 1987, **28**, 4593.
20 D. H. R. Barton, R. H. Hesse, S. D. Lindell and M. M. Pechet, following paper.
21 A. I. Vogel, *Practical Organic Chemistry*, Longmans, Green and Co., London, New York, 1957, p. 1037.

Paper 1/01757H
Received 16*th April* 1991
Accepted 22*nd May* 1991