Steroidal Sulphur Compounds. Part XII.[1] Regiospecific Formation of Steroidal Olefins by Thermolysis of Sulphoxides

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The first examples of the regiospecific generation of isomeric olefins from two sulphoxides diastereoisomeric at sulphur are reported. Thermolysis of (*R*)- and (*S*)-3α-(1-adamantylsulphinyl)-5α-cholestane at 110 °C gave respectively 5α-cholest-3-ene and 5α-cholest-2-ene; (*S*)-3β-(1-adamantylsulphinyl)-5β-cholestane gave 5β-cholest-3-ene at a rate much greater than that at which the diastereoisomeric (*R*)-sulphoxide decomposed to 5β-cholest-2-ene, so providing a convenient preparation of these erstwhile rather inaccessible olefins. In contrast, thermolysis of 3α-(1-naphthyl)- and 3α-(anthracen-9-yl)-5α-cholestanes was not highly regioselective, and the corresponding steroidal diphenyl sulphoxides underwent stereomutation at sulphur more readily than elimination to give olefins.

THE thermal decomposition of sulphoxides provides a convenient synthesis of olefins,[2] and the regioselectivity of elimination depends upon the chirality and the substituents at sulphur.[3] The influence of these factors has been illustrated by the thermolytic behaviour of the diastereoisomeric 3α-t-butylsulphinyl-5α-cholestanes (Ig) and (IIIg).[3c] The (*S*)-isomer (Ig) at 100 °C gave 5α-cholest-2-ene (IV) and 5α-cholest-3-ene (V) in the ratio 7 : 3, whereas the (*R*)-isomer (IIIg) gave the olefins in the ratio 3 : 7. The predominant formation of (IV) from (Ig) was rationalized in terms of steric effects,[3c] the transition state (A) linking (Ig) with (IV) being less sterically compressed than the transition state (B) connecting (Ig) with (V), because in (B) there are severe non-bonded repulsive interactions between the t-butyl group and the underside of ring A which are absent in (A).† Similarly, the predominance of 5α-cholest-3-ene (V) from the (*R*)-isomer (IIIg) was attributed to the greater steric energy of the transition state (C) than of (D).

It is conceivable that a sulphoxide (I) in which R is sufficiently bulky could undergo regiospecific thermolysis to one olefin (IV), whereas its diastereoisomer (III) could furnish only the alternative olefin (V). Since both sulphoxides (I) and (III) may be formed by oxidation of the sulphide (II), the Scheme provides a potential method for the regiospecific generation of two isomeric olefins from a common precursor; its success hinges on the ease of separation of the sulphoxides (I) and (III). The principle is not confined to sulphoxides such as (I) and (III), but we have examined its validity with steroidal sulphoxides of this type because of our familiarity with such systems.[3a-c] The sulphoxides used in this study were prepared by oxidation of the appropriate sulphide (II) with peroxydodecanoic acid in light petroleum, and they were separated by chromatography. Further oxidation of the sulphoxides furnished the same sulphone (VI), indicating that the sulphoxides differed only in configuration at sulphur.

The goal of regiospecific olefin formation from each of two diastereoisomeric sulphoxides was partly achieved previously in the thermolysis of the steroidal benzyl sulphoxides (Ia) and (IIIa),[3b] the (*R*)-isomer (Ia) at 110 °C giving 5α-cholest-2-ene (IV) regiospecifically, whereas the (*S*)-isomer (IIIa) gave a mixture of (IV) and 5α-cholest-3-ene (V) in the ratio 27 : 73. Steric effects of the type discussed above were clearly operating, but an additional factor was invoked to explain why (IIIa) underwent thermolysis only with high regioselectivity whereas (Ia) did so regiospecifically. This factor was associated with the presence of appreciable double-bond character in the transition states,[3b] the relative energies of which were consequently influenced by the greater thermodynamic stability of 5α-cholest-2-ene (IV) over 5α-cholest-3-ene (V).[4]

In commencing the present investigation we reasoned that the greater steric demands of a diphenylmethyl over a benzyl group might be sufficient to overcome the adverse effect of relative olefin stability, but our intention of studying the thermolytic olefin-forming elimination of the steroidal diphenylmethyl sulphoxides (Ib) and (IIIb) was frustrated by their ease of stereomutation at sulphur, which proceeded with a ' half-life ' of *ca.* 3 h at 70 °C in toluene. No olefin was formed. It is pertinent that the steroidal benzyl sulphoxides (Ia) and (IIIa) were configurationally stable at 110 °C,[3b] and that (+)-benzyl *p*-tolyl sulphoxide was racemized at 135 °C by a mechanism involving homolysis–recombination of a C–S bond, giving benzyl and *p*-tolylsulphinyl

† Steric effects in the transition state have been illustrated in the Scheme by reference to the conformations of the sulphoxides in their ground states. The steric effects in these conformations are qualitatively similar to those in the transition states, which have not been depicted because they are difficult to visualize in two-dimensional drawings. Such drawings have been presented previously,[3] and the interested reader may wish to refer to them.

[1] Part XI, D. N. Jones, D. A. Lewton, J. D. Msonthi, and R. J. K. Taylor, *J.C.S. Perkin I*, 1974, 937.

[2] C. A. Kingsbury and D. J. Cram, *J. Amer. Chem. Soc.*, 1960, **82**, 1810; C. Walling and L. Bollyky, *J. Org. Chem.*, 1964, **29**, 2699; I. D. Entwistle and R. A. W. Johnstone, *Chem. Comm.*, 1965, 29; D. W. Emerson, A. P. Craig, and I. W. Potts, *J. Org. Chem.*, 1967, **32**, 102; J. K. Kice and J. D. Campbell, *ibid.*, p. 1631; J. R. Shelton and K. E. Davis, *Internat. J. Sulphur Chem.*, 1973, **8**, 197; *inter alia* D. N. Brattesani and C. H. Heathcock, *Tetrahedron Letters*, 1974, 2279; P. A. Grieco, D. Boxler, and C. S. Pogonowski, *J.C.S. Chem. Comm.*, 1974, 497; B. M. Trost and R. A. Kunz, *J. Org. Chem.*, 1974, **39**, 2648.

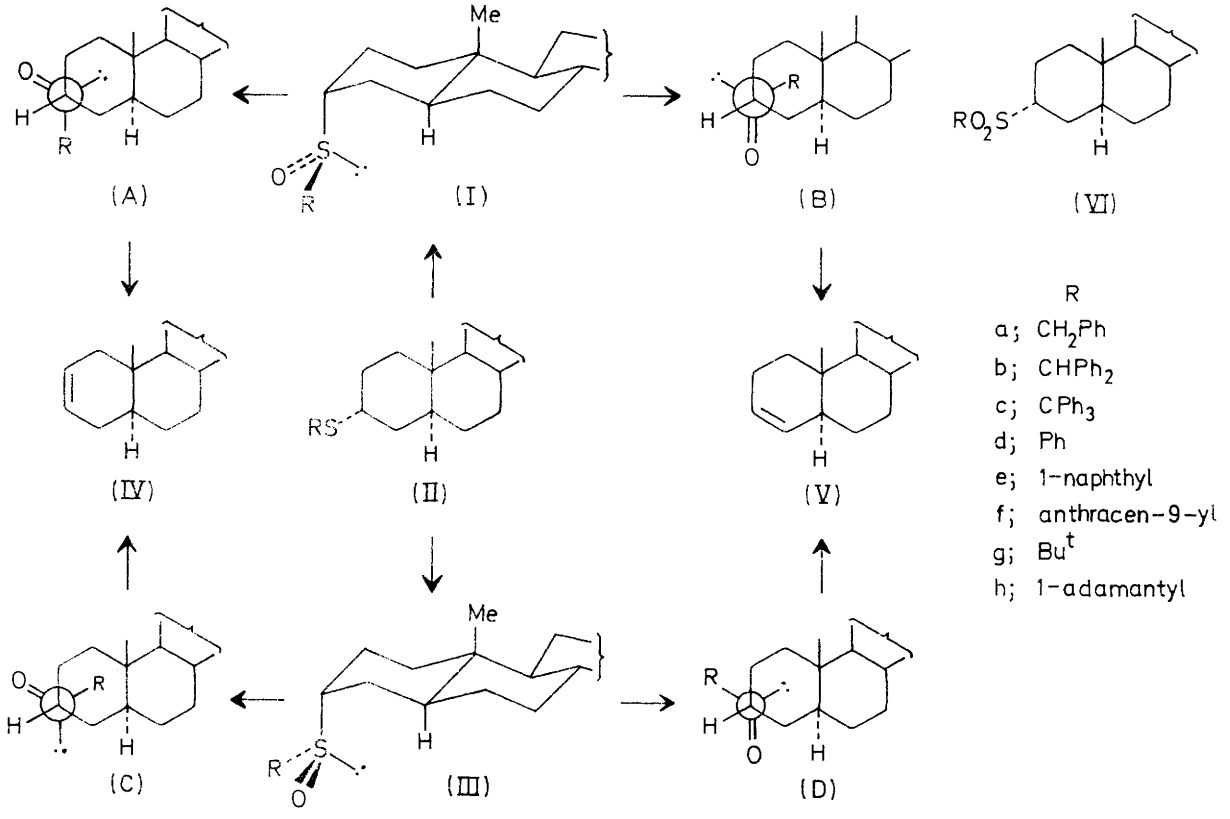
[3] (*a*) D. N. Jones and M. J. Green, *J. Chem. Soc.* (*C*), 1967, 532; (*b*) D. N. Jones and W. Higgins, *ibid.*, 1969, 2159; (*c*) D. N. Jones, E. Helmy, and A. C. F. Edmonds, *ibid.*, 1970, 833; (*d*) S. I. Goldberg and M. S. Sahli, *J. Org. Chem.*, 1967, **32**, 2059.

[4] P. Bladon, J. M. Fabian, H. B. Henbest, H. P. Koch, and G. W. Wood, *J. Chem. Soc.*, 1951, 2802; R. B. Turner, W. R. Meador, and R. W. Winkler, *J. Amer. Chem. Soc.*, 1957, **79**, 4116, 4122.

radicals.[5] It is reasonable to attribute the stereomutation of the steroidal diphenylmethyl sulphoxides (Ib) and (IIIb) to a similar homolysis and non-stereospecific recombination, the greater ease of initial homolysis of the diphenylmethyl sulphoxides than of the benzyl sulphoxides being a consequence of the greater stability of the diphenylmethyl over the benzyl radical. According to this rationale, triphenylmethyl alkyl sulphoxides should undergo homolysis even more readily, and consonantly we found that the sulphoxides (Ic) and (IIIc) were unstable at room temperature. Oxidation of the sulphide (IIc) with peroxydodecanoic acid in light petroleum at 20 °C, or with ozone in chloroform at −50 °C gave, according to t.l.c., a mixture of the two sulphoxides which rapidly decomposed to an intractable mixture.

The products of prolonged heating of the steroidal diphenylmethyl sulphoxides (Ib) and (IIIb) at 61 °C in toluene under nitrogen were the sulphone (VIb) (41%), the disulphide (II; R = 5α-cholestan-3α-ylthio) (21%), 5α-cholestan-3-one (10%), and benzophenone (5%). Sulphones, disulphides, and carbonyl compounds have been detected previously as products of thermolysis of sulphoxides,[3c,5,6] but the formation of sulphone as major product (in an inert atmosphere) is without precedent; we consider speculation about the mechanism of formation of the sulphone to be unwarranted in view of the limited evidence available.

We next investigated the thermolysis of the diastereoisomeric steroidal 3-(1-naphthyl) sulphoxides (Ie) and (IIIe), and the steroidal 3α-(anthracen-9-yl) sulphoxides (If) and (IIIf). A previous investigation had revealed that (*R*)-3α-phenylsulphinyl-5α-cholestane (IIId) in boiling toluene gave a mixture of (IV) and (V) in the ratio 62 : 38, whereas the (*S*)-isomer (Id) gave a mixture of the olefins in the ratio 83 : 17.[3a] The preponderance of 5α-cholest-2-ene (IV) from both diastereoisomers was ascribed to conjugation of the phenyl group through sulphur with the incipient double bond, which consequently was sufficiently well developed in the transition state for the proportions of product olefins to be governed in large part by their relative thermodynamic stability, (IV) being the more stable. Our hope that the greater steric requirements of the 1-naphthyl and anthracen-9-yl groups over phenyl would overcome such conjugative effects was not realised, the (*R*)- and (*S*)-(1-naphthyl) sulphoxides, (IIIe) and (Ie), giving mixtures of olefins (IV) and (V) in the ratios 57 : 43 and 89 : 11, respectively, whereas whilst the (*R*)- and (*S*)-(anthracen-9-yl) sulphoxides, (IIIf) and (If), gave the olefins in the ratios 67 : 33 and 84 : 16, respectively. Under these con-



SCHEME

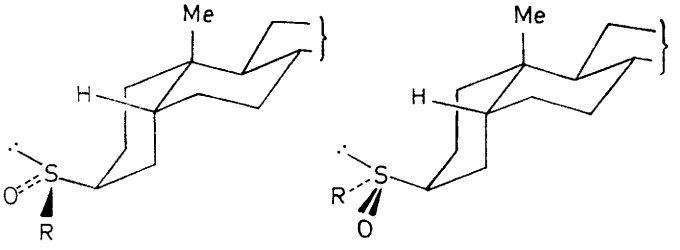
[5] E. G. Miller, D. R. Rayner, H. T. Thomas, and K. Mislow, *J. Amer. Chem. Soc.*, 1968, **90**, 4861.

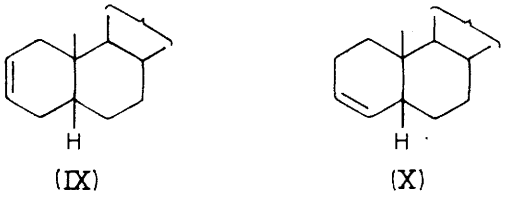
[6] D. G. Barnard-Smith and J. F. Ford, *Chem. Comm.*, 1965, 120; W. Carruthers, I. D. Entwistle, R. A. W. Johnson, and B. J. Millard, *Chem. and Ind.*, 1966, 342.

ditions these aryl sulphoxides did not undergo stereomutation at sulphur.

As indicated earlier, the choice of a t-butyl group as *R* in the Scheme did not lead to regiospecific elimination.[3c] A further drawback was that the yield of olefins was low (12—23%) because of the statistical factors favouring elimination involving the nine hydrogen atoms of the t-butyl group over elimination of the two hydrogen atoms at the steroid 2α- and 4α-positions.[3c] However, the antipodal relationship between the ratios of steroidal olefins obtained from the (*S*)- and (*R*)-isomers, (Ig) and (IIIg), suggested that the transition states for the eliminations had little double-bond character, in contrast to the case for the aryl and benzyl sulphoxides. This factor, together with the presumed reluctance for β-elimination into an adamantyl group because it would violate Bredt's rule (although adamantene has been formed transiently by way of radical processes) [7] and evidence that increasing rigidity of alkyl systems causes major increases in steric effects,[8] encouraged us to study the thermolysis of the diastereoisomeric adamantyl sulphoxides (Ih) and (IIIh).

In toluene at 110 °C (*R*)-3α-(1-adamantylsulphinyl)-5α-cholestane (IIIh) gave only 5α-cholest-3-ene (V) (73%) after 146 h, whereas the (*S*)-isomer (Ih) under the same conditions gave only 5α-cholest-2-ene (IV) (75%), providing the first example of the generation of isomeric olefins by regiospecific elimination of a pair of sulphoxides diastereoisomeric at sulphur. It also provided a convincing demonstration, further to those found for solvolytic reactions,[8] that the steric requirement of the rigid adamantyl system is effectively greater than that of the t-butyl group. However, this is not the best method of preparing 5α-cholest-2-ene and 5α-cholest-3-ene because the sulphoxides (Ih) and (IIIh) are not readily separated by chromatography. Nevertheless the procedure did appear to be potentially advantageous for the preparation of less accessible olefins, and we tested this possibility by applying the method to the generation of 5β-cholest-2-ene (IX) and 5β-cholest-3-ene (X); we had found these olefins difficult to make by the published procedures.[9] The appropriate sulphoxides (VII) and (VIII) were prepared by sequential treatment of 3α-methylsulphonyloxy-5β-cholestane with adamantane-1-thiolate anions and peroxydodecanoic acid, and in contrast to the case for (Ih) and (IIIh) the sulphoxides (VII) and (VIII) were easily separated by chromatography. Further oxidation of (VII) and (VIII) gave the same sulphone. Thermolysis of the (*S*)-isomer (VIII) in boiling toluene (110 °C) gave only 5β-cholest-3-ene (X) (98%) after 8 h, but under the same conditions after 96 h the (*R*)-isomer (VII) gave a mixture of 5β-cholest-2-ene (IX) and 5β-cholest-3-ene (X) quantitatively in the ratio 9 : 1. Crystallization of this mixture of (IX) and (X) readily gave pure 5β-cholest-2-ene (IX), so for preparative purposes the lack of regiospecificity of elimination was not too disadvantageous. Regiospecific elimination of the (*R*)-3β-adamantyl sulphoxide (VII) to 5β-cholest-2-ene (IX) was achieved in boiling benzene (80 °C), albeit slowly, the decomposition being 60% complete after 500 h. For the preparation of 5β-cholest-2-ene (IX) and 5β-cholest-3-ene (X) it was not necessary to separate the sulphoxides (VII) and (VIII), since they decomposed at markedly different rates; thermolysis of a mixture of (VII) and (VIII) at 100 °C for 4 days gave, after simple





chromatography, pure 5β-cholest-3-ene (X) and unchanged (*R*)-sulphoxide (VII), which in turn could be thermally decomposed to give pure 5β-cholest-2-ene (IX).

Configurations at sulphur in all the sulphoxides, except (Ib) and (IIIb), were deduced from the ratios of the isomeric olefins formed on thermolysis, by use of the transition state arguments outlined in the text (*cf.* refs. 3*a*—*c*). For the (*R*)- and (*S*)-3α-diphenylmethyl sulphoxides (IIIb) and (Ib) allocation of configuration at sulphur followed from the similarity of the chiroptical properties (Experimental section) of (IIIb) and (Ib) with those of the (*R*)- and (*S*)-3α-benzyl sulphoxides (Ia) and (IIIa), respectively, the configurations of which were established by the pyrolytic method.[3b] The allocations of configuration to the steroidal adamantyl sulphoxides were consistent with their chiroptical properties (see Experimental section). The o.r.d. and c.d. characteristics of (*R*)-3α-(1-adamantylsulphinyl)-5α-cholestane (IIIh) were almost identical with those of (*R*)-3β-(1-adamantylsulphinyl)-5β-cholestane (VII), and very similar to those of (*R*)-3α-t-butylsulphinyl-5α-cholestane (IIIg), whilst the chiroptical properties of the (*S*)-isomers (Ih) and (VIII) were almost identical, being in turn similar to those of (*S*)-3α-t-butylsulphinyl-5α-cholestane (Ig). The o.r.d. and c.d. curves for the

[7] D. Grant, M. A. McKervey, J. T. Rooney, N. G. Sammon, and G. Step, *J.C.S. Chem. Comm.*, 1972, 1186; D. Lenoir, *Tetrahedron Letters*, 1972, 4049; A. H. Alverts, J. Strating, and H. Wynberg, *ibid.*, 1973, 3047.

[8] E. N. Peters and H. C. Brown, *J. Amer. Chem. Soc.*, 1974, **96**, 263.

[9] (*a*) G. Bellucci, F. Macchia, and V. Malaguzzi, *Tetrahedron Letters*, 1966, 4973; (*b*) B. R. Davies and P. D. Woodgate, *J. Chem. Soc.* (*C*), 1966, 2006; (*c*) A. Nickon, N. Schwartz, J. B. DiGiorgio, and D. A. Widdowson, *J. Org. Chem.*, 1965, **30**, 1711.

(*R*)-isomers (IIIh) and (VII) were almost ' enantiomeric ' with those for the (*S*)-isomers (Ih) and (VIII). It is apparent that the chiroptical properties of the steroidal adamantyl sulphoxides are determined by chirality at sulphur, the influence of changes of configuration at C-3 and C-5 being minimal.

EXPERIMENTAL

M.p.s were determined with a Kofler hot-stage apparatus. I.r. spectra were determined with a Unicam SP 100 spectrophotometer, u.v. spectra for solutions in hexane with a Cary 14 spectrophotometer, and n.m.r. spectra with a Varian HA-100 spectrometer for solutions in deuteriochloroform. Optical rotations were determined with a Perkin-Elmer 141 automatic polarimeter, or a Bendix–Ericson polarimeter (ETL-NPL, model 143A) for solutions in chloroform. O.r.d. and c.d. data were measured (hexane as solvent) with a Bendix Polarmatic 62 automatic recording instrument. Mass spectra were determined with an A.E.I. MS9 double-focusing spectrometer operating at 70 eV. Preparative thick-layer chromatography (p.l.c.) was performed with a 1 mm layer of silica gel G (Merck). Light petroleum refers to the fraction b.p. 40—60°.

Preparation of the Steroidal Sulphides.—The following procedure was typical. 3β-*p*-Tolylsulphonyloxy-5α-cholestane (1 g) was added to a solution of sodium (0.2 g) and diphenylmethanethiol (0.2 g) in propan-2-ol (10 ml) and toluene (10 ml) under nitrogen. After 29 h on a steam-bath the mixture was worked up with ether to give an oil which was chromatographed on alumina (50 g). Elution with light petroleum gave 3α-*diphenylmethylthio-5α-cholestane* (IIb) (306 mg, 57%) as an oil, $[\alpha]_D$ +26° (*c* 1.2), τ 4.90 (Ph_2C), 7.03 ($W_{\frac{1}{2}}$ 8 Hz, 3β-H), 9.16 (10-Me), and 9.34 (13-Me) (Found: C, 83.95; H, 10.4; S, 5.6. $C_{40}H_{58}S$ requires C, 84.1; H, 10.2; S, 5.6%).

3α-*Triphenylmethylthio-5α-cholestane* (IIc) (88%), double m.p. 115—117 and 139—141° (from acetone), $[\alpha]_D$ +30° (*c* 0.7), τ 7.30 ($W_{\frac{1}{2}}$ 8 Hz, 3β-H), 9.18 (10-Me), and 9.36 (13-Me) (Found: C, 85.6; H, 9.75; S, 4.9. $C_{46}H_{62}S$ requires C, 85.4; H, 9.7; S, 5.0%), 3α-(1-*naphthylthio*)-5α-*cholestane* (IIe) (78%), m.p. 131—132° (from ether–methanol), $[\alpha]_D$ +12° (*c* 0.6), τ 6.36 ($W_{\frac{1}{2}}$ 8 Hz, 3β-H), 9.16 (10-Me), and 9.34 (13-Me) (Found: C, 83.7; H, 10.0; S, 6.1. $C_{37}H_{54}S$ requires C, 83.7; H, 10.25; S, 6.0%), 3α-(*anthracen*-9-*ylthio*)-5α-*cholestane* (IIf) (73%), m.p. 147—148° (needles from ether–methanol), $[\alpha]_D$ +24° (*c* 0.9), τ 6.56 ($W_{\frac{1}{2}}$ 8 Hz, 3β-H), 9.16 (10-Me), and 9.37 (13-Me) (Found: C, 84.7; H, 9.4; S, 5.5%; M^+, 580. $C_{41}H_{56}S$ requires C, 84.8; H, 9.7; S, 5.5%; *M*, 580), and 3α-(1-*adamantylthio*)-5α-*cholestane* (IIh) (80%), m.p. 149—151° (from dichloromethane–acetone), $[\alpha]_D$ +23° (*c* 0.5), τ 6.83 ($W_{\frac{1}{2}}$ 9 Hz, 3β-H), 8.0—8.35 (adamantane protons), 9.11 (10-Me), and 9.36 (13-Me) (Found: C, 82.5; H, 11.7. $C_{37}H_{62}S$ requires C, 82.5; H, 11.6%) were prepared in a similar way from 3β-*p*-tolylsulphonyloxy-5α-cholestane, and 3β-(1-*adamantylthio*)-5β-*cholestane* (73%), m.p. 141—143°, $[\alpha]_D$ +19° (*c* 1.2), τ 6.76 ($W_{\frac{1}{2}}$ 8 Hz, 3α-H), 9.08 (10-Me), and 9.36 (13-Me) (Found: C, 82.55; H, 11.7%) was obtained from 3α-methylsulphonyloxy-5β-cholestane (see below) by the same procedure.

Adamantane-1-thiol,[10] naphthalene-1-thiol,[11] anthracene-9-thiol,[12] and triphenylmethanethiol [13] were prepared by the published procedures. Diphenylmethanethiol was prepared as follows. A solution of diphenylmethyl chloride (24 ml) and tetrabutylammonium thioacetate (40 g) in butan-2-one (500 ml) was boiled for 18 h, then evaporated under reduced pressure, and the resulting oil was taken up in ether and washed repeatedly with water. The residue obtained by evaporation was distilled under reduced pressure to give diphenylmethyl thioacetate (10 g), b.p. 140—144° at 0.04 mmHg, which crystallized from light petroleum. The deliquescent thioacetate (4.2 g) was immediately treated with lithium aluminium hydride (1 g) in boiling ether (250 ml) for 2 h, and the usual work-up gave diphenylmethanethiol as a colourless, viscous oil with an extremely offensive odour.

3β-*p*-Tolylsulphonyloxy-5α-cholestane was prepared as before; [14] 3α-*methylsulphonyloxy-5β-cholestane* (82%), m.p. 108—110° (from acetone–methanol), τ 5.37 ($W_{\frac{1}{2}}$ 19 Hz, 3β-H), 7.03 ($MeSO_3$), 9.07 (10-Me), and 9.36 (13-Me) (Found: C, 71.9; H, 10.8; S, 7.05%; M^+, 466. $C_{28}H_{50}SO_3$ requires C, 72.0; H, 10.8; S, 6.9%; *M*, 466) was obtained by reaction of 5β-cholestan-3α-ol [15] with methanesulphonyl chloride in pyridine at room temperature for 24 h.

Preparation of the Steroidal Sulphoxides.—(*a*) 3α-Diphenylmethylthio-5α-cholestane (IIb) (2.4 g, 4.2 mmol) was added to peroxydodecanoic acid (70% pure; 1.32 g, 4.2 mmol) in light petroleum (250 ml). After 1 h at room temperature the mixture was chromatographed on alumina (90 g). Elution with light petroleum gave 3α-diphenylmethylthio-5α-cholestane (IIb) (70 mg); elution with ether gave a mixture of sulphoxides which was subjected to further chromatography on silica (p.l.c.) with ether–benzene (1 : 13) as eluant. Two bands were separately extracted to give (R)-3α-*diphenylmethylsulphinyl-5α-cholestane* (IIIb) (1.17 g, 27%), m.p. 136—137° (from methanol), $[\alpha]_D$ +96° (*c* 0.5), $\nu_{max.}(CCl_4)$ 1 053 cm^{-1}, $\lambda_{max.}$ 244 (ε 4 850) and 222 nm (17 200), o.r.d. $[\phi]_{400}$ +1 000, $[\phi]_{263}$ +17 500, $[\phi]_{250}$ 0, $[\phi]_{238}$ −28 000, $[\phi]_{227}$ 0, $[\phi]_{213}$ +32 000°, c.d. $[\theta]_{326}$ −34 500, $[\theta]_{254}$ −48 000, τ 5.23 (Ph_2CH), 7.26 ($W_{\frac{1}{2}}$ 9 Hz, 3β-H), 9.18 (10-Me), and 9.38 (13-Me) (Found: C, 80.9; H, 9.8. $C_{40}H_{58}OS,0.5CH_3OH$ requires C, 80.8; H, 10.0%), and the (S)-*isomer* (Ib) (900 mg, 21%), m.p. 113—115° (from methanol), $[\alpha]_D$ −52° (*c* 0.5), $\nu_{max.}(CCl_4)$ 1 053 cm^{-1}, $\lambda_{max.}$ 244 (ε 4 870) and 222sh nm (16 400), τ 5.25 (Ph_2CH), 7.29 ($W_{\frac{1}{2}}$ 9.5 Hz, 3β-H), 9.19 (10-Me), and 9.38 (13-Me), o.r.d. $[\phi]_{400}$ −560, $[\phi]_{263}$ −14 000, $[\phi]_{250}$ 0, $[\phi]_{238}$ +42 000, $[\phi]_{227}$ 0, $[\phi]_{213}$ −27 500° (Found: C, 80.8; H, 9.6. $C_{40}H_{58}OS,0.5CH_3OH$ requires C, 80.8; H, 10.0%).

(*b*) Oxidation of 3α-(1-naphthylthio)-5α-cholestane (IIe) (4.0 g) as above gave, after p.l.c. on silica, (R)-3α-(1-*naphthylsulphinyl*)-5α-*cholestane* (IIIe) (1.7 g, 34%), m.p. 159—161° (from ether–chloroform), $[\alpha]_D$ −68° (*c* 0.6), $\nu_{max.}$(KBr) 1 050 cm^{-1}, $\lambda_{max.}$ 300 (ε 6 150) and 220 nm (50 400), o.r.d. $[\phi]_{400}$ −2 000, $[\phi]_{323}$ −11 000, $[\phi]_{301}$ 0, $[\phi]_{286}$ +16 000, $[\phi]_{267}$ 0, $[\phi]_{250}$ −27 000, $[\phi]_{237}$ 0, $[\phi]_{208}$ +51 000°, c.d. $[\theta]_{232}$ +206 000, $[\theta]_{298}$ +27 500, τ 6.95 ($W_{\frac{1}{2}}$ 9 Hz, 3β-H), 9.16 (10-Me), and 9.35 (13-Me) (Found: C, 81.3; H, 10.0; S, 6.15. $C_{37}H_{54}OS$ requires C, 81.3; H, 10.0; S, 5.9%), and the (S)-*isomer* (Ie) (1.5 g, 30%), m.p. 174—175° (from ether–chloroform), $[\alpha]_D$ +68° (*c* 0.6), $\nu_{max.}$(KBr)

[10] H. Stetter, M. Kranse, and W. D. Last, *Chem. Ber.*, 1969, **102**, 3357.
[11] E. Bourgeois, *Rec. Trav. chim.*, 1899, **18**, 441.
[12] P. Friedlander and A. Simon, *Ber.*, 1922, **55**, 3972; W. Conway and D. S. Tarbell, *J. Amer. Chem. Soc.*, 1956, **78**, 2228.
[13] D. Vorlander and E. Mittag, *Ber.*, 1913, **46**, 3450.
[14] H. R. Nace, *J. Amer. Chem. Soc.*, 1952, **74**, 5937.
[15] C. W. Shoppee and G. H. R. Summers, *J. Chem. Soc.*, 1950, 687.

1 046 cm^{-1}, $\lambda_{max.}$ 300 (ε 5 200) and 218 nm (46 000), o.r.d. $[\phi]_{400}$ +2 600, $[\phi]_{323}$ +11 500, $[\phi]_{303}$ 0, $[\phi]_{286}$ −18 400, $[\phi]_{263}$ 0, $[\phi]_{250}$ +16 000, $[\phi]_{237}$ 0, $[\phi]_{208}$ −115 000°, c.d. $[\theta]_{230}$ −86 000, $[\theta]_{294}$ −17 000, τ 6.82 ($W_{\frac{1}{2}}$ 9 Hz, 3β-H), 9.16 (10-Me), and 9.34 (13-Me) (Found: C, 81.5; H, 10.2; S, 5.9%).

(*c*) A solution of peroxydodecanoic acid (90% pure; 576 mg, 2.45 mmol) and 3α-(anthracen-9-ylthio)-5α-cholestane (IIf) (1.3 g, 2.24 mmol) in chloroform (50 ml) was kept at room temperature for 20 min, diluted with petroleum (40 ml; b.p. 80—100°), and then boiled down until crystallization commenced. Cooling, filtration, and recrystallization from chloroform–ethanol gave (R)-3α-(*9-anthracylsulphinyl*)-5α-*cholestane* (IIIf) (340 mg, 27%), m.p. 187—188°, $[\alpha]_D$ +25° (*c* 0.6), $\nu_{max.}$(CCl$_4$) 1 040 and 1 051 cm^{-1}, $\lambda_{max.}$ 397 (ε 6 500), 378 (7 300), 364 (5 600), 257 (90 000), 252sh (80 000), and 218 nm (24 000), o.r.d. $[\phi]_{385}$ 0, $[\phi]_{263}$ −17 000, $[\phi]_{244}$ −75 000, $[\phi]_{234}$ 0, $[\phi]_{227}$ +75 000, $[\phi]_{213}$ +60 000°, c.d. $[\theta]_{247}$ −175 000, $[\theta]_{260}$ −295 000, $[\theta]_{270}$ −42 000, τ 5.92 ($W_{\frac{1}{2}}$ 9 Hz, 3β-H), 9.18 (10-Me), and 9.37 (13-Me) (Found: C, 82.6; H, 9.3; S, 5.5. $C_{41}H_{56}OS$ requires C, 82.5; H, 9.5; S, 5.4%). The residue obtained on evaporation of the combined filtrates and mother liquors was chromatographed on silica (p.l.c.) with ether–benzene (1 : 9) as eluant. Extraction of the two bands separately with ether gave the (*R*)-sulphoxide (IIIf) (190 mg, 15%), and the (S)-*isomer* (If) (420 mg, 34%), m.p. 181—184° (from acetone), $[\alpha]_D$ 0° (*c* 0.3 and 0.6), $\nu_{max.}$(CCl$_4$) 1 050 cm^{-1}, $\lambda_{max.}$ 398 (ε 5 700), 378 (6 400), 364 (5 860), 256 (84 000), 252 (80 000), and 218 nm (21 800), o.r.d. $[\phi]_{385}$ 0, $[\phi]_{278}$ +7 600, $[\phi]_{270}$ 0, $[\phi]_{267}$ −9 000, $[\phi]_{263}$ 0, $[\phi]_{255}$ +35 000, $[\phi]_{249}$ 0, $[\phi]_{222}$ −66 000°, c.d. $[\theta]_{247}$ +42 000, $[\theta]_{260}$ −55 000, $[\theta]_{270}$ −16 000, τ 5.85 ($W_{\frac{1}{2}}$ 9 Hz, 3β-H), 9.19 (10-Me), and 9.36 (13-Me) (Found: C, 82.1; H, 9.3; S, 5.4%).

(*d*) Peroxydodecanoic acid (90% pure; 880 mg, 3.7 mmol) was added to 3α-(1-adamantylthio)-5α-cholestane (IIh) (2.0 g, 3.7 mmol) in light petroleum (100 ml) and after 1 h at room temperature the solution was diluted with benzene (50 ml) and passed on to a column of alumina (150 g). Elution first with benzene and then with ether–benzene (1 : 9) gave a mixture of the *sulphoxides* (Ih) and (IIIh) (1.9 g, 90%), m.p. 190—191° (from benzene–di-isopropyl ether) (Found: C, 79.9; H, 11.2; S, 6.0. $C_{37}H_{62}OS$ requires C, 80.1; H, 11.3; S, 5.8%). Chromatography of this mixture (1 g) on a column of silica (Merck silica gel G; 200 g) eluted under slight positive pressure by ether–benzene (1 : 4) gave (R)-3α-(1-*adamantylsulphinyl*)-5α-*cholestane* (IIIf) (400 mg), m.p. 182—184°, $[\alpha]_D$ +22° (*c* 0.4), $\nu_{max.}$(CCl$_4$) 1 032 and 1 056 cm^{-1}, $\lambda_{max.}$ 230 (ε 1 230) and 209 nm (5 000), o.r.d. $[\phi]_{286}$ 0, $[\phi]_{244}$ −8 600, $[\phi]_{236}$ 0, $[\phi]_{217}$ +50 700, $[\phi]_{204}$ +27 000°, c.d. $[\theta]_{208}$ +172 000, $[\theta]_{230}$ −76 000, τ 6.95 ($W_{\frac{1}{2}}$ 10 Hz, 3β-H), 9.17 (10-Me), and 9.35 (13-Me) (Found: M^+, 554.451 3. $C_{37}H_{62}OS$ requires *M*, 554.452 0), followed by mixtures of the (*R*)- and (*S*)-sulphoxides. Rechromatography of some of this mixture (250 mg), containing 80% of the (*S*)-isomer (according to o.r.d.), on silica (200 g) in the above manner gave the (S)-*isomer* (If) (100 mg), m.p. 180—184°, $[\alpha]_D$ +24° (*c* 0.9), $\nu_{max.}$(CCl$_4$) 1 032 and 1 057 cm^{-1}, $\lambda_{max.}$ 233 nm (ε 5 900), o.r.d. $[\phi]_{286}$ 0, $[\phi]_{244}$ +9 800, $[\phi]_{236}$ 0, $[\phi]_{217}$ −46 500, $[\phi]_{204}$ 0, c.d. $[\theta]_{208}$ −145 000, $[\theta]_{232}$ +74 500, τ 6.93 ($W_{\frac{1}{2}}$ 10 Hz, 3β-H), 9.18 (10-Me), and 9.36 (13-Me) (Found: M^+, 554.451 3).

(*e*) Peroxydodecanoic acid (91% pure; 275 mg, 1.15 mmol) in light petroleum (10 ml) was added to a solution of 3β-(1-adamantylthio)-5β-cholestane (625 mg, 1.15 mmol) in light petroleum (20 ml). After 1 h at room temperature the solution was diluted with ether, washed with sodium hydrogen carbonate, water, and dried (Na_2SO_4). Evaporation gave a white solid which was chromatographed on silica (p.l.c.), repeatedly eluted with ether–light petroleum (2 : 3). Extraction of the faster running band gave (S)-3β-(1-*adamantylsulphinyl*)-5β-*cholestane* (VIII) (207 mg, 31%), m.p. 156—157° (needles from acetone), $[\alpha]_D$ +15° (*c* 0.35), $\nu_{max.}$(CCl$_4$) 1 030 and 1 055 cm^{-1}; $\lambda_{max.}$ 233 (ε 987) and 208 nm (4 630); o.r.d. $[\phi]_{400}$ 0, $[\phi]_{260}$ +2 800, $[\phi]_{244}$ +10 400, $[\phi]_{236}$ 0, $[\phi]_{217}$ −45 400, $[\phi]_{213}$ −44 000, c.d. $[\theta]_{371}$ 0, $[\theta]_{263}$ +972, $[\theta]_{241}$ +22 600, $[\theta]_{233}$ +34 000, $[\theta]_{222}$ +13 600, τ 6.88 ($W_{\frac{1}{2}}$ 10 Hz, 3α-H), 9.04 (10-Me), and 9.35 (13-Me) (Found: C, 79.8; H, 11.5; S, 6.0%; M^+, 554. $C_{37}H_{62}SO$ requires C, 80.1; H, 11.3; S, 5.8%; *M*, 554); extraction of the slower running band gave the (R)-*isomer* (VII) (104 mg, 15%), m.p. 161—162° (from acetone), $[\alpha]_D$ +20° (*c* 0.31), $\nu_{max.}$(CCl$_4$) 1 012 and 1 050 cm^{-1}; $\lambda_{max.}$ 233 (ε 1 020) and 209 nm (4 970), o.r.d. $[\phi]_{303}$ 0, $[\phi]_{285}$ −790, $[\phi]_{265}$ −2 400, $[\phi]_{244}$ −11 030, $[\phi]_{237}$ 0, $[\phi]_{232}$ +16 600; c.d. $[\theta]_{340}$ 0, $[\theta]_{280}$ +2 000, $[\theta]_{256}$ +3 960, $[\theta]_{250}$ 0, $[\theta]_{244}$ −12 672, $[\theta]_{233}$ −31 680, $[\theta]_{222}$ −5 544, τ 6.88 ($W_{\frac{1}{2}}$ 9.5 Hz, 3α-H), 9.03 (10-Me), and 9.34 (13-Me) (Found: C, 80.15; H, 11.15; S, 5.8%; *M*, 554).

Preparation of the Sulphones.—Oxidation of the sulphides (IIb, e, f, and h) and 3β-(1-adamantylthio)-5β-cholestane, respectively, with peroxydodecanoic acid in light petroleum as described previously [3c] gave 3α-*diphenylmethylsulphonyl*-5α-*cholestane* (VIb) (79%), m.p. 175° (from ether–methanol), $[\alpha]_D$ +25° (*c* 0.6), $\nu_{max.}$(CCl$_4$) 1 127 and 1 316 cm^{-1}, τ 4.48 (Ph_2CH), 6.92 ($W_{\frac{1}{2}}$ 10 Hz, 3β-H), 9.18 (10-Me), and 9.37 (13-Me) (Found: C, 79.9; H, 9.9; S, 5.3. $C_{40}H_{58}O_2S$ requires C, 79.9; H, 9.7; S, 5.3%); 3α-(1-*naphthylsulphonyl*)-5α-*cholestane* (VIe) (86%), m.p. 234—235° (from ether), $[\alpha]_D$ +14° (*c* 1.0), $\nu_{max.}$(KBr) 1 305 and 1 123 cm^{-1}, τ 6.56 ($W_{\frac{1}{2}}$ 6.5 Hz, 3β-H), 9.16 (10-Me), and 9.35 (13-Me) (Found: C, 78.7; H, 9.7; S, 5.8. $C_{37}H_{54}O_2S$ requires C, 78.9; H, 9.7; S, 5.7%); 3α-(*anthracen-9-ylsulphonyl*)-5α-*cholestane* (VIf) (53%), m.p. 257—258° (decomp.), $[\alpha]_D$ +11° (*c* 0.7), $\nu_{max.}$(KBr) 1 122 and 1 294 cm^{-1}, τ 6.39 ($W_{\frac{1}{2}}$ 8.5 Hz, 3β-H), 9.16 (10-Me), and 9.36 (13-Me) (Found: C, 79.7; H, 9.3; S, 4.7. $C_{41}H_{56}O_2S$ requires C, 80.3; H, 9.2; S, 5.2%); 3α-(1-*adamantylsulphonyl*)-5α-*cholestane* (VIh) (72%), m.p. 244—246° (from dichloromethane–acetone), $[\alpha]_D$ +57° (*c* 0.5), $\nu_{max.}$(CCl$_4$) 1 289 and 1 297 cm^{-1}, τ 6.65 ($W_{\frac{1}{2}}$ 10 Hz, 3β-H), 9.22 (10-Me), and 9.36 (13-Me) (Found: C, 77.85; H, 10.7; S, 5.9. $C_{37}H_{62}O_2S$ requires C, 77.8; H, 10.9; S, 5.6%); and 3β-(1-*adamantylsulphonyl*)-5β-*cholestane* (94%), m.p. 198—200° (from acetone), $\nu_{max.}$($CHCl_3$) 1 280 and 1 127 cm^{-1}, τ 6.57 ($W_{\frac{1}{2}}$ 10 Hz, 3α-H), 9.04 (10-Me) and 9.36 (13-Me) (Found: C, 77.8; H, 10.9; S, 5.9. $C_{37}H_{62}O_2S$ requires C, 77.8; H, 10.9; S, 5.6%).

3α-Diphenylmethylsulphonyl-5α-cholestane (VIb) was obtained also by oxidation separately, in the above manner, of the sulphoxides (Ib) and (IIIb); (VIe) was similarly formed from (Ie) and (IIIe), (VIf) from (If) and (IIIf), (VIh) from (Ih) and (IIIh), and 3β-(1-adamantylsulphonyl)-5β-cholestane from the sulphoxides (VII) and (VIII).

Thermolysis of the Sulphoxides.—(*a*) (*R*)-3α-(1-Naphthylsulphinyl)-5α-cholestane (IIIe) (202 mg) in toluene (50 ml) was kept at 100 °C for 12 h under nitrogen. The solvent was evaporated off under reduced pressure, and the residue was chromatographed on alumina (25 g). Elution with

light petroleum gave a crude mixture of olefins, (IV) and (V); elution with ether gave starting material (IIIe) (77 mg, 38%). Traces of impurities were removed from the olefins by rechromatography (p.l.c.) on silica impregnated with silver nitrate.[16] Elution with light petroleum, and extraction of the band at R_F *ca.* 0.2 gave a mixture of 5α-cholest-2-ene (IV) and 5α-cholest-3-ene (V) (101 mg, 78% based on sulphoxide consumed) containing no impurity (n.m.r.[17] and t.l.c.). Control experiments showed that this procedure did not affect the ratio of olefins.

(*b*) The thermolysis of the sulphoxides (Ie), (If), (Ih), (IIIf), and (IIIh) was performed in the above manner, except that in many cases (see Table) boiling toluene (110 °C) was employed. The results are collected in the Table.

Regioselectivity and yield of steroidal olefins formed by pyrolysis of sulphoxides

				Olefin mixture		
					Composition (%)	
Sulphoxide	Temp. (°C)	Time/h	Sulphoxide recovered (%)	Yield (%)	(IV)	(V)
(Ie)	100	12	32	79	89	11
(IIIe)	100	12	38	78	57	43
(If)	110	166	0	84	84	16
(IIIf)	110	166	0	83	67	33
(Ih)	110	146	0	78	100	0
(IIIh)	110	146	0	73	0	100
					(IX)	(X)
(VII)	110	96	0	99	90	10
(VII)	80	500	40	98	100	0
(VIII)	110	8	0	98	0	100

(*c*) (*R*)- and (*S*)-3α-Diphenylmethylsulphinyl-5α-cholestane, (IIIb) and (Ib), underwent stereomutation at sulphur on heating in toluene at 61 °C, according to t.l.c., to give an equilibrium mixture in the ratio 1 : 1. The stereomutation of the (*R*)-isomer (IIIb) was followed polarimetrically, by using 280 nm light and a cell of 0.5 cm pathlength containing a solution of (IIIb) (4 mg) in toluene (10 ml) thermostatted at 70 °C. A plot of log (rotation) *vs.* time was linear over the first two ' half-lives ' of reaction, being therefore compatible with a first-order reversible reaction;[18] from the data and the equilibrium constant the ' half-life ' was 184 min. Treatment of a mixture of the sulphoxides (Ib) and (IIIb) (630 mg) in toluene at 61 °C for 168 h under nitrogen gave a mixture which was chromatographed on silica (p.l.c.), eluted with light petroleum. A band at R_F *ca.* 0.5 was extracted to give 5α-cholestan-3α-yl disulphide (91 mg, 21%), identical with an authentic sample;[3c] the band at R_F *ca.* 0.05 was extracted and rechromatographed on silica (p.l.c.), eluted with ether–benzene (1 : 9). Extraction of the four most prominent bands gave 3α-diphenylmethylsulphonyl-5α-cholestane (VIb) (239 mg, 41%), 5α-cholestan-3-one (43 mg, 10%), benzophenone (10 mg, 5%), and starting sulphoxides (Ib) and (IIIb) (105 mg, 17%).

(*d*) A solution of (*S*)-3β-(1-adamantylsulphinyl)-5β-cholestane (VIII) (200 mg) in toluene (10 ml) was boiled under nitrogen for 8 h. The solvent was removed under reduced pressure and the residual oil chromatographed on a column of alumina (6 g). Elution with light petroleum gave 5β-cholest-3-ene (X) (131 mg, 98%), pure according to g.l.c., m.p. 47—48° (from acetone), $[\alpha]_D$ +18° (*c* 0.4) {lit.,[9a] m.p. 50—50.5°, $[\alpha]_D$ +19°}, τ 4.37 (d, *J* 10 Hz, 3-vinyl proton broadened by coupling with protons at C-2), 4.69 (dd, *J* 10, *J'* 1.5 Hz, 4-vinyl proton), 9.07 (10-Me), and 9.36 (13-Me) (Found: C, 87.6; H, 12.5. $C_{27}H_{44}$ requires C, 87.6; H, 12.4%).

(*e*) A solution of (*R*)-3β-(1-adamantylsulphinyl)-5β-cholestane (VII) (150 mg) in toluene (10 ml) was boiled under nitrogen; t.l.c. showed that decomposition was complete after 96 h. The solvent was removed under reduced pressure and the residual oil was chromatographed on a column of alumina (5 g). Elution with light petroleum gave an oil (101 mg, 99%) which was a mixture of 5β-cholest-2-ene (IX) and 5β-cholest-3-ene (X) in the ratio 9 : 1 (g.l.c.). Crystallization from acetone–methanol gave 5β-cholest-2-ene (IX), m.p. 45—46°, $[\alpha]_D$ +17° (*c* 0.35) {lit.,[9a] m.p. 47.5—48°, $[\alpha]_D$ +19.9°}, τ 4.45 (m, $W_{\frac{1}{2}}$ 6 Hz, 2- and 3-vinyl protons), 9.06 (10-Me), and 9.37 (13-Me) (Found: C, 87.8; H, 12.5. $C_{27}H_{46}$ requires C, 87.6; H, 12.4%). When the (*R*)-sulphoxide (VII) was heated in toluene at 80 °C under nitrogen for 21 days the sole product was 5β-cholest-2-ene (IX) (60%) (g.l.c.). Starting material (VII) (40%) was recovered.

(*f*) A solution of an approximately equimolar mixture (958 mg) of (*R*)-3β-(1-adamantylsulphinyl)-5β-cholestane (VII) and its (*S*)-isomer (VIII) in toluene (50 ml) was kept at 100 °C under nitrogen for 4 days. After this time no (*S*)-sulphoxide (VIII) remained (t.l.c.). The solvent was removed under reduced pressure, and the residue was chromatographed on alumina (25 g). Elution with petroleum ether gave 5β-cholest-3-ene (X) (285 mg); elution with ether gave the (*R*)-sulphoxide (VII) (314 mg).

Analysis of Olefin Mixtures.—The ratio of olefins (IV) and (V) was determined by o.r.d. analysis of their osmate ester–pyridine complexes,[3a] and by g.l.c. The compositions of mixtures of (IX) and (X) was determined by g.l.c. [Perkin-Elmer F11 instrument with a flame ionization detector, and a 6 ft column prepared by treating pre-siliconized and acid-washed Chromosorb G with FFAP-SP1000 (Phase Separation Ltd., 5% by weight of support)]. Typical retention times (in min) for a column temperature of 255 °C with nitrogen as a carrier gas at a flow rate of 30 ml min^{-1} were: 5α-cholest-2-ene 17.6, 5α-cholest-3-ene 19.5, 5β-cholest-2-ene 16.5, 5β-cholest-3-ene 16.8.

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