Calciferol and its Relatives. Part 21.[1] A Synthesis of (*S*)-(*Z*)-2-(5-Hydroxy-2-methylenecyclohexylidene)ethanol

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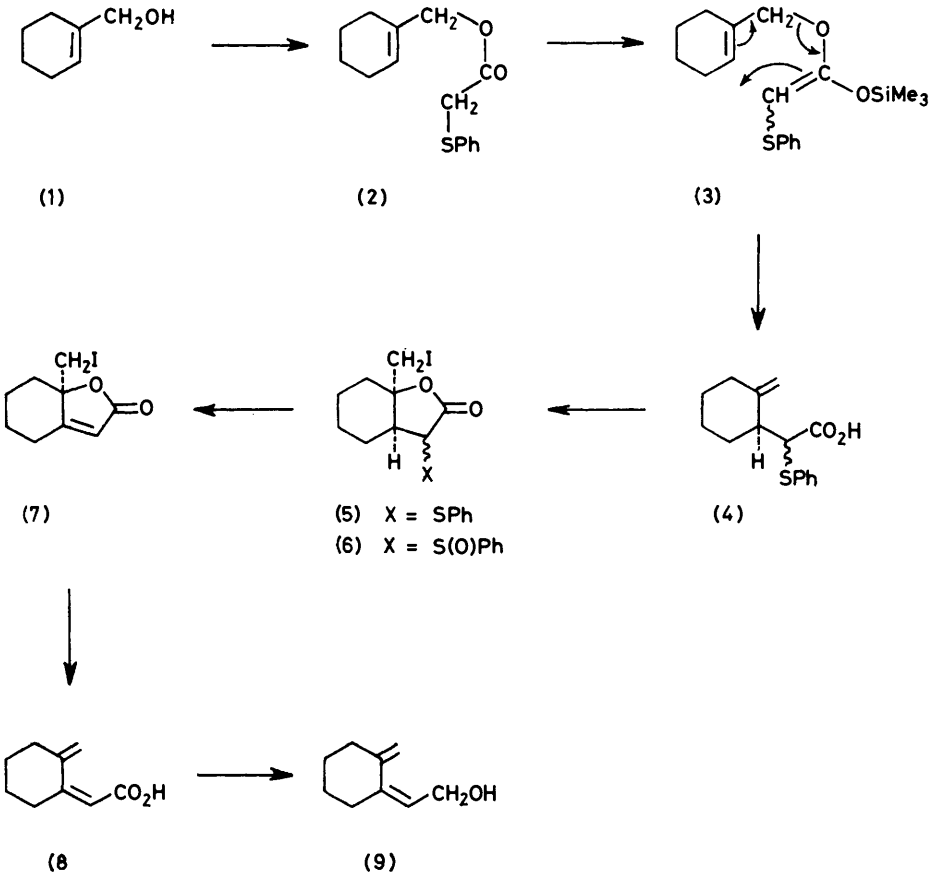
The paper describes experiments on the synthesis of the title compound, which is of interest as a ring A intermediate for a synthesis of the vitamins D. The primary α-phenylthioacetate of (±)-4-hydroxycyclohex-1-enemethanol was protected and subjected to Claisen rearrangement to give mixed α-phenylthio-γδ-unsaturated acids which were converted into iodo-lactones and, after oxidation, into sulphoxides, which were thermolysed to provide δ-iodo-αβ-unsaturated γ-lactones: these were then converted into the racemic form *rac*-(27) † of the title compound.

In a second (preferred) route, (+)-cyclohex-4-ene-1,*trans*-2-dimethanol (29) † was first converted by standard methods into (1*S*,5*R*)-6-methylene-2-oxabicyclo[3.3.1]nonan-3-one (36) and then into the diol (43), from which the synthesis of the optically active compound (27) was completed by a sulphoxide thermolysis.

THE optically active dienediol (27),† obtained [2] by degradation of vitamin D_2, was of interest to us as a ring A intermediate for a synthesis of vitamins D_2 and D_3. Some synthetic routes to the related model dienol (9) have already been reported,[2] but none of them was capable of easy extension to the dienediol (27), so that further exploratory work was necessary. We now report experiments which provide a new route to the dienol (9), and its extension to give the racemic dienediol *rac*-(27). Finally, a modified synthesis is described, leading to the optically active compound (27).

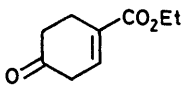
In one of the existing syntheses [2] of the model dienol (9) the unsaturated lactone *rac*-(7) † is used as an intermediate; treatment with zinc dust and methanol provides the dienoic acid (8), from which the dienol (9) is obtained by reduction. In the present work we proposed to introduce the double bond of the iodolactone *rac*-(7), which becomes the *Z*-trisubstituted



† All the structures in the present paper represent absolute configurations. Racemates are denoted by the prefix *rac*-; thus *rac*-(27) means the racemate corresponding to the optically active compound (27).

[1] Part 20, B. Lythgoe, D. A. Roberts, and I. Waterhouse, *J.C.S. Perkin I*, 1977, 2608.

[2] J. V. Frosch, I. T. Harrison, B. Lythgoe, and A. K. Saksena, *J.C.S. Perkin I*, 1974, 2005.



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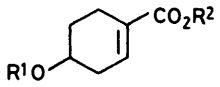
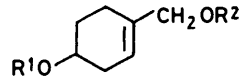
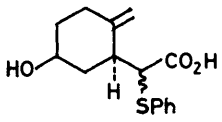


(11) R^1 = H, R^2 = Et
(12) R^1 = R^2 = H
(13) R^1 = Thp, R^2 = Me
Thp = tetrahydropyranyl



(14) R^1 = Thp, R^2 = H
(15) R^1 = R^2 = H
(16) R^1 = Thp, R^2 = $COCH_2SPh$



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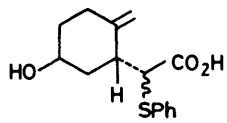

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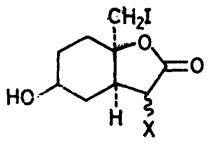
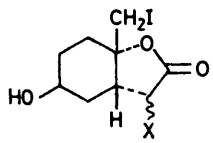
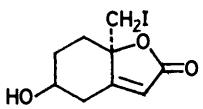


(21) X = SPh
(22) X = S(O)Ph



(19) X = SPh
(20) X = S(O)Ph



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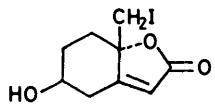

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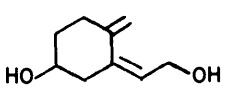

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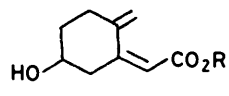


(25) R = H
(26) R = Me

double bond of the dienol (9), by the method of sulphoxide thermolysis.[3] In preliminary work[4] we found that relatively easy access to the α-phenylthio-acids *rac*-(4), from which the iodo-lactones *rac*-(5) and *rac*-(7) are obtained, is provided by a Claisen rearrangement of the α-phenylthioacetate (2) of cyclohex-1-enemethanol.

The ester (2) was converted into its trimethylsilyl enolate (3), which rearranged at 60 °C to give, after hydrolysis, the diastereoisomeric acids *rac*-(4) as a crystalline mixture (*ca.* 2 : 3) (^{1}H n.m.r.). As they were not readily separable, they were converted into the mixed iodo-lactones *rac*-(5). Oxidation of this mixture gave a mixture of sulphoxides *rac*-(6), one component of which was obtained pure by crystallisation. Thermolysis of the mixture *rac*-(6) gave the crystalline unsaturated lactone *rac*-(7) in a yield which showed that both the diastereoisomers *rac*-(6) were contributing. By using existing methods the dienol (9) was then obtained in over 20% yield from cyclohex-1-enemethanol.

In order to extend the foregoing work to a synthesis of the dienediol *rac*-(27) we required as a starting material 4-hydroxycyclohex-1-enemethanol *rac*-(15), which has not so far been described. It was obtained from the ketonic ester (10), prepared[5] by diene addition of 2-ethoxybuta-1,3-diene to ethyl propiolate, followed by acidic hydrolysis of the resulting enol ether. Attempts to obtain the diol *rac*-(15) by direct reduction of the ester (10) with lithium aluminium hydride gave poor results. However, reduction with sodium borohydride gave the liquid hydroxy ester *rac*-(11), which was characterised as the *p*-nitrobenzoate. Hydrolysis of this, or of the parent hydroxy-ester gave the crystalline hydroxy-acid *rac*-(12). Its methyl ester was converted into the tetrahydropyranyl ether *rac*-(13), which reacted satisfactorily with lithium monoethoxyaluminium hydride, giving the primary alcohol *rac*-(14). Acidic hydrolysis gave 4-hydroxycyclohex-1-enemethanol *rac*-(15), which formed a crystalline bis-*p*-nitrobenzoate.

Reaction of the diol *rac*-(15) with 1 mol. equiv. of α-(phenylthio)acetic acid and dimethylformamide dineopentyl acetal[6] gave the primary alcohol ester, which was converted by reaction with 2,3-dihydropyran into the ester *rac*-(16). It was, however, simpler to obtain this compound by similar esterification of the alcohol *rac*-(14). Claisen rearrangement of the trimethylsilyl enolate prepared from *rac*-(16), followed by removal of the protecting groups, gave a mixture of the α-phenylthio-acids *rac*-(17) and *rac*-(18), each of which contained two racemates differing in the configuration of the SPh group. No separation was attempted; instead, the mixed acids were subjected to iodo-lactonisation, and the product was then separated by chromatography into a major, more polar fraction, containing a mixture of lactones *rac*-(19), and a minor, less polar fraction containing the mixed lactones *rac*-(21). The composition of these fractions was indicated by the doublet n.m.r. signals due to >C*H*·SPh. A mixture containing (n.m.r.) the same two components *rac*-(21) as those of the less polar fraction (though not in the same proportions) was obtained by alkaline hydrolysis of a mixture of the epimeric unsaturated δ-lactones *rac*-(41) and *rac*-(42) (see later), followed by iodo-lactonisation; this observation forms the basis for the present assignment of configurations to the isomers *rac*-(19) and *rac*-(21).

The mixed lactones *rac*-(19) were oxidised to the corresponding sulphoxides, which were then heated to 120 °C to give the unsaturated iodo-lactone *rac*-(23). Treatment with zinc dust in methanol and acidification gave the hydroxy-acid *rac*-(25), from which the methyl ester *rac*-(26) was obtained with diazomethane. The same methyl ester was also obtained similarly from the lactones *rac*-(21). The sulphoxides *rac*-(22) were separated by chromatography; both gave on thermolysis the same unsaturated iodo-lactone *rac*-(24) which, unlike the isomer *rac*-(23), was obtained crystalline. For preparative purposes the sulphoxides *rac*-(22) were thermolysed without separation. The lactone *rac*-(24) was converted into the methyl ester *rac*-(26) by methods similar to those used for the isomer *rac*-(23).

The methyl ester *rac*-(26) was protected as its ethoxyethyl derivative by reaction with ethyl vinyl ether and was reduced with lithium monoethoxyaluminium hydride.[7] Removal of the protecting group, and esterification with *p*-nitrobenzoyl chloride, gave the bis-*p*-nitrobenzoate of the dienediol *rac*-(27). Alkaline hydrolysis gave the crystalline dienediol itself; its spectral characteristics were identical with those of the optically active dienediol (27) obtained from vitamin D_2.

On account of the proliferation of stereoisomeric intermediates, and the difficulty of obtaining them pure, the above route was thought unsuitable for use in the synthesis of the optically active compound (27). Instead, a related route, based on the use of the intermediate unsaturated lactone (36), was followed. The racemic lactone *rac*-(36) was first obtained from the *cis*-hydroxymethyl-δ-lactone *rac*-(38), which had been prepared[8] (in connection with another problem) from cyclohex-4-ene-1,*cis*-2-dicarboxylic acid. The tosylate *rac*-(39) was converted into the iodide *rac*-(40), which when treated with diazabicycloundecene[9] (DBU) gave the unsaturated δ-lactone *rac*-(36) in good yield. One series of pilot experiments then showed that from the lactone *rac*-(36) the racemic dienediol *rac*-(27) could be obtained relatively easily (see later). A second series of experiments showed that the lactone *rac*-(36) could also

[3] *Inter alia* C. A. Kingsbury and D. J. Cram, *J. Amer. Chem. Soc.*, 1960, **82**, 1810; D. N. Jones, E. Helmy, and A. C. F. Edwards, *J. Chem. Soc.*, (*C*), 1970, 833; B. M. Trost and T. N. Salzmann, *J. Amer. Chem. Soc.*, 1973, **95**, 6840.

[4] B. Lythgoe, J. R. Milner, and J. Tideswell, *Tetrahedron Letters*, 1975, 2593.

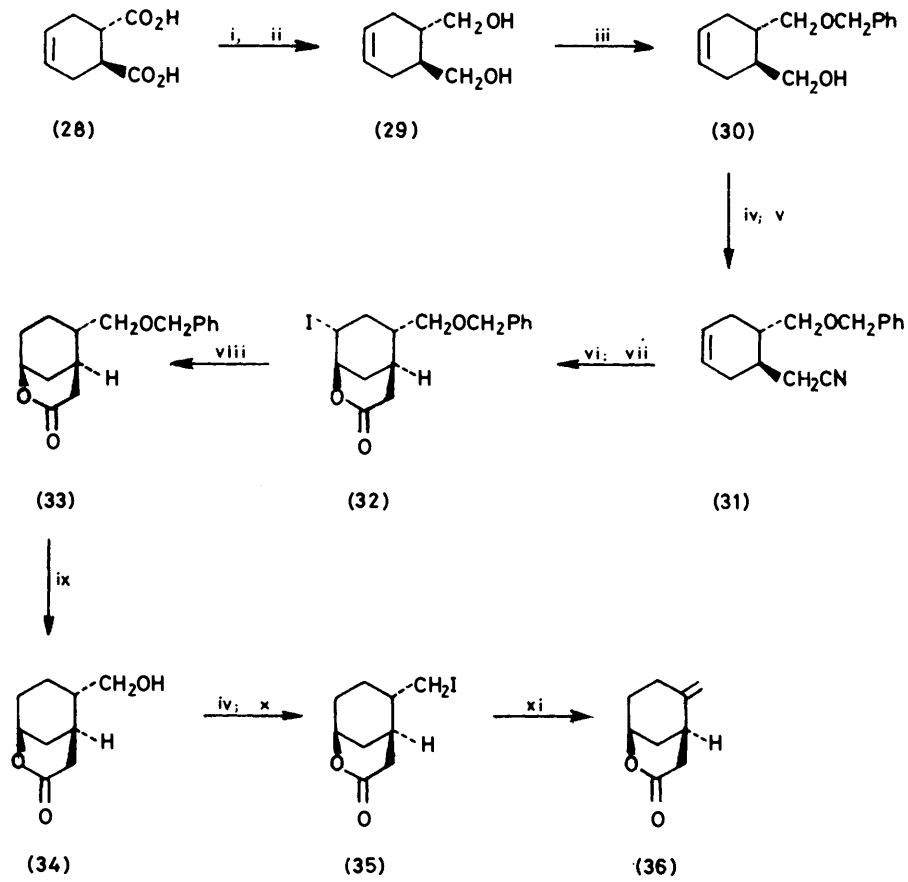
[5] A. L. Logothetis and N. A. Nelson, *J. Org. Chem.*, 1962, **27**, 1438.

[6] A. Brechbühler, H. Büchi, E. Hartz, J. Schreiber, and A. Eschenmoser, *Helv. Chim. Acta*, 1965, **48**, 1746.

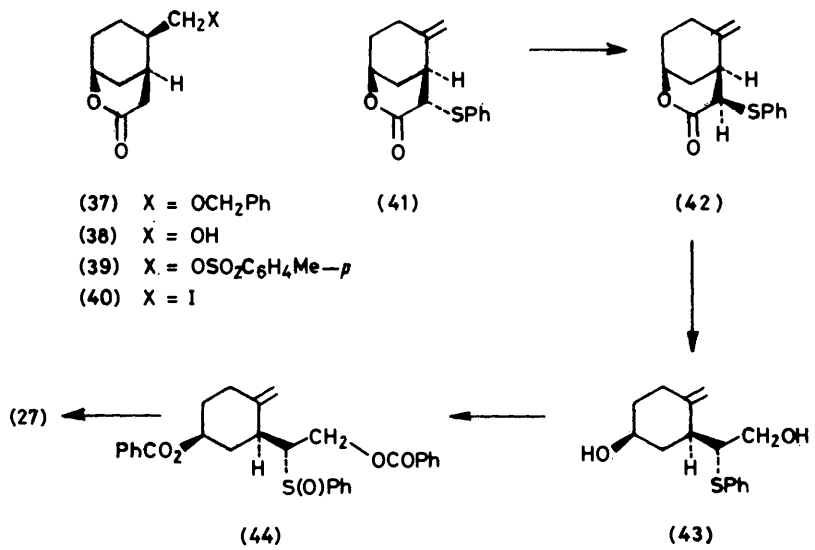
[7] R. S. Davidson, W. H. H. Günther, S. M. Waddington-Feather, and B. Lythgoe, *J. Chem. Soc.*, 1964, 4907.

[8] R. Manwaring, Ph.D. Thesis, Leeds, 1969.

[9] H. Oediger and F. Moller, *Angew. Chem. Internat. Edn.*, 1967, **6**, 76.



SCHEME Reagents: i, CH_2N_2; ii, $LiAlH_4$; iii, Na–dioxan; $PhCH_2Br$; iv, *p*-$MeC_6H_4SO_2Cl$–pyridine; v, NaCN–Me_2SO; vi, KOH–EtOH–H_2O; H_3O^+; vii, KI_3 on Na salt; viii, Ph_3SnH–C_6H_6; ix, H_2–Pd; x, NaI–MeCOEt; xi, diazabicycloundecene



be obtained efficiently from racemic cyclohex-4-ene-1,*trans*-2-dicarboxylic acid. Experiments with optically active intermediates could then be undertaken.

(+)-Cyclohex-4-ene-1,*trans*-2-dicarboxylic acid, which can readily be obtained by diene synthesis using asymmetric induction, as well as by resolution of the racemate, has the absolute configuration shown in (28), and can be converted efficiently into the (+)-diol (29).[10] This diol was transformed, as outlined in the Scheme, first into the hydroxymethyl-lactone (34) and then into the unsatur-

[10] H. M. Walborsky, L. Barash, and T. C. Davis, *Tetrahedron*, 1963, **19**, 2333.

ated lactone (36) in ten steps and with an overall yield of *ca.* 38.5%.

Phenylsulphenylation of the lactone (36) gave in 80% yield a mixture of two thioethers (41) and (42), in which the latter isomer predominated. Its separation was relatively easy because it crystallised from the mixture. Moreover, as might be expected from the equatorial disposition of its SPh group in the lactone ring, it was more stable than its liquid isomer, and when mixtures containing more of the latter were kept at 25 °C with DBU in benzene, equilibration took place and more of the isomer (42) could be obtained by crystallisation. This isomer was identified by its n.m.r. spectrum, in which, in contrast to those of the isomer (41) and of the parent lactone (36), the signal of *one* of the two vinyl protons was brought to low field by the influence of the SPh group; this will readily be understood by reference to a model of the compound.

Reduction of the lactone (42) with lithium aluminium hydride gave the crystalline diol (43). It was converted into the dibenzoate which was then oxidised with periodate to give the sulphoxide (44) (probably a mixture). Thermolysis followed by debenzoylation gave the optically active dienediol (27) in 25.7% yield from the unsaturated lactone (36) [10.6% overall from the (+)-diol (29)]. Its physical and spectral properties were identical with those of material obtained by degradation of vitamin D_2.

EXPERIMENTAL

Unless otherwise specified, optical rotations refer to solutions in chloroform, u.v. data to solutions in ethanol, and n.m.r. data to solutions in deuteriochloroform. T.l.c. and p.l.c. were carried out with Kieselgel GF_{254}. Light petroleum refers to the fraction b.p. 60—80 °C unless otherwise specified.

The Mixed α-Phenylthio-acids rac-(4).—A solution of α-(phenylthio)acetyl chloride (2.5 g) in chloroform (15 cm³) was added dropwise to a stirred solution of cyclohex-1-enemethanol (2 g) in pyridine (20 cm³) at 0 °C; the mixture was kept at 20 °C for 18 h, and water (0.1 cm³) was then added. After 1 h solvents were removed under reduced pressure, water (200 cm³) was added, and the product was isolated with ether. Chromatography on silica gel (benzene) gave the ester (2) (3.95 g) as an oil, $\nu_{max.}$ (film) 740s, 1 270m, and 1 735s cm^{-1}, τ 4.3 (1 H, m, =CH) and 6.39 (2 H, s, CH_2SPh).

A solution of lithium isopropylcyclohexylamide [from the amine (770 mg) and ethereal N-n-butyl-lithium (5.25 cm³)] in tetrahydrofuran (5 cm³) was stirred under nitrogen at −78 °C and to it a solution of the ester (2) (1.3 g) in tetrahydrofuran (5 cm³) was added during 15 min. Stirring and cooling were continued for 30 min, after which chlorotrimethylsilane (555 mg) was added; the mixture was allowed to attain room temperature and was then kept at 60 °C for 2 h. Ether (100 cm³) was added, and the solution was washed first with dilute hydrochloric acid and then with aqueous sodium hydrogen carbonate. Evaporation of the ether phase gave the starting material (2) (375 mg). The sodium hydrogen carbonate extract was acidified, and the product was isolated with ether and crystallised from light petroleum to give the mixed acids *rac*-(4) as needles (650 mg), m.p. 105—110°. One of the isomers showed a >C*H*·SPh signal at τ 4.01 (d, *J* 5 Hz), the other at τ 4.20 (d, *J* 5.5 Hz) (Found: C, 68.4; H, 6.95; S, 12.2. Calc. for $C_{15}H_{18}O_2S$: C, 68.6; H, 6.9; S, 12.2%).

The Unsaturated Iodo-lactone rac-(7).—The mixed acids *rac*-(4) (400 mg) were dissolved in water (10 cm³) containing sodium hydrogen carbonate (200 mg), and to the stirred solution at 0 °C a solution of iodine (400 mg) and potassium iodide (1.25 g) in water (5 cm³) was added slowly; the mixture was then kept at 25 °C for 3 h. It was extracted with chloroform, and the extract was washed with aqueous sodium sulphite and with water, and was evaporated to give the mixed iodo-lactones *rac*-(5) as an oil (425 mg), homogeneous to t.l.c., $\nu_{max.}$ (film) 750m, 960m, 1 582m, and 1 775s cm^{-1}. One of the isomers showed a >C*H*·SPh signal at τ 5.60 (d, *J* 6.5 Hz), the other at 6.1 (d, *J* 11.5 Hz); both showed τ 6.5 (2 H, s, CH_2I).

The mixture of iodo-lactones *rac*-(5) (980 mg) in methanol (10 cm³) was stirred for 18 h with sodium periodate (260 mg) in water (3 cm³). Extraction with methylene chloride, washing, and evaporation gave the mixed sulphoxides *rac*-(6) as a gum (900 mg), $\nu_{max.}$ (film) 750m, 960m, and 1 775s cm^{-1}, >C*H*·SPhO signals at τ 5.65 (d, *J* 10.5 Hz) and 6.12 (d, *J* 9.5 Hz), and CH_2I signals at 6.42 (s) and 6.80 (s). On one occasion, crystallisation of the above mixture from ether at 0 °C gave one of the isomers as needles, m.p. 128—130°, τ 6.12 (1 H, d, *J* 9.5 Hz, >C*H*·SPhO) and 6.42 (2 H, s, CH_2I).

The mixed sulphoxides (450 mg) were heated at 120 °C for 2 h under nitrogen, and the resulting mixture was separated by p.l.c. (50% benzene–light petroleum; then benzene), giving the unsaturated iodo-lactone *rac*-(7) as an oil. Crystallisation from ether gave pure material (235 mg), m.p. 82—83°, $\lambda_{max.}$ 215 nm (ε 11 560) (lit.,[2] m.p. 81—83°).

4-Hydroxycyclohex-1-enecarboxylic Acid rac-(12).—A solution of the ester (10) (25 g) in ethanol (100 cm³) was added dropwise to a stirred solution of sodium borohydride (5.9 g) in ethanol (200 cm³) at 0 °C, and the mixture was then kept at 25 °C for 2 h. Most of the ethanol was then removed under reduced pressure, and water and ether were added, and dilute hydrochloric acid was added until effervescence ceased. The washed and dried ether layer was evaporated to give the hydroxy ester *rac*-(11) as an oil (24 g), $\nu_{max.}$ (film) 720s, 1 610m, 1 650m, 1 710s, and 3 300s cm^{-1}. The *p-nitrobenzoate* of *ethyl 4-hydroxycyclohex-1-enecarboxylate* separated from light petroleum as needles, m.p. 90—91°, τ 1.79 (4 H, s, ArH), 3.1 (1 H, m, =CH), 4.66 (1 H, m, >CH–O), 5.81 (2 H, q, *J* 7 Hz, O–CH_2Me), 7.5 (4 H, m, CH_2), 8.0 (2 H, m, CH_2), and 8.75 (3 H, t, *J* 7 Hz, CH_2*Me*) (Found: C, 59.6; H, 5.7; N, 4.55. $C_{16}H_{17}NO_6$ requires C, 60.1; H, 5.6; N, 4.4%).

Hydrolysis with aqueous ethanolic potassium hydroxide and acidification gave *4-hydroxycyclohex-1-enecarboxylic acid* rac-(12), m.p. 135—137° (from ethyl acetate–cyclohexane) (Found: C, 59.2; H, 6.75. $C_7H_{10}O_3$ requires C, 59.2; H, 7.1%).

4-Hydroxycyclohex-1-enemethanol rac-(15).—The hydroxy-acid *rac*-(12) (13.1 g) was converted with diazomethane into the oily methyl ester (13.4 g). Its solution in ether (200 cm³) was kept with dihydropyran (13.4 g) and toluene-*p*-sulphonic acid (25 mg) at 20 °C for 24 h to give, after normal work-up, the ether ester *rac*-(13) (20.1 g) as an oil. Reduction at 0 °C with lithium monoethoxyaluminium hydride [from lithium aluminium hydride (4.56 g)] in ether

(250 cm³) for 1 h, and then at 25 °C for 2 h, followed by the addition of N-sodium hydroxide (23 cm³) and normal work-up, gave the alcohol *rac*-(14) as an oil (17.2 g) showing no carbonyl absorption near 1 700 cm^{-1}. A portion (346 mg) hydrolysed with ethanolic N-hydrogen chloride at 22 °C for 30 min gave 4-hydroxycyclohex-1-enemethanol as an oil (198 mg). The *bis*-p-*nitrobenzoate* separated from benzene–cyclohexane; m.p. 145—147°, τ 1.72 (4 H, s, ArH), 1.76 (4 H, s, ArH), 4.15br (1 H, s, =CH), 4.62 (1 H, m, >CH–O), 5.16 (2 H, s, CH_2–O), and 7.1—8.3 (6 H, m, $>CH_2$) (Found: C, 59.05; H, 4.5; N, 6.35. $C_{21}H_{18}N_2O_8$ requires C, 59.15; H, 4.25; N, 6.6%).

The Mixed Acids rac-(17) *and* rac-(18).—The alcohol *rac*-(14) (4.91 g), α-(phenylthio)acetic acid (4.25 g) and dimethylformamide dineopentyl aceta l(6.9 g) were heated together under reflux in benzene (300 cm³) for 1 h. The mixture was kept at 25 °C overnight, washed with aqueous sodium hydrogen carbonate and with water, and then dried and evaporated. Chromatography on neutral alumina (grade III) with benzene as eluent gave the ester *rac*-(16) as an oil (6.94 g), $\nu_{max.}$ (film) 1 735s cm^{-1}, τ 2.5—2.8 (5 H, m, ArH), 4.42 (1 H, m, =CH), 5.29 (1 H, m, O·CH·O), 5.53 (2 H, s, $-CH_2$·O), and 6.37 (2 H, s, PhSCH_2).

Lithium isopropylcyclohexylamide [from the amine (7.4 g)] was stirred in hexamethylphosphoric amide (7.4 g) and tetrahydrofuran (75 cm³) at −78 °C under nitrogen, and a solution of the ester *rac*-(16) (6.94 g) in tetrahydrofuran (20 cm³) was added dropwise. After 30 min chlorotrimethylsilane (10 cm³) was added; the solution was allowed to warm to room temperature, and was then kept at 60 °C for 2 h. To the cooled mixture 2N-hydrochloric acid (100 cm³) was added, and the mixture was stirred for 1 h, then diluted with water, and extracted with ether. The acidic material was then isolated with aqueous sodium hydrogen carbonate, giving the mixed acids *rac*-(17) and *rac*-(18) as an oil (2.85 g).

The (Phenylthio)-lactones rac-(19) *and* rac-(21).—(*a*) The above mixture of acids (3.6 g) was subjected to iodolactonisation in the usual way, and the product was separated by p.l.c. (1% methanol in chloroform) into a more polar fraction *rac*-(19) (2.2 g), $\nu_{max.}$ (film) 750s, 1 775s, and 3 450m cm^{-1}, τ 6.24 (d, *J* 12 Hz, >C*H*·SPh), and 6.52 (s, CH_2I), and a less polar fraction *rac*-(21) (1.1 g), $\nu_{max.}$ (film) 750s, 1 775s, and 3 450m cm^{-1}, τ 5.36 (d, *J* 11 Hz, >C*H*·SPh), 5.59 (d, *J* 6.5 Hz, >C*H*·SPh), 5.83 (m, >CHO of isomer giving the signal at τ 5.36), and 6.53 and 6.57 (? singlets, CH_2I).

(*b*) A mixture (5.32 g) of the lactones *rac*-(41) and *rac*-(42) was heated under reflux with 2N-potassium hydroxide (200 cm³) for 1 h, after which the cooled mixture was acidified (pH 2) with hydrochloric acid, and the acidic product (5.175 g) was isolated with ether. Iodo-lactonisation in the usual way gave an iodo-lactone fraction (7.17 g) with spectral properties as recorded above for *rac*-(21).

The Dienoic Ester rac-(26).—(*a*) The more polar iodo-lactone fraction *rac*-(19) (2.2 g) in methanol (50 cm³) was stirred with sodium periodate (2.3 g) in water (20 cm³) for several days until oxidation was complete. The precipitate was filtered off and washed with methylene chloride; the filtrate was evaporated and the residue was extracted with methylene chloride. The combined methylene chloride solutions were washed with water and evaporated to give the crude sulphoxides *rac*-(20) as a gum (2.2 g) which contained two isomers, showing >C*H*·SPhO signals at τ 5.60 (d, *J* 11 Hz) and 6.21 (d, *J* 10 Hz). Thermolysis of the mixture (2.3 g) neat at 120 °C for 1 h under nitrogen, and p.l.c. of the product (30% ethyl acetate–benzene) gave the unsaturated iodo-lactone *rac*-(23) as a gum (1.08 g), $\nu_{max.}$ (film) 925s, 1 000m, 1 060s, 1 650m, 1 740s, 1 765s, and 3 420s cm^{-1}, τ 4.10 (1 H, d, *J* 1.5 Hz, =CH), 6.26 (1 H, m, >CHO), and 6.36 (2 H, s, CH_2I). Reaction of the unsaturated iodo-lactone *rac*-(23) (1.08 g) with zinc dust (18 g) in hot methanol (40 cm³), followed by work-up in the usual way, gave the hydroxy-dienoic acid *rac*-(25) as an oil (568 mg). It was treated with ethereal diazomethane, and the product was purified by p.l.c. (50% ethyl acetate–benzene) to give the methyl ester *rac*-(26) as an oil (482 mg), $\lambda_{max.}$ 219 nm (ε 6 400), $\nu_{max.}$ (film) 910m, 1 020m, 1 070s, 1 110m, 1 145m, 1 200s, 1 270s, 1 440s, 1 640s, 1 720s, 1 870w, 2 955s, 3 090w, and 3 440s cm^{-1}, τ 4.37 (1 H, s with incipient splitting to t, =CH–), 4.99br (1 H, s, $=CH_2$), 5.06br (1 H, s, $=CH_2$), 6.03 (1 H, m, >CH–O), and 6.35 (3 H, s, OMe).

(*b*) The iodo-lactones *rac*-(21) (7.17 g) were oxidised with sodium periodate in aqueous methanol at 22 °C for 8 days with work-up as described for the isomer, giving the sulphoxides *rac*-(22) (7.29 g) which still contained a little starting material (t.l.c.). This material could be separated by p.l.c. (ethyl acetate) into a more polar sulphoxide, $\nu_{max.}$ (Nujol) 750s, 1 000s, 1 150s, 1 445s, 1 460s, 1 775s, and 3 420s cm^{-1}, τ 4.68 (d, *J* 11 Hz, >C*H*·SPh), 5.82 (m, >CH–O), and 6.78 (s, CH_2I) and a less polar sulphoxide, τ 5.35 (d, *J* 10 Hz, >C*H*·SPh), 6.08 (m, >CH–O), and 6.44 (s, CH_2I). Both fractions gave on pyrolysis the same unsaturated iodo-lactone *rac*-(24), which was conveniently obtained from the mixed sulphoxides *rac*-(22) as follows. The mixture (6.4 g) was heated under reflux in toluene (200 cm³) for 1½ h; the solvent was then removed and the residue crystallised from acetone–light petroleum; the mother-liquor material was then purified by p.l.c., giving more of the crystalline material. Recrystallisation from the same solvents gave the pure *unsaturated lactone rac*-(24) (2.82 g), m.p. 170.5—171.5°, $\nu_{max.}$ (KCl) 938m, 1 008m, 1 020m, 1 240m, 1 640m, 1 722s, and 3 420m cm^{-1}, τ ($CDCl_3$ containing CD_3SOCD_3) 4.10 (1 H, d, *J* 1 Hz, =CH), 5.74 (1 H, m, >CH–O), and 6.32 (2 H, s, CH_2I) (Found: C, 36.85; H, 3.75; I, 43.05. $C_9H_{11}IO_3$ requires C, 36.7; H, 3.7; I, 43.2%). Treatment of *rac*-(24) (882 mg) in tetrahydrofuran (80 cm³) and methanol (80 cm³) with freshly activated zinc dust at 22 °C under nitrogen with stirring for 1½ h, and normal work-up, gave a crude acidic product *rac*-(25) (391 mg). Esterification with ethereal diazomethane and purification gave the methyl ester *rac*-(26) (238 mg), $\lambda_{max.}$ 221 nm (ε 5 600) (*ca.* 80% pure), with i.r. and ^1H n.m.r. characteristics identical with those of material obtained by route (*a*).

The Racemic Dienediol rac-(27).—The hydroxy-ester *rac*-(26) ($\varepsilon_{max.}$ 5 600; 220 mg) in ether (25 cm³) was stirred and cooled (0 °C) during the addition of toluene-*p*-sulphonic acid (15 mg) and ethyl vinyl ether (1.5 cm³). After 3 h, sodium carbonate powder (0.5 g) was added, and stirring was continued for 15 min after which solvents were evaporated off, the residue was extracted with ether, and the extract was washed with aqueous sodium hydrogen carbonate and with water, and then dried and evaporated to give the ethoxyethyl derivative (307 mg). This (302 mg) was kept at 22 °C under nitrogen for 1½ h with a 70% solution of sodium bis-(2-methoxyethoxy)aluminium hydride (0.75 cm³) in ether (35 cm³). Normal work-up gave an oil (273 mg) which was stirred with tetrahydrofuran (22 cm³)

containing 2N-hydrochloric acid (13 cm³) for 1½ h at 22 °C. The mixture was then neutralised with sodium carbonate powder (1 g), solvents were removed under reduced pressure, and the residue was treated with aqueous sodium hydrogen carbonate and continuously extracted with ether, which gave the crude dienediol *rac*-(27) as a gum (189 mg). Reaction with *p*-nitrobenzoyl chloride in pyridine and p.l.c. (benzene) gave the *bis*-p-*nitrobenzoate* of (±)-(Z)-2-(5-*hydroxy*-2-*methylenecyclohexylidene*)*ethanol* (203 mg), m.p. 120—121° (from chloroform–light petroleum), τ 1.77 (4 H, s, ArH), 1.82 (4 H, s, ArH), 4.36 (1 H, t, *J* 6.5 Hz, =C*H*·CH_2), 4.69 (1 H, m, >CH–O), 4.82 (1 H, s, =CH_2), 4.98 (2 H, d, *J* 6.6 Hz, =CH–CH_2O), and 5.12 (1 H, s, =CH_2) (Found: C, 60.9; H, 4.55; N, 6.45. $C_{23}H_{20}N_2O_8$ requires C, 61.1; H, 4.5; N, 6.2%).

Hydrolysis with aqueous ethanolic potassium hydroxide and crystallisation of the product from ether–light petroleum gave (±)-(Z)-2-(5-*hydroxy*-2-*methylenecyclohexylidene*)*ethanol* (85%), m.p. 74—75°, $\lambda_{max.}$ 219 nm (ε 6 400), τ 4.52 (1 H, t, *J* 7 Hz, =CH), 5.02br (1 H, s, =CH_2), 5.37br (1 H, s, =CH_2), 5.79 (2 H, d, *J* 7 Hz, >CH–CH_2O), 6.07 (1 H, m, >CHO) (Found: C, 70.1; H, 8.9. $C_9H_{14}O_2$ requires C, 70.1; H, 9.1%).

The Benzyl Ether (30).—The acid (28) (34 g; $[\alpha]_D^{22}$ +159°) was esterified with ethereal diazomethane; distillation of the product at 84 °C and 1 mmHg gave the dimethyl ester (38.83 g, 98%), $[\alpha]_D^{22}$ +143°. Reduction with ethereal lithium aluminium hydride of the ester (29.5 g), and crystallisation from ether–light petroleum (b.p. 40—60 °C) gave the diol (29) (17.3 g, 82%), m.p. 62—63°, $[\alpha]_D^{22}$ +73°. The diol (19.3 g) was dissolved in dioxan (500 cm³) and sodium (3.14 g) in small pieces was added with stirring; the mixture was then stirred vigorously and heated under reflux for 3 h. It was cooled, and stirring was continued during the addition of benzyl bromide (16.12 cm³) in dioxan (20 cm³); the stirred mixture was then heated under reflux for 18 h. It was cooled, methanol (15 cm³) was added, and it was filtered, the precipitate being washed with acetone (100 cm³). Filtrate and washings were evaporated under reduced pressure, and the residue was dissolved in ether (250 cm³), and washed with water (5 × 100 cm³). Continuous extraction of the aqueous washings with ether, and crystallisation of the product from ether–light petroleum (b.p. 40—60 °C) gave the starting diol (29) (2.46 g). Evaporation of the washed ether phase, and distillation at 160 °C and 0.5 mmHg gave the benzyl ether (30) (24.77 g, 90% based on diol consumed), $[\alpha]_D^{22}$ +63° (EtOH); $\nu_{max.}$ (film) 669s, 702s, 741s, 1 031s, 1 078s, 1 210w, 1 367m, 1 438m, 1 456m, 1 498w, 1 658w, 2 900s, 3 035s, and 3 410s cm⁻¹, τ 2.67 (5 H, s, ArH), 4.35 (2 H, s, =CH–), 5.47 (2 H, s, OCH_2Ph), and 6.4 (4 H, m, OCH_2).

(1R)-2-trans-*Benzyloxymethylcyclohex*-4-*eneacetonitrile* (31).—A solution of toluene-*p*-sulphonyl chloride (35.1 g) in pyridine (200 cm³) was added to a cooled (0 °C) and stirred solution of the benzyl ether (30) (33.5 g) in pyridine (90 cm³), and the mixture was kept at 0 °C for 2 days, and then treated at 0 °C with water (35 cm³), and stirred for a further 1 h. It was then poured into cold 2.5N-hydrochloric acid, and the mixture was extracted with chloroform, the extract being washed with water, aqueous sodium hydrogen carbonate, and water, and then dried and evaporated. The tosylate formed an oil (54.9 g; 98.5%), $[\alpha]_D^{22}$ +57° (EtOH), $\nu_{max.}$ (film) 1 603m, 1 365s, 1 194s, and 1 181s cm⁻¹, τ 4.41 (2 H, s, =CH), 5.57 (2 H, s, OCH_2Ph), and 7.56 (3 H, s, Ar*Me*).

A solution of the tosylate (54.23 g) in dry dimethyl sulphoxide (125 cm³) was added during 15 min to a stirred slurry of sodium cyanide (10.7 g) in dimethyl sulphoxide (62 cm³) at 90—95 °C under nitrogen, and stirring was continued for 1½ h, after which the cooled mixture was poured into water (1.5 l) and the product was isolated with ether. Distillation at 142—144 °C and 0.1 mmHg gave the *nitrile* (31) (31.2 g; 92%), $[\alpha]_D^{22}$ +84° (EtOH), $\nu_{max.}$ (film) 2 255 cm⁻¹, τ 4.35 (2 H, s, =CH) and 5.50 (2 H, s, OCH_2Ph) (Found: M^+, 241.146 66. $C_{16}H_{19}NO$ requires *M*, 241.146 65.

(1S,5R,6R)-6-*Benzyloxymethyl*-2-*oxabicyclo*[3.3.1]*nonan*-3-*one* (33).—The nitrile (31) (31 g) was heated under reflux with potassium hydroxide (75 g) in ethanol (125 cm³) and water (155 cm³) for 2 days; the ethanol was then removed under reduced pressure. The solution was cooled, diluted with water (450 cm³), and extracted with ether, the extract being discarded. The aqueous phase was acidified with concentrated hydrochloric acid, and the product was isolated with ether. The acid (32.7 g, 98%) had $[\alpha]_D^{22}$ +53.5° (EtOH), $\nu_{max.}$ (film) 1 710 cm⁻¹, τ 4.37 (2 H, s, =CH), 5.50 (2 H, s, OCH_2Ph), and 6.54 (2 H, d, *J* 5 Hz, OCH_2CH<). The acid (32.46 g) dissolved in water (1 225 cm³) containing sodium hydrogen carbonate (51.5 g) was added during 1 h to a stirred solution of potassium iodide (187 g) and iodine (95.4 g) in water (520 cm³), and the mixture was stirred for 48 h. It was then extracted with ether, and the ether phase was washed with aqueous sodium thiosulphate and with water, dried, and evaporated. Crystallisation from ether–light petroleum (b.p. 40—60 °C), and chromatography of the mother-liquor material on silica gel (ether–light petroleum; then ether), followed by crystallisation as before, gave the *iodo-lactone* (32) (34.51 g, 71.6%), m.p. 58.5—59.5°, $[\alpha]_D^{22}$ −46.5° (EtOH), $\nu_{max.}$(KCl) 736, 1 044, 1 070, 1 103, 1 115, 1 206, 1 360, and 1 745 (all s) cm⁻¹, τ 5.17br (1 H, m, OCH<) and 5.43 (2 H, d, *J* 1.5 Hz, OCH_2Ph) (Found: C, 49.7; H, 4.9. $C_{16}H_{19}IO_3$ requires C, 49.8; H, 5.0%).

The *racemic iodo-lactone rac*-(32) had m.p. 53—53.5° (from ether–hexane at −10 °C) (Found: C, 49.7; H, 4.8%).

To a stirred solution of the iodo-lactone (32) (33.8 g) in benzene (150 cm³) under nitrogen, exposed to daylight, a solution of triphenyltin hydride (33.8 g) in benzene (30 cm³) was added during 15 min, the mixture being maintained at 20 °C by cooling; it was then kept for 48 h, and chromatographed on silica gel (1 700 g) (ether–light petroleum mixtures; then ether). The later fractions crystallised from ether at −10 °C giving the δ-*lactone* (33) (20.74 g, 91%), m.p. 52—52.5°, $[\alpha]_D^{22}$ +5.4° (EtOH), $\nu_{max.}$(KCl) 750, 1 086, 1 111, 1 240, and 1 729 (all s) cm⁻¹, τ 2.66 (5 H, s, ArH), 5.32br (1 H, s, OCH<), 5.48 (2 H, s, OCH_2Ph), 6.69 (2 H, d, *J* 7 Hz, OCH_2·CH<), 7.15 (1 H, dd, *J* 7 and 18 Hz, $OCOCH_2$), and 7.50br (1 H, d, *J* 18 Hz, $OCOCH_2$) (Found: C, 73.85; H, 7.8. $C_{16}H_{20}O_3$ requires C, 73.8; H, 7.7%). More of the lactone (33) (610 mg) was obtained by dehalogenation of non-crystalline mother-liquor material from the iodo-lactone (32).

The corresponding *racemate rac*-(33) had m.p. 55.5° [from ether–light petroleum (b.p. 40—60 °C) at −10 °C] (Found: C, 74.1; H, 7.55%).

(1S,5R)-6-*Methylene*-2-*oxabicyclo*[3.3.1]*nonan*-3-*one* (36).—Hydrogenation of the δ-lactone (33) (20.66 g) in ethanol (400 cm³) over 5% palladised charcoal (6 g), and normal work-up, with crystallisation of the product from ethyl

acetate at −10 °C gave (1S,5R,6R)-6-*hydroxymethyl*-2-*oxabicyclo*[3.3.1]*nonan*-3-*one* (34) (13.4 g, 99%), m.p. 112—113°, $[\alpha]_D^{22}$ −10.9°, $\nu_{max.}$(KCl) 1 084, 1 236, 1 392, 1 700, and 3 437 (all s) cm^{-1}, τ 5.30 (1 H, m, $W_{\frac{1}{2}}$ 8 Hz, OCH<), 6.34 (2 H, d, *J* 8 Hz, OCH_2), 7.15 (1 H, dd, *J* 6.5 and 18 Hz, $OCOCH_2$), and 7.55br (1 H, d, *J* 19 Hz, $OCOCH_2$) (Found: C, 63.4; H, 8.35. $C_9H_{14}O_3$ requires C, 63.5; H, 8.3%).

The corresponding *racemate rac*-(34) had m.p. 101.5° (from ethyl acetate–light petroleum) (Found: C, 63.7; H, 8.3%).

The *toluene*-p-*sulphonate* of (34) separated from ethyl acetate–light petroleum as crystals (99%), m.p. 130—131.5°, $[\alpha]_D^{22}$ +5.0°, $\nu_{max.}$(KCl) 678, 947, 975, 1 173, 1 355, and 1 724 (all s) cm^{-1}, τ 2.18 (2 H, d, *J* 9 Hz, ArH), 2.60 (2 H, d, *J* 9 Hz, ArH), 5.30 (1 H, m, $W_{\frac{1}{2}}$ 9 Hz, OCH<), 5.90 (2 H, d, *J* 8 Hz, OCH_2), 7.12 (1 H, dd, *J* 6.5 and 18 Hz, $OCOCH_2$), and 6.55br (1 H, d, *J* 18 Hz, $OCOCH_2$) (Found: C, 59.45; H, 6.0. $C_{16}H_{20}O_5S$ requires C, 59.2; H, 6.2%).

The *toluene*-p-*sulphonate* of *rac*-(34) had m.p. 119.5° (from ethyl acetate–light petroleum) (Found: C, 59.05; H, 6.05%).

The tosylate from (34) (8.4 g) and sodium iodide (8.6 g) were stirred together in boiling butan-2-one (110 cm^3) for 5 h. The solvent was then removed under reduced pressure, and the product was isolated by partition between methylene chloride and water. Crystallisation from ethyl acetate–light petroleum gave the *iodide* (35) (6.14 g, 84.6%), m.p. 122.5—123.5°, $[\alpha]_D^{22}$ +15.7°, $\nu_{max.}$(KCl) 1 085, 1 149, 1 227, 1 389, 1 456, and 1 719 (all s) cm^{-1}, τ 5.27 (1 H, m, $W_{\frac{1}{2}}$ 8 Hz, OCH<), 6.66 (2 H, d, *J* 8 Hz, CH_2I), 7.07 (1 H, dd, *J* 7 and 19 Hz, $OCOCH_2$), and 7.50br (1 H, d, *J* 19 Hz, $OCOCH_2$) (Found: C, 38.6; H, 4.65. $C_9H_{13}IO_2$ requires C, 38.6; H, 4.7%).

The corresponding *racemate rac*-(35) had m.p. 118.5° (from ethyl acetate–light petroleum) (Found: C, 38.75; H, 4.65%).

The iodide (35) (5.99 g) and diazabicycloundecene [9] (4.26 g) were stirred together at 25 °C for 1 h and then at 70 °C for ½ h. The cooled mixture was diluted with methylene chloride (100 cm^3) and washed successively with water, N-sulphuric acid, and water, and then dried, and evaporated. The residue was dissolved in ether (25 cm^3) and passed through silica gel (65 g) which was washed with ether (400 cm^3). The eluate was evaporated and the residue was crystallised from ether–light petroleum at −10 °C; the mother-liquor material was distilled at 105 °C and 0.2 mmHg, and then crystallised as before. The (1S,5R)-6-*methylene*-2-*oxabicyclo*[3.3.1]*nonan*-3-*one* (36) (2.93 g, 90%) had m.p. 51.5—52.5°, $[\alpha]_D^{22}$ +108°, $\nu_{max.}$(KCl) 1 076s, 1 213s, 1 235s, 1 385s, 1 650m, and 1 730s cm^{-1}, τ *ca.* 5.2 (3 H, m, $=CH_2$ and OCH<) (Found: C, 71.05; H, 8.0. $C_9H_{12}O_2$ requires C, 71.0; H, 7.95%).

The corresponding *racemate rac*-(36) had m.p. 59° (from ether at −10 °C) (Found: C, 71.1; H, 7.95%).

(±)-cis-6-*Hydroxymethyl*-2-*oxabicyclo*[3.3.1]*nonan*-3-*one* rac-(38).— (±)-*cis*-2-Benzyloxymethylcyclohex-4-eneacetonitrile was prepared from cyclohex-4-ene-1,*cis*-2-dicarboxylic acid by methods similar to those used for the *trans*-isomer *rac*-(31); it was hydrolysed to the corresponding acid, which provided on iodo-lactonisation (±)-trans-8-*iodo*-cis-6-*benzyloxymethyl*-2-*oxabicyclo*[3.3.1]*nonan*-3-*one* as prisms, m.p. 75—76°, $\nu_{max.}$(KCl) 740s and 1 730s cm^{-1} (Found: C, 49.6; H, 5.05; I, 32.65. $C_{16}H_{19}IO_3$ requires C, 49.8; H, 5.0; I, 32.8%). Deiodination with triphenyltin hydride gave (84%) (±)-cis-6-*benzyloxymethyl*-2-*oxabicyclo*[3.3.1]*nonan*-3-*one* *rac*-(37) as needles, m.p. 71—72° (from ether–light petroleum), $\nu_{max.}$(KCl) 1 720s cm^{-1} (Found: C, 74.3; H, 7.9. $C_{16}H_{20}O_3$ requires C, 73.8; H, 7.7%). Hydrogenolysis over palladised charcoal in ethanol gave (90%) (±)-cis-6-*hydroxymethyl*-2-*oxabicyclo*[3.3.1]*nonan*-3-*one* *rac*-(38) as prisms, m.p. 102—103° (from ethyl acetate–light petroleum), $\nu_{max.}$ ($CHCl_3$) 1 720 and 3 500 cm^{-1}, τ 5.25 (1 H, m, >CH–OCO), and 6.47 (2 H, d, *J* 6.5 Hz, CH_2OH) (Found: C, 63.35; H, 8.3. $C_9H_{14}O_3$ requires C, 63.5; H, 8.3%).

(±)-cis-6-*Iodomethyl*-2-*oxabicyclo*[3.3.1]*nonan*-3-*one* rac-(40).—Reaction of *rac*-(38) with toluene-*p*-sulphonyl chloride in pyridine gave (97.6%) the *toluene*-p-*sulphonate* *rac*-(39), m.p. 124—125° (from ethyl acetate), $\nu_{max.}$ (Nujol) 672s, 835s, 958s, 1 179s, 1 603m, and 1 717s cm^{-1}, τ 2.2 (2 H, d, *J* 9 Hz, ArH), 2.62 (2 H, d, *J* 9 Hz, ArH), 5.27 (1 H, m, >CH–OCO), 6.10 (2 H, d, *J* 6.5 Hz, CH_2OTs), and 7.52 (3 H, s, Ar*Me*) (Found: C, 59.15; H, 6.1. $C_{16}H_{18}O_4S$ requires C, 59.2; H, 6.2%). Reaction of *rac*-(39) with sodium iodide in boiling acetone gave (99%) (±)-cis-6-*iodomethyl*-2-*oxabicyclo*[3.3.1]*nonan*-3-*one* *rac*-(40), m.p. 101° (from ethyl acetate), $\nu_{max.}$ (Nujol) 1 066s, 1 225s, and 1 720s cm^{-1}, τ 5.30 (1 H, m, >CH–O) and 6.86 (2 H, m, CH_2I) (Found: C, 38.85; H, 4.65. $C_9H_{13}IO_2$ requires C, 38.6; H, 4.7%). When heated with diazabicycloundecane it gave (82%) the unsaturated lactone *rac*-(36), m.p. 58—59°.

(1S,5S,4R)-6-*Methylene*-4-*phenylthio*-2-*oxabicyclo*[3.3.1]-*nonan*-3-*one* (42).—A solution of the lactone (36) (770 mg) in tetrahydrofuran (10 cm^3) was added dropwise at −72 °C to a stirred solution of lithium isopropylcyclohexylamide [from the base (719 mg) in tetrahydrofuran (12 cm^3) and 1.47M-n-butyl-lithium (3.5 cm^3)] under oxygen-free nitrogen. After 15 min a solution of diphenyl disulphide (1.2 g) in hexamethylphosphoric amide (7 cm^3) was added with stirring at −60 °C, and the solution was then brought to 20 °C during 1 h, and was stirred for a further ½ h. It was then partitioned between ether (150 cm^3) and 10% hydrochloric acid (100 cm^3); the ethereal phase was washed successively with more hydrochloric acid, water, saturated aqueous sodium hydrogen carbonate, and brine, and was then dried and evaporated. Crystallisation from chloroform–light petroleum (b.p. 40—60 °C) (seeding is necessary) gave a first crop (388 mg) of the crystalline thioether (42). The mother-liquor material was then freed from the less polar impurities, arising from diphenyl disulphide, by chromatography on silica gel (benzene); elution with chloroform and purification by p.l.c. (chloroform) gave a mixture (669 mg) of the lactones (41) and (42) from which by crystallisation as before a second crop (107 mg) of the isomer (42) was obtained. The remaining material was kept overnight at 25 °C with diazabicycloundecene [9] (463 mg) in benzene (30 cm^3); the solution was diluted with ether, washed with dilute hydrochloric acid and with water, and then dried and evaporated. Crystallisation from chloroform–light petroleum gave a third crop of the lactone (42) (102 mg). Two repetitions of the equilibration process, and a final separation of the isomeric lactones by p.l.c., provided further crops (101 mg) of the lactone (42) (total 698 mg, 52.9%). The *lactone* (42) separated from ether–light petroleum (b.p. 40—60 °C) as needles, m.p. 132—134°, $[\alpha]_D^{16}$ +64.6°, $\nu_{max.}$(KCl) 690, 750, 897, 1 083, 1 106, 1 143, 1 162, 1 176, 1 220, 1 444, 1 723 (all s), and 1 650m cm^{-1}, τ 2.3—2.8 (5 H, m, ArH), 5.04 (1 H, s, =CH), 5.18 (1 H, m, >CH–O), 5.26 (1 H, s, =CH), 5.87 (1 H, d, *J* 6.5 Hz, >C*H*–SPh), and 7.05 (1 H, m, $W_{\frac{1}{2}}$ 13 Hz,

=C–CH<) (Found: C, 69.1; H, 6.1; S, 12.5. $C_{15}H_{16}O_2S$ requires C, 69.2; H, 6.15; S, 12.3%).

The epimeric lactone (41) was readily distinguished from the lactone (42) by its n.m.r. spectrum [τ 5.24 (2 H, s, $=CH_2$) and 6.17 (1 H, broadened s, >C*H*·SPh)].

The *racemate rac*-(42) separated from chloroform–light petroleum (b.p. 40—60 °C) as needles, m.p. 99—100.5° (Found: C, 68.95; H, 5.75; S, 12.7%).

The Diol (43).—The lactone (42) (1.58 g) and lithium aluminium hydride (1.75 g) were stirred together in tetrahydrofuran (75 cm³) and ether (75 cm³) under nitrogen at 18 °C for 6½ h. After decomposition of the excess of reagent with water and 15% aqueous sodium hydroxide, the precipitate was filtered off and washed with tetrahydrofuran and ether. The filtrate and washings were concentrated, and the solid which separated was recrystallised from ether–light petroleum to give the *diol* (43), m.p. 116.5—117.5°, $[\alpha]_D^{16}$ +7.56° (pyridine), $\nu_{max.}$(KCl) 695s, 745s, 889s, 1 015s, 1 952s, 1 585m, 1 648m, and 3 300s cm^{-1} (Found: C, 68.2; H, 7.45; S, 12.2. $C_{15}H_{20}O_2S$ requires C, 68.2; H, 7.6; S, 12.1%). From the mother-liquor material more pure diol (total 1.194 g, 74.4%) was isolated by p.l.c. (ethyl acetate).

The *racemate rac*-(43) had m.p. 101—102° (Found: C, 68.2; H, 7.4; S, 11.9%).

(S)-(Z)-2-(5-*Hydroxy*-2-*methylenecyclohexylidene*)*ethanol* (27).—The diol (43) (500 mg) was converted by reaction with benzoyl chloride in pyridine into its dibenzoate, $[\alpha]_D^{16}$ +61.8°, $\nu_{max.}$ (film) 714s, 760s, 1 112s, 1 275s, 1 652m, and 1 720s cm^{-1}, τ 1.85—3.00 (15 H, m, ArH), 4.62 (1 H, m, >C*H*·OBz), 5.08br (2 H, s, $=CH_2$), 5.53 (2 H, m, CH_2·OBz), and 5.92 (1 H, m, =C–CH). The dibenzoate was stirred with sodium periodate (1.1 g) in methanol (200 cm³) and water (7.5 cm³) at 18 °C for 7 days; the product, isolated in the usual way, still contained (t.l.c.) *ca.* 30% of unchanged dibenzoate. It was heated for 4 h in boiling toluene containing calcium carbonate powder (2 g), and, after filtration and removal of the solvent, the thermolysate was separated by p.l.c. (benzene) into three fractions. The least and most polar fractions were discarded; the second fraction in order of polarity, which contained the dibenzoates of the diols (27) and (43), was stirred for 16 h at 18 °C with methanolic 10% potassium hydroxide (30 cm³). The methanol was removed under reduced pressure, and the residue was dissolved in water (25 cm³) and extracted with ether and light petroleum (b.p. 40—60 °C) (1 : 1; 2 × 20 cm³); the extract was then washed with a little water (2 × 1 cm³). The organic phase was evaporated, and the residue (165 mg) was purified by p.l.c. (ethyl acetate) after which it crystallised from ether–light petroleum (b.p. 40—60 °C) giving the starting diol (43) (124 mg), m.p. 116—117°.

The aqueous phase and the washings were combined and extracted continuously with ether to give an oil (180 mg). Crystallisation from ether gave the dienediol (27) (139 mg), m.p. 99—101.5°; after one recrystallisation it had m.p. 101—102°, undepressed on admixture with authentic material, and $[\alpha]_D^{19}$ +26.8°; the i.r. and n.m.r. spectra were identical with those of authentic material. The mother-liquor material was treated with *p*-nitrobenzoyl chloride in pyridine, and gave the known bis-*p*-nitrobenzoate (38 mg), m.p. 104.5—106.5°, $[\alpha]_D^{22}$ +67°. The total yield of the dienediol (27) was therefore equivalent to 152 mg or 65.5% based on the diol (43) used in the reaction.

We thank the S.R.C. for a Studentship (to R. M.) and the University of Leeds for a Scholarship (to J. R. M.).

[7/1490 *Received*, 16*th August*, 1977]