Synthetic Studies on Terpenoids. Part 24.† Stereocontrolled Synthesis of 3aβ-*H*,3bα-*H*,5aα-*H*,9aα-*H*,11aβ-*H*-9bβ-Methylperhydrophenanthro-[2,1-*b*]furan-7-one, an Intermediate to Epoxynorcafestanone [1]

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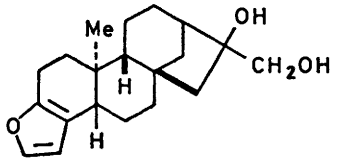
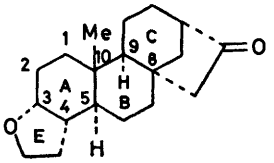
The title compound (17), incorporating rings A, B, C, and E of epoxynorcafestanone (2), has been synthesized. Stereochemical assignments of all the six asymmetric centres present in (17) have been confirmed by an *X*-ray crystallographic analysis.

CAFESTOL (1), one of the earliest examples of the rearranged furanoid diterpenes, has been intensively studied [2] for over 30 years because of its reported oestrogenic activity, and the antipodal relation of rings A and B. The structure and stereochemistry of (1) have been established [3] from *X*-ray studies of the bromo-derivative of epoxynorcafestanone (2). For the synthesis of (2) with the correct stereochemistry at each of the seven asymmetric centres, it is apparent that the development of the *cis*-B/C ring-junction and the incorporation of the tetrahydrofuranyl ring E with C-3α, C-4α configuration are the two most salient aspects. Compounds (3) and (7) were considered suitable starting materials for the purpose.



(1)



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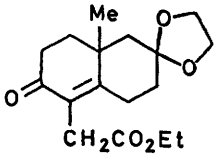
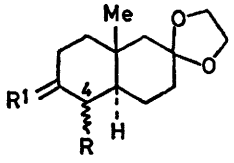
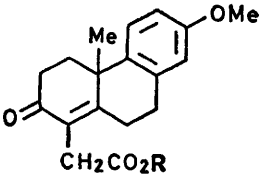


(3)



(4) R = β-CH_2·CO_2Et; R′ = =O
(5) R = α-CH_2·CO_2Et; R′ = =O
(6) R = α-CH_2·CH_2OH; R′ = β-OH, α-H



(7) R = H
(7a) R = Me

RESULTS AND DISCUSSION

Experiments were initiated [4] in 1962 with the keto-ester (3), because a method [5] had been developed in this laboratory to introduce a C_3-chain at C-9 in a 10-methyl-decalin-8-one. The synthesis of (3) was carried out *via* annelation of 4,4-ethylenedioxy-2-methylcyclohexanone with the methiodide of 1-diethylaminobutan-3-one in the presence of base, followed by alkylation with ethyl bromoacetate. Catalytic reduction of (3) furnished compound (4) with a *trans*-ring junction, evidently because of the presence of the acetic acid side-chain. This was treated with sodium methoxide to epimerise the C-4 centre leading to (5), reduction of which with lithium aluminium hydride afforded the crystalline diol (6) in excellent yield. Some amount of stereoselectivity in the reduction was expected from the influence of the ester function [6] and on steric grounds. The same diol was also obtained from Birch reduction of (3), thereby supporting the *trans*-configuration of the two rings. The hydroxy-group at C-3 should be equatorial, and this assignment was further supported by the formation of the *trans*-oxide (10a) in poor yield, and relevant observations on the corresponding tricyclic compound (see below). As no efficient method was then available for isomerisation of the 3β-OH group the work could not progress further. Recently a number of methods (see below) have been developed for the selective reduction of the carbonyl group to an axial alcohol in a cyclohexane ring. The work was initiated again with the tricyclic acid (7), since the possibility of isolating crystalline intermediates was much better. The compound (7) was prepared through condensation of the Mannich base,[7] from ethyl levulinate in the presence of an excess of

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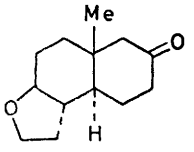
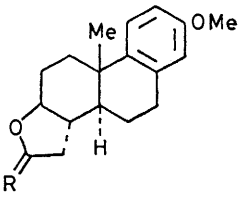
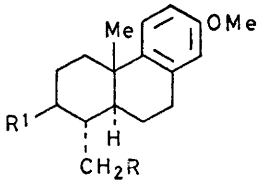
sodium methoxide or ethyl 6-chloro-4-oxohexanoate in presence of potassium t-butoxide, with 6-methoxy-1-methyltetralin-2-one. The compound (7) on reduction with lithium–liquid ammonia furnished the saturated



(10a)



(10) R = =O
(12) R = H_2



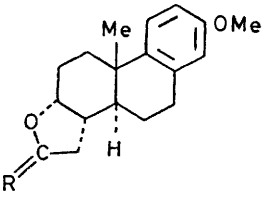
(8) R = CO_2H, R′ = =O
(8a) R = CO_2Me, R′ = =O
(9) R = CO_2H, R′ = β-OH, α-H
(9a) R = CO_2Me, R′ = β-OH, α-H
(11) R = CH_2OH, R′ = β-OH, α-H
(14) R = CH_2OH, R′ = α-OH, β-H

acid (8) in excellent yield. An optimum ratio of the solvent (tetrahydrofuran) to liquid ammonia was found essential for efficient reduction of (7), perhaps due to a solubility factor. Reduction of (8) with sodium borohydride led to the hydroxy-acid (9) in a very good yield, along with a small amount of an oily product, which was identified as the desired *cis*-lactone (13). The hydroxy-acid (9) did not undergo cyclisation, but could be converted into the crystalline *trans*-lactone (10) by heating with toluene-*p*-sulphonic acid [8] or dicyclohexylcarbodiimide [9] in a suitable solvent. The compound (10) was reduced to the diol (11) and converted into the ether (12) under moderately drastic condition.

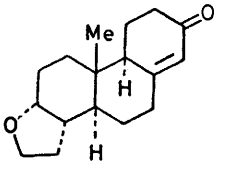
In a series of efforts to generate the 3α-OH group, (9a) was converted into the toluene-*p*-sulphonate and subjected to an S_N2 displacement with acetate anion in dimethyl sulphoxide, as used in the case of steroids.[10] After alkaline hydrolysis of the product, a part of the hydroxy-acid easily underwent lactonisation and the major fraction was the unchanged material. The ready formation of lactone (13) indicated the desired stereochemistry at C-3. The lactone (13) was isolated as a liquid, and its homogeneity was tested through t.l.c. In order to generate the 3α-OH group, reduction of the keto-ester (8a) was attempted with isobornyloxyaluminium dichloride [11] but the keto-acid (8) was recovered unchanged. Catalytic reduction [12] of the saturated acid (8) in acetic acid in the presence of a little hydrochloric acid and platinum oxide catalyst resulted in a poor yield of the lactone (13). The toluene-*p*-sulphonate of the ester (8a) in *NN*-dimethylformamide solution, on warming [13] furnished the *cis*-lactone (13) in a moderate yield. Finally the *cis*-lactone (13) was isolated [14] in good yield from (8a) by reduction in isopropyl alcohol with phosphorous acid and water in the presence of iridium tetrachloride. Compound (13) was reduced with lithium aluminium hydride to afford the crystalline diol (14), which underwent smooth cyclisation to give (15) in good yield. Compound (15) has the desired stereochemistry at C-3, C-4, C-5, and C-10. Reduction of (15) with an excess of lithium and alcohol in liquid ammonia, and subsequent treatment of the enol ether with acid, readily afforded (16) with the right stereochemistry at C-9, assigned by analogy with compounds of known stereochemistry.

For the development of ring D according to the method developed in this laboratory,[15] addition of potassium cyanide to the double bond of (16) was attempted, but the product was a mixture and it was difficult to separate into pure constituents. Kitadani has recently developed [16] a method, *via* intramolecular keto-carbene insertion in a B/C *cis*-perhydrophenanthrene-13-carboxylic acid, for the formation of the cyclopentanone ring in excellent yield, and also with the correct stereochemistry.

With this end in view, (16) was catalytically reduced in *NN*-dimethylformamide solution [17] and the expected compound (17), with the 8α-configuration, was obtained. The structure of compound (17) has been confirmed by *X*-ray analysis (through the courtesy of Professor Venkatesan of the Indian Institute of Science, Bangalore); details of the structure will be published elsewhere. The crystals are triclinic, space group *P*1, with $a = 8.5126$, $b = 8.9702$, $c = 11.7410$ Å, $\alpha = 120.515$, $\beta = 93.298$, $\gamma = 68.435°$, and $Z = 2$. A total of 1 213 reflections having net amplitudes above their standard



(13) R = =O
(15) R = H_2



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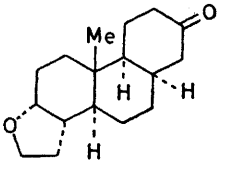

(17)

deviations were determined with Cu-K_α radiation using the moving-crystal–moving-counter technique on a CAD-4 diffractometer. The structure was solved by direct methods with the aid of programme MULTAN.[18]

Nine reflections (three for defining the origin and six for multisolution) were used in the starting set, and the best set revealed all the nineteen non-hydrogen atoms. The structure was refined by block-diagonal least-squares methods.

Further progress at this stage was not possible because of an insufficient amount of (17).

EXPERIMENTAL

M.p.s were taken for samples in open capillaries in a sulphuric acid bath. U.v. spectra were recorded for solutions in 95% ethanol with a Beckmann DU spectrophotometer (manually operated), and i.r. spectra with a Perkin-Elmer 21 instrument for solutions in chloroform. N.m.r. spectra were determined with Varian A–60D and T–60 instruments (tetramethylsilane as internal reference). Mass spectra were recorded with CEC 21–110B double-focusing spectrometer. T.l.c. plates were coated (0.2 mm thick) with silica gel G (200 mesh) and spots were located by exposing the dried plates to iodine vapour. Petroleum refers to the fraction of b.p. 60—80 °C, light petroleum to the fraction of b.p. 40—60 °C. The compounds described are all racemic.

Ethyl 2,2-*Ethylenedioxy*-7-*oxo*-10-*methyl*-Δ^5-*octalin*-6-*acetate* (3).—5,5-Ethylenedioxy-1-methylcyclohexan-2-one (17 g) was slowly added with stirring to a solution of sodium (2.3 g) in methanol (100 ml) at 0 °C under nitrogen. The mixture was refluxed for 2 h. The methiodide of the amino-ketone (17 g; b.p. 76 °C at 16 mmHg) [prepared from diethylamine hydrochloride (22 g), paraformaldehyde (8.4 g), acetone (60 ml), and ethanol (40 ml)] in methanol (25 ml) was added dropwise to the above mixture at 0 °C. After standing at room temperature overnight it was heated under gentle reflux for 8 h. The usual work-up and distillation afforded 2,2-ethylenedioxy-10-methyl-Δ^5-octalin-7-one (9 g), b.p. 145 °C at 0.6 mmHg. It solidified on standing, m.p. 94 °C (light petroleum); $\lambda_{max.}$ 236 nm (log ε 4.18); $\nu_{max.}$ 1 660 and 1 620 cm^{-1} (Found: C, 69.9; H, 8.1. $C_{13}H_{18}O_3$ requires C, 70.2; H, 8.1%). The *semicarbazone* had m.p. 210—211 °C (decomposition) (methanol) (Found: C, 60.2; H, 7.6. $C_{14}H_{21}N_3O_3$ requires C, 60.2; H, 7.5%). To a suspension of dry potassium t-butoxide [from potassium (4.7 g)] in benzene (200 ml), the above unsaturated keto-acetal (11 g), in benzene (50 ml) was slowly added with stirring under nitrogen at room temperature. The mixture was warmed at 60 °C for 1 h, cooled with ice, and treated with ethyl bromoacetate (16 g) with stirring. This was kept at room temperature overnight, heated under reflux for 8 h and worked up in the usual way to afford the acetate (3) (5 g), b.p. 190—200 °C at 0.6 mmHg; $\lambda_{max.}$ 243 nm (log ε 4.01); $\nu_{max.}$ 1 730, 1 660, and 1 620 cm^{-1} (Found: C, 66.1; H, 7.9. $C_{17}H_{24}O_5$ requires C, 66.2; H, 7.8%).

Ethyl 2,2-*Ethylenedioxy*-7-*oxo*-10β-*methyl*-trans-*decalin*-6β-*acetate* (4).—The unsaturated acetal keto-ester (3) (6 g) was hydrogenated in alcohol (25 ml) over palladium–charcoal (10%, 0.5 g). After filtration and concentration it furnished a compound which was sublimed to afford (4) as a colourless semiviscous liquid (5.8 g), b.p. 195—200 °C at 0.6 mmHg; $\nu_{max.}$ 1 730 and 1 700 cm^{-1}. T.l.c. [benzene–light petroleum (4 : 1)] revealed a single spot, with some trailing evidently due to contamination with the epimeric products (Found: C, 65.8; H, 8.5. $C_{17}H_{26}O_5$ requires C, 65.7; H, 8.4%).

Ethyl 2,2-*Ethylenedioxy*-7-*oxo*-10β-*methyl*-5α-trans-*decalin*-6α-*acetate* (5).—The saturated acetal keto-ester (4) (5 g) dissolved in methanol (40 ml) was added to a solution of sodium (0.02 g) in methanol (5 ml) and warmed at 70 °C for 3 h under nitrogen. The resulting product was sublimed to furnish (5) as a colourless product (4 g), b.p. 195—196 °C at 0.6 mmHg; $\nu_{max.}$ 1 730 and 1 700 cm^{-1}; t.l.c. revealed a single spot (Found: C, 65.8; H, 8.4. $C_{17}H_{26}O_5$ requires C, 65.7; H, 8.4%).

2,2-*Ethylenedioxy*-6α-(2-*hydroxyethyl*)-10β-*methyl*-trans-*decalin*-7β-*ol* (6).—(*a*) The acetal keto-ester (3) (8 g) in ether (80 ml) was slowly added to a solution of lithium (4 g) in liquid ammonia (600 ml). The blue colour of the mixture was discharged after 1 h by careful addition of ethanol, and the usual work-up afforded the crystalline diol (6) (6.0 g), m.p. 136 °C (ethyl acetate) (Found: C, 66.5; H, 9.8. $C_{15}H_{26}O_4$ requires C, 66.6; H, 9.7%).

(*b*) The acetal ester (5) (6 g) in ether (50 ml) was added dropwise to a stirred suspension of lithium aluminium hydride (1.2 5 g) in ether (100 ml), and stirring was continued under brisk reflux for 4 h. It was worked up to afford the acetal diol (6) (3.9 g), m.p. and mixed m.p. [with the sample obtained from method (a)] 136 °C (ethyl acetate).

3aα-H,9aα-H,9bβ-H-5aβ-*Methylperhydronaphtho*-[2,1-b]*furan*-7-*one* (10*a*).—The acetal diol (6) (6.5 g) in pyridine (60 ml) was treated with toluene-*p*-sulphonyl chloride (6.5 g) and the mixture allowed to stand at room temperature for 3 h. The product was worked up in the usual way and the residue was heated under reflux for 3 h with a solution of potassium hydroxide (6.5 g) in methanol (97 ml) and water (6.5 ml). On working up an oily product was obtained which was dissolved in acetone (80 ml) and heated under reflux in the presence of a catalytic amount of toluene-*p*-sulphonic acid for 3 h. Most of the acetone was removed under reduced pressure, and the residue was diluted with water and worked up in the usual way to furnish the ether (10a) (1.5 g), b.p. 150—155 °C at 1.5 mmHg; $\nu_{max.}$ 1 080 and 1 700 cm^{-1} (Found: C, 74.9; H, 9.6. $C_{13}H_{20}O_2$ requires C, 74.9; H, 9.7%); t.l.c. [benzene–light petroleum (1 : 1)] revealed a single spot.

2-*Oxo*-4a-*methyl*-7-*methoxy*-2,3,4,4a,9,10-*hexahydrophenanthrene*-1-*acetate* (7) *and the Methyl Ester* (7a).—(*a*) 6-Methoxy-1-methyl-β-tetralone (7.6 g) in benzene (30 ml) was added rapidly to a well-stirred ice-cooled solution of sodium (1.5 g) in methanol (30 ml) under nitrogen and the methiodide (15.3 g) of the Mannich base [prepared from ethyl levulinate] in methanol (15 ml) was added slowly at 0 °C, and stirring was continued for 1 h at 0 °C. The reaction mixture was then heated under reflux for 1 h and worked-up in the usual way to furnish a crystalline acid (7) (8 g), m.p. 168 °C (ethyl acetate), along with a viscous neutral portion, which on alkaline hydrolysis furnished a further quantity of the same crystalline acid (7) (0.5 g); $\nu_{max.}$ 1 710, 1 660, and 1 615 cm^{-1}; $\lambda_{max.}$ 227 and 247 nm (log ε 4.2 each); δ($CDCl_3$) 7.3—6.6 (3 H, m, aromatic), 5.2 (1 H, broad, CO_2H), 3.8 (3 H, s, OMe), 3.5 (2 H, s, CH_2CO_2H), and 1.6 (3 H, s, Me). A portion of the acid (7) was esterified with an ethereal diazomethane solution and the ester (7a) was isolated, m.p. 74 °C (light petroleum); $\nu_{max.}$ 1 730, 1 660, and 1 710 cm^{-1} (Found: C, 72.4; H, 7.2. $C_{19}H_{22}O_4$ requires C, 72.5; H, 7.0%). The scarlet 2,4-*dinitrophenylhydrazone* had m.p. 180 °C (ethyl acetate) (Found: C, 60.7; H, 5.5. $C_{25}H_{26}N_4O_7$ requires C, 60.7; H, 5.3%).

(*b*) To a stirred dispersion of potassium t-butoxide [from potassium (1.3 g)] in benzene (20 ml) was added a solution of

6-methoxy-1-methyl-β-tetralone (5.7 g) in benzene (30 ml) at room temperature under nitrogen and the reaction was heated at 70 °C for 1 h. Methyl 6-chloro-4-oxohexanoate (7 g) (prepared from the reaction of ethylene with the half-ester chloride of succinic acid in the presence of anhydrous aluminium chloride) was dissolved in benzene (5 ml) and added slowly to the ice-cold dark mixture and kept at room temperature overnight. It was then heated under reflux for 5 h, cooled, and worked up. The crude residue was then heated with sodium (1.78 g) in methanol (25 ml) under reflux for 8 h, and then worked up and the acidic portion esterified to afford the methyl ester (7a) (2 g), m.p. 74 °C (light petroleum), the m.p. being undepressed when mixed with the above sample from (*a*).

2-*Oxo*-4aβ-*methyl*-7-*methoxy*-1,2,3,4,4a,9,10,10aα-*octahydrophenanthrene*-1α-*acetic Acid* (8) *and the Methyl Ester* (8a).—(*a*) The unsaturated keto-acid (7) (1.6 g) in dry tetrahydrofuran (120 ml) was rapidly added to a stirred solution of lithium (0.4 g) in liquid ammonia (900 ml). The mixture was stirred vigorously for 6 min, then ammonium chloride was added portionwise, whereupon the blue colour was discharged. Ammonia was allowed to evaporate off and the mixture acidified with cold concentrated hydrochloric acid. The precipitated solid was extracted with ethyl acetate, and removal of the solvent afforded the saturated keto-acid (8) (1.26 g), m.p. 218 °C (ethyl acetate); $\nu_{max.}$ 1 700 and 1 605 cm^{-1} (Found: C, 71.5; H, 7.3. $C_{18}H_{22}O_4$ requires C, 71.5; H, 7.3%). A portion of the acid (8) (0.1 g) was esterified with ethereal diazomethane solution to afford the corresponding ester (8a) (0.1 g), b.p. 160 °C at 0.1 mmHg; $\nu_{max.}$ 1 730 and 1 605 cm^{-1}; δ(CCl_4) 7.2—6.4 (3 H, m, aromatic), 3.7 (3 H, s, OMe), 3.6 (3 H, s, CO_2Me), and 1.36 (3 H, s, Me). The orange 2,4-*dinitrophenylhydrazone* had m.p. 175 °C (ethyl acetate–methanol) (Found: C, 60.2; H, 5.8. $C_{25}H_{28}N_4O_7$ requires C, 60.4; H, 5.7%).

(*b*) The unsaturated keto-ester (7a) (1.2 g) was hydrogenated in alcohol (30 ml) containing acetic acid (1 ml) in the presence of palladium–charcoal (10%, 0.2 g). After filtration and work-up with ether, it furnished a transparent viscous liquid which was passed through a column of alkaline alumina (20 g). The product, after alkaline hydrolysis, afforded the crystalline acid (8) (1 g), m.p. 218 °C, identical in all respects with the acid obtained from method (*a*).

2β-*Hydroxy*-4aβ-*methyl*-7-*methoxy*-1,2,3,4,4a,9,10,10aα-*octahydrophenanthrene*-1α-*acetic Acid* (9).—Sodium borohydride (0.2 g) was added pinchwise to the keto-acid (8) (1.5 g) in sodium hydroxide solution (10 ml, 1.5N). The reaction mixture was stirred at room temperature for 24 h, acidified with cold concentrated hydrochloric acid, extracted with ether, and the extract washed with sodium bicarbonate solution (10%). The neutral layer afforded the gummy (13) (0.15 g). The alkaline extract was acidified to furnish the hydroxy-acid (9) (1 g), m.p. 178 °C (ethyl acetate); $\nu_{max.}$ 3 620 and 1 700 cm^{-1} (Found: C, 71.1; H, 8.0. $C_{18}H_{24}O_4$ requires C, 71.0; H, 7.9%).

Lactone of 2β-*Hydroxy*-4aβ-*methyl*-7-*methoxy*-1,2,3,4,4a,9,10,10aα-*octahydrophenanthrene*-1α-*acetic Acid* (10).—(*a*) A mixture of the hydroxy-acid (9) (0.3 g) and toluene-*p*-sulphonic acid (0.15 g) in benzene (40 ml) was heated under reflux for 4 h (Dean–Stark water separator). After the usual work-up the *trans*-lactone (10) was obtained as crystals (0.2 g), m.p. 180 °C (methanol); $\nu_{max.}$ 1 770 cm^{-1} (Found: C, 75.8; H, 7.7. $C_{18}H_{22}O_3$ requires C, 75.5; H, 7.7%).

(*b*) A solution of the hydroxy-acid (9) (0.15 g) and dicyclohexylcarbodi-imide (0.1 g) in dioxan (5 ml) was stirred for 20 h under nitrogen. The solvent was distilled off and the residue worked up to afford the *trans*-lactone (10) (0.1 g), m.p. 180 °C (methanol), which showed no depression of m.p. when mixed with the sample from procedure (*a*).

2β-*Hydroxy*-1α-(2-*hydroxyethyl*)-4aβ-*methyl*-7-*methoxy*-1,2,3,4,4a,9,10,10aα-*octahydrophenanthrene* (11).—The saturated ester (8a) (1.1 g) was reduced with lithium aluminium hydride (0.35 g) in ether (50 ml) in the usual way, and on work-up it furnished the solid diol (11) (0.9 g), m.p. 151 °C (ethyl acetate) (Found: C, 74.2; H, 9.1. $C_{18}H_{26}O_3$ requires C, 74.4; H, 9.0%).

9bβ-*Methyl*-7-*methoxy*-2,3,3aβ,3bα,4,5,9β,10,11,11aα-*decahydrophenanthro*[2,1-b]*furan* (12).—The *trans*-diol (11) (0.5 g) in dry pyridine (5 ml) was treated with toluene-*p*-sulphonyl chloride (0.6 g) at room temperature; the reaction mixture was then allowed to stand overnight and worked-up. The residue obtained was chromatographed over activated neutral alumina (15 g), and the oil eluted with benzene afforded the crystalline ether (12) (0.16 g), m.p. 109 °C (light petroleum); $\nu_{max.}$ 1 230 and 1 075 cm^{-1} (Found: C, 79.0; H, 8.4. $C_{18}H_{24}O_2$ requires C, 79.3; H, 8.8%).

Lactone of 2α-*Hydroxy*-4aβ-*methyl*-7-*methoxy*-1,2,3,4,4a,-9,10,10aα-*octahydrophenanthrene*-1α-*acetic Acid* (13).—(*a*) The neutral product (0.15 g) obtained from borohydride reduction of the saturated ketone (8) was chromatographed over neutral alumina (5 g) to give the colourless viscous lactone (13) (0.1 g), b.p. 155—160 °C at 0.4 mmHg; $\nu_{max.}$ 1 770 cm^{-1}; t.l.c. [ethyl acetate–benzene (2 : 1)] revealed a single spot; δ(CCl_4) 7.1—6.4 (3 H, m, aromatic), 4.37 (2 H, m, lactone CH_2), 3.66 (3 H, s, OMe), and 1.00 (3 H, s, Me) (Found: C, 75.5; H, 7.8. $C_{18}H_{22}O_3$ requires C, 75.5; H, 7.7%).

(*b*) The gummy toluene-*p*-sulphonate (0.52 g) [prepared from the hydroxy-ester (9a) (0.5 g)] and freshly fused sodium acetate (1 g) in dimethyl sulphoxide (10 ml) was stirred at 70 °C for 80 h under nitrogen. The product, obtained by the usual work-up, was hydrolysed with methanolic sodium hydroxide solution (5 ml, 5%). The acidic and neutral parts were separated. The crude neutral part on sublimation furnished the *cis*-lactone (13) (0.1 g), b.p. 157 °C at 0.4 mmHg; $\nu_{max.}$ 1 770 cm^{-1}, identical in all respects with the sample from (*a*). From the acidic part the hydroxy-acid (9) (0.2 g), m.p. 178 °C, was recovered.

(*c*) The saturated keto-ester (8a) (2.2 g) in isopropyl alcohol (49 ml) was mixed with phosphorous acid (9.4 g), iridium tetrachloride (0.28 g), and water (12.5 ml). The mixture was heated at 100 °C for 10 h under nitrogen. Most of the solvent was distilled off and the residue worked up with ether. The crude product was hydrolysed with methanolic potassium hydroxide solution (8%) on a boiling water-bath for 4 h, then diluted with water and extracted with ether to remove any unreacted material. The alkaline portion was cooled to 0 °C, acidified with ice-cold dilute hydrochloric acid (1 : 1) and kept at room temperature for 1 h. The acidic and neutral parts were separated. The neutral part was evaporatively distilled to afford (13) as a transparent viscous liquid (0.85 g), b.p. 156—158 °C at 0.4 mmHg; i.r. and n.m.r. spectra were identical with those of the *cis*-lactone obtained by procedures (*a*) and (*b*). From the acidic part the saturated keto-acid (8) (1.2 g), m.p. 218 °C, was recovered.

(*d*) The viscous toluene-*p*-sulphonate ester (0.4 g) [obtained from the hydroxy-acid (9) (0.35 g) by esterification with ethereal diazomethane solution and subsequent tosyl-

ation] in dry *NN*-dimethylformamide (16 ml) was warmed in an oil bath (85 °C) for 24 h under nitrogen. The crude product (0.35 g) was hydrolysed with methanolic potassium hydroxide (10 ml, 5%), and the alkaline portion, on acidification, afforded a neutral part identified as the *cis*-lactone (13) (0.1 g), and the acidic part as the hydroxy-acid (9) (0.15 g), m.p. 178 °C.

2α-*Hydroxy*-1α-(2-*hydroxyethyl*)-4aβ-*methyl*-7-*methoxy*-1,2,3,4,4a,9,10,10aα-*octahydrophenanthrene* (14).—A solution of the *cis*-lactone (13) (0.2 g) in dry ether (50 ml) was added dropwise to a stirred suspension of lithium aluminium hydride (0.1 g) in ether (50 ml); after addition was over, gentle reflux was maintained for 3 h. The product, on the usual work-up, afforded the needle-shaped crystalline diol (14) (0.18 g), m.p. 173—174 °C (ethyl acetate) (Found: C, 74.4; H, 8.8. $C_{18}H_{26}O_3$ requires C, 74.4; H, 9.0%).

9bβ-*Methyl*-7-*methoxy*-2,3,3aβ,3bα,4,5,9b,10,11,11aβ-*decahydrophenanthro*[2,1-b]*furan* (15).—The diol (14) (0.88 g) and toluene-*p*-sulphonyl chloride (1.15 g) were dissolved in pyridine (22 ml) and kept at 0 °C for 2 h, then at room temperature for 2 h. On the usual work-up it furnished compound (15) (0.8 g), m.p. 107 °C (light petroleum); $\nu_{max.}$ 1 605 and 1 140 cm^{-1}; δ($CDCl_3$) 7.2—6.6 (3 H, m, aromatic), 3.7 (3 H, s, OMe), 4.02—3.62 (3 H, m, CH–O–CH_2), and 1.05 (3 H, s, Me) (Found: C, 79.4; H, 8.8. $C_{18}H_{24}O_2$ requires C, 79.3; H, 8.8%).

9bβ-*Methyl*-2,3,3aβ,3bα,4,5,7,8,9,9aα,9bα,10,11,11aβ-*tetradecahydrophenanthro*[2,1-b]*furan*-7-*one* (16).—A solution of compound (15) (0.7 g) in ether (40 ml) was added in a rapid stream to a stirred solution of lithium (1.1 g) in liquid ammonia (250 ml). The mixture was stirred vigorously for 6 min, then absolute ethanol (10 ml) was added dropwise, whereupon the steel-blue colour of the solution was discharged. The mobile liquid, obtained on the usual work-up, was mixed with methanol (35 ml) and dilute hydrochloric acid (22 ml, 3N), and kept at 60 °C for 0.5 h under nitrogen. The resulting product was evaporatively distilled to furnish a viscous liquid (0.5 g), b.p. 130—135 °C at 0.01 mmHg. The material was chromatographed over activated neutral alumina (10 g), and the portion eluted with benzene–light petroleum (1 : 10) afforded fine needle-shaped crystals of (16) (0.2 g), m.p. 87 °C (ether–light petroleum); $\nu_{max.}$ 1 660 and 1 620 cm^{-1}; $\lambda_{max.}$ 242 nm (log ε 4.3); δ(CCl_4) 5.73 (1 H, s, vinyl), 3.9—3.5 (3 H, m, CH–O–CH_2), and 0.7 (3 H, s, Me) (Found: C, 78.5; H, 9.3. $C_{17}H_{24}O_2$ requires C, 78.4; H, 9.3%).

3aβ-H,3bα-H,5aα-H,9aα-H,11aβ-H-9bβ-*Methylperhydrophenanthro*[2,1-b]*furan*-7-*one* (17).—The unsaturated ketone (16) (0.18 g) was hydrogenated in *NN*-dimethylformamide (20 ml) over palladium–charcoal (10%, 0.1 g) to afford a viscous liquid (0.17 g), b.p. 155 °C at 0.05 mmHg. The product was passed through a column of neutral alumina (5 g); the fraction eluted with benzene–light petroleum (3 : 7) furnished the *cis*-saturated ketone (17) (0.04 g) as crystalline plates, m.p. 70 °C (ether–light petroleum); $\nu_{max.}$ 1 700 cm^{-1}; t.l.c. revealed a single spot under different solvent systems; *m/e* 262 (M^+); δ(CCl_4)4.00—3.62 (3 H, m, CH–O–CH_2), 2.4—2.18 (4 H, m, CH_2COCH_2), and 1.00 (3 H, s, Me) (Found: C, 77.7; H, 9.9. $C_{17}H_{26}O_2$ requires C, 77.8; H, 9.9%).

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