Polycyclic Analogues of *trans*-Decalones. Part 5.[1] Synthesis, Optical Resolution and Circular Dichroism of *trans-transoid-trans*-Perhydrophenanthren-3-one and *trans-transoid-trans*-Perhydrophenanthren-9-one

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Racemic perhydrophenanthren-3-one and perhydrophenanthren-9-one have been synthesised from the tricyclic enones (±)-(3) and (±)-(12), respectively. The derived saturated equatorial hydroxy-compound (8a) (as well as its enantiomer) and (13a), resolved as their 3β-acetoxyandrost-5-ene-17β-carboxylates, afforded (+)-(4a*S*,4b*S*,8a*R*,10a*S*)-perhydrophenanthren-3-one (1) (and its enantiomer) and (−)-(4a*S*,4b*R*,8a*S*,10a*R*)-perhydrophenanthren-9-one (2), respectively, both of high optical purity. The c.d. data of compound (+)-(1) do not agree with previous empirical predictions and the consequences of this are discussed. The c.d. measurements for compound (−)-(2), which represents the simplest rigid 'middle-ring' ketone of the 'all-*trans*' perhydrophenanthrene class hitherto studied, clearly show that for such systems additivity of effects of individual rings does not hold.

EMPIRICAL analysis of the contribution of key structural features to the chiroptical properties of carbonyl compounds has been of great interest, as it allowed the proposal of some useful generalizations [2,3] of straightforward application for practicising chemists and in turn should be of interest to theoreticians. However, in order to check such empirical generalisations, a study of some simple, unsubstituted structures is needed, by which the contribution of their basic molecular skeleton to the chiroptical properties could be ascertained. With this aim we have already studied the c.d. properties of simple 'all-*trans*' polycarbocyclic ketones belonging to the perhydro-naphthalene,[4] -anthracene,[4,5] -naphthacene,[6] and -phenanthrene [1] series.

In this paper we report novel c.d. data for the hitherto unknown *trans-transoid-trans*-perhydrophenanthren-3-one (1) and for the *trans-transoid-trans*-perhydrophenanthren-9-one (2), previously described only in its racemic form.

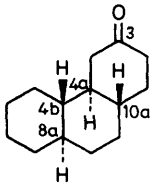
RESULTS AND DISCUSSION

Synthesis and Optical Resolution.—The racemic ketone (1) was prepared by reducing the enone (±)-(3) with Li in liquid ammonia. This enone had first been obtained in low yield by Haworth and Turner,[7] from a 1-decalone of unspecified stereochemistry, making use of Robinson's classical annelation process. Our attempts to duplicate their synthesis [from (±)-*trans*-2-hydroxymethylene-1-decalone (4), *NN*-diethyl-*N*-methyl-3-oxobutanaminium iodide, and MeONa in pyridine] were unsuccessful, leading only to a small amount of an enone fraction, as a mixture of products, separable only with difficulty. A different attempt to obtain the ketone (±)-(2), by condensing the *trans*-1-decalone pyrrolidine enamine (±)-(5) with but-3-en-2-one, also failed. A Dreiding model of compound (5) showed that a strong steric interaction between the hydrogen atoms depicted in its formula hinders the coplanarity required for enamine conjugation, which could explain the lack of reactivity of the enamine (5) towards but-3-en-2-one and the subsequent failure of this method of annelation which we had previously used to good effect in other cases.[4,6] Finally, reaction of compound (±)-(4) with but-3-en-2-one and Bu^{t}OK in Bu^{t}OH, followed by alkaline condensation, after the general procedure of Bloch and Ourisson [8] for building pentacyclic steroids, yielded the tricyclic enone (±)-(3), with a m.p. identical with that of Haworth and Turner's enone,[7] but with an i.r. spectrum clearly different from that of a stereoisomeric *cis*-enone, obtained by Christol *et al.*[9] using a quite different synthetic approach. In our work, two previously undescribed compounds—the tetracyclic dienone (±)-(6) and the pentacyclic trienone (±)-(7)—were isolated as by-products.

Optical resolution was achieved by fractional crystallisation of the mixture of diastereoisomeric esters obtained from the (HO-equatorial) tricyclic alcohol (±)-(8a) and 3β-acetoxyandrost-5-ene-17β-carbonyl chloride (9a). Compound (±)-(8a) was formed as the sole product by reduction of the ketone (±)-(1) with $NaBH_4$, the corresponding axial epimer not being detected. Reductive cleavage ($LiAlH_4$) of the diastereoisomeric androstenecarboxylate ester (10) gave the (+)-alcohol (8a), which was oxidized to the corresponding (+)-ketone (1). Similarly, from the diastereoisomeric ester (11) we obtained the (−)-alcohol, (−)-(8a), which in turn afforded the (−)-ketone, (−)-(1), on oxidation. Within the limits of experimental error both pairs of enantiomers showed equal, but opposite sign, chiroptical properties ($[\alpha]_D$ for alcohols; $[\alpha]_D$ and $\Delta\varepsilon$ for ketones); we believe this supports our belief that all four compounds are enantiomerically pure. Henceforth, for ease of discussion, we shall refer only to the (+)-enantiomers. The absolute configuration of the (+)-ketone (1), shown in the formula, was assigned from its positive ($n \longrightarrow \pi^*$) Cotton effect.

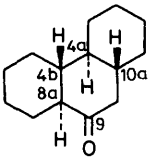
The previously known ketone (±)-(2) [10] was prepared

by catalytic hydrogenation of the enone (±)-(12), which was obtained by condensation between cyclohexanone and 1-acetylcyclohexene in the presence of sodium amide, according to the method of Rapson and Robinson.[11]



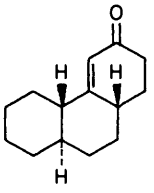
(1)

4aS,4bS,8aR,10aS

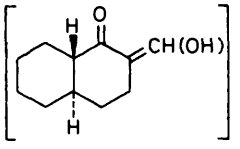


(2)

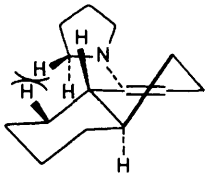
4aS,4bR,8aS,10aR



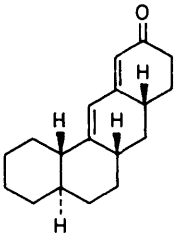
(3)



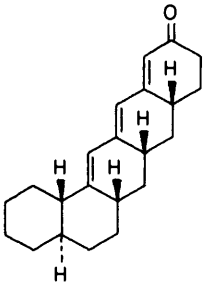
(4)



(5)



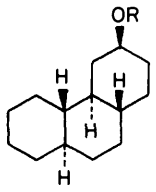
(6)



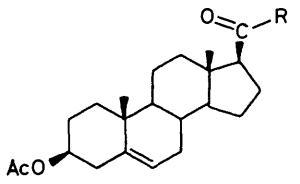
(7)

Hydride reduction of the ketone (±)-(2) gave a mixture of epimeric alcohols, the HO-equatorial one, (±)-(13), being predominant (*eq* : *ax* 55 : 45 with $NaBH_4$–ethanol and 70 : 30 with $LiAlH_4$–diethyl ether) (g.l.c.). Both epimers were isolated from the mixture and the alcohol (±)-(13a) was optically resolved as follows. Multiple fractional crystallisations of the mixture of the corresponding androstenecarboxylate derivatives afforded one diastereoisomer (14) of constant m.p.; the more soluble diastereoisomer could not be purified. Reductive cleavage of (14) by $LiAlH_4$ gave the (+)-alcohol (13a) which was oxidized to the corresponding (−)-ketone; its negative ($n \longrightarrow \pi^*$) Cotton effect showed this ketone to have the absolute configuration illustrated in formula (2).

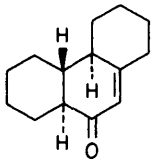
C.d. Properties.—The Table gives the values of Δε



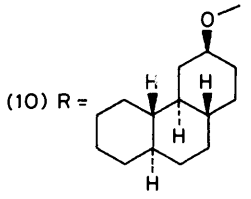
(8)a; R = H
b; R = Ac



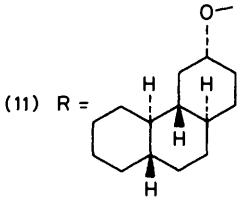
(9)a; R = Cl
b; R = OH



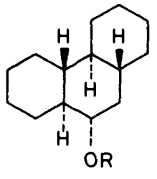
(12)



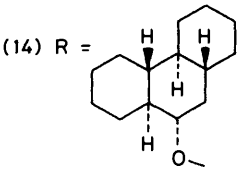
(10) R =



(11) R =



(13) a; R = H
b; R = Ac



(14) R =

($n \longrightarrow \pi^*$) experimentally determined for (±)-(4aS,4bS,8aR,10aS)-perhydrophenanthren-3-one (1) and (−)-(4aS,4bR,8aS,10aR)-perhydrophenanthren-9-one (2), in two solvents of opposite polarity, together with those previously predicted for such structures by Kirk and Klyne.[2] With regard to ketone (1), Kirk and Klyne had

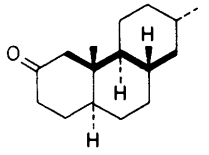
Cotton effects for (+)-(4aS,4bS,8aR,10aS)-perhydrophenanthren-3-one (1) and (−)-(4aS,4bR,8aS,10aR)-perhydrophenanthren-9-one (2) (wavelength in parentheses)

		Δε ($n \longrightarrow \pi^*$)	
Ketone	Solvent	Found	Calc.
(1)	Hexane	+1.40 (298)	+1.05 [a]
(1)	MeOH	+1.70 (290)	+1.35 [a]
(2)	Hexane	−0.47 (296)	−0.30 [b]
(2)	MeOH	−0.75 (293)	−0.40 [b]

[a] From ref. 2. [b] From simple additivity of the two *trans*-decalone systems (ref. 2). Δε Values of −0.6 to −0.7 had previously been predicted (see text).

based their prediction on available data [Δε +1.50 (hexane), +1.95 (MeOH)] for (13βH)-des-D-5α-androstan-2-one (15), by discounting the contributions (δΔε) of the angular methyl group; they gave δΔε values of +0.45 (hexane) and +0.60 (MeOH) for a β-axial methyl group on a primary zig-zag chain of more than two C–C

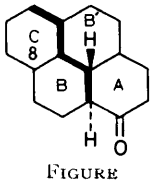
bonds [thickened bonds in structure (15)]. Now, as both ' calculated ' and experimental sets of values differ by more than Kirk and Klyne allowed in their predictions, our present results clearly indicate that increments attributed to a β-axial methyl group in such a system must be smaller [$\delta\Delta\varepsilon$ *ca.* +0.1 (hexane) and +0.2 (MeOH)] which, in turn, would mean that the previously proposed, clear-cut distinction between two classes of β-axial methyl groups—depending on length of primary zig-zag chain—is no longer valid and that there may be a wide range of values for such methyl groups, probably depending on ring-structure type: there is therefore no unique $\delta\Delta\varepsilon$ value for a β-axial methyl group. This does not necessarily mean a breakdown of the supposed additivity rule, but it does show that one must be very cautious in its application with regard to this structural feature.



(15)

Contributions of the ' third ring ' to c.d., expressed as $\delta\Delta\varepsilon$, can now be obtained as the difference between experimental values of $\Delta\varepsilon$ (smoothed to the nearest 0.05 unit) for ketone (1) and for (4a*S*,8a*S*)-*trans*-2-decalone,[2] leading to a result of *ca.* +0.30 in both hexane and MeOH. As these new $\delta\Delta\varepsilon$ values are established with a minimum of previous hypotheses (only that of simple additivity for the unsubstituted, rigid molecular skeleton) we consider them as more reliable than those previously estimated by Kirk and Klyne [$\delta\Delta\varepsilon$ −0.05 (hexane), 0.0 (MeOH)].[2]

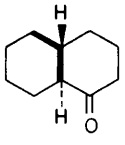
These results suggest the need for a revision of some other concepts. For example, the marked difference in $\Delta\varepsilon$ shown by Kirk and Klyne [2] between building a third ring, C, from either an AB′ system (see Figure) or an AB system, is greatly reduced. Their explanation was partially based on equalizing the influence of a methine group (C-8 in Figure) with that of a methyl group in the same position, and this may well not be a valid proposition. Nonequivalences between contributions to c.d. of C–H *vs.* C–C bonds have been shown in other sites closer to the chromophore.[3a,b] This not being the case in our present study, we may conclude that values hitherto admitted for the contributions of substituents on a primary zig-zag chain (thickened bonds in the Figure) need some adjustment.



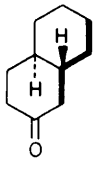
FIGURE

Compound (2) is a particularly interesting case, as the simplest rigid model of a ' middle-ring ' ketone with which the principle of the additivity of effects of individual rings can be properly checked. Kirk and Klyne foresaw that for such structures additivity does not hold, but their analysis of some well known molecules of the same kind, such as 6-, 7-, 11-, and 12-oxo-steroids, was complicated by the additional assumptions which had to be brought in to allow for angular methyl groups, pentagonal rings and/or ' front-octant ' rings, so the need for the study of the c.d. behaviour of ketone (2) was then claimed.[2] Even so, they predicted $\Delta\varepsilon$ values for (2) of between −0.6 and −0.7 (depending on solvent polarity) and tentatively advanced the generalization that, in ' middle-ring ' ketones of the ' all-*trans* ' perhydrophenanthrene class, deviation of additivity occurs in the sense of a more important contribution of the fragment of the 2-decalone type than that of the 1-decalone type.

Algebraic addition of the contributions of zig-zag chains present in (4a*R*,8a*S*)-1-decalone (16) [$\Delta\varepsilon$ +0.81 (hexane), +0.95 (MeOH)] and in (4a*R*,8a*R*)-2-decalone (17) [$\Delta\varepsilon$ −1.12 (hexane), −1.37 (MeOH)], smoothed to the nearest 0.05 unit, are shown in the Table for comparison. Clearly, additivity does not hold and the prediction of Kirk and Klyne with regard to this kind of structure is essentially confirmed. Besides, it may be noteworthy that deviation from additivity is greater the more polar the solvent.



(16)



(17)

Values of $\Delta\varepsilon$ for the short-wavelength transition of the ketone (1) are −1.0 (195 nm; hexane) and −7.2 (193 nm; CF_3CH_2OH), and have already been used by Kirk in his empirical analyses of this transition for extended *trans*-decalones.[3c,d] Those corresponding to compound (2) could not be properly measured due to the small amount of sample available and the subsequent relatively low signal-to-noise ratio. In hexane, $\Delta\varepsilon$ seems to lie at -0.7 ± 0.4 (190 nm), while simple additivity of the two *trans*-decalone fragments present in compound (2) would require a value of *ca.* +3.0 (in hexane).

The c.d. of the alcohol (8a) in the region 185—195 nm, presumably due to the C–OH group as chromophore, is clearly negative [measurement was made on the enantiomer of alcohol (8a), having opposite sign]. For 2α-hydroxy-5α-steroids, with a similar structure in the proximity of the chromophore, there was no clear prediction of the $\Delta\varepsilon$ value.[12] Rather surprisingly, the alcohol (13a) gave no measurable c.d. down to 190 nm, while existing data for 6α-hydroxy-5α-steroids [12] led us to expect that a $\Delta\varepsilon > 0$ should have been observed. On

the other hand, c.d. measurements on their acetates in the region 210—220 nm agree reasonably well with expectations. Thus, on the basis of the analysis of contributions to c.d. of significant C–C bonds made by Kirk and his co-workers,[13] the $\Delta\varepsilon$ value predicted for the acetate (8b) in MeOH would be −0.1, and that for the acetate (13b) −0.50, while experimental data now found are −0.07 and −0.66, respectively.

EXPERIMENTAL

Alumina was Merck grade I (Brockman); ' deactivated alumina ' refers to alumina grade I containing 2% of water. M.p.s were determined on a hot-plate and are uncorrected. I.r. spectra were obtained for KBr discs, u.v. spectra for solutions in ethanol, and n.m.r. spectra for solutions in $CDCl_3$ unless otherwise stated. Microanalyses were performed at Centro Nacional de Química Orgánica (C.S.I.C. Madrid). C.d. spectra were provided by Dr. P. M. Scopes and Professor D. N. Kirk, Westfield College, London. Light petroleum refers to that fraction boiling in the range 50—70 °C.

Starting Materials for Syntheses.—(±)-*trans*-1-Decalone was prepared from 1-naphthol by catalytic hydrogenation on Raney Ni [14] followed by chromic oxidation of the mixture of 1-decalols and final acidic isomerisation.[4] (±)-*trans*-2-Hydroxymethylene-1-decalone [15] (4) was prepared using known procedures for analogous compounds, with sodium methoxide [16] or sodium hydride; [17] 1-acetylcyclohexene was prepared using the method of Saunders.[18]

(±)-1,4bβ,5,6,7,8,8aα,9,10,10aβ-*Decahydrophenanthren*-3(2H)-*one*, rac-(3).—To a stirred solution of compound (±)-(4) (50 g) in anhydrous Bu^tOH (700 ml) at 25 °C under N_2 was quickly added a solution of potassium (1 g) in anhydrous Bu^tOH (120 ml) and then, through a different dropping funnel, freshly distilled but-3-en-2-one (30 ml) was added. The yellow-orange mixture was left under N_2 at room temperature for 42 h and was then made just acid with 10% acetic acid. Removal of the solvents under reduced pressure left a reddish oil which was dissolved in MeOH (600 ml) and, under N_2, mixed with 45% aqueous KOH (300 ml) and the mixture was refluxed for 5 h. Removal of most of the MeOH, dilution with water, and extraction with diethyl ether afforded a crude product (34 g) which was chromatographed on deactivated alumina (700 g) with light petroleum as eluant to separate any unchanged decalone; fractions eluted with light petroleum–benzene (1 : 1) and benzene which contained the required enone (u.v.) were evaporated to dryness to afford a residue (25 g) which, after two crystallisations from light petroleum, gave the pure enone (±)-(3) (14 g, 23%), m.p. 54—55 °C (lit.,[7] 53—54 °C); $\nu_{max.}$ 1 670 and 1 610 cm^{-1}; $\lambda_{max.}$ 239 nm (ε 16 300); δ(CCl_4) 2.2 (2 H, m, CH_2CO) and 5.7 (1 H, s, C=CH) (Found: C, 82.1; H, 10.05. Calc. for $C_{14}H_{20}O$: C, 82.3; H, 9.87%).

Later fractions, eluted with benzene–diethyl ether (8 : 2) gave, after work-up, a crude residue (3.8 g) which was recrystallised from light petroleum to give a faintly coloured solid, m.p. 149—150 °C, to which the structure (±)-1,3,4,-4aα,5,6,6aβ,7,7aβ,8,9,12bβ-*dodecahydrobenz*[a]*anthracen*-10-(2H)-*one* [rac-(6)] was assigned on the basis of its origin and of the following data: $\nu_{max.}$ 1 650, 1 605, and 1 575 cm^{-1}; $\lambda_{max.}$ 293 nm (ε 30 700); δ 2.4 (2 H, m, CH_2CO), 5.8 (1 H, s, 12-H), and 6.0 (1 H, s, 11-H) (Found: C, 84.2; H, 9.40. $C_{18}H_{24}O$ requires C, 84.3; H, 9.44%).

The last fractions, eluted with benzene–ether (1 : 1), gave a crude residue (2.0 g) which was recrystallised from ethanol to give a yellow solid, m.p. 226—228 °C, to which the structure (±)-1,3,4,4aα,5,6,6aβ,7,7aβ,8,8aβ,9,10,14bβ-*tetradecahydrobenzo*[a]*naphthacen*-11(2H)-*one* [rac-(7)], was assigned on the basis of its origin and of the following data: $\nu_{max.}$ 1 640, 1 610, 1 580, and 1 555 cm^{-1}; $\lambda_{max.}$ 345 nm (ε 34 600); δ 2.4 (2 H, m, CH_2CO), 5.8 (1 H, s, 14-H), and 6.0 (2 H, s, 12- and 13-H) (Found: C, 85.7; H, 9.09. $C_{22}H_{28}O$ requires C, 85.7; H, 9.15%).

(±)-trans-transoid-trans-*Perhydrophenanthren*-3-*one*, rac(1).—A solution of the enone (±)-(3) (22 g) in tetrahydrofuran (THF) (350 ml) was added to a stirred solution of lithium (3.5 g) in liquid ammonia (350 ml) and the mixture was stirred for a further 1 h. The product (21 g), isolated by work-up with diethyl ether, was a mixture containing the tricyclic alcohol (±)-(8a), the derived ketone (±)-(1), and a little unchanged enone (±)-(3) (g.l.c.). The mixture was oxidised by stirring for 5 h in acetic acid (250 ml) at room temperature with a mixture of chromium(VI) oxide (12 g) in water (12 ml). Extraction with light petroleum gave a crude product (20.6 g) which was chromatographed on deactivated alumina with light petroleum–benzene (95 : 5 and then 90 : 10) as eluant to give the *saturated ketone* (±)-(1) (18.2 g) as an oil which slowly crystallised with time. An analytical sample was obtained by sublimation (50 °C at 20 mmHg): m.p. 59 °C; $\nu_{max.}$ 1 705 cm^{-1}; δ(CCl_4) 2.0—2.8 (4 H, m, CH_2COCH_2) (Found: C, 81.4; H, 10.73. $C_{14}H_{22}O$ requires C, 81.5; H, 10.75%). 2,4-*Dinitrophenylhydrazone*, m.p. 175—176 °C (MeOH) (Found: C, 62.4; H, 6.75; N, 14.55. $C_{20}H_{26}N_4O_4$ requires C, 62.2; H, 6.78; N, 14.49%). Later fractions, with benzene–diethyl ether (8 : 2) as eluant, afforded unchanged enone (±)-(3) (0.4 g).

(±)-trans-transoid-trans-*Perhydrophenanthren*-3_{eq}-*ol*, rac-(8a).—A solution of the ketone (±)-(1) (12 g) in anhydrous EtOH (145 ml) was stirred for 2 h with $NaBH_4$ (1.45 g) at room temperature. Extraction with chloroform gave the crude alcohol (11 g), crystallisation of which from ethyl acetate at 0 °C gave the pure (g.l.c.) *alcohol* (±)-(8a) (9.0 g), m.p. 108—109 °C; $\nu_{max.}$ 3 320, 1 060, 1 045, 1 035, and 1 020 cm^{-1}; δ 3.5 (1 H, $w_{\frac{1}{2}}$, 20 Hz, C*H*OH) (Found: C, 8.1; H, 11.45. $C_{14}H_{24}O$ requires C, 80.7; H, 11.61%). *Acetate* (±)-(8b), m.p. 49—50 °C. 3,5-*Dinitrobenzoate*, m.p. 166—168 °C (from ethyl acetate) (Found: C, 62.9; H, 6.55; N, 7.05. $C_{21}H_{26}N_2O_6$ requires C, 62.7; H, 6.51; N, 6.96%).

trans-transoid-trans-*Perhydrophenanthren*-3_{eq}-*yl* 3β-*Acetoxyandrost*-5-*ene*-17β-*carboxylate* (10) *and* (11).—A crude mixture of diastereoisomeric esters (33 g) was obtained from 3β-acetoxyandrost-5-ene-17β-carboxylic acid [19] (9b) (22 g), *via* the acid chloride (9a) in pyridine (130 ml), with a solution of the equatorial alcohol (±)-(8a) (11 g) in pyridine (60 ml) by the usual procedure [4] (extraction with chloroform). Chromatography on deactivated alumina [(800 g); light petroleum–benzene (1 : 1) as eluant] afforded, first, the pure esters (10) and (11) as a mixture (14 g) of both diastereoisomers, inseparable on alumina; elution with diethyl ether–ethyl acetate (1 : 1) then gave the unchanged alcohol (±)-(8a) (5.1 g). The aforementioned mixture of esters (14 g) was successively fractionally crystallised seven times from ethyl acetate, then twice from acetone and once from ethanol to give the *ester* (11) (1.3 g). The last two recrystallisations gave crystals with unchanged m.p. (206—207 °C) (Found: C, 78.3; H, 10.0. $C_{36}H_{54}O_4$ requires C, 78.5; H, 9.88%).

The mother liquor from the first crystallisation (ethyl acetate) was concentrated to a quarter of its initial volume. After several days, two very different kinds of crystals had appeared: needles and buttons, which could be hand-separated. The crop of buttons, after crystallisation once from ethyl acetate and then four times from acetone, yielded the *ester* (10) (1.5 g), m.p. 170—171 °C, unchanged by the two final crystallisations (Found: C, 78.5; H, 9.95. $C_{36}H_{54}O_4$ requires C, 78.5; H, 9.88%).

(+)-(3S,4aS,4bS,8aR,10aS)-*Perhydrophenanthren*-3-*ol* (8a).—The pure ester * (10) (1.02 g) in dry ether (250 ml) was reductively cleaved with $LiAlH_4$ (500 mg) at room temperature for 4 h. Hydrolysis with cold dilute HCl, extraction with diethyl ether, and removal of the solvent gave an equimolecular mixture (0.94 g) of the alcohol (8a) and 21-norpregn-5-ene-3β,20-diol which was chromatographed on silica gel (20 g) with benzene–diethyl ether (8 : 2) as eluant to give the (±)-*alcohol* (8a) (0.37 g), m.p. 114—116 °C (after sublimation at 90 °C and 18 mmHg); $[\alpha]_D^{23}$ +36 ± 2° (*c*, 0.5 in $CHCl_3$).† The acetate (8b) was prepared from the alcohol (8a) (47 mg) and Ac_2O (2.5 ml) in pyridine (5 ml) at room temperature during 24 h. The usual work-up and chromatography on alumina [(8 g); light petroleum–diethyl ether (8 : 2) as eluant] gave the *ester* (8b) (45 mg) as an oil which slowly crystallised, m.p. 47—48 °C; Δε −0.07 (212 nm, in MeOH).

(−)-(3R,4aR,4bR,8aS,10aR)-*Perhydrophenanthren*-3-*ol* [*Enantiomer of compound* (8a)].—The pure ester (11) (1.30 g) was reductively cleaved as for compound (10) to give the *title* (−)-*perhydrophenanthren*-3_{eq}-*ol* (0.48 g), m.p. 114—116 °C (after sublimation at 90 °C and 18 mmHg); $[\alpha]_D^{23}$ −38 ± 2° (*c*, 0.5 in $CHCl_3$); Δε +0.23 (195 nm!, in hexane). *Acetate* [*enantiomer of* (8b)], m.p. 47—48 °C.

(+)-(4aS,4bS,8aR,10aS)-*Perhydrophenanthren*-3-*one* (1).—The (+)-alcohol (8a) (180 mg) in acetic acid (10 ml) was oxidised with chromium(VI) oxide (200 mg) for 18 h at room temperature. The usual work-up and sublimation (50 °C; 20 mmHg) procedure gave the (+)-*ketone* (1) (133 mg), m.p. 88—88.5 °C; $[\alpha]_D^{23}$ +59 ± 1° (*c*, 0.5 in $CHCl_3$).

(−)-(4aR,4bR,8aS,10aR)-*Perhydrophenanthren*-2-*one* [*Enantiomer of Compound* (1)].—Oxidation of the (−)-alcohol [*enantiomer of compound* (8a)] (280 mg) as above afforded, after work-up, the (−)-*perhydrophenanthren*-3-*one* (160 mg) after sublimation, m.p. 88—88.5 °C; $[\alpha]_D^{23}$ −59 ± 1° (*c*, 0.5 in $CHCl_3$).

(±)-trans-transoid-trans-*Perhydrophenanthren*-9-*one*, rac-(2).—This was prepared following the procedure of Allinger *et al.*,[10] and had m.p. 48—49 °C (lit.,[10] 48—50 °C). 2,4-*Dinitrophenylhydrazone*, m.p. 207—208 °C (MeOH) (Found: C, 61.9; H, 6.85; N, 14.3. $C_{20}H_{26}N_4O_4$ requires C, 62.2; H, 6.78; N, 14.49%).

(±)-trans-transoid-trans-*Perhydrophenanthren*-9_{eq}-*ol*, rac-(13a).—A solution of the ketone (±)-(2) (4.5 g) in anhydrous EtOH (100 ml) was treated with $NaBH_4$ (0.7 g) for 19 h at room temperature. Dilution with water and extraction with diethyl ether afforded a crude mixture of epimeric alcohols [*eq*-OH : *ax*-OH 55 : 45 (g.l.c.)] (4.5 g). Three crystallisations from ethyl acetate gave the pure racemic equatorial alcohol (±)-(13a) (1.07 g), m.p. 118—119 °C (lit.,[20] 119 °C); $\nu_{max.}$ 3 350, 1 045, and 1 030 cm^{-1}; δ 3.15 (1 H, $w_{\frac{1}{2}}$ 18 Hz, *CH*OH) (Found: C, 80.7; H, 11.8. $C_{14}H_{24}O$ requires C, 80.7; H, 11.61%). *Acetate* (±)-(13b), m.p. 68—69 °C (Found: C, 77.0; H, 10.3. $C_{16}H_{26}O_2$ requires C, 76.8; H, 10.46%). Oxidation of the residue from the EtOAc crystallisations (3.1 g) in acetic acid (100 ml) with chromium(VI) oxide (1.7 g), followed by the usual work-up and chromatography on deactivated alumina (benzene as eluant) gave the pure ketone (±)-(2) (2.6 g) which was refluxed with $LiAlH_4$ (0.45 g) in dry diethyl ether for 3 h. The usual work-up led to a mixture (2.4 g) of epimeric alcohols [*eq*-OH : *ax*-OH 70 : 30 (g.l.c.)]. Two crystallisations from ethyl acetate afforded the pure alcohol (±)-(13a) (1.06 g). Chromatography (deactivated alumina) of a residual mixture of both epimeric alcohols and crystallisation from light petroleum at 0 °C gave an analytical sample of the axial alcohol, m.p. 79—80 °C (lit.,[20] 80 °C); $\nu_{max.}$ 3 330, 1 035, and 1 010 cm^{-1}; δ 3.62 (1 H, $w_{\frac{1}{2}}$ 6 Hz, *CH*OH) (Found: C, 80.5; H, 11.85. Calc. for $C_{14}H_{24}O$: C, 80.7; H, 11.61%).

trans-transoid-trans-*Perhydrophenanthren*-9_{eq}-*yl* 3β-*Acetoxyandrost*-5-*ene*-17β-*carboxylate* (14) *and Diastereoisomer*.—A solution of the steroidal acid chloride (9a), prepared from the acid (9b) (5 g), in pyridine (40 ml) was mixed with a solution of the racemic alcohol (±)-(13a) (2.0 g) in pyridine (40 ml) and the mixture was refluxed for 16 h. The usual work-up (extraction with diethyl ether) gave a dark, thick mass (6.7 g), chromatography of which on deactivated alumina (250 g) (benzene as eluant) afforded the pure esters as a mixture (4.5 g) of both diastereoisomers, inseparable on alumina. This material was fractionally crystallised ten times from ethyl acetate to give the (4aS,4bR,8aS,9S,10aR)-*ester* (14) (270 mg). The two final recrystallisations did not change the m.p. of the product (192—193 °C) (Found: C, 78.3; H, 10.1. $C_{36}H_{54}O_4$ requires C, 78.5; H, 9.88%).

(+)-(4aS,4bR,8aS,9S,10aR)-*Perhydrophenanthren*-9-*ol* (13a).—The pure ester (14) (260 mg) was reductively cleaved with $LiAlH_4$ (220 mg) in dry diethyl ether (60 ml) under reflux for 14 h. The usual work-up gave a mixture (250 mg) of the alcohol (13a) and 21-norpregn-5-ene-3β,20-diol which was chromatographed on deactivated alumina (20 g) with benzene and then with benzene–diethyl ether (9 : 1) as eluant to afford the (+)-alcohol (13a) (90 mg) which was crystallised from ethyl acetate, m.p. 145—146 °C; $[\alpha]_D^{25}$ +58 ± 1° (*c*, 0.7 in $CHCl_3$); Δε, not detectable (down to 190 nm, in hexane). *Acetate* (13b), m.p. 69—70 °C; $[\alpha]_D^{25}$ +70 ± 2° (*c*, 0.3 in $CHCl_3$); Δε −0.67 (212 nm, in MeOH), −0.51 (215 nm, in hexane).

(−)-(4aS,4bR,8aS,10aR)-*Perhydrophenanthren*-9-*one* (2).—The (+)-alcohol (13a) (35 mg) in acetic acid (10 ml) was oxidised with chromium(VI) oxide (25 mg) for 16 h at room temperature. The usual work-up followed by percolation in benzene through deactivated alumina (5 g) gave the (−)-ketone (2) (33 mg), m.p. 64—65 °C (after sublimation at 60 °C and 18 mmHg); $[\alpha]_D^{25}$ −13 ± 1° (*c*, 0.2 in $CHCl_3$).

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* The optical purity of all the present products rests upon the criterion of constancy of m.p. of the 3β-acetoxyandrostene-carboxylate esters, which has given good results in other cases (refs. 1, 4, 5, 6). Neither $[\alpha]_D$ nor the ^1H n.m.r. spectra of mixtures of diastereoisomeric esters varied significantly, whilst m.p.s asymptotically approached the value of that of the pure ester.

† All optically resolved alcohols and ketones showed i.r spectra and g.l.c. behaviour identical with those of the corresponding racemates.

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