175. The Chemistry of Thujone. VIII[1]). Thujone as a Chiral Synthon for the Synthesis of Optically Active Steroid Analogues. The Enol Lactone Route

by **James P. Kutney*, Peter Grice, Keith O. Pascoe, Krystyna Piotrowska, Steven J. Rettig, Jerzy Szykula** and **James Trotter***

Department of Chemistry, University of British Columbia, Vancouver, B. C., V6T 1Y6, Canada

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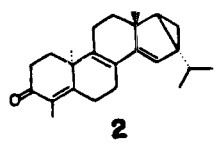
Summary

The thujone-derived enone **1** is converted *via* enol lactone intermediates **4** and **5** to the optically active steroidal analogue **13** and the corresponding 19-norsteroid analogue **14**. The structure of **13** was determined by X-ray diffraction analysis. The acid-catalyzed cyclopropane-ring opening of **13** and ozonolysis of the resulting olefin provided the 16-keto-steroid analogue **18**.

Introduction. – Recently we reported a one-step synthesis of the optically active steroid analogue **2** from the thujone-derived enone **1** [2]. The mechanistic course of this reaction indicated that steroid molecules with the normal 10β-configuration would not be accessible by this route. We therefore initiated a program to convert **1** into steroid analogues bearing the required 10β-substituent.



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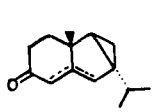

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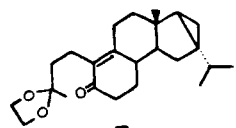


3

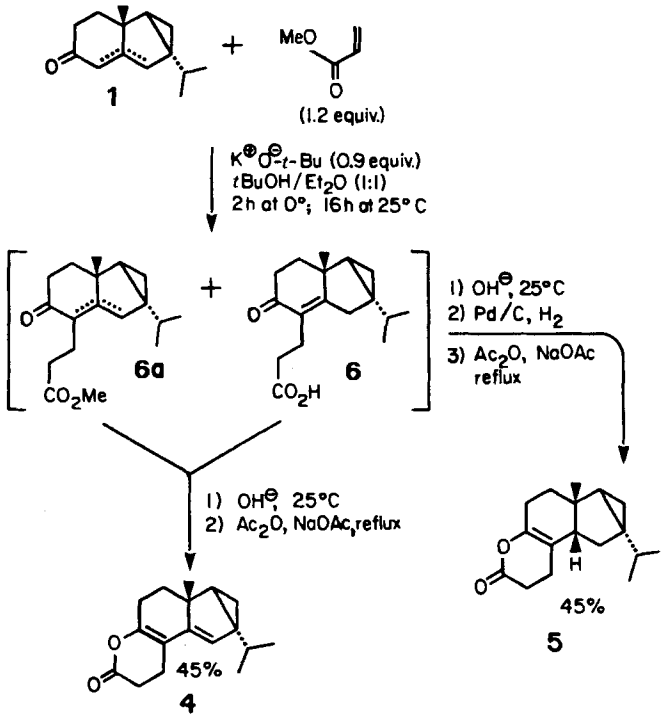
Examination of the literature [3] showed that our initial target should be enone **3**. This intermediate should be easily transformed into all three major classes of steroids, *i.e.* 19-CH_3-, 19-nor-, and A-ring-aromatic steroids. Enone **3** should be accessible *via* addition of the *Grignard* reagent **7c** to either dienol lactone **4** or to enol lactone **5** *(cf. Scheme 3)*.

Synthesis of the Unsaturated Lactones *4* and *5* and their Reaction with *Grignard* Reagents *(Schemes 1–3)*. – Reaction of **1** with methyl acrylate under basic conditions gave a mixture of the acid **6** and the corresponding ester **6a** in addition to a small amount of dialkylated material. Careful control of reaction conditions was essential to minimize the formation of dialkylated material. The crude product from this

[1]) For Part VII, see [1].

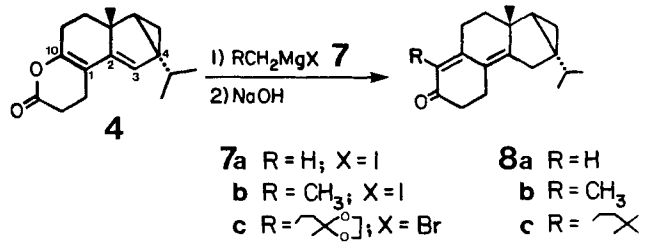
reaction was not routinely purified but subjected directly to one of two sets of transformations as summarized in *Scheme 1*. Alkaline hydrolysis followed by enol-lactonization gave the dienol lactone **4** in 45% overall yield. Alternatively, the crude product, after hydrolysis, could be hydrogenated prior to enol-lactonization to afford enol lactone **5** also in 45% overall yield.

Scheme 1



The reaction of an enol lactone with one equiv. of a *Grignard* reagent derived from a primary alkyl halide followed by treatment with base to give an α-substituted enone is known as the *Fujimoto-Belleau* reaction [4]. We have applied this reaction to include the transformation of the dienol lactone **4** into α-substituted dienones **8** *(Scheme 2)*. Thus, treatment of dienol lactone **4** with the *Grignard* reagents **7a–c**

Scheme 2



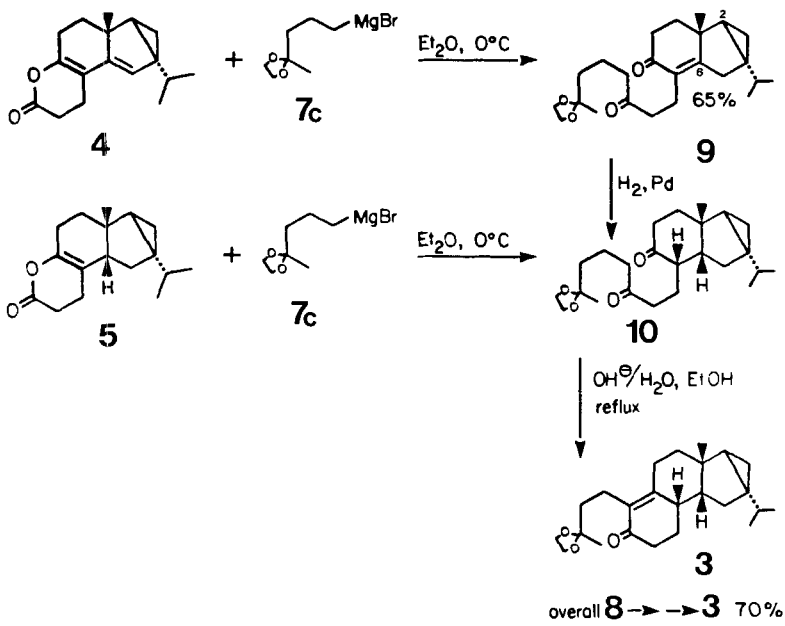
gave, after treatment with aqueous ethanolic NaOH, dienones **8a–c**, respectively, in good yields *(Table 1)*. Optimum yields of dienone were obtained at 0–20° in ether solution. Lower yields were realized in tetrahydrofuran. At very low temperatures ($\leq -40°$), deprotonation of the dienol lactone appeared to be the predominant reaction.

Table 1. *Reaction of Dienol Lactone* **4** *with* Grignard *Reagents*

Grignard reagent	Solvent	Temp.	Product	Yield
7a	Et_2O	−40°	**8a**	24%
7a	Et_2O	−20°	**8a**	37%
7a	Et_2O	0°	**8a**	57%
7a	Et_2O	20°	**8a**	53%
7b	Et_2O	0°	**8b**	36%
7c	Et_2O	0°	**8c**	65%

A further modification of this procedure allowed, in the case of *Grignard* reagent **7c**, the isolation of the uncyclized enedione **9** *(Scheme 3)* as the major product (65%), in addition to a small amount (10%) of dienone **8c**.

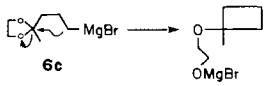
Scheme 3



The yield of reactions of dienol lactone **4** with **7a** and **7b** did not vary significantly from run to run. However, yields of reactions involving **7c** varied widely. Typical average yields were 55–65%, however, on occasion and under identical reaction conditions yields below 30% and greater than 90% were also recorded. We have found the preparation of *Grignard* reagent **7c** to be an extremely capricious reaction. The methods described in [5] for the preparation of this and closely related *Grignard* reagents, in our hands, failed to produce any desirable product (**8c** or **9**). When the halide is rigorously purified, the

reaction with magnesium starts spontaneously without addition of an initiator or entrainer. We have found that for optimum yields the reaction of halide with magnesium must be strictly controlled to 25-30° and that the *Grignard* reagent thus formed must be used immediately. The use of the bromide was found to be optimum. The iodide resulted in extensive *Wurtz*-type coupling, whilst reaction of the chloride with magnesium was difficult to start and generally gave poorer yields. We believe that the *Grignard* reagent **6c** undergoes a cyclization to the cyclobutane alkoxide *(Scheme 4)*. A similar reaction has been proposed for a related *Grignard* reagent [6].

Scheme 4



Hydrogenation of Acid *6* and Enedione *9*. – The enedione **9** was converted into enone **3** by initial hydrogenation in weakly basic media to give the saturated diketone **10** and subsequent treatment of **10** with base (overall yield 70%). It was thus clear that the hydrogenation of the double bond in **9** had proceeded stereospecifically. An identical product was obtained by reaction of enol lactone **5** with **7c** and treatment of the resultant intermediate **10** with base *(Scheme 3)*.

We had considered that the course of the hydrogenation of enedione **9** and keto-acid **6** might be comparable to that of a 4-substituted steroidal 4-ene-3-one intermediate [7] and thus lead to a product with a *trans* ring junction. Molecular models reveal that approach from the β-face of the molecule is more severely hindered by the angular CH_3-group and the cyclopropane methylene-C-atom than approach from the α-face in which only the isopropyl group is involved. The latter is oriented to the side away from the double bond when the normal planarity of the cyclopentane ring is considered. On this basis it was expected that catalytic reduction of **6** and **9** would provide the *trans*-fused product. In fact, chiroptical data and X-ray diffraction analysis (see below) of products derived from **3** revealed that reduction occurred from the β-face thereby providing the configuration depicted in **5** and **10**. Such a result may be rationalized on the basis that the severe nonbonded interactions between the angular CH_3-group and the cyclopropane system which are present when the five-membered ring is essentially planar causes this ring to distort into an 'envelope' conformation. The latter situation decreases such interaction, opens up approach from the β-face, and simultaneously causes the isopropyl to orient into a pseudoaxial position thereby increasing hindrance to approach from the α-face. In this manner, the exclusive attack from the β-face is explicable. It should be noted that a similar reduction course was observed with the α,β-unsaturated ester **6a** under strongly acidic, alkaline, and neutral conditions [8].

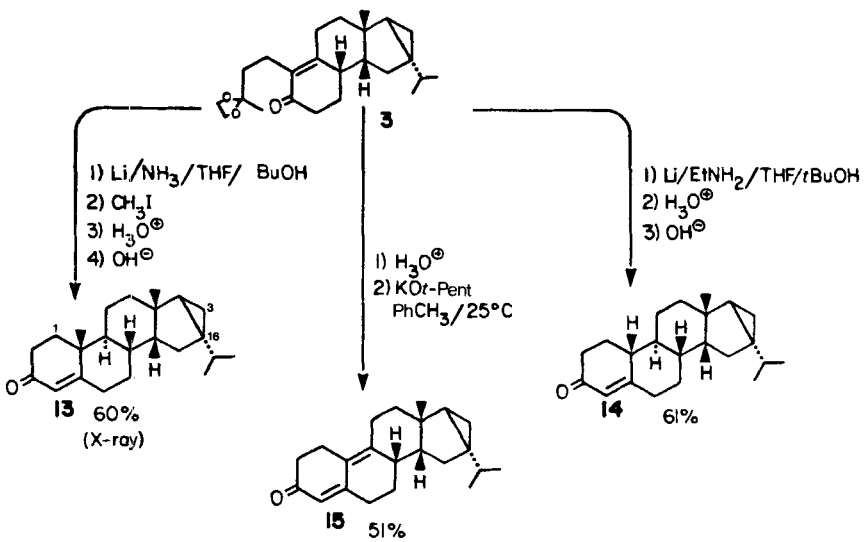
To provide a possible entry into the *trans*-fused system from reduction of **6** to **9** the *Birch* reduction was considered. A rationalization for the stereochemical course of the *Birch* reduction of α,β-unsaturated ketones has been provided by *Stork & Darling* [9]. *Stork* has considered the importance of continual overlap of the developing orbital at the β-C-atom in the transition state of the enone undergoing reduction with the result that the newly introduced H-atom is axial to the ketone ring. Such a consideration in our case would require the conformations **11** and **12** in the transition states arising from the reduction of **6** or **9** (M = metal). Obviously, the lesser interactions noted in **11** would be expected to favor this conformation, and consequently, the *trans*-fused product should be obtained. However,

reduction of the keto-acid **6** with Li in ethylamine gave, after enol lactonization, the *cis*-fused product **5** as the only isolable compound, thereby suggesting conformation **12** in the transition state of the reaction. The reasons for this stereochemical course are unclear and are not easily explicable in terms of the *Stork* postulate, unless the cyclopropyl system through additional orbital overlap in the transition state aids in the development of conformation **12**. An alternative rationalization may be available from the consideration of dynamic stereochemistry principles of 5-, and 6-membered rings as detailed by *Toromanoff* [10]. For example, in the case of **6**, if the presence of the cyclopropane ring effectively locks the molecule into the *quasi-cis*-conformation as defined by *Toromanoff*, then the *cis*-fused product is expected.

Conversion of *3* to Steroid Analogues *(Scheme 4).* – Enone **3** was converted into steroid **13** by a sequence of reactions involving reductive alkylation [11] followed by acid hydrolysis of the acetal and base-promoted cyclization. Steroid analogue **13** was obtained in 60% yield along with a small amount of unmethylated steroid analogue **14**. Alternatively, this 19-norsteroid analogue was obtained in 61% yield by conventional *Birch* reduction of **3** followed by acid and base treatments as before.

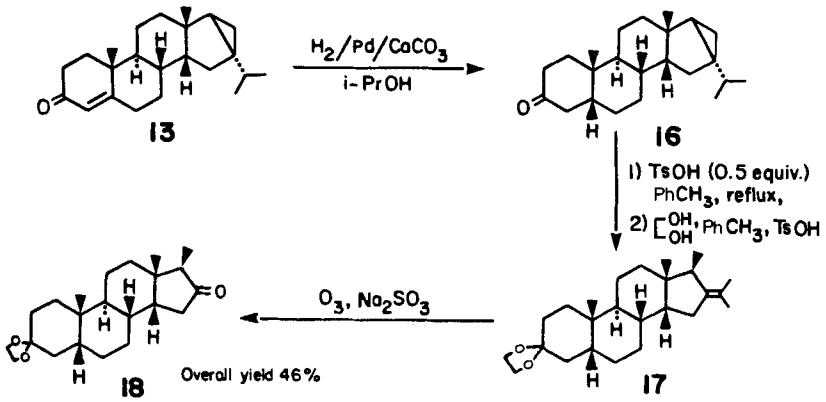
Enone **3** was also converted into dienone **15** *(Scheme 4)* by hydrolysis of the acetal followed by base-promoted cyclization (51% overall yield). Compound **15** is expected to be a precursor of A-ring-aromatic steroid analogues. In the accompanying publication [15] we report an alternative synthesis of **15**.

Scheme 5



Further transformations of **13** are shown in *Scheme 6.* Hydrogenation of **13** over $Pd/CaCO_3$ gave exclusively **16**. The stereochemical course of the reduction was apparent from the correlation of the CD curve of **16** ($\Delta\varepsilon = -0.83$ at 291 nm) with that of known 5β-3-keto steroids [16].

Scheme 6



To ascertain the configuration of the newly created asymmetric C-atoms C(9) and C(10) in **13** and **14**, circular dichroism (CD) studies were undertaken with appropriate steroids for comparison. The CD curves of **13** and **14** compared with testosterone are recorded in *Fig. 1*. It is noted that these curves are similar in shape

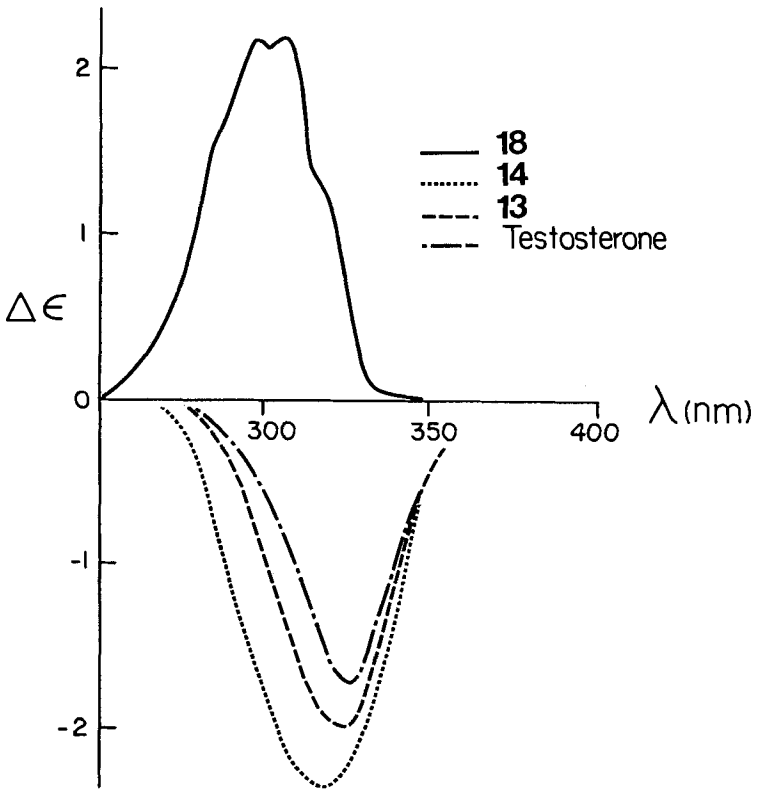


Fig. 1. *CD Curves of* **13**, **14**, **18**, *and Testosterone*

and intensity. The differences in intensity may be attributed to the 14βH-configuration (see X-ray results below) which places the D-ring and its substituants substantially into a negative octant. Since the D-ring is relatively remote, changes in magnitude are expected to be small.

Although the data presented above provided suggestive evidence concerning the overall structures of **13** and **14**, and probable asymmetry of C(10), C(9), and C(8), no direct evidence was available to determine the configuration at C(14). X-ray crystallography was undertaken to furnish these data and indeed establish the total structure for **13**.

X-Ray Diffraction Analysis of *13*. – Compound **13** crystallized from iso-octane and provided crystals suitable for X-ray diffraction analysis. The structure and absolute configuration of **13** are shown in *Fig. 2*. The A-ring adopts a distorted C(1) α-sofa conformation, while the fully saturated B- and C-rings have distorted chair conformations. The asymmetry parameters $\Delta C_5(5)$ and $\Delta C_2(5\text{–}10)$ which measure the deviations of the B-ring from mirror and twofold symmetry [12] are 8.2 and 4.1, respectively. The D-ring has a C(14) β-envelope conformation, necessitated by the fusion to the three-membered ring. The configuration at C(14) is opposite to that usually found for steroids, the C/D-ring junction being *cis* rather than the usual *trans*. The maximum angle of torsion ($\varnothing_m$) and the phase angle of pseudorotation (Δ) [13] for the D-ring are -33.6 and $-20.5°$, respectively, the negative sign of $\varnothing_m$ reflecting the inversion at C(14). The molecule is, overall, convex towards the β-face with the D-ring being oriented well out of the approximate plane of the A-, B-, and C-rings.

Bond lengths and angles are normal, mean C,C-double-bond-, C(sp^3),C(sp^3)-(exclusive of the three-membered ring), and C(sp^3),C(sp^2)-distances being 1.358, 1.533, and 1.490 Å, respectively. Several bond lengths differ significantly from the

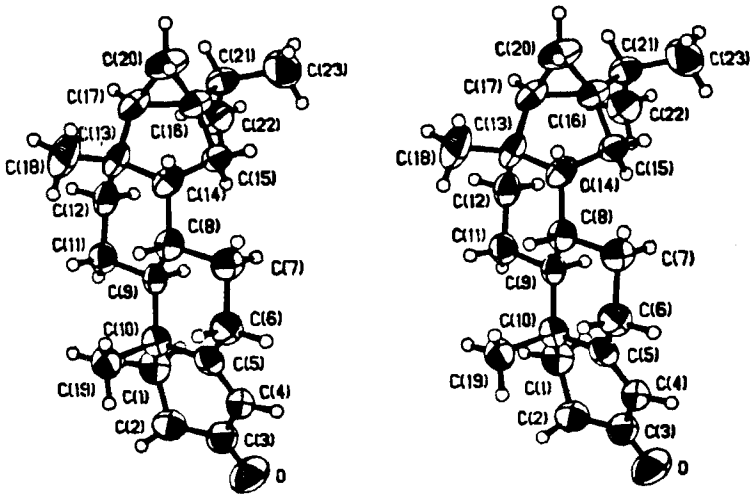


Fig. 2. *Stereoview of* **13**. 50%-Probability thermal ellipsoids are shown for O- and C-atoms. H-atoms have been assigned artificially small thermal parameters for the sake of clarity. Numbering of C(20) to C(23) is not systematic.

expected values: C(3)–C(4), C(13)–C(17), C(16)–C(21), and C(21)–C(22) are shortened, while C(10)–C(19) and C(5)–C(10) are lengthened. The mean C,C-distance in the cyclopropane ring (1.502(8) Å) is as expected [14].

Cyclopropane-Ring Opening. – The next phase of our synthetic program within this series concerned studies of cyclopropane-ring opening in the analogue **16** so as to provide the conventional 5-membered D-ring of natural steroids. Earlier investigations [2] had already provided a basis for the present requirements, and therefore, **16** was reacted with *p*-toluenesulfonic acid in toluene under reflux to afford an intermediate which without isolation was converted directly to the acetal **17** *(Scheme 6)*. This illustrated that the ring opening had occurred exclusively to the exocyclic olefin which was required for our subsequent studies.

Cleavage of the double bond in **17** was accomplished by ozone and afforded the 16-keto-steroid analogue **18** in 46% overall yield from **13**. Compound **18** displayed a strong positive *Cotton* effect in its CD curve ($\Delta\varepsilon = +2.13$ at 300 nm, *Fig. 1*). This result is in contrast to the very intense negative *Cotton* effect typical of 16-keto steroids having 14α H-configuration, and therefore, in accord with the 14β H-configuration obtained from the X-ray study. Since the 17β-substituent, lying essentially in a nodal plane, makes little or no contribution to the *Cotton* effect, it is clear that the difference is entirely due to the configuration at C(14) [17].

Conclusions. – Hence we have shown that thujone may be converted into various steroid analogues all having the correct absolute configuration at all asymmetric C-atoms except C(14). Further studies are in progress to correct this defficiency are also well advanced for the conversion of **13** into cardiac active steroids in which the asymmetric C(14)-atom in the intermediates described above must carry an OH-group.

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Experimental Part

General Remarks. See [2].

4α-Isopropyl-7β-methyl-11-oxatetracyclo[8.4.0.0^{2,7}.0^{4,6}]tetradeca-1(10),2-dien-12-one (**4**). A solution of enone **2** (20.4 g, 0.1 mol) in *t*-BuOH/Et_2O 1:1 (*v/v;* 300 ml) was purged with Ar for 10 min, then cooled to 0°. KO*t*Bu (10.08 g, 0.09 mol) was added in one portion. After 10 min, a solution of methyl acrylate (10.32 g, 0.12 mol) in Et_2O (25 ml) was added dropwise within 2 h, then the mixture was warmed to r.t. and kept overnight. H_2O (50 ml) was added and the mixture evaporated. The residue was stirred with 2N NaOH (100 ml) for 1 h and then extracted with Et_2O (2 × 50 ml). The Et_2O-extracts were discarded, and the aq. solution was acidified to pH 1, then extracted with CH_2Cl_2 (3 × 50 ml). The combined extracts were dried (Na_2SO_4) and evaporated to leave a viscous yellow syrup of crude acid **6**. This syrup was dissolved in Ac_2O (100 ml), anh. NaOAc (16.4 g, 0.2 mol) was added and the mixture heated under reflux for 1 h. After evaporation of AcOH *in vacuo*, the residue was triturated with Et_2O (500 ml). The Et_2O extracts were evaporated and the residue chromatographed over silica gel to give

4 (11.6 g, 45%) as a colourless oil, $[\alpha]_D = +195°$ ($c = 1.1$, $CHCl_3$). UV (CH_3CN): 268.5 (4.02). IR (film): 1770. ^{1}H-NMR (400 MHz, $CDCl_3$): 0.53 (*t*, $J = 4$, 1 H, H_α–C(5)); 0.74 (*dd*, $J = 8, 4$, 1 H, H_β–C(5)); 0.88, 0.98 (2 *d*, $J = 7$, 6 H, $(CH_3)_2CH$); 1.05 (*s*, 3 H, H_3C–C(7)); 1.25 (*dd*, $J = 8, 4$, 1 H, H–C(6)); 1.40 (*sept.*, $J = 7$, 1 H, $(CH_3)_2CH$); 1.71 (*m*, 2 H); 2.22 (*m*, 2 H); 2.50 (*m*, 2 H); 2.66 (*m*, 2 H); 5.45 (*s*, 1 H, H–C(3)). ^{13}C-NMR (100.6 MHz, $CDCl_3$); 20.46, 20.61, 20.79, 20.94, 21.42, 25.24, 29.00, 31.75, 33.50, 35.62, 42.36, 108.28, 125.59, 147.00, 147.89, 169.71. MS: 258 (100, M^+). MS (HR): 258.1619 (M^+, calc. 258.1619).

$C_{17}H_{22}O_2$ (258.36) Calc. C 79.03 H 8.58% Found C 78.90 H 8.64%

4α-Isopropyl-7β-methyl-11-oxatetracyclo[8.4.0.0^{2,7}.0^{4,6}]tetradec-1(10)-en-12-one (**5**). A mixture of crude acid **6** (derived from 13.5 g of **2**, see synthesis of **4**) and 5% Pd/C (2 g) was dissolved in EtOAc/Et_3N 10:1 (550 ml) and stirred under H_2 for 20 h. The catalyst was removed by filtration and washed with hot EtOAc (100 ml). The combined filtrate and washings were evaporated. The residue was taken up in Ac_2O (60 ml), and anh. NaOAc (3.5 g, 42.7 mmol) was added. After heating under reflux for 2 h, the mixture was poured onto ice (400 g) and extracted with Et_2O (3 × 100 ml). The combined extracts were washed with H_2O (3 × 100 ml), dried ($MgSO_4$), and evaporated. The residue was chromatographed on silica gel to afford 7.27 g (45%) of **5** as a colourless oil, $[\alpha]_D = 89.4°$ ($c = 0.11$, $CHCl_3$). UV (EtOH): 222 (3.54). IR (film): 1750. ^{1}H-NMR (400 MHz, $CDCl_3$): 0.24 (*dd*, $J = 8, 5$, 1 H, H_β–C(5)); 0.42 (*dd*, $J = 5, 4$, H_α–C(5)); 0.88 (*dd*, $J = 8, 4$, 1 H, H–C(6)); 0.89, 0.93 (2 *d*, $J = 7$, 6 H, $(CH_3)_2CH$); 0.94 (*s*, 3 H, H_3C–C(7)); 1.31 (*sept.*, $J = 7$, 1 H, $(CH_3)_2CH$); 1.35–2.67 (*m*, 11 H). MS: 260 (17, M^+), 164 (100). MS (HR): 260.1778 (M^+, calc. 260.1776).

$C_{17}H_{24}O_2$ (260.36) Calc. C 78.42 H 9.29% Found C 78.21 H 9.33%

4α-Isopropyl-7β-methyltetracyclo[8.4.0.0^{2,7}.0^{4,6}]tetradeca-1,10-dien-12-one (**8a**). To a solution of **4** (0.230 g, 0.89 mmol) in Et_2O (10 ml) at 0° was added a solution of MeMgI (1.1 ml of 0.88M, 0.97 mmol) within 5 min. After 1 h, H_2O (5 ml) was added and the mixture evaporated. The residue was taken up in EtOH (10 ml) and 1N NaOH (5 ml) was added. After 3 h at r.t., the mixture was extracted with CH_2Cl_2 (3 × 25 ml). The combined extracts were dried (Na_2SO_4) and evaporated. Chromatography of the residue over silica gel gave **8a**, 0.131 g (57%), as a colourless oil, $[\alpha]_D = -278°$ ($c = 4.5$, $CHCl_3$). UV (EtOH): 305 (4.18). IR (film): 1660, 1640, 1585. ^{1}H-NMR (400 MHz, $CDCl_3$): 0.74 (*m*, 2 H, 2 H–C(5)); 0.86, 0.89 (2 *d*, $J = 7$, 6 H, $(CH_3)_2CH$); 0.96 (*s*, 3 H, H_3C–C(7)); 1.07 (*dd*, $J = 8, 4$, 1 H, H–C(6)); 1.29 (*sept.*, $J = 7$, 1 H, $(CH_3)_2CH$); 1.65 (*td*, $J = 13, 5$, 1 H, H_α–C(8)); 1.87 (*ddd*, $J = 13, 5, 2$, 1 H, H_β–C(8)); 2.28 (*d*, $J = 18$, 1 H, H_β–C(3)); 2.35–2.60 (*m*, 5 H); 2.64 (*d*, $J = 18$, 1 H, H_α–C(3)); 2.78 (*dddd*, $J = 17$, 12, 5, 2, 1 H, H_β–C(9)); 5.73 (*s*, 1 H, H–C(11)). ^{13}C-NMR (100.6 MHz, $CDCl_3$): 19.84, 20.00, 21.68, 21.79, 25.95, 27.64, 33.64, 35.05, 35.72, 35.82, 36.04, 37.21, 42.63, 122.11, 123.11, 155.66, 162.23, 192.10. MS: 256 (70, M^+), 213 (100). MS (HR): 256.1828 (M^+, calc. 256.1827).

$C_{18}H_{24}O$ (256.39) Calc. C 84.32 H 9.44% Found C 84.10 H 9.28%

4α-Isopropyl-7β,11-dimethyltetracyclo[8.4.0.0^{2,7}.0^{4,6}]tetradeca-1,10-dien-12-one (**8b**) was obtained in 36% yield in a similar manner to **8a** by using EtMgI. It was identified by comparison with an authentic sample [2].

Preparation of Grignard *Reagent* **7c**. A solution of 5-bromo-2-pentanone ethylene acetal (4.26 g, 20 mmol) in dry Et_2O (20 ml) was added to Mg turnings (0.72 g, 30 mmol). The reaction was initiated by breaking some of the Mg turnings to expose fresh surfaces. The reaction was maintained at 25–30° (internal temp.) until the reaction was complete, typically 30 min, then cooled to 0° prior to use.

11-(3′,3′-Ethylenedioxybutyl)-4α-isopropyl-7β-methyltetracyclo[8.4.0.0^{2,7}.0^{4,6}]tetradeca-1,10-dien-12-one (**8c**). To a solution of **4** (0.280 g, 1.09 mmol) in Et_2O (10 ml) maintained at 0° was added a solution of **7c**, dropwise until TLC showed that no **4** remained. H_2O (1 ml) was added and the Et_2O evaporated. The residue was taken up in EtOH (10 ml), and 2N NaOH (5 ml) was added. After 16 h, the mixture was neutralized and extracted with CH_2Cl_2 (3 × 25 ml). The combined extracts were dried (Na_2SO_4) and evaporated. The residue was chromatographed over silica gel to give **8c**, 0.258 g (65%), as a colourless oil, $[\alpha]_D = -254°$ ($c = 0.6$, $CHCl_3$). UV (EtOH): 310 (4.15). IR (film): 1660, 1630. ^{1}H-NMR (400 MHz, $CDCl_3$): 0.65 (*t*, $J = 5$, 1 H, H_α–C(5)); 0.73 (*m*, 1 H, H_β–C(5)); 0.86, 0.89 (2 *d*, $J = 7$, 6 H, $(CH_3)_2CH$); 0.92 (*s*, 3 H, H_3C–C(7)); 1.08 (*dd*, $J = 9, 5$, 1 H, H–C(6)); 1.20–1.33 (*m*, 4 H); 1.37 (*s*, 3 H, $H_3C(4')$); 1.52–1.76 (*m*, 4 H); 1.92 (*m*, 1 H); 2.26–2.71 (*m*, 6 H); 3.96 (*m*, 4 H, OCH_2CH_2O). MS: 370 (2, M^+), 87 (100). MS (HR): 370.2500 (M^+, calc. 370.2508).

$C_{24}H_{34}O_3$ (370.53) Calc. C 77.79 H 9.18% Found C 77.81 H 9.35%

7-(7',7'-Ethylenedioxy-3'-oxooctyl)-4α-isopropyl-1β-methyltricyclo[4.4.0.0^{2,4}]dec-6-en-8-one (**9**). To a solution of **4** (2.10 g, 8.14 mmol) in Et_2O (80 ml) maintained at 0° was added a solution of **7c** (34.5 ml) within 10 min. At this time, TLC analysis indicated that **4** had been consumed. H_2O (10 ml) was added and the Et_2O evaporated from the mixture. The residue was taken up in EtOH (100 ml) and 1N NaOH (10 ml) added. After 10 min, the mixture was neutralized and evaporated. The residue was extracted with CH_2Cl_2 (3×50 ml). The combined extracts were dried (Na_2SO_4) and evaporated. Chromatography of the residue gave **9**, 1.96 g (62%), as a colourless oil, $[\alpha]_D = 45°$ ($c = 0.865$, $CHCl_3$). UV (EtOH): 247 (3.98). IR (film): 1720, 1660. ^{1}H-NMR (400 MHz, $CDCl_3$): 0.78 (*m*, 2H, $H_2C(3)$); 0.89, 0.91 (2 *d*, $J = 7$, 6H, $(CH_3)_2CH$); 1.07 (*s*, 3H, $H_3C-C(1)$; 1.09 (*m*, 1H, H–C(2)); 1.32 (*s*, 3H, $H_3C(8')$); 1.63 (*m*, 4H); 2.04 (*m*, 2H); 2.27–2.63 (*m*, 10H); 2.78 (*dd*, $J = 18$, 2, 1H, $H_a-C(5)$); 3.97 (*m*, 4H, OCH_2CH_2O). MS: 388 (1, M^+), 87 (100). MS (HR): 388.2630 (M^+, calc. 388.2614).

$C_{24}H_{36}O_4$ (388.55) Calc. C 74.18 H 9.34% Found C 74.45 H 9.45%

11-(3',3'-Ethylenedioxybutyl)4α-isopropyl-7β-methyltetracyclo[8.4.0.0^{2,7}.0^{4,6}]tetradec-10-en-12-one (**3**). A solution of **9** (1.45 g, 3.74 mmol) in EtOAc (100 ml) containing Et_3N (2 ml) and 10% Pd/C (0.2 g) was stirred under H_2 for 16 h. The catalyst was removed by filtration and washed with hot EtOAc (50 ml). The combined filtrate and washings were evaporated. The residue was taken up in EtOH (50 ml) and 1N NaOH added (10 ml). The mixture was heated under reflux for 1 h, then cooled, neutralized, and extracted with CH_2Cl_2 (3×50 ml). The combined extracts were dried (Na_2SO_4) and evaporated. The residue was chromatographed over silica gel to afford **3**, 0.956 g (69%), as a colourless oil, $[\alpha]_D = +20.9°$ ($c = 1$, $CHCl_3$). UV (EtOH): 250 (4.16). IR (film): 1665. ^{1}H-NMR (400 MHz, $CDCl_3$): 0.24 (*dd*, $J = 8$, 5, 1H, $H_\beta-C(5)$); 0.33 (*t*, $J = 5$, 1H, $H_\alpha-C(5)$); 0.85–1.00 (*m*, 7H); 1.09 (*s*, 3H, $H_3C-C(7)$); 1.24–2.60 (*m*, 20H); 3.97 (*m*, 4H, OCH_2CH_2O). MS: 372 (100, M^+). MS (HR): 372.2659 (M^+, calc. 372.2664).

$C_{24}H_{36}O_3$ (372.55) Calc. C 77.37 H 9.68% Found C 77.23 H 9.83%

Enone **3** via **5**. To a solution of **5** (4.0 g, 15.38 mmol) in dry Et_2O (100 ml) maintained at 0° was added a solution of **7c**, dropwise until no **5** remained (44 ml within 10 min). H_2O (200 ml) was added and the mixture extracted with Et_2O (3×100 ml). The combined extracts were dried ($MgSO_4$) and evaporated. The residue was taken up in EtOH (200 ml) and 1N NaOH (50 ml) added. The mixture was stirred at r.t. for 20 min, then heated under reflux for 30 min. The cooled mixture was diluted with H_2O (500 ml) and extracted with Et_2O (4×100 ml). The combined extracts were washed with H_2O (3×150 ml), then dried ($MgSO_4$) and evaporated. The residue was chromatographed to give 2.06 g (36%) of **3** which was identical with a previously characterized sample.

4α-Isopropyl-1β-methyl-8-oxotricyclo[4.4.0.0^{2,4}]decen-6-ene-7-propionic Acid (**6**). Although it was possible to separate **6** from the crude mixture from the reaction of **2** with methyl acrylate, it was found to be more convenient to prepare **6** by hydrolysis of **4**: To a solution of **4** (1.032 g, 4 mmol) in EtOH (25 ml) was added 2N NaOH (5 ml). After 30 min, the mixture was acidified and extracted with CH_2Cl_2 (3×50 ml). The combined extracts were dried and evaporated. Chromatography of the residue gave pure **6** as a colourless syrup, 1.08 g (98%), $[\alpha]_D = 69.5°$ ($c = 1.41$, $CHCl_3$). UV (EtOH): 245 (4.01). IR (film): 1695, 1620. ^{1}H-NMR (400 MHz, $CDCl_3$): 0.78 (*m*, 2H, $H_2C(3)$); 0.89, 0.91 (2 *d*, $J = 7$, 6H, $(CH_3)_2CH$); 1.08 (*s*, 3H, $H_3C-C(1)$); 1.09 (*dd*, $J = 8$, 4, 1H, H–C(2)); 1.31 (*sept.*, $J = 7$, 1H, $(CH_3)_2CH$); 2.03 (*m*, 2H); 2.29–2.66 (*m*, 10H); 2.79 (*d*, $J = 18$, 1H, H–C(5)). MS: 276 (62, M^+), 215 (100). MS (HR): 276.1724 (M^+, calc. 276.1725).

$C_{17}H_{24}O_3$ (276.38) Calc. C 73.87 H 8.75% Found C 73.85 H 8.70%

Synthesis of **5** via Birch *Reduction of* **6**. A solution of **6** (0.54 g, 1.96 mmol) and *t*-BuOH (1.85 g, 25 mmol) in dry THF (5 ml) was added over 2 min to a solution of Li (0.35 g, 50 mmol) in anh. $EtNH_2$ (50 ml) maintained at −78°. After 15 min, H_2O (5 ml) was added and the mixture warmed to r.t. HCl (1N, 100 ml) was added to the residue which was then extracted with CH_2Cl_2 (3×50 ml). The combined extracts were dried (Na_2SO_4) and evaporated to leave 0.55 g of colourless glass. A portion of this material (0.50 g) was treated with Ac_2O (5 ml) and anh. NaOAc (0.1 g, 1.22 mmol) under reflux for 2 h. The mixture was cooled, poured into H_2O (50 ml) and extracted with CH_2Cl_2 (3×50 ml). The combined extracts were dried (Na_2SO_4) and evaporated. Chromatography of the residue afforded **5**, 0.309 g (68%), as a colourless oil. This sample was identical in all respects to a previously characterized sample.

16α-Isopropyl-16,17β-dihydro-3'H-cycloprop[16,17]-14β-androst-4-en-3-one (**13**). A solution of **3** (0.84 g, 2.26 mmol) and *t*-BuOH (0.133 g, 1.8 mmol) in dry THF (10 ml) was added within 5 min to a

solution of Li (0.09 g, 12.8 mmol) in liq. NH_3 (100 ml) maintained at $-78°$. After 20 min, a solution of CH_3I (6 ml, *ca.* 90 mmol) in dry THF (10 ml) was added over 5 min. After 3 h at $-78°$, the mixture was left overnight at r.t. to allow the NH_3 to evaporate. H_2O (100 ml) was added to the residue and the mixture extracted with Et_2O (3×50 ml). The combined extracts were evaporated and the residue dissolved in EtOH (25 ml). To this solution was added 1N HCl (10 ml). After stirring at r.t. for 1 h, solid KOH was added until the pH was >12. After 1 h, the mixture was neutralized and extracted with CH_2Cl_2 (3×50 ml). The combined extracts were dried (Na_2SO_4) and evaporated. The residue was chromatographed over silica gel to give 0.580 g of **13/14**. Crystallization from iso-octane afforded **13**, 0.44 g (60%), as colourless crystals, m.p. 81–82°, $[\alpha]_D = 136°$ ($c = 1.085$, $CHCl_3$). UV (CH_3CN): 237 (4.21). CD (MeCN, $c = 5.58\times 10^{-5}$): 324 ($\Delta\varepsilon = -2.04$). IR ($CHCl_3$): 1670. ^{1}H-NMR (400 MHz, $CDCl_3$): 0.10 (*dd*, $J = 6$, 4, 1 H, H_β–C(3′)); 0.39 (*t*, $J = 4$, 1 H, H_α–C(3′)); 0.82 (*dd*, $J = 6$, 4, 1 H, H–C(17)); 0.88, 0.93 (2 *d*, $J = 7$, 6 H, $(CH_3)_2CH$); 0.99 (*s*, 3 H, $H_3C(18)$); 1.02–2.48 (*m*, 21 H); 5.72 (*s*, 1 H, H–C(4)). MS: 326 (100, M^+). MS (HR): 326.2612 (M^+, calc. 326.2609).

$C_{23}H_{34}O$ (326.53) Calc. C 84.60 H 10.50% Found C 84.80 H 10.45%

Chromatography of the mother liquors followed by crystallization from Et_2O/hexane gave 0.070 g (10%) of the 19-norsteroid **14**.

*16α-Isopropyl-16,17β-dihydro-3′*H*-cycloprop[16,17]-19-nor-14β-androst-4-en-3-one* (**14**). A solution of **3** (0.325 g, 0.87 mmol) and *t*-BuOH (1.11 g, 15 mmol) in dry THF (3 ml) was added over 2 min to a solution of Li (0.21 g, 30 mmol) in anh. $EtNH_2$ (35 ml) maintained at $-78°$. After 30 min, H_2O (2 ml) was added and the mixture was allowed to warm to r.t. The residue was extracted with Et_2O (3×25 ml). The combined extracts were dried (Na_2SO_4) and evaporated to leave 0.327 g of colourless oil. Thereof, a portion (0.300 g) was dissolved in EtOH (12 ml) and 1N HCl (6 ml) added. After 1 h, solid KOH was added until pH >12. After 1 h, the mixture was neutralized and extracted with CH_2Cl_2 (3×25 ml). The combined extracts were dried (Na_2SO_4) and evaporated, and the residue chromatographed over silica gel to afford 0.149 g (61%) of **14** as a colourless solid. Crystallization from Et_2O/hexane gave an analytical sample, m.p. 128–129°, $[\alpha]_D = 72°$ ($c = 0.975$, $CHCl_3$). UV 239 (4.04). CD (EtOH, $c = 4.57\times 10^{-5}$): 318 (−2.36). IR ($CHCl_3$): 1660, 1620. ^{1}H-NMR (400 MHz, $CDCl_3$): 0.12 (*dd*, $J = 6$, 4, 1 H, H_β–C(3′)); 0.42 (*t*, $J = 4$, 1 H, H_α–C(3′)); 0.84 (*dd*, $J = 6$, 4, 1 H, H–C(17)); 0.87, 0.94 (2 *d*, $J = 7$, 6 H, $(CH_3)_2CH$); 1.00 (*s*, 3 H, $H_3C(18)$); 1.02–2.50 (*m*, 19 H); 5.79 (*s*, 1 H, H–C(4)). MS: 312 (100, M^+). MS (HR): 312.2453 (M^+, calc. 312.2453).

$C_{22}H_{32}O$ (312.50) Calc. C 84.55 H 10.32% Found C 84.39 H 10.20%

*16α-Isopropyl-16,17β-dihydro-3′*H*-cycloprop[16,17]-19-nor-14β-androsta-4,9-dien-3-one* (**15**). A solution of **3** (0.55 g, 1.48 mmol) in EtOH (10 ml) and 1N HCl (5 ml) was stirred at r.t. for 1 h. The solution was neutralized and extracted with CH_2Cl_2 (3×35 ml). The combined extracts were dried (Na_2SO_4) and evaporated. The residue was taken up in toluene (20 ml), and 0.5M NaO(*t*-pentyl) in *t*-pentyl alcohol (5 ml) was added. After 90 min, the mixture was washed with H_2O (5×25 ml), dried (Na_2SO_4) and evaporated. Chromatography of the residue gave 0.243 g (53%) of **15** as a colourless oil, $[\alpha]_D = -86.3°$ ($c = 1$, $CDCl_3$). UV 304 (4.25). IR (film): 1660. ^{1}H-NMR (400 MHz, $CDCl_3$): 0.20 (*dd*, $J = 8$, 5, 1 H, H_β–C(3′)); 0.34 (*t*, $J = 5$, 1 H, H_α–C(3′)); 0.85, 0.93 (2 *d*, $J = 7$, 6 H, $(CH_3)_2CH$); 0.87 (*dd*, $J = 8$, 5, 1 H, H–C(17)); 1.09 (*s*, 3 H, $H_3C(18)$); 1.24–1.65 (*m*, 7 H); 1.75 (*m*, 1 H); 2.08 (*m*, 1 H); 2.30–2.64 (*m*, 7 H); 2.82 (*dt*, $J = 15$, 6, 1 H); 5.70 (*s*, 1 H, H–C(4)). MS: 310 (100, M^+). MS (HR): 310.2296 (M^+, calc. 310.2296).

*16α-Isopropyl-16,17β-dihydro-3′*H*-cycloprop[16,17]-5β14β-androstan-3-one* (**16**). A solution of **13** (0.475 g, 1.46 mmol) in 2-propanol (50 ml) containing 10% Pd/$CaCO_3$ (50 mg) was stirred under H_2 for 30 min. The catalyst was removed by filtration and washed with hot 2-propanol (50 ml). The combined filtrate and washings were evaporated to leave a colourless oil. The crude product was not routinely purified but used directly in the synthesis of **17** and **18**. Chromatography of crude **16** gave an analytical sample, $[\alpha]_D = 103°$ ($c = 1.05$, $CHCl_3$). CD (MeCN, $c = 3.25\times 10^{-3}$): 291 (−0.83). IR (film): 1715. ^{1}H-NMR (400 MHz, $CDCl_3$): 0.11 (*dd*, $J = 8$, 4, 1 H, H_β–C(3′)); 0.39 (*t*, $J = 4$, 1 H, H_α–C(3′)); 0.83 (*dd*, $J = 8$, 4, 1 H, H–C(17)); 0.87, 0.96 (2 *d*, $J = 7$, 6 H, $(CH_3)_2CH$); 0.98 (*s*, 6 H, $H_3C(18)$, $H_3C(19)$); 1.03–2.48 (*m*, 20 H); 2.70 (*t*, $J = 14$, 1 H, H_β–C(4)). MS: 328 (44, M^+), 285 (100). MS (HR): 328.2769 (M^+, calc. 328.2766).

$C_{23}H_{36}O$ (328.54) Calc. C 84.08 H 11.04% Found C 84.12 H 11.10%

Table 2. *Final Positional* (Fractional × 10^4) *Parameters with Estimated Standard Deviations in Parentheses*

Atom	*x*	*y*	*z*
O	7567 (3)	– 1113 (3)	– 1386 (3)
C(1)	5624 (4)	– 1812 (4)	517 (3)
C(2)	6740 (4)	– 1990 (4)	– 68 (3)
C(3)	7024 (4)	– 1023 (4)	– 653 (4)
C(4)	6672 (4)	28 (4)	– 292 (3)
C(5)	6103 (3)	172 (4)	530 (3)
C(6)	5928 (4)	1292 (4)	927 (3)
C(7)	4634 (4)	1486 (3)	1203 (3)
C(8)	4219 (4)	614 (3)	1891 (3)
C(9)	4366 (3)	– 529 (3)	1470 (3)
C(10)	5641 (3)	– 778 (3)	1113 (3)
C(11)	3881 (4)	– 1390 (4)	2136 (3)
C(12)	2595 (4)	– 1167 (4)	2415 (3)
C(13)	2401 (4)	– 43 (4)	2868 (3)
C(14)	2956 (4)	849 (3)	2250 (3)
C(15)	2005 (3)	1090 (3)	1515 (3)
C(16)	817 (4)	879 (3)	1997 (3)
C(17)	1081 (4)	229 (4)	2859 (3)
C(18)	2921 (5)	– 34 (5)	3859 (3)
C(19)	6541 (4)	– 923 (4)	1934 (3)
C(20)	700 (4)	1393 (4)	2942 (4)
C(21)	– 301 (4)	680 (4)	1429 (3)
C(22)	– 224 (4)	– 367 (4)	871 (4)
C(23)	– 560 (5)	1651 (5)	778 (4)

Table 3. *Final Anisotropic Thermal Parameters* ($U_{ij} \times 10^3$ *Å*^{2})[a] *and their Estimated Standard Deviations*

Atom	U_{11}	U_{22}	U_{33}	U_{12}	U_{13}	U_{23}
O	113 (3)	109 (3)	70 (2)	4 (3)	30 (2)	– 12 (2)
C(1)	78 (4)	51 (3)	63 (3)	– 5 (3)	– 5 (3)	– 7 (3)
C(2)	68 (3)	61 (3)	70 (3)	4 (3)	3 (3)	– 12 (3)
C(3)	63 (3)	77 (4)	56 (3)	0 (3)	– 2 (3)	– 1 (3)
C(4)	56 (3)	61 (3)	51 (3)	4 (3)	1 (3)	8 (3)
C(5)	39 (2)	49 (3)	62 (3)	– 4 (2)	– 10 (3)	3 (3)
C(6)	53 (3)	53 (3)	71 (3)	– 9 (2)	0 (3)	5 (3)
C(7)	56 (3)	45 (3)	65 (3)	– 8 (2)	6 (3)	– 2 (2)
C(8)	53 (3)	50 (3)	42 (3)	– 5 (2)	– 8 (2)	– 6 (2)
C(9)	48 (3)	41 (2)	43 (3)	– 6 (2)	– 5 (2)	7 (2)
C(10)	51 (3)	45 (3)	51 (3)	– 5 (2)	– 6 (2)	– 2 (2)
C(11)	59 (3)	57 (3)	59 (3)	– 2 (3)	– 2 (3)	8 (3)
C(12)	69 (3)	58 (3)	55 (3)	– 13 (3)	1 (3)	18 (3)
C(13)	71 (3)	68 (3)	30 (3)	– 14 (3)	3 (2)	2 (3)
C(14)	61 (3)	54 (3)	36 (3)	– 13 (2)	3 (2)	– 13 (2)
C(15)	46 (2)	56 (3)	50 (3)	– 1 (2)	11 (2)	2 (2)
C(16)	57 (3)	58 (3)	52 (3)	– 4 (3)	17 (3)	– 8 (3)
C(17)	71 (3)	74 (4)	45 (3)	– 8 (3)	22 (3)	0 (3)
C(18)	113 (4)	124 (5)	39 (3)	– 15 (4)	– 5 (3)	3 (3)
C(19)	59 (3)	64 (3)	62 (3)	4 (3)	– 5 (3)	6 (3)
C(20)	85 (4)	84 (4)	75 (4)	– 1 (3)	32 (3)	– 26 (3)
C(21)	46 (3)	79 (4)	71 (4)	– 2 (3)	16 (3)	7 (3)
C(22)	57 (3)	100 (4)	75 (4)	– 10 (3)	– 10 (3)	– 6 (3)
C(23)	70 (4)	111 (5)	122 (5)	8 (4)	4 (4)	25 (4)

[a]) The anisotropic thermal parameters employed in the refinement are U_{ij} in the expression:

$$f = f^{\circ} \exp(-2\pi^2 \Sigma \Sigma U_{ij} h_i h_j a_i^* a_j^*)$$

16-Isopropylidene-17β-methyl-5β,14β-androstan-3-one ethylene acetal (**17**). To a solution of crude **16** (from hydrogenation of 0.475 g (1.46 mmol) of **13**) in toluene (100 ml) was added *p*-toluenesulfonic acid (0.1 g, 0.52 mmol). The mixture was heated under reflux for 1 h when ethylene glycol (5 ml) and a *Dean-Stark* trap were added. Heating was continued for 3 h. The reaction was cooled, washed with 5% $NaHCO_3$ (25 ml), dried (Na_2SO_4) and evaporated. The residue was chromatographed on silica gel to give **17** as a colourless foam, 0.415 g (77% from **13**), $[\alpha]_D = 60.8°$ ($c = 0.255$, $CHCl_3$). ^{1}H-NMR (400 MHz, $CDCl_3$): 0.85 (*d*, $J = 7$, 3 H, $H_3C(20)$); 0.90 (*s*, 3 H, $H_3C(18)$); 0.94 (*s*, 3 H, $H_3C(19)$); 0.98–2.32 (*m*, 27 H); 3.94 (*s*, 4 H, OCH_2CH_2O). MS: 372 (100, M^+). MS (HR): 372.3043 (M^+, calc. 372.3029).

$C_{25}H_{40}O_2$ (372.60) Calc. C 80.59 H 10.82% Found C 80.26 H 10.74%

17β-Methyl-5β,14β-androstane-3,16-dione 3,3-ethylene acetal (**18**). O_2/O_3 was bubbled through a solution of **17** (0.415 g, 1.12 mmol) in EtOAc/MeOH 15:1 (32 ml) maintained at –78° until the solution was pale blue. The solution was purged with Ar whilst warming slowly (30 min) to r.t.; sat. aq. Na_2SO_3 (50 ml) was added and the mixture stirred for 16 h. The mixture was extracted with CH_2Cl_2 (3 × 50 ml). The combined extracts were dried (Na_2SO_4) and evaporated, and the residue chromatographed over silica gel to afford **18**, 0.227 g (59%), as a colourless solid. Crystallization from Et_2O gave an analytical sample, m.p. 125–126°, $[\alpha]_D = 94°$ ($c = 0.5$, $CHCl_3$). CD (MeCN, $c = 2.39 \times 10^{-3}$): 306 (+2.13), 302 (+2.04), 298 (+2.10). IR ($CHCl_3$): 1730. ^{1}H-NMR (400 MHz, $CDCl_3$): 0.95 (*s*, 3 H, $H_3C(18)$); 0.99 (*d*, $J = 7$, 3 H, $H_3C(20)$); 1.04 (*s*, 3 H, $H_3C(19)$); 1.10–2.32 (*m*, 21 H); 3.92 (*m*, 4 H, OCH_2CH_2O). MS: 346 (13, M^+), 99 (100). MS (HR): 346.2507 (M^+, calc. 346.2508).

$C_{22}H_{34}O_3$ (346.51) Calc. C 76.24 H 9.89% Found C 76.10 H 9.87%

X-ray Crystallographic Analysis of **13**. A crystal *ca.* 0.20 × 0.40 × 0.55 mm was used. Unit-cell parameters were calculated from θ-values for 25 reflections ($\theta = 12.5 - 17.5°$) measured on a diffractometer with Mo$K\alpha_1$ radiation ($\lambda = 0.70930$ Å). Crystal data at 22° are: $C_{23}H_{34}O$, mol.w. = 326.52. Orthorhombic: $a = 11.2024$ (8), $b = 12.2162$ (8), $c = 14.3775$ (10) Å, $V = 1967.5$ (2) Å^3, $Z = 4$, $\rho_c = 1.102$ gcm^{-3}, $F(000) = 720$, μ(Mo$K\alpha$) = 0.60 cm^{-1}. Absent reflections: $h00$, $h \neq 2n$, $0k0$, $k \neq 2n$, and $00l$, $l \neq 2n$, uniquely indicate the space group $P2_12_12_1$ (D_2^4, No. 19).

Intensities were measured with graphite-monochromated Mo$K\alpha$ radiation ($\lambda = 0.71073$ Å) on an *Enraf-Nonius-CAD4-F* diffractometer. An ω-2θ scan at 1.26–10.06° · min^{-1} over a range of (0.70 + 0.35 · tanθ) degrees in ω (extended by 25% on both sides for background measurement) was employed. Data were measured to $2\theta = 50°$. The intensities of 3 check reflections, measured every 3600 s throughout the data collection, remained constant to within ±4%. Of the 1978 independent reflections measured, 881 (44.5%) had intensities greater than $3\sigma(I)$ above background where $\sigma^2(I) = s + 2B + (0.04(s-B))^2$ with s and B being the normalized scan and background counts, respectively. No absorption correction was made in view of the low value of μ.

The structure was solved by direct methods, all 24 non-H-atoms being positioned from an *E*-map. After full-matrix leastsquares refinement of the C- and O-atoms with anisotropic thermal parameters to $R = 0.096$, a difference map clearly revealed all 34 H-atoms. Due to the paucity of data, the H-atoms were placed in idealized positions (C–H = 0.98 Å, $B_H = B_c + 1.0$) and included as fixed atoms in subsequent cycles of refinement. H-coordinates and thermal parameters were recalculated after each cycle of refinement. The scattering factors of reference [18] were used for non-hydrogen atoms and those of reference [19] for H-atoms. The weighting scheme, $w = 1/\sigma^2(F)$ where $\sigma^2(F)$ is derived from the previously defined $\sigma^2(I)$, gave uniform average values of $w(|F_o| - |F_c|)^2$ over ranges of $|F_o|$ and $\sin\theta/\lambda$ and was employed in the final stages of refinement. Convergence was reached at $R = 0.034$ and $R_w = 0.038$ for 881 reflections with $I \geq 3\sigma(I)$. The function minimized was $\Sigma w(|F_o| - |F_c|)^2$, $R = \Sigma \| F_o| - |F_c \| / \Sigma |F_o|$, and $R_w = (\Sigma w(|F_o| - |F_c|^2) / \Sigma w(|F_o|^2)^{1/2}$.

On the final cycle of refinement the mean and maximum parameter shifts corresponded to 0.07 and 0.34σ, respectively. The mean error in an observation of unit weight was 1.514. A final difference map showed no unusual features. The final positional and thermal parameters for the non-H-atoms appear in *Tables 2* and *3*, respectively. The ellipsoids of thermal motion for the non-H-atoms are shown in *Fig. 2*. The thermal motion has been analyzed in terms of the rigid-body modes of translation, libration, and screw-motion [20]. The rms-standard error in the temperature factors σU_{ij} (derived from the least-squares analysis) is 0.0030 Å^2. Analysis of all non-H-atoms gave rms $\Delta U_{ij} = 0.0063$ Å^2 and physically reasonable rigid-body parameters. The bond lengths have been corrected for libration,

using shape parameters q^2 of 0.08 for all atoms [20] [21]. Corrected bond distances appear in *Table 4* along with the uncorrected values. Calculated H-coordinates and isotropic thermal parameters, bond angles, intraannular torsion angles, and measured and calculated structure factor amplitudes are available on request from Dr. *J. Trotter.*

Table 4. *Bond Lengths (Å) with Estimated Standard Deviations in Parentheses*

Bond	Uncorr.	Corr.	Bond	Uncorr.	Corr.
O–C(3)	1.223 (5)	1.224	C(10)–C(19)	1.563 (6)	1.566
C(1)–C(2)	1.523 (6)	1.525	C(11)–C(12)	1.520 (6)	1.522
C(1)–C(10)	1.526 (6)	1.531	C(12)–C(13)	1.535 (6)	1.539
C(2)–C(3)	1.484 (6)	1.489	C(13)–C(14)	1.537 (6)	1.541
C(3)–C(4)	1.439 (6)	1.443	C(13)–C(17)	1.516 (7)	1.517
C(4)–C(5)	1.355 (6)	1.358	C(13)–C(18)	1.539 (6)	1.540
C(5)–C(6)	1.495 (6)	1.500	C(14)–C(15)	1.530 (5)	1.534
C(5)–C(10)	1.522 (6)	1.528	C(15)–C(16)	1.522 (5)	1.523
C(6)–C(7)	1.523 (6)	1.525	C(16)–C(17)	1.501 (6)	1.506
C(7)–C(8)	1.526 (6)	1.531	C(16)–C(20)	1.503 (6)	1.507
C(8)–C(9)	1.531 (5)	1.537	C(16)–C(21)	1.515 (6)	1.518
C(8)–C(14)	1.533 (6)	1.536	C(17)–C(20)	1.490 (6)	1.493
C(9)–C(10)	1.548 (5)	1.551	C(21)–C(22)	1.513 (7)	1.516
C(9)–C(11)	1.523 (5)	1.527	C(21)–C(23)	1.539 (7)	1.540

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