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STEROID PHOTOCHEMISTRY

SINGLET PHOTOCYCLOADDITION OF A 3-KETO-4,6-DIENIC STEROID TO CYCLIC AND ACYCLIC OLEFINS

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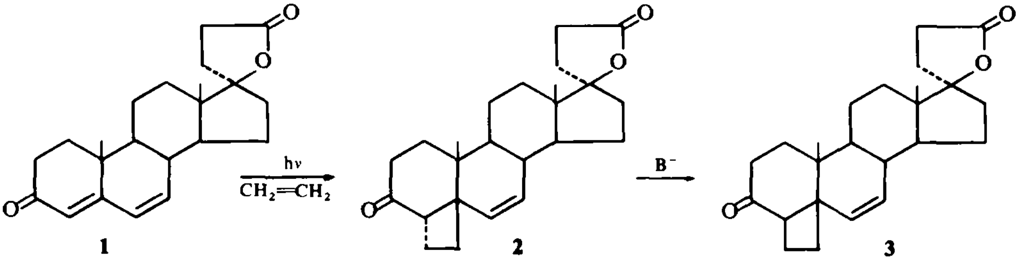
Abstract—The photochemical cycloaddition of linear dienone steroid **1** to various substituted and unsubstituted ethylenes, cyclopentenes, cyclohexene and dihydropyran yields only 4α,5β-*trans*-substituted cyclobutanes as the head-to-tail adducts. On the basis of regio- and stereospecific addition and the non-quenching by dienic quenchers, the photocycloaddition is ascribed to the singlet excited state of the dienone.

INTRODUCTION

WHILE there has been extensive investigation in the addition of excited enones to olefins, very little is known about the addition of excited dienones to olefins.[1] Rubin reported a few years ago on the formation of only one cyclobutane isomer in addition of Δ^6-testosterone propionate to cyclopentene, as well as stereospecific formation of only one dimer.[2] His studies further indicated that simple heteroannular dienones did not dimerize or cycloadd but simply polymerized. Recently the full paper was published, assigning the 4α,5β-stereochemistry to the cyclopentene adduct on the basis of ORD/CD and correlation with the cyclopentene adducts of testosterone propionate.[3] Fried has investigated the addition of ethylene and maleic anhydride to Δ^6-testosterone acetate.[4] Ethylene was reported to add to give two adducts in low yield which were assigned the 4β,5α- and the 4α,5α-configurations. Maleic anhydride added predominantly across the steroidal 6,7-double bond, either by excitation of a complex or addition of excited maleic anhydride to the more electron rich 6,7-double bond.[4] Rubin was unable to repeat Frieds addition of ethylene to Δ^6-testosterone propionate. We should like to present here our results on the photocycloaddition of the $\Delta^{4,6}$-3-keto steroid **1**, Aldadiene to various cyclic and acyclic olefins and to indicate that the stereochemical and orientation selectivity of the addition is the result of the dienone in its singlet excited state. The photocycloaddition proceeding from the singlet is very novel, and apparently unique, since photocycloadditions are generally triplet reactions.[1a]

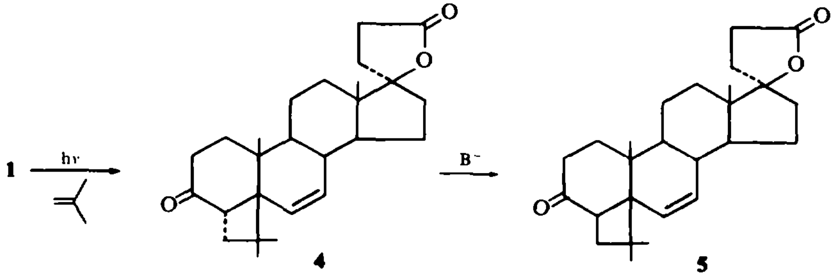
RESULTS

Ethylene. The photocycloaddition of **1** to ethylene proceeds but very slowly, allowing secondary reactions to occur and results in a low yield (6%) of the cyclobutane adduct. The only compound isolated (**2**) was assigned the *trans*-4α,5β-cyclobutane configuration on the basis of ORD/CD measurements, and the epimerization to the *cis*-4β,5β-cyclobutane (**3**). The ORD spectrum of **2** showed a strong positive Cotton effect, (a = + 228) in agreement with the 6,7-dihydroisomer where both *cis* and *trans* isomers were obtained.[5] Additionally *in situ* NaOMe epimerization generated the *cis*-4β,5β-isomer with a negative Cotton effect and a molecular amplitude of *a* = − 129. The 4β,5β-isomer was not isolated as a crystalline compound, but was generated by treating the MeOH ORD solution with NaOMe for 18 hr and redetermining the spectra.

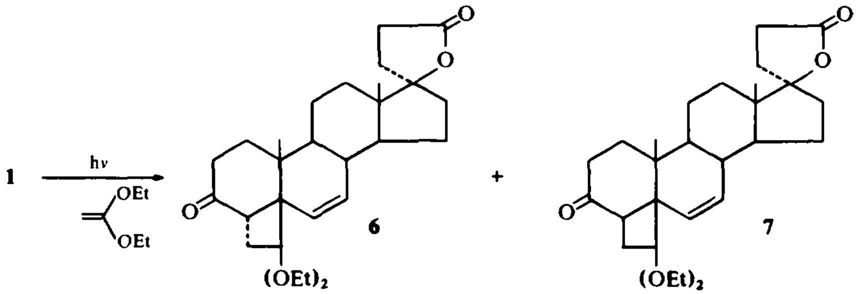


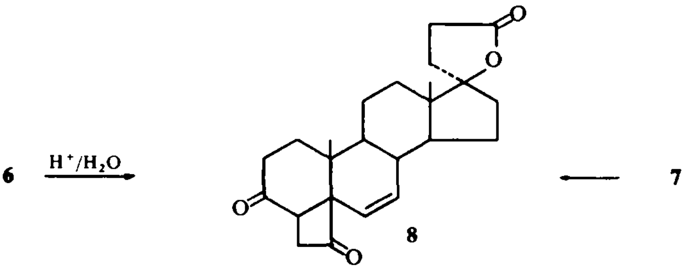
There was no difference between the spectra of the *cis*-4β,5β-isomers generated by this method, and spectra determined from the crystalline *cis*-4β,5β-isomers. It is necessary to allow sufficient time for complete epimerization. Since the *trans*-4α,5β-isomer has a much stronger and opposite rotation, the presence of a small amount of the *trans*-4α,5β-isomer in the solution of the 4β,5β-isomer will result in a weak positive ORD/CD spectra.

Isobutylene. The addition of **1** to isobutylene proceeded approximately twenty times faster than the addition of ethylene to produce a single cyclobutane adduct (**4**) in 90% yield. The cycloadduct showed a strong positive Cotton effect characteristic of the *trans*-fused isomers (a = + 317) and in addition, the 4β-proton appeared as the X portion of an ABX spectrum; indicating head-to-tail addition. NaOMe in MeOH gave the *cis*-4β,5β-isomer (**5**), which was characterized by a negative Cotton effect with a molecular amplitude of a = − 81.

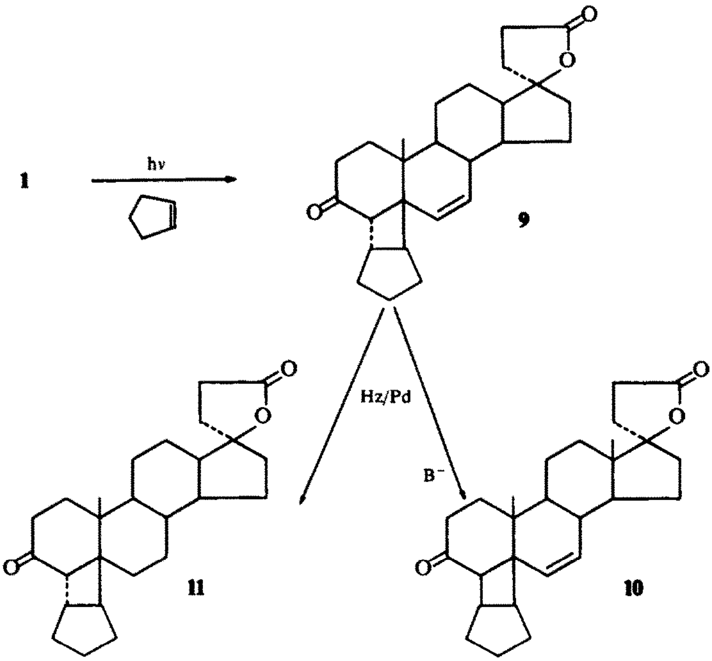


1,1-*Diethoxyethylene.* The addition of **1** to diethoxyethylene gave a 70% yield of two adducts **6** and **7** in a ratio of 3 : 1, which were separated by column chromatography. The first adduct eluted was the *cis*-4β,5β-cyclobutane ketal (**7**) which was characterized by a negative Cotton effect (a = − 78), and inertness to methanolic NaOMe. The major isomer (**6**) was the *trans*-4α,5β-ketal identified by the strongly positive Cotton effect (a = + 320), and the *in situ* epimerization to *cis*-4β,5β-isomer (7). That **1** added diethoxyethylene to form the head-to-tail adduct may be inferred from the isobutylene adduct **4**, but was proved by hydrolysis to the single cyclobutanone **8**, from either **6** or **7**. Since **8** could be formed from either **6** or **7** by treatment with HCl in aqueous AcOH, this suggests the more stable *cis*-4β,5β-epimer. The lack of reaction with $FeCl_3$ and an ABX-spectrum in the NMR, demonstrate that diethoxyethylene added in head-to-tail fashion. The formation of stable ketals from **1** may be contrasted with the Δ^4-3-ketone (6-dihydro **1**) where only an enol ether and the two *cis*-cyclobutanones were formed.[5] The isolation of **6** and **7** and the ORD/CD curves of **8**, together with other physical measurements, allowed accurate assignment of stereochemistry to the two epimeric cyclobutanones isolated from the addition of diethoxyethylene to 6-dihydro **1**.[5]

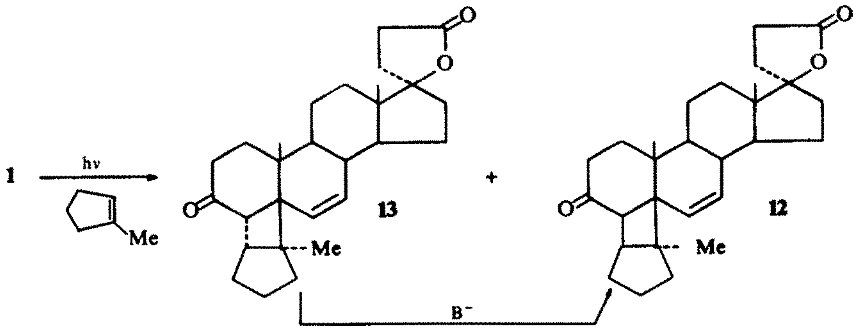




Cyclopentene. The addition of Δ^6-testosterone propionate to cyclopentene has previously been studied by Rubin.[2, 3] The photocycloaddition of **1** to cyclopentene produced the *trans*-4α,5β-cyclobutane (**9**), in agreement with Rubin's findings. Compound **9** possessed the strong positive Cotton effect (a = + 302), and the 19-angular Me group was shifted significantly downfield (1·23 δ) from the 18-Me group (1·00 δ). Epimerization proceeded slowly to give the *cis*-4β,5β-cyclobutane (**10**) where the 19-Me group has shifted upfield (0·95 δ) of the 18-Me group. This positioning of the angular 19-Me group of the *trans*-adducts downfield of the angular 18-Me group is characteristic. The 4β-proton of **9** appeared as part of broad multiplet at 3·03 δ, which was resolved in perdeuteriobenzene to a doublet at 2·71 δ (J = 7·6 Hz).[6] Hydrogenation of **9** in dioxane over Pd/C gave the 6,7-dihydro-*trans*-isomer (**11**) which had previously been isolated from the addition of the 6,7-dihydro derivative of **1** to cyclopentene. This allowed correlation of the adducts from **1** with the previously studied Δ^4-3-one steroid and indicated that the Δ^6-double bond made no contribution to the ORD/CD spectra.



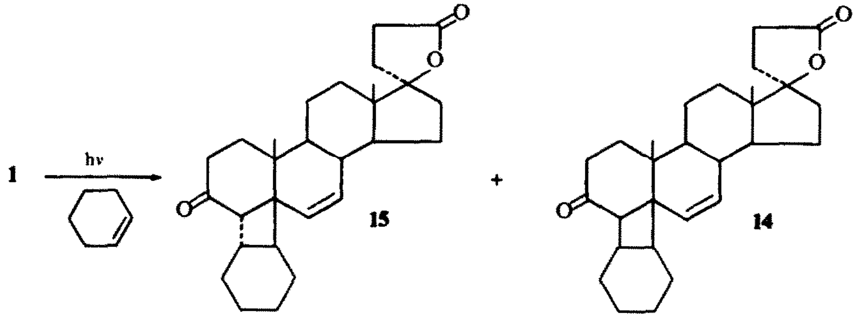
1-*Methylcyclopentene*. The addition of 1-methylcyclopentene to **1** indicated the presence of two isomers by TLC which were separated by column chromatography. The initial adduct isolated was the *cis*-4β,5β-cyclobutane (**12**); identical with the compound obtained by epimerization of the *trans*-4α, 5β-isomer (**13**). The second



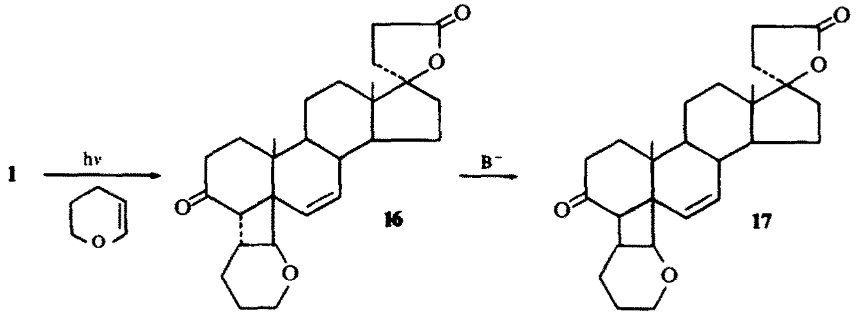
compound eluted was the *trans*-4α,5β-isomer on the basis of its ORD/CD spectrum and epimerization to **12**. Compound **13** had a doublet for the 4β-proton with a coupling constant of 8 Hz, in agreement with that found for the *trans*-cyclopentene adduct

(**9**). The cyclopentene adducts (**9** and **13**) have been assigned the anti-structure based on arguments presented previously for the 6,7-dihydrocyclopentene adducts.[5]

Cyclohexene. Since Δ^4-3-ene steroids form four distinct adducts with cyclohexene, it was of interest to determine whether the previously observed stereospecificity and orientational specificity might still be observed. Irradiation of **1** in the presence of cyclohexene yielded (25%), at a fairly slow rate, two isomers (**14** and **15**) in a ratio of 1 : 1·5 which were separable by chromatography. Again, the initial isomer eluted was the *cis*-4β,5β-isomer (**14**), which could be formed by epimerization of the second compound eluted, the *trans*-4α,5β-isomer (**15**). Compound **15** possessed the strong positive Cotton effect (a = + 338), and the europium shift reagent (*tris* (dipivalomethanato)europium(III)) shifted the 4β-proton from the methylene envelope to indicate a doublet at 5·24 δ with a coupling constant of 9 Hz. The coupling constant observed is in good agreement with that observed in compounds **9** and **13**.



Dihydropyran. Since the addition of **1** to cyclohexene gave a fairly low yield of cyclobutane adduct, dihydropyran was studied with the expectation that the enol ether double bond would substantially increase not only the rate but also the yield.



Irradiation of **1** in the presence of dihydropyran gave a 50% yield of *trans*-adduct **16** which had a positive Cotton effect (a = + 231), and the 4β-proton appeared as a doublet at 3·68 δ (J = 9 Hz). Compound **16** could be epimerized to the *cis*-4β,5β-isomer by methanolic NaOMe and had a negative Cotton effect and CD curve.

DISCUSSION

Initial experiments on the photocycloaddition of 6,7-dihydro **1** to various olefins, indicated the relative rates of addition to the olefins were the same as determined by Corey.[7] The same sensitivity to the degree of positive substitution on the olefins is observed with the dienone 1, however, in an exaggerated sense. The addition to ethylene is very slow, requiring 50 hr and resulting in a 6% yield; due to the formation of much highly polar material, while 1 adds as fast as 6,7-dihydro 1 to diethoxyethylene and dihydropyran.

Rubin initially studied the addition of Δ^6-testosterone propionate to cyclopentene and found only one isomer although no stereochemistry was established.[2] Subsequently the cyclopentene adduct was determined to have the *trans*-4α,5β-configuration by ORD/CD measurements.[3]

In the interim between the publication of the two articles by Rubin, Fried investigated the addition of Δ^6-testosterone acetate to ethylene and isolated two adducts to the 4,5-positions in 5% and 7% yields, to which they assigned the 4α,5α- and 4β,5α-stereochemistry by ORD.[4] Rubin was not able to repeat Fried's addition to ethylene.[3] Ethylene is by far the least reactive olefin studied in the present work and we have found only one isomer formed in 6% yield, which has been assigned the 4α,5β-configuration on the basis of its strong positive ORD/CD and the epimerization to the 4β,5β-adduct with a negative ORD/CD. It was found during the course of our experimentation on the use of *in situ* epimerization using NaOMe that if sufficient time were not allowed for complete epimerization, weak positive ORD/CD spectra were obtained. The reason for this lies in the very strong positive rotations of the *trans*-fused adducts and the weak negative rotations of the *cis*-fused epimer. Then the presence of a small amount of *trans*-adduct admixed with the *cis*-epimer will result in a weak positive ORD/CD curve. The additions of all the other olefins to 1 also have the same strong positive ORD curves, and the *trans*-cyclopentene adduct has been related to *trans* adduct of the Δ^4-3-one series by hydrogenation where the *trans*-4α,5β, *cis*-4α,5α, and *cis*-4β,5β-adducts are known.[2,3,5] On this basis we feel the assignment of the *trans*-4α,5β-stereochemistry to the ethylene adduct is secure.

The most surprising aspect of the photochemical addition of the dienone 1 to olefins is the complete orientational and stereochemical specificity, giving only the *trans*-4α,5β-adduct. The small amount of epimeric 4β,5β-adduct occasionally found with the *trans*-isomer is the result of fortuitous epimerization since the *cis*-adduct if it occurred, would be formed from the least hindered side of the steroid generating the *cis*-4α,5α-adduct. The 4α,5α-isomer is the major photoproduct from Δ^4-3-one steroids.[2-5] Sterospecific *trans*-addition in the photochemical [2 + 2] cycloaddition is very rare. Chapman has found that 4,4-dimethylcyclohexenone gives stereospecific *trans*-addition with tetramethylethylene and 1,1-diphenylethylene together with oxetane.[8,9] The addition of 4,4-dimethylcyclohexenone to 1,1-diphenylethylene was reported to be a singlet reaction on the basis of the stereospecificity of addition together with the reaction of the enone with dienic quenchers, analogous to the addition of enes and dienes to alkanals in the Paterno-Büchi Reaction.[10,11] Interestingly, oxetanes were also found in this reaction. However, the addition of 4,4-dimethylcyclohexenone to 1,1-dimethoxyethylene gave a mixture of an oxetane, and *cis*- and *trans*-head-to-tail adducts.[12] The formation of the *cis*- and *trans*-adducts could be quenched at different rates by di-t-butyl nitroxide implying different reactive triplet states. Apparently 4,4-dimethylcyclohexenone can react to form cyclobutanes and oxetanes from either its singlet or triplet excited state. Since the addition of 1 to all the olefins studied was completely stereospecific, the quenching of the photocycloaddition by piperylene was attempted. Irradiation of **1** in the presence of piperylene gave a rapid reaction with the diene to generate a number of adducts.[*] The stereospecificity of the addition, coupled with the non-quenching by dienes indicate that the linear dienone **1** reacts exclusively from its singlet state. This is the first example of an enone reaction only from its singlet excited state. An alternative explanation implicating the triplet state, by having the apparent reactive $n \rightarrow \pi^*$ triplet below 55 Kcal/mole by virtue of the extended conjugation and inefficient energy transfer for steric reasons, is untenable in view of the stereospecificity.[13] Whether the cycloaddition is concerted is not known. However, if the reaction is not concerted then the ring closure to the cyclobutane must be faster than rotation about a single bond, otherwise more than one isomer would have been formed.[14]

In conclusion, the photocycloaddition of the linear dienone (**1**) to olefins is synthetically useful, yielding a single head-to-tail *trans* cyclobutane, usually in good yield; and also is the first example of a [2 + 2] cycloaddition of the enone system to proceed by way of its singlet excited state.

EXPERIMENTAL

The same experimental techniques were used as previously.[5]

Photocycloaddition of Aldadiene to ethylene. The dienone (5 g) was dissolved in benzene (550 ml), and a stream of ethylene slowly passed through the solution. The magnetically stirred solution was irradiated, through pyrex, with a 450 watt medium pressure mercury arc for 50 hr. Polymeric material formed which was occasionally filtered. The solution was evaporated and the residue (3·25 g) chromatographed on 300 g of Mallinckrodt CC-7 silica. Elution with 10% EtOAc/benzene gave 380 mg of 17β-hydroxy-1′βH-cyclobut(4,5)-5β-3-oxoandrost-6-ene-17β-propionic acid-γ-lactone, m.p. 170–3°: IR, 1770 cm^{-1} (sh), 1760 cm^{-1}, 1710 cm^{-1}; NMR ($CDCl_3$), 1·00 δ (s, 6H); ORD, $[\phi]_{306}$ + 5,160°, $[\phi]_{284}$ 0°, $[\phi]_{260}$ − 17,700°, a = +228; HD, $[\theta]_{290}$ +14,900°. NaOMe epimerization (*in situ*) gave the 4β,5β-isomer: ORD, $[\phi]_{308}$ −9,950°, $[\phi]_{285}$ 0°, $[\phi]_{272}$ +2,950°, a = −129; CD, $[\theta]_{292}$ −11,600°. (Calc for $C_{24}H_{32}O_3$: C, 78·22; H, 8·75. Found: C, 78·53; H, 9·01%).

Photocycloaddition of Aldadiene to isobutylene. A solution of 3·0 g of the dienone in 500 ml of benzene was irradiated for 4·5 hr. with a 450 watt medium pressure arc (corex filter) while slowly passing a stream of isobutylene through the solution. Evaporation and crystallization from EtOAc/ether gave 1·5 g of 3′,3′-dimethyl-17β-hydroxy-1′βH-cyclobut(4,5)-5β-3-oxoandrost-6-ene-17α-propionic acid-γ-lactone, m.p. 170–2°: IR, 1775 cm^{-1} (sh), 1760 cm^{-1}, 1710 cm^{-1}; NMR ($CDCl_3$), 3·45 δ (q, ABX, J = 7·7, 9·6 Hz), 1·47 δ (s, 3H), 1·27 δ (s, 3H), 1·00 δ (s, 6H); (C_6D_6), 3·02 δ (q, ABX), 1·20 δ (s, 3H), 1·12 δ (s, 3H), 1·03 δ (s, 3H), 0·98 δ (s, 3H), ORD, $[\phi]_{305}$ + 7,500°, $[\phi]_{294}$ 0°, $[\phi]_{262}$ − 24,200, a = + 317, CD, $[\theta]_{290}$ + 17,500. (Calc. for $C_{26}H_{36}O_3$. C, 78·74; H, 9·15. Found. C, 78·89; H, 9·43%). Chromatography on 170 g of silica gave, with 5% EtOAc/benzene, an additional 1·05 g of the *trans*-isomer, accompanied by traces of the epimer.

Epimerization of the trans-*isobutylene adduct.* The *trans*-isomer (460 mg) was dissolved by heating in MeOH (30 ml) and 10 mg of NaOMe added. The solution was stirred overnight and poured into water, and the basic solution acidified with HCl and extracted with EtOAc. The solvent was removed and crystallized from ether/petroleum ether to give 420 mg of 3′,3′-dimethyl-17β-hydroxy-1′αH-cyclobut(4,5)-5β-3-oxoandrost-6-ene-17α-propionic acid-γ-lactone, m.p. 215–17°: IR, 1770 cm^{-1}, 1710 cm^{-1}; NMR ($CDCl_3$), 1·32 δ (s, 3H), 1·07 δ (s, 3H), 1·00 δ (s, 3H); 0·93 δ (s, 3H); ORD, $(\phi)_{311}$ −4,300°, $[\phi]_{294}$ 0°, $[\phi]_{272}$ +3,800°, a = −81; CD, $[\theta]_{295}$ −8,300°. (Calc. for $C_{26}H_{36}O_3$: C, 78·74; H, 9·15. Found: C, 78·89; H, 9·15%).

Photocycloaddition of Aldadiene to 1,1-*diethoxyethylene.* The solution of 10·0 g of dienone and diethoxyethylene (15 ml) in EtOAc (550 ml) was irradiated, under N_2 through pyrex with a 450 watt medium pressure mercury arc for 17 hr. The irradiated solution slowly turned opaque, and was clarified by treatment with decolorizing carbon and filtration through celite. Evaporation of solvent gave a residue of 14·12 g

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[*] The addition of **1** to dienes will be detailed in a forthcoming communication.

which was chromatographed on 1400 g of Mallinckrodt silica CC-7. Elution with 10% EtOAc/benzene gave 1·98 g of 3′,3′-diethoxy-17β-hydroxy-1′αH-cyclobut(4,5)-5β-3-oxoandrost-6-ene-17α-propionic acid-γ-lactone, m.p. 155–65°: IR, 1780 cm^{-1}, 1770 cm^{-1} (sh), 1705 cm^{-1}; NMR, 1·08 δ (s, 3H), 1·00 δ (s, 3H), ORD, $[\phi]_{304}$ − 6,300°, $[\phi]_{280}$ 0°, $[\phi]_{259}$ + 1,500°, a = − 78; $[\theta]_{288}$ − 7,300°. (Calc. for $C_{28}H_{40}O_5$: C, 73·65; H, 8·83. Found: C, 73·53; H, 8·77%). Continued elution gave two fractions (0·79 g) containing a mixture of the 4α,4β- and 4β,5β-isomers, followed by 6·26 g of 3′,3′-diethoxy-17β-hydroxy-1′βH-cyclobut-(4,5)-5β-3-oxoandrost-6-ene-17α-propionic acid-γ-lactone, m.p. 190–2°: IR, 1770 cm^{-1}, 1725 cm^{-1}; NMR, 1·36 δ (s, 3H), 1·00 δ (s, 3H); ORD, $[\phi]_{306}$ + 4,600°, $[\phi]_{297}$ 0°, $[\phi]_{275}$ − 27,000°, a = + 320; CD, $[\theta]_{288}$ + 20,500°. (Calc. for $C_{28}H_{40}O_5$: C, 73·65; H, 8·83. Found: C, 73·94; H, 9·03%). Continued elution gave 1·70 g of starting material.

Hydrolysis of the 1,1-*diethoxyethylene photoadducts*. The irradiation was as above excepting that it was continued for 31 hr. until the disappearance of starting material. The solvent was evaporated at reduced pressure and the residue dissolved in 100 ml of 80% AcOH, containing a few drops of conc. HCl. A product started to crystallize as water was slowly added. When crystallization was completed, 8·30 g of 17β-hydroxy-1′αH-3′-oxocyclobut(4,5)-5β-3-oxoandrost-6-ene-17α-propionic acid-γ-lactone was collected, m.p. 228–30°: IR, 1775 cm^{-1}, 1765 cm^{-1}, 1725 cm^{-1}; NMR, 1·23 δ (s, 3H), 1·00 δ (s, 3H), 4·52 δ (q, $AB\underline{X}$, J_{13} = 8·6 Hz, J_{12} = − 16·3 Hz), 5·57 δ ($A\underline{B}X$, J_{23} = 10·7 Hz), 5·71 δ ($\underline{A}BX$); ORD, $[\phi]_{312}$ − 9,850°, $[\phi]_{298}$ 0°, $[\phi]_{286}$ +6,900°; CD, $[\theta]_{310}$ −13,400°, $[\theta]_{280}$ +4,300°. (Calc. for $C_{24}H_{30}O_4$: C, 75·36; H, 7·91. Found: C, 75·22; H, 7·83%).

Photocycloaddition of Aldadiene to cyclopentene. The dienone (5·0 g) was dissolved in 20 ml of cyclopentene and 525 ml EtOAc, and irradiated, under N_2, for 16 hr. (pyrex filter). Solvent was evaporated and chromatographed on 500 g of silica. Elution with 8% EtOAc/benzene gave 3·03 g of 1′α,5′α-dihydro-17β-hydroxy-6′βH-4,5-(6′,7′-bicyclo[3.2.0]heptano)-5β-3-oxoandrost-6-ene-17α-propionic acid-γ-lactone, m.p. 220–3°: IR, 1770 cm^{-1}, 1720 cm^{-1}; NMR ($CDCl_3$), 3·03 δ (m, 2H), 1·23 δ (s, 3H), 1·00 δ (s, 3H); (C_6D_6), 2·71 δ (d, J = 7·6 Hz), 0·97 δ (s, 3H); 0·82 δ (s, 3H), ORD, $[\phi]_{306}$ + 4,100°, $[\phi]_{290}$ 0°, $[\phi]_{264}$ − 26,200°, a = + 302; CD, $[\theta]_{291}$ + 16,300°. (Calc. for $C_{27}H_{36}O_3$: C, 79·37; H, 8·88. Found: C, 79·52; H, 9·00%). Continued elution gave only very polar material which was non-crystalline and not further investigated.

Epimerization of the trans-*cyclopentene adduct*. A solution of 100 mg of the 4α,5β-*trans*-cyclopentene adduct was dissolved in MeOH (10 ml) and 10 mg of NaOMe added and stirred overnight. The methanolic solution was poured into water, acidified with dil HCl, extracted with $CHCl_3$, dried with Na_2SO_4, and the solvent evaporated. Crystallization from ether/petroleum ether gave 85 mg of 1′α,5′α-dihydro-17β-hydroxy-6′αH-4,5-(6′,7′-bicyclo[3.2.0]heptano)-5β-3-oxoandrost-6-ene-17α-propionic acid-γ-lactone, m.p. 223–5°, m.m.p. with 4α,5β isomer 200–12°: IR, 1780 cm^{-1}, 1690 cm^{-1}; NMR, 1·00 δ (s, 3H), 0·95 δ (s, 3H). (Calc. for $C_{27}H_{30}O_3$: C, 79·39; H, 8·88. Found: C, 79·53; H, 8·83%).

Hydrogenation of the trans-4α,5β-*cyclopentene adduct*. A solution of 130 mg of the 4α,5β-*trans*-isomer in 100 ml of dioxane was hydrogenated with 5% Pd/C at rt and atmospheric pressure. Filtration and evaporation of the solvent gave a residue which was crystallized from ether/petroleum ether to give 80 mg of the 6,7-dihydroderivative, identical in every respect, IR, NMR, TLC, ORD/CD, to the 4α,5β-*trans*-isomer obtained by irradiating the 6,7-dihydro-derivative in the presence of cyclopentene.

Photocycloaddition of Aldadiene to 1-*methylcyclopentene*. The dienone (6 g) was dissolved in 550 ml of EtOAc and 16 ml of 1-methylcyclopentene (Chem. samples 99%) was irradiated, under N_2, for 45 hr. through pyrex with a 450 watt medium pressure mercury arc. Evaporation of solvent and chromatography on silica (800 g) gave, with 5% EtOAc/benzene, 0·923 g of 5′α-hydro-17β-hydroxy-1′α-methyl-6′αH-4,5-(6′,7′-bicyclo[3.2.0]heptano)-5β-3-oxoandrost-6-ene-17α-propionic acid-γ-lactone, m.p. 182–4°: IR, 1775 cm^{-1}, 1695 cm^{-1}; NMR, 1·42 δ (s, 3H); 1·00 (s, 3H); 0·81 δ (s, 3H) (Calc. for $C_{28}H_{38}O_3$: C, 79·58; H, 9·06. Eound: C, 79·59; H, 9·18%). Continued elution with 10% EtOAc gave 1·291 g of 5′α-hydro-17β-hydroxy-1′α-methyl-6′βH-4,5-(6′,7′-bicyclo[3.2.0]heptano)-5β-3-oxoandrost-6-ene propionic acid-γ-lactone, m.p. 187–9°: IR, 1780 cm^{-1} (sh), 1765 cm^{-1}, 1720 cm^{-1}; NMR, 3·00 (d, J = 8 Hz, 1H), 1·20 δ (s, 3H), 0·98 δ (s, 3H); ORD, $[\phi]_{308}$ + 5,900°, $[\phi]_{298}$ 0°, $[\phi]_{267}$ − 25,000°, a = + 308; CD, $[\theta]_{290}$ + 19,000°. (Calc. for $C_{28}H_{38}O_3$: C, 79·58; H, 9·06. Found: C, 79·58; H, 9·10%). The *trans*-isomer could be epimerized to 4β,5β-*cis*-isomer identical to that eluted.

Photocycloaddition of Aldadiene to cyclohexene. A solution of the dienone (6·0 g) in cyclohexene (50 ml) and EtOAc (550 ml) was irradiated through pyrex, under N_2, for 40 hr with a 450 watt mercury arc. Evaporation of solvent and chromatography on 800 g of silica gave, with 10% EtOAc/benzene, 730 mg of 1′α,6′α-dihydro-17β-hydroxy-7′αH-4,5-(7′,8′-bicyclo[4.2.0]octano)-5β-3-oxoandrost-6-ene propionic acid-γ-lactone, m.p. 218–20°: IR, 1770 cm^{-1}, 1695 cm^{-1}, NMR, 0·95 δ (s, 6H). Addition of 35 mg of tris(dipivalomethanato)europium (Eu(dpm)$_3$) to a 9% $CDCl_3$ solution indicated the following peaks, 5·11 δ (d, J = 9 Hz, 1H), 1·74 δ (s, 3H), 1·54 δ (s, 3H). (Calc. for $C_{28}H_{38}O_3$: C, 79·58; H, 9·06. Found: C, 79·24; H, 9·09%). Continued elution gave 860 mg of 1'α,6'α-dihydro-17β-hydroxy-7'βH-4,5-(7',8'-bicyclo[4.2.0]octano)-5β-3-oxoandrost-6-ene propionic acid-γ-lactone, m.p. 209–11°: IR, 1770 cm^{-1}, 1725 cm^{-1}; NMR, 1·09 δ (s, 3H), 0·94 δ (s, 3H), ORD, $[\phi]_{306}$ + 7,400°, $[\phi]_{295}$ 0° $[\phi]_{264}$ − 26,400°, a = + 388; CD, $[\theta]_{290}$ + 21,000°. Addition of 35 mg of tris(dipivalomethanato)europium (Eu(dpm)$_3$) to a 8% $CDCl_3$ solution indicated the following peak shifts: 5·24 δ (d, J = 9 Hz, 1H), 1·78 δ (s, 3H), 1·63 δ (s, 3H). (Calc. for $C_{28}H_{38}O_3$: C, 79·58; H, 9·06. Found: C, 79·31; H, 9·26%). Continued elution gave 1·35 g of recovered dienone.

Photocycloaddition of Aldadiene to dihydropyran. The dienone (6 g) was dissolved in EtOAc (550 ml) and dihydropyran (27 ml), and irradiated through pyrex, under N_2 with a 450 watt mercury arc for 24 hr. Chromatography of the residue, after solvent removal, on 600 g of silica gave, with EtOAc/benzene, 1·918 g of 1'α,6'α-dihydro-17β-hydroxy-7'βH-4,5-(7',8'-2-oxabicyclo[4.2.0]octano)-5β-3-oxoandrost-6-ene propionic acid-γ-lactone, m.p. 242–4°: IR, 1775 cm^{-1}, 1725 cm^{-1}; NMR, 3·83 δ (m, 2H), 3·68 δ (d, J = 9 Hz, 1H), 3·05 δ (q, 1H), 1·30 δ (s, 3H), 0·97 δ (s, 3H); ORD, $[\phi]_{306}$ + 4,250, $[\phi]_{297}$ 0°, $[\phi]_{260}$ − 18,850°, a = + 231; CD, $[\theta]_{290}$ + 14,900°. (Calc. for $C_{27}H_{36}O_4$: C, 76·38; H, 3·55. Found: C, 76·15; H, 8·59. Continued elution gave 2·184 g of dienone.

Epimerization of the trans-*dihydropyran photoadduct.* A methanolic solution of 604 mg of the *trans*-dihydropyran photoadduct is treated with 1 g of NaOMe, and stirred overnight. The alcohol solution was poured into water, acidified with HCl and extracted with CH_2Cl_2, dried with Na_2SO_4 and crystallized from ether/petroleum ether to give 550 mg of 1'α,6'α-dihydro-17β-hydroxy-7'αH-4,5-(7',8'-2-oxabicyclo[4.2.0]-octano)-5β-3-oxoandrost-6-ene propionic acid-γ-lactone, m.p. 196–198°: IR, 1780 cm^{-1}, 1700 cm^{-1}; NMR, ($CDCl_3$), 0·98 δ (s, 6H); (C_6D_6), 1·03 δ (s, 3H), 0·84 δ (s, 3H); ORD, $[\phi]_{306}$ −2,700°, $[\phi]_{268}$ slit cutoff; CD, $[\theta]_{303}$ −2,800°. (Calc. for $C_{27}H_{36}O_4$: C, 76·38; H, 8·55. Found: C, 76·18; H, 8·75%).

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