particular *N*-chloroaziridine system is reluctant to form a nitrenium ion and undergo ring cleavage. This might be attributed to the presence of the electron deficient benzoyl group attached to the adjacent carbon atom.

Irradiation of a solution of Ia (or Ib) in benzene at 25° in a Pyrex immersion apparatus with a 450-W Hanovia lamp for 7 hr led to complete disappearance of starting material. Conventional isolation procedures afforded 2,5-diphenyloxazole in high yield. The formation of the oxazole and the complete absence of the isooxazole ring suggest that the reaction proceeds by exclusive C–C bond scission. Subsequent ring closure to a 2,3-dihydrooxazole followed by dehydrochlorination readily accounts for the observed product.

Experimental Section

***N*-Chloro-2-benzoyl-3-phenylaziridine (Ia and Ib).**—To a solution of 2.0 g of 2-benzoyl-3-phenylaziridine[8] in 50 ml of methylene chloride was added 2.0 g of *tert*-butyl hypochlorite. After stirring for 2 hr at room temperature, the solvent was removed under reduced pressure and the crude solid was subjected to preparative thick layer chromatography.[9] Elution with benzene afforded two bands which were taken up in acetone. Removal of the solvent from the lower band gave material with mp 83.5–84°.

Anal. Calcd for $C_{15}H_{12}ClNO$: C, 69.89; H, 4.69; N, 4.45; Cl, 13.75. Found: C, 69.71; H, 4.75; N, 5.52; Cl, 13.73.

The nmr spectrum showed an AB quartet centered at τ 5.91 (J = 5.5 Hz) and a multiplet centered at τ 2.20 (10 H). Removal of the solvent from the upper band of the thick layer plate gave an isomeric material, mp 86–86.5°.

Anal. Calcd for $C_{15}H_{12}ClNO$: C, 69.89; H, 4.69; N, 5.45; Cl, 13.75. Found: C, 69.75; H, 4.75; N, 5.50; Cl, 13.73.

The nmr spectrum showed an AB quartet at τ 5.80 (J = 5.8 Hz) and a multiplet for the aromatic hydrogens.

Photolysis of *N*-Chloro-2-benzoyl-3-phenylaziridine.—A solution of 1.0 g of Ia (or Ib) in 1 l. of benzene was irradiated with an internal water-cooled mercury arc lamp (450-W) using a Pyrex filter. After 7 hr the solution was concentrated to give a brown oil. The residue was dissolved in benzene and chromatographed on a Florisil column. Elution with benzene gave 2,5-diphenyloxazole (80%) as white needles. Further elution of the column afforded only ill-defined tars.

Attempted Dehydrohalogenation and Solvolysis of *N*-Chloro-2-benzoyl-3-phenylaziridine.—In a typical case, 0.10 g of I was dissolved in 10 ml of methanol. To the above solution was added 5 ml of a 10% sodium methoxide–methanol solution. The mixture was allowed to stir for 12 hr. The resulting solution was washed with water, extracted with CH_2Cl_2, and dried (Na_2SO_4). Removal of the solvent under reduced pressure, followed by infrared and nmr analysis showed the presence of only *trans*-benzoylphenylaziridine. Similar results were obtained when sodium hydride, phenyl lithium, 1,5-diazabicyclo[4.3.0]non-5-ene, and potassium *tert*-butoxide were used as bases.

In an attempt to investigate the solvolytic behavior of I, a 0.10-g sample of I was added to a 10% aqueous methanol solution containing 0.85 g of silver nitrate. The resulting solution was allowed to stir for 12 hr at room temperature. The solvent was removed under reduced pressure and the residue was dissolved in benzene and washed with water, and the extracts were dried. Removal of the solvent showed only the presence of unreacted starting material.

Registry No.—1a, 26823-97-2; 1b, 26823-98-3.

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(9) Thick layer plates were prepared by spreading a slurry of 150 g of Merck $HH_{254+366}$ silica gel and 350 ml of water onto 10 × 20 cm glass plates to an average thickness of 1.5 cm. The plates were allowed to dry at room temperature for 24 hr.

Stereochemistry of the Palladium-Catalyzed Hydrogenation of 3-Oxo-4-ene Steroids. III. The Effects of the Functional Groups at C-11, C-17, and C-20 on the Hydrogenation[1,2]

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It has been previously reported from our laboratories that during the hydrogenation of 4-cholesten-3-one (**9**) and testosterone (**3a**) with palladium catalyst in alcohols, acetic acid, or in these solvents containing mineral acid, a larger amount of 5β ketone was formed from **9** than from **3a**. In comparison with **3a**, testosterone acetate (**3b**) gave the 5β ketone in considerably higher yield. Such an increase in the yield of 5β ketone on changing a 17β-hydroxyl group to a 17β-acetoxyl group was also observed in the corresponding compounds of the 19-nor series, which led to the suggestion that the effect of a 17β-hydroxyl group is to decrease the formation of 5β ketones.[2,4] Such influence of substituents, which lie far from the reaction site, on the stereochemistry of hydrogenation has already been noted by Pataki, Rosenkranz, and Djerassi[5] during the hydrogenation of 11β-hydroxy- and 11-oxo-substituted 3-oxo-4-ene steroids, and similar observations were made by other investigators[6,7] while our work was in progress. It seems rather difficult to explain these phenomena in terms of steric effect alone.

With the aim of getting more quantitative and systematic information on the influence of functional groups on hydrogenation, we have now hydrogenated 25 3-oxo-4-ene steroids with or without functional groups at C-11, 17, or 20 over prereduced palladium hydroxide. Products were analyzed by gas–liquid chromatography.

The results are given in Table I. From the Table it is seen that 17β-acetoxy-11β-hydroxy-4-androsten-3-one (**5**), 11β-hydroxy-4-androstene-3,17-dione (**7a**), and 11β-hydroxyprogesterone (**15a**), which are all 3-oxo-4-ene steroids containing an 11β-hydroxyl group, afford apparently rather different ratios of 5β to 5α ketone. However, when the results are compared with those for

(1) Presented in part at the 20th Annual Meeting of the Chemical Society of Japan in Tokyo, Japan, April 1967, and the 21st Annual Meeting of Chemical Society of Japan in Osaka, Japan, April 1968.

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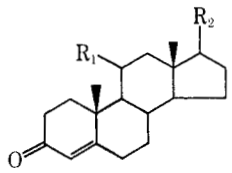
TABLE I
RATIO OF 5β TO 5α KETONE IN THE HYDROGENATION OF 3-OXO-4-ENE STEROIDS WITH PALLADIUM CATALYST



Compd	Solvent: i-PrOH	i-PrOH–HCl	AcOH	AcOH–HCl
1, $R_1 = R_2 = H$	1.0	0.95	1.1	3.4
2a, $R_1 = H$; $R_2 = \alpha$-OH	4.1	4.0	3.2	2.3
2b, $R_1 = H$; $R_2 = \alpha$-OAc	2.7	2.9	2.7	3.1
2c, $R_1 = H$; $R_2 = \alpha$-OBz	3.5	3.5	6.9	8.8
3a, $R_1 = H$; $R_2 = \beta$-OH	0.73	0.57	0.84	0.63
3b, $R_1 = H$; $R_2 = \beta$-OAc	1.9	2.3	1.3	2.5
3c, $R_1 = H$; $R_2 = \beta$-OBz	1.5	1.3	2.6	3.1
4, $R_1 = H$; $R_2 = O$	0.55	0.91	1.3	1.3
5, $R_1 = \beta$-OH; $R_2 = \beta$-OAc	0.62	0.48	1.3	2.0
6, $R_1 = O$; $R_2 = \beta$-OAc	0.13	0.20	0.30	0.47
7a, $R_1 = \beta$-OH; $R_2 = O$	0.26	0.19	0.69	1.0
7b, $R_1 = \beta$-OAc; $R_2 = O$	0.27	0.33	0.91	1.1
8, $R_1 = O$; $R_2 = O$	0.09	0.07	0.17	0.27
9, $R_1 = H$; $R_2 = \beta$-C_8H_{17}	1.5	0.86	0.89	3.9
10, $R_1 = H$; $R_2 = \beta$-C_2H_5	2.7	1.2	2.2	3.5
11a, $R_1 = H$; $R_2 = \beta$-CH_3CH (α-OH)	1.3	0.67	2.3	1.6
11b, $R_1 = H$; $R_2 = \beta$-CH_3CH (α-OAc)	0.58	0.37	2.8	2.3
12a, $R_1 = H$; $R_2 = \beta$-CH_3CH (β-OH)	1.4	1.0	1.7	2.5
12b, $R_1 = H$; $R_2 = \beta$-CH_3CH (β-OAc)	1.0	0.67	0.98	2.7
13, $R_1 = H$; $R_2 = \beta$-CH_3CO	0.34	0.21	0.48	0.62
14a, $R_1 = \alpha$-OH; $R_2 = \beta$-CH_3CO	0.38	0.28	0.59	0.66
14b, $R_1 = \alpha$-OAc; $R_2 = \beta$-CH_3CO	0.71	0.28	0.68	1.1
15a, $R_1 = \beta$-OH; $R_2 = \beta$-CH_3CO	0.16	0.08	0.32	0.35
15b, $R_1 = \beta$-OAc; $R_2 = \beta$-CH_3CO	0.33	0.22	0.84	0.86
16, $R_1 = O$; $R_2 = \beta$-CH_3CO	0.03	0.02	0.04	0.04

the corresponding parent steroids without the substituent at C-11, it appears that the 11β-hydroxyl group has a tendency to decrease the formation of the 5β ketone (compare **5**, **7a**, and **15a** with **3b**, **4**, and **13**, respectively).

In order to describe our observations on the effect of various substituents, we will define an effect which increases the proportion of 5β isomers in the product as positive and the reverse effect as negative.[8]

The ratio of ketones obtained from **9** (with a 17β-C_8H_{17} side chain) is almost the same as that from 4-androsten-3-one (**1**) with no substituent at C-17. A 17β-ethyl group appears to have a positive effect, but the result in acetic acid containing hydrochloric acid is the same as that for **1** (compare **10** with **1**).

With respect to the effect of hydroxyl groups, the 11α-hydroxyl group has scarcely any effect and 20α- and 20β-hydroxyl groups show slightly negative effects (compare **14a** with **13**; **11a** and **12a** with **10**). While 11β- and 17β-hydroxyl groups have certainly negative effects, some difference is found between them when the solvent is changed (compare **5**, **7a**, and **15a** with **3b**, **4**, and **13**, respectively; **3a** with **1**). It is difficult to estimate which of the substituents at C-11 and C-17 has a more significant effect on the stereochemistry. Although Pataki, Rosenkranz, and Djerassi[5] observed the perponderant formation of 5α ketones for 11β-hydroxyl derivatives (corticosterone acetate and cortisol acetate), it has been pointed out by Liston and Howarth[6] that hydrogenation of 11β-ols (11β-hydroxy-4-androsten-3-one and **5**) results in predominant formation of 5β ketones. Certainly the 11β-hydroxyl group has the effect of decreasing the formation of 5β ketone as compared with the result obtained by hydrogenating the parent compounds. However, when the parent compound produces a very large amount of the 5β ketone as in the case of **3b**, introduction of an 11β-hydroxyl group may still result in predominant formation of the 5β ketone in acetic acid and acetic acid containing hydrochloric acid, even though the ratio is smaller. By contrast, when the parent compound already contains a 20-oxo group which considerably inhibits the formation of 5β ketone, introduction of an 11β-hydroxyl group results in predominant formation of 5α ketone due to combined effect of the effects of the substituents as in **15a**. On the other hand, the 17α-hydroxyl group has a positive effect (compare **2a** with **1**).[9] The order of the substituent effects of the hydroxyl groups is as follows: 17α-OH > 11α-OH > H > 20α-OH ≅ 20β-OH > 17β-OH ≅ 11β-OH.

Among ketones, the 17-oxo group has a barely negative effect, while the 20-oxo and 11-oxo groups have much more negative effects which are also much greater than those of the corresponding hydroxyl groups (compare **4** with **1**; **13** with **10**; **6**, **8**, and **16** with **3b**, **4**, and **13**, respectively). The negative effect is more pronounced for the 11-oxo group than for the 20-

(8) It is convenient to use the ratio of $(5\beta/5\alpha)_R$ to $(5\beta/5\alpha)_H$. $(5\beta/5\alpha)_R$ is 5β/5α ketone of hydrogenated products of 3-oxo-4-ene steroid with substituent R. $(5\beta/5\alpha)_H$ is 5β/5α ketone of hydrogenated products of parent steroid without substituent.

(9) Such behavior slightly decreases in the hydrogenation in acetic acid, and even a negative effect is observed in acetic acid containing hydrochloric acid or hydrobromic acid.

oxo group.[10] Consequently, the order of substituent effects of the oxo groups is as follows: H > 17-oxo > 20-oxo > 11-oxo.

Finally, concerning the acetoxyl groups, the 11α-acetoxyl group gives a slightly more positive effect than the 11α-hydroxyl groups, and 5β-ketone formation in an 11α-acetoxyl derivative increases in comparison with that from the corresponding parent compound (compare **14b** with **13**). The 11β- and 17β-acetoxyl groups have certainly less negative effects than those of the corresponding β-hydroxyl groups, the 17β-acetoxy compound giving the 5β ketone in even greater yield than the parent compound (compare **7b** and **15b** with **4** and **13**, respectively; **3b** with **1**). The 17α-acetoxyl group provides a strongly positive effect except when hydrochloric acid in acetic acid is added, although the effect is somewhat smaller than that of the hydroxyl group (compare **2b** and **2a** with **1**). The effects of 20α- and 20β-acetoxyl groups are similar to those of the corresponding hydroxyl groups and more negative than that of 11β-acetoxyl group (compare **11b** and **12b** with **10**; **7b** and **15b** with **4** and **13**, respectively). The order of substituent effects of the acetoxyl groups is therefore as follows: 17α-OAc > 17β-OAc ≅ 11α-OAc > H > 11β-OAc > 20α-OAc ≅ 20β-OAc.

The fact that the equatorial 11α-acetoxyl group has a slightly more positive effect than an equatorial 11α-hydroxyl group which shows nearly the same effect as that of 11α hydrogen, does not contradict the concept of steric effect. On the other hand, the 11β-hydroxyl (axial) group has a more negative effect than the corresponding acetoxyl group, while the 17α-hydroxyl (quasiaxial) group has definitely a more positive effect than the 17α-acetoxyl group. These result cannot be interpreted in steric terms. The negative effect of the quasiequatorial 17β-hydroxyl group is as great as that of the axial 11β-hydroxyl group, but such an effect is scarcely noticeable when a 17β-acetoxyl group is present. These facts suggest that the effect of hydroxyl groups is electronic rather than steric. The large negative effect of the oxo group is also considered as arising from electronic factors.[11]

Experimental Section

Materials.—4-Androsten-3-one (**1**) was supplied from Teikoku Hormone Manufacturing Company, Ltd. Testosterone (**3a**), testosterone acetate (**3b**), and 4-cholesten-3-one (**9**) were described in a previous paper.[4] Epitestosterone (**2a**), progesterone (**13**), 11α-hydroxyprogesterone (**14a**), and 11-oxoprogesterone (**16**) were obtained commercially and recrystallized. 17β-Acetoxy-11β-hydroxy-4-androsten-3-one (**5**),[12] 11β-hydroxy-4-androstene-3,17-dione (**7a**),[13] 11β-acetoxy-4-androstene-3,17-dione (**7b**),[14] 4-androstene-3,11,17-trione (**8**),[13] 4-pregnene-3-one (**10**),[15] 20α-hydroxy-4-pregnen-3-one (**11a**),[16] 20β-hydroxy-4-pregnen-3-one (**12a**),[17] 11β-hydroxyprogesterone (**15a**),[18] and 11β-acetoxyprogesterone (**15b**)[14] were prepared by published procedures. Epitestosterone acetate (**2b**), 20α-acetoxy-4-pregnen-3-one (**11b**), 20β-acetoxy-4-pregnen-3-one (**12b**), 11α-acetoxyprogesterone (**14b**), epitestosterone benzoate (**2c**), testosterone benzoate (**3c**), 4-androstene-3,17-dione (**4**), and 17β-acetoxy-4-androstene-3,11-dione (**6**) were prepared from the corresponding hydroxy steroids by acetylation, benzoylation, or oxidation in the usual way. Purity of these compounds was checked by gas–liquid partition chromatography (glpc). Palladium hydroxide was prepared as previously described.[4,19]

Hydrogenation and Analysis.—The steroid (10 mg) was hydrogenated in the solvent (10 ml) with prereduced palladium hydroxide (5 mg) at 25° and under atmospheric pressure. After hydrogenation of the catalyst in isopropyl alcohol or acetic acid, 3 *N* hydrochloric acid (0.05 ml), if necessary, was added to the suspension. After the steroid had been hydrogenated for 0.5 hr, the reaction was stopped to analyze the products by glpc. A Shimazu Seisakusho Model GC-4APF gas chromatograph equipped with dual flame detectors was employed. The glass columns (2 m × 4 mm inside diameter) contained 1.5% OV-17 on 80–100 mesh Shimalite W (Shimazu Co.) washed with acid and silanized with dichlorodimethylsilane. The carrier gas was nitrogen at a flow rate of 70 ml/min and the column tempearature was suitably selected for each product between 205 and 260°. Quantitative estimation of the products was carried out by multiplying the height of the peak by the width at half-height.

Acknowledgment.—The authors are grateful to Teikoku Hormone Manufacturing Company, Ltd., for providing 4-androsten-3-one.

(10) Since the negative effects of the oxo groups are great, **8** with an 11,17-dioxo group and especially **16** with an 11,20-dioxo group mainly lead to the formation of the 5α ketones.

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An Improved Synthesis of Phenyl Benzohydroxamate and Its Conversion to Phenyl *O*-Phenyl- and *O*-Ethylbenzohydroxamate

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Although alkyl benzohydroxamates may be prepared by simple alkylation,[2] aryl benzohydroxamates are not readily accessible and, in fact, only two representatives of this class of derivatives have been previously reported. Thus, arylation of potassium benzohydroxamate with diphenyliodonium bromide gave phenyl benzohydroxamate in 24% yield,[3] while treatment of the same salt with 2,4-dinitrofluorobenzene gave 2,4-dinitrophenyl benzohydroxamate in 20% yield.[4]

We have recently reported[5] the formation of an unstable *N*-chlorosulfite by reaction of thionyl chloride with 1-hydroxy-2(1*H*)-pyridone; subsequent treatment with thallium(I) carboxylates gave 1-acyloxy-2(1*H*)-pyridones. Extension of this reaction to open-chain hydroxamic acids would have provided simple access to aryl hydroxamate derivatives. In order to explore this possibility, we treated an ethereal solution of benzo-

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