seems to afford the best rationalization of the observations. The reaction thus differs, on the one hand, from the reaction of triphenylphosphine with peresters, 5-8and, on the other hand, from that of 1 with benzoyl peroxide,^{2,3} where 3 is formed at a later stage of the reaction.

For the reaction of triphenylphosphine with peresters, a homolytic reaction has in general been discounted.^{6,7} In the reaction of 1, the absence of carbon dioxide in the products and the inertness of the solvent seem also to exclude a radical reaction. However, traces of copper ion accelerate the reaction, and since copper ions are known to accelerate homolytic processes of peresters,⁹ it seems possible that at least the copper ion catalyzed part of the reaction between 1 and 5 might be proceeding by a radical route. By an adaptation of our mechanism of the perester reaction,⁹ the following steps are proposed for the formation of intermediate 9 (eq 5-7).

$$RC(O)OO-t-Bu + Cu^{+} \longrightarrow RC(O)OCu^{+} + t-BuO \cdot (5)$$



(9) G. Sosnovsky and O. S. Lawesson, Angew. Chem. Intern. Ed. Engl., 3, 269 (1964).

Experimental Section

Compounds 1 (Stauffer Chemical Company), 5a, and 5b (75% solution in benzene) (Lucidol Division, Wallace and Tiernan, Inc.) were gifts. t-Butyl benzoate, ¹⁰ 7, ¹¹ 4, ¹² 6, ¹³ and ²¹⁴ were made by literature methods. Compound 3b was prepared by a method analogous to that used previously to make 3a, which is more convenient than the literature method.¹⁵ All other chemicals were purchased.

The experimental approach was similar¹⁶ to that described in a previous paper.³ In preparative-scale experiments, the products were either isolated by distillation and recrystallization, or, in some cases, detected by ir spectroscopy without isolation. Ir spectra were used to follow the progress of the reactions and isolation procedures, and to confirm the characterization of isolated materials.

Registry No.-1, 1079-66-9; 5a, 614-45-9; 5b, 107-71-1.

Acknowledgment.-The authors wish to thank Mr. W. J. Mertz for technical assistance.

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(12) P. Hauke and G. Hurst, J. Amer. Chem. Soc., 88, 2544 (1966)

(13) L. R. Ocone, et al., U. S. Dept. Comm., Office Tech. Serv., P. B. Rept., AS262, 806 (1961); Chem. Abstr., 59, 2853h (1963). (14) R. L. Dannley and K. R. Kabre, J. Amer. Chem. Soc., 87, 4805

(1965). (15) D. L. Venesky and C. F. Poranski, Jr., J. Org. Chem., 32, 838 (1967). (16) Full experimental details have been deposited as Document No. 00496 with the ASIS National Auxiliary Publications Service, % CCM Information Corp., 909 Third Ave., New York, N. Y. 10022. A copy may be secured by citing the document number and by remitting \$3.00 for photoprints, or \$1.00 for microfiche. Advance payment is required. Make checks or money orders payable to: ASIS-NAPS.

Synthesis of 7- and 11-Oxygenated Abietanes^{1,2} Resin Acids. XVII.

WERNER HERZ AND J. J. SCHMID³

Department of Chemistry, Florida State University, Tallahassee, Florida 32306

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The oxidation of methyl 13β -abiet-8-(9)-en-18-oate (4b) with t-butyl chromate is described. The structure and stereochemistry of the oxidation products has been elucidated and the conversion of some of them to methyl 11-oxo-13 β -abietan-18-oate (17) is described. 17 and its 9 β epimer 25 were obtained also by transformations of the epoxide of 4b. Hydroboration of 4b provides a simple route to 7-oxygenated abietanes.

In earlier paper⁴ we described results which led to the unambiguous specification of configuration for the abietanoic acids, 1, 2, and 3a.^{5,6} These substances were needed as reference compounds for other investigations. In the present communication we describe that part of our work which had as its goal the transformation of abietic acid to 11-oxygenated derivatives which were

(1) Resin Acids. XVI: W. Herz and J. J. Schmid, J. Org. Chem., 34, 2775 (1969).

(2) Supported in part by National Science Foundation Grant GP-6362.

(3) National Science Foundation Fellow, 1967-1968.

(4) J. W. Huffman, T. Kamiya, L. H. Wright, J. J. Schmid, and W. Herz, ibid., 31, 4128 (1966). (5) Similar conclusions have been reached by A. W. Burgstahler, J. N.

Marx, and D. F. Zinkel, *ibid.*, **34**, 1550 (1969). (6) The numbering and nomenclature employed by us follows a recent

proposal (third revision, Oct 1968) by J. W. Rowe, Forest Products Laboratory, Madison, Wis., "The Common and Systematic Nomenclature of Cyclic Diterpenes," subscribed to by most workers in the field. The parent abietane skeleton as proposed by E. Fujita, T. Fujita, and H. Katayama, Chem. Commun., 968 (1967), has the trans-anti-trans configuration with a 13α isopropyl group. Thus 1 is referred to as abietan-18-oic acid. Inverted configurations are designated by the position number and the correct stereochemistry before the skeletal name.

envisioned as intermediates for the partial synthesis of more highly functionalized naturally occurring diterpenoids. In the course of this effort a number of other interesting observations bearing on stereochemical aspects in the perhydrophenanthrene series were made and are reported herewith.

Although previous attempts at allylic oxidation of methyl 13β -abiet-8(9)-en-18-oate (4b) had resulted only in aromatization of ring C,⁷ oxidation of **4b** with *t*-butyl chromate in refluxing carbon tetrachloride gave a mixture of five nonaromatic substances which were separated by column chromatography. In order of increasing polarity, these were three ketones, A (15%), B (15%), and C (35%), a hydroxy ketone D (10%), and a hydroxy ketone E (2%). The balance consisted of a very polar mixture of further oxidation products.

The least polar ketone, A, mp 108–109°, was α , β -un-saturated [ir band at 1650 cm⁻¹, λ_{max} 245 nm (ϵ

(7) W. Herz and H. J. Wahlborg, J. Org. Chem., 30, 1881 (1965); H. J. Wahlborg, Ph.D. Dissertation, Florida State University, 1965.



11,500)] and was assigned formula **5** because it was unreactive toward 2,4-dinitrophenylhydrazine and because its nmr spectrum exhibited a deshielded C-10 methyl signal at 1.19 ppm⁸ as well as the characteristic somewhat broadened one proton doublet (J = 12 Hz) at 2.90 ppm due to the 1 β proton which is deshielded by an 11-keto group¹⁰ and the 8,9 bond.¹¹ Comparison of the nmr spectra of the deuterated and nondeuterated ketone showed that, as expected, six protons in the region 2.0–2.7 ppm had been replaced by deuterium, but that the signal at 2.90 had not been affected.

Analysis and spectral properties of the yellow ketone, B, $C_{21}H_{30}O_4$ [mp 88–89.5°, ir band at 1672 cm⁻¹ (double strength), λ_{max} 265 nm (ϵ 8900)], suggested that it was a conjugated enedione. The nmr spectrum exhibited a broadened one-proton doublet at 2.82 ppm (J = 12 Hz) which suggested that one of the two carbonyls was at C-11. The other carbonyl group might then be placed at the unhindered 7 position as in 6, an assignment which



was supported by the appearance of the C-10 methyl resonance at unusually low field (1.31 ppm).⁹ Chemical evidence for formula **6** will be presented subsequently.

The oily ketone, C, was also an α,β -unsaturated ketone (ir band at 1650 cm⁻¹, λ_{max} 248 nm, ϵ 10,400). Since it was the major product, it was not unreasonable to assume that its carbonyl group was at the unhindered 7 position, a supposition supported by the facile formation of a 2,4-dinitrophenylhydrazone. The nmr spectrum displayed the C-10 methyl signal at 1.28 ppm, 24 Hz downfield from that of 2.¹³ Hence ketone C was

(8) This represents a paramagnetic shift of 19 Hz relative to 13 β -abietan-18-oic acid (2).⁴ In the steroid series the $\Delta^{s_1s_2}$ -11-oxo grouping deshields the C-10 methyl group by 17 Hz.⁹

(9) R. F. Zürcher, Helv. Chim. Acta, 46, 2054 (1963).

(10) D. H. Williams, N. S. Bhacca, and C. Djerassi, J. Amer. Chem. Soc., 85, 2810 (1963).

(11) The 12-Hz splitting arises from geminal spin coupling to the 1α proton; the broadening is the result of small couplings to the 2α , 2β , and 3α protons (w coupling).¹²

(12) N. S. Bhacca and D. H. Williams, "Applications of NMR Spectroscopy in Organic Chemistry," Holden-Day, Inc., San Francisco, Calif., 1964, pp 115-121.

(13) Cf. the 24-Hz paramagnetic shift produced by a Δ^{4} -3-oxo function on the C-10 methyl group of steroids.⁹



Figure 1.—Possible ring-C conformations of 3.

assigned formula 7. In accordance with this deduction, further oxidation of 7 with t-butyl chromate gave 6 although the yield was low (15%) and much starting material was recovered.

Hydroxy ketone D, C₂₁H₃₂O₄, mp 126-127.5°, had a conjugated carbonyl group (ir band at 1662 cm⁻¹, λ_{max} 247 mµ, ϵ 12,000) and was rapidly oxidized to 6 by Jones reagent.¹⁴ Hence the oxygen functions were at C-7 and C-11. In the nmr spectrum the proton geminal to the hydroxyl group appeared as a broadened multiplet $(w_{1/2} \sim 11 \text{ Hz})$ at 4.47 ppm. If the carbonyl group were at C-11, the characteristic doublet (J = 12 Hz) of the deshielded 1β proton should be present near 2.9 ppm. While there was a slightly broadened one-proton doublet at 2.90 ppm the splitting was only 7 Hz and the signal disappeared on addition of D₂O, thus identifying the doublet as being due to the hydroxyl proton. Simultaneously, the signal at 4.47 ppm sharpened considerably $(w_{1/2} \sim 7 \text{ Hz})$. Hence the proton geminal to the hydroxyl group was equatorial or quasi-equatorial.¹⁵ Since the 1β proton was not deshielded, the carbonyl group was attached to C-7 and the hydroxyl group to C-11. Location of the hydroxyl group at the relatively hindered 11 position also accounted for the appearance of the hydroxyl proton as a doublet, exchange being sufficiently slow to allow coupling with the C-11 proton. The latter could be either α or β oriented and still be quasi-equatorial depending on the conformation of ring C, as shown in Figure 1. However, since the resonance of the C-10 methyl group was at 1.28 ppm, identical with that of the C-10 methyl group of 7, it experienced no additional deshielding due to the hydroxyl group, an observation which was inconsistent with structure B of Figure 1. Hence the hydroxy ketone had to be 8.

The keto alcohol E, $C_{21}H_{30}O_5$, mp 183–185°, was an unconjugated ketone (ir band at 1708 cm⁻¹). The nmr spectrum displayed a broadened doublet of triplets (J = 10.5, 3.2 Hz) at 4.31 and a sharp doublet (J =10.5 Hz) at 2.45 ppm. Addition of deuterium oxide caused disappearance of the 2.45-ppm doublet and collapse of the 4.31-ppm signal to a broadened triplet (J = $3.2, w_{1/2} = 8 \text{ Hz})$, thus identifying the former as a hydroxyl proton and the latter as an equatorial or quasiequatorial proton geminal to the hydroxyl group. The similarities to the nmr spectrum of **8** were apparent and suggested that the hydroxyl group occupied the 11 α position.

The fifth oxygen atom to be accounted for was tentatively ascribed to the presence of an α -oriented 8,9 epoxide α to a ketone group at C-7, introduced as the result of attack from the less hindered α face as in 9. The formation of α -keto epoxides during chromate oxi-

(14) L. F. Fieser and M. Fieser, "Reagents for Organic Synthesis," John Wiley & Sons, Inc., New York, N. Y., 1967, p 142.
(15) Reference 12, pp 49-52.



Figure 2.—Conformation of 9.

dations has been reported previously.^{16,17} The chemical shift of the C-10 methyl signal (0.92 ppm) which represents a deshielding of only 4 Hz relative to 2 appeared at first to be inconsistent with the proposed structure 9, since an $8,9-\alpha$ -epoxide function alone should deshield the C-10 methyl group by 11 Hz.⁷ However inspection of a model of 9 suggested that the conformation shown in Figure 2, with the isopropyl group equatorial and ring B in a conformation approaching that of a boat, would be preferred owing to the removal of an interaction between the C-10 methyl group and the 6β hydrogen. In this conformation, the 7-keto function would now be expected to exert a shielding effect on the C-10 methyl group.

The proposed conformation also accounted for one other feature of the nmr spectrum, a sharp doublet of doublets at 2.84 ppm (J = 10.5, 8 Hz). This resonance was at too low a field to be ascribed to one of the C-6 methylene protons,¹⁸ both of which are accounted for by a two-proton multiplet at 2.10–2.35 ppm. However, in the proposed conformation of Figure 2 the carbonyl group would be expected to deshield strongly the 14- β hydrogen atom whose resonance should appear as a doublet of doublets due to geminal splitting by 14α -H and vicinal axial-quasiaxial splitting by 13α -H, as actually observed. The ORD curve of **9** displayed a weakly negative Cotton effect in accord with the "inverted octant rule."¹⁹

Verification of structure 6 assigned to the enedione B was obtained in the following manner (Scheme I). Hydroboration-oxidation of methyl 133-abiet-7,9(11)dien-18-oate (10b) with excess diborane afforded a mixture, the principal constituent of which (30-35%) was a diol. Its nmr spectrum contained a two-proton singlet at 2.60 ppm, which vanished on addition of D_2O , and two signals characteristic of protons geminal to hydroxyl groups at 4.17 and 3.81 ppm. The small half-height widths $(w_{1/2} = 6 \text{ and } 7 \text{ Hz})$ signified that both hydroxyl groups were axial. Since hydroboration involves cis addition to the two double bonds, this required formula 11 for the diol. The nmr spectrum also displayed a broadened one-proton doublet (J = 12.5 Hz) at 2.33 which could be assigned to 5α -H deshielded by 7α -OH and the carbomethoxy group. The large splitting arises from diaxial coupling to 6β-H and broadening results from small coupling to the equatorial 6α -H and still smaller "w" coupling to the C-4 and C-10 methyl groups.

Brief treatment of 11 with Jones reagent, conditions which would not be expected to epimerize the B/C ring

(17) H. Heusser, G. Saucy, R. Anliker, and O. Jeger, Helv. Chim. Acta, 35, 2090 (1952).





junction,²⁰ afforded the diketone 12 (double intensity carbonyl band at 1700 cm⁻¹ as well as ester band at 1720 cm⁻¹) which was epimerized to a second diketone 13 (double-intensity carbonyl band at 1705 cm⁻¹, C-10 methyl signal at 1.31 ppm as expected for a *trans*-B/C fused 7,11 diketone).²¹ The diketone 13 was identical with a compound produced in 80% yield by zinc-acetic acid reduction of 6.²² Hence the carbonyl groups of 6 were indeed located at C-7 and C-11.

Comparison of the retention times showed that 12 was more polar than 13 as could be predicted from the models which indicated that the 11-keto group of 12 should be relatively unhindered, while that of 13 would be subject to the normal encumbrances found also in 11-keto steroids. As expected on the basis of the models, 12 furnished a dithioketal 14 which was converted into *trans-anti-cis*-methyl 8α , 13β -abietan-18oate (3b) of established configuration.⁴ On the other hand, treatment of 13 with a molar excess of ethanedithiol gave only a monothioketal, (80%), presumably 15, because the infrared spectrum displayed two carbonyl bands of equal intensity at 1722 (ester) and 1710

(21) The observed downfield shift of 26 Hz relative to the C-10 methyl signal of 2 compares adequately with the sum of the deshielding effects of a 7-oxo group (16.5 Hz) and an 11-oxo group (13.5 Hz).⁹

⁽¹⁶⁾ L. F. Fieser, J. Amer. Chem. Soc., 75, 4395 (1953).

⁽¹⁸⁾ Reference 12, p 65.
(19) P. Crabbé, "Optical Rotatory Dispersion and Circular Dichroism in Organic Chemistry." Holden-Day, Inc., San Francisco, Calif., 1965.

⁽²⁰⁾ R. E. Ireland and P. W. Schiess, Tetrahedron Lett., 37 (1960).

⁽²²⁾ Zinc-acetic acid reduction of 7,11-dioxo- $\Delta^{5,9}$ steroids and triterpenes yields stable *trans*-7,11 diketones.^{23,24}

⁽²³⁾ L. F. Fieser, J. E. Herz, and W. Y. Huang, J. Amer. Chem. Soc., 73, 2397 (1951).

⁽²⁴⁾ L. F. Fieser and J. E. Herz, ibid., 75, 121 (1953).

 cm^{-1} (11 ketone), and the nmr spectrum contained a slightly broadened four-proton singlet at 3.24 ppm.²⁵ Confirmation for structure 15 was the diamagnetic shift of the C-10 methyl assigned to 1.14 (12 Hz upfield relative to 13) since the strong deshielding effect of the 7-keto group has been removed and a 7-thioketal group deshields by only 2.5 Hz.²⁶ The ORD curve exhibited a negative Cotton effect of moderate amplitude as predicted by the octant rule, the main contributing factor being the thicketal group which falls mostly in the upper right rear (negative) octant. Because epimerization may occur in the course of thicketal formation.⁴ alternative formulas such as 16 were also considered. Structure 16 would not be expected to show a Cotton effect of moderate amplitude, although the actual sign of the Cotton effect would be difficult to predict since all contributing factors appear to cancel. The 7-monothicketal derivative of 12 would be expected to give a negative Cotton effect but would have been converted into 14 in the presence of excess dithiol.

Desulfurization of 15 afforded the desired methyl 11- $\infty - 13\beta$ -abietan-18-oate (17) whose inspectrum exhibited an intense carbonyl band at 1712 cm^{-1} due to the ester and the ketone function. The C-10 methyl resonance appeared at 1.09 ppm ($\Delta\delta$ 13 Hz relative to 2, in accordance with the Zürcher⁹ value of 13 Hz). The nmr spectrum also displayed signals due to three protons in the region 2.1-2.6 ppm, apparently a narrow twoproton doublet (J = 3.2 Hz) at 2.34 ppm being superimposed on a broadened one-proton doublet (J = 12)Hz) at 2.44 ppm. The former could reasonably be assigned to the 12-methylene protons coupled equally to 13α -H which bisects the angle subtended by them, if one assumes that 12α - and 12β -H have the same chemical shift. The latter could be assigned to 1β -H which is deshielded by the 11-keto group and coupled to 1α -H.²⁷ Deuteration of 17 resulted in disappearance of the narrow two-proton doublet, a result consistent only with the assigned formula.²⁸

The ORD curve of 17 displayed a negative Cotton effect, an observation which initially caused some concern since 11-keto steroids with *trans* B/C ring junctions display weakly positive Cotton effects.¹⁹ However, ring D which falls in the upper left rear (positive) octant is absent. The isopropyl group of 17 should give a positive contribution since its most likely orientation places two carbon atoms in the upper left rear octant and leaves one carbon atom with no contribution or in the upper left front (negative) octant. Negative contri-

 $(27)\,$ Compare with the nmr spectrum of and rostan-11-one which exhibits very similar signals. 10 butions should be forthcoming from C-2 (lower right front), C-6 and C-7 (upper right rear), and the carbomethoxy group in its most likely orientation. Hence a negative Cotton effect appears to be compatible with structure 17.

The pronounced steric hindrance of 11-keto steroids was apparent in the present instance also. The carbonyl group of 17 was unreactive toward 2,4-dinitrophenylhydrazine and sodium borohydride although forcing conditions²⁹ resulted in the formation of hydroxy ester 18. The β orientation of the hydroxyl group, predictable on steric grounds, was apparent from the nmr spectrum which displayed a narrow quartet (J = 3 Hz) at 4.25 ppm characteristic of the 11 α proton which should be equally coupled to the three vicinal protons. The C-10 methyl resonance appeared at 1.14 ppm, deshielded by 15.5 Hz relative to 2 and in excellent agreement with the predicted³ value.

Although a route to 17 had now been developed, it was somewhat circuitous and the yield of the critical intermediate 6 was low. The accompanying paper³⁰ describes our failure to obtain 17 more directly by lithium-liquid ammonia reduction of 5, the results being unusual in that *cis* B/C ring fusion was produced. This failure induced us to explore other methods for the synthesis of 11-oxygenated abietanes. Attention was therefore directed to the preparation of compounds containing a 9,11 double bond³¹ whose hydroboration might be expected to occur from the α face to give 11 α hydroxy derivatives with the normal *trans* B/C ring fusion.³²

The epoxide 19' (Scheme II) appeared to be a suitable precursor since a short sequence of reactions beginning with a 4,4-dimethyl- 8α , 9α -oxido steroid had accomplished a similar objective.³³

Treatment of 4b with *m*-chloroperbenzoic acid (Scheme II) gave in addition to 19 about 15% of a less polar product whose properties were consonant with formula 20. This substance would be expected to be less polar than 19 since its epoxide function is less "accessible" because of its proximity to the C-10 methyl group.

Reduction of 19 with lithium-ethylamine in the presence of t-butyl alcohol gave a mixture of two components readily separable by chromatography. The minor, less polar product (20%) was identified as 21a by comparison with material produced more directly by lithium aluminum hydride reduction of 4b.³⁴ The more polar product (60–65%) was the desired diol 22a. A broadened two-proton signal at 2.78 ppm disappeared on addition of deuterium oxide, thus corroborating the presence of two hydroxyl groups. The C-10 methyl group resonated at 1.00 ppm, 8 Hz downfield relative to

(29) W. S. Allen, S. Bernstein, and R. Littell, J. Amer. Chem. Soc., 76, 6116 (1954).

(30) W. Herz and J. J. Schmid, J. Org. Chem., 34, 3473 (1969).

(31) Attempts to prepare such a compound by selective hydrogenation of **10a** were unsuccessful. Regardless of catalyst, the product mixture contained 80% **4a** and 20% dehydroabietic acid, the latter presumably arising via a disproportionation reaction.

(32) M. Nussim and F. Sondheimer, Chem. Ind. (London), 400 (1960);
 M. Nussim, Y. Mazur, and F. Sondheimer, J. Org. Chem., 29, 1120 (1964).
 (33) J. Fried, J. W. Brown, and M. Applebaum, Tetrahedron Lett., 849

(1965). (34) The analogous $\Delta^{3,9}$ derivative was obtained in the 4,4-dimethyl

steroid series.³³ In the present work, reduction of the carbomethoxy group proceeded more readily than reduction of the epoxide function and could not be avoided.

⁽²⁵⁾ The nmr spectrum of 14 displayed the methylene protons of the thioketal rings as a slightly broadened four-proton singlet superimposed on a complex four-proton multiplet. Comparison with the nmr spectra of a number of other thioketals established that the nonequivalent protons belong to the methylene groups of the 11-thioketal ring and that the 7-thioketal methylene groups give rise to a slightly broadened singlet. This affords a facile means for distinguishing between 7- and 11-ketoperhydrophenanthrenes.

⁽²⁶⁾ Compare with the effect of a 7-thioketal group on the C-10 methyl resonances of 14 ($\Delta\delta$ 2.5 Hz) and 31b ($\Delta\delta$ 2.5 Hz).

⁽²⁸⁾ A priori one might have expected the resonance of 9α -H in the 2.0-2.6-ppm region as well, but it was comforting to find that the nmr spectrum of androstan-11-one did not display it in this region either. Williams, Bhacca, and Djerassi¹⁰ suggested that the 9α proton normally resonates at relatively high field in the methylene region of androstane and that the paramagnetic shift caused by the carbonyl group is insufficient to move it into the "visible" region. In the nmr spectrum of deuterated **17** there was a noticeable decrease in the intensity of the methylene region near 1.18 ppm which suggested that the envelope contained the signal of the 9α proton prior to deuterium exchange.



2, which was in agreement with the predicted value.³⁵ Since oxidation of 22a gave an unpromising mixture, the primary hydroxyl group was protected as the ace-

(35) A 9a-hydroxyl group deshields the C-10 methyl group by 8.5 Hs.*

tate prior to dehydration. Treatment of 22b with thionyl chloride-pyridine (conditions which in the 4,4dimethyl steroid series had effected smooth introduction of a 9,11 double bond) gave an inseparable mixture of 21b (60%) and 23 (40%), the analysis being based on the methyl resonances at 0.99 (of 21b) and 1.05 ppm (of 23).³⁶ Lithium aluminum hydride reduction of the mixture followed by hydroboration-oxidation under the modified conditions of Sondheimer and Wolfe³⁷ afforded another mixture, the two predominant components of which were isolated by preparative tlc.

The less polar of the major products (55%) yield based on 23) was a diol whose nmr spectrum displayed a hydroxylic two-proton singlet at 2.33 (disappears on deuterium exchange), AB doublets at 3.08 and 3.43 (J = 11 Hz) of the hydroxymethyl group, and a triplet of doublets (J = 10, 5 Hz) at 4.10 ppm characteristic of the axial 11β proton in the expected product 24. However, the chemical shift of the C-10 methyl group (1.09 ppm) was perplexing since its paramagnetic shift relative to 2 (13.5 Hz) was considerably larger than predicted (7.0 Hz).⁹ To resolve this discrepancy, the diol was oxidized with Jones reagent. Methylation furnished a mixture containing 20% 17 and a new ketone (80%) which would not be separated satisfactorily but was isomerized completely to 17 on treatment of the mixture with base. Since 17 is stable to acid and to base (vide supra), it was clear that the new ketone represented an initial oxidation product 25 which was partially isomerized to 17 under the acidic reaction conditions.³⁸ Subtraction of the ORD curve of pure 17 from the curve of the ketone mixture led to calculation of a weak Cotton effect for the new ketone which was in accordance with the one predicted for 25 by the octant rule.

Since hydroboration-oxidation proceeds in a *cis* fashion, the precursor of 25 had to be formulated as 26. Formula 26 accounts for the chemical shift of the C-10 methyl resonance which is deshielded by only 2 Hz relative to 8β , 9β , 13β -abietan-18-oic acid.³⁰ This is reasonable; inspection of a model (Figure 3) shows that the 11 β -hydroxyl group does not exert a significant influence on the C-10 methyl group.

That some 24 was also formed during hydroboration of the mixture of 21b and 23 was shown by lithiumliquid ammonia reduction of 17. This furnished authentic diol 24 which had identifying nmr signals at 3.63 (triplet of doublets, J = 9.5, 5.0 Hz, axial H-11), 2.37 (doublet, J = 11.5, 1β proton deshielded by equatorial C-11 hydroxyl), and 1.00 ppm (C-10 methyl, $\Delta \delta 8.5$ relative to 2, predicted 7 Hz). Its tlc retention time was identical with one of the minor hydroboration products. The predominant formation of 26 as the result of attack by diborane on the β face of 23 is, however, contrary to observations in the steroid series and may be due to the circumstance that of the two possible conformations of ring C in 23 (Figure 4), B in which the isopropyl group is equatorial is probably preferred. In this conformation the isopropyl group no longer obstructs attack on the β face and the α face appears to be more hindered. In $\Delta^{9,11}$ steroids this choice of con-

(36) This represents a paramagnetic shift of 11.5 Hz relative to $\mathbf{3}$, compared with the Zürcher' value of 8.5 Hz.

(37) F. Sondheimer and S. Wolfe, Can. J. Chem., 37, 1870 (1959).

(38) Attempts to prepare 25 in pure form by reducing the reaction time failed because of incomplete oxidation of the primary alcohol function.

formations is not available owing to the attachment of ring D. The C-13 methyl group must remain axially oriented and severely hinders attack on the double bond from the β face.

Conformation B also affords an explanation for the observation that the paramagnetic shift of the C-10 methyl group was 3 Hz greater than predicted.⁹ The deshielding constant is derived from the nmr spectra of compounds in conformation A. In B, the C-10 methyl group "sees less" of the remaining carbon skeleton which results in an additional small downfield shift.³⁹

We now return to consideration of the second major product isolated from hydroboration-oxidation of the mixture of 21b and 23. Since very little 21b was recovered from the mixture of hydroboration products, it was logical to conclude that this new substance, a very polar diol, was produced by hydroboration of 21b. This was indeed the case. Hydroboration of pure 21b furnished the new diol in 60% yield, together with several other, less polar products. Since the hydroxyl group was secondary and equatorial (relatively narrow one-proton signal at 3.80 ppm, $w_{1/2} = 5.5$ Hz), migration of the double bond and subsequent hydroboration had to be called upon. Although isomerization of organoboranes is well documented, it usually occurs only at elevated temperatures, but a few examples of isomerization at room temperature have been reported.40-42 However, rearrangement of organoboranes is catalyzed by the presence of excess boron-hydrogen single bonds,⁴³ as was the situation in the present work.

In view of the relatively high yield of the diol and the mild reaction conditions, it seemed unlikely that the migration had proceeded beyond the first stage.44 Keeping in mind the requirements for cis addition and for the presence of an axial secondary hydroxyl group, a decision had to be made between two possible structures, 28a and 29. The latter seemed less probable, because migration normally proceeds toward a less hindered position, and was eliminated when oxidation of the diol followed by reesterification did not give the known³⁰ 8α , 13β -11 ketone. Hence the diol was **28a** and arose by hydroboration of the intermediate 27 from the less hindered α face. Additional spectral evidence was the small diamagnetic shift of the C-10 methyl resonance (1 Hz) relative to 3a (predicted⁹ shift 0.5 Hz) and the small paramagnetic shift (1 Hz) on acetylation to 28b (predicted⁹ 1 Hz).

Direct correlation of 28a with a substance of known configuration was achieved as follows. Treatment of the dimesylate 28c with lithium aluminum hydride in ether resulted in a 1:1 mixture of 30^{45} and an olefin which was difficult to separate. Hydrogenation of the mixture afforded pure 30 which was oxidized to 3a. Hence the configuration of 28a was confirmed. The olefinic component of the mixture was assigned structure

- (39) Reference 12, p 19.
- (40) P. Pesnelle and G. Ourisson, J. Org. Chem., 30, 1744 (1965).
- (41) B. E. Cross and P. L. Myers, J. Chem. Soc., 471 (1968).
- (42) A. M. Krubiner, N. Gottfried, and E. P. Oliveto, J. Org. Chem., 33, 1715 (1968).
- (43) H. C. Brown and G. Zweifel, J. Amer. Chem. Soc., 88, 1433 (1966).
- (44) Increase in the reaction time greatly reduced the diol yield, presumably owing to further isomerization. Decrease in the reaction time resulted in recovery of a significant amount of starting material.
- (45) In our experience (unpublished work with Y. Y. Lin) the relatively hindered C-19 mesylate function suffers oxygen-sulfur cleavage on exposure to lithium aluminum hydride in ether, while less hindered mesyl groups are displaced by hydride ion.



Figure 4.—Conformations of 23.

31 arising from bimolecular *trans*-diaxial elimination of the 7α -mesyl group⁴⁶ because of the nmr spectrum which exhibited a slightly broadened two-proton singlet at 5.56 ppm ($w_{1/2} = 3$ Hz).⁴⁸

Attempts to convert 28a into the corresponding keto acid 33 by treatment with excess Jones reagent produced a complex mixture owing to epimerization at C-8 and overoxidation. In an alternate approach to 33hydroboration-oxidation of 4b under conditions which would minimize reduction of the carbomethoxy group was considered since conversion of 32 into 33 should



(46) The high proportion of elimination product can be ascribed to steric hindrance to backside displacement by hydride ion (i). Hanson and White⁴⁷ observed that the equatorial mesylate ii underwent elimination rather than displacement.



(47) J. R. Hanson and A. F. White, *Tetrahedron*, **24**, 2533 (1968). (48) The shape of the signal indicates that the chemical shift of the two protons is nearly identical which is not unreasonable when a model is examined. The slight broadening would be the result of small vicinal or allylic couplings to the protons at C-5 and C-8. The C-10 methyl signal had $\Delta\delta$ 7 Hz relative to **3a** in accordance with expectations.⁹



Figure 5.—Conformation of 33.

not require the prolonged exposure to oxidizing agent necessary in the case of 28a. Although reduction of the carbomethoxy group could not be avoided altogether. 32 was in fact obtained in 35% yield. Its nmr spectrum, like that of 28a, exhibited the C-10 methyl resonance at 1.05 ppm; an added feature was a broadened doublet at 2.30 ppm (J = 12.5 Hz) which could be assigned to the 5α proton now being deshielded by the carbomethoxy as well as by the 7α -hydroxyl group.⁴⁹

Brief exposure of 32 to Jones reagent in the hope of avoiding epimerization of the initially formed *cis* fused ketone 33 resulted, nevertheless, in the formation of a 4:1 mixture of 33 and 34 which could not be separated satisfactorily. Treatment of the mixture with base produced pure 34 which had a negative Cotton effect of moderate amplitude as would have been predicted from the octant rule since C-2, C-3, and a major portion of the carbomethoxy group fall into the upper right rear octant. C-12 resides in the upper left rear octant. The only other contribution comes from the isopropyl group which is in the lower left rear octant.

In the nmr spectrum of 34 the C-10 methyl resonance appeared at 1.08 ppm ($\Delta\delta$ 13 Hz relative to 2).⁵⁰ Signals in the region 2.0-2.5 ppm integrated for five protons rather than three and after deuteration for two. This is consistent with the model of 34 which indicates that both protons attached to C-14 should be deshielded by the 7-keto group.

An interesting feature of the nmr spectrum of 33, obtained by subtraction of the signals of 34 from the spectrum of the mixture, was the appearance of the C-10 methyl resonance at 1.03 ppm ($\Delta \delta - 2$ Hz relative to **3a**). If ring B had the normal chair configuration, the 7-keto group would be expected to exercise a much stronger deshielding effect. Inspection of the model (Figure 5) shows that if ring B assumes the five atoms in a plane conformation⁵¹ ring C is removed from the proximity of the methyl group, thus lessening some severe interactions. This conformation would result in a substantial diamagnetic shift of the C-10 methyl resonance. The strongly negative Cotton effect of 33 obtained by subtracting the ORD curve of 34 from the curve of the mixture would be in accord with either the normal chair form or the one depicted in Figure 5 since C-2, C-3, the carbomethoxy function, C-13, C-14, and the isopropyl group all lie in negative octants.

Experimental Section⁵²

133-Abiet-8(9)-en-18-oic Acid (4a).-The procedure used for preparation of this substance was somewhat modified from that described in the literature.53 Abietic acid was partially hydrogenated at 1 atm in absolute ethanol with 5% Pd-C until the rapid uptake of hydrogen ceased (approximately 15 min). The resulting mixture of dihydro- and tetrahydroabietic acids was dissolved in chloroform, and hydrogen chloride was bubbled in for 2 hr. The solution was washed, dried, and evaporated. The residue was recrystallized from methanol until the nmr spectrum indicated the required degree of purity, yield 30-40%.

Oxidation of 4b with t-Butyl Chromate.—A solution of 1.0 g of 4b in 18 ml of carbon tetrachloride was mixed with 14.5 ml of t-butyl chromate solution⁵⁴ and refluxed for 16 hr. The solvent was allowed to evaporate; the residue was diluted with water and extracted with ether. The ether extract was washed, dried, evaporated, and taken up in hexane and chromatographed over alumina. Elution was accomplished with ether-hexane solution of varying polarity. Eluted in order were 5, 6, 7, and 8. The keto alcohol was isolated subsequently from a much larger run when it precipitated from a hexane solution of the crude product mixture prior to chromatography.

The first fractions contained 5 (15% yield) which was recrystallized from methanol and had mp 108-109°; $[\alpha]^{25} + 104^{\circ}$ (EtOH, c 0.774); ir 1720, 1250 (ester) and 1650, 1605 cm⁻¹ (conjugated enone); λ_{max} 245.5 nm (ϵ 11,500); nmr 3.62 (methoxy) 2.90 d br $(J = 12, \beta H-1)$, 1.20 (C-4 methyl), 1.19 (C-10 methyl), and $0.88 \,\mathrm{d}\,\mathrm{ppm}\,(J = 5.9, \mathrm{isopropyl})$. The substance did not react with 2,4-dinitrophenylhydrazine reagent.

Anal. Calcd for C21H32O3: C, 75.86; H, 9.70; O, 14.44. Found: C, 76.04; H, 9.75; O, 14.49.

Fractions containing 6 (15%) were always contaminated with 5 or 7. Purification was achieved by preparative tlc and re-crystallization from cold methanol. The product had mp 88-89.5°; $[\alpha]^{25}D + 87^{\circ}$ (CHCl₃, c 1.03); ir 1725, 1250 (ester), and 1672, 1605 cm⁻¹ (enedione), λ_{max} 265 nm (ϵ 8900); nmr 3.62 (methoxyl), 2.82 d br (J = 12, β H-1), 1.31 (C-10 methyl), 1.28 (C-4 methyl), and 0.95 d ppm (J = 5.5, isopropyl). Anal. Calcd for $C_{21}H_{30}O_4$: C, 72.80; H, 8.73; O, 18.47.

Found: C, 72.48; H, 8.72; O, 18.85.

Ketone 7 (35%) was an oil: ir 1725, 1250 (ester), and 1650, 1605 cm⁻¹ (conjugated enone), λ_{max} 248 nm (ϵ 10,400); nmr 3.62 (methoxyl), 1.28 (C-10 methyl), 1.11 (C-4 methyl), 0.89 d ppm (J = 6.5, isopropyl). The red-orange 2,4-dinitrophenylhydrazone was purified by chromatography over Florisil and recrystallization from ethanol and melted at 169°

Anal. Calcd for C₂₇H₃₆O₆N₄: C, 63.26; H, 7.08; N, 10.93. C, 62.79; H, 6.93; N, 11.05. Found:

Oxidation of 0.5 g of 7 in 20 ml of carbon tetrachloride with 8 ml of t-butyl chromate solution under reflux for 22.5 hr and work-up as described at the beginning of this section gave on chromatography over alumina 80 mg of 6 and ca. 300 mg of recovered starting material. Elution with methanol furnished 100 mg of a very polar mixture of hydroxylated ketones.

Hydroxy ketone 8 (10%) was recrystallized from petroleum ether and had mp $126-127.5^{\circ}$; $[\alpha]^{25}D + 79^{\circ}$ (CHCl₃, c 0.99); λ_{max} 247 nm (ε 12,000); ir 3600 (hydroxyl), 1721, 1200 (ester), 1662, 1619 cm⁻¹ (conjugated enone); nmr 4.47 m ($w_{1/2} = 11$, β H-11), 3.64 (methoxyl), 2.90 d (J = 7, hydroxyl), 1.28 (C-10 methyl), 1.11 (C-4 methyl), and 0.92 d (J = 5.8, isopropyl).

Anal. Caled for C21H32O4: C, 72.38; H, 9.26; O, 18.37. Found: C, 72.61; H, 9.23; O, 18.17

Dropwise addition of Jones reagent¹⁴ to a stirred solution of 75 mg of 8 in acetone until the brown color persisted, destruction of

⁽⁴⁹⁾ Compare with a similar signal in the nmr spectrum of 11

⁽⁵⁰⁾ The deshielding value of the 7-keto group in the 8β and 9β series was invariably 12-13 Hz (cf. 13, 28, and 29b) instead of the Zürcher⁹ constant of 16.5 Hz. The reason for this small but constant difference is not apparent.

⁽⁵¹⁾ N. L. Allinger and M. DaRooge, J. Amer. Chem. Soc., 84, 4561 (1962).

⁽⁵²⁾ Melting points are uncorrected. Analyses were performed by F. Pascher, Bonn, Germany. Nmr spectra were run on a Varian A-60 in deuteriochloroform with tetramethylsilane. Apparent coupling constants are given in hertz. Multiplicities are expressed as follows: d. doublet: t, triplet; br, broadened singlet; m, unresolved multiplet. Deuterium exchange for nmr studies of ketones was performed by the method of Williams, Bhacca, and Djerassi.¹⁰ Ir spectra were run in chloroform on a Perkin-Elmer Infracord or Model 257 grating spectrometer. Uv spectra were recorded in 95% ethanol on a Cary 14 spectrophotometer. Rotations were measured in 95% ethanol or chloroform, as specified. Optical rotatory dispersion curves were obtained on a JASCO ORD/UV-5 recording spectrophotometer in methanol. Column chromatograms were run using Alcoa F-20 alumina (basic or neutralized by washing with ethyl acetate) unless otherwise specified. Silica gel PF254+ 866 (Merck) was used for preparative tlc, silica gel G for analytical tlc. Petroleum ether was low boiling (30-60°). (53) L. Velluz, G. Muller, A. Petit, and J. Mathieu, Bull. Soc. Chim. Fr.,

^{21, 401 (1954).} (54) W. Herz, A. R. Pinder, and R. N. Mirrington, J. Org. Chem., 31,

^{2257 (1966).}

excess reagent with methanol, dilution with water, and extraction with ether gave, after washing, drying, and evaporating in vacuo, 70 mg of 6, mp 88-89.5°, mixture melting point undepressed, nmr and ir spectra superimposable.

The epoxide 9 (vide supra) was recrystallized twice from methanol and had mp 183-185°; ir 3600 (hydroxyl), 1726, 1230 (ester), and 1708 cm⁻¹ (ketone); nmr 4.31 br dt (J = 10.5, 3.2, β H-11), 3.67 (methoxyl), 2.84 dd (J = 10.5, 8.0, β H-14), 2.45 d (J = 10.5, hydroxyl), 1.18 (C-4 methyl), 0.92 (C-10 methyl), and 0.88 d (J = 6.1, isopropy); ORD curve $(c \ 0.45)$, $[\alpha]_{400}$ -27°, $[\alpha]_{225}$ -385°, $[\alpha]_{275}$ +677°. Anal. Calcd for C₂₁H₃₂O₅: C, 69.58; H, 8.34; O, 22.07. Found: C, 69.63; H, 8.85; O, 21.95.

Attempts to prepare 9 from 8 by epoxidation with m-chloroperbenzoic acid or alkaline hydrogen peroxide resulted in recovery of starting material.

The balance of the material from the *t*-butyl chromate oxidation of 4b was a mixture (15-25%) of very polar hydroxylated material which was eluted with methanol. Attempts to increase the yield of 11-oxygenated products by employing an excess of oxidant increased the yield of highly polar material.

Methyl 7α , 11α -Dihydroxy- 8α , 13β -abietan-18-oate (11). — To a solution of 0.7 g of 80% pure 10b and 0.19 g of sodium borohydride in 30 ml of diglyme was added 0.721 g of boron trifluoride ethereate at ice bath temperature in a nitrogen atmosphere over 30 min. The mixture was stirred at room temperature for 3 hr, chilled, and gradually diluted with 15 ml of 3 N sodium hydroxide solution followed by 15 ml of 30% hydrogen peroxide solution. After several hours at room temperature, the mixture was poured into water and extracted with ether. The washed and dried ether extracts were evaporated at reduced pressure, the residue heated to 100° in vacuo to remove excess diglyme, and the residual oil, weight 0.71 g, chromatographed over alumina. Elution with benzene-petroleum ether (1:1) gave 0.18 g of 80% pure 10b and elution with ether-benzene (3:7) gave 0.25 g of a mixture of monohydroxy derivatives. Elution with ether-chloroform (4:1) afforded 0.19 g of diol 11 which was recrystallized from methanol-water (1:1). Although it was pure by the usual criteria, it did not melt sharply, apparently owing to sublimation, and had $[\alpha]^{24}D + 35^{\circ}$ (CHCl₃, c 2.25); ir 3600 (hydroxyl) and 1720, 1240 cm⁻¹ (ester); nmr 4.17 and 3.81 ($w_{1/2} = 6.7$, β H-7 and β H-13), 3.63 (methoxyl), 6.20 (two protons, hydroxyls), 2.33 d $(J = 12.5, \alpha H-5)$, 1.21 (C-4 methyl), 1.02 (C-10 methyl), and 0.88 d (J = 6.5, isopropyl).

A nol. Caled for $C_{21}H_{36}O_4$: C, 71.55; H, 10.30; O, 18.15. ound: C, 71.73; H, 10.02; O, 18.03. Found:

Methyl 7,11-Dioxo- 8α ,13 β -abietan-18-oate. (12).—A solution of 80 mg of 11 in acetone was allowed to stand with a slight excess of Jones reagent at room temperature for 10 min and worked up as described for the oxidation of 8. The crude solid residue (75 mg) was recrystallized from methanol-water to give 12 which had mp 133-134°; $[\alpha]^{25}D - 120^{\circ}$ (CHCl_s, c 1.09); ir at 1720, 1240 (ester), and 1700 cm⁻¹ (double intensity, two ketones); nmr 3.63 (methoxyl), 1.23 (C-4 and C-10 methyls), and 0.89 d (J = 6, isopropyl).

Anal. Caled for $\tilde{C}_{21}H_{32}O_4$: C, 72.38 H, 9.26; O, 18.37. Found: C, 72.50; H, 9.25; O, 18.45.

Methyl 7,11-Dioxo-13\beta-abietan-18-oate (13). A.-To 0.2 g of crude enedione 6 (70% pure) in 10 ml of acetic acid was added with stirring and heating 0.1 g of powdered zinc. After 1.5 hr the yellow color of 6 had disappeared. The mixture was filtered, and the filtrate diluted with water and extracted with ether. The washed and dried ether extract was evaporated and the residue, wt 185 mg, chromatographed over alumina. Benzenepetroleum ether eluted a small amount of gum; benzene alone, 105 mg of crystalline material. Recrystallization from methanol-water gave 13 which had mp 123.5–124.5°; $[\alpha]^{35}D - 39^{\circ}$ (CHCl₃, c 0.760); ir 1720, 1230 (ester), and 1705 cm⁻¹ (double intensity, two ketones); nmr 0.91 d and 0.88 d (J = 5.5, isopropyl).

Anal. Caled for $C_{21}H_{32}O_4$: C, 72.38; H, 9.26; O, 18.37. Found: C, 72.56; H, 9.01; O, 18.66.

B.-Treatment of a solution of 60 mg of 12 in methanol-water with methanolic sodium hydroxide for 0.5 hr, acidification, dilution with water, extraction with ether, washing and drying of the ether extract, and evaporation gave 60 mg of an oil. Comparison of tlc retention times and nmr spectra indicated that the product was 13 contaminated by a small amount of a less polar product which was not identified. No starting material was present. Preparative tle gave pure 13 identical in every respect with material obtained in A.

Dithioketal 14.- A solution of 0.1 g of 12 in 2 ml of ethanedithiol was mixed with 1 ml of boron trifluoride ethereate and allowed to stand overnight. The reaction mixture was poured into water and extracted with ether. The ether extract was washed, dried, and evaporated in vacuo. The residue was recrystallized from methanol and furnished 85 mg of 14 which had mp 167-168°; ir 1720 and 1210 cm⁻¹ (ester); nmr 3.62 (methoxyl), 3.28 m (four protons, methylenes of 11-thioketal), 3.23 (four protons, methylenes of 7-thioketal), 1.20 (C-10 methyl), 1.17 (C-4 methyl), and 0.89 d (J = 6, isopropyl). The substance was taken up in 50 ml of absolute ethanol, refluxed with 1 teaspoon of freshly prepared Raney nickel for 25 hr, cooled, filtered, evap-orated, and recrystallized from methanol. The product, wt 50 mg, mp 97–98°, was identical with authentic methyl 8α , 13 β -abietan-18-oate⁴ in every respect (tlc, ir, nmr, mixture melting point).

Thicketal 15.—Reaction of 0.2 g of 13 with ethanedithic in the manner described in the previous paragraph afforded a crystalline residue which was recrystallized from methanol. The product 15, wt 0.19 g, had mp 189–190°; $[\alpha]^{25}$ D –29° (CHCl_s, c 1.35); ir 1722, 1250 (ester), and 1710 cm⁻¹ (ketone); nmr 3.62 (methoxyl), 3.24 (four protons, 7-thioketal methylenes), 1.17 (C-4 methyl), 1.14 (C-10 methyl), and 0.91 d (J = 5.5, isopropyl); ORD curve (c 0.043), [a] 550 -29°, [a] 321 -978°, [a] 278 +1605.

Anal. Calcd for C₂₃H₃₆O₃S₂: C, 65.10; H, 8.55; S, 15.08. Found: C, 65.75; H, 8.58; S, 14.86.

Methyl 11-Oxo-3\beta-abietan-18-oate (17).—A solution of 0.19 g of 15 in 90 ml of absolute ethanol was refluxed with Raney nickel for 24 hr and worked up as described for 14. The crude product, wt 0.15 g, was recrystallized from methanol-water and then had mp 97–98°; $[\alpha]^{24}$ D –45° (CHCl₃, c 0.655); ir 1712 (ester and ketone) and 1250 cm⁻¹ (ester); nmr 3.62 (methoxyl), 1.17 (C-4 methyl), 1.09 (C-10 methyl), 0.91 d, and 0.88 d (J = 5, isopropyl); ORD curve (c 0.18), $[\alpha]_{400} - 139^{\circ}$, $[\alpha]_{321} - 725^{\circ}$, $[\alpha]_{272} + 1380^{\circ}$. This substance was also obtained as a minor product from the lithium-ammonia reduction of 5³⁰ and was formed by base treatment of 25 (vide infra). It was recovered unchanged on acidification of a sodium methoxide-methanol solution which had been refluxed for several hours and was unreactive toward sodium borohydride in methanol and 2,4-dinitrophenylhydrazine.

Anal. Calcd for $C_{21}H_{34}O_3$: C, 75.40; H, 10.25; O, 14.35. Found: C, 75.08; H, 10.39; O, 14.33.

Methyl 113-Hydroxy-133-abietan-18-oate (18).—A solution of 0.6 g of 17 and 1 g of sodium borohydride in 35 ml of tetrahydrofuran and 3 ml of 5% aqueous sodium hydroxide was refluxed for 17 hr, cooled, cautiously acidified with 10% hydrochloric acid solution, diluted with water, and extracted with ether. The ether extract was washed, dried, and evaporated, and the solid residue, wt 0.55 g, was recrystallized from methanol-water. Pure 18, wt 0.47 g, had mp 156–158°; $[\alpha]^{25}D$ +19° (CHCl₃, c 1.55); ir 3600 (hydroxyl) and 1716, 1250 cm⁻¹ (ester); nmr 4.25 d (J = 3.5, H-11), 3.61 (methoxyl), 1.46 (hydroxyl), 1.19 (C-4 methyl), 1.14 (C-10 methyl), 0.96 d, and 0.89 d (J = 6.1, J)isopropyl).

Anal. Caled for C21H36O3: C, 74.95; H, 10.78; O, 14.26. Found: C, 75.63; H, 10.61; O, 14.15.

Epoxidation of 4b.-Thin layer chromatography of the crude product obtained by the method described earlier⁷ showed the presence of a second product (15%) in addition to 19 (75%). Chromatography and recrystallization from methanol-water furnished 20 which had mp 79-81°; $[\alpha]^{25}D + 83^{\circ}$ (CHCl₃, c 4.58); ir 1718 and 1230 cm⁻¹ (ester); nmr 3.62 (methoxyl), 1.13 (C-4 methyl), 1.04 (C-10 methyl), and 0.81 d (J = 6, isopropyl).

Anal. Calcd for C₂₁H₃₄O₃: C, 75.40; H, 10.25; O, 14.35. Found: C, 75.25; H, 10.47; O, 14.19.

Reduction of 19.-To a solution of 1 g of 19 in 30 ml of ethylamine was added with stirring 2 equiv of t-butyl alcohol distilled over calcium hydride followed by an excess of freshly cut lithium until the blue color persisted. After 1 hr of stirring ammonium chloride was added until the blue color was discharged. Work-up as in the lithium-liquid ammonia reduction gave 0.95 g of a mixture which was separated by chromatography over alumina. The less polar product (21a, 20%) was a gum which could not be induced to solidify and had infrared bands at 3600 (hydroxyl); nmr at 3.43 d and 3.15 d $(J = 11, AB d oublets, of <math>-CH_2OH)$, 0.98 (C-10 methyl), 0.85 d (J = 7, isopropyl), and 0.79 ppm (C-4 methyl). This substance was obtained in quantitative yield by lithium aluminum hydride reduction of 4b.

The more polar product 22a (60%) was recrystallized from hexane and had mp 133-135°; $[\alpha]^{25}$ -7° (CHCl₃, c 0.865); ir 3600 cm⁻¹ (hydroxyl); nmr 3.44 d and 3.00 d (J = 11, AB doublets of -CH₂OH), 2.60 br (two protons, hydroxyls), 1.00 (C-10 methyl), 0.89 d (J = 6.5, isopropyl), and 0.76 ppm (C-4 methyl). Anal. Calcd for C₂₀H₃₆O₂: C, 77.86; H, 11.76; O, 10.37. Found: C, 78.03; H, 11.60; O, 10.37.

Acetylation of 0.5 g of 22a with 1 ml of acetic anhydride in 10 ml of pyridine for 12 hr gave 0.51 g of a gum which crystallized on standing. Two recrystallizations from hexane afforded 340 mg of pure 22b which had mp 79-80°; $[\alpha]^{25}D - 18°$; ir 3600 (hydroxyl) and 1715, 1230 cm⁻¹ (acetate); nmr 3.82 d and 3.65 d (J = 10.5, AB doublets of -CH₂OAc), 2.05 (acetate), 1.00 (C-10 methyl), 0.89 d (J = 6.5, isopropyl), and 0.86 ppm (C-4 methyl).

Anal. Caled for C₂₂H₃₈O₃: C, 75.38; H, 10.93; O, 13.69. Found: C, 75.22; H, 10.88; O, 13.77.

Dehydration of 22b.—An ice-cooled solution of 0.3 g of 22b in 15 ml of pyridine was mixed with 0.2 g of thionyl chloride. After 5 hr in the refrigerator it was poured into ice water and extracted with ether. The washed and dried ether extracts were evaporated to give a colorless oil which gave a single spot on tlc, but was a mixture of 21b (60%) and 23 (40%), the composition being determined by the nmr spectrum. The relative yields were not altered by changing the reaction conditions. Attempts to separate the components by chromatography over silica gel impregnated with silver nitrate were not successful. The nmr spectrum of 23 had signals at 5.25 t br (J = 3.6, H-11) and 1.05 (C-10 methyl), the acetate and C-4 methyls being superimposed on those of 21b. The latter (a gum which could not be induced to crystallize) was prepared in pure form by acetylation of 21a. Its spectrum showed ir bands at 1722 and 1230 cm⁻¹ (acetate), and nmr signals at 3.88 d and 3.64 d (J = 11, AB doublets of -CH₂OAc), 2.06 (acetate), 0.99 (C-10 methyl), 0.89 d (J 5.9, isopropyl), and 0.88 ppm (C-4 methyl).

11 β ,19-Dihydroxy-9 β ,13 β -abietane (26).—The mixture of 21b and 23 obtained as described in the previous section was first refluxed with lithium aluminum hydride in ether to ensure complete reduction of the acetate function. A solution of 2.78 (0.009 mol) of the diol mixture in dry ether was added with stirring to a solution of diborane prepared by dropwise addition of 3.70 g (0.027 mol) of boron trifluoride ethereate to a suspension of 0.80 g (0.021 mol) of lithium aluminum hydride in 100 ml of dry ether. After 60 hr at room temperature excess diborane was destroyed with acetone. The mixture was filtered, the solid was washed with ether, and the combined filtrate and washings were evaporated. The residual borane was taken up in 40 ml of ethanol and oxidized by addition of 1 g of sodium hydroxide and 10 ml of 30% hydrogen peroxide solution with stirring. Stirring was continued for 2 hr; the solution was diluted with water and extracted with ether. The washed and dried ether extracts were evaporated; the residue, 2.7 g of gum, was a mixture of two major polar components and several minor ones (tlc) including a weak spot characteristic of 21a. A comparison of tlc retention times identified 24 (vide infra) as a second minor product.

A 180-mg portion of the crude mixture was subjected to preparative tlc. The least polar of the two major bands contained 45 mg of 26 which was recrystallized from methanol-water and had mp 144–145°; $[\alpha]^{25}$ D +22° (CHCl₃, c 0.72); ir 3600 cm⁻¹ (hydroxyl); nmr 4.10 t d (J = 10.5, α H-11), 3.43 d and 3.08 d $(J = 11, AB \text{ doublets of } -CH_2OH), 2.33 \text{ (two protons, hydroxyls),}$ 1.09 (C-10 methyl), 0.85 d (J = 5.5, isopropyl), and 0.75 ppm (C-4 methyl).

Anal. Calcd for $C_{20}H_{36}O_2$: C, 77.86; H, 11.76; O, 10.37. Found: C, 77.76; H, 11.82; O, 10.85.

Oxidation of 80 mg of diol 26 with excess Jones reagent in acetone for 2 hr and work-up in the usual manner yielded 70 mg of an oil which was methylated with diazomethane and then crystallized on standing. Although the solid gave a single spot on tlc in several solvent systems, the nmr spectrum indicated that it was a mixture of 17 (20%) and 25 (80%); ORD curve of the mix-ture (c 0.066), $[\alpha]_{400} - 212^{\circ}$, $[\alpha]_{316} - 410^{\circ}$, $[\alpha]_{272} + 91^{\circ}$. The predominating component 25 displayed nmr signals at 3.61 (methoxyl), 1.19 (C-4 methyl), 0.98 (C-10 methyl), and 0.87 d ppm (J = 5.8, isopropyl). When the mixture was allowed to stand in a solution of 0.25 g of sodium hydroxide in 5 ml of aqueous methanol for 0.5 hr, it was quantitatively isomerized into pure 17: mp 95–98°, mmp 96–98°, nmr and ir spectra superimposable. The more polar of the two bands contained 80 mg of **28a** (*vide*

11 α , 19-Dihydroxy-13 β -abietane (24).—Lithium-liquid ammonia reduction of 150 mg of 17 by the method of Sondheimer and coworkers⁵⁵ gave a crude product which was purified by preparative tlc. There was obtained 35 mg of 24: mp 169-171°; ir 3600 cm⁻¹ (hydroxyl); nmr 3.63 t d ($J = 9.5, 5, \beta$ H-11), 3.39 d and 3.04 d $(J = 11, AB \text{ doublets of } -CH_2OH), 2.37 \text{ d } (J =$ 11.5, β H-1), 1.59 (two protons, hydroxyls), 1.01 (C-10 methyl), 0.86 d (J = 6.5, isopropyl), and 0.79 ppm (C-4 methyl). This material was identical with the minor hydroboration product of 23.

Anal. Calcd for C₂₀H₃₆O₂: C, 77.86; H, 11.76; O, 10.37. Found: C, 77.68; H, 11.80; O, 10.56.

 7α , 19-Dihydroxy- 8α , 13 β -abietane (28a).—A solution of 2.5 g of 4a contaminated with a small amount of dehydroabietic acid in anhydrous ether was reduced with lithium aluminum hydride to 21a which, without isolation, was subjected to reaction with excess diborane and subsequent oxidation in the manner described for the hydroboration of the mixture of 21a and 23. The nmr spectrum of the crude product indicated that 28a had been formed in 60% yield. It was purified by chromatography over neutral alumina. Impurities were eluted with ether-hexane (1:1) and **28a** was eluted with acetone. Recrystallization from methanol afforded 1.2 g of pure **28a**: $[\alpha]^{25}D + 11^{\circ}$; ir 3600 cm⁻¹ (hydroxyl); nmr 3.80 br ($w_{1/2} = 5.5, \beta H$ -7), 3.57 (two protons, hydroxyls), 3.45 d and 2.87 d $(J = 11, AB \text{ doublets of } -CH_2OH)$, 1.05 (C-10 methyl), 0.86 d (J = 5.8, isopropyl), and 0.72 ppm (C-4 methyl). The substance did not melt sharply but gradually sublimed in the capillary. For further characterization it was converted to the diacetate 28b by treatment with acetic anhydride-pyridine, yield 75 mg from 90 mg of 28a. It was recrystallized from methanol and had mp 104–105°; $[\alpha]^{25}$ D – 7° (CHCl₃, c 1.98); ir 1725 (double intensity, esters) and 1260 cm⁻¹; nmr 4.82 br $(w_{1/2})$ $= 6, \beta$ H-7), 3.75 d, and 3.59 d (J = 11, AB doublets of $-CH_2$ -OAc), 2.03 and 2.01 (acetates), 1.07 (C-10 methyl), 1.05 d

(J = 5.7, isopropyl), and 1.04 ppm (C-4 methyl). Anal. Calcd for $C_{24}H_{40}O_4$: C, 73.43; H, 10.27; O, 16.30. Found: C, 73.27; H, 10.26; O, 16.55.

Reaction of 1.5 g of 28a in 12 ml of pyridine with 6 ml of meth-anesulfonyl chloride at 0° for 20 hr followed by dilution with ice water, extraction with ether, washing and drying of the ether extracts, and evaporation of the ether extracts at reduced pressure furnished 2.1 g of crude dimesylate 28c which was recrystallized from ether-hexane. The pure material, wt 1.5 g, had mp 79-80°; $[\alpha]^{25}$ D -13° (CHCl₃, c 1.25); ir 1355, 1332, and 1158 cm⁻¹ (mesylate); nmr 4.76 br ($w_{1/2} = 6$, β H-7), 3.93 d and 3.62 d (J = 9.5, AB doublets of -CH₋₂OMS), 3.03 (six protons, mesylates), 1.08 (C-10 methyl), 0.87 (C-4 methyl), and 0.86 d (J = 5.6, isopropyl). Because the substance decomposed on standing, it was not analyzed.

19-Hydroxy-8 α , 13 β -abietane (30).—A solution of 1.2 g of 28c in dry ether was added gradually to a suspension of 2.4 g of lithium aluminum hydride in dry ether. The mixture was refluxed for 18 hr; excess hydride was decomposed by addition of wet ether and then water. The mixture was shaken with 10%hydrochloric acid solution until both layers were clear. The ether layer was washed, dried, and evaporated. The residue, wt 0.45 g, was a mixture displaying two spots on tlc. Preparative tlc gave 20% of less polar material which was a mixture of dihydro and tetrahydro components resulting from hydride displacement of the primary mesyl group. The nmr spectrum of the more polar band (80%) showed that it was a 1:1 mixture of 30 and 31 as indicated by the relative intensities of the C-10 methyl signals (C-10 methyl of 31 1.07, C-10 methyl of 31 0.96, vinyl proton of 31 5.56 ppm, $w_{1/2} = 3$). Catalytic hydrogenation of 0.2 g of this mixture in 15 ml of absolute ethanol with platinum oxide at 1 atm gave homogeneous 30 which could not be induced to solidify: nmr signals at 3.33 d and 3.04 d (J = 10.5, AB doublets of -CH₂OH), 2.30 (hydroxyl), 1.07 (C-10 methyl), 0.88 d (J = 6, isopropyl), and 0.78 ppm (C-4 methvl).

Oxidation of 30 with excess Jones reagent gave 3a, identical with authentic material⁴ in melting point, mixture melting point, and nmr spectrum

Methyl 7 α -Hydroxy-8 α , 13 β -abietan-18-oate (32).—Hydroboration-oxidation of 4b was carried out with diborane prepared from lithium aluminum hydride and boron trifluoride as in the case of 21a, but without the prior lithium aluminum hydride

infra).

⁽⁵⁵⁾ F. Sondheimer, O. Mancera, G. Rosenkranz, and C. Djerassi, J. Amer. Chem. Soc., 75, 1282 (1953).

reduction step. Reaction time was limited to 21 hr to minimize reduction of the carbomethoxy group. Tlc analysis of the crude product indicated that some reduction of the carbomethoxy group had taken place but chromatography over alumina gave 32 in 35% yield. It was recrystallized from methanol-water and had mp 88-89°; $[\alpha]^{25}D - 11$ (CHCl₃, c 1.81); ir 3600 (hydroxyl) and 1719, 1250 cm⁻¹ (ester); nmr 3.72 br $(w_{1/2} = 6, \beta$ H-7), 3.61 (methoxyl), 2.53 (hydroxyl), 2.30 br d $(J = 12.5, \alpha$ H-5), 118 (C 4 metha) b 10.6 (C 10.6 metha) 1.18 (C-4 methyl), 1.05 (C-10 methyl), and 0.86 d (J = 5.8, isopropyl).

Anal. Calcd for C21H36O3: C, 74.95; H, 10.78; O, 14.26. Found: C, 74.89; H, 10.87; O, 14.25. Methyl 7-Oxo-13β-abietanoate (34).—Oxidation of 0.3 g of

32 in acetone with excess Jones reagent at 0° for 10 min followed by the usual work-up yielded 0.26 g of a mixture of 33 (80%) and 34 (20%) as determined by the nmr spectrum. Preparative the did not effect any purification of 33 which had ir bands at 1720, 1250 (ester), and 1706 cm⁻¹ (ketone); nmr 3.61 (methoxyl), 1.22 (C-4 methyl), 1.03 (C-10 methyl), and 0.86 d (J = 5.9, isopropyl); ORD curve (c 0.22, contaminated with 20% of **34**), $[\alpha]_{400} - 150^{\circ}$, $[\alpha]_{806} - 1140^{\circ}$, $[\alpha]_{767} - 1140^{\circ}$

The mixture, wt 0.1 g, was dissolved in methanol-water (4:1) containing 1 g of sodium hydroxide and was allowed to stand for 38 hr. After acidification of the solution, dilution with water,

extraction with ether, washing, and drying of the ether extract, there was obtained 90 mg of 34 which was recrystallized from methanol-water and then had mp 88-89°; $[\alpha]^{35}D - 19^{\circ}$ (CHCl₃, c 1.14); ir 1720, 1250 (ester), and 1705 cm⁻¹ (ketone); nmr 3.61 (methoxyl), 1.20 (C-4 methyl), 1.08 (C-10 methyl), and 0.87 d (J = 5.6, isopropyl); ORD curve (c 0.055), $[\alpha]_{400} - 27^{\circ}$, $[\alpha]_{299}$ $-200^{\circ}, [\alpha]_{250} + 364^{\circ}$

Anal. Calcd for C21H34O3: C, 75.40; H, 10.25; O, 14.35. Found: C, 75.37; H, 10.07; O, 14.46.

Registry No.—5, 21559-75-1; 6, 21559-76-2; 7, 7 (2,4-dinitrophenylhydrazone), 21559-21562-96-9; 77-3; 8, 21559-78-4; 9, 21559-79-5; 11, 21559-80-8; 12, 21559-81-9; 13, 21559-83-0; 14, 21559-83-1; 15, 21559-84-2; 17, 21559-85-3; **18,** 21559-86-4; 20, 21559-87-5; 21a, 21559-88-6; 21b, 21562-60-7; 22a, 21562-61-8; 22b, 21562-62-9; 23, 21562-63-0; 24, 21562-64-1; **25**, 21562-65-2; **26**, 21562-66-3; **28a**, **28b**, 21562-73-2; **28c**, 21562-68-5; **30**, 21562-67-4; 21562-69-6; 32, 21562-70-9; 33, 21562-71-0; 34, 21562-72-1.

Resin Acids. XVIII. The Lithium-Ammonia Reduction of Some **Resin Acid Enones**^{1,2}

WERNER HERZ AND J. J. SCHMID³

Department of Chemistry, Florida State University, Tallahassee, Florida 32306

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The reduction of $11-\infty-13\beta$ -abiet-8(9)-en-18-oate (3) with lithium-liquid ammonia afforded primarily the less stable B/C cis-fused methyl 11-oxo- 8α , 13 β -abiet-8(9)-en-18-oate (5). Methyl 7-oxo-13 β -abiet-8(9)-en-18-oate (10) gave quite unexpectedly the B/C cis-fused methyl 7-oxo-8\$,9\$,13\$,abietan-18-oate (18b). The lack of parallelism between the reductions of these abietanes and their steroidal counterparts which undergo conversion into the more stable B/C trans system is ascribed to the absence of ring D which allows ring C of abietanes to assume conformations not permitted in the steroid series. The formation of 18b appears to result from protonation of the most stable carbanion intermediate rather than from overlap control.

Although the accompanying paper¹ describes a route to 1 which was desired as an intermediate for further synthetic work in the diterpene area, the route was somewhat circuitous and the yield of the critical intermediate 2 was low. Lithium-liquid ammonia reduction of **3** which was much more easily purified than **2** was expected to provide 1 more directly since steroidal $\Delta^{8,9}$ -11-ketones afford the stable *trans*-fused 11-ketones in fair yield by this method.⁴ The unexpected mode of reduction of 3 and of 10 which resulted in compounds possessing undesired B/C cis stereochemistry is discussed in the present paper.

Initially, a solution of **3** in dry ether was added to a solution of lithium in liquid ammonia. After 5 min the reaction was guenched by addition of ammonium chloride. Chromatography of the crude product resulted in recovery of much starting material and the formation of 1 and another saturated keto ester in a 1:9 ratio. See Scheme I. When tetrahydrofuran was employed as cosolvent and the time was extended to 2 hr. the starting material was consumed completely. However, under these conditions the carbomethoxy group was reduced to the corresponding alcohol and it was necessary to reoxidize the crude products and to methylate the resulting mixture of keto acids. Subsequent chromatography furnished only 8% 1 and 62% new saturated keto ester (ir bands at 1722 and 1689 cm⁻¹). Hence the reduction had taken an unexpected course.

The new substance was not affected by exposure to sodium methoxide, an experiment which eliminated formula 4^5 and left as the most plausible alternative structure 5 whose trans-anti-cis ring system would not be expected to epimerize to the much less stable transsyn-trans system.⁶ Comparison of the nmr spectra of undeuterated and deuterated keto ester demonstrated that signals of three protons in the 2.0-2.5-ppm region had disappeared after deuterium exchange as expected for a substance of formula 5 and that the undeuterated compound did not exhibit the characteristically deshielded 1β -proton signal of a trans-anti-trans system. Figure 1 demonstrates that in an 8α , 13β -11-oxoabietane the carbonyl group would be oriented so as to shield rather than deshield the 1β proton; while ring C is probably somewhat distorted from the normal chair form depicted in Figure 1, this would not be expected to induce any long-range paramagnetic shift. The ORD

⁽¹⁾ Part XVII: W. Herz and J. J. Schmid, J. Org. Chem., 34, 3464 (1969). (Reference 6 of this paper describes numbering and nomen-clature used throughout the series.)

⁽²⁾ Supported in part by National Science Foundation Grant GP-6362.

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 C. Djerassi, "Steroid Reactions," Holden-Day, Inc., San Francisco, Calif., 1963, pp 308-310.

⁽⁵⁾ Since 1 and 4 differ only in the stereochemistry at C-9, one or the other should be epimerizable or the same equilibrium mixture should be produced from both. Since 1 is stable to base, 4 should be convertible to 1. This was corroborated in subsequent work.
(6) E. L. Eliel, "Stereochemistry of Carbon Compounds," McGraw-

Hill Book Co., Inc., New York, N. Y., 1962, pp 282-286.