Resin Acids. XI. Configuration and Transformations of the Levopimaric Acid–*p*-Benzoquinone Adduct[1,2]

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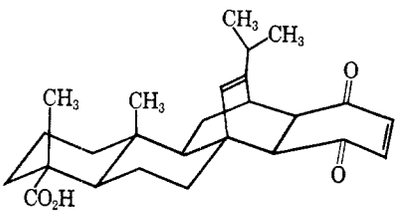
The configuration of the adduct formed by reaction of levopimaric acid with *p*-benzoquinone has been established. The substance has been reduced by several methods. Structures have been assigned to all of the reduction products and their stereochemistry has been determined.

In the course of a program[4,5] aimed at the utilization of Diels–Alder adducts of levopimaric acid (**1**) for complex syntheses, we found it necessary to investigate more closely the chemical behavior of the adduct of **1** with *p*-benzoquinone, a substance which had received only cursory attention previously. Earlier workers[6,7] differed with respect to the physical properties of this substance,[6a,7] provided no configurational assignment, and reported merely a few transformations into substances of indeterminate gross structure[6a,7] or stereochemistry.[6b] In the present article we present evidence for the formulation of the adduct as **2a** and describe its reduction to a number of different products whose gross structure and stereochemistry has been elucidated.



2a

In view of earlier work on the Diels–Alder reactions of levopimaric acid[4,8–11] it appeared likely that the benzoquinone adduct, whose physical properties corresponded to those reported by Wienhaus and Sandermann[6a] rather than those reported by Ruzicka and Kaufmann,[7] possessed the *endo,cis* structure **2a**. This was confirmed by photolysis of the methyl ester **2b** to a cage structure **3** (Scheme I) in the manner first described by Cookson and co-workers.[12,13] Additional chemical evidence in favor of the *endo,cis* configuration will be presented subsequently.[14] Only one of the carbonyl groups of **3** could be oxidized by *m*-chloroperbenzoic acid to what was presumed to be the keto lactone **4**. Other transformations of **2b** to be discussed in the sequel also demonstrated this differential reactivity of the two carbonyls.

Catalytic hydrogenation of **2a** has been reported[6a] to yield a dihydro derivative **5a** (also obtainable[6] by reduction with zinc in acetic acid), a diol[7] of unspecified properties, and a tetrahydro derivative[7] of unsharp melting point which furnished a monoacetate. In our hands catalytic reduction of **2a** (platinum oxide–acetic acid) resulted after esterification in the isolation of three substances. One of these was the diketone **5b**, prepared more conveniently and in better yield with zinc–acetic acid. Its nmr spectrum (broadened singlet at 5.54 ppm) clearly demonstrated that the conjugated double bond had been reduced and the unconjugated double bond retained. Conversion of **5b** to a monoketal and monothioketal indicated that one of its two ketone groups was sterically hindered.

The other two reduction products, mp 207–208° (A) and 188–191° (B), were isomeric hydroxyketo esters (infrared bands at 3610, 1735, 1715 and 3500, 1738 and 1709 cm^{-1}, respectively) in which the 13,14 double bond[15] was still present (infrared bands at 1650 cm^{-1}, nmr spectrum).

Compound A had a hindered secondary hydroxyl group (complex nmr signal at 4.00 ppm, failure to form an acetate) and an unhindered ketone function, since it formed a ketal and thioketal with ease. By contrast the ketone group of B was hindered (nonformation of ketal and thioketal), and its secondary hydroxyl (nmr signal at 3.90 ppm) was normal as indicated by its facile conversion to an acetate.

That A had been formed by reduction of the more hindered carbonyl group of **2b**, presumably the one at C-4, and B by reduction of the less hindered carbonyl, presumably the one at C-1, was also shown in the following manner. Sodium borohydride reduction of **2b** furnished a doubly unsaturated (nmr spectrum) hydroxy keto ester, C, which could be hydrogenated catalyti-

(1) Previous paper: J. W. Huffman, T. Kamiya, L. H. Wright, J. J. Schmid, and W. Herz, *J. Org. Chem.*, **31**, 4128 (1966).

(2) Supported in part by a grant from the National Science Foundation (GP-1962).

(3) U. S. Public Health Service Fellow, 1962–1964; Ethyl Corp. Fellow, 1964–1965.

(4) N. Halbrook, R. V. Lawrence, R. L. Dressler, R. C. Blackstone, and W. Herz, *J. Org. Chem.*, **29**, 1017 (1964).

(5) W. Herz, R. C. Blackstone, and M. G. Nair, *ibid.*, **31**, 1800 (1966).

(6) (a) H. Wienhaus and W. Sandermann, *Ber.*, **69**, 2203 (1936); (b) W. Sandermann and K. Striesow, *ibid.*, **90**, 693 (1957).

(7) L. Ruzicka and S. Kaufmann, *Helv. Chim. Acta*, **21**, 1425 (1941).

(8) W. D. Lloyd and G. W. Hedrick, *J. Org. Chem.*, **26**, 2029 (1961).

(9) L. H. Zalkow, R. A. Ford, and J. P. Kutney, *ibid.*, **27**, 3535 (1962).

(10) W. L. Meyer and R. W. Huffman, *Tetrahedron Letters*, No. 16, 691 (1962).

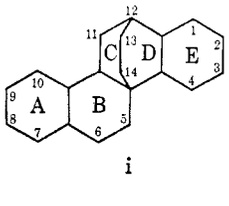
(11) W. A. Ayer, C. E. McDonald, and J. B. Stothers, *Can. J. Chem.*, **41**, 1113 (1963).

(12) R. C. Cookson, E. Crundwell, and J. Hudec, *Chem. Ind.* (London), 1003 (1959); R. C. Cookson, R. R. Hill, and J. Hudec, *J. Chem. Soc.*, 3043 (1964); R. C. Cookson, E. Crundwell, R. R. Hill, and J. Hudec, *ibid.*, 3062 (1964).

(13) This compound is probably identical with a so-called dimethyl ester (properties not given) formed[6a] from **2a** by exposure to ultraviolet light and subsequent methylation, since it stubbornly retains one molecule of methanol of crystallization.

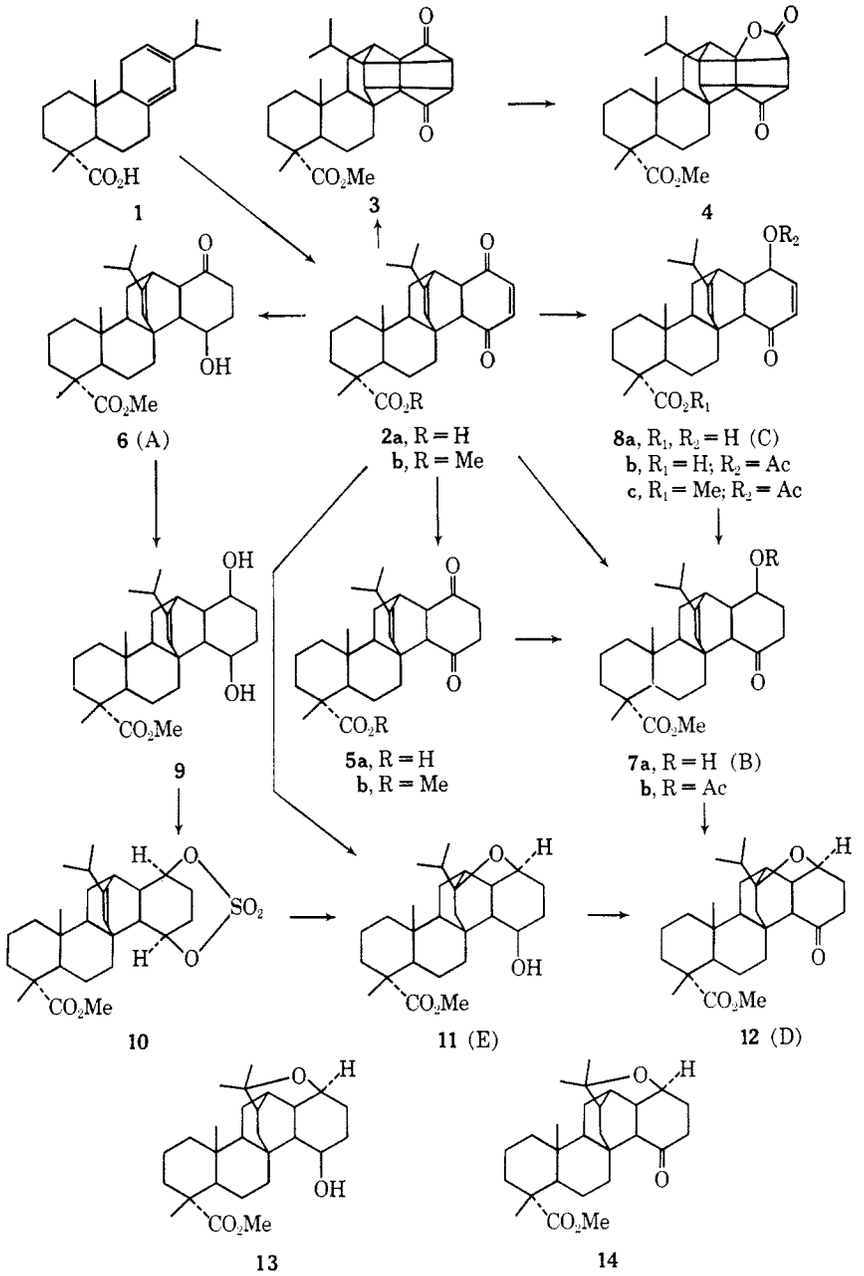
(14) This evidence assumes importance because of a cautionary note concerning the use of the photocyclization reaction appended to a recent review. See R. N. Warrener and J. B. Bremner, *Rev. Pure Appl. Chem.*, **16**, 117 (1966).

(15) Compounds are numbered in accordance with the *Chemical Abstracts* system, the adduct **2a** being a derivative of 1H-4b,12-ethenochrysene (i).



i

SCHEME I



cally to B. Reduction of the less hindered carbonyl group of **5b** with sodium borohydride also yielded B. Addition of excess sodium borohydride to B at room temperature resulted in recovery of starting material, thus providing further evidence for the hindered nature of the carbonyl group, but treatment of A with sodium borohydride resulted in reduction and formation of a diol (**9**).[16] The action of thionyl chloride–pyridine on this diol produced the sulfite **10**, an observation which requires that the two hydroxyl groups of **9** be *cis*.

The absolute configuration of the hydroxyl groups, predicted to be β on the basis of models which require attack of reducing agents from the rear, or α, side, could be established in the following manner. Catalytic hydrogenation of **2b** in the presence of added perchloric acid yielded two ethers which no longer retained the C-13,14 double bond (no infrared band at 1650 cm^{-1}, absence of the typical vinyl proton resonance near 5.5 ppm). The first of these ethers, D which also contained a ketone group (infrared spectrum), could be prepared independently from B by treatment with hydrogen chloride–methanol. The second, E, an alcohol (infrared and nmr spectrum), was synthesized subsequently by hydrogen chloride–methanol treatment of the diol **9** and could be oxidized to the ketone D. Hence the unhindered alcohol function of B and **9** was involved in ether formation, a conclusion which was corroborated by the observation that A (hindered alcohol) underwent no conversion to an ether upon mild acid treatment.

The absence in the nmr spectra of D and E of new signals in the range 3–5 ppm clearly demonstrated that the ether bridge was attached to a tertiary position, *i.e.*, C-13 or C-13a. This immediately eliminated C-4 as the other terminus of the ether linkage and therefore as the location for the (unhindered) hydroxyl group of B.[17] The latter must be placed at C-1 and because of the facile formation of an ether bridge must be β

(16) The diol **9** was also produced when **5** was refluxed with excess sodium borohydride for a prolonged period.

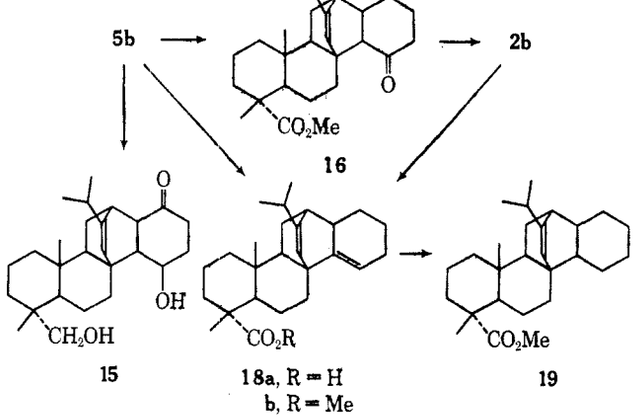
(17) Inspection of Dreiding models shows that it is impossible to link C-4 and C-13 or C-13a by an ether bridge.

oriented. Hence B is represented by **7a**, C by **8a**, and A by **6**, since in the diol **9** the two hydroxyl groups are *cis* to each other. Moreover the conversion of **2b**, **7**, and **9** to ethers provides independent evidence for the *endo,cis* fusion of rings D and E in **2** and all compounds derived from it, an *exo* fusion being incapable of providing for ether formation.

Models show that an ether bridge from C-1 to C-13 or to C-13a is equally strain free, although a junction to C-13a would require a prior hydride shift (or isomerization of the double bond) from C-13a to C-13. Of the two alternatives, **11** or **13**, for ether E, and **12** or **14**, for ether D, **13** and **14** could be eliminated by inspection of the nmr spectra. These displayed the two methyl singlets and the two methyl doublets of the isopropyl group, rather than the four methyl singlets expected for **13** and **14**.

Having settled the configuration of the diketone **5b** and the ketols **6** and **7**, we were now concerned with the selective removal of the two carbonyl groups of **5a**. As will be recalled, this substance formed a monoethylene ketal and monoethylene thioketal, presumably by reaction with the less hindered carbonyl group at C-1. However all attempts to subject the ketal to various modifications of the Wolff–Kishner reaction resulted in recovery of starting material (except for hydrolysis of the ester function). Lithium aluminum hydride reduced the hindered carbonyl as well as the ester group, as has been observed earlier,[6b] but the product **15** (Scheme II) resulting from ketal cleavage during the work-up was unsuitable for further work.

SCHEME II

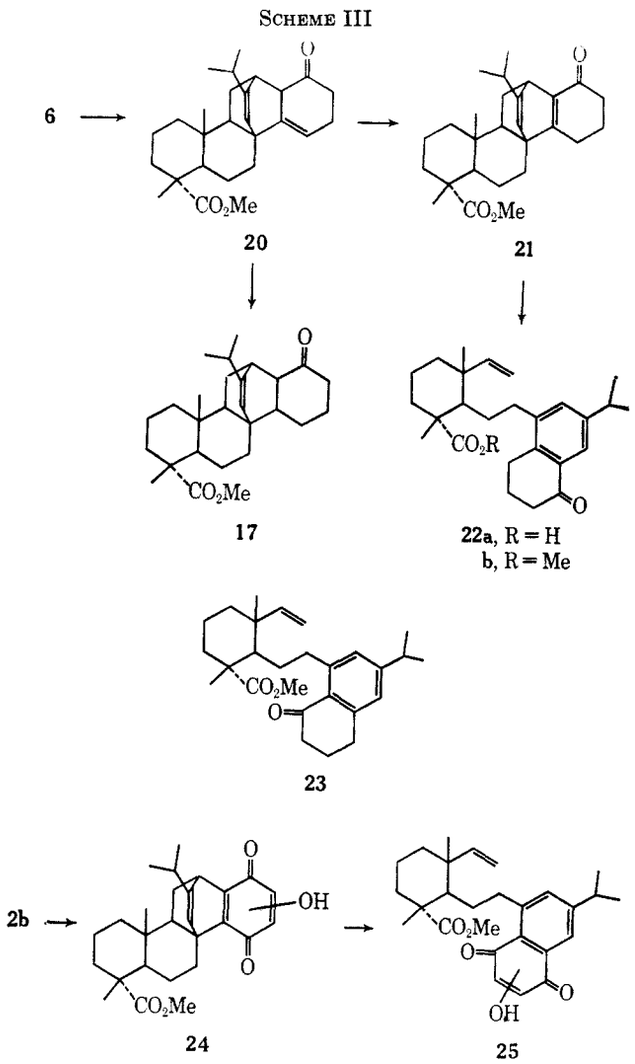


Nickel desulfurization of the thioketal produced a monoketo ester tentatively assigned formula **16**. This conclusion was supported by the ORD curve which displayed a strong positive Cotton effect. Examination of models indicates that **16**, with all of its carbon atoms in the upper left octant,[18] should exhibit a strong positive Cotton effect, and that the isomeric C-4-ketone **17**, with most, if not all, of its carbon atoms in the upper right octant, should exhibit a negative Cotton effect.

An attempt to remove the remaining carbonyl group of **16** by the Wolff–Kishner reaction resulted in reductive elimination, as has been noted previously in the case of hindered ketones,[19] and formation of **18a** (H-14 singlet at 5.30, H-4 broad doublet at 5.60 ppm). This substance was also formed more directly and in good yield from **5b** and, surprisingly enough, from **2b** where, we suppose, diimide produced under the reaction conditions served to reduce the double bond. Catalytic hydrogenation of **18b** proceeded without difficulty to **19**, the *cis* fusion being assumed on the basis of steric considerations.

The isomeric ketone **17** was produced from **6** of established structure and stereochemistry as follows (see Scheme III). Treatment of **6** with thionyl chloride–pyridine resulted in facile elimination to the β,γ-unsaturated ketone **20** (infrared bands at 1732, 1709, 1655, and 1640 cm^{-1}, significant nmr signals at 5.30 t (1.5, H-14) and 5.53 ppm ddbr (H-4)), a reaction which is in conformity with the quasi-axial nature of the C-4 hydroxyl group. By contrast, similar treatment of **7**,

SCHEME III



whose hydroxyl group should be equatorial, did not result in elimination. Further treatment of **20** with hydrogen chloride–methanol or passage over an alumina column caused isomerization to the α,β-unsaturated ketone **21** (infrared bands at 1739, 1660, and 1630 cm^{-1},

(18) P. Crabbé, "Optical Rotatory Dispersion and Circular Dichroism in Organic Chemistry," Holden-Day, Inc., San Francisco, Calif., 1965, pp 72–158.

(19) D. Todd, *Org. Reactions*, **4**, 381 (1948); C. W. Shoppee and D. A. Prins, *Helv. Chim. Acta*, **26**, 185 (1943); T. F. Gallagher, *J. Biol. Chem.*, **162**, 539 (1946); D. H. R. Barton, N. J. Holness, and W. Klyne, *J. Chem. Soc.*, 2456 (1949).

λ_{max} 248 mμ (ϵ_{max} 3220)) which in accordance with the postulated structure exhibited only one vinyl proton resonance due to H-14 (narrow triplet, J = 1.5 cps at 5.45 ppm). A significant nmr signal supporting the assigned structure was the broad singlet of the doubly allylic H-12, further deshielded by proximity to the ketone group at C-1. Catalytic hydrogenation of **20** finally gave the desired **17** (infrared bands at 1735, 1710, and 1650 cm^{-1}) whose ORD curve (negative Cotton effect) was fully in accord with the prediction discussed earlier in this paper.[20]

Although the structural assignments for **16** and **17** appeared to be based on solid grounds (ether formation in the precursor **7**, ORD measurements, and application of the octant rule), the conclusions leading to them were derived largely from an examination of Dreiding models, a procedure which has occasionaly proved deceptive. It was desirable, therefore, to adduce independent evidence for the location of the unhindered and the hindered carbonyl group at C-1 and C-4, respectively. This could be achieved by application of the Alder–Rickert reaction to an oxidation product of **2b** and to **21**.

Barton oxidation[21] of **2b** gave a mixture from which one of the two possible hydroxyquinones **24** could be isolated in 20% yield. The exact location of the hydroxyl group on the quinone ring was immaterial for our purpose. Thermolysis of **24** in the manner described earlier[5] for adducts of levopimaric acid and acetylenic dienophiles resulted in the hydroxynaphthoquinone **25** whose nmr spectrum displayed the resonances of two *meta* coupled aromatic protons (narrow doublets at 7.85 and 7.15 ppm, J = 2.5 cps), a quinoid proton (singlet at 6.2 ppm), and the typical ABC system of the vinyl group. The great difference in the chemical shifts of the aromatic protons is ascribable to the circumstance that one of them, *i.e.*, H-12, is deshielded by the *peri*-carbonyl group.[22]

Similarly, thermal rearrangement of **21** furnished an α-tetralone whose nmr spectrum had two *meta* coupled aromatic signals at 7.80 and 7.10 ppm (J = 2.5 cps), one of which was again obviously deshielded by a *peri*-carbonyl group. This required that the thermolysis product be formulated as **22b** rather than **23**, verified **21** as the structure of the precursor, and reaffirmed the arguments employed previously in this paper. The corresponding acid **22a** was obtained directly when an attempt was made to saponify **20** with the lithium iodide–collidine[23] reagent.

Experimental Section[24,25]

Adduct of Levopimaric Acid–*p*-Benzoquinone (7-Carboxy-7,-10a-dimethyl-13-isopropyl-4,4a,5,6,6a,7,8,9,10,10a,10b,11,12,12a-tetradecahydro-1H-4b,12-ethenochrysene-1,4-dione, 2a).—A solution of 24 g of levopimaric acid (αD −273°) and 10 g of *p*-benzoquinone in 300 ml of benzene was allowed to stand for 12 hr (the initially brown color had faded to yellow), and the solvent was removed in a rotary evaporator. Crystallization of the crude adduct, obtained in practically quantitative yield, from methanol or acetone–petroleum ether gave 25 g of the pure adduct (73%), mp 212–214°, [α]D −150° (lit. mp 214°, [α] −148°;[6a] mp 192°, [α] −163°[7]), infrared bands at 3500 (acid OH) broad, 1700 (carboxyl), 1670 (two conjugated ketones), and 1605 cm^{-1} (conjugated double bond), nmr signals at 6.56 (two quinone vinyl protons), 5.42 t (J = 1.5 cps, H-14), 1.16 and 0.60 (C-7 and C-10a methyls), and 0.96 d ppm (isopropyl).

The methyl ester **2b** was prepared directly from 40 g of methyl levopimarate and 15 g of *p*-benzoquinone in 300 ml of acetone with stirring. The solution became dark brown and warm; after 4 hr the color had largely faded. On cooling in the refrigerator, the solution deposited large yellow crystals of the adduct, yield 45 g (84%). Recrystallization from acetone raised the melting point to 163°, [α]D −131° (ethanol), infrared bands at 1722 (ester), 1680 (two conjugated ketones), and 1613 cm^{-1} (conjugated double bond), nmr signals at 6.48 (2 H, quinoid vinyls), 5.40 br (H-14), 3.65 (methoxyl), 1.15 (C-7 methyl), 0.97 d (J = 7 cps, isopropyl), and 0.60 ppm (C-10a methyl).

Photolysis of 2b.—A solution of 20 g of **2b** in 2 l. of methanol in a Pyrex flask was exposed to direct sunlight until the yellow color had completely faded. The solution was concentrated to small volume at reduced pressure and the solid which separated was recrystallized from methanol, yield 12 g of **3** (58%), mp 170° with frothing, then resolidifying sharply at 241°, [α]D +46.0° (ethanol), infrared bands at 3580 (sharp, methanol of crystallization), 1736 (ester), and 1718 cm^{-1} (two ketones), nmr signals at 4.72 (br, exchangeable with D_2O, CH_3OH), 3.65 (methoxy), 3.47 (CH_3OH), 1.19 (C-7 methyl), 1.02 d and 0.78 d (J = 7 cps, isopropyl), and 0.87 ppm (C-10a methyl).

Anal. Calcd for $C_{27}H_{36}O_4 \cdot CH_3OH$: C, 73.65; H, 8.83; O, 17.52. Found: C, 73.26; H, 8.83; O, 17.82.

Baeyer–Villiger Oxidation of 3.—A solution of 4 g of **3** in the minimum quantity of chloroform was mixed with 3 g of *m*-chloroperbenzoic acid and allowed to stand at room temperature for 2 weeks. The reaction mixture was diluted to 100 ml with ether and extracted with 5% sodium bicarbonate solution. The organic layer was thoroughly washed with water, dried, and evaporated to dryness and the residue was recrystallized from methanol, yield 3 g of **4**, mp 240–245°. Recrystallization from methanol–acetone (3:1) gave an analytical sample, infrared bands at 1760 (strained lactone), 1740 and 1722 cm^{-1} (ketone and ester), nmr signals at 4.76 dbr (J = 9 cps, H-12a), 3.65 (methoxy), 3.33–2.50 c (3 H, protons α to carbonyls), 1.19 (C-7 methyl), 1.03 d and 1.01 d (J = 7 cps, isopropyl), and 0.94 ppm (C-10a methyl).

Anal. Calcd for $C_{27}H_{36}O_5$: C, 73.60; H, 8.24; O, 18.16. Found: C, 73.61; H, 8.28; O, 18.19.

Zinc–Acetic Acid Reduction of 2a. Preparation of 5a.—A mixture of 50 g of **2a** and 500 ml of glacial acetic acid was heated to effect solution and 20 g of powdered zinc was added with rapid stirring which was continued until the yellow color had disappeared (about 2 hr). The hot solution was filtered, slowly diluted with water to the cloud point while still hot, and placed in the refrigerator. The crude product which separated overnight, yield 47 g (93%), was recrystallized from methanol and had mp 184–187°, [α]D +61.0° (ethanol), yield 42 g, infrared bands at 3200 br carboxyl), 1706 (two ketones), and 1700 cm^{-1} sh (carboxyl), nmr signals at 5.56 br (H-14), 1.18 (C-7 methyl), 1.05 d (J = 7 cps, isopropyl), and 0.60 ppm (C-10a methyl).

Anal. Calcd for $C_{26}H_{36}O_4$: C, 75.69; H, 8.80; O, 15.51. Found: C, 75.79; H, 9.05; O, 15.88.

(20) The resistance of the C-13,14 double bond to catalytic hydrogenation observed in this and earlier papers is in accord with the *endo, cis*, structure and finds its counterpart in the difficulty with which the levopimaric acid–maleic anhydride is reduced and oxidized.[8-18] See also J. Simonsen and D. H. R. Barton, "The Terpenes," Vol. 3, Cambridge University Press, London, 1952, pp 428–445; L. H. Zalkow and N. N. Girotra, *J. Org. Chem.*, **28**, 2033 (1963); L. H. Zalkow, M. V. Kulkarni, and N. N. Girotra, *ibid.*, **30**, 1678 (1965).

(21) E. J. Bailey, D. H. R. Barton, J. Elks, and J. F. Templeton, *J. Chem. Soc.*, 1578 (1962).

(22) For an early example of this effect, see W. Herz and G. Caple, *J. Am. Chem. Soc.*, **84**, 3517 (1962).

(23) F. Elsinger, J. Schreiber, and A. Eschenmoser, *Helv. Chim. Acta*, **43**, 113 (1960); E. Wenkert, P. Beak, R. W. J. Carney, J. W. Chamberlin, D. B. R. Johnston, C. D. Roth, and A. Tahara, *Can. J. Chem.*, **41**, 1924 (1963).

(24) Melting points are uncorrected. Analyses were by Dr. F. Pascher, Bonn, Germany. Infrared spectra were run in chloroform solution on Perkin-Elmer Model 137 and 257 spectrophotometers, rotations in chloroform, and nmr spectra in deuteriochloroform, unless otherwise specified, on an A-60 spectrometer with tetramethylsilane serving as internal standard. Signals are characterized in the usual way: d doublet, t triplet, br broad singlet or unresolved doublet, c complex band whose center is given. Petroleum ether is the fraction of bp 35–60°. ORD curves were run on a JASCO Model ORD-5 recording spectropolarimeter.

(25) We are grateful to Dr. G. W. Hedrick for generous gifts of long-leaf yellow pine coresin and crude levopimaric acid salts for the preparation of starting material.

The methyl ester **5b** was recrystallized from methanol and had mp 160–161.5°, $[\alpha]_D$ +63.8° (ethanol), infrared bands at 1730 (ester), 1710 (two ketones), and 1665 cm^{-1} (very weak, double bond), nmr signals at 5.54 br (H-14), 3.64 (methoxyl), 1.15 (C-7 methyl), 1.04 d (J = 7 cps, isopropyl), and 0.59 ppm (C-10a methyl).

Anal. Calcd for $C_{27}H_{38}O_4$: C, 76.02; H, 8.98; O, 15.00. Found: C, 75.93; H, 8.92; O, 14.81.

Monoethylene Ketal of 5b.—A solution of 10 g of **5b**, 15 ml of ethylene glycol, and 20 mg of toluenesulfonic acid in 150 ml of benzene was refluxed in a Dean–Stark apparatus for 48 hr, cooled, and washed with 5% sodium bicarbonate solution and water. The benzene layer was dried and evaporated to dryness *in vacuo*. The residue was recrystallized from ethanol and methanol. The ketal melted at 175–177°, yield 7.9 g (72%), $[\alpha]_D$ +74.5° (ethanol), infrared bands at 1730 (ester) and 1710 cm^{-1} (ketone), nmr signals at 5.47 br (H-14), 3.90 br (4 H, $-OCH_2CH_2O-$), 3.61 (methoxyl), 1.14 (C-7 methyl), 1.09 d (J = 7 cps, isopropyl), and 0.60 ppm (C-10a methyl).

Anal. Calcd for $C_{29}H_{42}O_5$: C, 74.01; H, 9.00; O, 17.00. Found: C, 73.75; H, 9.07; O, 17.07.

Monoethylene Thioketal of 5b.—A mixture of 3 g of **5b**, 2 ml of ethanedithiol, and 5 ml of boron trifluoride etherate was allowed to stand for 1 hr, washed with 5% sodium hydroxide solution and then with water, and concentrated at reduced pressure. The solid residue was recrystallized twice from methanol, yield of monothioketal 2–5 g, mp 95–98° dec, $[\alpha]_D$ +57°, infrared bands at 3700, 3500 (water of crystallization), 1735 (ester), and 1710 cm^{-1} (ketone), nmr signals at 5.46 br (H-14), 3.53 (methoxyl), 3.30 (4 H, SCH_2CH_2S-), 1.15 (C-7 methyl), 1.09 d (J = 7 cps, isopropyl), and 0.60 ppm (C-10a methyl).

Anal. Calcd for $C_{29}H_{42}O_3S_2 \cdot H_2O$: C, 66.90; H, 8.52; O, 12.28. Found: C, 66.64; H, 8.11; O, 12.35.

Sodium Borohydride Reduction of 2a. Preparation of 8a.—To a solution of 4.6 g of **2a** in 200 ml of methanol was added dropwise with stirring in a nitrogen atmosphere a solution of 2 g of sodium borohydride in 50 ml of absolute ethanol until the yellow color had entirely faded. Upon acidification with acetic acid and dilution with water to the cloud point, the product **8** crystallized in the form of long, silky needles in 90–95% yield. Recrystallization from ethanol furnished an analytical sample, mp 250–255° dec, $[\alpha]_D$ +24.7° (pyridine), infrared bands (KBr pellet) at 3500 (broad, acid OH), 1685 (conjugated ketone), and 1645 cm^{-1} (conjugated double bond), nmr signals (pyridine) at 6.78 dbr (J = 10 cps, H-2), 5.87 dd (J = 10 cps, 2, H-3), 5.31 br (H-14), 4.89 c (H-1), 1.40 (C-7 methyl), 1.14 d and 1.12 d (J = 7 cps, isopropyl), and 0.63 ppm (C-10a methyl).

Anal. Calcd for $C_{26}H_{36}O_4$: C, 76.59; H, 8.80. Found: C, 76.35; H, 8.57.

The acetyl derivative **8b** was prepared by refluxing 2.0 g of **8a** with 10 g of acetic anhydride for 1 hr, concentrating to small volume at reduced pressure and recrystallizing the residual gum from ethanol–water (1:1). The product melted at 233–235°, $[\alpha]_D$ +41.0° (pyridine), yield 1.8 g, infrared bands (KBr pellet) at 3400 br (acid OH), 1740 (acetate), 1680 (conjugated ketone), and 1660 cm^{-1} (conjugated double bond).

Anal. Calcd for $C_{28}H_{38}O_5$: C, 73.98; H, 8.43. Found: C, 74.07; H, 8.59.

The methyl ester **8c** was prepared from **8b** and diazomethane in the usual manner. Recrystallization from ethanol–ether (1:1) furnished small colorless needles which melted at 217–220°, $[\alpha]_D$ +94.2°, infrared bands at 1745 and 1735 (esters), 1675 (conjugated ketone), and 1638 cm^{-1} (conjugated double bond), nmr signals at 6.29 dbr (J = 10 cps, H-2), 5.50 dd (J = 10 cps, 3, H-3), 5.50 c (H-1), 5.12 br (H-14), 3.62 (methoxyl), 2.14 (acetate), 1.13 (C-7 methyl), 1.04 d and 0.98 d (J = 7 cps, isopropyl), and 0.57 ppm (C-10a methyl).

Anal. Calcd for $C_{29}H_{40}O_5$: C, 74.32; H, 8.60; O, 17.07. Found: C, 74.36; H, 8.54; O, 17.36.

Sodium Borohydride Reduction of 5b. Preparation of 7a.—To a solution of 10 g of **5b** in 200 ml of ethanol, was added dropwise with stirring 0.35 g of sodium borohydride in ethanol. After 30 min, excess hydride was destroyed with acetic acid. Concentration to 100 ml and cooling to 0° resulted in 8 g (80%) of crude **7a**, which was recrystallized from ethanol and then melted at 190–192°, $[\alpha]_D$ +27°, infrared bands at 3500 br (bonded –OH), 1735 (ester), 1709 (ketone), and 1650 cm^{-1} (weak, double bond), nmr signals at 5.60 br (H-14), 3.90 c (H-1), 3.54 (methoxyl), 1.15 (C-7 methyl), 1.09 d (J = 7 cps, isopropyl), and 0.62 ppm (C-10a methyl).

Anal. Calcd for $C_{27}H_{40}O_4$: C, 75.66; H, 9.41; O, 14.93. Found: C, 75.42; H, 9.45; O, 14.78.

Acetylation of **7a** in ether with excess ketene at 0°, thorough washing, drying, and evaporation *in vacuo* furnished **7b** which was recrystallized from methanol and then had mp 217–220°, $[\alpha]_D$ +45.5°, infrared bands at 1740 and 1730 (esters), 1708 (ketone) and 1650 cm^{-1} (weak, double bond), nmr signals at 5.53 br (H-14), 4.85 c (H-1), 3.62 (methoxyl), 2.01 (acetate), 1.14 (C-7 methyl), 1.10 d (J = 7 cps, isopropyl), and 0.62 ppm (C-10a methyl).

Anal. Calcd for $C_{29}H_{42}O_5$: C, 74.01; H, 9.00; O, 17.00. Found: C, 73.64; H, 9.13; O, 17.21.

When 10 g of **5b** in 100 ml of absolute ethanol was mixed with 5 g of solid sodium borohydride and the mixture refluxed for 72 hr, the hindered ketone group was reduced as well. Dilution of the cooled solution with water and acidification with diluted hydrochloric acid resulted in a precipitate which after recrystallization from methanol melted at 201–202° and was identical with **9** to be described subsequently. The yield was 7 g (70%).

Catalytic Hydrogenation of 2a. A.—A suspension of 40 g of **2a** in 250 ml of glacial acetic acid was shaken with 0.25 g of platinum oxide in a Parr hydrogenator at 40 psi for 12 hr. During this period, the material dissolved and the yellow color disappeared. The solution was filtered and concentrated to dryness *in vacuo*, and the residue dissolved in ether, washed thoroughly with water and evaporated. A small portion of the crude product was recrystallized from ethyl acetate and then melted at 255–260°, but tlc and nmr analysis showed it to be a mixture.[26] The crude product was therefore esterified with excess ethereal diazomethane. During this process a crystalline product, characterized by its insolubilitiy, separated and was collected by filtration. Recrystallization of this substance (**6**), 8.8 g, from ethyl acetate gave an analytical sample which had mp 207–208°, $[\alpha]_D$ −91°, infrared bands at 3610 (sharp, nonbonded OH), 1735 (ester), 1715 (ketone), and 1650 cm^{-1} (weak, double bond), nmr signals at 5.36 br (H-14), 4.00 br (H-4), 3.53 (methoxyl), 1.11 (C-7 methyl), 1.01 d and 0.95 d (J = 7 cps, isopropyl), and 0.58 ppm (C10-10a methyl).

Anal. Calcd for $C_{27}H_{40}O_4$: C, 75.66; H, 9.41; O, 14.93. Found: C, 75.70; H, 9.36; O, 14.91.

The ether solution containing the remainder of the esterified product was evaporated to dryness and the residue recrystallized from ethyl acetate. This furnished 15 g of a substance, mp 189–191°, identical with **7a**. The mother liquors were evaporated and the residue chromatographed over an alumina column (Alcoa F-20). Elution with chloroform and then with chloroform–ether gave two major fractions, the first consisting of 9 g of diketone **5b**, mp 159–161°, the second containing an additional 6 g of **7a**, mp 188–191°.

B.—A solution of 10 g of **2b** in 100 ml of glacial acetic acid and 2 ml of 70% perchloric acid solution was reduced with 0.2 g of platinum oxide at a hydrogen pressure of 40 psi for 12 hr. The perchloric acid was neutralized with 3 g of anhydrous sodium acetate and the solvents were removed at reduced pressure. The residue was taken up in ether, washed thoroughly, dried, concentrated and chromatographed over 300 g Alcoa F-20 alumina. Elution with benzene–chloroform yielded about 1.0 g of impure **5b**. This was followed closely by 2.4 g of **12**, identical in all respects with the product formed by acid treatment of **7a** (*vide infra*). Elution with chloroform yielded 1.5 g of **11**, mp 139–142° after several recrystallizations from hexane, $[\alpha]_D$ +29°, infrared bands at 3440 br (bonded OH), 1720 (ester), 1436, and 1390 cm^{-1} (isopropyl), nmr signals at 3.9 c (H-1 and H-4), 3.62 (methoxyl), 1.18 (C-7 methyl), 0.98 (C-10a methyl) and 0.96 d ppm (J = 7 cps, isopropyl). Oxidation of **11** with chromic acid–acetic acid furnished **12**.

Anal. Calcd for $C_{27}H_{42}O_4$: C, 75.31; H, 9.83; O, 14.86. Found: C, 75.54; H, 9.75; H, 14.97.

Further elution with more polar solvents yielded 1.5 g of a mixture containing some **7b** (nmr spectrum).

Sodium Borohydride Reduction of 6. Preparation of 9.—To a solution of 1 g of **6** in 50 ml of hot methanol was added 0.4 g of sodium borohydride. After 3 hr excess borohyride was decomposed with acetic acid. Concentration of the solution resulted in formation of a precipitate which was filtered and recrystallized from ethyl acetate. The product **9** weighed 0.6 g, mp 198–201°,

(26) The properties of the mixture make it probable that it is identical with the material assumed to be a homogeneous tetrahydro derivative by the Swiss workers.[7]

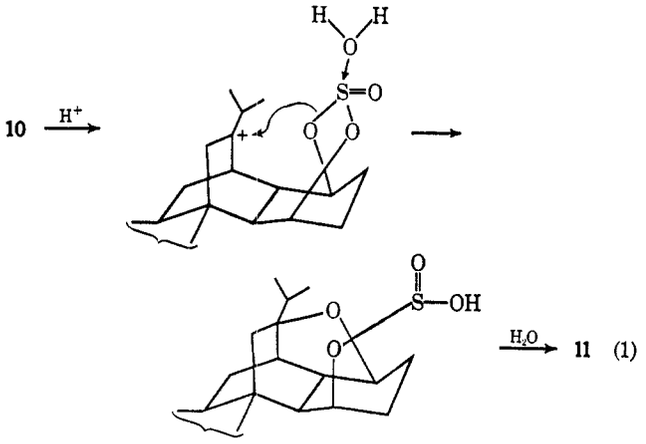
$[\alpha]_D$ −42.4° (chloroform), infrared bands at 3600–3500 br (OH), 1735 (ester), and 1650 cm^{-1} (weak, double bond), nmr signals at 5.46 br (H-14), 4.03 c and 3.80 c (H-1 and H-4), 3.56 (methoxyl), 1.17 (C-7 methyl), 1.02 d (J = 7 cps, isopropyl) and 0.63 ppm (C-10a methyl). For a more convenient preparation of this substance directly from **5b**, *vide supra*.

Anal. Calcd for $C_{27}H_{42}O_4$: C, 75.31; H, 9.83; O, 14.86. Found: C, 75.64; H, 9.76; O, 15.10.

Solution of the diol **9** in pyridine at 0°, treatment with thionyl chloride at 0° for 15 min, stirring at room temperature for an additional 30 min, and dilution with water resulted in precipitation of the sulfite **10** which after recrystallization from methanol, melted at 210° (45% yield), infrared bands at 1705 (ester) and 1375 cm^{-1} (sulfite), nmr signals at 5.35 br (H-14), 4.60 c and 4.45 c (H-1 and H-4), 3.65 (methoxyl) 1.20 (C-7 methyl), 1.15 d and 0.95 d (J = 7 cps, isopropyl) and 0.65 ppm (C-10a methyl).

Anal. Calcd for $C_{27}H_{40}O_5S$: C, 67.90; H, 8.40; O, 16.78; S, 6.71. Found: C, 67.33; H, 8.49; O, 16.90; S, 6.93.

A solution of 2 g of the sulfite **10** in 30 ml of methanol and 2.5 ml of perchloric acid was refluxed for 18 hr, evaporated *in vacuo*, diluted with water, and filtered. The crude product was chromatographed over 25 g of silicic acid and the fraction eluted with chloroform was recrystallized from methanol. The product melted at 145–146° and was identical in all respects with the ether **11**. A suggested mechanism of formation is given in eq 1.



(1)

Preparation of 12.—A solution of 4 g of **7a** in 200 ml of methanol and 20 ml of concentrated hydrochloric acid was refluxed for 14 hr and poured into 1 l. of cold water with stirring. The precipitate was filtered, dried, and recrystallized twice from hexane to give 2.5 g of **12**, mp 170–171.5°, $[\alpha]_D$ +120.1°, infrared bands at 1725 (ester), 1705 (ketone), 1394, and 1384 cm^{-1} (isopropyl), no –OH or double-bond absorption, nmr signals at 3.97 br (H-1), 3.64 (methoxyl), 1.13 (C-7 methyl), 1.05 d and 0.95 d (J − 7 cps, isopropyl) and 0.94 ppm (C-10a methyl).

Anal. Calcd for $C_{27}H_{40}O_4$: C, 75.66; H, 9.41; O, 14.93. Found: C, 75.72; H, 9.33; O, 15.23.

This substance was also prepared by oxidation of **11** with chromic acid–acetic acid. Treatment of **9** with methanol–hydrochloric acid furnished **11**.

Preparation of 15.—A solution of 5 g of the ethylene ketal of **5b** in 300 ml of anhydrous ether was added during a 2 hr period to a solution of 5 g of lithium aluminum hydride in 300 ml of ether with stirring. The mixture was stirred overnight and worked up in the usual way, excess hydride being decomposed with dilute hydrochloric acid. The ether layer furnished 3.8 g of crude **15**, mp 180–184°, which was difficult to purify because of its low solubility. Recrystallization from a large volume of ethanol resulted in material which had mp 185–187°, infrared bands at 3400 br (bonded hydroxyl), and 1708 cm^{-1} (ketone), nmr spectrum (trifluoroacetic acid) 5.72 br (H-14), 4.65–4.0 c (three protons, H-4 and $-CH_2OH$), 1.07 d and 0.94 d (J = 7 cps, isopropyl), and 0.75 ppm (C-10a methyl).

Anal. Calcd for $C_{26}H_{40}O_3$: C, 77.95; H, 10.07; O, 11.98. Found: C, 78.20; H, 9.70; O, 12.25.

Wolff–Kishner reduction conditions left the ketal unchanged.

Preparation of 16.—A solution of 1 g of the thioketal of **5b** in 40 ml of ethanol was refluxed overnight with 8 g of freshly prepared Raney nickel, filtered, and diluted with water to induce crystallization. After standing overnight at 0°, 0.5 g of colorless needles **16** were obtained and recrystallized from ethanol. The analytical sample melted at 142–143.5°, $[\alpha]$ +19.6°, λ_{max} 298 mμ (ε 34.5), infrared bands at 1730 (ester), 1708 (ketone), and 1650 cm^{-1} (weak, double bond), nmr signals at 5.54 br (H-14), 3.60 (methoxyl), 1.14 (C-7 methyl), 1.02 d (J = 7 cps, isopropyl), and 0.60 ppm (C-10a methyl), ORD curve (methanol, c 0.265) $[\alpha]_{400}$ 85.5°, $[\alpha]_{350}$ 188.5°, $[\alpha]_{318}$ 659.8°, $[\alpha]_{301}$ 0°, $[\alpha]_{277}$ −1018°, $[\alpha]_{246}$ −753.8°, $[\alpha]_{218}$ −1734° (last reading).

Anal. Calcd for $C_{27}H_{40}O_3$: C, 78.59; H, 9.77; O, 11.63. Found: C, 78.91; H, 9.54; O, 11.78.

Wolff–Kishner Reduction of 2a, 5b, and 16. Formation of 18a.—A solution of 2 g of **2a** in 10 ml of anhydrous hydrazine and 10 ml of absolute ethanol was refluxed for 24 hr in a nitrogen atmosphere. The solvent was removed *in vacuo*. The residue was mixed with 45 ml of ethylene glycol, refluxed in a nitrogen atmosphere for 5 min, 7 g of potassium hydroxide pellets was added cautiously in the course of 15 min and the temperature of the mixture was maintained at 210 for 3.5 hr while the lower boiling fraction was allowed to distil out of the reaction flask. The solvent was removed at reduced pressure; the residue was diluted with water and acidified with dilute (1:1) hydrochloric acid. The precipitate was extracted with chloroform. The organic layer was washed, dried, and concentrated, and the residue was chromatographed over 30 g of silicic acid. The fraction eluted with benzene was recrystallized from methanol and furnished 1.1 g (60%) of **18a**, mp 213–214°, no carbonyl absorption in the ultraviolet, infrared bands at 3300 br and 1670 (carboxyl) and 1615 cm^{-1} (double bond), nmr signals at 5.60 dbr (J = 8 cps, H-4), 5.3 br (H-14), 1.20 (C-7 methyl), 1.05 d and 0.95 d (J = 7 cps, isopropyl) and 0.70 ppm (C-10a methyl).

Anal. Calcd for $C_{26}H_{38}O_2$: C, 81.62; H, 10.01; O, 8.36. Found: C, 81.53; H, 10.35; O, 8.20.

The same procedure, when adopted for the reduction of **5b** and **16**, also furnished **18a**.

The methyl ester **18b** was prepared with diazomethane in the usual manner and had mp 93–94°, infrared bands at 1750 (ester) and 1600 cm^{-1} (double bond), nmr signals at 5.60 dbr (J = 8 cps, H-4), 5.3 br (H-14), 3.6 (methoxyl), 1.19 (C-7 methyl), 1.05 d and 0.95 d (J = 7 cps, isopropyl) and 0.70 ppm (C-10a methyl).

Anal. Calcd for $C_{27}H_{40}O_2$: C, 81.76; H, 10.17; O, 8.07. Found: C, 82.07; H, 10.21; O, 8.02.

Hydrogenation of 18b.—A solution of 0.3 g of **18b** in 25 ml of absolute ethanol was hydrogenated at 38 psi for 24 hr with 0.1 g of 5% palladium charcoal, filtered and evaporated. The residue crystallized slowly from a methanol solution kept at 0° and had mp 61–62°, nmr signals at 5.35 br (H-14), 3.6 (methoxyl), 1.20 (C-7 methyl), 1.10 d and 1.00 d (J = 7 cps, isopropyl), and 0.70 ppm (C-10a methyl).

Anal. Calcd for $C_{27}H_{42}O_2$: C, 81.35; H, 10.62; O, 8.03. Found: C, 81.44; H, 10.37; O, 8.21.

Preparation of 20.—A solution of 14 g of **6** in 50 ml of anhydrous pyridine was cooled in an ice bath and 5 ml of thionyl chloride was added with stirring over 5 min. Stirring was continued for 1 hr while the mixture was allowed to warm to room temperature. The solution was poured into 500 ml of ice water and the precipitate (**20**), yield 7.7 g (55%), was filtered and recrystallized from methanol. The yield was 6.1 g, mp 158–161°, infrared bands at 1732 (ester), 1709 (ketone), 1655 and 1640 cm^{-1} (double bonds), nmr signals at 5.53 qbr (J = 3.5 cps, H-4), 5.30 t (J = 1.5 cps, H-14), 3.66 (methoxyl), 3.21 br (H-12a), 1.17 (C-7 methyl), 1.05 d and 0.91 d (J = 7 cps, isopropyl) and 0.68 ppm (C-10a methyl), ORD curve (ethanol, c 0.0445) $[\alpha]_{400}$ −225°, $[\alpha]_{350}$ −675°, $[\alpha]_{306}$ −3710°, $[\alpha]_{290}$ 0°, $[\alpha]_{260}$ +5630°, λ_{max} 275 mμ (ε 78.5, enhanced n − π* transition of β,γ unsaturated ketone).

Anal. Calcd for $C_{27}H_{38}O_3$: C, 78.98; H, 9.33; O, 11.69. Found: C, 78.89; H, 9.44; O, 11.89.

Hydrogenation of 20. Preparation of 17.—A solution of 2 g of **20** in 30 ml of acetic acid was hydrogenated with 0.1 g of platinum oxide at 40 psi overnight, filtered, and concentrated at reduced pressure. The residue (**17**) was recrystallized twice from methanol and had mp 114–116°, yield 11 g, infrared bands at 1735 (ester), 1710 (ketone), and 1650 cm^{-1} (weak, double bond), nmr signals at 5.33 br (H-14), 3.66 (methoxyl), 1.15 (C-7 methyl), 0.98 d and 0.88 d (J = 7 cps, isopropyl) and 0.60 ppm (C-10a methyl), ORD curve (methanol, c 0.288) $[\alpha]_{400}$ −294.6° $[\alpha]_{350}$ −554.6°, $[\alpha]_{318}$ −1178°, $[\alpha]_{294}$ 0°, $[\alpha]_{276}$ 502.6°, $[\alpha]_{232}$ 0°, $[\alpha]_{217}$ −1421° (last reading).

Anal. Calcd for $C_{27}H_{40}O_3$: C, 78.59; H, 9.77; O, 11.63. Found: C, 78.32; H, 9.62; O, 11.95.

Isomerization of 20 to 21.—A solution of 2 g of **20** in 30 ml of methanol and 2 ml of concentrated hydrochloric acid was refluxed on the steam bath for 30 min, diluted to the cloud point and chilled. There precipitated 1.4 g (70%) of crude **21**, mp 127–133°. Several recrystallizations raised the melting point to 135–136°, $[\alpha]D$ +96° (ethanol), λ_{max} 248 mμ (ε 3220), infrared bands at 1730 (ester), 1660 (conjugated ketone), and 1630 cm^{-1} (conjugated double bond), nmr signals at 5.45 t (J = 1.5 cps, H-14), 4.05 br (H-12), 3.71 (methoxyl), 1.19 (C-7 methyl), 1.06 d and 1.00 d (J = 7 cps, isopropyl), and 0.70 ppm (C-10a methyl).

Anal. Calcd for $C_{27}H_{38}O_3$: C, 78.98; H, 9.33; O, 11.69. Found: C, 78.99; H, 9.17; O, 12.06.

Thermal Rearrangement of 21.—The α,β-unsaturated ketone **21**, 0.1 g, was heated at 150–160° in a nitrogen atmosphere for 3 hr. The resulting gum **22b** exhibited only one spot on tlc, but could not be induced to crystallize. It exhibited nmr signals at 7.8 d (J = 2.5 cps, H-12), 7.1 d (J = 2.5 cps, H-14), 5.95, 5.8, 5.65, 5.5, 5.0 c, 5.85 d, 5.7 d (typical ABC system of H-10b, H-11a and H-11b), 3.65 (methoxyl), 1.25 (C-7 methyl), 1.15 d (J = 7 cps, isopropyl), and 1.10 ppm (C-10a methyl). The product was characterized as the brick-red 2,4-dinitrophenylhydrazone, mp 136–137°.

Anal. Calcd for $C_{33}H_{44}N_4O_6$: C, 66.87; H, 7.48; N, 9.45. Found: C, 67.46; H, 7.27; H, 9.24.

The crystalline acid **22a** was obtained directly from **20** as follows. A powdered mixture of 0.8 g of **20** and 2 g of lithium iodide was refluxed with 35 ml of redistilled collidine for 8 hr in a nitrogen atmosphere. The solvent was removed by distillation *in vacuo*, and the last traces were removed by codistillation with *m*-xylene. The brown residue was acidified with dilute hyrochloric acid and extracted with methylene chloride. The organic layers were combined, washed, dried, and evaporated. The residue was chromatographed over 12 g of silicic acid, the product **22a** (total weight 0.6 g) being eluted with benzene. Recrystallization from cyclohexane afforded material which melted at 185–186° and had nmr signals at 7.82 d (J = 2.5 cps, H-12), 7.08 d (J = 2.5 cps, H-14), 5.9, 5.75, 5.6, 5.45, 5 c, 4.85 d, 4.7 d (ABC system), 1.25 (C-7 methyl), 1.10 d (J = 7 cps, isopropyl), and 1.00 ppm (C-10a methyl).

Anal. Calcd for $C_{26}H_{38}O_3$: C, 78.35; H, 9.61; O, 12.04. Found: C, 78.34; H, 9.37; O, 12.24.

Preparation of 24.—A solution of 5 g of **2b** in 75 ml of *t*-butyl alcohol was added to 0.7 g of potassium dissolved in 50 ml of *t*-butyl alcohol. Oxygen was bubbled through; the color immediately changed to deep purple. After 3 hr the reaction was stopped, 10 ml of water was added and the solvent was removed *in vacuo*. The dark purple residue was dissolved in 50 ml of water and acidified with 40 ml of 1 *N* hydrochloric acid. A yellow precipitate formed and was extracted with ether–benzene (1:1). The organic layer was washed, dried, and evaporated, and the brown residue was chromatographed over 60 g of silicic acid. Benzene eluted 0.15 g (20%) of a bright yellow substance which after recrystallization from methanol melted at 162–163°. It gave a violet color with ferric chloride and had λ_{max} 282.5 and 345 mμ (ε 12640 and 800, diosphenol), infrared bands at 3250 (bonded OH), 1750 (ester), 1650 and 1625 (conjugated carbonyls), and 1600 cm^{-1} (intense, double bonds), nmr signals at 7.24 (–O*H*, disappears on addition of D_2O), 5.8 (quinoid vinyl proton), 5.51 (H-14), 4.15 dbr (H-12), 3.6 (methoxyl), 1.15 (C-7 methyl), 1.05 d and 1.15 d (J = 7 cps, isopropyl), and 0.65 ppm (C-10a methyl).

Anal. Calcd for $C_{27}H_{43}O_5$: C, 73.94; H, 7.82; O, 18.24. Found: C, 74.13; H, 7.69; O, 18.23.

Thermal Rearrangement of 24.—A 0.5-g sample of **24** was heated at 160–170° in a nitrogen atmosphere for 6 hr. The viscous glassy brown product could not be induced to crystallize but was homogeneous by tlc criteria. An analytical sample of **25** was prepared by dissolving the material in acetone and precipitating a microcrystalline solid by dilution with petroleum ether. This melted at 132–133° and had infrared bands at 3255 (bonded, hydroxyl), 1765 (ester), 1645, and 1620 (quinone carbonyls), 1605 and 1600 cm^{-1} (double bonds), nmr signals at 7.85 d (J = 2.5 cps, H-12), 7.15 d (J = 2.5 cps, H-14), 6.2 (quinoid vinyl proton), 5.95, 5.8, 5.65, 5.5, 4.95 c, 4.75 d (ABC system) 3.65 (methoxyl), 1.30 (C-7 methyl) 1.25 d (J = 6 cps, isopropyl), and 1.00 ppm (C-10a methyl).

Anal. Calcd for $C_{27}H_{34}O_6$: C, 73.94; H, 7.82; O, 18.24. Found: C, 74.15; H, 7.62; O, 18.20.

Registry No.—**2a**, 13473-15-9; **2b**, 13462-97-0; **3**, 13447-00-2; **4**, 13447-01-3; **5a**, 13447-02-4; **5b**, 13447-03-5; **5b** monoethylene ketal, 13447-04-6; **5b** monoethylene thioketal, 13447-05-7; **6**, 13447-06-8; **7a**, 13447-07-9; **7b**, 13447-08-0; **8a**, 13447-09-1; **8b**, 13473-16-0; **8c**, 13447-10-4; **9**, 13447-11-5; **10**, 13447-12-6; **11**, 13447-13-7; **12**, 13447-14-8; **15**, 13447-15-9; **16**, 13447-16-0; **17**, 13447-17-1; **18a**, 13447-18-2, **18b**, 13447-19-3; **19**, 13447-20-6; **20**, 13447-21-7; **21**, 13447-22-8; **22a**, 13447-23-9; **22b**, 13447-24-0; **22b** 2,4-dinitrophenylhydrazone, 13473-17-1.