droxide, and water. After drying, the ethyl acetate was evaporated to a small volume; hexane (200 ml.) was added, and the crystals which formed were collected (11.63 g., m.p. 167–169°). A second crop (7.3 g.), m.p. 157–165°, on recrystallization from hot 95% ethanol gave a product (1.4 g.), m.p. 171–173.5°. This was combined with the main crop and recrystallized from 95% ethanol yielding 8.4 g., m.p. 172.5–175°, $[\alpha]^{24}D$ −44° (*c* 4, MeOH). Additional crystallization did not raise this melting point.

Anal. Calcd. for $C_{18}H_{26}N_2O_5$: C, 61.70; H, 7.48; N, 8.00; OCH_3, 8.80. Found: C, 61.85; H, 7.56; N, 7.75; OCH_3, 9.20.

B. Benzyloxycarbonyl-L-isoleucyl-L-alanine.—A sample of the protected dipeptide ester was saponified in aqueous methanol with the calculated amount of sodium hydroxide. On acidification, the protected dipeptide acid, m.p. 155–160°, was obtained in 90% yield. After recrystallization from dilute ethanol, it melted at 169–171°, $[\alpha]^{22}D$ −27° (*c* 4.95, ethanol).

Anal. Calcd. for $C_{17}H_{24}N_2O_5$: C, 60.70; H, 7.19; N, 8.33; neut. equiv., 336.4. Found: C, 60.94; H, 7.27; N, 8.53; neut. equiv., 340.

The same protected dipeptide acid (m.p. 167–168°) was obtained by acylating L-alanine in dilute pyridine with *p*-nitrophenyl benzyloxycarbonyl-L-isoleucinate at pH 9.5, kept constant by the addition of dilute sodium hydroxide.

C. L-Isoleucyl-L-alanine.—The protected dipeptide acid (1.58 g.) in a mixture of methanol (26 ml.), acetic acid (4 ml.), and water (20 ml.) was hydrogenated in the presence of a 10% palladium-on-charcoal catalyst (0.35 g.). After removal of the catalyst and evaporation of the solvents *in vacuo*, the residue was triturated with absolute ethanol. The precipitate which formed was collected and washed on the filter with ethanol (0.79 g., m.p. 234–237°). Recrystallization from water–ethanol raised the m.p. to 236–238°, while a small second crop melted at 240–242°, $[\alpha]^{23}D$ +6.5° (*c* 4, 1 *N* acetic acid).

Anal. Calcd. for $C_9H_{18}N_2O_3$: C, 53.44; H, 8.97; N, 13.85. Found: C, 53.30; H, 8.87; N, 13.77.

D. L-Ileu-L-ala.—The protected dipeptide methyl ester (3.5 g.) was hydrogenated in methanol (90 ml.) containing acetic acid (10 ml.) in the presence of a 10% palladium-on-charcoal catalyst (0.70 g.). After the evolution of carbon dioxide ceased, the catalyst was filtered off and the solvents were removed. A 50% aliquot of the residue was heated on a steam bath to give a solid (0.90 g.), m.p. 232–239°, $[\alpha]^{22}D$ −22° (*c* 1, 95% ethanol). Sublimation *in vacuo* raised the melting point to 243–246°, $[\alpha]^{20}D$ −30°.

Anal. Calcd. for $C_9H_{16}N_2O_2$: C, 58.67; H, 8.75; N, 15.21. Found: C, 58.95; H, 8.98; N, 14.90.

Acknowledgment.—The authors express their gratitude to Dr. James Dutcher for his helpful discussions during the studies here presented and to Dr. John Vandeputte for the generous sample of highly purified thiostrepton.

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, UNIVERSITY OF CALIFORNIA, BERKELEY 4, CALIF.]

Photochemical Transformations. XVI.[1] The Structure of Photolevopimaric Acid[2]

BY WILLIAM G. DAUBEN AND ROBERT M. COATES[3]

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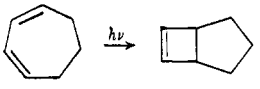
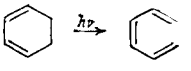
Levopimaric acid (**9**) upon ultraviolet irradiation was transformed into its valence isomer **10**. The presence of a bicyclo[2.2.0]hexene structure was established by conversion of **10** to the triester **25** by a series of specific degradations.

Conjugated cyclic dienes upon ultraviolet irradiation have been found to undergo two modes of reactions, bond formation and bond cleavage. The pathway to be followed depends upon the particular system at hand. When the diene moiety is enclosed in a seven-membered ring, irradiation effects valence isomerization to a bicyclo[3.2.0]heptene[4] and the numerous cycloheptadienes which have been transformed in this fashion attest to the generality of the process.[5,6] The photochemistry of cycloheptatrienes,[4,7] tropolones,[1,8]



and functionalized cycloheptadienes[9] usually follows the same course. The consistent behavior in this series may be attributed, in part, to the fact that simple ring cleavage is not possible in an odd-membered ring system.[10]

With six-membered ring analogs the photochemistry generally takes the alternative course of ring opening. Having a carbon–carbon bond allylic to each terminus of the diene, a cyclohexadiene may undergo the cleavage reaction. That ring opening to trienes is most frequently observed is not to be unexpected since valence isomerization demands the formation of a highly strained bicyclo[2.2.0]hexene system. Thus, cyclohexadiene,[11–13] α-phellandrene,[12] α-terpinene,[14] allo-ocimene,[15] and 5,6-dimethyl-1,3-cyclohexadiene[15] all furnish the corresponding trienes by radiative scission of the doubly allylic bond. In a similar fashion, *o*-cyclohexadienones[11,16,17] are converted to ketene derivatives.



(1) For previous paper in this series, see W. G. Dauben, K. Koch, S. L. Smith, and O. L. Chapman, *J. Am. Chem. Soc.*, **85**, 2616 (1963).

(2) This investigation was supported in part by PHS Grant No. A-709, National Institute of Arthritis and Metabolic Diseases, Public Health Service.

(3) National Science Foundation Cooperative Fellow, 1960–1963.

(4) W. G. Dauben and R. L. Cargill, *Tetrahedron*, **12**, 186 (1961).

(5) O. L. Chapman, D. J. Pasto, G. W. Borden, and A. A. Griswold, *J. Am. Chem. Soc.*, **84**, 1220 (1962).

(6) P. Courtot, *Ann. Chim.*, **8**, 217 (1963).

(7) R. Srinivasan, *J. Am. Chem. Soc.*, **84**, 3432 (1962); O. L. Chapman and S. L. Smith, *J. Org. Chem.*, **27**, 2291 (1962); O. L. Chapman and G. W. Borden, *Proc. Chem. Soc.*, 221 (1963).

(8) W. G. Dauben and D. A. Cox, *J. Am. Chem. Soc.*, **85**, 2130 (1963), and references cited therein; O. L. Chapman, H. G. Smith, and R. W. King, *ibid.*, **85**, 903 (1963); O. L. Chapman, H. G. Smith, and P. A. Barks, *ibid.*, **85**, 3171 (1963).

(9) G. Büchi and E. M. Burgess, *ibid.*, **82**, 4333 (1960); J. J. Hurst and G. H. Whitham, *J. Chem. Soc.*, 710 (1963); G. J. Fonken, *Chem. Ind.* (London), 1575 (1961); D. J. Pasto, *J. Org. Chem.*, **27**, 2786 (1962).

(10) Whether the photochemical excitation of the diene moiety is responsible for the observed fragmentation of 3,5-cycloheptadienones to carbon monoxide and 1,3,5-hexatriene is not certain; see ref. 5 and O. L. Chapman and G. W. Borden, *J. Org. Chem.*, **26**, 4185 (1961).

(11) D. H. R. Barton, *Helv. Chim. Acta*, **42**, 2604 (1959).

(12) R. J. de Kock, N. G. Minnaard, and E. Havinga, *Rec. trav. chim.*, **79**, 922 (1960).

(13) R. Srinivasan, *J. Am. Chem. Soc.*, **82**, 5063 (1960).

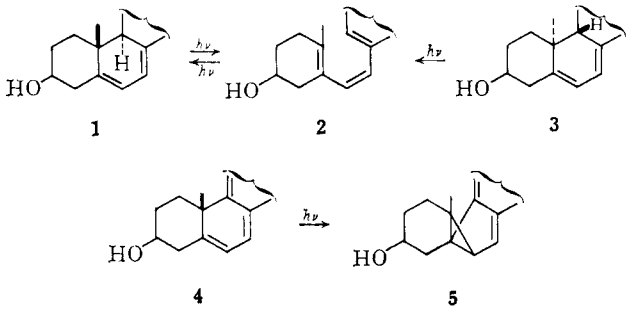
(14) W. H. Schuller, R. N. Moore, J. E. Hawkins, and R. V. Lawrence, *J. Org. Chem.*, **27**, 1178 (1962).

(15) G. J. Fonken, *Tetrahedron Letters*, 549 (1962).

(16) D. H. R. Barton and G. Quinkert, *J. Chem. Soc.*, 1 (1960).

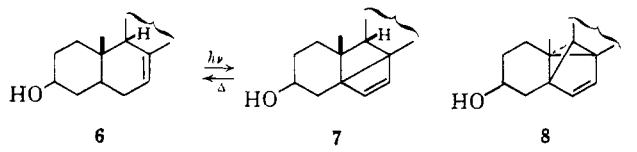
(17) P. DeMayo and S. T. Reid, *Quart. Rev.* (London), **15**, 393 (1961), and pertinent references included therein.

This bond cleavage reaction is quite important in the production of the D vitamins, and, consequently, has received much attention.[18] Ergosterol (**1**) undergoes photochemical ring opening to precalciferol (**2**), the immediate precursor of vitamin D_2. Another compound formed in this complex circuit of interconversions is lumisterol (**3**), the 9,10-*anti* isomer of ergosterol,



which also suffers ring cleavage to precalciferol upon irradiation. Quite a number of related steroids[19] and triterpenoids[20] have been subjected to ultraviolet radiation and in each case the appropriate triene was formed.

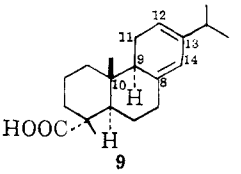
The exceptions to the rule of ring opening are few but significant. With dehydroergosterol (**4**)[21] and dehydrolumisterol,[22] irradiation induces a stereospecific rearrangement to an isomer containing a cyclopropane ring (**5**). It is to be noted, however, that normal cleavage has been virtually prohibited by the $\Delta^{9,11}$-double bond since the ring-opened product would contain an allene grouping in a six-membered ring. The same type of cyclopropyl system arises from 1,2,3,4,5-pentaphenyl-1,3-cyclohexadiene.[23] The most striking deviations from the rule of ring opening are the pyrocalciferols.[24] Differing from ergosterol and lumisterol only in having 9,10-*syn* configurations, the pyrocalciferols, *e.g.*, isopyrocalciferol (**6**), are transformed into photoisomers to which 5,8-bridged structures, *e.g.*, **7**, have been ascribed.[24] However, an alternate structure having a bicyclo[2.1.1]hexene ring (**8**) would be equally compatible with most of the chemical evidence.



The latter possibility was considered unlikely because upon pyrolysis the photoproducts return stereospecifically to their respective dienes in high yield. However, since the Δ^2-bicyclo[2.1.1]hexene structure is unknown, such evidence is equivocal.

In the recent literature there have appeared examples for the photochemical formation of both types of bicyclic systems. Sensitized irradiation of diethyl 1,3-cyclohexadiene-1,4-dicarboxylate yields the corresponding valence isomer[25] while 1,5-hexadiene undergoes an intramolecular cyclo addition to yield bicyclo[2.1.1]-hexane.[26]

The factors which enable the bond formation process to take precedence over the more common ring cleavage are not yet clear. In this connection it would be of interest to study other cyclohexadienes having the diene chromophore in different structural environments. Levopimaric acid (**9**), a major acid in certain pine oleoresins, is readily available and possesses such a diene system. Accordingly, an investigation of its photochemistry was initiated.



It was found that levopimaric acid behaved in a manner similar to the pyrocalciferols. Photolevopimaric acid, prepared by direct irradiation of the resin acid in ether solution and purified by the amine salt method, could be obtained in a high degree of purity in a yield of 47%. The photoproduct was found to be isomeric with the starting material but to have only an isolated trisubstituted double bond (ϵ_{205} 3800, 1 H at 4.25 τ). Upon pyrolysis at 120° the starting diene was reformed from the photoproduct. The recovery of the diene acid was low, owing to the known thermal instability of levopimaric acid itself.[27]

During the course of this present work, Lawrence and his collaborators[14] published an account of their study on the photochemistry of levopimaric acid. Using principally the above data and the analogy with the pyrocalciferols[24] for evidence, they proposed the 8,12-bridged structure **10** for photolevopimaric acid. But as in the photopyrocalciferols, the bicyclo[2.1.1]hexene structure **11** warrants attention. In view of the exceptional behavior of the pyrocalciferols and levopimaric acid, it was considered prudent to obtain a definitive structure proof for at least one of these anomalous photoisomers. Our study was continued on photolevopimaric acid with this thought in mind.

In addition to the two bicyclic isomers **10** and **11**, it was also necessary to consider the possibility of cyclopropane ring formation, a process for which there exists some analogy.[21-23] Since the diene of levopimaric acid is not in a symmetrical environment, two different cyclopropane systems **12** and **13** may be visualized (neglecting stereoisomerism). With the exception of the pyrolytic evidence, the data offered by Lawrence do not allow a choice to be made among the four structures **10**–**13**.[28]

(18) For an excellent review of the field, see E. Havinga and J. L. M. A. Schlatmann, *Tetrahedron*, **16**, 146 (1961); E. Havinga, *Chimia*, **16**, 146 (1962).

(19) G. Cooley, B. Ellis, and B. Petrow, *J. Chem. Soc.*, 2998 (1955); E. Ohki, *Chem. Pharm. Bull.*, **8**, 46 (1960); L. Velluz, B. Goffinet, and G. Amiard, *Tetrahedron*, **4**, 241 (1958).

(20) R. L. Autrey, D. H. R. Barton, A. K. Ganguly, and W. H. Reusch, *J. Chem. Soc.*, 3313 (1961).

(21) D. H. R. Barton and A. S. Kende, *ibid.*, 688 (1958).

(22) D. H. R. Barton, R. Bernasconi, and J. Klein, *ibid.*, 511 (1960).

(23) G. R. Evanega, W. Bergmann, and J. English, Jr., *J. Org. Chem.*, **27**, 13 (1962).

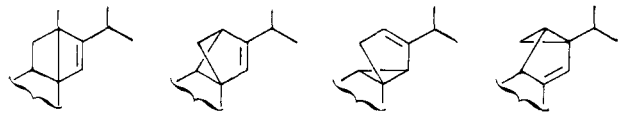
(24) W. G. Dauben and G. J. Fonken, *J. Am. Chem. Soc.*, **81**, 4060 (1959).

(25) H. Prinzbach and J. H. Hartenstein, *Angew. Chem.*, **74**, 651 (1962); **75**, 639 (1963).

(26) R. Srinivasan, *J. Am. Chem. Soc.*, **85**, 819 (1963); *J. Phys. Chem.*, **67**, 1367 (1963).

(27) V. W. Loeblich, D. E. Baldwin, R. T. O'Connor, and R. V. Lawrence, *J. Am. Chem. Soc.*, **77**, 6311 (1955).

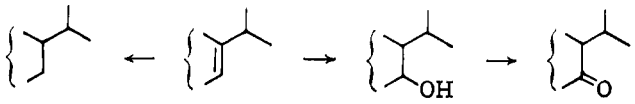
(28) From the absence of high-field absorption in the n.m.r. spectrum of photolevopimaric acid, it is unsafe to rule out the structure **13**, for the double bond being in conjugation with the cyclopropane ring may shift the characteristic cyclopropane methylene absorption downfield from its usual position; see S. Forsen and T. Norin, *Acta Chem. Scand.*, **15**, 592 (1961).



10 11 12 13

The initial chemical studies were aimed at gaining information about the locale of the isolated double bond. Catalytic reduction led to the uptake of 1 molar equivalent of hydrogen. The major product (**14**), isolated as its methyl ester, was saturated (ϵ_{205} 270), tetracyclic (mol. wt. 318, mass spectrum), and stable to treatment with hydrogen chloride in chloroform solution. No high-field absorption (>9.4 τ) was found in the n.m.r. spectrum of this substance. These data argue against a three-membered ring in the molecule.

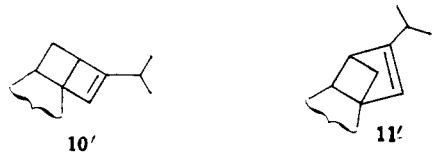
Decisive information enabling the elimination of the cyclopropane derivatives **12** and **13** was obtained through hydroboration of methyl photolevopimarate. The secondary alcohol **15** was obtained and, in turn, oxidized to the ketone **16.** The new carbonyl group



14 15 16

displayed absorption in the infrared at 1775 cm.$^{-1}$, a frequency suggestive of a cyclobutanone[29] or a highly strained cyclopentanone,[30] but one which clearly rules out both cyclopropane structures. A ketone in a bicyclo[3.1.0]hexane ring system should not absorb any higher[31,32] than the upper limit of the normal cyclopentanone range (1740–1750 cm.$^{-1}$).[33]

The problem that now remains is to differentiate between structures **10** and **11.** As the representations **10′** and **11′** clearly illustrate, the principal structural difference lies in the orientation of the olefinic bridge. Each has a cyclobutane ring fused to the 8- and 9-positions of the B ring. In **10** the bridge is attached laterally to the four-membered C ring, resulting in the [2.2.0] system; **11**, on the other hand, has the fourth ring fused in a diagonal fashion, giving the [2.1.1] nucleus. Hence, if a distinction is to be made, a degradation must be carried out in such a way as to demonstrate the orientation of the unsaturated two carbon bridge with respect to the cyclobutane ring.



10′ 11′

(29) J. M. Conia and J. Gore, *Bull. soc. chim. France*, 726 (1963); J. J. Bonet, H. Wehrli, and K. Schaffner, *Helv. Chim. Acta*, **45**, 2615 (1962).

(30) The keto ester i has a carbonyl stretching frequency at 1764 cm.$^{-1}$ (G. Büchi and I. M. Goldman, *J. Am. Chem. Soc.*, **79**, 4741 (1957)). With the additional influence of the ring B fusion, the ketone ii derived from **11** might possibly show a carbonyl absorption as high as 1775 cm.$^{-1}$.

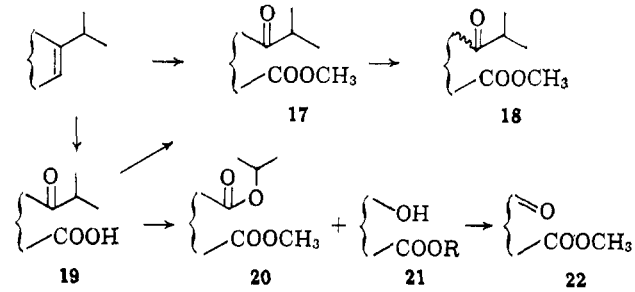
i ii

(31) T. Norin, *Acta Chem. Scand.*, **15**, 1676 (1961).

(32) S. Winstein and J. Sonnenberg, *J. Am. Chem. Soc.*, **83**, 3235 (1961).

(33) L. J. Bellamy, "The Infrared Spectra of Complex Molecules," John Wiley and Sons, Inc., New York, N. Y., 1958, p. 132.

The first step in the degradation was the cleavage of the double bond. Oxidation of photolevopimaric acid with the periodate–permanganate combination[34] afforded a keto diacid, characterized as the dimethyl ester **17.** Hydrolysis of this keto diester with dilute aqueous base apparently also effected epimerization of the isobutyryl side chain, for upon re-esterification an isomeric keto diester **18** was obtained. By ozonization of methyl photolevopimarate according to the procedure of Lawrence,[14] the keto half-ester **19** was prepared. This material could be converted by esterification to the keto diester **17** derived from the periodate–permanganate oxidation.



17 18 19 20 21 22

The removal of the isobutyryl side chain was achieved by means of the Baeyer–Villiger oxidation. Treatment of the half-ester **19** with peroxytrifluoroacetic acid[35] followed by mild alkaline hydrolysis of the reaction mixture and finally esterification with diazomethane gave two products, readily separable by column chromatography on silica gel. The more polar substance proved to be the alcohol **21** (R = CH_3) obtained in 33% yield. The other substance **20,** obtained in 20% yield, was the expected triester arising from oxidation on the side of the isopropyl group. Apparently the side chain ester in **20** is too hindered to permit ready hydrolysis since the isopropyl ester remained after the base treatment.

That the hydroxyl function in **21** (R = CH_3) was situated on a four-membered ring was substantiated by oxidation[36] to a ketone **22** which displayed an infrared stretching frequency at 1789 cm.$^{-1}$.[29] When the alcohol **21** (R = CH_3) was absorbed onto a column of neutral alumina (Activity III), isomerization occurred and an oily aldehydo ester **23** was eluted. The material was characterized by its low field n.m.r. absorption at 0.12 τ and conversion to a 2,4-dinitrophenylhydrazone. The ketone **22** in dilute methanolic sodium hydroxide at room temperature was transformed into a triester **24** (designated henceforth as the isotriester, for reasons which are given later). The isotriester **24** was also obtained by oxidation of the aldehyde **23,** followed by esterification.

The lability to basic conditions of both the alcohol **21** (R = CH_3) and the ketone **22** can be reasonably inter-

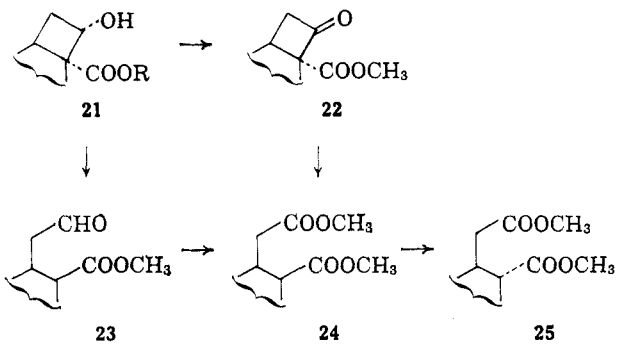
(34) R. U. Lemieux and E. von Rudolff, *Can. J. Chem.*, **33**, 1701, 1710, 1714 (1955).

(35) W. D. Emmons and G. B. Lucas, *J. Am. Chem. Soc.*, **77**, 2287 (1955).

(36) It is noteworthy that the standard chromic acid reagent[37] served well in the oxidation of the cyclobutanols **15** and **21**, obviating the use of the less convenient procedures often employed.[29]

(37) A. Bowers, T. G. Halsall, E. R. H. Jones, and A. J. Lemin, *J. Chem. Soc.*, 2548 (1953); C. Djerassi, R. R. Engle, and A. Bowers, *J. Org. Chem.*, **21**, 1547 (1956).

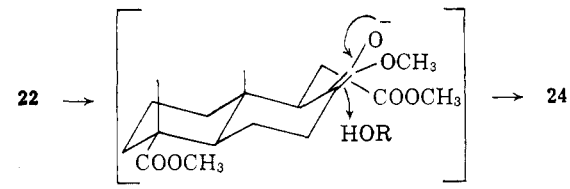
preted only with a β relationship between the functional groups on the cyclobutane ring.[38] The facile isomerization of **21** (R = CH_3) to the aldehyde derivative **23** is then essentially a retroaldol condensation.[39] Since the



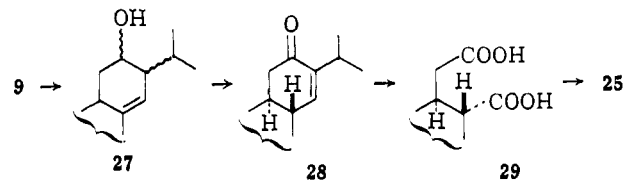
strain of the four-membered ring is relieved in the process, the facility of the reaction is to be expected. The conversion of **22** into the isotriester **24** may be readily explained in terms of a reverse Dieckmann reaction, the strain release again being the driving force. It must then be concluded that the hydroxyl and ester functions in **21** are situated in a β relationship as indicated. Furthermore, since the alcohol grouping is located on the position at which the olefin bridge had been attached, photolevopimaric acid must have structure **10** with the bicyclo[2.2.0]hexene ring system.

It is of interest to note that the acid **21** (R = H) is stable to base in sharp contrast to the lability of its methyl ester **21** (R = CH_3). The difference in stability may be attributed to the fact that the carboxyl group in **21** (R = H) would exist as the anion under alkaline conditions. Bearing a negative charge, the carboxylate anion is unable to facilitate the reverse aldolization. Hence, it was necessary to carry the C-8 function as the free acid through the Baeyer–Villiger oxidation in order to keep the cyclobutane ring intact in the subsequent alkaline hydrolysis. Indeed, preliminary studies showed that even though the oxidation of the keto diester **17** could be successfully carried out, basic hydrolysis of the product (**21**, R = CH_3 and the isobutyrate ester on C-12) led to rupture of the four-membered ring.

The isotriester **24** was shown to have the less stable configuration with an axial carbomethoxy group at C-8 by its equilibration under vigorous conditions to the equatorial isomer **25.** The stereochemical control in the ring-opening reactions is apparently the result of a specific protonation[40] of the intermediate enolate (*e.g.*, **26**) from the less hindered bottom side,[41] generating the axial orientation in **23** and **24.**



The constitution of the stable triester **25** was confirmed by its synthesis from levopimaric acid. Selective hydroboration of methyl levopimarate[42] afforded the β,γ-unsaturated alcohol **27** which, in turn, was converted to the conjugated ketone **28.** The diacid **29** obtained by ozonization of **28** furnished upon esterification a sample of the triester **25,** identical with the material obtained from the degradation of the photoproduct.

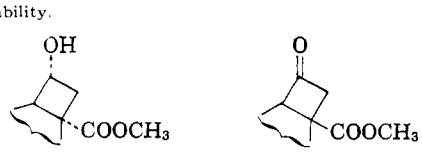


The structure of photolevopimaric acid as the bicyclo[2.2.0]hexene derivative **10** thus is securely established. The photopyrocalciferols by analogy must be similarly constituted, reaffirming the original assignment.[24]

Attention can now be directed to the stereochemistry of photolevopimaric acid. The correlation of the photoisomer with levopimaric acid by pyrolysis and degradation proves that the C-9 hydrogen must have the α-configuration.[42] There are, however, two possible configurations for the geometry at C-8, one of which must have the cyclobutane ring *trans* fused to the six-membered B ring. Although the *trans* arrangement would seem unlikely, such an arrangement must be considered in view of the syntheses[43] of *trans*-bicyclo[4.2.0]octane systems. One fact which may be put forth in defense of the *cis* fusion can be obtained from examination of the n.m.r. spectrum of photolevopimaric acid. The construction of models of the two isomers indicates that *trans* geometry forces the olefin bridge into a spatial position near the angular methyl substituent on C-10. The proximity of the π-electrons of the double bond to the methyl group should result in a long range shielding effect.[44] A similar situation is present in maleopimaric acid and, indeed, a considerable upfield shift in the resonance position of the angular methyl group is observed.[45] With photolevopimaric acid, however, the highest absorption appears at 9.07 τ.

A feature of particular significance in the photochemistry of levopimaric acid is that valence isomerization

(38) Such a reactivity would not be anticipated with the alternate formulations iii and iv. Both 3-carboethoxycyclobutanol and the corresponding cyclobutanone have been synthesized (M. Avram, C. D. Nenitzescu, and M. Maxim, *Ber.*, **90**, 1424 (1957)); neither material seemed to show any particular instability.



(39) A similar process has been postulated in the photochemical addition of acetylacetone to cyclohexene; however, the intermediate equivalent to **21** was not isolated (P. DeMayo, H. Takeshita, and A. B. M. A. Sattar, *Proc. Chem. Soc.*, 119 (1962)); see also P. Yates and M. J. Jorgenson, *J. Am. Chem. Soc.*, **85**, 2956 (1963).

(40) A small amount of the stable triester **25** also was isolated in the product from **22**.

(41) Such specificity has precedence in diterpene chemistry; see J. D. Cocker and T. G. Halsall, *J. Chem. Soc.*, 4262 (1956); U. Scheidegger, K. Schaffner, and O. Jeger, *Helv. Chim. Acta*, **45**, 400 (1962).

(42) W. G. Dauben and R. M. Coates, *J. Org. Chem.*, **28**, 1698 (1963).

(43) E. J. Corey, R. B. Mitra, and H. Uda, *J. Am. Chem. Soc.*, **85**, 362 (1963); M. P. Cava and E. Moroz, *ibid.*, **84**, 115 (1962); J. Meinwald, G. G. Curtis, and P. G. Gassman, *ibid.*, **84**, 116 (1962).

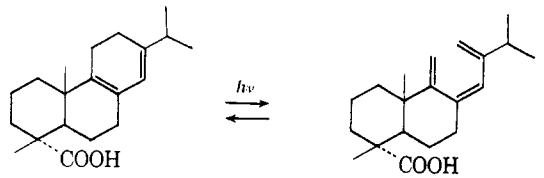
(44) L. M. Jackman, "Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry," Pergamon Press, New York, N. Y., 1959, p. 129.

(45) W. L. Meyer and R. W. Hoffman, *Tetrahedron Letters*, 691 (1962); W. A. Ayers, C. E. McDonald, and J. B. Stothers, *Can. J. Chem.*, **41**, 1113 (1963).

prevails over ring opening. To explain the analogous bridging reaction of the pyrocalciferols, Havinga[18] has suggested that the *syn* arrangement of the methyl group and the hydrogen atom at C-10 and C-9, respectively, sterically hinders the normal ring opening reaction. In addition, it was suggested that the movement of C-5 and C-8 in going to the excited state will be such as to orient the two atoms toward one another and thus aid in bond formation. This concept that a half-boat conformation of the excited state can directly lead to the bond-forming reaction has been extended by Lawrence and co-workers.[27] These latter investigators postulate that the conformational aspects of the excited state alone can control the reaction course; *i.e.*, a half-chair conformation leads to ring opening and a half-boat conformation to bond formation.

Applying these concepts to the formation of photolevopimaric acid, Lawrence[27] concluded that the two possible conformations would differ little in energy content and, given an equal opportunity to occur, the bridging reaction, as opposed to the ring-opening reaction, is the preferred course of the general photoreaction of a 1,3-cyclohexadiene. Our examination of models of these two conformations, however, leads to the conclusion that the half-chair conformation is much favored and we would have predicted a ring opening reaction. As to the steric hindrance aspect of the latter reaction, in the present case there is a 1,3-methyl hydrogen interaction in contrast to the 1,2-type of repulsion found in the pyrocalciferol series. With this lesser repulsion in the levopimaric acid, a predominance of valence isomerization would not be expected.

It would appear, nevertheless, that both of the above concepts have merit since when they are applied to the isomeric diene system contained in palustric acid (**30**) a ring opening would be predicted and such has been found to be the case.[46,47] Perhaps levopimaric acid is a



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poor case to be studied since it is known that the material possesses unusual conformational properties. It has been shown that the diene prefers, for reasons yet unknown, to exist in the less preferred folded conformation.[48] If for the same unknown reasons the excited state is so controlled and thus exists as a folded conformation, a bond-forming reaction would certainly be preferred.[49] It is of interest to note that this preferred ground state conformation of levopimaric acid greatly resembles the conformation of the pyrocalciferols. Thus, in line with the suggestion of Lawrence, it is indicative that conformational aspects can strongly control the course of the photochemical reaction. However, the levopimaric acid example clearly shows us our present inadequacy in being able to predict ground state preferences and, until such predictions can be made, it will not be possible to evaluate the role of steric hindrance suggested by Havinga.

(46) W. G. Dauben and R. M. Coates, *J. Org. Chem.*, in press.

(47) W. H. Schuller and R. V. Lawrence (U. S. Patent 3,086,989, April 23, 1963; *Chem. Abstr.*, **59**, 11575 (1963)) have reported that palustric acid upon irradiation gave a small yield of the bridged valence isomer. However, until the detailed properties of this material are published, this structural assignment must be considered as only tentative.

(48) A. W. Burgstahler, H. Ziffer, and U. Weiss, *J. Am. Chem. Soc.*, **83**, 4660 (1961); A. Moscowitz, E. Charney, U. Weiss, and H. Ziffer, *ibid.*, **83**, 4661 (1961); U. Weiss, H. Ziffer, and E. Charney, *Chem. Ind.* (London), 1286 (1962).

(49) It cannot be stated that the photolysis of levopimaric acid follows a unique course; n.m.r. analysis of the crude reaction product (containing less than 2% of starting diene) showed that the maximum amount of bridged product present was about 70%. Furthermore, the remaining 30% appeared to possess between 2 and 3 vinyl protons. Unfortunately, attempts to isolate a minor reaction product were not successful. The above results may indicate that both reaction pathways are being followed.

Experimental[50]

Photolevoprimaric Acid (10).—A total of 57 g. (0.19 mole) of levopimaric acid[51] dissolved in 4 l. of dry ether was irradiated with an unfiltered 450-watt Hanovia lamp (Model 79-A36) in the standard Hanovia quartz probe. Two separate irradiations were performed using a 2-l. irradiation flask. The solution was flushed with helium for 30 min. prior to irradiation and during the irradiation the solution was agitated with a magnetic stirrer and a slow helium flush. Six hours of illumination on each run reduced the ultraviolet absorption at 270 mμ by 98% and at that point the irradiation was stopped.

The two portions of the irradiated material were combined and the solvent was removed under reduced pressure. The residual white crystalline solid, m.p. 85–108°, $[\alpha]_D$ +60°, was dissolved in 400 ml. of acetone and the solution cooled in an ice–water bath. A solution of 19.2 g. (0.216 mole) of 2-amino-2-methyl-1-propanol in 20 ml. of acetone was added in one portion, with swirling. The precipitated salt was collected by suction filtration, washed with acetone, and dried under reduced pressure at room temperature; yield 61 g. (82%), $[\alpha]_D$ +48° (ethanol). The mother liquor was concentrated and cooled to yield an additional 8 g. (10.7%) of amine salt. The combined material was recrystallized twice from methanol; yield 22 g. (29.6%), m.p. 178–181° (rapid heating), $[\alpha]^{23}_D$ +53° (*c* 1.50, ethanol). Concentration of the mother liquor yielded an additional 16 g. (21.5%) of amine salt. An analytical sample was dried for 3 days over phosphorus pentoxide at room temperature and 0.03 mm.

Anal. Calcd. for $C_{24}H_{41}O_3N$ (391.58): C, 73.61; H, 10.55; N, 3.58. Found: C, 73.42; H, 10.50; N, 3.56.

The free acid was regenerated from the two portions of salt separately. The 22-g. portion of salt was placed in a separatory funnel with 200 ml. of ether and shaken vigorously with three 25-ml. portions of 10% phosphoric acid. When all the salt had dissolved, the ethereal layer was washed twice with water and dried. The solvent was removed under reduced pressure and the crystalline residue recrystallized from aqueous ethanol; yield 15 g. (26.4%), m.p. 114–116°, $[\alpha]^{16}_D$ +70°, ϵ_{272} 30, ϵ_{205} 3800.

Anal. Calcd. for $C_{20}H_{30}O_2$ (302.44): C, 79.42; H, 10.00. Found: C, 79.69; H, 10.28; mol. wt., 291, 293 (osmometric in acetone).

The 16-g. portion of the salt was regenerated in the identical manner and yielded 12.0 g. (21.0%) of photolevopimaric acid, m.p. 113–116°, $[\alpha]^{20}_D$ +67°. The total yield was 27 g. (47.4%).

The photolevopimaric acid was esterified with diazomethane (prepared from N-methyl-N-nitrosourea) and the resulting liquid methyl ester was purified by chromatography on alumina (Activity III). After drying the ester for 3 days at 0.08 mm. the material had the properties: $[\alpha]^{25}_D$ +56°, n^{25} 1.5037, ϵ_{205} 4400.

Anal. Calcd. for $C_{21}H_{32}O_2$ (316.47): C, 79.70; H, 10.19. Found: C, 79.41; H, 10.23.

Pyrolysis of Photolevopimaric Acid (10).—In a sealed tube under nitrogen 499 mg. (1.65 mmoles) of photolevopimaric acid was heated in an oil bath at 120° for 3 hr. The glassy pyrolysate (λ_{max} 272 mμ (ϵ 3700), $[\alpha]_D$ −84°) was dissolved in 5 ml. of ace-

(50) All melting points were taken in evacuated sealed capillaries and are uncorrected. Optical rotations were measured in chloroform unless otherwise specified. The n.m.r. spectral data are relative to tetramethylsilane as an internal standard. Chromatographies were performed on Woelm neutral alumina which had been deactivated to the desired activity by the addition of distilled water. The v.p.c. analyses were conducted at 210° on a column containing 5% SE-30 silicone oil using a Wilkens Aerograph Model 600 apparatus. Combustion analyses were obtained from the Microanalytical Laboratory, College of Chemistry, University of California.

(51) The acid was obtained from *Pinus palustris* oleoresin (Sheldon Naval Stores Co., Valdosta, Ga.) by the procedure of V. M. Loeblich, D. E. Baldwin, R. T. O'Connor, and R. V. Lawrence, *J. Am. Chem. Soc.*, **77**, 6311 (1955).

tone and to this solution there was added 591 mg. of 2-amino-2-methyl-1-propanol in 1 ml. of acetone. The white precipitate was collected and dried in an evacuated desiccator at room temperature; yield 538 mg., λ_{max} 272 mμ (ε 5100), $[\alpha]_D$ −173° (ethanol). The salt was recrystallized twice from methanol; yield 194 mg., λ_{max} 272 mμ (ε 5800), $[\alpha]_D$ −219° (ethanol). The free acid was regenerated from the salt with 10% phosphoric acid in the usual way; yield 134 mg. The crude acid was recrystallized from ethanol; yield 90 mg. (18%), λ_{max} 272 mμ (ε 5500), $[\alpha]_D$ −243°. The infrared spectrum was identical with the spectrum of authentic levopimaric acid.

Methyl Dihydrophotolevopimarate (14).—A solution of 601 mg. (1.98 mmoles) of photolevopimaric acid in 50 ml. of ethanol was hydrogenated over prereduced platinum oxide (76 mg.) at atmospheric pressure and room temperature. In 90 min. hydrogen absorption had ceased and 2.0 mmoles of gas had been absorbed. The catalyst was filtered and the ethanol removed under reduced pressure. The residual solid was methylated with diazomethane and the ester was recrystallized three times from methanol; yield 240 mg. (38%), m.p. 101–106°. A sample of the pure dihydro ester was obtained after two further recrystallizations; m.p. 103.5–105.5°, $[\alpha]^{25}_D$ (*c* 1.51), ϵ_{205} 270.

Anal. Calcd. for $C_{21}H_{34}O_2$ (318.48): C, 79.19; H, 10.76. Found: C, 79.31; H, 10.62; mol. wt., 318 (mass spectrum).

A solution of 35 mg. of ester in 5 ml. of dry chloroform was saturated with dry hydrogen chloride and the solution flushed with hydrogen chloride for 8 hr. Upon processing the reaction solution in the usual manner, unchanged starting ester was obtained, m.p. 102.5–105.5°.

Methyl 14-Hydroxydihydrophotolevopimarate (15).—To a solution of 559 mg. (1.77 mmoles) of methyl photolevopimarate in 10 ml. of tetrahydrofuran there was added 50 mg. (1.32 mmoles) of sodium borohydride followed by the addition of 200 mg. (1.41 mmoles) of freshly distilled boron trifluoride etherate.[52] The reaction mixture was stirred under an atmosphere of nitrogen for 2 hr. at room temperature, 3 ml. of 3 *N* sodium hydroxide was added slowly, followed by the addition of 3 ml. of 30% hydrogen peroxide. The mixture was allowed to stir for 2 hr., the layers separated, and the organic layer extracted twice with saturated aqueous sodium chloride. The extract was dried over magnesium sulfate, the solvent removed under reduced pressure, and there was obtained 442 mg. of a cloudy oil which solidified to a waxy solid, m.p. 70–125°.

The product was chromatographed on 14 g. of alumina (Activity III). Elution with pentane gave 221 mg. of starting ester, elution with benzene (two 30 ml. portions) yielded 66 mg. of a white solid alcohol (m.p. 135–165°) which was not investigated further, and elution with benzene–ether (9:1) gave 91 mg. of an alcohol, m.p. 115–130°.

The recovered methyl photolevopimarate was recycled with 155 mg. (4.1 mmoles) of sodium borohydride and 580 mg. (4.06 mmoles) of boron trifluoride etherate. The crude product was chromatographed on alumina (Activity III). Elution with benzene and benzene–ether (9:1) gave only the lower melting alcohol, m.p. 125–131°, yield 140 mg.

All the lower melting alcohol fractions were combined and recrystallized from aqueous methanol; yield 219 mg. (37%), m.p. 126–130°. A small portion was recrystallized twice to obtain the analytical sample, m.p. 129–131°, $[\alpha]^{25}_D$ +58° (*c* 1.26).

Anal. Calcd. for $C_{21}H_{34}O_3$ (334.48): C, 75.40; H, 10.25. Found: C, 75.29; H, 10.07.

Methyl 14-Oxodihydrophotolevopimarate (16).—To a solution of 190 mg. (0.57 mmole) of methyl 14-hydroxydihydrophotolevopimarate in 20 ml. of acetone cooled to −20° there was added 0.2 ml. (0.8 mmole) of 8 *N* chromic acid solution (prepared from 26.7 g. of chromium trioxide and 23 ml. of concentrated sulfuric acid diluted to 100 ml. with distilled water).[37] The solution was swirled for 5 min. and the excess oxidant destroyed with methanol. The solution was diluted with water and ether, and the organic phase was separated and washed twice with 5% sodium bicarbonate solution. The ethereal solution was dried, the solvent evaporated, and the residual solid (m.p. 80–100°) was chromatographed on 6 g. of alumina (Activity III). The ketonic product was eluted slowly by changing the solvent from pentane to pentane–benzene (1:1). The crystalline fractions were combined and recrystallized from aqueous methanol; yield 121 mg. (65%), m.p. 102.5–104.0°. The analytical sample was obtained by two additional recrystallizations; m.p. 103.5–104.5°, $[\alpha]^{25}_D$ −2.6° ± 0.4° (*c* 1.70), $\nu^{CCl_4}_{max}$ 1776, 1730 cm.$^{-1}$.

Anal. Calcd. for $C_{21}H_{32}O_3$ (332.47): C, 75.86; H, 9.70. Found: C, 75.55; H, 9.47.

Periodate–Permanganate Oxidation of Photolevopimaric Acid to Keto Diester 17.—A solution of 1.06 g. (3.5 mmoles) of photolevopimaric acid, 968 mg. (7.0 mmoles) of anhydrous potassium carbonate, 6.35 g. (27.6 mmoles) of potassium metaperiodate, and 65 mg. (0.42 mmole) of potassium permanganate in 1500 ml. of water was allowed to react for 16 hr., an additional 482 mg. (3.5 mmoles) of potassium carbonate added, and the reaction allowed to continue for an additional 20 hr. The reaction mixture was acidified with 35 ml. of concentrated hydrochloric acid, the organic products removed by extraction with ether, and the acidic material esterified with diazomethane.

The esterified material was chromatographed on 32 g. of alumina (Activity III). Elution with pentane gave 274 mg. of unoxidized methyl photolevopimarate. Elution with pentane–benzene (2:1) through benzene–ether (9:1) yielded 560 mg. of keto diester **17** which was recrystallized from aqueous methanol; yield 462 mg. (40%), m.p. 103–106°. The analytical sample was obtained after two additional recrystallizations; m.p. 105.5–107.0°, $[\alpha]^{34}_D$ +59° (*c* 1.38).

Anal. Calcd. for $C_{22}H_{34}O_5$ (378.49): C, 69.81; H, 9.05. Found: C, 69.92; H, 9.19.

Elution with benzene–ether (5:1) gave 36 mg. (3%) of a more polar product, m.p. 108–124°. From subsequent oxidations sufficient material was obtained to permit further characterization. The substance was recrystallized from ethanol and from hexane–ethyl acetate; m.p. 127.5–130.0°, $[\alpha]^{23}_D$ +56° (*c* 1.32), λ^{EtOH}_{max} 294 mμ (ε 60), λ^{EtOH}_{205} 1000, $\nu^{CCl_4}_{max}$ 1733 and 1715 cm.$^{-1}$, mol. wt. 392 (mass spectrum).

Isomerization of Keto Diester 17.—A solution of 157 mg. (0.42 mmole) of keto diester **17** and 7 ml. of 5% aqueous sodium hydroxide in 7 ml. of methanol was stirred for 22 hr. under a nitrogen atmosphere. The solution was acidified with 10% sulfuric acid and the product extracted with ether. The acidic material was isolated by extraction of the ethereal solution with 5% sodium carbonate, the carbonate solution acidified, and the organic material removed by ether extraction, the ethereal solution dried, and the solvent evaporated; yield 155 mg. of a waxy solid.

The acidic material was esterified with diazomethane and the crystalline isomeric keto diester **18** recrystallized from methanol; yield 79 mg. (50%), m.p. 106–110°. A specimen of analytical purity was obtained after three additional recrystallizations; m.p. 109.5–110.5°, mixture m.p. with keto diester **17** 83–86°, $[\alpha]^{26}_D$ −116° (*c* 1.64).

Anal. Calcd. for $C_{22}H_{34}O_5$ (378.49): C, 69.81; H, 9.05. Found: C, 69.56; H, 8.99.

Ozonization of Methyl Photolevopimarate.—Four 605-mg. (2.0 mmoles each) portions of photolevopimaric acid were esterified with diazomethane and ozonized separately in 60 ml. of methanol at −78°. The four runs were combined and a stream of chlorine gas passed into the solution while 160 ml. of water was added. After 1 hr. the excess chlorine was removed by a stream of nitrogen, water and ether were added until phases separated, and the ethereal layer separated. The aqueous layer was extracted twice with ether and the combined ether solutions were extracted three times with 5% sodium carbonate solution. The ether solution retained 864 mg. of neutral material which was not examined.

The carbonate extracts were acidified and extracted with ether. The ether solution was dried, the solvent removed under reduced pressure, and the residual keto half-ester **19** recrystallized from carbon tetrachloride; yield 1.59 g. (54%), m.p. 100.0–103.5°. The analytical sample had the properties: m.p. 107.5–109.5° (gas evolution), $[\alpha]^{26}_D$ +52° (*c* 1.47).

Anal. Calcd. for $C_{21}H_{32}O_5$ (364.47): C, 69.20; H, 8.55. Found: C, 69.33; H, 9.02.

A small portion of the acid was esterified with diazomethane. The ester has m.p. 100–104° and an infrared spectrum identical with keto diester **17**.

Baeyer–Villiger Oxidation of Keto Half-ester 19.—A solution of 83.6 mmoles of peroxytrifluoroacetic acid in 15 ml. of methylene chloride was prepared in the usual manner from 2.30 ml. (83.6 mmoles of peroxide) of 90% hydrogen peroxide and 14.3 ml. (83.6 mmoles) of distilled trifluoroacetic anhydride.[35] This solution was added, slowly with stirring and cooling, to a mixture of 30 g. (0.21 mole) of anhydrous dibasic sodium phosphate and 3.40 g. (9.3 mmoles) of keto half-ester **19** in 40 ml. of methylene

(52) H. C. Brown, K. J. Murray, L. J. Murray, J. A. Snover, and G. Zweifel, *J. Am. Chem. Soc.*, **82**, 4233 (1960).

chloride. The mixture was allowed to stand at room temperature for 30 min. and then heated under reflux for 12 hr.

The methylene chloride solution was filtered, the inorganic salts washed well with the solvent, and the combined organic solutions were extracted with water, 5% ferrous sulfate–sulfuric acid solution, and water. The solution next was extracted three times with 5% sodium carbonate solution, the alkaline solution acidified, and the acidic material isolated.

The solution of the acidic material and 695 mg. of sodium hydroxide in 37 ml. of methanol was allowed to stand for 12 hr. at room temperature, acidified with 8.5 ml. of 10% sulfuric acid, and the product extracted with chloroform. The solvent was removed and the residue was esterified with diazomethane.

The ester mixture was chromatographed on a column containing 167 g. of silica gel (80–200 mesh) packed in benzene, 300-ml. fractions being used. The benzene and the first three benzene–ether (20:1) eluates were discarded. The ester **20** was in the following nine fractions: 1 benzene–ether (20:1), 6 benzene–ether (40:3), and 2 benzene–ether (10:1); yield 780 mg. (20%). An additional benzene–ether (10:1) fraction contained a mixture of two products. The desired hydroxy ester **21** was obtained in the following nine fractions: 1 benzene–ether (10:1), 3 benzene–ether (5:1), 3 benzene–ether (3:1), and 2 benzene–ether (1:1); yield 1.27 g. (33%).

The less polar product **20** was purified by chromatography on alumina (Activity III), the product being eluted with pentane–benzene and with benzene. The oily eluate crystallized on storage overnight in a vacuum desiccator at 0°. The product was recrystallized from hexane and sublimed at 65° (1.5 mm.); m.p. 71.5–74.0°, $[\alpha]^{24}D$ +33° (*c* 1.72).

Anal. Calcd. for $C_{22}H_{34}O_6$ (394.49): C, 66.98; H, 8.69. Found: C, 66.75; H, 8.51.

The more polar product **21** crystallized upon storage overnight in a vacuum desiccator at 0° and the material was utilized for subsequent transformation without further purification. A purified sample was obtained by slow crystallization from hexane; m.p. 69–74°, $[\alpha]^{27}D$ +43° (*c* 1.44), $\nu_{max}^{CCl_4}$ 3510, 1724, and 1704 (shoulder) $cm.^{-1}$.

Anal. Calcd. for $C_{18}H_{28}O_5$ (324.40): C, 66.64; H, 8.70. Found: C, 66.49; H, 8.48.

Oxidation of Alcohol 21.—A solution of 430 mg. (1.33 mmoles) of alcohol **21** in 20 ml. of acetone at 0° was treated with 0.4 ml. (1.6 mmoles) of 8 *N* chromic acid solution[37] over a 10-min. period. The excess reagent was destroyed with methanol after 20 min. and the product extracted with ether. The ethereal solution was washed with 5% sodium carbonate solution and water, dried, and the solvent evaporated under reduced pressure. The product (371 mg.) was chromatographed on 37 g. of silica gel, using 75-ml. fractions (the material is destroyed by alumina). The cyclobutanone **22** was eluted with benzene–ether (20:1) and benzene–ether (15:1); yield 258 mg. (60%). Owing to the sensitivity of the ketone, it generally was used without further purification.

An analytical sample was prepared by two recrystallizations from methanol at 0° and one from hexane; m.p. 67–71°, $[\alpha]^{27}D$ +61° (*c* 1.16), $\nu_{max}^{CCl_4}$ 1789 and 1733 $cm.^{-1}$. Recovery of the material from the methanol mother liquors indicated that some ring opening had occurred during the recrystallizations.

Anal. Calcd. for $C_{18}H_{26}O_5$ (322.39): C, 67.06; H, 8.13. Found: C, 66.77; H, 7.89.

Ring Opening of Ketone 22 to Isotriester 24.—To a solution of 121 mg. (0.38 mmole) of ketone **22** in 10 ml. of methanol which had been flushed with nitrogen, there was added 117 mg. (2.9 mmoles) of sodium hydroxide dissolved in 3 ml. of methanol. The solution was allowed to stand for 12 hr. at room temperature under an atmosphere of nitrogen, acidified with 10% sulfuric acid, and most of the methanol removed under reduced pressure. The residue was dissolved in chloroform, the solution washed with 5% sodium carbonate solution, and the solvent removed under reduced pressure.

The neutral residue was chromatographed on 4.0 g. of alumina (Activity III) and the isotriester **24** was eluted with pentane and pentane–benzene (yield 100 mg.) and the crystalline material was recrystallized from methanol; yield 76 mg. (57%), m.p. 78–82°. An analytical sample was prepared by further recrystallization from methanol; m.p. 81.5–82.5°, mixture m.p. with triester **25**, 45–53°, $[\alpha]^{26}D$ +33° (*c* 0.80).

Anal. Calcd. for $C_{19}H_{30}O_6$ (354.43): C, 64.38; H, 8.53. Found: C, 64.44; H, 8.39.

Ring Opening of Alcohol 21 to Aldehyde 23.—A solution of 80 mg. of alcohol **21** in hexane–benzene (5:1) was adsorbed onto 2.4 g. of alumina (Activity III) and allowed to stand for 12 hr. The oily aldehyde **23** was eluted with pentane–benzene (3:1), pentane–benzene (1:1), and benzene; yield 54 mg. (66%), $\nu_{max}^{CCl_4}$ 2725 $cm.^{-1}$.

The 2,4-dinitrophenylhydrazone was prepared in ethanol and the crude product was filtered through alumina. The product was obtained as a yellow-orange glass, $[\alpha]^{27}D$ +48° (*c* 1.36).

Anal. Calcd. for $C_{24}H_{32}O_8N_4$ (504.43): C, 57.13; H, 6.39. Found: C, 57.18; H, 6.47.

A 67-mg. portion of the aldehyde, prepared from 110 mg. of alcohol **21**, was oxidized with alkaline hydrogen peroxide in methanol and the crude acid esterified with diazomethane. The material was chromatographed on alumina and there was obtained 24 mg. of crude isotriester **24** which after repeated recrystallizations from methanol yielded 5 mg. of pure **24**, m.p. 80.0–82.0°, mixture m.p. with authentic **24** was 80.5–82.0°.

Preparation of Triester 25 from Isotriester 24.—A solution of 76 mg. (0.43 mmole) of isotriester **24** and 171 mg. of potassium hydroxide in 10 ml. of methanol (flushed with nitrogen and kept under a nitrogen atmosphere) was heated under reflux for 12 hr. The solution was poured into water, the organic material isolated in the usual manner, and methylated with diazomethane. This material was added to 510 mg. of potassium hydroxide in 7 ml. of methanol and the solution heated under reflux for 48 hr. Again the organic material was isolated and esterified with diazomethane.

The ester mixture was chromatographed on alumina (Activity III). Elution with pentane gave 4 mg. of crystalline isotriester **24**, and the earlier fractions from pentane–benzene (5:1) yielded a mixture of **24** and **25**. The later pentane–benzene (5:1) and benzene fractions totaled 37 mg. of triester **25**. The product was recrystallized twice from hexane; yield 20 mg. (26%), m.p. 62.0–63.5°, mixture m.p. with authentic triester **25**, 62.5–64.0°. The infrared spectrum of the sample was identical with the spectrum of the authentic material prepared from levopimaric acid (see below).

Preparation of Triester 25 from Methyl 12-Oxo-Δ^{13}-dihydrolevopimarate (28).—A solution of 162 mg. (0.49 mmole) of unsaturated ketone **28**[42] in 16 ml. of ethyl acetate and 8 ml. of acetic acid was treated with ozone (0.28 mmole/min.) at −15° for 2 hr.; 0.49 mmole of ozone was absorbed. A solution of 4 ml. of 30% hydrogen peroxide in 8 ml. of water was added, the solution allowed to stand at room temperature for 2 hr., and then heated under reflux for 12 hr.

Water was added and the mixture extracted with chloroform. The organic layer was washed twice with 5% ferrous sulfate–sulfuric acid solution and twice with 5% sodium carbonate solution. The basic extracts were acidified, the mixture extracted with chloroform, and the solvent evaporated. The residual diacid **29** was recrystallized from methanol; yield 64 mg. (40%), m.p. 245–247° (gas evolution), $[\alpha]^{30}D$ +18° (*c* 0.81, methanol).

Anal. Calcd. for $C_{17}H_{26}O_6$ (326.38): C, 62.56; H, 8.03. Found: C, 62.57; H, 8.03.

A 47-mg. portion of the diacid was esterified with diazomethane, filtered through alumina (Activity III), and recrystallized several times from hexane; yield 34 mg. (67%), m.p. 62.5–63.5°, $[\alpha]^{26}D$ +23° (*c* 0.72).

Anal. Calcd. for $C_{19}H_{30}O_6$ (354.43): C, 64.38; H, 8.53. Found: C, 64.40; H, 8.25.