placed. Correction of this coordinate and further refinement reduced the R index to 11.0%. A difference Fourier indicated no misplaced or missing Br, C, or O atoms. The difference Fourier was also used to locate the hydrogen atoms. The addition of the hydrogen atoms and five anisotropic temperature factors[19] to the refinement reduced the R index to its final value of 9.0%.

Results of X-Ray Analysis.—The structure obtained in the analysis was stereographically plotted (Figure 1) using the ORTEP computer program of C. K. Johnson.[20] An estimate of errors in positional parameters, bond lengths, and bond angles are summarized in Table VI.[21] Owing to limitations in space, other pertinent crystallographic data and parameters cannot be listed here. F tables, atomic coordinates, temperature factors, bond angles, and distances have been filed with NAPS.[7]

TABLE VI
DATA FIT AND DEVIATIONS

Final R index	0.090
Standard deviations[a] of coordinates	
Br	0.001 Å
C, O	0.006 Å
Uncertainties in C–O–Br bond lengths	0.01 Å
Uncertainties in C–O–Br bond angles	0.5°

[a] Standard deviations in the coordinates were derived from the residuals and the diagonal elements of the inverse matrix of the final least-squares cycle.

Registry No.—**6**, 21436-28-2; **7**, 21436-29-3; **8**, 21436-30-6; **12b**, 21436-31-7; **13**, 21436-32-8; **14a**, 21436-33-9; **14b**, 21436-34-0; **15a**, 21436-35-1; **15b**, 21436-36-2; **16a**, 21436-37-3; **16b**, 21436-38-4; **17a**, 21436-39-5; **17b**, 21436-40-8.

(19) Anisotropic temperature factors for atoms Br(1), O(24), O(26), C(27), O(29), and C(30) were used during refinement since these atoms displayed the largest isotropic temperature factors.

(20) C. K. Johnson, ORTEP, ORNL-3794, Oak Ridge National Laboratories, Oak Ridge, Tenn.

(21) Error estimates involving the hydrogen positions have not been made since no effort was made to refine their coordinates rigorously. Moreover, any error estimate involving even well-refined hydrogen positions is at best dubious.

Synthesis and Conformational Analysis of Tricyclic Ring-C Aromatic 20-Nor Diterpenoid Resin Acid Analogs

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Received October 31, 1968

A simple synthesis of the tricyclic unsaturated acid **8** and its conversion into lactone **9** is described. All four possible racemates of ring-C aromatic 20-nor diterpenoid resin acid analogs **1**, **2**, **3**, and **4** have been synthesized by catalytic and chemical reduction of **8** and **9**. Lithium–ammonia reduction of the benzylic lactone **9** proceeds with retention of configuration at C-12 to give *trans* acid **1**, while catalytic hydrogenation of **9** proceeds with inversion at C-12 to give *cis* acid **3**. Lithium–ammonia reduction of **8** yields *trans* acid **2** exclusively, whereas catalytic hydrogenation of **8** gives 75% *cis* acid **3** and 9% *cis* acid **4**. Some chemical and conformational properties of **1**, **2**, **3**, and **4** are reported. In contrast to the corresponding *cis* resin acid analogs where the conformation of ring A is "steroid," ring A for the *cis* acids **3** and **4** is "nonsteroid."

The first synthesis of a 20-*nor* resin acid analog was achieved by Haworth and Barker.[2] These authors obtained a compound, mp 187–188°, from a sulfuric acid–acetic acid catalyzed cyclization of **5**, but could not assign stereochemistry to it. Mori and coworkers[3] later established the stereochemistry of Haworth's acid as **1**.

When Mori's publication appeared, we were prompted to report a portion of our work in a preliminary communication.[4] As part of our synthetic studies[5-7] of diterpenoids related to rosenonolactone and gibberellin, we had synthesized the four possible racemates of tricyclic ring-C aromatic 20-nor diterpenoid resin acid analogs **1**, **2**, **3**, and **4**.

At about the same time Tahara and Hirao[8] reported the conversion of dehydroabietic acid to the *enantiomers* of **1** and **3** and conformational studies of some derivatives of the *cis* acid **3**. Dasgupta and Antony[9] also had developed a synthesis of racemic acid **3**.

The present paper describes in detail the synthesis of the racemic acids **1**, **2**, **3**, and **4** and presents data on conformational–configurational relationships in these compounds.

Synthesis of Intermediates.—Compound **7** could be prepared in 77% yield by cyclization of the keto ester **6**[10] in concentrated sulfuric acid–benzene solution.[11] Attempted cyclodehydration of **6** with polyphosphoric acid under various conditions,[7] however, failed to produce pure **8**. Saponification of **7** yielded the corresponding acid **8** in almost quantitative yield. The structures of **7** and **8** were assigned from the electronic spectra and secured when **8** was dehydrogenated to 1-methylphenanthrene.

Lactonization of **8** with concentrated sulfuric acid at −10° proceeded cleanly to **9**[12] (Scheme I) as shown by the single carbonyl band at 1760 cm^{-1} in the infrared spectrum. We have assigned a *trans* A/B ring junction to lactone **9**, as a molecular model (Dreiding)

(1) To whom inquiries regarding this work should be made: Calcutta, India.

(2) R. D. Haworth and R. L. Barker, *J. Chem. Soc.*, 1299 (1939).

(3) K. Mori, M. Matsui, and H. Tanaga, *Tetrahedron*, **22**, 885 (1966).

(4) U. R. Ghatak, A. K. Banerjee, N. R. Chatterjee, and J. Chakravarty, *Tetrahedron Lett.*, 247 (1967).

(5) U. R. Ghatak, A. K. Banerjee, and N. R. Chatterjee, *Indian J. Chem.*, **5**, 457 (1967).

(6) U. R. Ghatak, J. Chakravarty, and R. Dasgupta, *ibid.*, **5**, 459 (1967).

(7) U. R. Ghatak, J. Chakravarty, and A. K. Banerjee, *Tetrahedron*, **24**, 1577 (1968).

(8) A. Tahara and K. Hirao, *Chem. Commun.*, 326 (1967). We thank Dr. Tahara for providing us with a copy of this manuscript prior to publication.

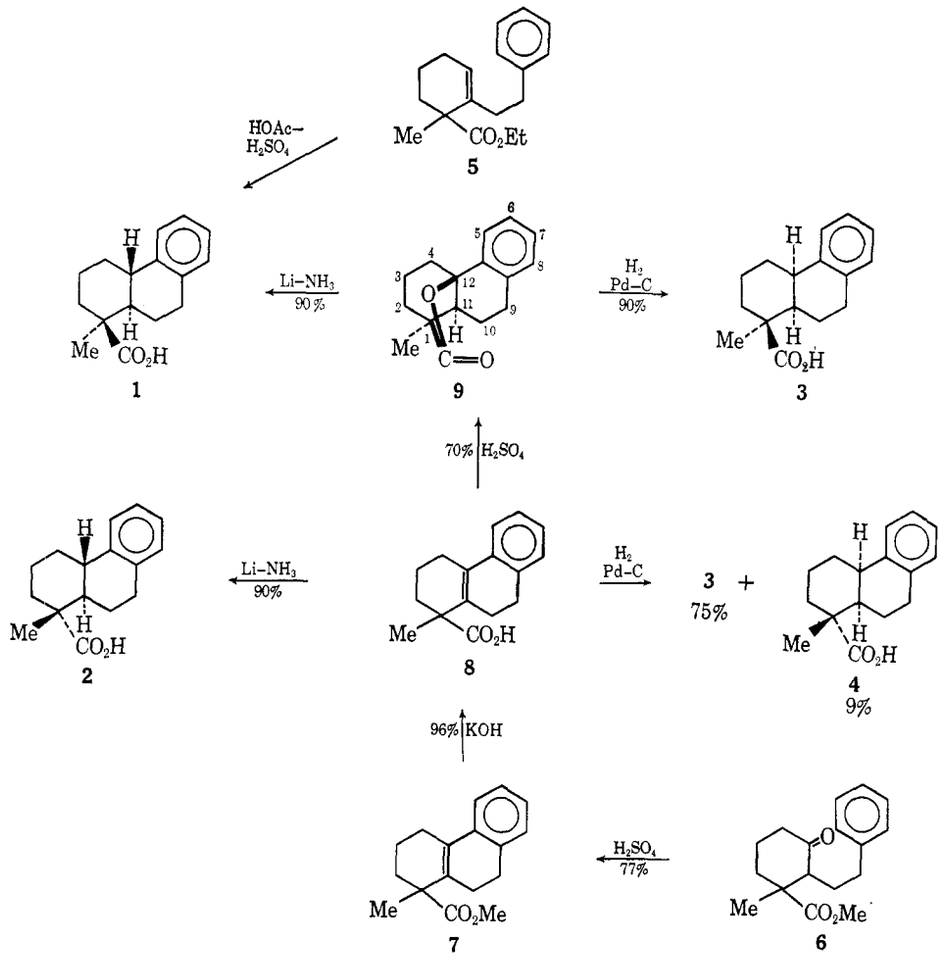
(9) S. K. Dasgupta and P. C. Antony, *Tetrahedron Lett.*, 4997 (1966).

(10) U. R. Ghatak, D. K. Datta, and S. C. Ray, *J. Amer. Chem. Soc.*, **82**, 1728 (1960).

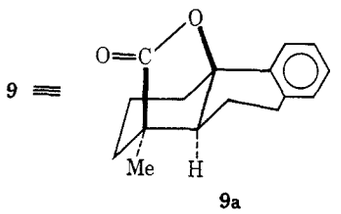
(11) B. R. T. Keene and K. Schofield, *J. Chem. Soc.*, 3181 (1957).

(12) Mori, *et al.*[3] have described a different method for the synthesis of lactone **9**. They assigned a *trans* A/B ring junction to lactone **9** on the basis that a monoketo derivative is obtained on chromic acid oxidation of **9**.

SCHEME I



indicates that lactone **9** with this stereochemistry is practically free of any strain (depicted in **9a**). Con-



9a

struction of the corresponding *cis* A/B-ring fused lactone is permitted only after serious bond deformations. Also several nonbonded interactions occur in the *cis* model. Whether lactonization of the acid **8** proceeds in a concerted fashion[13] or through a benzyl carbonium ion intermediate (at C-12 in **8**) the product[14] is *trans* lactone **9**.

We chose to synthesize the epimeric acids **1**, **2**, **3**, and **4** by reduction of the γ-lactone **9** and the unsaturated acid **8**. We were very interested in determining the stereochemical course[15–17] of hydrogenolysis at a benzylic asymmetric center (at C-12 in lactone **9**) in catalytic and chemical reductions. We also wanted to evaluate the influence of a neighboring *gem*-methylcarboxyl residue (at C-1 in **8**) on the catalytic and chemical reduction of a styrenoid double bond such as that found in the unsaturated acid **8** (or the ester **7**).

Synthesis of the *trans* Acids 1 and 2.—Attempted hydrogenolysis of lactone **9** with Raney nickel using conditions known to retain configuration at the benzylic asymmetric center[15a,c,16,17] of certain benzyl alcohols led either to the recovery of starting material or to the formation of *cis* acid **3** (see below) through inversion[18] at C-12.

We next investigated whether lithium–ammonia could be used to retain configuration at C-12 in the hydrogenolysis of the benzylic C–O bond of lactone **9**. Metal–ammonia has been widely used to cleave benzyl alcohol derivatives,[19] but nothing is known about

(13) (a) G. Stork and A. W. Burgstahler, *J. Amer. Chem. Soc.*, **79**, 5063 (1955); (b) M. F. Ansell and M. H. Palmer, *Quart. Rev.* (London), **18**, 211 (1964) and references cited therein.

(14) *Cf.* M. D. Bachi, J. W. Epstein, and H. J. E. Loewenthal, *Tetrahedron Lett.*, 5333 (1966).

(15) (a) W. A. Bonner and J. A. Zderic, *J. Amer. Chem. Soc.*, **78**, 3218 (1956), and other papers in this series; (b) S. Mitsui, S. Imaizumi, Y. Senda and K. Koono, *Chem. Ind.* (London), 233 (1964); (c) S. Mitsui and Y. Kudo, *ibid.*, 381 (1965), and other papers in this series.

(16) (a) A. M. Khan, F. J. McQuillin and I. Jardine, *Tetrahedron Lett.*, 2644 (1966); (b) R. L. Augustine, "Catalytic Hydrogenation," Marcel Dekker, Inc., New York, N. Y., 1965, p 142.

(17) E. W. Garbisch, Jr., *J. Org. Chem.*, **27**, 3363 (1962).

(18) E. W. Garbisch, Jr., *Chem. Commun.*, 806 (1967), has mentioned that hydrogenolysis of *cis*- and *trans*-4-*t*-butyl-1-phenyl-1-acetoxycyclohexanes with Raney nickel occurs stereospecifically but with complete inversion of configuration and this is in agreement with our observation with lactone **9**.

(19) (a) A. J. Birch, *J. Chem. Soc.*, 809 (1945); (b) H. Smith in "Organic Reactions in Liquid Ammonia," Vol. I, part 2, Interscience Publishers, New York, N. Y., 1963, pp 156 and 304.

the stereochemical fate of the benzylic asymmetric center in such a hydrogenolysis.[20-23]

The reaction of lactone **9** in tetrahydrofuran–ether with an excess of lithium in ammonia followed by decomposition with ammonium chloride led to acid **1**, mp 189–190°, in almost quantitative yield. The corresponding methyl ester **10**, prepared from methylation of **1** with diazomethane, had mp 78–79°. Acid **1** and ester **10** showed no depression in melting point when mixed with samples of Haworth's acid, mp 189–190°, and methyl ester, mp 76–77°.[2]

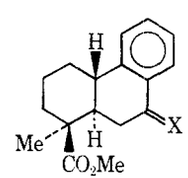
We are in agreement with Mori[3] that acid **1** has the assigned stereochemistry. Our assignment is based on the marked resistance of **10** toward saponification (Table I) and a detailed nmr study of the

TABLE I

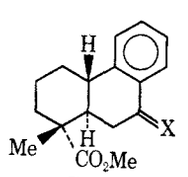
THE SAPONIFICATION OF METHYL ESTERS OF RING-C AROMATIC 20-NOR DITERPENOID RESIN ACID ANALOGS

Ester	Strength of KOH soln in ethanol–water (4:1), %	Refluxing time, hr	Ester hydrolyzed, %	Recovered ester, %
10	7	3	*ca.* 3	96
	10	4	6	90
13	7	3	78	20
16	7	3	87	10
19	7	3	30	69
	7	5	43	54
	10	4	84	12

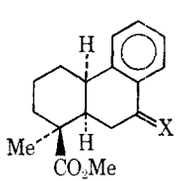
keto ester **11** and the alcohol **12** (see below). Mori bases his assignment on finding that chromic acid oxidation of **10** produces the keto ester **11** and that **10** is resistant toward hydrolysis. We have found that



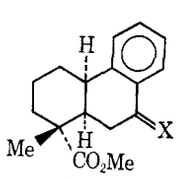
10, X = H_2
11, X = O



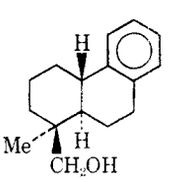
13, X = H_2
14, X = O



16, X = H_2
17, X = O



19, X = H_2
20, X = O



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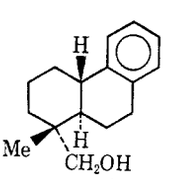

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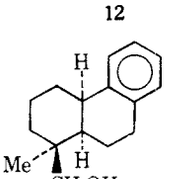

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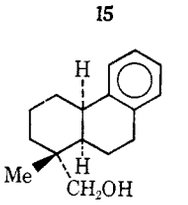
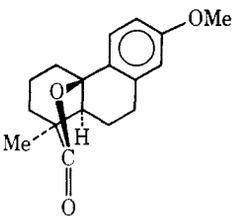
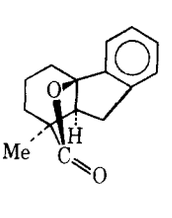


21

the racemic lactones **22**[24] and **23**[6] also undergo reduction to the corresponding acids **24** and **25** with complete



22



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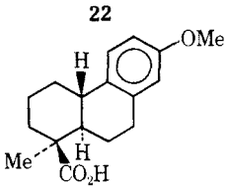

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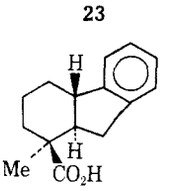

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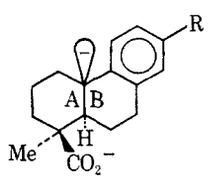
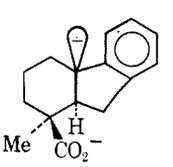
retention of configuration. The lithium ammonia induced reductive fission of the benzylic C–O bond of these γ-lactones probably proceeds *via* open benzylic carbanions such as **26**, **27**, and **28**, arising through



26, R = H
27, R = OMe



28

the displacement of carboxylate anion in a two-electron addition process.[23,25] In order to explain the retention of configuration in the resulting products, though, one is led to the conclusion that the carbanion is most stable when the electron pair at the benzylic position is *trans* to the adjacent proton of the A/B ring junction. A study of the lithium–ammonia reduction of the unsaturated acid **29**, however, indicates that these carbanions may not retain configurational stability (see below).

Reduction of the unsaturated acid **8** with lithium–ammonia[26] in tetrahydrofuran–ether afforded *trans* acid **2**, mp 209–210°, as the sole product. Esterification of **2** with diazomethane gave the methyl ester **13**, mp 54-55°. The stereochemistry of **2** has been established from the saponification rate of **13** relative

(20) It is reported [M. C. Hoff, K. W. Grennlee, and C. E. Boord, *J. Amer. Chem. Soc.*, **73**, 3329 (1951)] that reductive cleavage of vinylic chlorides with sodium–ammonia occurs with retention of configiration.

(21) The results in ref 20 have been verified [W. E. Truce and J. J. Breiter, *ibid.*, **84**, 1623 (1962)]. In addition it has been shown that reductive cleavage of vinylic sulfides with lithium–ammonia proceeds with more than 90% retention of configuration.

(22) Reduction of (−)-6-chloro-2,6-dimethyloctane with sodium–ammonia gives (+)-2,6-dimethyloctane with overall retention of configuration and an optical purity of about 20% [P. E. Verkade, K. S. DeVries, and B. M. Wepster, *Rec. Trav. Chim. Pays-Bas*, **83**, 367 (1964)].

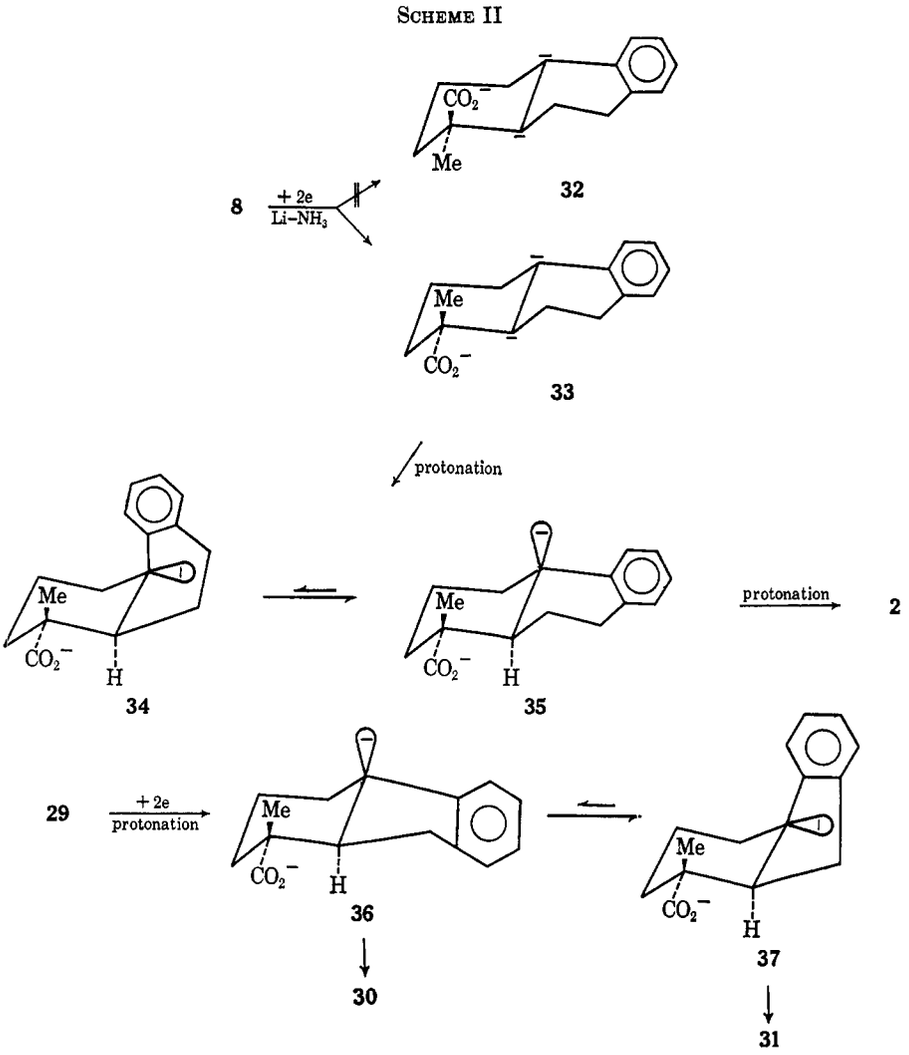
(23) H. M. Walborsky, F. P. Johnson, and J. B. Pierce, *J. Amer. Chem. Soc.*, **90**, 5222 (1968), have reported a detailed study on the reductive dehalogenation of (−)-(*R*)-1-halo-1-methyl-2,2-diphenylcyclopropane with sodium–ammonia to the optically active (+)-(*S*)-1-methyl-2,2-diphenylcyclopropane with overall retention of configuration along with two other ring-opened products. The amount of the optical activity observed in the dehalogenated cyclopropane is dependent on the nature of the starting halogen, the concentration of sodium in liquid ammonia solution, and a heterogeneity factor.

(24) N. R. Chatterjee, Ph.D. (Science) dissertation, University of Calcutta, July 1967.

(25) *Cf.* H. E. Zimmerman, *Tetrahedron*, **16**, 169 (1961).

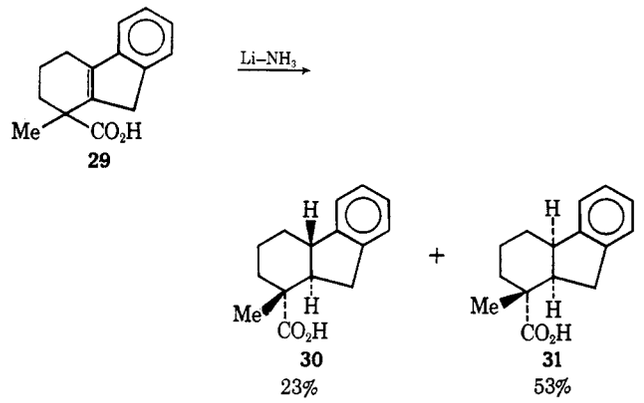
(26) For an excellent review, see ref 19b, pp 226–230 and 307–308.

SCHEME II



to **10** (Table I) and from a nmr study of the keto ester **14** and alcohol **15** (see below). Acid **2** can also be synthesized by an aluminum chloride–hydrogen chloride catalyzed cyclization of **5**.[4,24]

In contrast to the reduction of **8**, lithium–ammonia reduction of the styrenoid bond of acid **29**[27] resulted in a mixture of the epimeric acids **30** and **31** with the *cis* acid predominating.



In most cases[26] alkali metal–ammonia reduction of a cyclic styrenoid system results in the most stable of the possible stereoisomers. Several examples of metal–ammonia reductions giving mixtures containing less stable isomers have been reported.[28] Smith[29] has proposed a mechanism where the "conformational" and "steric approach" factors control the stepwise protonation of the intermediate dianions and monoanions in the reduction.[30] We have explained[27] the high degree of stereoselectivity in the lithium–ammonia reduction of **8** using arguments similar to those of Smith.[29] Of the possible dianions **32** and **33**, arising from the addition of two electrons[30] to the styrenoid bond in **8**, the dianion **32** is energetically unfavored owing to an electrostatic repulsion of the axial carboxylate anion[31] and the anionic center at C-12. Protonation[29] at the more basic C-11 position in the dianion **33** can proceed only from the α side to give two possible monoanions **34** and **35**. The monoanion **35** appears to be conformationally favored as **2** is the sole product of the reaction. In the reduction of **29**, however, the monoanion **37** appears to be more stable[7,32]

(27) U. R. Ghatak, J. Chakravarty, A. K. Banerjee, and N. R. Chatterjee, *Chem. Commun.*, 217 (1967).

(28) (a) W. S. Johnson, J. Ackerman, J. F. Eastham, and H. A. DeWalt, Jr., *J. Amer. Chem. Soc.*, **78**, 6302 (1956); (b) H. E. Zimmerman, *ibid.*, **78**, 1168 (1956); (c) W. S. Johnson, S. G. Boots, and E. R. Habicht, Jr., *J. Org. Chem.*, **33**, 1754 (1968).

(29) Reference 19b, pp 228–229.

(30) (a) A. J. Birch, *Quart. Rev.* (London), **4**, 69 (1950); (b) W. Nagata, T. Terasawa, S. Hirai, and H. Takeda, *Chem. Pharm. Bull.* (Tokyo), **9**, 709 (1961).

(31) The carboxyl group in the dianion is evidently present as the carboxylate anion in lithium–ammonia [*cf.* W. Voss and R. Guttmann, *Ber.*, **63**, 1726 (1930)].

(32) H. O. House and R. G. Carlson, *J. Org. Chem.*, **29**, 74 (1964), and other papers in this series.

than the monoanion **36** as the *cis* acid **31** is the major product (Scheme II).

Synthesis of the *cis* Acids 3 and 4.—The catalytic hydrogenolysis of lactone **9** in ethanol in the presence of Pd–C proceeded rapidly and yielded a single stereoisomer **3**, mp 193–194°, in excellent yield.

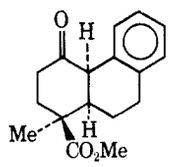
Catalytic hydrogenation of **8** in ethanol or acetic acid in the presence of Pd–C gave acid **3**, in over 75% yield. The acid left in the mother liquors after separation of **3** had mp 160–164°, indicating clearly the presence of another epimer. Separation of this mixture could not be achieved by fractional crystallization or chromatography. However, when the acid was esterified with diazomethane and the resulting ester saponified under controlled conditions, acid **4**, mp 205–206°, was obtained in 9% yield. Hydrogenation of **8** in the presence of Pd–C in ethanol containing triethylamine proceeded more slowly and acid **3** was isolated in 70% yield. This time acid **4** crystallized directly from the mother liquors after separation of **3**, in 5% yield. Methylation of **4** with diazomethane yielded the ester **19** as an oil which could not be induced to crystallize.

Alternatively, acid **4** could be made from cyclization of **5** with aluminum chloride–hydrogen chloride[4,24] or polyphosphoric acid.[24]

Hydrogenation of the unsaturated ester **7** in ethanol or acetic acid in the presence of Pd–C afforded ester **16**, mp 83–84°, in 75–80% yield. It was identical with the methyl ester obtained from methylation of acid **3** with diazomethane. The semisolid product left in the mother liquors after crystallization of **16** failed to produce any other crystalline material on attempted chromatography.

The assigned stereochemistry for the epimeric acids **3** and **4** is based on the following data. Since hydrogenation of the styrenoid double bond in **8** is rapid,[33] a *cis* A/B ring junction[34] is indicated for acids **3** and **4**. The same conclusion is reached from detailed nmr studies on derivatives of these two compounds (see below). The formation of acid **3** from catalytic hydrogenolysis of lactone **9** in a neutral medium[35] establishes the complete stereochemistry of **3**. Inversion of configuration at the benzylic assymetric center during a catalytic hydrogenolysis with palladium has been observed before.[15b,c,16a] The keto ester **38** of assigned stereochemistry has been converted into **3**.[9] Finally, establishment of the stereochemistry of **3** leads automatically to the complete stereochemical assignment of **4**.

The interesting feature of the catalytic hydrogenation of the styrenoid double bond in **7** and **8** is the high degree of absorption of hydrogen from the side *opposite* to that of the carboxyl (or ester) function. We have observed the same stereoselectivity in the hydrogenation of **29**[6] as have others in our laboratory for similar examples.[9,36] It is now easier to understand the diversity in the course of catalytic hydrogenation of the unsaturated ketones **39** and **40**[37a] and similar cases.[37b,c] There is a clear indication that the steric course of catalytic hydrogenation depends not only the size of neighboring substitutents but on their electronic nature.[38]



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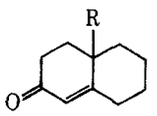
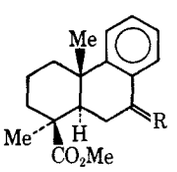
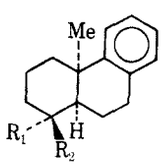


39, R = Me
40, R = CO_2Et

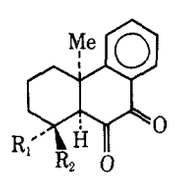
Chromic Acid Oxidation of Esters 10, 13, 16, and 19.—Wenkert and Jackson[39] discovered a decade ago that there is a significant difference in reactivity of ring-C aromatic diterpenes toward chromic acid oxidation depending upon whether the A/B ring junction is *trans* or *cis*. The *trans* racemate **41**, for example, produces the monoketone **42** on chromic acid oxidation,[10] whereas the *cis* racemates **43** and **44** give the diketones **45** and **46**, respectively.[10,40] Chromic acid oxidation of our 20-nor esters **10**, **13**, **16**, and **19** under similar or even relatively drastic conditions afforded *only* the corresponding monoketo esters **11**, **14**, **17**, and **20** respectively. The *cis* esters **16** and **19** gave the keto esters **17** and **20** in yields of 67 and 72%, whereas the *trans* esters **10** and **13** gave **11** and **14** in lower yields of 30 and 57%, respectively. This drastic difference in the oxidative behavior of the *cis* resin acids and the 20-nor analogs indicates that the angular C-10 (at C-12 using the phenanthrene numbering system) methyl group in the resin acids is exerting a significant influence on the oxidation. Our data show clearly that Wenkert's "diagnostic oxidation"[10,40,41] cannot be used for elucidating the stereochemistry in the 20-nor resin acid series.[42] The hypothesis[39] given to account for the



41, R = H_2
42, R = O



43, R_1 = Me; R_2 = CO_2Me
44, R_1 = CO_2Me; R_2 = Me



45, R_1 = Me; R_2 = CO_2Me
46, R_1 = CO_2Me; R_2 = Me

(33) H. O. House in "Modern Synthetic Reactions," W. A. Benjamin, Inc., New York, N. Y., 1965, p 16.

(34) (a) R. P. Linstead, W. E. Doering, S. B. Davis, P. Levine, and R. R. Whetstone, *J. Amer. Chem. Soc.*, **64**, 1985 (1942), and other papers in this series; (b) R. L. Augustine in "Catalytic Hydrogenation," Marcel Dekker, Inc., New York, N. Y., 1965, p 142.

(35) The remote possibility of the formation of **8** prior to the hydrogenolysis of **9** in acidic medium is also completely eliminated.

(36) C. T. Mathew, G. C. Banerjee, and P. C. Dutta, *J. Org. Chem.*, **30**, 2754 (1965).

(37) (a) W. G. Dauben, R. C. Tweit, and R. L. MacLean, *J. Amer. Chem. Soc.*, **77**, 48 (1955); (b) R. B. Turner, R. E. Lee, and E. G. Hildenbrand, *J. Org. Chem.*, **26**, 4800 (1961); (c) F. J. McQuillin and P. L. Simpson, *J. Chem. Soc.*, 4726 (1963).

(38) (a) T. G. Halsall, W. J. Rodewald, and D. Willis, *ibid.*, 2798 (1959); (b) N. B. Haynes and C. J. Timmons, *Proc. Chem. Soc.*, 345, (1958); (c) T. J. Howard, *Rec. Trav. Chim. Pays-Bas*, **83**, 992 (1964); (d) S. Mitsui, Y. Senda, and H. Saito, *Bull. Chem. Soc.* (Tokyo), **39**, 694 (1966).

(39) E. Wenkert and B. G. Jackson, *J. Amer. Chem. Soc.*, **80**, 211 (1958).

(40) N. N. Saha, B. K. Ganguly, and P. C. Dutta, *ibid.*, **81**, 3670 (1959).

(41) (a) *Cf.* J. A. Barltrop and A. C. Day, *J. Chem. Soc.*, 671 (1959); (b) M. Sharma, U. R. Ghatak, and P. C. Dutta, *Tetrahedron*, **19**, 985 (1963).

(42) Mori, *et. al.*,[3] used this "diagnostic oxidation" for assigning the stereochemistry of Haworth's ester **10**.

TABLE II

NMR SPECTRA OF METHYL ESTERS OF RING-C AROMATIC 20-NOR DITERPENOID RESIN ACID ANALOGS AND THEIR 9-KETO ESTERS

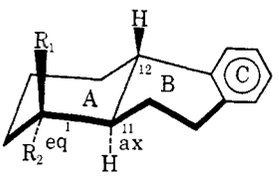
	Chemical shift[a] in $CDCl_3$						
Compound	C-1 Me	C-1 CO_2Me	C-2 β-H[b] and C-3 α-H[c]	C-10 β-H[c]	C-10 α-H[b]	C-11 H	C-12 H
10	1.29	3.65	n.d.[d]	n.d.	n.d.	n.d.	2.89
11	1.28	3.67	2.18[e] and 2.61	2.96[f,g]	2.88[f,g]	1.76[f,h,i]	3.39[h-j]
13	1.21	3.68	n.d.	n.d.	n.d.	n.d.	1.97[e]
14	1.28	3.68	2.58[e,k]	2.46[g,l]	2.46[g,l]	2.42[h]	2.87[h]
16	1.38	3.71	n.d.	n.d.	n.d.	n.d.	n.d.
17	1.41	3.69	n.d.	2.76[g,m]	2.30[g,m]	2.60[m,n]	3.16[n]
19	1.19	3.71	n.d.	n.d.	n.d.	n.d.	n.d.
20	1.17	3.72	2.12[e]	2.58[g,o]	2.67[g,o]	2.97[o]	2.91[p]

[a] Determined on a Varian HA-100 instrument and reported as δ units relative to TMS (δ 0). [b] Equatorial. [c] Axial. [d] Not determined. [e] Tentative assignment. [f] $J_{gem} = -16.5$ cps; the two vicinal coupling constants were not determined. [g] Signal disappears on treatment with sodium methoxide in deuterium methoxide. [h] $J_{11,12} = 11.5$ cps from an examination of the spectrum of the corresponding 10,10-dideuterio compound. [i] Unaffected by irradiation (NMDR) of C-2 and C-3 protons. [j] Collapses to a broad band ($W_{1/2} = 8$ cps) when irradiated at 176 cps. [k] Only one proton determined. [l] Approximate center of complex multiplet. [m] $J_{gem} = -14.3$; $J_{vic} = 13.8$ and 1.3 cps. [n] $J_{11,12} = 3.9$ cps. [o] The sum of the two vicinal coupling constants is estimated to be 18 cps. [p] $J_{11,12}$ is estimated to be 1–4 cps.

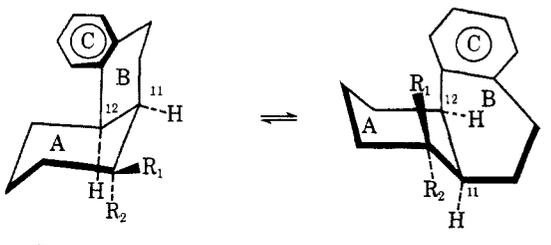
difference in oxidation behavior of the *cis* and *trans* ring-C aromatic tricyclic diterpenoids does not explain the oxidation products in the case of 20-nor resin acid analogs.

Saponification Rates of the Esters 10, 13, 16, and 19.—In order to determine the conformation of the carbomethoxy group in the epimeric esters **10, 13, 16,** and **19**, a qualitative comparative study of their alkaline hydrolysis rates was carried out. The results of this study are summarized in Table I.

The conformationally rigid *trans* esters **10** and **13** show hydrolysis rates quite consistent[43] with the axial and equatorial nature of the ester functions, respectively, as depicted in **10a** and **13a**. The hydrolysis rate of the *cis* ester **16** is comparable with that of the *trans* ester **13**, showing that the ester group is oriented equatorially. The sluggishness in the saponification of the *cis* ester **19** indicates an appreciable axial character for the carbomethoxy group. The saponification rate data of **16** and **19** thus suggest that the "nonsteroid"[8] conformations **16a** and **19a** (C-12 hydrogen in **16a** and **19a** is axial to ring A and equatorial to ring B, whereas in the *cis* A/B ring fused steroids a substituent at this position is equatorial to ring A and axial to ring B) are energetically more stable than the "steroid conformers" **16b** and **19b**, respectively, for these flexible *cis* esters, assuming of course that ring A has a chair conformation.



10a, $R_1 = CO_2Me$; $R_2 = Me$
13a, $R_1 = Me$; $R_2 = CO_2Me$



16a, $R_1 = CO_2Me$; $R_2 = Me$
19a, $R_1 = Me$; $R_2 = CO_2Me$

16b, $R_1 = CO_2Me$; $R_2 = Me$
19b, $R_1 = Me$; $R_2 = CO_2Me$

Nmr Studies.—Proton chemical shifts of esters **10, 13, 16,** and **19** and keto esters **11, 14, 17,** and **20** in $CDCl_3$ are given in Table II.

In the 100-Mc nmr spectrum of keto ester **11** the lines in the region of 2.72–3.16 ppm are ascribed to the C-10 protons (phenanthrene numbering; see **9**). When the C-10 protons are exchanged with deuterium, these lines disappear. The line pattern is immediately recognized as the AB part of an ABX spectrum. The X part of the spectrum, *i.e.*, the absorption due to the C-11 proton, is found as a triplet of doublets at δ 1.76. Not all of the X lines, however, are readily discernible in the spectrum taken in $CDCl_3$. The C-11 absorption is seen clearly when the spectrum is determined in C_6D_6. In both solvents the X lines are doubled owing to additional coupling of the C-11 proton to the C-12 proton.[44] The multiplet at δ 3.39 is assigned to the C-12 proton. The latter absorption is absent in the spectrum of **42**.

Analysis of the four-spin system[45,46] gives the following spectral parameters for the C-10, C-11, and C-12 protons of **11** in C_6D_6: $\nu_A = 293.4$ (axial C-10 proton), $\nu_B = 284.8$ (equatorial C-10 proton), $\nu_M = 325.0$ (C-12 proton), and $\nu_X = 127.6$ cps (C-11 proton) for the chem-

(43) (a) E. L. Eliel, N. L. Allinger, S. J. Angyal, and G. A. Morrison, "Conformational Analysis," Interscience Publishers, New York, N. Y., 1965, p 269; (b) U. R. Ghatak and J. Chakravarty, *Tetrahedron Lett.*, 2449 (1966), and references cited therein.

(44) In the spectrum of the 10,10-dideuterio derivative of **11**, the C-11 proton should appear as a broad doublet. Unfortunately in $CDCl_3$ this doublet is obscured by absorptions of other protons, presumably on C-4.

(45) Spectral parameters were obtained using the iterative program LAOCOON II [S. Castellano and A. A. Bothner-By, *J. Chem. Phys.*, **41**, 3836 (1964)].

(46) For **42** in C_6D_6 a three-spin analysis gives the following spectral parameters for the C-10 and C-11 (C-5 and C-6 using the steroid nomenclature) protons: $\nu_X = 161.4$ (C-11 proton), $\nu_A = 297.5$ (C-10 axial proton), and $\nu_B = 312.9$ cps (C-10 equatorial proton) for the chemical shifts; $J_{AX} = 3.3$, $J_{BX} = 14.2$, and $J_{AB} = -17.6$ cps for the spin–spin coupling constants. For **42** in $CDCl_3$ the following data were obtained: $\nu_X = 205.0$, $\nu_A = 298.9$, $\nu_B = 320.8$ cps; $J_{AX} = 3.1$, $J_{BX} = 14.6$, and $J_{AB} = -17.8$ cps.

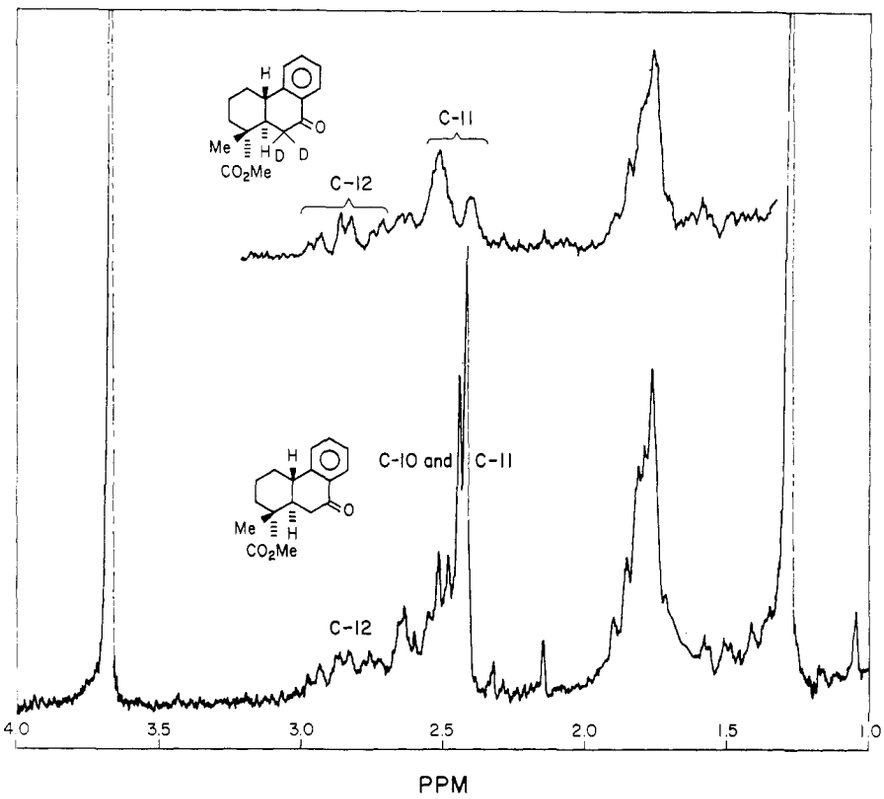


Figure 1.—Nmr spectra of keto ester **14** and the corresponding 6,6-dideuterio compound.

ical shifts; $J_{AB} = -16.8$,[47,48] $J_{AX} = 14.6$,[48,49] $J_{BX} = 2.8$,[48,49] $J_{MX} = 11.8$, and J_{AM}, $J_{BM} = 0.0$ cps for the spin–spin coupling constants. The large coupling between the C-11 and C-12 protons reflects the *trans* fusion of rings A and B.[49]

When the C-11 proton is irradiated,[50] the multiplet for the C-10 proton is reduced to an ill-defined AB quartet. In addition the triplet of doublets for the C-12 proton collapses to a broad band ($W_{1/2} = 8$ cps). At least two and possibly all three of the protons coupled to the C-12 proton resonate at or very near to 1.76 ppm. The signals for the C-11 and C-12 protons are unaffected by irradiation of the protons absorbing at δ 2.18 and 2.61. The C-12 proton must be at least four σ bonds from the protons absorbing at 2.18 and 2.61 ppm.

We tentatively assign the signals at 2.18 and 2.61 ppm (1.94 and 2.18 in C_6D_6) to the two equatorial protons on C-2 and C-3. Each signal is a doublet of multiplets separated by 12–13 cps (due most likely to geminal coupling[48]). The smaller couplings are only compatible with vicinal axial–equatorial and equatorial–equatorial interactions.[48,49] Essentially the same signals are observed in the spectrum of **42** (2.35 ppm in $CDCl_3$ and 2.01 and 2.20 in C_6D_6).

The 100-Mc nmr spectrum of keto ester **14** is shown in Figure 1. Electronic integration indicates that five protons absorb in the region of 2.25–3.0 ppm. Four of these protons are the C-10, C-11, and C-12 protons. Only three protons are found in this region after deuteration at C-10 (upper trace of Figure 1). Note that after deuteration at C-10 the C-11 proton appears as a broad doublet (J = 11.5 cps) at δ 2.46. The large coupling shows diaxial interaction with the C-12 proton at δ 2.87[51] and secures the assignment that rings A and B are fused *trans*. The shapes of the multiplets for the C-12 hydrogens of **11** and **14** are essentially identical.

We were not able to assign unequivocally the stereochemistry at C-1 from an nmr study of **11** and **14**. The corresponding alcohols **12** and **15**, however, yielded the desired information. It is reported[52] that axial hydroxymethyl protons resonate at lower field than equatorial hydroxymethyl protons. As expected the CH_2OH signal of **12** is paramagnetically displaced 0.22 ppm from that of **15** (Table III). These data confirm the axial and equatorial assignments of the carboxy group in **1** and **2**, respectively.

The 100-Mc nmr spectrum of keto ester **17** is shown in Figure 2. The lines in the region of 2.2–3.0 ppm are ascribed to the C-10 and C-11 protons. When the C-10 protons are exchanged with deuterium, several of these lines disappear and the signal for the C-11 proton is re-

(47) The angle subtended between the π orbital of the C-9 carbonyl and one of the C-10 methylene protons is 0° as indicated from a Dreiding model. The observed geminal coupling is therefore reasonable. For a discussion of π contribution to geminal coupling, see N. S. Bhacca and D. H. Williams, "Applications of Nmr Spectroscopy in Organic Chemistry," Holden-Day, Inc., San Francisco, Calif., 1964, p 59.

(48) The proton couplings in cyclohexane have recently been determined [E. W. Garbisch, Jr., and M. G. Griffith, *J. Amer. Chem. Soc.*, **90**, 6543 (1968)]. The a,a *trans*, e,e *trans*, *cis*, and geminal couplings are 13.12, 2.96, 3.65, and −13.05 cps, respectively.

(49) A Dreiding model shows that the *trans* and *cis* dihedral angles are approximately 180 and 60°, respectively. This is entirely consistent with the observed coupling constants. For a discussion of the effect of the dihedral angle on vicinal coupling, see ref 47, p 49–51.

(50) Double resonance experiments were performed in the frequency-sweep mode.

(51) The axial carbomethoxy at C-1 (C-4 using the steroid nomenclature) has been found to shield the C-12 methyl of methyl podocarpate compared with methyl dehydroabietate where the carbomethoxy at C-1 is equatorial [see ref 54 and C. R. Narayanan and N. R. Bhadane, *Tetrahedron Lett.*, 1565 (1968)]. In the nor series the C-12 proton of **11** must lie in the deshielding cone [G. J. Karabatsos, G. C. Sonnichsen, N. Hsi, and D. J. Fenoglio, *J. Amer. Chem. Soc.*, **89**, 5067 (1967)] of the carbonyl of the axial carbomethoxy group at C-1 as the C-12 proton of **13** resonates at higher field compared with that of **11**.

(52) A. Gaudemer, J. Polonsky, and E. Wenkert, *Bull. Chim. Soc. Fr.*, 407 (1964).

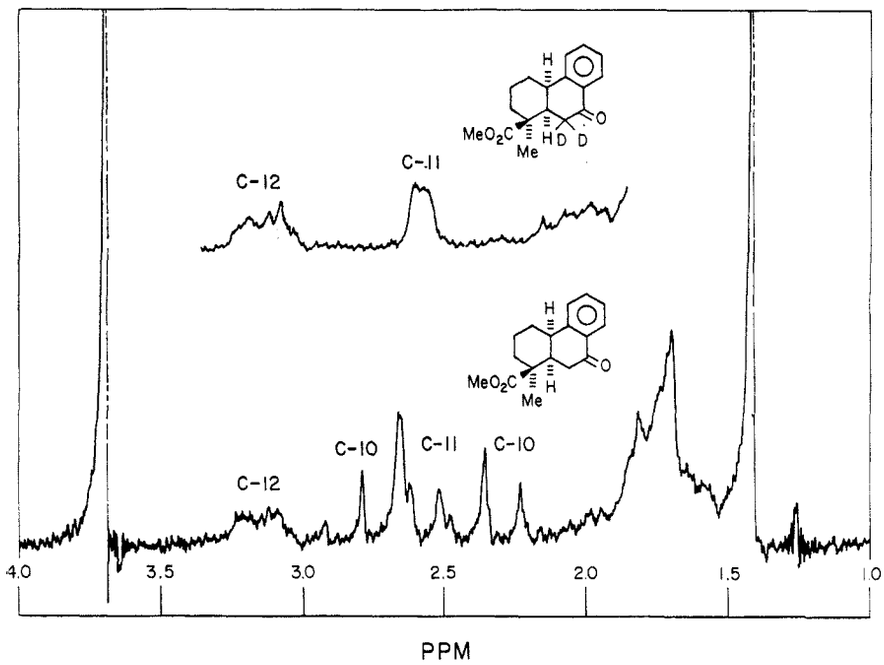


Figure 2.—Nmr spectra of keto ester **17** and the corresponding 6,6-dideuterio compound.

TABLE III
NMR SPECTRA OF RING-C AROMATIC 20-NOR DITERPENOID RESIN ALCOHOL ANALOGS

Compound	Chemical shift[a] in $CDCl_3$ C-1 Me	C-1 CH_2OH
12	1.06	3.69[b]
15	0.88	3.47[c]
18	1.15	3.45[d]
21	0.98	3.65[e]

[a] Determined on a Varian HA-100 instrument and reported as δ units relative to TMS (δ 0). [b] Center of AB quartet with parameters $\Delta\nu = 26.0$ and $J = 10.5$ cps. [c] Center of AB quartet with parameters $\Delta\nu = 20.2$ and $J = 11.0$ cps. [d] Center of AB quartet with parameters $\Delta\nu = 27.6$ and $J = 10.5$ cps. [e] Singlet.

duced to a broad doublet (upper trace of Figure 2). The small coupling constant is consistent with an axial–equatorial interaction between the C-11 and C-12 protons and therefore rings A and B are fused *cis*. The multiplet at δ 3.16 is assigned to the C-12 proton. Its shape is entirely different compared with the C-12 signals of the *trans* keto esters. Analysis of the four-spin system[45] gives the following spectral parameters for the C-10, C-11, and C-12 protons of **17** in $CDCl_3$: ν_X = 316.0 (C-12 proton), ν_A = 275.8 (axial C-10 proton), ν_B = 259.5 (C-11 proton), and ν_C = 230.1 (equatorial C-10 proton) for the chemical shifts; $J_{BX} = 3.9$, $J_{AB} = 13.8$, $J_{AC} = -14.3$, $J_{BC} = 1.3$, and J_{AX}, $J_{CX} = 0.0$ cps for the spin–spin coupling constants. The nmr data can only be rationalized if ring A of **17** has a nonsteroid conformation. In such a conformation the two dihedral angles separating the C-10 and C-11 protons are 60 and 180° which predict small and large couplings, respectively. In the steroid conformation, both couplings would be small as both dihedral angles are approximately 60°.

The 100-Mc nmr data of keto ester **20** is given in Table II. The strong lines 267, 259, and 256 cps are assigned to the C-10 protons and represent the inner lines of the two AB quartets of an ABX spectrum. These lines disappear upon deuteration at C-10. The distance from the two unresolved lines at 267 cps to the center of mass of the two lines at 259 and 256 cps (*i.e.* 258 cps) represents approximately $\frac{1}{2} \mid J_{AX} + J_{BX} \mid$. The sum of J_{AX} and J_{BX}, *i.e.* the sum of the two vicinal coupling constants for the C-10 and C-11 protons, is 18 cps which is about the same as that observed in the spectra of **11** and **17**. Although far from conclusive, it is suggested that rings A and B of **20** have conformations similar to those of **17**. The C-11 proton (X part) is found at δ 2.97 and is seen clearly only after deuteration at C-10. The coupling between the C-11 and C-12 is estimated to be 1–4 cps. The low field line of the expected broad doublet could not be resolved as it is perturbed owing to the proximity of the C-12 proton (*ca.* δ 2.91). The small coupling between the C-11 and C-12 protons shows that rings A and B are fused *cis*. No further analysis of the C-10, C-11, and C-12 protons was performed.

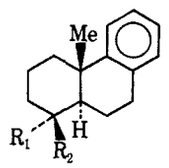
The stereochemistry at C-1 for the *cis* esters **16** and **19** and the *cis* keto esters **17** and **20** could not be deduced from nmr. However, one could conclude that at least one ester and one keto ester must have ring A in the nonsteroid conformation as the chemical shifts for the carbomethoxy protons of **16**, **17**, **19**, and **20** are all normal (δ 3.69–3.72).[53] Compound **43** exhibits this peak at 3.40 as ring A is steroid and the carbomethoxy group lies above the aromatic ring and is shielded.[54]

Examination of the nmr spectra of alcohols **18** and **21** gives the stereochemistry at C-1 for the *cis* series. The hydroxymethyl function of **21** is axially disposed as the methylene protons resonate at 0.20 ppm lower field with respect to the CH_2OH group of **18** which must be equatorially oriented (Table III). Evidence for the nonsteroid conformation of ring A in the *cis* nor alcohols is seen from the normal chemical shifts for the C-1 methyl and hydroxymethyl groups. It is reported[54] that com-

(53) In ref 10 it is reported that the chemical shift of the carbomethoxy protons of the nor series appears in the usual region (δ 3.68–3.73) but the corresponding absorption of the C-12 methyl compounds is shifted to a considerably higher field (2.94–3.37).

(54) E. Wenkert, A. Afonso, P. Peak, R. W. J. Carney, P. W. Jeffs, and J. D. McChesney, *J. Org. Chem.*, **30**, 713 (1965).

pound **47** shows the C-1 methyl at δ 0.32 and **48** the C-1 CH_2OH at 2.96. In both **47** and **48** ring A is steroid and the axial substituent at C-1 lies above the aromatic ring and is shielded. It is interesting that the axial C-1 methyl of **18** is paramagnetically displaced from the equatorial C-1 methyl of **21**, whereas the equatorial C-1 methyl of **12** is paramagnetically displaced from the axial C-1 methyl of **15**.[55]



47, $R_1 = CH_2OH$; $R_2 = Me$
48, $R_1 = Me$; $R_2 = CH_2OH$

The nmr data supports the chemical evidence that ring A of the *cis* acids **3** and **4** has a nonsteroid conformation. The equatorial and axial assignments of the carboxy group in **3** and **4**, respectively, are confirmed.

Experimental Section[56]

1-Methyl-1-carbomethoxy-1,2,3,4,9,10-hexahydrophenanthrene (7).—In a three-necked flask fitted with a stirrer and a dropping funnel was placed 20 g of the keto ester (**6**)[10] in 400 ml of dry thiophene-free benzene. The mixture was cooled in an ice–salt bath (−5°) and precooled concentrated sulfuric acid (240 ml) was added dropwise to the vigorously stirred mixture over a period of 30–35 min. The reaction mixture developed a deep red color. It was stirred in the cold (−5 to 0°) for an additional hour and poured onto crushed ice. The aqueous layer was extracted with benzene and the combined benzene layers were washed with 5% sodium carbonate and water and dried over sodium sulfate. The solvent was evaporated and distillation of the residual oil afforded 14.4 g (77%) of the ester **7**: bp 158–162° (0.4 mm); uv spectrum λ_{max} 264 mμ (log ϵ 4.09); ir spectrum ν_{max} 1716 cm^{-1}.

Anal. Calcd for $C_{17}H_{20}O_2$: C, 79.6; H, 7.8. Found: C, 79.4; H, 7.5.

1-Methyl-1-carboxy-1,2,3,4,9,10-hexahydrophenanthrene (8).—The ester **7** (35 g, 0.14 mol) was heated to reflux for 1 hr in a solution of potassium hydroxide (18 g, 0.32 mol), water (18 ml) and ethylene glycol (180 ml) under a nitrogen atmosphere. The cooled reaction mixture was diluted with water and the unhydrolyzed ester was extracted with ether. Acidification of the cooled aqueous layer with 6 *N* hydrochloric acid afforded a light yellow crystalline acid, which was collected by filtration, washed with water, and air dried. The acid **8**, 32 g (96%), mp 168–171°, on two recrystallizations from dichloromethane–methanol afforded colorless prisms: mp 180–181°; ultraviolet spectrum λ_{max} 265 mμ (log ϵ 4.09).

Anal. Calcd for $C_{16}H_{18}O_2$: C, 79.3; H, 7.5. Found: C, 79.3; H, 7.5.

Dehydrogenation of 8 to 1-Methylphenanthrene.—The acid **8** (50 mg) was mixed intimately with 50 mg of 10% palladium–charcoal and heated at 280–290° for 10 hr. The crude product was dissolved in 10 ml of benzene and chromatographed on a 5 g. column of alumina. Elution with petroleum ether–benzene and benzene removed 28 mg of 1-methylphenanthrene, mp and mmp 120–121°, identical with an authentic sample.

Lactone of 1α-Methyl-1,2,3,4,9,10,11,12-*trans*-octahydrophenanthrenene-12β-hydroxy-1β-carboxylic Acid (9).—Unsaturated acid **8** (300 mg) was added to 5 ml of concentrated sulfuric acid and the mixture cooled in an ice–salt bath (~−10°). Stirring in the cold was continued for 1 hr. The homogeneous red reaction mixture was poured onto crushed ice (*ca.* 20 g). The resulting white precipitate was extracted with ether, washed with 5% sodium carbonate solution and water, and finally dried over sodium sulfate. After removal of solvent, 211 mg (70%) of lactone **9**, mp 124–126°, was obtained. Recrystallization from ethyl acetate–petroleum ether (bp 40–60°) afforded prisms of **9**: mp 130–131° (lit.[3] mp 129–130°); infrared spectrum ν_{max} 1760 cm^{-1}.

Anal. Calcd for $C_{16}H_{18}O_2$: C, 79.3; H, 7.5. Found: C, 79.0; H, 7.4.

Seventy milligrams (23%) of acid **8**, mp and mmp 179–180°, was recovered from the alkaline washings on acidification and extraction with ether.

Hydrogenolysis of the Lactone 9 with Raney Nickel.—The lactone **9** (200 mg) was added to 5 g of W-6 Raney nickel in 40 ml of acetone and the mixture was refluxed for 2 hr. The acetone was removed by decantation, the catalyst was washed several times with fresh acetone, and the washings were combined with the main fraction. Evaporation of the acetone left a residue which was dissolved in ether. The ethereal solution was extracted with 2% aqueous potassium hydroxide solution and water. The combined aqueous extracts were acidified with 6 *N* hydrochloric acid and the product was extracted with ether. The 170 mg of crude acid **3** gave crystalline solid, mp 186–187°, on two recrystallizations from methanol. Further recrystallization from methanol afforded the pure acid **3**, mp and mmp 193°.

Hydrogenolysis of Lactone 9 with Lithium Ammonia. Preparation of (±)-20-Nordeoxypodocarpic Acid (1).—A solution of 200 mg (0.82 mmol) of lactone **9** in 10 ml of dry ether and 10 ml of dry tetrahydrofuran was added to *ca.* 150 ml of anhydrous liquid ammonia in a three-necked flask fitted with a stirrer and a drying tube (KOH). Small pieces of lithium wire (100 mg, 14.3 mg-atoms) were added to the well-stirred reaction mixture in a 5-min period. The blue color rapidly disappeared with the initial addition of lithium. About 10 g of solid ammonium chloride was added slowly and the ammonia was allowed to evaporate at room temperature. The residue was treated with 100 ml of moist ether and the mixture was carefully acidified with excess concentrated hydrochloric acid. The product was extracted with several portions of ether, washed into 3% aqueous sodium hydroxide, and transferred back into ether after acidification with 6 *N* hydrochloric acid and saturation with sodium chloride. The ether layer was washed with water, dried over sodium sulfate, and evaporated to give 190 mg of crystalline acid **1**, mp 176–180°. Recrystallization from ethyl acetate–petroleum ether afforded 180 mg (90%) of **1** as colorless needles, mp and mmp 189–190° (lit.[2] 187–188°), identical with a sample prepared according to Haworth, *et al.*[2]

(±)-Methyl 20-Nordeoxypodocarpate (10).—The acid **1** (100 mg) was esterified with ethereal diazomethane. The crude methyl ester on crystallization from petroleum ether afforded 95 mg (95%) of the ester **10**, mp and mmp 78–79° (lit.[2] 75–76°), identical with a sample prepared according to Haworth, *et al.*[2]

Lithium–Liquid Ammonia Reduction of Unsaturated Acid 8. Preparation of (±)-20-Nordeisopropyldehydroabietic Acid (2).—A solution of 200 mg (0.82 mmol) of unsaturated acid **8** in 10 ml of dry ether and 10 ml of dry tetrahydrofuran was added to about 150 ml of anhydrous liquid ammonia. The mixture was well stirred; 90 mg (13 mg-atoms) of lithium, cut into small pieces, was added over about 5 min. After the addition of lithium was complete, the deep blue solution was stirred for an additional 10 min and decomposed with solid ammonium chloride. The ammonia was allowed to evaporate and the residue was dissolved in water and the mixture acidified with 6 *N* hydrochloric acid. The product was extracted with ether, washed into 2% aqueous potassium hydroxide, and transferred back into ether after acidification with 6 *N* hydrochloric acid. Work-up in the usual manner yielded 195 mg of white solid. Recrystallization from ethyl

(55) It is reported [A. Segre and J. I. Musher, *J. Amer. Chem. Soc.*, **89**, 706 (1967)] that the axial methyl protons of *cis,trans*-1,3,5-trimethylcyclohexane are deshielded relative to the equatorial methyl protons by 0.14 ppm. Obviously the prediction of chemical shifts for methyl groups becomes increasingly more difficult in more complicated ring system, especially one which bears substituents known to exert large anisotropic effects.

(56) The compounds described are all racemic forms. The terms α and β have only relative significance and refer to the orientation of substituent groups according to steroid nomenclature. The phenanthrene numbering system is used throughout this paper, even in the discussion of natural diterpenes. Melting points were taken in an open capillary and are uncorrected. The purity of all compounds was determined by tlc on 0.2-mm silica gel G and aluminum oxide G plates using benzene–methanol and benzene–petroleum ether as the solvent systems. The spots were located by exposing the dried plates to iodine vapor. Petroleum ether (bp 40–60°) was used for column chromatography. Elemental analyses were performed by Mrs. C. Dutta in the microanalytical laboratory of the Indian Association for the Cultivation of Science, Calcutta. Ultraviolet spectra were determined in ethanol on a Beckman DU spectrophotometer by Mr. A. Ghosal and infrared spectra were determined in chloroform on a Perkin-Elmer Model 21 double-beam recording spectrophotometer.

acetate–petroleum ether afforded 180 mg (90%) of acid **2**, mp 209–210°, identical with a sample prepared by a different procedure:[4] ultraviolet spectrum λ_{max} 266 mμ (log ε 2.5) and 274 mμ (log ε 2.5).

Anal. Calcd for $C_{16}H_{20}O_2$: C, 78.7; H, 8.3. Found: C, 78.8; H, 8.4.

(±)-Methyl 20-Nordeisopropyldehydroabietate (13).—The acid **2** (100 mg) in 15 ml of ether was esterified with ethereal diazomethane. The crude ester **13** (100 mg) had mp 40–45° and after crystallization from methanol 88 mg (83%) of the pure ester was obtained as microneedles: mp 54–55°; ultraviolet spectrum λ_{max} 266 mμ (log ε 2.74) and 274 mμ (log ε 2.67).

Anal. Calcd for $C_{17}H_{22}O_2$: C, 79.0; H, 8.6. Found: C, 78.5; H, 8.5.

Catalytic Hydrogenolysis of Lactone 9. Preparation of 1α-Methyl-1β-carboxy-*cis*-1,2,3,4,9,10,11,12α-octahydrophenanthrene (3).—The lactone **9** (200 mg) in 10 ml of 95% EtOH was hydrogenated in the presence of 100 mg of 10% Pd–C catalyst at room temperature and pressure. The initial uptake of hydrogen was very rapid and absorption essentially ceased within a few minutes. After 20 minutes the catalyst was removed by filtration and the solvent was evaporated to give 180 mg (90%) of a white solid, mp 186–188°, which after one crystallization from methanol afforded 130 mg of **3**: mp 193–194°; ultraviolet spectrum λ_{max} 266 mμ (log ε 2.71) and 273 mμ (log ε 2.77).

Anal. Calcd for $C_{16}H_{20}O_2$: C, 78.7; H, 8.3. Found: C, 78.4, H, 8.0.

1α-Methyl-1β-carbomethoxy-*cis*-1,2,3,4,9,10,11,12α-octahydrophenanthrene (16). A. Esterification of Acid 3.—To a cold solution of the acid **3** (100 mg.) in 25 ml of ether, an excess of ethereal diazomethane was added. After standing at room temperature for 2 hr, the excess diazomethane was decomposed with acetic acid. The ether solution was washed with 2% sodium hydroxide solution and water and dried over sodium sulfate. Evaporation of the solvent afforded 100 mg of the ester **16**, mp 80–82°. It was recrystallized from methanol to give 90 mg (86%) of colorless leaflets: mp 83–84°; ultraviolet spectrum λ_{max} 266 mμ (log ε 2.62) and 274 mμ (log ε 2.69).

Anal. Calcd for $C_{17}H_{22}O_2$: C, 79.0; H, 8.6. Found: C, 79.0; H, 8.3.

B. Catalytic Hydrogenation of Unsaturated Ester 7.—The unsaturated ester **7** (100 mg) in 10 ml of 95% ethanol was hydrogenated in the presence of 50 mg of 10% Pd–C catalyst at room temperature and pressure. The initial uptake of hydrogen was quite rapid and was complete after about 30 min. Work-up in the usual manner gave 95 mg of a white solid which on two recrystallizations from methanol afforded 80 mg (85%) of the pure ester **16**, mp and mmp 83–84°. The mother liquors from crystallization of **16** contained an amorphous solid which could not be purified further by column chromatography on acid-washed alumina.

Essentially the same results were obtained when the hydrogenation of **7** was carried out in acetic acid. The yield of **16** was 76%.

Catalytic Hydrogenation of Unsaturated Acid 8. Preparation of Acid 3 and 1β-Methyl-1α-carboxy-*cis*-1,2,3,4,9,10,11,12α-octahydrophenanthrene (4). A.—To a hydrogen-saturated suspension of 100 mg of 10% Pd–C catalyst in 20 ml of ethanol containing 0.3 ml of triethylamine was added a solution of 1 g. of acid **8**, in 10 ml of ethanol. The mixture was stirred and 1 *M* equiv of hydrogen was absorbed in about 2.5 hr at room temperature and pressure. Work-up in the usual manner afforded 900 mg of crude product, which on two recrystallizations from ether gave 695 mg (70%) of the pure acid **3**, mp and mmp 192–193°.

The mother liquors from crystallization of **3** were combined and allowed to evaporate slowly at room temperature whereupon 80 mg of a colorless solid, mp 195–198°, separated. Recrystallization from ethyl acetate yielded 50 mg (5%) of **4** as small colorless cubes: mp and mmp 205–206°; ultraviolet spectrum λ_{max} 266 mμ (log ε 2.58) and 273 mμ (log ε 2.58).

Anal. Calcd $C_{16}H_{20}O_2$: C, 78.7; H, 8.3. Found: C, 78.6; H, 8.2.

B.—The unsaturated acid **8** (500 mg.) in 15 ml of glacial acetic acid was hydrogenated in the presence of 100 mg of 10% Pd–C catalyst at room temperature. Hydrogen (1 *M* equiv) was absorbed within about 15 min. Work-up in the usual manner afforded 460 mg. (92%) of a white solid, mp 180–182°, which after two recrystallizations from methanol gave 350 mg (70%) of the pure acid **3**, mp and mmp 193–194°.

C.—The unsaturated acid **8** (1.4 g) was hydrogenated in 75 ml of ethanol in the presence of 600 mg 10% Pd–C catalyst saturated with hydrogen. The uptake of 1 *M* equiv of hydrogen was complete in about 1 hr. Work-up in the usual manner yielded 1.35 g of the crude hydrogenated product, mp 182–185°. Recrystallization from methanol gave 850 mg of the pure acid **3**, mp and mmp 193°.

Concentration of the mother liquors of **3** gave 480 mg of a light brown solid, mp 160–164°, which was esterified with ethereal diazomethane. The crude semisolid methyl ester (450 mg) was partially saponified with 10 ml of 7% aqueous–ethanolic (1:1) potassium hydroxide at reflux for 2 hr. The cooled mixture was diluted with water, acidified with 6 *N* hydrochloric acid, saturated with sodium chloride, and extracted several times with ether. The ether extracts were washed with 2% aqueous potassium hydroxide and water. The alkaline wash was acidified and extracted with ether to give 280 mg of a light brown solid, which on crystallization from methanol yielded 200 mg of acid **3**, mp 192–193°. The total yield of **3** was 75%.

Evaporation of the ether gave unhydrolyzed ester which was saponified with a boiling solution of 500 mg of potassium hydroxide in 4 ml of ethanol and 1 ml of water for 3 hr. The resulting crude acid (170 mg) was sublimed at 165–175° (0.2 mm) to give 150 mg of a light yellow–white solid, mp 192–195°, which on recrystallization from ethyl acetate afforded 120 mg (9%) of **4**, mp and mmp 205–206°.

1β-Methyl-1α-carbomethoxy-*cis*-1,2,3,4,9,10,11,12α-octahydrophenanthrene (19).—The acid **4** (1.2 g) was esterified with ethereal diazomethane following the procedure described above. The resulting light brown viscous liquid (1.1 g) failed to crystallize. The ester was chromatographed on 35 g of acid-washed alumina and 800 mg of **19** as a colorless oil was eluted with petroleum ether–benzene (1:1). Further purification of **19** was achieved by a short-path distillation at 135–140° (0.2 mm): ultraviolet spectrum λ_{max} 266 mμ (log ε 2.75) and 273 mμ (log ε 2.73).

Anal. Calcd for $C_{17}H_{22}O_2$: C, 79.0; H, 8.6. Found: C, 78.9; H, 8.3.

Chromic Acid Oxidation of the Methyl Esters 10, 13, 16, and 19. A. Preparation of Keto Ester 17.—A solution of the ester **16** (450 mg, 1.75 mmol) in 6 ml of acetic acid was mixed with a solution of 600 mg (6 mmol) of chromium trioxide in 2 ml of water and 7 ml of acetic acid. After vigorous shaking for 2–3 min, the reaction mixture was allowed to stand overnight at room temperature and finally heated to 60–65° for 1 hr. The cooled reaction mixture was diluted with water, saturated with sodium chloride, and thoroughly extracted with ether. The ethereal extract was washed with 2% aqueous sodium hydroxide and water and dried over sodium sulfate. Evaporation of the ether left 400 mg of a yellow gum which was chromatographed on 15 g of acid-washed alumina. Elution with petroleum ether removed 50 mg (11%) of recovered ester **16**. Elution with 250 ml of petroleum ether–benzene (9:1) afforded 280 mg (67%) of **17** as a light yellow solid. Crystallization from petroleum ether gave 255 mg of pure keto ester **17** as colorless cubes: mp 91–92°; ultraviolet spectrum λ_{max} 248 mμ (log ε 4.08) and 294 mμ (log ε 3.27); ir spectrum ν_{max} 1679 (aromatic ketone C=O) and 1722 cm^{-1} (ester C=O).

Anal. Calcd for $C_{17}H_{20}O_3$: C, 75.0; H, 7.4. Found: C, 75.0; H, 7.6.

B. Preparation of Keto Ester 20.—The ester **19** (200 mg, 0.77 mmol) in 2 ml of acetic acid was oxidized with a solution of 200 mg (2 mmol) of chromium trioxide in 3 ml of acetic acid and 1 ml of water. After standing overnight at room temperature the reaction mixture was heated for 45 min at 65–70°. Work-up as described above gave 190 mg of a semisolid product which was chromatographed on 15 g of acid-washed alumina. Elution with petroleum ether removed 30 mg (15%) of the recovered ester **19**. Elution with petroleum ether–benzene (1:1) gave 150 mg (72%) of crude **20** as a light yellow solid. Recrystallization from petroleum ether resulted in 125 mg of the pure keto ester **20** as needles: mp 88–89°; ultraviolet spectrum λ_{max} 250 mμ (log ε 4.14) and 293 mμ (log ε 3.38); infrared spectrum ν_{max} 1678 and 1725 cm^{-1}.

Anal. Calcd for $C_{17}H_{20}O_3$: C, 75.0; H, 7.4. Found: C, 75.0; H, 7.2.

C. Preparation of Keto Ester 11.—Oxidation of 200 mg (0.77 mmol) of the ester **10** with chromium trioxide (200 mg, 2 mmol) using conditions described above gave 150 mg of a brown semisolid neutral product which was chromatographed on 20 g of

acid-washed alumina using petroleum ether–benzene as the eluent. The first fraction contained about 20 mg of a gum and the second fraction about 90 mg of a gummy solid. Two recrystallizations of fraction 2 from methanol afforded 60 mg (30%) of the pure keto ester **11** as colorless prisms: mp 102° (lit.[3] mp 102–103°); ultraviolet spectrum λ_{max} 250 mμ (log ε 4.11) and 290 mμ (log ε 3.33); ir spectrum ν_{max} 1678 and 1724 cm^{-1}.

Anal. Calcd for $C_{17}H_{20}O_3$: C, 75.0; H, 7.4. Found: C, 74.7; H, 7.1.

Elutions with benzene–ether (9:1 to 1:1) gave *ca.* 30 mg of a dark yellow gummy solid (fraction 3) which could not be induced to crystallize and was not investigated further.

D. Preparation of Keto Ester 14.—A solution of ester **13** (300 mg, 1.17 mmol) in 3 ml of acetic acid was oxidized using the above procedure with a solution of 300 mg (3 mmol) of chromium trioxide in 3 ml of acetic acid and 1 ml of water. The resulting crude neutral oxidation product (280 mg) was chromatographed on 15 g acid-washed alumina using petroleum ether–benzene and benzene as the eluent. From the later petroleum ether–benzene and benzene effluents was obtained 180 mg (56.6%) of the keto ester **14**, mp 102–104°. Recrystallization from petroleum ether afforded 165 mg of pure **14**, as colorless needles: mp 109°; ultraviolet spectrum λ_{max} 250 mμ (log ε 4.11) and 290 mμ (log ε 3.33); infrared spectrum ν_{max} 1678 and 1724 cm^{-1}.

Anal. Calcd for $C_{17}H_{20}O_3$: C, 75.0; H, 7.4. Found: C, 74.6; H, 7.3

Saponification of Esters 10, 13, 16, and 19 —Each of the esters (250 mg) in 4:1 ethanol–water potassium hydroxide (10 ml) was refluxed under a nitrogen atmosphere. The unsaponified ester was repeatedly extracted with ether after dilution with saturated brine (50 ml). After acidification of the alkaline aqueous layer the corresponding acid was isolated by repeated extraction with ether. The product was characterized by melting point, mixture melting point, and its ir spectrum. The results of the comparative study are shown in Table I.

Deuteration of Keto Esters 11, 13, 15, and 17.—Each of the keto esters (5 mg) was treated with 0.5 ml of 4 *N* sodium methoxide in deuterium methoxide.[57] After 3 hr the mixture was diluted with 1 ml of D_2O and the product was extracted with chloroform. Examination of the nmr spectrum showed essentially complete exchange of the C-9 methylene protons.

Preparation of Alcohols 12, 15, 18, and 21.—Each of the acids **1**, **2**, **3**, and **4** (7–40 mg) in 10 ml of dry ether was treated with an excess of lithium aluminum hydride. After standing at room temperature for 6 hr, the excess hydride was decomposed with ethyl acetate and the mixture was shaken with 10 ml of 10% aqueous potassium hydroxide. The ethereal layer was dried over sodium sulfate and evaporated to give essentially a quantitative yield of the alcohol. Alcohol **12** had mp 117–118° but alcohols **15**, **18**, and **21** were colorless oils which could not be induced to crystallize.

Anal. Calcd for $C_{16}H_{22}O$: mol wt, 230. Found: mol wt (mass spectrometry), 230.

Registry No.—**1**, 21995-83-5; **2**, 21995-84-6; **3**, 21995-85-7; **4**, 21995-86-8; **7**, 21995-87-9; **8**, 21995-88-0; **9**, 13936-31-7; **10**, 5708-86-1; **11**, 5708-87-2; **12**, 21995-92-6; **13**, 21995-93-7; **14**, 21995-94-8; **14** (6,6-dideuterio), 21995-72-2; **15**, 21995-95-9; **16**, 21995-96-0; **17**, 21995-97-1; **17** (6,6-dideuterio), 21995-73-3; **18**, 21995-98-2; **19**, 21995-99-3; **20**, 21996-00-9; **21**, 21996-01-0.

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(57) Under the reaction conditions no change in the configuration of C-12 occurs.

Studies on Reactions of Isoprenoids. IV.[1] The Reactivity of Myrcene in 1,4-Cycloaddition Reactions

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Cycloaddition reactions of myrcene have been investigated. This 2-substituted 1,3-butadiene is not so reactive as isoprene and failed to give adducts with phenylacetylene, N-*t*-butylpropiolamide, furan, isoprene, and benzoxazole. With cyclopentadiene, it reacted as a dienophile. With stronger dienophiles, adducts were formed in 10–60% yields along with undistillable by-products. The long unsaturated chain appears to contribute in lowering the activity of the diene and in the formation of by-products. However, its regiospecificity in orientation in cycloaddition reactions with acrylonitrile, cyanoacetylene, and chlorocyanoacetylene is the same as the methyl group in isoprene, but it differs in the reaction with thionylaniline.

Although many Diels–Alder reactions of simple 2-substituted butadienes such as isoprene have been reported,[2] little is known about those of 2-substituted butadienes containing a long, functional group. Myrcene (**1**), 7-methyl-3-methylen-1,6-octadiene, belongs to this type. Its 1,4-cycloaddition reactions are expected to afford a class of compounds that might be interesting for model studies on certain biogenetic-like cyclizations[3] and for a possible synthetic route to certain types of terpenes.[4] Diels–Alder reactions of myrcene with maleic anhydride[5] and with acrolein and its analogs[6] have been described, but without any detailed structural elucidation of the cycloadducts. This paper deals with 1,4-cycloaddition re-

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