NaOH solution and the product was isolated with ether[16b] and distilled, affording 235 mg (90%) of material, bp 80° (0.04 mm), containing 89% β-vetivone (**29**) and 11% of the isopropenyl isomer **28** according to the gas chromatogram and nmr spectrum. Material with mp 43.5–46° was secured after several recrystallizations from pentane at low temperature. The infrared and nmr spectra and the gas chromatographic retention times coincided exactly with those of natural β-vetivone.

*Anal.*[16c] Calcd for $C_{15}H_{22}O$: C, 82.52; H, 10.16. Found: C, 82.36; H, 10.17.

The 2,4-DNP derivative crystallized from ethanol as red needles, mp 157–159° [lit.[8] for the 2,4-DNP derivative of (+)-β-vetivone, mp 188–191°].

The semicarbazone derivative crystallized from isopropyl alcohol as white prisms, mp 209–211° [lit. for the semicarbazone derivative of (−)-β-vetivone, mp 228–229[2] and 227°[25]].

**Registry No.**—**3**, 22196-17-4; **4**, 22196-18-5; **4** (2,4-dinitrophenylhydrazone), 22196-19-6; **5**, 22196-20-9; **5** (2,4-dinitrophenylhydrazone), 22196-21-0; **6**, 22196-22-1; **7**, 22196-23-2; **8**, 22196-24-3; **8** (2,4-dinitrophenylhydrazone), 22196-25-4; **9**, 22196-26-5; **10**, 22196-27-6; **11**, 22196-28-7; **12**, 22196-29-8; **13**, 22196-30-1; **14**, 22196-31-2; **16**, 22196-32-3; **17**, 22196-33-4; **17** (semicarbazone), 22196-34-5; **18**, 22196-35-6; **19**, 22196-36-7; **19** (semicarbazone), 22196-37-8; **20**, 22196-38-9; **21**, 22196-39-0; **22**, 22196-40-3; **23**, 22196-41-4; **24**, 22196-42-5; **25**, 22196-43-6; **26**, 22196-44-7; **27**, 22196-45-8; **29**, 22196-46-9.

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(25) M. Romanuk and V. Herout, *Collect. Czech. Chem. Commun.*, **25**, 2540 (1960).

# Hydroboration of Terpenes. VI. Hydroboration of α- and β-Cedrenes. Configurational Assignments for the Related Cedrane Derivatives

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*Received March 27, 1969*

The convenient synthesis of (+)-β-cedrene was achieved by hydrochlorination of (−)-α-cedrene followed by elimination of the tertiary chloride by bases of large steric requirements. Study of a number of representative reactions reveals that the stereochemical course of reaction for both olefins and their derivatives is apparently dominated by the *gem*-dimethyl groups, with the reaction occurring preferentially at the side away from this group (*exo*). Thus, hydroboration and epoxidation of both α- and β-cedrenes (**2**, **11**) take place predominantly from this direction. Similarly, hydrogenation of β-cedrene, although less selective, also takes place from this direction to give 88% (−)-isocedrane (**21**) and 12% (−)-cedrane (**22**). The hydroboration of β-cedrene gives the *endo* intermediate predominantly, corresponding to the preferred *exo* attack of the hybroborating agent. Isomerization of the intermediate converts it predominantly into the more stable *exo* isomer (76% *exo* and 24% *endo*). Similarly, epimerization of 9-isocedranal (**18**) with base yielded the two isomeric aldehydes, **19** and **18**, in a ratio of 80:20. Borohydration–oxidation of α-cedrene yields essentially pure (−)-2-isocedranone (**4**) with the methyl and *gem*-dimethyl groups in a *cis* relationship. The presence of base induces a rapid epimerization, producing 92% (−)-2-cedranone (**5**), having the 3-methyl in the quasiaxial position, and 8% of (−)-2-isocedranone (**4**), having the 3-methyl in the equatorial position. Reduction of the borohydration–oxidation ketone, (−)-2-isocedranone (**4**), with lithium trimethoxyaluminohydride takes place almost exclusively from the *exo* direction, providing (−)-2-neoisocedranol (**8**) with only traces of (+)-2-isocedranol (**3**). Likewise, the epimer, (+)-2-cedranone (**4**), undergoes preferential reduction by this reagent from the *exo* direction to give predominantly (−)-2-cedranol (**7**) with minor amounts of (−)-2-neocedranol (**6**). The tosylate of (−)-2-cedranol (**24**) is readily reduced by lithium aluminum hydride to (−)-cedrane (**22**), but the corresponding reaction with the tosylate of (−)-2-isocedranol (**3**) failed. (The latter reaction would have required attack of the reagent from the *endo* direction.) However, (−)-isocedrane (**21**) was obtained from the reduction of the tosylate of 9-isocedranol (**23**), the reaction path involving far less steric interference from the *gem*-dimethyl substituents. (−)-*exo*-(2,3)Epoxycedrane (**9**) undergoes a facile opening of the epoxide ring by boron trifluoride etherate to give exclusively (−)-2-cedranone (**5**), involving a stereospecific hydride shift from the *endo* direction. On the other hand, the corresponding rearrangement of (−)-*exo*-(3,9)epoxycedrane (**12**), which can involve either *exo* or *endo* hydride shifts, gives preferentially (80%) 9-isocedranal (**18**), indicating a preference for the hydride shift from the *exo* direction. The various compounds were subjected to nmr study and configurations and preferred conformations were assigned.

α-Cedrene (**1**, **2**), a tricyclic sesquiterpenoid hydrocarbon, was first isolated by Walter,[1] in 1841, but its structural features,[2] including its total synthesis[3] and absolute configurational assignments[4] were achieved only recently.

At the time this study had been initiated only a few of the possible derivatives were known; one 2-cedranol,[5,6a] one 2-cedranone,[6] one 9-cedranol,[7–9] one

(1) P. Walter, *Ann. Chem.*, **39**, 247 (1841); **48**, 35 (1843).

(2) G. Stork and R. Breslow, *J. Amer. Chem. Soc.*, **75**, 3291 (1953); P. A. Plattner, A. Fürst, A. Eschenmoser, W. Keller, H. Kläui, S. Meyer, and M. Rosner, *Helv. Chim. Acta*, **36**, 1845 (1953).

(3) G. Stork and F. H. Clarke Jr., *J. Amer. Chem. Soc.*, **77**, 1072 (1955), **83**, 3114 (1961).

(4) G. Büchi, R. E. Erickson, and N. Wakabayashi, *ibid.*, **83**, 927 (1961).

(5) G. Lucius and C. Schäfer, *Z. Chem.*, **2**, 29 (1962).

(6) (a) M. I. Goryaev and G. A. Tolstikov, *J. Gen. Chem. USSR* (Engl. Transl.), **31**, 594 (1961); (b) *ibid.*, **32**, 982 (1962); (c) *Chem. Abstr.*, **59**, 1496 (1963).

(7) Y. R. Naves, G. Papazian, and E. Perrottet, *Helv. Chim. Acta*, **26**, 302 (1943).

(8) M. I. Goryaev and G. A. Tolstikov, *Proc. Acad. Sci. USSR, Chem. Sect.* (Engl. Transl.), **139**, 673 (1961).

(9) M. I. Goryaev and G. A. Tolstikov, *Chem. Abstr.*, **59**, 6443 (1963).

cedranal[10,11] and one cedrane.[7] These were characterized with undefined stereochemistry and with variable physical properties, including conflicting sign of rotation for some of the compounds.[6a] The preparative methods used often gave a mixture of components with undefined stereochemistry and undefined content of each product. Hence we decided to include α-cedrene and β-cedrenes in our systematic study of the hydroboration of some representative terpenes.[12]

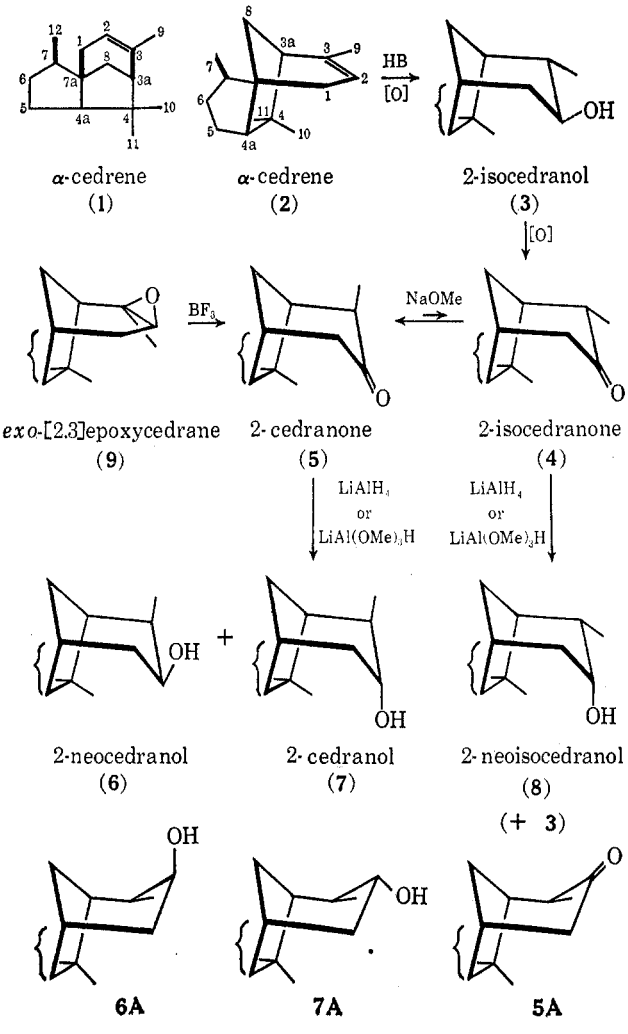
In this investigation we concentrated on reactions which would define the stereochemical direction of attack for both α- and β-cedrene and the stereochemical relationships of the individual products. In many cases derivatives from both α- and β-cedrenes could be related to each other by conversion into the same reference compounds. We also utilized pmr spectra to obtain information on the configurations and preferred conformations.

Recently, a study with related objectives for α-cedrene has been described.[13] However, the experimental procedures in this study differ considerably from those that we utilized, so that the overlap is not major.

**Hydroboration of (−)α-Cedrene (2).**—(−)-α-Cedrene (**1**),[14] represented by its stereoformula (**2**), can be conveniently looked upon as derived from the bicyclo[3.2.1]octane system in which the *endo* side of the double bond is evidently screened by the 4a-H and 10-$CH_3$ groups for reactions involving significant steric requirements. As a matter of fact, hydroboration of (−)-α-cedrene by diborane in tetrahydrofuran, followed by oxidation with alkaline hydrogen peroxide, gave only a single isomer, mp 146–147°, $[\alpha]^{27}D$ +3.6°, assigned the structure of (+)-2-isocedranol (**3**)[15] (Scheme I).

SCHEME I

HYDROBORATION AND EPOXIDATION OF α-CEDRENE AND THE STEREOSPECIFIC PREPARATION OF FOUR 2-CEDRANOLS AND TWO 2-CEDRANONES WITH THEIR POSSIBLE CONFORMATIONS




The exclusive formation of this single isomer is supported by glpc analysis of the alcohol and acetate on a number of columns, and by examination of the pmr spectra, which are unique compared to the spectra of all other isomeric 2-cedranols and their acetates. The exclusive formation of the single isomer can only be accounted for on the basis of a marked difference in the facility of the stereochemical approach of the reagent to the two possible sides of the double bond. An examination of the molecular model indicates that approach of the reagent from the side away from the *gem*-dimethyl group (*exo* attack) must be sterically far more facile than approach of the reagent from the same side as this bulky group (*endo* attack). Even in the absence of such bulky groups as in bicyclo[3.2.1]octa-2-ene, epoxidation takes place exclusively from the *exo*

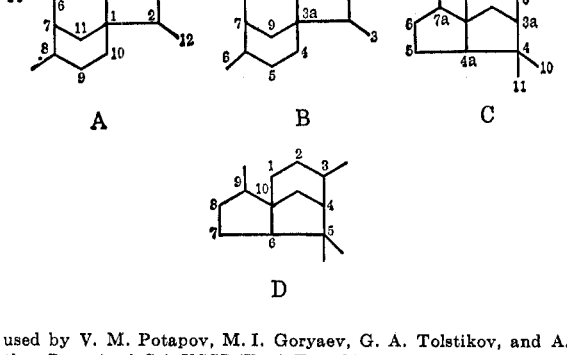
(10) L. A. Ignatova, G. A. Tolstikov, L. N. Lishtvanova, and M. I. Goryaev, *J. Appl. Chem. USSR* (Engl. Transl.), **37**, 1386 (1964).

(11) M. I. Goryaev, G. A. Tolstikov, L. A. Ignatova, and A. D. Dembitskii, *Proc. Acad. Sci., USSR, Chem. Sect.* (Engl. Transl.), **146**, 920 (1962).

(12) (a) Myrcene: H. C. Brown, K. P. Singh, and B. J. Garner, *J. Organometal. Chem.*, **1**, 2 (1963). (b) α- and β-Pinene: G. Zweifel and H. C. Brown, *J. Amer. Chem. Soc.*, **86**, 393 (1964). (c) 2-Carene: S. P. Acharya and H. C. Brown, *ibid.*, **89**, 1925 (1967). (d) 3-Carene: H. C. Brown and A. Suzuki, *ibid.*, **89**, 1933 (1967). (e) α-Thujene and Sabinene: S. P. Acharya, H. C. Brown, A. Suzuki, S. Nozawa, and M. Itoh, *J. Org. Chem.*, **34**, 3015 (1969). (f) Thujopsene: S. P. Acharya and H. C. Brown, manuscript in preparation. (g) Limonene: H. C. Brown and C. D. Pfaffenberger, *J. Amer. Chem. Soc.*, **89**, 5475 (1967), and manuscript in preparation. (h) Caryophyllene; S. P. Acharya, K. R. Varma, and H. C. Brown, manuscript in preparation.

(13) P. Teisseire, M. Plattier, W. Wojnarowski, and G. Ourisson, *Bull. Soc. Chim. Fr.*, 2749 (1966); *Recherches* (Paris), **16**, 89 (1967).

(14) The carbon skeleton of cedrane corresponds to the systematic nomenclature: 2,6,6,8-tetramethyltricyclo[5.3.1.$1^{1,7}0^{1,8}$]undecane with numbering as in A. This is in accordance to the rule proposed by J. Meinwald and Y. C. Meinwald, *Advan. Alicycl. Chem.*, **1**, 2 (1966). However, *Chemical Abstracts* follows an entirely different nomenclature, the numbering being 2,3,4,5,6,-7β,8,8aβ-octahydro-3β,6,8,8-tetramethyl-3a,7-methanoazulene, as in B. In the present paper we have used the popular nomenclature C used by G. Stork, *et al.*,[4] in his total synthesis of α-cedrene and cedrol. Numbering

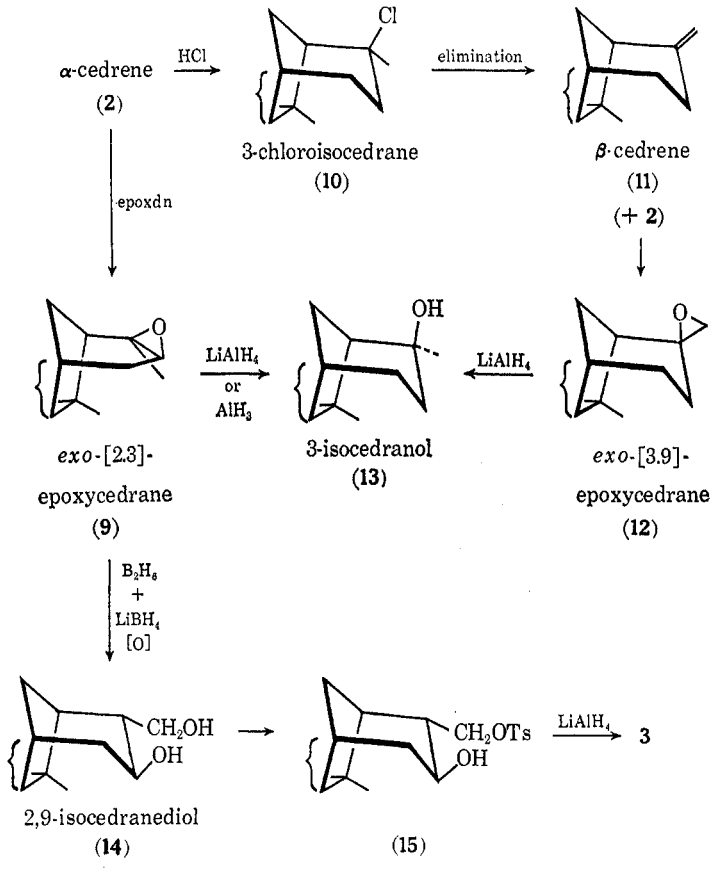



D is used by V. M. Potapov, M. I. Goryaev, G. A. Tolstikov, and A. P. Terert'ev, *Proc. Acad. Sci. USSR* (Engl. Transl.), **140**, 1059 (1961).

(15) The prefix iso is used to indicate that the *gem*-dimethyl and 3-methyl are *cis* to each other, and neo is used to indicate that the hydroxyl and 9-methyl are *cis* to each other. The same nomenclature is extended to 9-ol, 9-al and the parent hydrocarbons.

SCHEME II

PREPARATION OF β-CEDRENE, CONFIGURATIONAL ASSIGNMENTS OF THE EPOXIDES, AND THEIR REACTION WITH LEWIS ACID TYPE REDUCING AGENTS




side.[16] On this basis we identify the hydroboration alcohol, mp 146–147°, as (+)-2-isocedranol.

The same compound has been obtained previously by the oxidation of β-cedrene[5] with selenium dioxide to an allylic alcohol, which was then isomerized to the ketone and the latter reduced to the alcohol of mp 147°. Similarly epoxidation of α-cedrene, followed by the isomerization of the epoxide with zinc bromide[6a] or with lithium aluminum hydride,[6b] with subsequent hydrogenation over Adams[6] or nickel aluminum catalyst, gave the alcohol mp 145–146°. This alcohol is undoubtedly also (+)-2-isocedranol, identified from its melting point, but its formation under the reaction conditions utilized is difficult to rationalize.

(+)-2-Isocedranol (**3**), on oxidation with sodium dichromate–sulfuric acid in the presence of ether at 0°, [12c] gave (−)-2-isocedranone (**4**), which readily epimerized with sodium methoxide to give an equilibrium mixture containing 92% **5** and 8% **4**. This behavior resembled that of 2-isopinocamphone[12b] or 2-isocaranone[12c] in our previous studies. The ratio of the isomers is very similar to that obtained in the acid-catalyzed epimerization, reported by Ourisson,[13] 94% **5** and 6% **4**. These equilibration studies indicate the marked preference of the 9-methyl group to move from the more hindered *endo* position to the less hindered *exo* position.

**Epoxidation of (−)-α-Cedrene.**—Epoxidation of α-cedrene, like hydroboration, also takes place exclusively from the *exo* side, to give exclusively (−)-*exo*-2,3-epoxycedrane (**9**). The structure of this epoxide was confirmed by its conversion by boron trifluoride etherate into (−)-2-cedranone (**5**), without any trace of the isomeric (−)-2-isocedranone (**4**). The reaction involves a stereospecific hydride shift from 2- to 3-position from the *endo* side. In our present study *this is the only transformation which involved reaction from the endo direction.* The molecule did not rearrange as in the case of the bicyclo[3.1.1]heptane system.[17]

**Reactions with (−)-2-Isocedranone (4) and (−)-2-Cedranone (5).**—Reduction of (−)-2-isocedranone by lithium trimethoxyaluminohydride, a reagent sensitive to the steric environment of the carbonyl group,[18] gave 99% (−)-2-neoisocedranol (**8**) (*exo* attack), with 1% the hydroboration–oxidation product, (−)-2-isocedranol (**3**), whereas reduction by lithium aluminum hydride gave the respective alcohols in the ratio 93.6:6.4. When (−)-2-cedranone was reduced with lithium trimethoxyaluminohydride, the ratio of (−)-2-cedranol (**7**) (*exo* attack), to (−)-2-neocedranol (**6**) (*endo* attack) was 83:17. Under identical conditions lithium aluminum hydride in tetrahydrofuran gave the respective alcohols in the ratio 70:30. These results indicate a marked preference for the *exo* attack, even in the case of 2-cedranone where the *exo* 9-methyl substituent would be expected to decrease somewhat the ease of *exo* attack.

**Reactions with (−)-*exo*-2,3-Epoxycedrane (9).**—Attempts were made to prepare (−)-2-neocedranol (**6**) from (−)-*exo*-2,3-epoxycedrane (**9**) by using aluminum

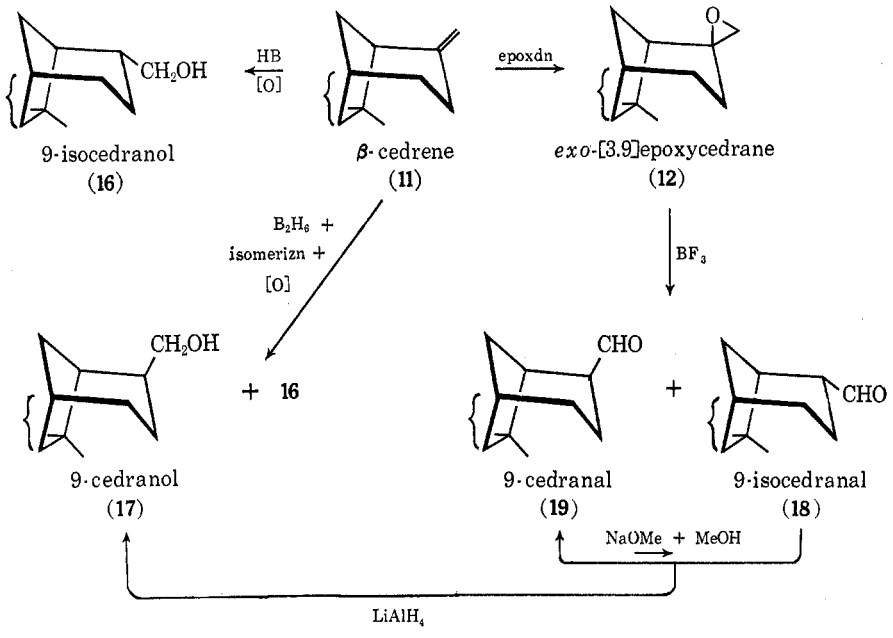
(16) R. R. Sauers, M. M. How, and H. Feilich, *Tetrahedron*, **21**, 983 (1965).

(17) D. V. Banthorpe and D. Whittaker, *Quart. Rev.*, (London) **20**, 373 (1966).

(18) H. C. Brown and H. R. Deck, *J. Amer. Chem. Soc.*, **87**, 5620 (1965).

SCHEME III

HYDROBORATION AND HYDROBORATION–EPIMERIZATION OF β-CEDRENE. THE REACTION OF *exo*-3,9-EPOXYCEDRANE WITH $BF_3$ AND THE CONFIGURATIONAL ASSIGNMENTS OF THE ALDEHYDES




hydride (Scheme II), a reagent known to convert 1-methylcyclohexene oxide predominantly into tertiary alcohol[19] with 20–30% of *cis*-2-methylcyclohexanol. But the product in the present case was entirely (−)-3-isocedranol (**13**), an authentic sample of which was obtained by lithium aluminum hydride reduction of the above epoxide and *exo*-3,9-epoxycedrane (**12**). The isomeric (+)-3-cedranol (**20**) is natural cedrol (11-$CH_3$, 58.5, 10-$CH_3$ 73 cps) and its pmr spectrum differs considerably from that of (−)-3-isocedranol (11-$CH_3$, 60, 10-$CH_3$, 67 cps). Incidently, these reaction sequences proved beyond doubt that the epoxidation of both α-cedrene and β-cedrene takes place from the *exo* side.

Recently we have shown[20] that borohydride catalyzed reaction of diborane with trisubstituted epoxides, such as 1-methylcyclohexene oxide or α-3,4-epoxycarane, gave predominantly the *cis* alcohols (*cis*-2-methylcyclohexanol and 4-neocaranol in the two cases mentioned) and the corresponding tertiary alcohols, without any traces of *trans* alcohols. But in the absence of borohydride *cis*-2-hydroxymethylcyclohexanol was obtained after the alkaline hydrogen peroxide oxidation of the intermediate organoborane. In the present investigation, when (−)-*exo*-2,3-epoxycedrane (**9**) was treated with borohydride-catalyzed diborane, all in molar proportions in tetrahydrofuran, there was an evolution of hydrogen, corresponding to 0.8 equiv in 1 hr, with the evolution of hydrogen ceasing in 3 hr. Hydrolysis of the excess hydride followed by oxidation with alkaline hydrogen peroxide failed to yield either **6** or 2,9-neocedranediol. The product was identified as (−)-2,9-isocedranediol (**14**). Evidently the borohydride fails to attack the polarized intermediate and the reaction involves solely opening of the epoxide ring by diborane with concurrent formation of the exocyclic double bond, exclusively from the *exo* side. In the case of 1-methylcyclohexene oxide, the opening of the epoxide and the hydroboration of the resulting exocyclic double bond takes place from both sides, whereas in the present case both of these reactions proceed from the *exo* side. The configuration of 2,9-isocedranediol is proved by the reduction of 2,9-isocedranediol 9-tosylate (**15**) to 2-isocedranol (**3**). These reactions also emphasize the marked preference for attack from the *exo* direction.

**Hydrochlorination of (−)-α-Cedrene.**—Since hydroboration and epoxidation occur from the *exo* side, it is assumed that hydrochlorination also takes place from this side to give 3-chloroisocedrane (**10**). No serious attempt was made to establish the structure by chemical means, since the compound is unstable and decomposes slowly at 25° to α-cedrene and hydrogen chloride. However, the structural assignment was confirmed by comparing its pmr spectra with those of the related isomeric tertiary alcohols, (−)-3-isocedranol (**13**) and (+)-3-cedranol (**20**) (otherwise known as natural cedrol). One would expect the chemical shift for the 10-$CH_3$ in **10** (69.5 cps) and **13** (67 cps) not to be significantly altered compared to the downfield shift (73 cps) for **20**. If the chlorine were *endo*, the chemical shift for the 10-$CH_3$ should have been higher than 73 cps, due to the proximity of the substituent chlorine.

**(+)-β-Cedrene (11).**—(+)-β-Cedrene has been previously obtained from (−)-α-cedrene, employing relatively tedious procedures, such as selenium dioxide oxidation[21] of α-cedrene to obtain cedrenal followed by the pyrolysis of the hydrazone, or by reducing cedrenal to primary alcohol followed by the pyrolysis of the amine oxide or the 2,4-dinitrobenzoate[8] of the primary alcohol, or by pyrolysis of cedrol acetate.[5] However, in all these methods β-cedrene is always obtained as a mixture with α-cedrene and the isolation of pure β-cedrene required column chromatography on alumina.

Attempts to isomerize α-cedrene to β-cedrene with potassium *t*-butoxide in dimethyl sulfoxide[12c] or by

(19) Research in progress with N. M. Yoon.

(20) H. C. Brown and N. M. Yoon, *J. Amer. Chem. Soc.*, **90**, 2686 (1968).

(21) G. A. Tolstikov, L. A. Ignatova, and M. I. Goryaev, *J. Appl. Chem. USSR* (Engl. Transl.), **37**, 2738 (1964).

ethylenediaminolithium,[22] hoping to obtain at least a few per cent of β-cedrene, failed. However, it proved practical to prepare it by a relatively simple and easy method involving hydrochlorination at −70° followed by elimination *in situ* with bases of large steric requirements, potassium *t*-butoxide, triethyl methoxide, or tricyclopentyl methoxide, in their respective alcohols or in undecane as solvents.[23] β-Cedrene was separated by column chromatography on silver nitrate–silic acid,[24] wherein α-cedrene is eluted with pentane and β-cedrene with benzene.

**Hydroboration of (+)-β-Cedrene.**—Hydroboration of β-cedrene with diborane in tetrahydrofuran followed by oxidation with alkaline hydrogen peroxide gave 96% (−)-9-isocedranol (**16**) and 4% (−)-9-cedranol (**17**). These compounds were difficult to analyze by pmr or by glpc. However, pmr analysis of the corresponding acetates was easily achieved by comparing the areas of the peak at 244 cps of the doublet at 241 cps assigned to the carbinyl proton of 9-isocedranol acetate to that of 233.5 of the doublet at 237 cps assigned to the carbinyl proton of 9-cedranol acetate. Hydroboration–isomerization of β-cedrene (Scheme III) at 140° either for 4 or 12 hr followed by alkaline hydrogen peroxide oxidation gave 24% **16** and 76% **17**, indicating a facile isomerization of the *endo* methylene organoborane to the *exo* methylene derivative, the analysis being done by pmr as described above.

**Epoxidation and the Reactions of the Epoxide from (+)-β-Cedrene.**—(+)-β-Cedrene on epoxidation with *m*-chloroperbenzoic acid at 0° in chloroform gave (−)-*exo*-3,9-epoxycedrane (**12**). The assignment was confirmed by the transformation of both *exo*-2,3- (**9**) and *exo*-3,9-epoxycedrane (**12**) with lithium aluminum hydride in tetrahydrofuran to the same tertiary alcohol, (−)-3-isocedranol (**13**).

Boron trifluoride etherate at 0° or at −20° in benzene and benzene–petroleum ether gave 80% (−)-9-isocedranal (**18**) and 20% (+)-9-cedranal (**19**), as determined by measuring the integrated area of the signals of the aldehydic protons appearing at 578 cps for **18** and at 572 cps for **19**. This mixture of aldehydes was reduced with lithium aluminum hydride to the corresponding alcohols and then converted into acetates to facilitate their pmr analysis. The ratio of the peaks at 244 cps due to 16-acetate and 233.5 cps due to 17-acetate is 80:20. The aldehydic mixture on treatment with sodium methoxide in methanol underwent rapid isomerization in a matter of minutes to the equilibrium mixture containing 80% 9-cedranal (**19**) and 20% 9-isocedranal (**18**), estimated from the signals of the aldehydic protons. A ratio of 78:22 was indicated by pmr analysis of the acetates obtained by reducing the aldehydes to the alcohols followed by acetylation.

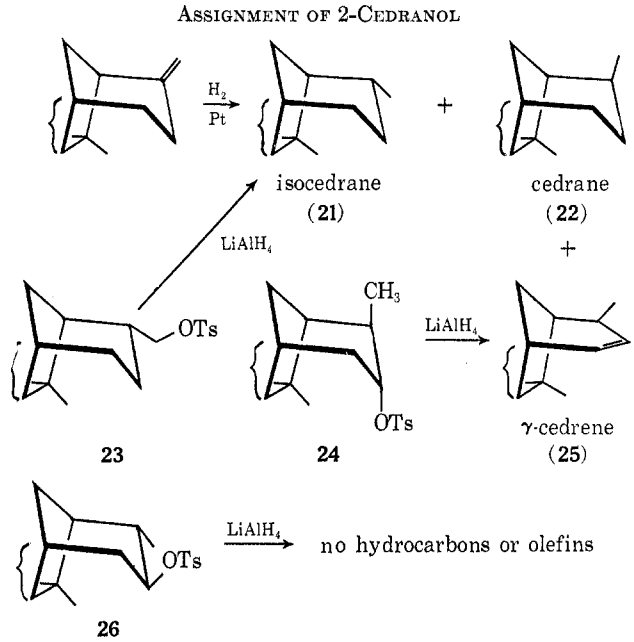
These reactions indicate that just as in α-cedrene both hydroboration and epoxidation take place preferentially from the *exo* side, although the selectivity for *exo* attack in the β isomer appears to be slightly smaller than that for the α.

It is of interest to note the difference in the behavior of the isomeric epoxides in the reaction with boron trifluoride etherate. In the case of *exo*-2,3-epoxycedrane the reaction involves a stereospecific hydride shift from the *endo* side, indicating a concerted mechanism. On the other hand, *exo*-3,9-epoxycedrane involves a hydride shift from both the *exo* and *endo* directions, with the *exo* shift being favored by a ratio of 80:20. This implies that the $CH_2OBF_3^-$ moiety must be capable of rotating so that a hydride shift can occur either from the *exo* or the *endo* direction. The fact that hydride shift occurs preferentially from the *exo* direction suggests that the steric congestion is less in the *exo* position.

**Hydrogenation of (+)-β-Cedrene.**—When β-cedrene is hydrogenated over Adams catalyst in ether, it gave 88% (−)-isocedrane (**21**) and 12% (−)-cedrane (**22**). Authentic samples of these hydrocarbons were obtained from lithium aluminum hydride reduction in tetrahydrofuran of 9-isocedranol tosylate (**23**) and 2-cedranol tosylate (**24**), respectively (Scheme IV). In

SCHEME IV

PREPARATION OF AUTHENTIC SAMPLES OF ISOCEDRANE, CEDRANE, AND THE CONFIGURATIONAL ASSIGNMENT OF 2-CEDRANOL




the latter case, the hydrocarbon fraction contained 44% (+)-γ-cedrene (**25**), 2% α-cedrene (**2**), and 54% cedrane (**22**). The structure of γ-cedrene is confirmed in its pmr spectra by the characteristic absorbance of olefinic protons 1 H, at 359.5 cps, doublet $J_{H_1-H_2}$ = 9 cps; 2 H at 311 cps, a quartet $J_{H_1-H_2}$ = 9 cps and $J_{H_2-H_3}$ = 4 cps. Attempts to prepare cedrane by the reduction of 2-isocedranol tosylate (**26**) failed. Only 2-isocedranol was obtained, again indicating the difficulty of hydride attack from the sterically congested *endo* side in such reactions.[25]

**Thermodynamic Stability of 2-Isocedranone (4) and 2-Cedranone (5).**—There are two possible conformations for 2-cedranone (**5**) and 2-isocedranone (**4**), namely chair as in **5** or boat as in **5A**. The boat form for 2-isocedranone can be neglected since the nonbonded interactions between the 9-*endo* methyl and the 10-*endo* methyl will be severe. In the chair form of 2-cedranone (**5**), the 9-methyl will be forced to exist

(22) G. Ohloff, K. H. Schulte-Elte, and W. Giersch, *Helv. Chim. Acta*, **48**, 1665 (1965).

(23) S. P. Acharya and H. C. Brown, *Chem. Commun.*, 305 (1968).

(24) A. S. Gupta and S. Dev, *J. Chromatogr.*, **12**, 189 (1963).

(25) Work in progress with S. Krishnamurthy.

in the axial conformation introducing the usual 1,3-diaxial interactions which we previously used to account for the greater stabilities of 2-isocaranone,[12c] 4-caranone[12d] and 2-thujone[12e] over their epimers. In the present case we believe that these 1,3-diaxial interactions do not dominate the situation. Thus, in the alternative boat conformation (**5A**), large nonbonded interactions would be introduced between the 4-a hydrogen and the 1-*endo* hydrogen and between the 10-*endo* methyl and the 3-*endo* hydrogen. These interactions should be quite large and would offset the advantages of having the 9-methyl in the more comfortable equatorial position. The pmr spectra of the two ketones in carbon tetrachloride and benzene provide some information regarding these preferred conformations. There is an upfield shift of 6 cps for the 9-methyl in 2-cedranone as compared to a shift of 12–18 cps anticipated for the conformation with an axial methyl and a very small downfield shift to be anticipated for the conformation with an equatorial methyl group.[26] Such a small downfield shift (1 cps) is noted in 2-isocedranone, supporting the conclusion that in this molecule the 9-methyl is equatorial. These studies indicate that 2-cedranone exists neither in the chair form (**5**) nor the boat form (**5A**), but somewhere in between these two extreme forms, whereas 2-isocedranone exists predominantly in the chair form.

In 2-isocedranone the distance between the hydrogen atoms of the 10-methyl and the 9-*endo* methyl, even though the latter is in the equatorial conformation, is relatively short, resulting in significant steric interactions. These interactions are at a minimum in 2-cedranone, a more flexible molecule, and hence the latter structure is favored.

**Assignment of Configurations for the 2-Cedranols.**—The configurational assignments for (−)-2-cedranol and 2-neocedranol is based on pmr spectral analysis and on the elimination reactions of the tosylate of 2-cedranol. There are two possible conformations for 2-cedranol, chair (**7**) or boat (**7A**). It is known[27] that the coupling constants between axial–equatorial or equatorial–equatorial protons is 3–7 cps and that between axial–axial is 7–11 cps. Hence, if there are axial protons in 2-cedranols to couple with an axial carbinyl proton (equatorial alcohol), the signal for the carbinyl proton will be spread over 20–30 cps. However, in the case of axial alcohols (equatorial carbinyl proton), the signal will be spread over 15–20 cps. On this basis, 2-isocedranol (**3**) (31 cps) and 2-neocedranol (**6**) (28 cps) have an equatorial OH, and 2-neoisocedranol (**8**) (14 cps) and 2-cedranol (**7**) (6 cps) have an axial OH. *In other words 2-cedranol exists in the chair form* **7** *even though the 9-methyl and the 2-OH groups are thereby forced to exist in the axial conformation.* The alternate conformation, boat form (**7A**), in which these two groups are in the equatorial conformation, is not preferred, for the same reasons presented earlier in the discussion of the conformation of cedranone.

Normally an axial carbinyl proton for an equatorial alcohol is shifted upfield (basic value 206 cps) and an equatorial carbinyl proton for an axial alcohol is shifted downfield (basic value 242 cps). However, in 2-cedranol, where our assignment places the carbinyl proton in the equatorial position, the pmr shift is upfield, opposite to that expected, and in 2-neocedranol, where our assignment place the carbinyl proton in the axial position, the pmr shift is downfield, once again opposite to that expected.

In the case of the parent cyclohexanol system, it has been observed that the presence of alkyl substituents can greatly modify the chemical shift of such carbinyl protons. Eliel has suggested a relationship which can be used to calculate the appropriate chemical shift for such highly substituted cyclohexanols.[28] It was of interest to attempt to apply his relationship to 2-cedranol and 2-neocedranol to see if the above anomaly could be accounted for. We considered 2-cedranol to be a cyclohexanol derivative with the following substituents, a 2-methyl (axial or equatorial), a tertiary butyl (axial), and a 3,3′-diisopropyl (axial and equatorial). In the calculation parameters, 3,3′-dimethyl (axial) were used for axial *t*-butyl and axial isopropyl, since values for these substituents are not presently available. This approximation may account for the slight variation observed between the calculated and experimental values. However, it is gratifying that the calculations summarized in Table I, do indicate the equatorial carbinyl proton in 2-cedranol may be expected to show an upfield shift and that in 2-neocedranol a downfield shift, as observed.

TABLE I
CALCULATED AND OBSERVED CHEMICAL SHIFTS[a] FOR 2-ISOCEDRANOLS

| | Chemical shift for cedranols | | | |
|---|---|---|---|---|
| | 2-Neoiso-(**8**) | 2-Iso-(**3**) | 2-(**7**) | 2-Neo-(**6**) |
| Basic value | 242 | 206 | 242 | 206 |
| 3-Methyl | −17 | −28 | −24 | +11.5 |
| 3a-*t*-Butyl (axial) | +5 | +11 | +5 | +11 |
| 7a-Isopropyl (axial) | +5 | +11 | +5 | +11 |
| 7a-Isopropyl (equatorial) | +1.5 | +2 | +1.5 | +2 |
| Calculated | 236.5 | 204 | 229.5 | 241.5 |
| Found | 236 | 224 | 217 | 239 |

[a] Expressed as a shift in cps downfield from internal standard tetramethylsilane on a 60-Mc instrument.

Last, if the configurational assignments are correct, the chemical shift of the 10-methyl group should be shifted downfield owing to the proximity of the 2-OH group, in **8** and **7**, as compared with those in **6** and **3**. Such shifts occur. In Table II are given the pmr spectral data. The chemical shifts for the 11-methyl and 12-methyl in this table are assigned on the assumption that because of their isolated position they should not change significantly with the change in the substituents at the 2, 3, and 9 positions.

## Experimental Section

**Materials.**—(−)-α-Cedrene, $\alpha_D$ −83.20°, $n^{20}D$ 1.4975, was supplied by International Flavors and Fragrances and by Aldrich Chemicals. The Aldrich sample contained 7% β-cedrene. The following columns were used to identify or separate the cedrane derivatives by gas–liquid partition chromatography:

(26) N. S. Bhacca and D. H. Williams, "Applications of Nmr Spectroscopy in Organic Chemistry," Holden-Day, Inc., San Francisco, Calif., 1964, p 158.

(27) Reference 26 p 80.

(28) E. L. Eliel and F. J. Biros, *J. Amer. Chem. Soc.*, **88**, 3334 (1966). We thank Professor Ernest L. Eliel for his helpful discussions in the interpretations of the pmr spectra of cedranols.

TABLE II

PHYSICAL AND NMR SPECTRAL[a] PROPERTIES OF CEDRANE DERIVATIVES

| Compound | No. | Bp (mm) or mp, °C | $n_D$ | $[\alpha]_D$, deg | 2-H | 12-$CH_3$ | 11-$CH_3$ | 10-$CH_3$ | 9-$CH_3$ -$CH_2$ -CH | $OCOCH_3$ or $ArCH_3$ | Aromatic | Miscellaneous |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| α-Cedrene | 2 | 100 (4) | 1.4973 | −83.23 | 309 | 50 (6.5) | 57 | 60.5 | 99 | | | |
| β-Cedrene | 11 | 120 (5) | 1.5040 | +9.7 | | 50 (6.5) | 56.5 | 58 | 270 | | | |
| β-Cedrene[b] | 11 | | | | | 50 (6.5) | 57.5 | 57.5 | 271 | | | |
| γ-Cedrene | 25 | | 1.5010 | +118.8 | 311[c] | 56.5 (7) | 57.5 | 63.5 | 56.5 (7) | | | 359.5 (9)[d] |
| Cedrene | | | 1.5180 | +171.2 | 344 (10) | 53 (6.5) | 56 | 53 | 272[e] | | | 369 (10)[d] |
| Isocedrane | 21 | | 1.4935 | −9 | | 50 (6.5) | 57.5 | 69.5 | 62 (4.5) | | | |
| Cedrane | 22 | | 1.4965 | −20 | | 49 (6) | 56 | 63 | 56 (7.5) | | | |
| 2-Neoisool | 8 | 120 (2) | 1.4511 | −33.4 | 236[f] | 50 (6.5) | 56 | 76 | | | | 147[g] |
| Acetate | | 125 (1.5) | 1.4900 | −56.6 | 305.5[h] | 49 (6.5) | 58 | 76 | 62 (5.5) | 119 | | 133[i] |
| PNB | | 99–100 | | | 333[f] | 50 (6) | 60.5 | 82.5 | 70 (4) | | 498 | |
| 2-Isool[j] | 3 | 146–147 | | +3.6 | 224[k] | 51 (7) | 57 | 68 | 69 (7) | | | |
| Acetate | | 135 (1.8) | 1.4885 | +23 | 297[l] | 51 (6.5) | 58.5 | 73 | 60.5 (7) | 117 | | 120[i] |
| p-$NO_2$ benzoate | | 69–70 | | | 320[m] | 52.5 (6) | 61 | 76.5 | 65.5 (8) | | 493 | |
| Tosylate | 26 | | | | 279[n] | 46 (6.5) | 56 | 67 | 54 (6.5) | 146 | 438[o] 464[p] | |
| 2-Ol | 7 | 120 (1.5) | 1.5070 | −43.5 | 217[q] | 50 (7.5) | 56 | 70 | 58 (7.5) | | | |
| p-$NO_2$ benzoate | | 77–78 | | | 298[r] | 52.5 (6) | 59.5 | 68 | 68 (7.5) | | | |
| Tosylate[s] | 24 | | | | 262[r] | 44.5 (6) | 55 | 67 | 58 (5.5) | 146 | 438[o] 464[p] | |
| 2-Neool | 6 | 79–80 | | −49.4 | 239[t] | 50.5 (7) | 56 | 64 | 52.5 (7) | | | |
| p-$NO_2$ benzoate | | 145–46 | | | 323[u] | 53 (6.5) | 60 | 73 | | | 493.5 | 145[i] |
| 2-Isoone | 4 | 124–126 (1.8) 31–32 | 1.5005 | −14.86[v] | | 53 (6.5) | 57 | 59 | 67.5 (7) | | | 146[w] |
| 2-Isoone[b] | 4 | | | | | 50 (7) | 49 | 56 | 68.5 (7) | | | |
| 2-One | 5 | 115 (1.2) | 1.4975 | −87.63 | | 52 (6.5) | 58.5 | 58.5 | 65 (7.5) | | | 154[i] |
| 2-One[b] | 5 | | | | | 42 (6) | 50 | 55.5 | 59 (6.5) | | | |
| *exo*-2,3-Epoxy | 9 | 120 (2) | 1.4960 | −74.7[x] | | 48 (6.5) | 58.5 | 69.5 | 78 | | | |
| *exo*-3,9-Epoxy | 12 | 108 (1.2) | 1.4993 | −5 | | 52.5 (7) | 57 | 66 | 147.5 | | | |
| 3-Isool | 13 | 118–120 (1.4) | 1.5070 | −5.45 | | 50.5 (6) | 60 | 67 | 75 | | | |
| 3-Ol[y] | 20 | 85.5 | | +10.2 | | 49.5 (6) | 58.5 | 73 | 77 | | | |
| 3-Chloro-iso | 10 | | | | | 52.5 (6) | 62.5 | 69.5 | 108 | | | |
| 2,9-Isodiol | 14 | 89–90 | | −7 | 244[z] | 51.5 (7) | 56 | 61.5 | 208[z] | | | |
| 2-Ol 9-iso-tosylate | 15 | 110–111 | | | 233.5[z] | 50 (7) | 53.5 | 56 | 260[z] | 146.5 | 440[aa] 468[bb] | |
| 9-Isool[cc] | 16 | 130 (1.5) | 1.5095 | −5.8 | | 51 (6.5) | 57.5 | 65 | 211.5 (5) | | | |
| Acetate[cc] | | 122 (1.2) | 1.4912 | −9 | | 50 (6.5) | 58 | 67.5 | 241 (6) | 117 | | |
| Tosylate[cc] | 23 | | | | | 49 (6) | 54.5 | 59 | 237.5 (6) | 146.5 | 437.5[aa] 463[aa] | |
| 9-Ol[dd] | 17 | 132 (1.2) | 1.5050 | −4.5 | | 49 (6) | 57 | 64 | 205 (5.5) | | | |
| Acetate[dd] | | 122 (1.2) | 1.4920 | −9 | | 50 (6) | 59.5 | 65 | 237 (6.5) | 117.5 | | |
| 9-Isoal[ee] | 18 | | | | | 50 (6.5) | 52 | 59 | 578 | | | |
| 9-Al[ff] | 19 | 110 (1.2) | 1.5054 | +21.2 | | 48 (6.5) | 62 | 67 | 572 | | | |

[a] All spectra were determined in $CCl_4$, unless otherwise mentioned, at 60 Mc using Varian Associates Model A-60 or A-60A spectrometer, and are expressed as shift downfield from internal standard tetramethylsilane in cps. The numbers given in the parentheses are the coupling constants for doublets. Whenever chemical shifts are mentioned in single numbers, they are singlets, unless otherwise mentioned. [b] In benzene. [c] Quartet, $J_{H_1-H_2} = 9$ and $J_{H_2-H_3} = 4$ cps. [d] For 1 H. [e] AB quartet, A = 268, B = 274.5, $J_{AB} = 2$ cps. [f] Band width 14 cps. [g] 3 H, quartet $J = 9$ cps. [h] Band width 15 cps. [i] 3 H. [j] In $CDCl_3$, the compound is sparingly soluble in $CCl_4$. [k] Band width 31 cps. [l] Band width 31 cps. [m] Band width 36 cps. [n] Band width 32 cps. [o] *m*-H with respect to $SO_2$, $J =$ 8 cps. [p] *o*-H with respect to $SO_2$, $J = 8$ cps. [q] Band width 16 cps. [r] Band width 15 cps. [s] Determined from the mixture of **24** and **7**. [t] Band width 28 cps. [u] Band width 36 cps. [v] Rotation containing 4% **5**. [w] Quartet, $J = 9$ cps. [x] Rotation containing 4% **5**. [y] From ref 13. [z] Broad multiplet, both these peaks are merged partially and splitting pattern is difficult to assign. [aa] *m*-H with respect to $SO_2$, $J = 9$ cps. [bb] *o*-H with respect to $SO_2$, $J = 9$ cps. [cc] Contains **17** or the corresponding derivatives, 4%. [dd] Contains **16** or the corresponding derivatives, (20–22%), but spectrum is for the pure compound. [ee] Contains **19** (20%), pmr spectrum for the pure compound. [ff] Contains **18** (20%), pmr spectrum for the pure compound.

column A, 10% free fatty acid phase (FFAP) on Chromosorb (20 ft × 0.25 in. o.d.) on an F & M Model 300 instrument; column B, 15% Carbowax 20M on Chromosorb (10 ft × 0.25 in. o.d.) on an F & M Model 300 instrument; column C, 15% Carbowax 20M on Chromosorb (8 ft × 0.75 in. o.d.) on preparative F & M Model 700 gas chromatograph; column D, 20% 1,2,3-tris(2-cyanoethoxy)propane (TCEP) on DMDC treated Chromosorb (8 ft × 0.25 in. o.d.) at 150° isothermal on F & M Model 300 instrument; column E, 10% polyphenyl ether on Chromosorb (8 ft × 0.25 in. o.d.) on F & M Model 300 in-

strument; column F, 50% SE-30 on Chromosorb (8 ft × 0.125 in. o.d.) on Varian Associates Model 1200 gas chromatograph; column G, Squalane, Golay column (150 ft) on Perkin-Elmer Model 226. The physical and nmr spectral properties of cedrane derivatives are listed in Table II.

(+)-2-Isocedranol (3).—(−)-α-Cedrene (20.4 g, 100 mmol), was dissolved in tetrahydrofuran (34.6 ml) and maintained at 0–5° in a round-bottom flask, previously flame dried and flushed with nitrogen. Diborane solution, in tetrahydrofuran (68.6 ml, 1.60 *M* in $BH_3$), was added with stirring in 30 min. The solution was stirred for 3 hr at 10° and 3 hr at room temperature. Excess of hydride was decomposed by adding 1 ml of water in 2 ml of tetrahydrofuran. From the amount of hydrogen evolved, it was calculated that 93 mmol of hydride had been used in the reaction. Oxidation with sodium hydroxide (35 ml, 3 *N*) and hydrogen peroxide (35 ml, 30%) at temperature 30–35° produced 22.5 g (92%) of (+)-2-isocedranol (pure by glpc on column A at 175°, column B at 200° and column E at 200°). An analytical sample crystallized from acetone had mp 146–147°, $[\alpha]^{26}D$ +3.6° (*c* 10, tetrahydrofuran) (lit.[13] mp 147–149°, $[\alpha]D$ +2.7°).

*Anal.* Calcd for $C_{15}H_{26}O$: C, 81.02; H, 11.78. Found: C, 80.84; H, 11.97.

**Acetate of 2-Isocedranol.**—The following general procedure was used to prepare the acetates for all the cedranols described. (+)-2-Isocedranol (2 g), in 5 ml of pyridine and 2 ml of acetic anhydride, was heated at 80° for 2 hr under anhydrous conditions. Excess reagents were removed under reduced pressure and the residue was diluted with water. The ethereal extract was dried ($MgSO_4$), concentrated, and distilled giving 2.16 g (89%) of the acetate: bp 135° (1.8 mm), $n^{20}D$ 1.4885, $\alpha^{22}D$ +23° (neat dm).

*Anal.* Calcd for $C_{17}H_{28}O_2$: C, 77.22; H, 10.67. Found: C, 77.57; H, 10.52.

***p*-Nitrobenzoate of 2-Isocedranol.**—The following general procedure was used to prepare the *p*-nitrobenzoates for all the cedranols described. In a previously flame dried flask, flushed with nitrogen, and cooled to 0° was placed 4 ml of tetrahydrofuran, 0.33 g of 2-isocedranol (1.5 mmol), and *n*-butyllithium (1.5 mol) in ether. An ethereal solution of *p*-nitrobenzoyl chloride (1.5 ml, 1.5 mmol) was added and stirred for 2 hr at room temperature. The reaction mixture was chromatographed on 3 ml of alumina and eluted with ether. The solvent was removed and the *p*-nitrobenzoate was crystallized from *n*-heptane, almost in quantitative yield, mp 69–70°.

*Anal.* Calcd for $C_{22}H_{29}NO_4$: C, 71.13; H, 7.87. Found: C, 71.32; H, 8.09.

(−)-2-Isocedranone (4).—In a 1-l. four-necked flask, fitted with a mechanical stirrer at the center, a condenser, a dropping funnel and a thermometer well at the sides, was placed 400 ml of ether and 10 g of 2-isocedranol (45.4 mmol, saturated solution). To this vigorously stirred solution, maintained at 0°, was added in 10 min 50 ml of a chromic acid solution (0°), prepared from 10 g of sodium dichromate dihydrate (33 mmol) and 13.6 g of sulfuric acid (130 mmol) and sufficient water to make 50 ml of the solution. After stirring the solution for 5 min, 50 ml of water previously cooled to 0° was added, and the lower layer was transferred into another flask containing 50 ml of ether. The ethereal extract was washed with water and with bicarbonate solution, dried ($MgSO_4$), and distilled giving 8.5 g (84%) of **4**: bp 124–126° (1.8 mm), mp 31–32°, $\alpha^{26}D$ −14.86° (neat), $n^{20}D$ 1.5005 (lit.[13] mp 32.5–34°, $[\alpha]D$ −8.4° ($CHCl_3$)). Glpc analysis on columns A and B at 175° indicated it to be a mixture of 95% 2-isocedranone and 5% 2-cedranone, the latter compound presumably coming from the isomerization of **4**, during work-up. (−)-2-Isocedranone (**4**) isomerizes on column A above 175° to (−)-2-cedranone (**5**), the precise amount of which depends upon the temperature of the column and the flow rate.

**Isomerization of (−)-2-Isocedranone (4) to (−)-2-Cedranone (5).**—(−)-2-Isocedranone (3.3 g, 15 mmol), dissolved in 5 ml of methanol, was added dropwise with stirring to 15 ml of a 1 *M* solution of sodium methoxide in methanol at 0° and allowed to come to room temperature. The reaction mixture was diluted with water, acidified with dilute phosphoric acid, and saturated with sodium chloride. It was extracted with pentane (35–37°) and the pentane extract was dried ($MgSO_4$), concentrated, and distilled giving 3.15 g (92%) of the epimerized ketone **5**, containing 8% 2-isocedranone (**4**), as indicated by the glpc analysis on the columns A and B ($t_r$ for **5** at 175° on column A with helium flow 133 ml/min was 11.5 min and that for **4**, under identical conditions, was 13 min). In a separate experiment, when the epimerization was followed at 0° and at 25°, the equilibrium mixture, 92% **5**–8% **4**, was reached in a few minutes. The mixture had the following properties: bp 124–126° (1.8 mm), $n^{20}D$ 1.4977, $[\alpha]^{27}D$ −72.27° (neat). Ourisson[13] equilibrated the two ketones using acetic acid and chlorohydrin and reports 94% **5** and 6% **4**.

(−)-2-Neoisocedranol (8).—The reagent was prepared as follows. A three-necked flask (300 ml) equipped with a magnetic stirring bar, thermometer, a serum cap attached to a side arm, and a condenser with a nitrogen inlet was flame dried and flushed with nitrogen. To a 30-ml solution of lithium aluminum hydride in tetrahydrofuran (1.03 *M*), dry methanol dissolved in tetrahydrofuran was slowly added until 2400 ml of gas was evolved. During the addition, a little gel appeared. The mixture was stirred vigorously until the gel was dissolved.

To the above solution of lithium trimethoxyaluminum hydride, 3.61 g of 2-isocedranone (16.4 mmol), dissolved in 5 ml of tetrahydrofuran, was added with stirring at 0° in 15 min and stirred at room temperature overnight. Water (1 ml) in 2 ml of tetrahydrofuran was added carefully to destroy the excess of the reducing agent. The residual hydride indicated almost the quantitative reaction. To the reaction mixture was added 30 ml of a saturated aqueous solution of potassium sodium tartrate and the aqueous phase was extracted with ether. The combined extracts were washed with brine, dried ($MgSO_4$), concentrated, and distilled, giving 3.39 g (93%) of (−)-2-neocedranol **8**, of 99% purity. 2-Isocedranol was present in less than 1%. The analytical sample of **8** was obtained by a preparative glpc on column B. On larger columns like C, **8** undergoes partial elimination giving α-cedrene. It had bp 120° (2 mm), $n^{20}D$ 1.4511, $[\alpha]^{25}D$ −33.4° (*c* 37, $CCl_4$).

*Anal.* Calcd for $C_{15}H_{26}O$: C, 81.02; H, 11.78. Found: C, 80.92; H, 11.84.

**Acetate of 2-Neoisocedranol.**—It was prepared as described above, bp 125° (1.5 mm), $n^{20}D$ 1.4900, $[\alpha]^{24}D$ −56.6° (*c* 28.8, $CCl_4$) (lit.[13] $[\alpha]D$ −59°).

*Anal.* Calcd for $C_{17}H_{28}O_2$: C, 77.22; H, 10.67. Found: C, 77.55; H, 10.52.

(−)-*exo*-2,3-Epoxycedrane (9).—A three necked round bottom flask, fitted with a mechanical stirrer and thermometer, was charged with 20.4 g of α-cedrene (100 mmol) and 150 ml of chloroform. It was cooled to 0–5° and a solution of *m*-chloroperbenzoic acid (85% pure, 21 g, 105 mmol), dissolved in 240 ml of chloroform, was added with stirring in 15 min. Glpc analysis indicated the absence of α-cedrene. The reaction mixture was then cooled to −10° and *m*-chlorobenzoic acid removed by filtration. The chloroform solution was washed with 10% potassium carbonate solution (twice with 50 ml), brine, dried ($MgSO_4$), and concentrated. The residue was dissolved in pentane and chromatographed on a 100 g silica gel column to remove residual traces of *m*-chlorobenzoic acid. The pentane solution was concentrated and distilled, giving 20 g (91%) of (−)-*exo*-2,3-epoxycedrane (**9**): bp 120° (2 mm), $\alpha^{27}D$ −74.7° (neat) $n^{20}D$ 1.4960 (lit.[13] $[\alpha]D$ −107.7°). The glpc analysis on the column B indicated the presence of 4% 2-cedranone (**5**). In a separate experiment and under similar conditions epoxidation of α-cedrene with *m*-chloroperbenzoic acid for 12 hr at room temperature gave 60% epoxide **9** and 40% 2-cedranone (**5**). Ourisson[13] also found that it was difficult to prepare the pure epoxide in large quantities without the concurrent formation of **5**.

**Isomerization of (−)-*exo*-2,3-Epoxycedrane with Boron Trifluoride Etherate. (−)-2-Cedranone (5).**—(−)-*exo*-2,3-Epoxycedrane (6.6 g, 30 mmol) was dissolved in 50 ml of dry benzene and stirred vigorously at 0° under nitrogen. Boron trifluoride etherate (1 ml, 9 mmol) was added. Glpc analysis on column B indicated that the reaction was complete in less than a minute. However, after 5 min the reaction mixture was treated with 10 ml of a saturated solution of bicarbonate, washed with brine, and extracted with ether. The combined benzene and ether extract was dried ($MgSO_4$), concentrated, and distilled giving 6.0 g (91%) of 2-cedranone (**5**): bp 115° (1.2 mm); $n^{22}D$ 1.4975; $\alpha^{29}D$ −87.6° (neat), −83.1° (*c* 10.6, $CCl_4$).

**Reduction of (−)-*exo*-2,3-Epoxycedrane (9) with Lithium Aluminum Hydride. (−)-3-Isocedranol (13).**—(−)-*exo*-2,3-Epoxycedrane (1.1 g, 5 mmol) in 2 ml of tetrahydrofuran was added at room temperature to 8.7 ml of lithium aluminum hydride solution in tetrahydrofuran (2.3 *M* in $LiAlH_4$, 20 mmol) and allowed to react for 24 hr. Excess of hydride was destroyed by adding water cautiously and worked up as described earlier,

giving 0.92 g (83%) of (−)-3-isocedranol: bp 118–120° (1.4 mm), $n^{22}D$ 1.5070, $[\alpha]^{27}D$ −5.45° (c 10, $CCl_4$) (lit.[13] $[\alpha]D$ −7°).

**Reduction of (−)-2-Isocedranone (4) and (−)-2-Cedranone (5).**—To a solution of lithium aluminum hydride in tetrahydrofuran (3 ml, 1.03 *M*) at 0°, 0.4 ml of 2-isocedranone or 2-cedranone in 1 ml of tetrahydrofuran was added and allowed to stand overnight with stirring under nitrogen. It was worked up as described earlier for the reduction and the product was analyzed for 2-neoisocedranol (8), 2-isocedranol (3), 2-cedranol (7) and 2-neocedranol (6), by glpc on column B, at 200°, with helium flow of 50 ml/min. The results are summarized in Table III. (−)-2-Cedranol (7) and (−)-2-neocedranol (6) were separated by preparative glpc on column C at 200° and the analytical samples had the properties listed in Table IV.

TABLE III

REDUCTION OF (−)-2-ISOCEDRANONE (4) AND (−)-2-CEDRANONE (5)

| | | | Cedranol distribution | | | |
|---|---|---|---|---|---|---|
| Ketone | Reducing agent | Solvent | Neoiso-(8) | Iso-(3) | 7 | Neo-(6) |
| 4 | $LiAlH(OCH_3)_3$ | THF | 99 | 1 | | |
| 4 | $LiAlH_4$ | THF | 93.6 | 6.4 | | |
| 5 | $LiAlH(OCH_3)_3$ | THF | | | 83 | 17 |
| 5 | $LiAlH_4$ | THF | | | 70 | 30 |
| 5 | $LiAlH_4$ | $Et_2O$[a] | | | 53 | 47 |
| 5 | Dibal[a] | ... | | | 60 | 40 |
| 5 | Tribal[a] | ... | | | 84 | 16 |

[a] Reference 13.

**Reaction of Disiamylborane with α- and β-Cedrenes.**—The sample of α-cedrene obtained from Aldrich Chemicals contained 7% β-cedrene. It is selectively and quantitatively removed from the mixture by reaction with disiamylborane.[29] To the mixture of cedrenes (185 g, 0.90 mol) in 200 ml of tetrahydrofuran was added 100 ml of disiamylborane (175 mmol) in tetrahydrofuran over 30 min at 0–5° and stirred for 12 hr under a nitrogen atmosphere. The reaction mixture was analyzed by glpc on column A periodically. The β-cedrene had disappeared after 3 hr. Excess of the hydride was decomposed with water, the organoborane was oxidized at 35–40° with 30 ml of sodium hydroxide (3 *N*) and 30 ml of hydrogen peroxide (30%). The aqueous phase was extracted with ether and combined extracts were dried ($MgSO_4$) and distilled, collecting the following fractions: fraction 1, the forerun, 4 g, bp 60–90° (1.5 mm); fraction 2, α-cedrene, 162 g, bp 90–91° (1.5 mm), $\alpha^{25}D$ −77.8° (neat), $n^{20}D$ 1.4945, 99% pure by glpc; fraction 3, residue, 25.2 g. The purified α-cedrene (fraction 2) was used for the epoxidation, isomerization of the epoxide to cedranone, and for the preparation of β-cedrene.

Fraction 3, when analyzed by glpc using 2-isocedranol as an external standard, showed 10% α-cedrene, 18% unknown, 51% 9-isocedranol, and 21% nonvolatile material by glpc. This fraction 3 was then distilled at 0.05 mm and the following fractions were collected: fraction A, 12.5 g, bp 90–130° (0.05 mm), glpc analysis on column B indicated 12% α-cedrene, 28% a mixture of three unknowns, and 60% 9-cedranols; fraction B, 4.8 g, bp 130–150° (0.05 m). It contained 55% 9-cedranols and the rest was nonvolatile by glpc. Fraction A was dissolved in pentane and chromatographed on 200 g of alumina, giving 4.18 g of a semisolid product with a garlic smell. This product was further purified by preparative glpc on column C to give a clear liquid, $n^{20}D$ 1.5180, $[\alpha]^{22.5}D$ +171.2° (c 10, $CCl_4$). This material was identified as $\Delta^{1,2},\Delta^{3,9}$-cedradiene by its pmr spectra (Table II). Continued chromatography of fraction A, utilizing elution with ether, gave 7.2 g of 9-cedranols. The separation of these two primary cedranols was difficult by glpc, but the ratio 82% 9-isocedranol (16) and 18% 9-cedranol (17) was determined by pmr. The formation of appreciable quantity of 9-cedranol (17) must be due to the isomerization of the *endo*-organoborane to the *exo*-organoborane and not due to nonstereoselectivity of the hydroboration reaction, as is apparent from further data presented below.

**Reduction of (−)-*exo*-2,3-Epoxycedrane (9) with Aluminum Hydride.**—(−)-*exo*-2,3-Epoxycedrane (2.2 g, 10 mmol) in 4 ml of tetrahydrofuran was slowly added to a 10.4 ml of a solution of aluminum hydride[30] in tetrahydrofuran (10 mmol) with stirring at room temperature. The excess of hydride was destroyed with water, and the water layer extracted with ether. The combined ethereal extracts were dried ($MgSO_4$), concentrated, and distilled, giving 2.18 g (98%) of the liquid, which was identical with the product obtained by the reduction of 9 with lithium aluminum hydride.

**Reduction of (−)-*exo*-2,3-Epoxycedrane (9) with Diborane and Lithium Borohydride. (−)-2-Isocedrane-9-diol (14).**—Diborane in tetrahydrofuran (10.8 ml, 14 mmol) and 4.62 ml of lithium borohydride in tetrahydrofuran (14 mmol) were mixed and cooled to 0° under nitrogen. (−)-*exo*-2,3-Epoxycedrane (2.75 g, 12.5 mmol) was added with stirring in 15 min. There was a slow evolution of gas, 10 mmol in 1 hr, and 14 mmol in 18 hr. The reaction mixture was treated with water and from the amount of hydrogen evolved 13 mmol of hydride had been utilized for reduction. The reaction mixture was saturated with bicarbonate and extracted with ether. The combined extracts were dried ($MgSO_4$) and evaporated, giving a gummy thick solid. This material contained boron, indicated by flame test, and did not elute from the glpc columns A and B. It was dissolved in 10 ml of tetrahydrofuran and oxidized with alkaline hydrogen peroxide (4.2 ml of sodium hydroxide, 3 *N*, and 4.2 ml of hydrogen peroxide, 30%). The reaction mixture was worked up as described for 2-isocedranol, giving 3.01 g of a gummy liquid which solidified in ether to a white crystalline solid, mp 84–85°. The precipitate was sublimed at 100° (0.05 mm) and collected as a thick liquid which again crystallized from ether to give 2.48 g (84%) of solid, mp 89–90°, $[\alpha]^{25}D$ −7° (c 5, $CCl_4$).

*Anal.* Calcd for $C_{15}H_{26}O_2$: C, 75.58; H, 10.99. Found: C, 75.25; H, 11.03.

**2,9-Isocedranediol 9-*p*-Tolylsulfonate (15).**—2,9-Isocedranediol (2.38 g, 10 mmol) in 5 ml of dry pyridine was cooled to 0° and 1.9 g of *p*-tolylsulfonyl chloride (10 mmol) in 5 ml of pyridine was added with stirring and allowed to stand in the cold room (0°) for 2 days. The solid was filtered and the filtrate was neutralized at 0° with 5% hydrochloric acid and extracted with ether. The ethereal extract was dried ($MgSO_4$) and evaporated giving 3.12 g (80%) of the product. This was crystallized from *n*-heptane, mp 110–111°.

*Anal.* Calcd for $C_{22}H_{32}O_4S$: C, 67.31; H, 8.22; S, 8.17. Found: C, 66.93; H, 8.43; S, 8.07.

**Reduction of 15 with Lithium Aluminum Hydride.**—To a solution of lithium aluminum hydride dissolved in tetrahydrofuran (5 ml, 2 *M* in $LiAlH_4$) at room temperature, 1.96 g of the tosylate 15 (5 mmol) dissolved in 3 ml of tetrahydrofuran was added and stirred for 48 hr. It was work up as described earlier. The combined ether extract was washed with sodium hydroxide, dried ($MgSO_4$), and evaporated, giving 0.98 g of a crystalline solid, mp 139–140°, mixed up with 2-isocedranol, 142–143°, and the pmr spectra was identical with that of 2-isocedranol.

**Attempted Base-Catalyzed Isomerization of (−)-α-Cedrene.**—α-Cedrene (1.02 g, 5 mmol) was allowed to react with ethylenediaminolithium (prepared from 0.07 g of lithium in 3 ml of ethylenediamine) or with potassium *t*-butoxide (6 mmol) in 10 ml of dimethyl sulfoxide at 75° or at 100°. The reaction was followed by glpc on column D. There was no reaction with either base in 12 hr.

**Hydrochlorination of (−)-α-Cedrene. 3-Chloroisocedrane (10).**—An automatic Brown□ hydrogenator[31] was used for the hydrochlorination. Ether (60 ml) was saturated with hydrochloric acid gas at −70° and 20.4 g of α-cedrene (100 mmol) was added through a hypodermic syringe to the reaction flask. The hydrochlorination was over in 5 min and a colorless crystalline solid was obtained. After 1 hr at 70°, the ether and dissolved hydrogen chloride were removed at 0° by attaching the reaction flask through a 1-m Drierite tube to a rotaevaporator. The crude hydrochloride was treated with 20 ml of pentane, cooled to −70°, and filtered to ensure complete removal of unreacted α-cedrene. The product was crystalline, but unstable, and attempts to purify it by crystallization or by sublimation *in vacuo* failed. No satisfactory elemental analysis was obtained. The crude hydrochloride was used for the preparation of (+)-β-cedrene.

**(+)-β-Cedrene (11).**—Potassium *t*-butoxide (35.5 g, 300 mmol) was dissolved at 60° in 100 ml of *t*-butyl alcohol in a round bottom flask fitted with a reflux condenser, nitrogen inlet and outlet

(29) H. C. Brown and G. Zweifel, *J. Amer. Chem. Soc.*, **82**, 3222 (1960).

(30) H. C. Brown and N. M. Yoon, *ibid.*, **88**, 1464 (1966).

(31) H. C. Brown and M. H. Rei, *J. Org. Chem.*, **31**, 1090 (1966).

TABLE IV

| Empirical formula | Compound | Bp (mm) or mp, °C | $n^{20}D$ | $[\alpha]^{27}D$, deg (concn) | Lit. values | Analyses, % Calcd C | Calcd H | Found C | Found H |
|---|---|---|---|---|---|---|---|---|---|
| $C_{15}H_{26}O$ | (−)-2-Cedranol, **7** | 120 (1.5) | 1.5070 | −43.5 (*c* 14.6, $CCl_4$) | $[\alpha]D$ −41° | 81.02 | 11.78 | 81.21 | 11.80 |
| $C_{22}H_{29}NO_4$ | *p*-Nitrobenzoate of 2-cedranol, | 77–78 | | | | 71.13 | 7.87 | 71.32 | 8.15 |
| $C_{15}H_{26}O$ | (−)-2-Neocedranol, **6** | 79–80 | | −49.4 (*c* 13.8, $CCl_4$) | Mp 83°, $[\alpha]^{21}D$ −48° (*c* 10, $CCl_4$) | 81.02 | 11.78 | 81.25 | 12.03 |
| $C_{22}H_{29}NO_4$ | *p*-Nitrobenzoate of 2-neocedranol | 145–146 | | | | 71.13 | 7.87 | 71.45 | 7.74 |

system, under anhydrous conditions. This hot solution was poured into the flask containing 100 mmol of crude cedrene hydrochloride **10**, maintained at 0°, and the reaction mixture was swirled vigorously. It was then heated at 60°. The precipitation of potassium chloride started in 3 hr and was completed in 6 hr. Periodically a 2-ml aliquot was removed, treated with water, and extracted with pentane. The pentane extract was cooled to −70°, and filtered to remove *t*-butyl alcohol. The filtrate, after evaporation, was analyzed by pmr for the content of the hydrochloride, α- and β-cedrenes. In 6 hr the ratio between α- and β-cedrenes was 61:39, as determined by comparing the integrated areas of signals at 309 and 270 cps, assigned to the olefinic protons of α- and β-cedrenes, respectively. In 12 hr, in a separate experiment, the ratio remained the same, indicating that the reaction was complete and that β-cedrene did not undergo isomerization under the experimental conditions. The reaction mixture was diluted with water and extracted with pentane. The pentane extract was cooled to −70°, and filtered. The process was repeated twice. The pentane extract was dried ($MgSO_4$), concentrated, and distilled giving 17.3 g (85%) of the liquid, bp 120° (1.5 mm). The pmr analysis indicated the presence of 38% of β-cedrene. This mixture of α- and β-cedrenes was chromatographed on a column (1.2 m long) of 350 g of silica acid (100–200 mesh), impregnated with 15% silver nitrate, with 1000 ml of pentane, and 1000 ml of benzene. The pentane eluent contained 99% α- and 1% β-cedrene, whereas the benzene eluent contained 96% β- and 4% α-cedrene as indicated by glpc on column D. After removal of the benzene, distillation gave 6.02 g (90% recovery from the column) of β-cedrene, bp 120° (5 mm), $n^{20}D$ 1.5040, $[\alpha]^{22}D$ +9.7 (*c* 20, $CCl_4$) (lit.[10] $[\alpha]^{20}D$ +11.3° (*c* 10, *n*-heptane)).

In other experiments, when the elimination of the hydrochloride was carried out for 18 hr at room temperature, the reaction was incomplete. Bases of larger steric requirements, such as potassium triethylmethoxide in triethylcarbinol or in undecane, in 6 hr at 60°, gave 52% β-cedrene.

**(−)-9-Isocedranol (18).**—(+)-β-Cedrene (0.505 g, 2.5 mmol) was dissolved in 5 ml of tetrahydrofuran and hydroborated with diborane in tetrahydrofuran (1.6 ml, 2.5 mmol in $BH_3$). The reaction mixture was decomposed with water and was oxidized with alkaline hydrogen peroxide (1 ml of sodium hydroxide, 3 *N*, and 1 ml of hydrogen peroxide, 30%). The product was extracted with ether, dried ($MgSO_4$), and distilled giving 0.425 g (90%) of the alcohol **18**: bp 130° (1.5 mm), $n^{20}D$ 1.5095, $[\alpha]^{25}D$ −5.8° (*c* 20, $CCl_4$).

*Anal.* Calcd for $C_{15}H_{26}O$: C, 81.02; H, 11.78. Found: C, 80.83; H, 11.57.

**(−)-9-Isocedranol Acetate.**—(−)-9-Isocedranol (0.440 g, 2 mmol), 2 ml of pyridine, and 0.504 g of acetic anhydride were used for the preparation of the acetate. It was 96% pure by glpc analysis on the column A: bp 122° (1.2 mm), $n^{20}D$ 1.4912, $[\alpha]^{23.5}D$ −9° (*c* 20, $CCl_4$).

*Anal.* Calcd for $C_{17}H_{28}O_2$: C, 77.22; H, 10.67. Found: C, 77.48; H, 10.78.

**Hydroboration–Isomerization–Oxidation of β-Cedrene.**—The same quantities which were used for the preparation of (−)-9-isocedranol were used for this reaction. However, after 2 hr at room temperature, tetrahydrofuran was removed under vacuum, 2 ml of diglyme and 0.2 ml of diborane in tetrahydrofuran (1.5 *M* in $BH_3$) were added, and the reaction mixture was heated for 12 hr at 140°. The reaction mixture was decomposed with water, oxidized with alkaline hydrogen peroxide, extracted with ether, dried ($MgSO_4$), and distilled to remove diglyme. Last traces of diglyme were removed by chromatography over alumina, using 100 ml of pentane and 500 ml ether–methanol (5%). After removal of the ether and methanol, there was obtained 0.395 g (71%) of the isomerized alcohol: bp 132° (1.2 mm), $n^{20}D$ 1.5050, $[\alpha]^{22}D$ −4.5° (*c* 20, $CCl_4$).

*Anal.* Calcd for $C_{15}H_{26}O$: C, 81.02; H, 11.78. Found: C, 80.92; H, 11.65.

**(−)-9-Cedranol Acetate.**—It was prepared from 0.444 g of 9-cedranol (2 mmol), 2 ml of pyridine, and 0.504 g of acetic anhydride (5 mmol). The product was a mixture of 24% 9-isocedranol acetate and 76% 9-cedranol acetate, as determined by glpc analysis on columns A, B, E, and F. The same ratio of the acetates was indicated by the pmr analysis of the reaction mixture. The products had bp 122° (1.2 mm), $n^{20}D$ 1.4920, $[\alpha]^{22}D$ −9° (*c* 20, $CCl_4$).

*Anal.* Calcd for $C_{17}H_{28}O_2$: C, 77.22; H, 10.67. Found: C, 77.14; H, 10.97.

In another experiment, the hydroboration was carried out with sodium borohydride and boron trifluoride etherate in diglyme, followed by isomerization of the organoborane at 140° for 4 hr. The product was oxidized and the alcohols were converted into acetates. The pmr analysis showed the same isomer distribution.

**(−)-*exo*-3,9-Epoxycedrane (12).**—*m*-Chloroperbenzoic acid (80% pure, 0.510 g, 2.8 mmol) was dissolved in 10 ml of chloroform and cooled to 0°. β-Cedrene (0.51 g, 2.5 mmol) was added dropwise and stirred for 15 min. The precipitated *m*-chlorobenzoic acid was filtered, and the filtrate evaporated at 0°. The residue was washed with pentane; the pentane extract was dried ($MgSO_4$) and distilled, giving 0.485 g (88%) of the epoxide (**12**): bp 108° (1.2 mm), $n^{20}D$ 1.4993, $[\alpha]^{22}D$ −5° (*c* 20, $CCl_4$). The epoxide was 96% pure by glpc. The remaining 4% was *exo*-2,3-epoxycedrane (**9**).

*Anal.* Calcd for $C_{15}H_{24}O$: C, 81.76; H, 10.98. Found: C, 82.00; H, 11.13.

**Action of Boron Trifluoride Etherate and Methanesulfonic Acid with *exo*-3,9-Epoxycedrane (12).**—A solution of 0.1 g of **12** in 0.3 ml of benzene was placed in a pmr tube. The peak at 147.5 cps, assigned to the methylene protons of the epoxide disappeared instantaneously when 10 μl of boron trifluoride etherate was added at room temperature, and a new broad peak at 565 cps, assigned to the aldehydic protons, appeared. The broad peak sharpened to two peaks at 578 and 572 cps when a saturated solution of sodium bicarbonate was added. Integration indicated that 90% of the epoxide had been converted into the aldehydes. The area ratio of the peaks at 578 and 572 cps was 60:40. In other experiments, when the reaction with boron trifluoride etherate was done at 0° or at −20°, or with methanesulfonic acid at room temperature, the ratio between these two aldehydes differs significantly. From Table V, it is evident that the initial reaction mixture contained 80% 9-isocedranal (**18**) and 20% 9-cedranal (**19**). On heating, or in the presence of acid, **18** slowly isomerizes to **19**.

**Isomerization of 9-Isocedranal (18) with Base.**—Crude 9-isocedranal (0.550 g, 2.5 mmol) was added to 0.102 g of sodium methoxide (2 mmol) in 5 ml of methanol at 0°. The reaction mixture was decomposed with water, extracted with ether, dried ($MgSO_4$), and distilled, giving 0.285 g of the product: bp 110° (1.2 mm), $n^{20}D$ 1.5054, $[\alpha]^{26}D$ +21.2° (*c* 20, $CCl_4$). The pmr analysis indicated a mixture of 20% **18** and 80% **19**.

**Reduction of 9-Isocedranal (18) and 9-Cedranal (19).**—To 0.220 g of the crude aldehydes, **18** or **19** (1 mmol), 2 ml of lithium aluminum hydride solution (4.6 mmol) was added. The alcohols **16** or **17** were then converted into acetates and analyzed by pmr.

TABLE V

REACTION OF BORON TRIFLUORIDE ETHERATE AND METHANESULFONIC ACID ON *exo*-3,9-EPOXYCEDRANE (12)

| Catalyst | Temp, °C | Time, min | % yield of the aldehydes | Isomer distribution, % 18 | 19 |
|---|---|---|---|---|---|
| $BF_3 \cdot OEt_2$ | 25 | Instantly | 90 | 60 | 40 |
| $BF_3 \cdot OEt_2$ | 0[a] | Instantly | 95 | 80 | 20 |
| $BF_3 \cdot OEt_2$ | −20[a] | Instantly | 95 | 80 | 20 |
| $BF_3 \cdot OEt_2$ | −20 | 15 | | 80 | 20 |
| $BF_3 \cdot OEt_2$ | | | | 70 | 30[b] |
| $MeSO_3H$ | 25 | 2 | 30 | 58 | 42 |
| $MeSO_3H$ | 25 | 5 | 29 | 45 | 55 |
| $MeSO_3H$ | 25 | 8 | 27 | 22 | 78 |
| $MeSO_3H$ | 25 | 12 | 29 | 22 | 78 |

[a] These reactions were done on a 0.2-g scale and the yields reported are for the crude mixture. [b] Analysis of the distilled product, bp 97° (0.5 mm).

TABLE VI

REDUCTION OF THE TOSYLATES 23, 26, AND 24 WITH LITHIUM ALUMINUM HYDRIDE

| Tosylate | Product, g |
|---|---|
| 23 | Isocedrane[a] (21), 0.22 |
| 26 | 2-Isocedranol (3), 0.31 |
| 24 | 44.4% γ-Cedrene (25), 0.175 |
| | 2.0% α-Cedrene (2), 0.175 |
| | 53.6% Cedrane (22), 0.175 |
| 24 | 2-Cedranol (7), 0.11 |

[a] Glpc analysis on column D.

TABLE VII

| Compound | Empirical formula | $t_r$, min | $n^{22}D$ | $[\alpha]^{25}D$ (c 10 $CCl_4$), deg | Analyses, % Calcd C | Calcd H | Found C | Found H |
|---|---|---|---|---|---|---|---|---|
| (−)-Isocedrane, 21 | $C_{15}H_{26}$ | 32 | 1.4935 | −9 | 87.30 | 12.70 | 87.18 | 12.64 |
| (−)-Cedrane, 22 | $C_{15}H_{26}$ | 30 | 1.4965 | −20 | 87.30 | 12.70 | 87.15 | 12.43 |
| (+)-γ-Cedrene, 25 | $C_{15}H_{24}$ | 24.5 | 1.5010 | 118.8 | 88.16 | 11.84 | 88.01 | 11.88 |

The isomer distribution between 9-isocedranol acetate and 9-cedranol acetate was 80:20 with **18** and 22:78 with **19**.

**Hydrogenation of (+)-β-Cedrene.**—In a Brown□ microhydrogenator was placed 0.1 g of platinum oxide, 0.1 g of Darco, and 2 ml of ether. The apparatus was flushed with hydrogen and the catalyst was generated. β-Cedrene (1.02 g, 5 mmol) was then added and the hydrogenation followed by the uptake of sodium borohydride solution of known concentration. The hydrogenation was over in 30 min. The reaction mixture was filtered, concentrated, and distilled, giving 1.0 g of the product: bp 100° (1.8 mm), $[\alpha]^{27}D$ −7° (*c* 20, $CCl_4$), $n^{22}D$ 1.4935. The glpc analysis on column G indicated 12% cedrane (**22**), and 88% isocedrane (**21**), with $t_r$ 82.5 and 87 min, respectively.

**Preparation of Tosylates of 9-Isocedranol (23), 2-Isocedranol (26), and 2-Cedranol (24). Reduction with Lithium Aluminum Hydride.**—The respective alcohols (0.440 g, 2 mmol) were dissolved in 1 ml of dry pyridine. Freshly sublimed *p*-tolylsulphonyl chloride (0.4 g, 2.2 mmol) in 1 ml of pyridine was added and the reaction mixture was then left in cold room (0°) for 48 hr. After this time pmr analysis of the supernatant liquid showed the presence of ~30% unreacted 2-cedranol (**7**), and no 2- (**3**) or 9-isocedranols (**16**). The crude tosylates were reduced with 2 ml of lithium aluminum hydride solution (5 mmol) in tetrahydrofuran for 24 hr at room temperature. The reaction mixture was decomposed with water and a saturated solution of sodium potassium tartrate was added. The ether extract was dried ($MgSO_4$), concentrated, dissolved in pentane and chromatographed on 2 g of alumina, using pentane followed by 95:5 ether–methanol for elution. The results are summarized in Table VI.

The retention times of the products on column D at 150° and their physical properties are described in Table VII.

**Registry No.**—**2**, 469-61-4; **3**, 19903-76-5; **3** acetate, 19903-81-2; **3**-PNB, 21996-64-5; **4**, 13794-73-5; **5**, 13567-40-3; **6**, 13567-44-7; **6**-PNB, 22037-83-8; **7**, 13567-42-5; **7**-PNB, 22037-85-0; **8**, 19903-78-7; **8** acetate, 19903-82-3; **8**-PNB, 21996-67-8; **9**, 21996-68-9; **10**, 22037-86-1; **11**, 546-28-1; **12**, 22037-88-3; **13**, 19903-73-2; **14**, 21996-69-0; **15**, 21996-70-3; **16**, 22037-90-7; **16** acetate, 22037-91-8; **17**, 21996-71-4; **17** acetate, 21996-72-5; **18**, 22037-92-9; **19**, 21996-73-6; **21**, 13567-54-9; **22**, 13567-55-0; **23**, 22037-94-1; **24**, 21996-75-8; **25**, 21996-77-0; **26**, 21996-76-9.

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