TABLE VI
PRODUCTS OF DEHYDRATION OF *cis*-4,4-DIMETHYLBICYCLO[4.1.0]HEPTAN-2-OL

Product	% of mixture Run 1	% of mixture Run 2	Relative retention time (column CW20M-2 at 90°)
18	45[a]	14	1.00
12	2	5	1.37
13	9	9	1.27
14	6	6	1.15

[a] Isolated along with 9% 11 (as determined by gc and nmr).

material, whereas at 528° there were no acetates and some charring was evident.

Dehydration of *cis*-4,4-dimethylbicyclo[4.1.0]heptan-2-ol (*cis*-5) was effected by heating 2.0 g (0.014 mol) of the alcohol with a few crystals of *p*-toluenesulfonic acid at ~230°. Products were slowly distilled from the reaction mixture (~1 g in 4.5 hr). In a second run a similar yield was produced in 0.5 hr by heating at 235° with a Wood's metal bath.

The product mixtures were analyzed by gc (column CW20M-2 at 90°; see Table VI) and several components were collected (column CW20M-4 at 90°). Cycloheptadienes **13** and **14** were identified by comparison of their ir spectra with those of authentic samples, **12** was tentatively identified by gc peak enhancement, and the major component in each run was identified as 4,4-dimethylbicyclo[4.1.0]hept-2-ene (**18**) on the basis of its nmr spectrum: τ 4.29 and 4.67 (AB quartet, 2, J = 10 Hz, CH=CH), 8.0–9.6 (m, 5, CH_2 and cyclopropyl H), 8.96 (s, 3, CH_3), 9.06 (s, 3, CH_3), and 9.72–10.02 (m, 1, cyclopropyl H).

Pyrolysis of 4,4-Dimethylbicyclo[4.1.0]hept-2-ene (18).—When the product mixture from dehydration run 1 was pyrolyzed, either in a sealed tube under argon at 320° for 5.5 hr, or in a flow system (described above) at 490°, analysis by gc (column CW-20M-2) and nmr showed that, in each case, about 50% of the product mixture was *m*-xylene.

Registry No.—**2**, 6267-39-6; **3**, 4694-17-1; **4**, 25866-56-2; *cis*-**5**, 25866-57-3; **6**, 25866-58-4; **10**, 25866-59-5; **11**, 25907-92-0; **12**, 25866-60-8; **13**, 25866-61-9; **14**, 25866-62-0; **16**, 25866-63-1; **17**, 25866-64-2; **18**, 25866-65-3; 3-acetoxy-1,1-dimethylcyclohexane, 25866-66-4.

Acknowledgement.—We thank the National Science Foundation for support of this work and for grants used for the purchase of an nmr and a mass spectrometer.

Hydroboration of Terpenes. VII. Hydroboration of (−)-Thujopsene. Configurations of the Isomeric 3-Thujopsanols and 3-Thujopsanones[1]

SHRINIVAS P. ACHARYA[2] AND HERBERT C. BROWN*

Richard B. Wetherill Laboratory, Purdue University, Lafayette, Indiana 47907

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Conformational analysis suggests that thujopsene (**1**) can exist in two possible conformations, steroidal I and nonsteroidal II. In the steroidal conformation, the side (α) away from the cyclopropane ring should be relatively inaccessible to reactions sensitive to steric requirements, whereas, in the nonsteroidal conformation, it is the side (β) toward the cyclopropane ring that should be relatively inaccessible. Hydroboration of (−)-thujopsene takes place exclusively from the β side, as indicated by the isolation of a single alcohol (+)-3-thujopsanol (**2**). The structure of (+)-3-thujopsanol has been established by determining the absolute configuration of the alcohol by Horeau's method. Similarly, epoxidation of thujopsene takes place predominantly from the β side to yield not the epoxide, but the rearranged product (−)-3-isothujopsanone (**5**). An equilibration study indicates nearly equal stability for (−)-3-thujopsanone and (−)-3-isothujopsanone. Consequently, it is concluded that thujopsene (**1**) reacts preferentially in the steroidal conformation I and probably exists preferentially in that conformation. In the course of this study all four of the isomeric 3-thujopsanols and both the two isomeric 3-thujopsanones were prepared and characterized.

The chemistry and structure of the sesquiterpene, thujopsene, has been the subject of considerable interest in the recent years. The structure of thujopsene was correctly deduced, in 1960, by Erdtman and Norin,[3] who assigned the relative stereochemistry shown in **1**. The cis relationship of the angular methyl substituent and the cyclopropane ring has subsequently been confirmed by a further degradative study[3d] and by a stereospecific synthesis.[4] Recently thujopsene has become of interest with respect to the problem of classical and nonclassical carbonium ion structures. Recognition of the existence of four rapidly equilibrating cyclopropyl carbinyl cations, from *cis*- and *trans*-thujopsenes, points to the essentially classical nature of these cations.[5]

Conformation and Steric Course of Reaction in Thujopsene.—Thujopsene is an interesting molecule, whose molecular model indicates the presence of considerable flexibility arising from the cis ring junction. The molecule (Figure 1) may adopt either the steroidal I or the nonsteroidal conformation II.[6] In the steroidal conformation I, the β side[7] provides a less crowded environment for the double bond. Hence the approach of any reagent with large steric requirements should be preferred from this side. On the other hand, in the nonsteroidal conformation II, the β side of the molecule is congested by the bridgehead 4a-methyl. However, the α side is relatively open to the reagent.

Hydroboration of olefins is highly sensitive to the steric environment of the double bond, taking place from the less hindered side.[8] The reaction is also highly exothermic but is remarkably free of skeletal rearrange-

* Author to whom correspondence should be addressed.

(1) Presented in part at the International Symposium on the Chemistry of Natural Products (IUPAC), London, July 1968.

(2) Postdoctoral Research Associate, 1966–1968, on Grant GM-10937 of the National Institutes of Health.

(3) (a) H. Erdtman and T. Norin, *Chem. Ind. (London)*, 622 (1960); (b) T. Norin, *Acta Chem. Scand.*, **15**, 1676 (1961); (c) S. Farsen and T. Norin, *ibid.*, **15**, 592 (1961); (d) T. Norin, *ibid.*, **17**, 738 (1963).

(4) (a) W. G. Dauben and A. C. Aschcraft, *J. Amer. Chem. Soc.*, **85**, 3673 (1963); (b) G. Büchi and J. D. White, *ibid.*, **86**, 2884 (1964).

(5) W. G. Dauben and L. E. Friedrich, *Tetrahedron Lett.*, **18**, 1735 (1967).

(6) For steroidal and nonsteroidal conformations, see C. Djerassi, "Optical Rotatory Dispersion," McGraw-Hill, New York, N. Y., 1960, p 186 ff.

(7) It is convenient to use β to indicate the side of the molecule toward the cyclopropane ring and the bridgehead 4a-methyl, and α to indicate the other side of the molecule.

(8) (a) G. Zweifel and H. C. Brown, *J. Amer. Chem. Soc.*, **86**, 393 (1964); (b) H. C. Brown and J. H. Kawakami, *ibid.*, **92**, 201 (1970).

ments,[9] even when the double bond is conjugated with a cyclopropane ring.[10] Consequently, hydroboration appears to possess real advantages to explore the steric requirements of reactions in flexible systems.

In the case of rigid bicyclic molecules, the direction of hydroboration can readily be interpreted in terms of the steric environment of the double bond.[8b] However, the situation is more complex in flexible cyclic systems, where ready interconversion of the ring system complicates the interpretation.[11] Fortunately, there are reasons for believing that hydroboration can minimize the ambiguities involved in interpreting the results realized with such systems.[12]

As was mentioned earlier, the hydroboration of olefins is a highly exothermic process. According to the Hammond postulate,[13] the transition state for such a reaction should resemble the reactants. Consequently, if the attack of the reagent occurs preferentially from the β side, this would indicate that the thujopsene moiety in the transition state exists preferentially in the steroidal conformation, and might imply that this steroidal conformation I is actually preferred in the ground state.[14]

It appeared appropriate therefore to establish the steric course of the hydroboration of thujopsene. In the course of this study we prepared and characterized all of the possible 3-thujopsanols and 3-thujopsanones.

Hydroboration of (−)-Thujopsene (1).—(−)-Thujopsene (1) on hydroboration, followed by alkaline hydrogen peroxide oxidation, gave only a single alcohol, confirmed by a detailed glpc examination and by a characteristic pmr spectrum, quite different from the spectra of the other three possible isomeric alcohols synthesized in the present study. Since the addition of diborane to the double bond is cis and the replacement of boron by hydroxyl in the oxidation proceeds with the retention of configuration,[15] the single alcohol obtained must be either 3-thujopsanol (2) or 3-isothujopsanol (4) depending upon whether the attack of diborane is from the β side or α side (Scheme I, a or b).[16]

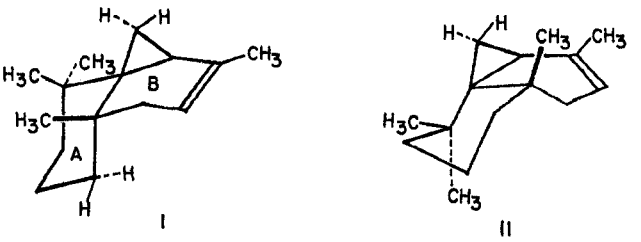
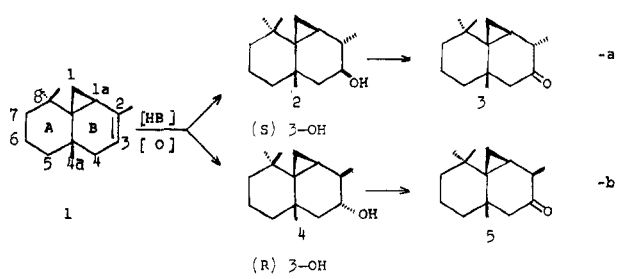


Figure 1.—Possible conformations of thujopsene.

SCHEME I
HYDROBORATION OF THUJOPSENE TO GIVE TWO POSSIBLE ALCOHOLS AND SUBSEQUENT OXIDATION TO TWO KETONES



Treatment of the alcohol with α-phenylbutyric anhydride left an excess of (−)-2-phenylbutyric acid behind, indicating the *S* configuration for the carbinol moiety in accordance with Horeau's rule.[17]

The absolute configuration of thujopsene has been firmly established[18,19] and is as shown in Scheme I. cis-Hydration of the double bond, a well established characteristic of hydroboration–oxidation, would require either the formation of 3-thujopsanol (2) with the *S* configuration, at the carbinol carbon atom, if the reaction had taken place from the β side, or the formation of 3-isothujopsanol (4) with the *R* configuration at the carbinol carbon atom, if the hydration had taken place from the α side. Horeau's method therefore indicates that the hydroboration–oxidation had taken place from the β side, and the hydroboration–oxidation alcohol is 3-thujopsanol (2).

It is interesting to note that, in our previous studies of the hydroboration of 2-carene,[10a] 3-carene[20] hydroboration had always taken place on the side away from the side of the cyclopropane ring, in contrast to the present case.

Oxidation of the alcohol by the chromic acid–ether procedure[21] gave only a single ketone. The ketone on reduction with lithium trimethoxyaluminum hydride afforded the isomeric alcohol, 3-neothujopsanol (11), and 3-thujopsanol in the ratio of 96:4 and with lithium

(9) H. C. Brown, "Hydroboration," W. A. Benjamin, New York, N. Y. 1962.

(10) (a) S. P. Acharya and H. C. Brown, *J. Amer. Chem. Soc.*, **89**, 1925 (1967); (b) S. P. Acharya, H. C. Brown, A. Suzuki, S. Nozawa, and M. Itoh, *J. Org. Chem.*, **34**, 3015 (1969).

(11) E. L. Eliel, "Stereochemistry of Carbon Compounds," McGraw Hill, New York, N. Y., 1962.

(12) J. Klein, E. Dunkelblum, and D. Avrahami, *J. Org. Chem.*, **32**, 935 (1967).

(13) G. S. Hammond, *J. Amer. Chem. Soc.*, **77**, 3341 (1955).

(14) One of the referees objected strongly to this suggestion. He took the position that the Curtin–Hammett principle made it impossible to conclude which conformer of thujopsene is preferred in the ground state from the hydroboration results which reveal which conformer possesses the lower transition state. The Curtin–Hammett principle is not applicable to a situation where the energy of activation for the interconversion of conformers is larger than the activation energy for the reaction the system is undergoing.[11] Unfortunately, precise data are lacking for the present situation. However, we believe that a reasonable case may be made that this is indeed the case for the hydroboration of thujopsene and related interconverting olefins.

The activation energy for the interconversion of cyclohexane and its derivatives is of the order of 10–11 kcal/mol.[11] No data is available for thujopsene, but there appears to be no reason to anticipate that it will be much smaller than this, and it might even be higher.

The activation energies for bimolecular reactions which proceed at a reasonable rate at ordinary temperatures can be quite low. For example, the value for the reaction of methyl iodide and triethylamine in nitrobenzene solution is 9.7 kcal/mol [K. J. Laidler and C. N. Hinshelwood, *J. Chem. Soc.*, 858 (1938)]. The reaction of diborane with olefins in ether solvents is enormously fast. We early observed that the reaction was over in a matter of seconds at 0°, far too fast for us to measure.[9] Consequently, it is not unreasonable that the activation energy for the hydroboration step may be less than that for the interconversion stage. In any event, in the absence of contradictory data, it appears reasonable to consider this possibility. See also ref 12 and G. Zweifel and J. Plamondon, *J. Org. Chem.*, **35**, 898 (1970).

(15) H. C. Brown and G. Zweifel, *J. Amer. Chem. Soc.*, **83**, 2544 (1961).

(16) The numbering system followed is in accordance with the generic name for thujopsene, 1,1a,4,4a,5,6,7,8-octahydro-2,4a,8,8-tetramethylcyclopropa[*d*]naphthalene, as given in *Chem. Abstr.* However, the trivial name thujopsene is retained throughout this article for convenience. The prefix iso is used to indicate that the cyclopropyl and 2-methyl are cis to each other and neo is used to indicate that 3-hydroxy and 2-methyl are cis to each other. See discussion in ref 10b.

(17) A. Horeau and B. Kagen, *Tetradedron*, **20**, 2431 (1964).

(18) C. Enzell, *Acta Chem. Scand.*, **16**, 1553 (1962).

(19) W. G. Dauben and P. Oberhänsli, *J. Org. Chem.*, **30**, 3947 (1965).

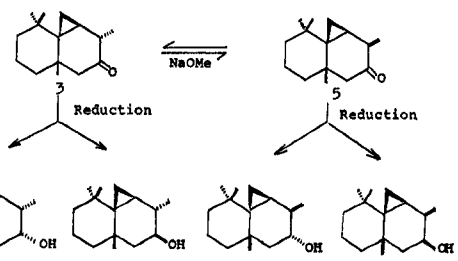
(20) H. C. Brown and A. Suzuki, *J. Amer. Chem. Soc.*, **89**, 1933 (1967).

(21) H. C. Brown and C. P. Garg, *ibid.*, **83**, 2952 (1961).

aluminum hydride in the ratio 81:19 (Scheme II). There was no contamination of the product with 3-isothujopsanol (**4**) or 3-neoisothujopsanol (**8**), indicating the stereoselectivity of both the hydroboration and the oxidation stages.

SCHEME II

REDUCTION AND INTERCONVERSION OF 3-THUJOPSANONE AND 3-ISOTHUJOPSANONE



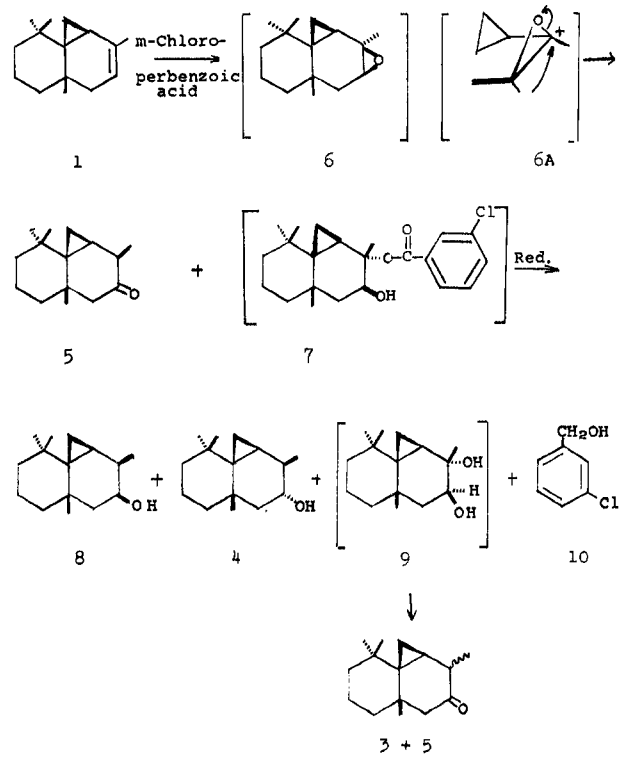
	11	2	4	8
$LiAlH_4$	81	19	65	35
$LiAl(OCH_3)_3H$	96	4	48	52

The ketone epimerized during glpc examination but was established to be essentially a single substance by the pmr spectrum. It also underwent epimerization to 3-isothujopsanone (**5**) in the presence of sodium methoxide in methanol to reach an about 50:50 equilibration of the two ketones by pmr analysis, indicating that the two ketones possess nearly equal ground state energies.

Epoxidation of (−)-Thujopsene (1).—The isomerization of epoxides to ketones with boron trifluoride etherate involves a stereospecific hydride shift.[22-24] Epoxidation, like hydroboration, appears also to involve an exothermic process proceeding through a cyclic transition state[25,26] with large steric requirements. Hence it would also be expected to take place on thujopsene from the β side to give a β-epoxide (**6**). We hoped to use the rearrangement of this epoxide with boron trifluoride etherate to obtain 3-isothujopsanone (Scheme III). Surprisingly, when thujopsene was epoxidized with *m*-chloroperbenzoic acid in chloroform at 25 or 0°, the β-epoxide (**6**) could not be obtained. Instead, 3-isothujopsanone (**5**) was realized directly in 72% yield, with 28% of another compound formed, probably 2-hydroxy-3-neoisothujopsanol 2-*m*-chlorobenzoate (**7**). All attempts to prepare the epoxide by modified procedures, such as epoxidation by perphthalic acid, or by benzonitrile–hydrogen peroxide in the presence of potassium bicarbonate,[27] failed. Likewise, all attempts to isolate pure 3-isothujopsanone (**5**) from the mixture of this ketone **5** and the benzoate **7** were futile because of the facile epimerization of the ketone. Hence the mixture was reduced with lithium aluminum hydride. The hydride uptake corresponded to a mixture containing 71% 3-isothujopsanone (**5**) and 29% benzoate (**7**). The reduced product contained 32% a mixture of *m*-chlorobenzyl alcohol (**10**), 3-thujopsanone (**3**), and 3-isothujopsanone (**5**), 44% 3-isothujopsanol (**4**), and 24% 3-neoisothujopsanol (**8**). These new alcohols were isolated as pure products by fractional distillation, followed by preparative glpc. The presence of some ketone mixture **3** and **5** in the reaction product is presumably due to a secondary reaction of the diol (**9**) which is transformed into the ketones *via* ionization of the highly reactive tertiary hydroxyl group.

SCHEME III

EPOXIDATION OF THUJOPSENE WITH *m*-CHLOROPERBENZOIC ACID AND SUBSEQUENT REDUCTION OF THE PRODUCTS



The mixture of **4** and **8** was oxidized by chromic acid–ether procedure[21] to obtain pure (−)-3-isothujopsanone (**5**). This ketone was reduced with lithium trimethoxyaluminohydride and with lithium aluminum hydride to establish the isomer distribution of 3-isothujopsanol (**4**) and 3-neoisothujopsanol (**8**) (Scheme II) formed in these reactions. All the four isomeric alcohols have been isolated in the pure state by preparative glpc. The melting points and the specific rotations of the two ketones, the four alcohols, and some of their corresponding *p*-nitrobenzoates are listed in Table I. Their pertinent pmr data are shown in Table II.

TABLE I

PROPERTIES OF 3-THUJOPSANONES AND 3-THUJOPSANOLS

Compd	Mp, °C	$[\alpha]_D$ (°C)	*c* (CCl_4)
(−)-3-Thujopsanone (**3**)	67–68	−85.5 (27)	13
(−)-3-Isothujopsanone (**5**)	45–46	−127.8 (25)	10
(+)-3-Neothujopsanol (**11**)	38–39	+64.41 (28)	10.9
(+)-3-Thujopsanol (**2**)	113.5–114	+14 (25)	13.4
p-Nitrobenzoate	118–119		
3-Isothujopsanol (**4**)	48–49	0 (26)	10
p-Nitrobenzoate	94–95		
(−)-3-Neoisothujopsanol (**8**)	106–107	−47.9 (26)	8.5
p-Nitrobenzoate	85–86		

It is known that the carbinyl proton of *cis*-2-methylcyclohexanols and of the corresponding steroids exhibits a chemical shift further downfield than that of the

(22) H. B. Henbest and T. T. Wrigley, *J. Chem. Soc.*, 4596 (1957).
(23) D. N. Kirk and V. Petrow, *ibid.*, 4657 (1960).
(24) J. P. Dusza, J. P. Joseph, and S. Bernstein, *J. Org. Chem.*, **28**, 92 (1963).
(25) P. D. Bartlett, *Rec. Chem. Progr.*, **11**, 51 (1950).
(26) H. Kwart and D. M. Hofmann, *J. Org. Chem.*, **31**, 419 (1966).
(27) G. B. Payne, *Tetrahedron*, **18**, 763 (1962).

TABLE II

PERTINENT PMR DATA[a] FOR THE 3-THUJOPSANONES AND 3-THUJOPSANOLS

Compd	2-H	2-CH_3	3-H	4-CH_2	*tert*-Methyls
3-Thujopsanone (3)	140[b]	70.5[e]		(α) 95,[l] (β) 127[l]	37, 66, 70.5
3-Isothujopsanone (5)	154[c]	65[e]		(α) 97,[m] (β) 120[n]	39, 68, 70
3-Thujopsanol (2)		68.5[f]	192[h]		31.5, 60, 66
3-Neothujopsanol (11)		64.5[e]	216[i]		41.5, 55, 64
3-Isothujopsanol (4)		62.5[e]	186.5[j]		46, 54, 64
3-Neoisothujopsanol (8)	141[d]	44.5[g]	231[k]		31.5, 59, 64

[a] All spectra were taken on a Varian A-60 or A-60A instrument. Chemical shift of the protons is expressed in terms of Hz from tetramethylsilane. [b] Quartet, $J \cong 7$ Hz. [c] Quintnet, $J = 7$ Hz. [d] Quartet, $J = 7.2$ Hz. [e] Doublet, $J = 7$ Hz. [f] Doublet, $J = 5$ Hz. [g] Doublet, $J = 7.2$ Hz. [h] Broad quartet, $J \cong 8$ Hz. [i] Doublet of triplet, $J = 8$ and 4 Hz. [j] Doublet of triplet, $J = 4.5$ and 8 Hz. [k] Doublet of doublet of doublet, $J = 12$, 8, and 4.5 Hz. [l] Doublet, $J = 14$ Hz. [m] Broad doublet, $J = 16$ Hz. [n] Doublet, $J = 16$ Hz.

trans-2-methyl isomers.[28,29] This can also be applied to the 3-thujopsanols, since the chemical shift of C-3 H of neothujopsanol is at 216 Hz and that of thujopsanol is at 192 Hz. The configurations of the two isomeric alcohols of the iso series were therefore assigned on the same basis. That is, the alcohol with a chemical shift of the carbinyl proton at 231 Hz is 3-neoisothujopsanol (**8**), and the one with this proton appearing at 186.5 Hz is the trans isomer, 3-isothujopsanol (**4**). The observed coupling constants of the carbinyl protons suggest that probably the hydroxy groups of all the four alcohols are equatorial if the B rings have half-chair conformations.

Conclusions

Both hydroboration and epoxidation of thujopsene evidently take place exclusively from the β side of the molecule. Both reactions are highly exothermic processes, suggesting that the transition states resemble the reactants.[13] It follows that the thujopsene moiety in the transition state must resemble the steroidal conformation of thujopsene I, rather than the nonsteroidal conformation II.

It is desirable to extend such studies to other exothermic processes involving reagents of large steric requirements. If the results exhibit a consistent pattern of behavior, predominant or exclusive reaction from the β side of the molecule, it would suggest that conformational preferences in the ground state are probably carried over into the transition state for reactions of this kind. Consequently, we may have a tool to explore for such flexible systems the conformational preferences in both the ground and the transition states.

Experimental Section

Materials.—(−)-Thujopsene, obtained from International Flavors and Fragrances, Inc., had $[\alpha]D$ −96.59° (neat) and was pure by glpc. The melting points are corrected and the boiling points are uncorrected. Ir spectra were taken on Perkin-Elmer 21, Serial No. 120. All pmr spectra were determined in carbon tetrachloride solution using tetramethylsilane as internal standard, added after the spectra was taken, on a Varian A-60 or A-60A spectrometer. Optical rotations were determined at room temperature (25–30°) in carbon tetrachloride solutions on a Carl Zeiss polarimeter.

(+)-3-Thujopsanol (2).—The apparatus consisted of a round-bottom flask fitted with a side arm stoppered by a serum cap, a thermometer and a reflux condenser, containing at the top a nitrogen inlet and outlet connected to a gas flow meter. In this flask, previously flame dried and flushed with nitrogen, was placed 21.4 ml of (−)-thujopsene (20.4 g, 100 mmol) in 40 ml of THF. Diborane in THF (60.6 ml of 1.66 *M*, 100 mmol of BH_3) was added at 0° with stirring. The reaction mixture was stirred for 2 hr at 0° and 3 hr at 25°. The excess of hydride was decomposed with water (2 ml) in THF (10 ml). From the hydrogen evolved, 105 mmol of hydride had been utilized for the 100 mmol of thujopsene. Thus, the cyclopropane ring had not been attacked. Oxidation with sodium hydroxide (20 ml of 3 *M*) and hydrogen peroxide (20 ml of 30%) and subsequent isolation gave 21.4 g (96.3% yield) of the compound. It was purified by elution with pentane and ether on neutral alumina (200 g of grade II). The ether eluent gave only a single isomeric alcohol, as indicated by glpc examination with a 150 ft × 0.01 in. Carbowax 20M column on a Perkin-Elmer Model 226, and with a 10 ft column of 20% Carbowax 20M on Chromosorb W on an F & M Model 300 gas chromatograph. An analytical sample had mp 113–114°: $[\alpha]^{25}D$ +14° (*c* 13.45, CCl_4); ir 3401 (O—H), 1379 [$C(CH_3)_2$], and 1031 cm^{-1} (—OH or cyclopropane).

Anal. Calcd for $C_{15}H_{26}O$: C, 81.02; H, 11.79. Found: C, 81.02; H, 12.00.

3-Thujopsanol *p*-Nitrobenzoate.—The following procedure was used to prepare the *p*-nitrobenzoates. 3-Thujopsanol (0.055 g, 0.25 mmol) was placed in a previously flame-dried test tube flushed with nitrogen. Then 0.2 ml of THF, 0.16 ml of 1.60 *M* *n*-butyllithium (0.25 mmol), and 0.25 ml of a 1.60 *M* solution of *p*-nitrobenzoyl chloride in THF were added in succession at 0°; the mixture was kept for 2 hr at 25°. It was eluted on neutral alumina (0.5 g of grade II) with ether, giving 0.065 g of the compound, mp 118–119°.

Anal. Calcd for $C_{22}H_{29}NO_4$: C, 70.75; H, 8.37. Found: C, 70.65; H, 8.42.

(−)-3-Thujopsanone (3).—The following procedure is representative of the two-phase oxidations which were carried out. In a 250-ml three neck flask, fitted with a mechanical stirrer, a dropping funnel, and a thermometer, was placed 100 ml of ether and 5.55 g of 3-thujopsanol (**2**) (25 mmol). To this vigorously stirred solution maintained at 0° was added over 10 min 25 ml of a chromic acid solution [prepared from 4 g of sodium dichromate dihydrate (13.5 mmol) and 5.4 g of sulfuric acid (55 mmol) and sufficient water to make 25 ml of the solution]. The solution was stirred for 30 min, and 25 ml of water, previously cooled to 0°, was added. The lower layer was transferred into another flask containing 25 ml of ether at 0°. The combined ether extracts were washed with cold water (2 × 10 ml), bicarbonate solution (5 × 5 ml), and brine (5 ml), and then dried and evaporated to give 4.9 g (85% yield) of 3-thujopsanone. The sample, purified by sublimation at 70° (1 mm), exhibited mp 67–68°: $[\alpha]^{27}D$ −85.5° (*c* 13, CCl_4); ir 1725 cm^{-1} (C=O).

Anal. Calcd for $C_{15}H_{24}O_2$: C, 81.76; H, 10.98. Found: C, 81.64; H, 11.06.

Equilibration of (−)-3-Thujopsanone (3).—(−)-3-Thujopsanone (2.2 g, 10 mmol) was added to a solution of 0.056 g of sodium methoxide (10 mmol) in 10 ml of methanol at 0° and maintained under nitrogen for 5 hr at 25°. The solution was then diluted with water, acidified with dilute phosphoric acid, saturated with sodium chloride, and extracted with pentane. The pentane extract was dried over magnesium sulfate and distilled, giving 2.03 g of the product, which on glpc examination (10 ft × 0.25 in. of 10% Carbowax 20M on Chromosorb W or on a 150 ft × 0.01 in Carbowax 20M column) showed a single peak. However, the pmr spectrum showed it to be a mixture of 50% 3-thujopsanone (**3**) and 50% isothujopsanone (**5**). The area by weight of the singlet at 41.5 Hz or the doublet at 128 Hz (J = 14 Hz) (**3**) and the singlet at 32.5 Hz or the doublet at 123 Hz

(28) E. L. Eliel, M. S. Gianni, Th. H. Williams, and J. B. Stothers, *Tetrahedron Lett.*, 741 (1962).

(29) J. W. ApSimon, W. G. Craig, P. V. Demarco, D. W. Mathieson, L. Saunders, and W. B. Whalley, *Tetrahedron*, **23**, 2339 (1967).

(J = 16 Hz for (5), all of which appear as single peaks, were used to establish the per cent of each ketone present in the product.

(+)-3-Neothujopsanol (11).—The reagent, lithium trimethoxyaluminohydride, was prepared in the usual manner by adding 3 mol of methanol to 1 mol of lithium aluminum hydride in THF.[30]

To such a solution containing an excess of reagent was added 0.44 g of 3-thujopsanone (3) (2 mmol), dissolved in 3 ml of THF, over 15 min at 0–5°. The excess of the reducing agent was destroyed by adding carefully 0.5 ml of water in 1 ml of THF. The thick white precipitate of aluminum hydroxide was treated with saturated solution of potassium sodium tartarate (15 ml), the upper THF layer separated, and the lower layer extracted with ether. The combined extract was washed with brine solution, dried over magnesium sulfate, and distilled, giving 0.418 g of the product, bp 140–145° (bath) (1.5 mm). Glpc analysis (10 ft × 0.25 in. column of 20% Carbowax 20M on Chromosorb W) indicated it to be a mixture containing 95.6% 3-neothujopsanol and 4.4% 3-thujopsanol. A pure sample of the alcohol was separated on the above column and sublimed: mp 38–39°; $[\alpha]^{26}D$ +64° (c 10.9, CCl_4); ir (CCl_4) 3425 (OH), 1375 [$C(CH_3)_2$] 1031 (—OH), and 958 cm^{-1} (cyclopropane).

Anal. Calcd for $C_{15}H_{26}O$: C, 81.02; H, 11.79. Found: C, 80.89; H, 11.94.

Epoxidation of (−)-Thujopsene (1).—To a vigorously stirred solution of 20.4 g of thujopsene (100 mmol) in 75 ml of chloroform was added 23.6 g of m-chloroperbenzoic acid (80% pure, 110 mmol) dissolved in 300 ml of chloroform over 25 min at 20–23°. The reaction mixture was followed by glpc. Thujopsene was absent as soon as the addition was over. The reaction mixture was cooled to −15° and filtered. The filtrate was washed with 5% sodium hydroxide (four 20-ml portions), brine (two 20-ml portions), and water, giving 25.5 g of thick turbid liquid. The pmr of the product indicated it to be a mixture of 3-isothujopsanone (5) (identified by its characteristic peaks at 32.5, 115, and 131 Hz) and of the m-chlorobenzoate ofthe alcohol (7) [identified by peaks at 449 and 480 Hz (multiplets) due to the aromatic protons and a broad quartet at 205 Hz (J = 7 Hz) due to HC(OH)]. The product is free from 3-thujopsanone, the ketone obtained by hydroboration–oxidation, as indicated by the absence of peaks at 41.5, 121, and 135 Hz. The integrated area of the aromatic protons due to m-chlorobenzoate (7) and that of the peaks appearing between 0–0.40 Hz due to methyl and cyclopropane protons of 3-isothujopsanone (5) gave the distribution 28% m-chlorobenzoate (7) and 72% ketone (5).

A number of attempts to separate 3-isothujopsanone (5) from the m-chlorobenzoate (7) failed. Distillation (even at 0.01 mm) decomposed the m-chlorobenzoate and epimerized 3-isothujopsanone to a 50:50 mixture with 3-thujopsanone. Sublimation at 60° (bath) (0.01 mm) also decomposed the ester and epimerized the ketone. Preparative glpc also gave the same mixture. Column chromatography over neutral alumina and elution with pentane gave a 50:50 mixture of the ketones which was completely free from the m-chlorobenzoate. A rapid filtration through alumina also gave the same mixture.

Reduction of the Mixture of 3-Isothujopsanone (5) and the m-Chlorobenzoate (7).—In a round-bottom flask fitted with a magnetic stirring bar, a reflux condenser, a nitrogen inlet, and a gas measuring meter, was placed 35 ml of 1.51 M lithium aluminum hydride in THF (212 mmol of hydride). The mixture of ketone and benzoate, 15 g, in 20 ml of THF was added in 2 hr to this excess of lithium aluminum hydride in THF and left overnight at 25°. The excess of hydride was destroyed with 50:50 water–THF. The hydrogen recovered revealed that the mixture had utilized 94 mmol of hydride, corresponding to the presence of 71% ketone (42.4 mmol) and 29% m-chlorobenzoate (17.2 mmol). This agrees with the pmr analysis 28% 7 as mentioned before. A saturated solution, 35 ml, of sodium potassium tartarate was added and the reaction mixture was worked up as described for 11, giving 13.9 g of the product. The glpc analysis on a 4 ft × 0.25 in. column of 20% Carbowax 20M on Chromosorb W indicated it to be a mixture of three components, namely, 32% A, 44% B, and 24% C. This mixture was distilled and separated into several fractions.

3-Isothujopsanol (4) and (−)-3-Neothujopsanol (8).—Fraction 5 was used to separate A and B which are, respectively, 4 and 8 by glpc at 200° on a 10 ft × 0.25 in. column of 20% Carbowax 20M on Chromosorb W. The separated components were recycled and purified by sublimation. 3-Isothujopsanol (4), component B, exhibited mp 48–49°, $[\alpha]^{26}D$ 0° (c 10, CCl_4); ir 3300 (O–H), 1379 [$C(CH_3)_2$] 1031 (–OH), and 1012 cm^{-1} (cyclopropane).

Anal. Calcd for $C_{15}H_{26}O$: C, 81.02; H, 11.79. Found: C, 80.87; H, 11.76.

3-Isothujopsanol p-nitrobenzoate had mp 94–95°.

Anal. Calcd for $C_{22}H_{29}NO_4$: C, 71.13; H, 7.86. Found: C, 70.94; H, 7.90.

(−)-3-Neoisothujopsanol (8) had mp 106–107°; $[\alpha]^{26}D$ −49.9° (c 8.5, CCl_4); ir 3356 (O–H), 1379 [$C(CH_3)_2$], 1036 (–OH), 1029 cm^{-1} (cyclopropane).

Anal. Calcd for $C_{15}H_{26}O$: C, 81.02; H, 11.79. Found: C, 80.62; H, 11.60.

3-Neoisothujopsanol p-nitrobenzoate had mp 85–86°.

Anal. Calcd for $C_{22}H_{29}NO_4$: C, 71.13; H, 7.86. Found: C, 71.34; H, 8.00.

(−)-3-Isothujopsanone (5).—Fraction 8 was chromatographed on alumina to separate A from the mixture of B and C. This mixture (0.271 g, 1.23 mmol) containing 60% 3-isothujopsanol (4) and 40% 3-neoisothujopsanol (8) was oxidized, as described earlier for 3, giving 0.24 g (88%) of 5. The ketone was purified by sublimation: mp 45–46°; $[\alpha]^{25}D$ −128° (c 10, CCl_4). The pmr spectrum indicated that it is free from 3-thujopsanone (3).

Anal. Calcd for $C_{15}H_{24}O$: C, 81.76; H, 10.98. Found: C, 81.65; H, 10.88.

Reduction of (−)-3-Thujopsanone (3) and (−)-3-Isothujopsanone (5) with Lithium Trimethoxyaluminohydride.—(−)-3-Thujopsanone (3) (52 mg) or (−)-3-isothujopsanone (0.56 mg) were individually added to a solution of lithium aluminum hydride in THF (200 ml, 1.6 M) or a solution of lithium trimethoxyaluminohydride in THF (1 ml, 1.5 M) and left overnight. All four reaction mixtures were worked up as described previously and tested for the distribution of the isomeric alcohols. The results are summarized in Table III.

TABLE III

REDUCTION OF (−)-3-THUJOPSANONE (3) AND (−)-3-ISOTHUJOPSANONE (5) WITH $LiAlH_4$ AND $LiAl(OCH_3)_3H$

Ketone	Reducing agent	Composition[a] of 3-thujopsanols Neo-11[b]	3-2[b]	3-Iso-4[c]	3-Neo-iso-8[c]
3	$LiAlH_4$	81	19		
3	$LiAl(OCH_3)_3H$	96	4		
5	$LiAlH_4$			65	35
5	$LiAl(OCH_3)_3H$			48	52

[a] Glpc analysis on 20% Carbowax 20M on Chromosorb W (10 ft × 0.25 in.) at 225°. [b] From thujopsanone. [c] From isothujopsanone.

Epoxidation of Thujopsene by Other Methods.—Thujopsene (2.02 g, 10 mmol), was mixed with potassium bicarbonate (0.2 g, 10 mmol), benzonitrile (1.67 g, 12 mmol), and methanol (6 ml). Then 30% hydrogen peroxide (1.4 g, 12 mmol) was added at room temperature with stirring. Periodically the reaction mixture was tested for thujopsene by glpc. The time and percentage of thujopsene reacted were 5 min, 3%; 45 min, 8.6%; 1.74 hr, 26%; 2.74 hr, 38%; 6.75 hr, 45%. More 30% hydrogen peroxide (0.7 g, 6 mmol) was added. After 18 hr there was present only 22% of residual thujopsene. The reaction mixture was diluted with water and extracted with pentane. The pentane extract was dried, evaporated, and examined by pmr. The residue contained mostly isothujopsanone (5), and probably a small quantity of the Baeyer–Villiger oxidation product of the ketone, indicated by a singlet at 194 cps attributed to the –(O=)C—O—CH_2– grouping. The peaks characteristic of thujopsanone (3) were absent. Analysis by glpc showed it to be a mixture of three products and no further attempt was made to characterize these products.

Thujopsene (2.02 g, 10 mmol) was epoxidized with perphthalic acid (11 mmol) in ether. The pmr analysis of the reaction mixture, after work-up as described earlier, indicated it to contain 3-isothujopsanone (5) and probably the corresponding phthalate ester of the diol (9).

Absolute Configuration of 3-Thujopsanol.—To a solution of 0.444 g of 3-thujopsanol (2) (2 mmol) in 6 ml of dry pyridine was

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

added 2-phenylbutyric anhydride (4 mmol) and the mixture was maintained at room temperature for 18 hr. To this mixture was added 2 ml of water and 2 ml of benzene. After 1 hr, the excess of acid was titrated with 1.0 *M* sodium hydroxide (phenolphthalein). The results indicated that only 40% of esterification had occurred. The slightly alkaline solution was extracted with chloroform (four 15-ml portions) and the extracts were discarded. The aqueous layer was acidified with concentrated hydrochloric acid and extracted with benzene (three 20-ml portions). The benzene extract was washed twice with brine, dried, evaporated, and sublimed, providing (−)-2-phenylbutyric acid, $[\alpha]^{28}D$ −1.5° (*c* 25, CCl_4). (+)-2-Phenylbutyric acid, obtained by the hydrolysis of the 3-thujopsanol 2-phenylbutyrate with aqueous alcoholic potassium hydroxide for 24 hr at reflux, exhibited $[\alpha]^{28}D$ +3° (*c* 25, CCl_4).

Registry No.—**2,** 25966-77-2; 2 *p*-nitrobenzoate, 25966-78-3; **3,** 25966-79-4; **4,** 26039-33-8; **4** *p*-nitrobenzoate, 25966-80-7; **5,** 25966-81-8; **8,** 25966-82-9; **8** *p*-nitrobenzoate, 25966-83-0; **11,** 25966-84-1.

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Addition of Silicon Hydrides to Olefinic Double Bonds. XII. Use of Aminosilicon Hydrides and Silazane Hydrides

W. E. DENNIS AND J. L. SPEIER

Dow Corning Corporation, Research Laboratories, Midland, Michigan 48640

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The addition of aminosilicon hydrides and silazane hydrides to olefins and to dimethylaminodimethylvinylsilane in the presence of chloroplatinic acid was studied. *n*-Butylaminodimethylsilane and hexene-1 formed 2-*n*-butyl-1-*n*-hexyl-1,1,3,3-tetramethyldisilazane which diminished as the reaction proceeded to form *n*-butylaminohexyldimethylsilane. Dialkylaminodimethylsilanes and trisdimethylaminosilane reacted very little, if at all, with olefins. *sym*-Tetramethyldisilazane behaved much like *sym*-tetramethyldisiloxane in having similar reactivity and in forming *sec*-alkyl adducts from pentene-2. Dimethylaminodimethylsilane added to hexene-1 smoothly in the presence of *sym*-tetramethyldisilazane, but not in its absence. Methyl methacrylate, methyl acrylate, allyl chloride, methallyl chloride, or allyl acetate each gave complex mixtures of many products with *sym*-tetramethyldisilazane. Allylamine gave hydrogen. Trisdimethylsilylamine formed the dihexyl adduct, no trihexyl adduct, and products that indicated redistribution of methyl groups and hydrogen on the silicon atoms during the reaction. Poly-*N*-allylmethylsilazane reacted to form a polymer which degraded in methanol to form 2-(dimethoxymethylsilyl)propylamine.

More than 2000 examples of the addition of siloxane, and of halo- or alkoxy-, aryl-, and alkylsilicon hydrides to olefins with platinum catalysts have been described.[1] However, the only report of an aminosilicon hydride adding to an olefin is that of *sym*-tetramethyldisilazane adding to tertiary allyl amines.[2] Chemical and physical data indicate that Si–N bonds of disilazanes and trisilylamines are different from those of monosilylated amines.[3-5] We wished to determine the effect of structure among silicon hydrides that were aminosilanes, silazanes, and trisilylamines on their addition to olefins with chloroplatinic acid as a catalyst. To do this a series of hydrides was prepared. The series included *n*-butylaminodimethylsilane (*n*-BuNHSiMe$_2$H), anilinodimethylsilane (PhNHSiMe$_2$H), dialkylaminodimethylsilanes (R$_2$NMe$_2$SiH, R = Me, Et, *n*-Bu), trisdimethylaminosilane [(Me$_2$N)$_3$SiH], *sym*-tetramethyldisilazane [HN(SiMe$_2$H)$_2$], *sym*-diphenyldimethyldisilazane [HN(SiMePhH)$_2$], and trisdimethylsilyl amine [N(SiMe$_2$H)$_3$]. Chloroplatinic acid in propanol-2 was used as a catalyst with hexene-1 or pentene-1 and pentene-2 as typical olefins. Other unsaturated compounds were also used including poly-*N*-allylmethylsilazane [CH_2=$CHCH_2$–N(–SiHMe)–]$_n$, allylamine, and other allyl or methallyl compounds.

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Results and Discussion

n-Butylaminodimethylsilane with hexene-1 and chloroplatinic acid at 100° reacted smoothly but followed an unexpected course. After 1 hr the chief products were 2-*n*-butyl-1-hexyl-1,1,3,3-tetramethyldisilazane and butylamine. After 3 hr the disilazane had been largely converted to *n*-butylaminohexyldimethylsilane. Formation of these products probably occurred by a sequence of reactions as in the following reactions.

$$2n\text{-BuNHSiMe}_2\text{H} \rightleftharpoons n\text{-BuN(SiMe}_2\text{H)}_2 + n\text{-BuNH}_2$$

$$n\text{-BuN(SiMe}_2\text{H)}_2 \xrightarrow{\text{hexene-1}} n\text{-BuN(SiMe}_2\text{H)SiMe}_2\text{-}n\text{-Hex}$$

$$n\text{-BuN(SiMe}_2\text{H)SiMe}_2\text{-}n\text{-Hex} \xrightarrow{\text{hexene-1}} n\text{-BuN(SiMe}_2\text{-}n\text{-Hex)}_2$$

$$n\text{-BuN(SiMe}_2\text{-}n\text{-Hex)}_2 + \text{BuNH}_2 \longrightarrow 2n\text{-BuNHSiMe}_2\text{Hex}$$

Anilinodimethylsilane under the same conditions formed a 96% yield of anilinodimethylhexylsilane and no intermediate step in its formation was noted.

Dimethylaminodimethylsilane, diethylaminodimethylsilane, and di-*n*-butylaminodimethylsilane under the same conditions formed little or no adducts with hexene-1. However these silanes added very smoothly, although slowly, to hexene-1 if *sym*-tetramethyldisilazane was in the mixture of reagents.

This strange behavior was thought to be the likely consequence of an inability of dialkylaminodimethylsilanes to form a complex with platinum necessary for catalytic activity in such a system. The formation of di-*n*-butylaminohexyldimethylsilane then must have

(5) K. Hedberg, *ibid.*, **77**, 6491 (1955).