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OXIDATIVE TRANSFORMATIONS OF CEMBRANE DITERPENOIDS.

V. REACTION OF CEMBRENE WITH N-BROMOSUCCINIMIDE IN AQUEOUS ACETONE

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and M. M. Shakirov

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The reaction of the diterpene hydrocarbon cembrane with N-bromosuccinimide in aqueous acetone takes place as the addition of the elements of hypobromous acid, leading to products of addition at the C_4-double bond — 5R- and 5S-bromoisocembrols and 5R-bromo-4-epiisocembrol. At the same time, products of the bromination of cembrene — 18-and 5-bromocembrenes — are formed. The structures of the compounds obtained were shown with the aid of chemical transformations and spectral characteristics. Under the action of pyridine, the bromohydrins obtained underwent dehydrobromination with the formation of products having a rearranged cembrane skeleton. The stereochemistry of the cembrane bromohydrins is discussed in connection with the stereochemistry of known addition reactions to cembrane and the biogenesis of natural methyl ketones.

It has been shown previously that electrophilic addition to the double bonds of cembrane (I) takes place as a highly stereospecific process for epoxidations with peracids [1], for photooxidation [2], and for hydroxylation with potassium permanganate [3]. In order to synthesize new cembrane derivatives and to elucidate the stereochemistry of the addition of electrophilic particles of comparatively small volume to the cembrane molecule, we have investigated the products of the reaction of cembrene with N-bromosuccinimide in aqueous acetone. The reactions of olefins with this reagent in polar solvents take place as the addition of the elements of hypobromous acid [4]. Since the first stage of the reaction is an electrophilic attack by the bromonium ion, then, in addition to the normal products of addition to double bonds, cyclization products may be obtained. This is frequently observed in the case of such complex substrates as terpenoids, and the occurrence of cyclization may be considered as modeling biosynthetic transformations [5].

When the reaction was performed under the conditions usually used [4] with a molar ratio of cembrene and N-bromosuccinimide of 1:1.2, we obtained a mixture in which, in addition to unchanged cembrane, substances of hydrocarbon nature similar to cembrene, and highly polar compounds, there were three products with R_f 0.58, 0.47, and 0.36 (Silufol, using petroleum ether containing 20% of diethyl ether as the mobile phase). The product with R_f 0.58 was the main component of the reaction mixture. During ordinary column chromatography on silica gel, this compound decomposed, giving a mixture of substances the predominating component of which coincided according to TLC with the initial compound but

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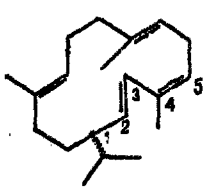
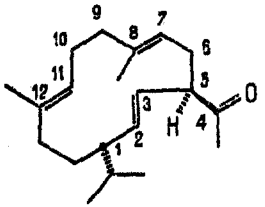
differed from it by the coloration of the spot. This decomposition product had the empirical formula $C_{20}H_{30}O$ (high-resolution mass spectrometry), and the absence of a bromine atom from its molecule was confirmed by the results of elementary analysis. It was a ketone (IR spectrum: 1720 cm^{-1}) containing a double bond in the β position to the keto group (and the UV spectrum, the value of ε at λ_{max} 282 nm was 195 [6]). The structured formula (II) of the product obtained followed from its PMR spectrum taking into account information from the IR and UV spectra. In the PMR spectrum (200 MHz, in deuterochloroform), the signals of the protons present in the C_2—C_3—C_5—C_6—C_7 system of atoms was observed (H_2 — doublet of doublets at 5.32 ppm, $J_{1,2}$ = 8 Hz, $J_{2,3}$ = 15 Hz; H_3 — doublet of doublets at 4.95 ppm, $J_{2,3}$ = 15 Hz, $J_{3,5}$ = 9 Hz; H_5 — doublet of doublets of doublets at 3.07 ppm, $J_{5,5}$ = 9 Hz, $J_{5,6a}$ = 12 Hz, $J_{5,6b}$ = 4 Hz; H_{6a} — doublet of doublets of doublets at 2.43 ppm, $J_{6a,6b}$ = 13 Hz, $J_{6a,5}$ = 12 Hz, $J_{6a,7}$ = 10 Hz; H_7 — doublet of doublets of multiplets, $J_{7,6a}$ = 10 Hz, $J_{7,6b}$ = 4.0 Hz). The assignments were conformed by double-resonance experiments. The protons of a methyl ketone group give a characteristic singlet at 2.15 ppm [7], and the protons of methyl groups at double bonds and the H_{11} protons appear in the spectrum as subdivided singlets and a multiplet, respectively, at 1.53, 1.56, and 4.90 ppm.



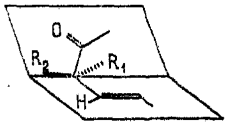
I



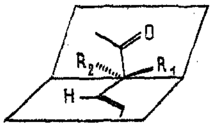
II

On reduction with lithium tetrahydroaluminate in diethyl ether, the ketone (II) gave a mixture (~1:1, TLC) of the corresponding epimeric secondary alcohols (IR spectrum: 3620 cm^{-1}), which were reconverted into the ketone (II) when they were oxidized with chromium trioxide in pyridine.

The absolute configuration of the asymmetric center at C_5 in the ketone (II) was established as R on the basis of the following facts. It is known [8] that on the ORD and CD curves asymmetric β-enones give a strong Cotton effect due to the n—π^* transition in the keto group, the sign of which is determined by the mutual orientation of the ketone group and the neighboring double bond. On the ORD curve of ketone (II) a strong negative Cotton effect is observed ($[M]_{268}$ + 11300°, $[M]_{297}$ 0°, $[M]_{315}$ — 7960°, for a solution in chloroform), which shows that the methyl ketone group is orientated predominantly with respect to the double bond as shown in A [8] or B [9].



A

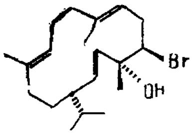


B

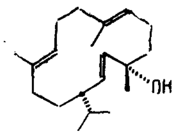
On the other hand, the large value of the spin-spin coupling constant between the H_3 and H_5 protons (9 Hz) shows that the dihedral angle formed by the fragment H_3—C_3—C_5—H_5 is definitely greater than 90° and amounts to about 145° [10]. In conformations A and B, consequently, R_1 corresponds to the hydrogen atom and R_2 to the residue of the ring. In both cases, at R_1 = H the asymmetric center of ketone (II) at C_5 has the R configuration.

The use of preparative TLC (silica gel + 20% of gypsum, with petroleum ether containing 5% diethyl ether as the eluent) on small (9 × 12 cm) plates proved to be successful for the isolation of the primary products of the reaction of cembrane with N-bromosuccinimide. In this way it was possible to isolate pure samples of the substances with R_f 0.58 and 0.47. The substance with R_f 0.36 proved by itself to be stable in relation to silica gel if it was not in contact with the products of the decomposition of the first two substances. This was utilized for its isolation by the rapid passage of the mixture of products through a column of silica gel, the collection of the fraction with the substance having R_f 0.36, and its rechromatography on silica gel. One of the three compounds formed contained the conjugated diene system that is present in cembrene and a keto group (UV spectra). According to IR spectra, they each contained a hydroxy group and a trans-disubstituted double bond. Elementary analysis indicated the presence of one bromine atom in the molecule of each of them.

In the PMR spectrum of the main product (R_f 0.58) a doublet of doublets (1 H, J = 9.5 and 2.5 Hz) was observed which, according to the value of its chemical shift (4.03 ppm), can be assigned to a methine proton adjacent to a bromine atom. The hydroxy group is tertiary and is located in the molecule adjacent to the tertiary C_4-methyl group, the protons of which appear in the PMR spectrum in the form of a singlet at 1.31 ppm. This interpretation of the PMR spectrum and the structure (III) that can be suggested for the compounds under investigation were confirmed by the formation of 4-epiisocembrol (IV) [11] on its debromination with tri-n-butylstannane in benzene.



III



IV

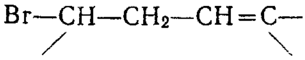
With the aid of double resonance, in the PMR spectrum (100 MHz) of the bromohydrin (III) a system of protons  $Br{-}CH{-}CH_2{-}CH{=}C{\underset{\diagdown}{\overset{}{-}}}$, located at C_5–C_6–C_7 (H_5, H_{6a}, H_{6b}, H_7 – at 4.03, 2.84, 2.60, and 5.12 ppm, respectively, with $J_{5,6a}$, $J_{5,6b}$, $J_{6a,6b}$, $J_{6a,7}$, and $J_{6b,7}$ = 9.5, 2.5, 15, 7, and 7.5 Hz) was isolated. However, from the formal point of view it is impossible from the PMR spectrum alone to distinguish compound (III) from its isomer with the bromine atom at C_9. A comparison of the ^{13}C NMR spectrum of compound (III) with the published [12] ^{13}C NMR spectrum of 4-epiisocembrol (4-epithunbergol) (IV) (Table 1) proved to be sufficiently informative in this respect. While the signals of the C_9 and C_8 atoms scarcely change their position on passing from (IV) to (III), for the C_5 atom the expected [13] downfield shift due to the appearance of a bromine atom near it is observed.

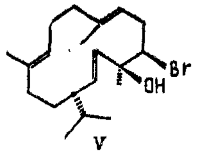
TABLE 1. Chemical Shift of the Carbon Atoms in the ^{13}C NMR Spectra of the Bromohydrin (III) and of 4-Epiisocembrol (internal standard TMS)

No. of the carbon atom	δ_{III}	δ_{IV}	$\delta_{III}-\delta_{IV}$
3	135,9 s*	138,9	- 3,0
12	132,9d	132,7	+0,2
8	132,4s	132,4	0
7	131,1d	127,9	+3,2
2	124,4d	126,9	—2,5
11	123,7d	124,4	—0,7
4	74,4s	73,8	+0,6
5	69,6d	44,1	+25,5
1	46,3d	46,2	+0,1
13	39,1t	39,1	0
9	37,0t	36,9	+0,1
6	35,7t	23,5	+12,2
15	33,3d	33,1	+0,2
14	27,8t	28,0	—0,2
18	25,0q	29,4	—4,3
10	23,8t	23,7	+0,1
16	20,7q	20,7	0
17	19,5q	19,4	+0,1
20	15,4q	15,1	+0,3
19	14,7q	14,8	—0,1

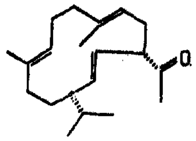
*Arbitrary symbols: s — singlet, d — doublet, t — triplet, q — quartet.

In the molecule of (III), the bromine is present in the β configuration, since only such a figuration can ensure the stereospecific formation of the ketone (II) through the occurrence of an intramolecular S_N2 substitution with the splitting out of HBr. It has been established that this reaction takes place not only on a sorbent but also when a pyridine solution of the bromohydrin (III) is heated. According to the PMR spectrum, the time of half-conversion at 75°C is about 25 min.

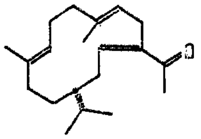
The second product of the reaction of cembrene with N-bromosuccinimide (R_f 0.47) gave isocembrol on debromination with tri-n-butylstannane, and the same ketone (II) on treatment with pyridine (1.5 h at 100°C). Consequently it was 5R-bromoisocembrol (V). The third product (R_f 0.36), as the result of the performance of the same reactions, gave isocembrol and the ketone (VI), epimeric with ketone (II) at C_5. The ketones (II) and (VI) were converted into one and the same conjugated ketone (VII) when they were treated with sodium methanolate in methanol. Consequently, the third product of the reaction of cembrene with N-bromosuccinimide was 5S-bromoisocembrol (VIII) and was formed as the result of the attack of Br^+ on cembrene from the less favorable [1] α side.



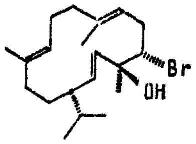
V



VI



VII



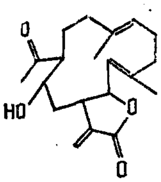
VIII

Thus, all three bromohydrins are normal products of the reaction of cembrene with the elements of the hypobromous acid generated from N-bromosuccinimide in aqueous acetone solution. The predominant attack of Br^+ on the C_4 double bond of cembrene from the β side (products (III) and (V)) is in harmony with results obtained previously on the preferred nature of such a stereochemistry of addition [1-3], but the presence of product (VIII) in the reaction mixture indicates that for such an electrophile as Br^+ attack on the cembrene molecule from the less suitable α side is possible.

According to preparative TLC and PMR spectroscopy, the ratio of compounds (III), (V), and (VIII) in the reaction mixture was 5:1:1. Hence, it may be concluded that the attack of Br^+ on cembrene, leading to hydroxy bromides (bromohydrins) takes place to the extent of ∿86% from the β side and ∿14% from the α side.

The formation of the methyl ketones (II) and (VI) from the bromohydrins (III), (V), and (VIII) was unexpected, since vicinal bromohydrins usually give the corresponding epoxides under the action of bases [14]. 4,5-Epoxycembrene can hardly be an intermediate compound in these transformations, since, as was established in a model experiment, it is stable to pyridine at 100°C and on silica gel it is converted not into the methyl ketone (II) (or (VI)) but into an aldehyde with a contracted cembrene ring and into a ketone forming the product of a 1,2-hydride shift from C_5 to C_4 [1]. In this case, these transformations are analogous to the classical pinacoline rearrangement but differ from this by the fact that the departing group is bromine. The preferential nature of a 1,2-shift of the ring residue over the formation of the epoxide is probably due to the electron-donating properties of the migrating residue of the ring with a trans-disubstituted double bond. The 1,2-migration of a vinyl group has been described for an acid-catalyzed rearrangement of acyclic epoxyolefins [15]. In this case, it is even possible to detect the retention of the trans configuration of the double bond in the migrating ring residue.

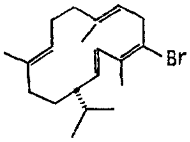
A compound with the same carbon skeleton as ketones (II) and (VI) — the oxo hydroxy lactone (IX) — has recently been found in nature [16]. It is possible that reactions of (III)—(II) type are responsible for the last stages of the biosynthesis of this and other natural terpenoid methyl ketones.



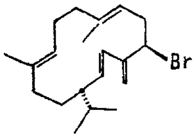
IX

The hydrocarbon fraction of the mixture of the products of the reaction of cembrene with N-bromosuccinimide (it was eluted by petroleum ether alone from a silica gel column) contained, in addition to unchanged cembrene, three components, and these were separated by chromatography. One of them, with mp 72.5-73.5°C, was identified from its spectral characteristics as 5-bromocembrene (X). The same compound was formed as the sole product in the dehydration of the bromohydrin (VIII) with phosphorus oxychloride in pyridine.

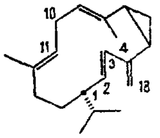
The second component (an oil) contained no bromine atom in its molecule (results of elementary analysis) and had the empirical formula $C_{20}H_{30}$ (mass spectrometry). This compound was obtained together with 5-bromocembrene (X) on the dehydration of the bromohydrin (III) with phosphorus oxychloride in pyridine. This shows that the compound with the empirical formula $C_{20}H_{30}$ was a product of the solvolytic dehydrobromination of the unstable 5-bromoisocembrene (XI) that should be formed in the dehydration of the bromohydrin (III) by phosphorus oxychloride in pyridine (under the same conditions, 4-epiisocembrol gives a mixture of cembrene and isocembrene [11]). IR, UV, and PMR spectroscopy, and also the origin of this compound, permit the assumption for it of structure (XII) with a cyclopropane carbon ring. As in the case of isocembrene [17], the presence of the fragment $C_1{-}C_2{-}C_3{-}C_4{-}C_{18}$ was established by IR, UV, and PMR spectroscopy. The two tertiary methyl groups on double bonds give in the PMR spectrum (200 Hz) subdivided singlets at 1.37 and 1.14 ppm, and the olefinic protons at the same bonds are present in spin—spin interaction with the magnetically nonequivalent protons of the C_{10}-methylene group. The protons of the cyclopropane ring do not give signals in the usual region for them of 0.2-0.6 ppm, which is apparently due to the descreening influence of the neighboring double bonds. The presence of this ring can be assumed by taking into account the IR spectrum, in which they are bands at 837 and 1025 cm^{-1} that are absent from the IR spectrum of isocembrene and are characteristics for cyclopropane [18].



X

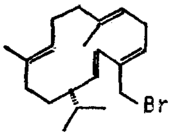


XI



XII

The third product accompanying compounds (X) and (XII) was an allyl bromide with the empirical formula $C_{20}H_{31}Br$ (mass spectrum). Under the action of lithium tetrahydroaluminate it was reduced quantitatively to cembrene. The IR and UV spectra of the compound obtained were similar to those of cembrene, but the PMR spectrum lacked the signal of the C_4-methyl group that is present in the PMR spectrum of cembrene and in place of it an AB system of protons of a CH_2Br group appeared (center at 3.96 ppm, $J_{AB} = 10$ Hz). The signal of the H_5 proton had shifted upfield (5.90 ppm) in relation to its position in the PMR spectrum of cembrene (5.48 ppm [19]). The spectral and chemical results obtained correspond to 18-bromocembrene (XIII). Two mechanisms may be suggested for its formation — radical and ionic. The latter can take place as the result of the solvolytic isomerization of the unstable 5-bromoisocembrene (XI), and the possibility of the former is confirmed by the fact that this bromide is obtained by the reaction of cembrene with N-bromosuccinimide under conditions favorable for radical allyl bromination [20] (in CCl_4 solution with illumination).



XIII

EXPERIMENTAL

PMR spectra (δ scale, HMDS) were recorded on Varian A56/A, HA-100 (for solutions in CCl_4) and Varian XL-200 (for solutions in $CDCl_3$) instruments. The ^{13}C NMR spectrum of substances (III) (in $CDCl_3$, TMS) were obtained on a Bruker HX-90 (22.63 MHz) instrument. The ORD curve of ketone (II) was recorded on a Spectropol I spectropolarimeter. High-resolution mass spectra were obtained in a MS-902 instrument; IR and UV spectra (in CCl_4 and ethanol, respectively, if not otherwise specified), on UR-20 and Specord UV-VIS instruments; optical rotations were measured on a Zeiss polarimeter for solutions in chloroform.

Air-dry silica gel (0.140-0.315 mm) of type KSK was used for chromatography with a ratio of substance and sorbent in all cases of ∿1:20, the eluent being petroleum ether with increasing (from 0 to 100%) concentrations of diethyl ether.

Reaction of Cembrene with N-Bromosuccinimide in Aqueous Acetone. With vigorous stirring and cooling to 0°C, a solution of 5.5 g of N-bromosuccinimide in 80 ml of a 1:1 mixture of acetone and water was added dropwise over 1 h to a solution of 7.00 g of cembrene in 350 ml of acetone. After the end of the addition of the reagent solution, the mixture was allowed to warm up to room temperature, with stirring (1 h), after which 200 ml of a saturated aqueous solution of sodium chloride was added to it and the products were extracted with petroleum ether. The extract was washed with saturated aqueous sodium bicarbonate and was dried with sodium sulfate. After the solvent had been distilled off, 9.12 g of a mixture products was obtained in the form of a pale yellow oil.

To determine the ratio of the bromohydrins (III), (V), and (VIII) that had been formed, a mixture of these three compounds was isolated by preparative TLC from part of the product obtained (spots revealed in UV light after the chromatogram had been sprayed with a methanolic solution of berberine). From the relative integral intensities of the signals of the H_3 protons (for (III), the $H_3 + H_2$ protons) in the PMR spectrum of this mixture the (III):(V):(VIII) ratio was found to be 5:1:1.

By preparative TLC, 0.25 g of the bromohydrin (III) and 0.05 g of the bromohydrin (V) were isolated from 0.60 g of the total mixture.

Column chromatography of 6.50 g of the mixture of products of the reaction of cembrene with N-bromosuccinimide yielded, successively, 1.3 g of a mixture of cembrene and substances (X), (XII), and (XIII), 3.2 g of the ketone (II) with n_D^{26} 1.5038, $[\alpha]_D^{26}$ − 88.2° (c 10.2) (M^+ 288.2399. Calculated for $C_{20}H_{30}O$: 288.2453), and 1.1 g of a mixture of the bromohydrin (VIII) and more polar compounds. The rechromatography of the last fraction yielded 0.13 g of the bromohydrin (VIII) and 0.9 g of unidentified compounds.

Isomerization of Ketone (II) into Ketone (VII). A solution of 0.32 g of the ketone (II) in 15 ml of ethanol was treated with 0.8 ml of an 8% aqueous solution of sodium hydroxide, and the resulting mixture was heated at 40-50°C for 4 h. After the usual working up, 0.31 g of a product was obtained the chromatography of which yielded 0.1 g of unchanged ketone (II) and 0.13 g of ketone (VII) in the form of an oil with n_D^{22} 1.5070, $[\alpha]_D^{22}$ − 64.3° (c 5.91). UV spectrum (in heptane): λ_{max} 228.5 nm (log ε 3.99). IR spectrum: 1640, 1670 cm^{-1} (C=C—C=O). For the PMR spectrum, see Table 2.

5R-Bromo-4-epiisocembrol (III). Oil with n_D^{21} 1.5251, $[\alpha]_D^{21}$ + 64.8° (c 10, 18). IR spectrum, cm^{-1}: 985 (trans-disubstituted C=C), 3580 (OH).

The Ketone (II) from the Bromohydrin (III). The bromohydrin (III) (0.10 g) was heated in 5 ml of pyridine at 65°C for 4 h. The cooled solution was diluted with water and extracted with petroleum ether. After chromatography of the product, 0.06 g of the ketone (II) was obtained and was shown to be identical with an authentic sample by IR and PMR spectroscopy and TLC.

Dehydration of the Bromohydrin (III). With stirring, 0.2 ml of phosphorus oxychloride was added to a solution of the bromohydrin (III) in 5 ml of pyridine cooled to −10°C, and the mixture was left at the same temperature for 2 days. After the usual working up and chromatography, 0.02 g of a mixture of compounds of hydrocarbon nature was obtained (it was eluted from a column by petroleum ether alone) and according to GLC (XE-60 as the liquid phase) it consisted of three components — 5-bromocembrene (19.2%), hydrocarbon (XII) (63.3%), and cembrene (18.5%), these being identified by the method of additives.

TABLE 2. Characteristics of the PMR Spectra of Compounds (V) (100 MHz) and (VI-VIII, X, and XIII) (60 MHz)*

Protons	Number of the compound					
	V	VI	VII	VIII	X	XIII
Me_4	1,34	2,01	2.15	1,28	1,90	3,98 (2H) J_{AB}=10Hz
Me_8, Me_{12}	1.47,1.60	1,50,1,50	1,46,1,46	1,46,1,60	1.50,1,45	1,44,1,53
H_2	5,25 dd (15,0; 8,0)	5,20 m	—	5,33 dd (16,0; 7,0)	5 20 dd (15; 8)	5,34 dd (15,0; 7,5)
H_3	5,62 d (15,0)		—	5,88 d (16,0)	5,93 d (15,0)	5,80 d (15,0)
H_5	4,14 dd (8,0; 3,3)	3,02 m	—	4,20 dd (4,6; 4,0)	—	5,88 dd (8; 6)
H_{6a}	2,94 dm (15)	—	2,4—3,3 m	—	3,71 dd (16; 10)	2,96 ddd (15; 11,5; 6,5)
H_{6b}	2,64 ddd (15; 9; 8)	—		—	3,0 dm (16)	—
H_7, H_{11}	5,0—5,4m	5,60—5,13m	4,5—5,2m	4,7—5,5m	4,8m, 5,12m	4,98m, 4,84m

*Arbitrary symbols: d — doublet; m — multiplet; dd — doublet of doublets, and so on. Values of the spin—spin coupling constants (Hz) are given in parentheses and above them the chemical shifts (ppm).

5R-Bromoisocembrol (V). Oil with n_D^{20} 1.5290, $[\alpha]_D^{20}$ — 69.5° (c 2.3). IR spectrum, cm^{-1}: 3620 (OH), 980 (trans-disubstituted C=C). For the PMR spectrum, see Table 2. It was wholly converted into the ketone (II) when its solution in pyridine was heated at 100°C for 1.5 h.

5S-Bromisocembrol (VIII). Oil with n_D^{20} 1.5300, $[\alpha]_D^{20}$ + 56.4° (c 8.16). IR spectrum, cm^{-1}: 3620 (OH), 980 (trans-disubstituted C=C). For its PMR spectrum, see Table 2.

Reduction of the Bromohydrin (III) with Tri-n-Butylstannane. A solution of 0.13 g of the bromohydrin (III) and 0.5 ml of tri-n-butylstannane in 15 ml of benzene was irradiated with the light of a high-pressure mercury lamp (DRSh-500) for 30 min with the passage of a current of argon through the solution, which was contained in a quartz cell. Chromatography of the product yielded 0.08 g of 4-epiisocembrol (IV), the IR and PMR spectra of which coincided with those for an authentic sample.

The debromination of the bromohydrins (V) and (VIII) was carried out similarly.

The Ketone (VI). A solution of 0.10 g of the bromohydrin (VIII) in 5 ml of pyridine was heated at 100°C for 1.5 h. After the usual working up and chromatography, 0.06 g of the ketone (VI) was obtained in the form of an oil with n_D^{25} 1.5068 and $[\alpha]_D^{25}$ — 19.9°. For the PMR spectrum, see Table 2. The mass spectrum practically coincides with that of the ketone (II).

The Bromocembrenes (X) and (XIII). The chromatography on silica gel of 1.3 g of the mixture of cembrene and substances (X), (XII), and (XIII) obtained as described above yielded a mixture could not be separated on this sorbent, of cembrene and compounds (X) and (XII) and also 0.26 g of 18-bromocembrene (XIII) in the form of an oil with n_D^{24} 1.5420, $[\alpha]_D^{20}$ + 192.08° (c 3.91). M^+ 350, 352 ($C_{20}H_{31}Br$). UV spectrum: λ_{max} 243 nm (log ε 3.84). For its PMR spectrum, see Table 2.

Rechromatography of the unresolved mixture on silica gel with 5% of silver nitrate yielded 0.65 g of cembrene, 0.17 g of 5-bromocembrene, and 0.12 g of the hydrocarbon (XII).

5-Bromocembrene (X) formed crystals with mp 72.5-73.5°C (from ethanol), $[\alpha]_D^{20}$ + 170° (c 1.0). M^+ 350, 352 ($C_{20}H_{31}Br$). UV spectrum: λ_{max} 254 nm (log ε 4.23). For the PMR spectrum, see Table 2.

The Hydrocarbon (XII). Oil with $[\alpha]_D^{23}$ + 214° (c 2.99). M^+ 270 ($C_{20}H_{30}$). UV spectrum (in heptane): λ_{max} 239 nm (log ε 4.36). IR spectrum, cm^{-1}: 980 (trans-disubstituted C=C), 895, 1655, 3090 (—C═CH$_2$), 837, 1025, 3020 (cyclopropane ring). PMR spectrum (200 MHz), ppm: 0.78, 0.82 (3 H each, doublets with J = 6 Hz each, methyls of an isopropyl group); 1.37, 1.41 (3 H each, singlets, Me$_8$ and Me$_{12}$); 2.31 (2 H, multiplet, superposed signals of H$_{10b}$ and of another allyl proton not present at C$_{10}$); 3.03 (1 H, doublet of doublet of doublets, H$_{10a}$, J$_{10a,10b}$, J$_{10a,9}$, J$_{10a,11}$ = 14.0, 8.5, and 11.0 Hz, respectively); 4.71, 4.68 (1 H each, narrow multiplets, W$_{1/2}$ = 4 Hz each, C═CH$_2$); 4.94 (1 H, doublet, H$_{11}$, J$_{11,10a}$ = 11.0 Hz, components of the doublet broadened, W$_1$/$_2$ = 8 Hz); 5.54 (1 H, triplet (H$_9$, J$_{9,10a}$ = J$_{9,10b}$ = 8.5 Hz); 5.49 (1 H, doublet of doublets, H$_2$, J = 8.5 and 16.0 Hz), 5.93 (1 H, doublet, H$_3$, J$_{3,2}$ = 16.0 Hz).

SUMMARY

The products and stereochemistry of the reaction of cembrene with N-bromosuccinimide in aqueous acetone, which takes place as the selective addition of the elements of hypobromous acid to the C$_4$ double bond of cembrene, have been studied.

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