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Registry No.—**1a,** 49686-55-7; **1b,** 49686-56-8; **2a,** 49686-57-9; **2b,** 49686-58-0; **3,** 24316-19-6; **4,** 49686-59-1; **5,** 49686-60-4; **7,** 49686-61-5; **9,** 49686-62-6.

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(10) (a) S. Asada, *Yakugaku Zasshi,* **93,** 916 (1973). (b) The nmr spectra of McKay's alkaloid G, Asada's alkaloid IV, and our alkaloid **2a** show most of the same major peaks with only minor differences in some of the reported chemical shifts. Strikingly similar are the two doublets (δ 1.44 and 2.64, J = 14.0 Hz) attributed to an isolated methylene group. However, there are considerable differences in the melting points of our sample of **2a** (70–72°), Asada's alkaloid IV (80–82°), and McKay's alkaloid G (131–131.5°). The nmr spectra of the acetate derivatives of all three samples are also nearly identical.

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(20) Leaf and stem samples were collected from a tree in Maryland during Nov 1968. The seed sample came from Italy in 1962.

Oxymercuration–Demercuration of Limonene

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The oxymercuration–demercuration procedure, in aqueous THF, was applied to limonene (1) to investigate the behavior of its two double bonds. It was shown that *cis*-1,8-terpin (*cis*-**7**) and 1,8-cineole (**9**) were produced when a 1:2 limonene–Hg(OAc)$_2$ mole ratio was used. Production of α-terpineol (**5**) together with *cis*-**7** and **9** was observed when the limonene–Hg(OAc)$_2$ mole ratio was reduced (1:1 and 1:0.5). The reactions were very fast and no oxidative side process was evident. Further information on the reactivity of the endocyclic limonene double bond was given by comparison of the behavior of **5** and 1-*p*-menthene under the same reaction conditions. The results indicate that the first hydroxyl group that adds onto the external limonene double bond enhances the reactivity of the internal double bond, promoting a high overall reaction rate. Moreover, the unexpected production of both *cis*-**7** and **9** indicates that, although the first hydroxyl group is in an ideal position to react, *via* a six-membered ring, to give the corresponding cyclic ether **9**, the latter only partially forms, the major product being the corresponding diol *cis*-**7**.

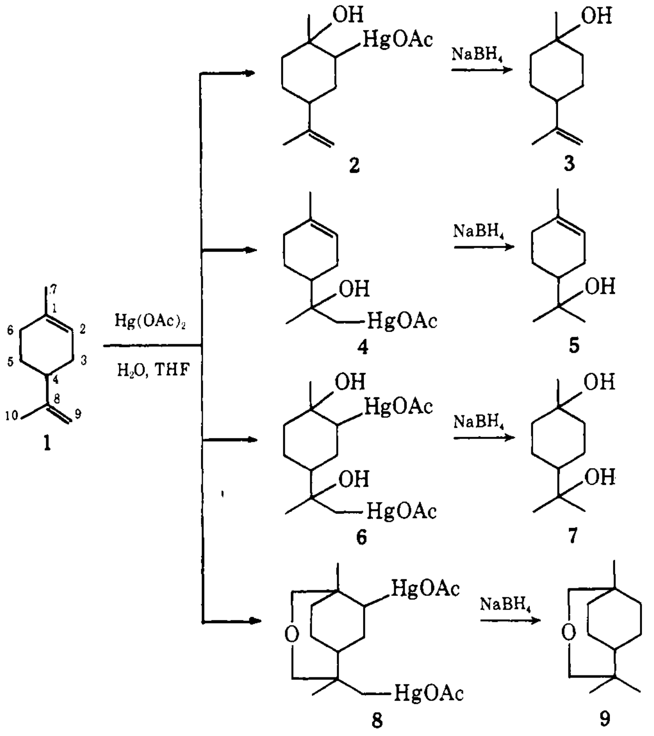
We undertook the present study in order to investigate the relative reactivity of the two differently hindered unconjugated double bonds of limonene, with respect to the mercuric acetate addition, as part of a program which involves the combined use of mercuric acetate addition and tlc as a qualitative analytical tool for the monoterpene hydrocarbon class.[1] The isolation for identification purposes of the hydroxymercurials obtained carrying out the addition reactions in aqueous medium, appeared to be a matter of considerable difficulty. We then monitored the reactions *via* the isolation and identification of the products obtained by reduction of the mercuric adducts with NaBH$_4$, according to Brown's procedure.[2] This consists of an oxymercuration–demercuration sequence which provides, in this case, a convenient method of obtaining known monoterpene alcohols, easily detectable by glpc.

Results and Discussion

The following oxymercuration–demercuration scheme might result if account is taken of both reaction sites on the limonene molecule (Scheme I).

The reaction carried out in a 1:2 limonene–mercuric acetate molecular ratio was very fast,[3] coming to completion in a matter of seconds. Analysis for alcohols, after reduction, showed an almost quantitative yield of *cis*-1,8-terpin (*cis*-**7**) (hydrate) and 1,8-cineole (**9**). This implies that the endo- and exocyclic double bonds, despite the different steric hindrance, show a similar high reactivity. On the other hand, a considerable difference in reactivity should have promoted a sequence in the mercuration stage, most likely initially involving the external double bond and then the internal one after the first attack arrived at completion. Accordingly, running a reaction in a 1:1 limonene–mercuric acetate molecular ratio, would give rise to the adduct **4** as the major product which, on reduction, leads to α-terpineol (**5**), while β-terpineol (**3**), *cis*- or *trans*-**7** and **9**, which originate respectively from **2**, **6**, and **8** adducts, should be absent or present in only very small amounts. On the contrary, a high yield of *cis*-**7** (hydrate) and **9**, together with the expected **5**, was observed carrying out this 1:1 reaction, which was complete in the same time as the 1:2 ratio reaction. Obviously a corresponding amount of unreacted limonene was also found. The same situation concerning both products and rate was also observed running a 1:0.5 limonene–mercuric acetate reaction. It should be emphasized that the reactions were ex-

Scheme I



tremely smooth under the standard experimental conditions and that no side oxidation process was evident even when an excess of mercuric salt was used (1:4).

From these results it was apparent that in the adduct 4 the reactivity of the endocyclic double bond was so tremendously enhanced as to compete favorably with the external limonene double bond.

To support this point of view we then explored the effect of oxymercuration on 1-*p*-menthene to ascertain the reaction rate of its endocyclic double bond. Under the standard operative conditions (1:1), the reaction was markedly slower with respect to limonene and, even in 30 min, the yield of alcohol was not quantitative. This made it evident that the limonene trisubstituted double bond, although seemingly comparable with that of 1-*p*-menthene, displayed more reactivity than expected. We therefore thought that the factor which might influence the overall reaction rate might be the presence of the exocyclic unsaturation in the limonene molecule. Assuming that mercuric salt attack took place primarily on this double bond, leading to the adduct 4 at an extremely high rate, the subsequent reactivity increase of the endocyclic double bond, leading to the adduct 4 at an extremely high oxymercuration elements (hydroxyl group and acetomercury group) or, more simply, only to the hydroxyl group in position 8.

In order to test these hypotheses, a reaction on α-terpineol was made using standard conditions in a 1:1 reagent ratio. The observed rate was as high as for limonene and a 2-min reaction time was sufficient to obtain an almost quantitative yield of *cis*-7 and 9 in relative amounts comparable to those from limonene.[4,5]

It must be noted that, in an early paper, Sand, *et al.*,[6] and most recently Brook, *et al.*,[7] reported the production of 9 and *trans*-7, without trace of its cis isomer, when the oxymercuration of α-terpineol was carried out with mercuric nitrate in a heterogeneous aqueous medium. However, applying the standard borohydride reduction procedure to the adducts obtained by Sand's method, we found that *cis*-7 was formed together with the trans isomer (≃1:2 relative ratio). 1,8-Cineole (9) was also present. See Table I.

Table I
Summary of Oxymercuration–Demercuration Reactions

Compd	Compd/ Hg(OAc)$_2$	Reaction products,[a] %: 1	5	*cis*-7	*trans*-7	9
1	1:2		3.2	72.2		24.6
1	1:1	30.5	35.1	26.0		8.4
1	1:0.5	68.3	15.5	13.0		3.2
5[b]	1:1		2.2	68.6		29.2
5[c]	1:1		22.4	20.2	48.8	8.6

[a] Calculated by taking the sum of glpc peak areas as 100. [b] Standard procedure. [c] Sand, *et al.*, modified procedure.

In conclusion, the overall results of this study reveal that, in the oxymercuration of limonene, the first hydroxyl group to enter influences the successive introduction of the mercuration elements on the endocyclic double bond by enhancing the corresponding reaction rate, so that the two 1,2-Markovnikov additions did not occur as competitive steps.

The operative reaction conditions play a decisive role on the adduct sterochemistry. The procedure used displays high stereospecificity leading only to the cis isomer of terpin while the earlier procedures, in heterogeneous medium, give rise to both cis and trans isomers.

Although it was observed that the possibility of formation of five- or six-membered cyclic ethers promotes an almost quantitative yield of these with respect to the corresponding diols,[8] in the present case limonene gives rise to considerable amounts of both types of products. This suggests that both the 8-hydroxyl internal group and water act as competitive nucleophiles with respect to the 1 position during oxymercuration and that neither of the two fully predominates.

Experimental Section

Materials. Limonene (1) and 5 were obtained commercially and purified before use by preparative glpc. 1-*p*-Menthene was prepared by sodium amyl alcohol reduction of α-phellandrene. The procedure was essentially identical with that described by Semmler[9] except for the removal of the excess amyl alcohol, which was performed by column chromatography over silica gel, using *n*-hexane as eluent. From the eluate 1-*p*-menthene was isolated by preparative glpc using a 2.7 m × 7.8 mm i.d. column packed with 20% Carbowax 20M on Chromosorb A, 60–80 mesh, 80–160°, 3°/min. The ir spectrum was identical with that reported in the literature.[10] *trans*-7 was obtained according to Baeyer's method.[11] All chemicals and solvents were reagent grade and used as obtained.

Oxymercuration–Demercuration Reactions. Limonene (1). Limonene (10 mmol) was added under stirring to the solvent system (10 ml H_2O + 10 ml THF) containing 20 mmol of Hg(OAc)$_2$, to perform the 1:2 mole ratio reaction. Mercuric acetate (10 mmol or 5 mmol) was employed in the 1:1 or 1:0.5 mole ratio reactions under the same conditions. The disappearance of the yellow suspension which formed when THF was added to the aqueous solution of Hg(OAc)$_2$ was used to monitor the reaction rate.[2] The time required was 7–10 sec in all cases; hence, all reactions were allowed to proceed for the same time period (2 min) before initiating the reduction. This was performed using 20, 10, or 5 ml of both 3 *M* NaOH and a 0.5 *M* solution of NaBH$_4$ in 3 *M* NaOH for the 1:2, 1:1, or 1:0.5 mole ratios, respectively. After stirring until all the mercury had coagulated, the aqueous layer was saturated with K_2CO_3 and the upper THF layer separated. The aqueous phase was again extracted twice with 10-ml portions of THF. The combined THF extracts were then dried over anhydrous K_2CO_3.

1-*p*-Menthene. The reaction, carried out in standard conditions in a 1:1 reagent ratio, required 3 min for the disappearance of the yellow suspension. A time period of 30 min was then allowed to elapse before reduction.

α-Terpineol (5). Standard Procedure. α-Terpineol (5) and Hg(OAc)$_2$ (both 10 mmol) were allowed to react under standard conditions to perform a 1:1 reaction. Since the yellow suspension vanished in 7 sec, the reaction was allowed to continue for 2 min.

α-Terpineol (5), Modified Sand Procedure. The original method[6] was exactly followed for the oxymercuration stage using 10 mmol of reagents (2.16 g of HgO and 1.54 g of **5**). When the addition was complete, the subsequent reduction was performed by the standard procedure adding 10 ml of 3 *M* NaOH and 10 ml of 0.5 *M* $NaBH_4$ in 3 *M* NaOH to the reaction mixture and extracting with THF as stated above.

Analyses. Qualitative and quantitative analyses were made by glpc. After evaluation of several types of glpc columns, the best choice was a 3 m × 3.5 mm i.d. glass column packed with 5% QF-1 on Anakrom ABS, 90-100 mesh (10 min at 80-170°, 3°/min), which also worked well for the separation of **9** from **1**. The dried THF extracts were gas chromatographed and the reaction products identified by comparison of their retention times with those of authentic samples. On the other hand, column chromatography on silica gel (Merck, 200 mesh ASTM) was found adequate for isolation of **1**, **9**, and **5**, eluting with a benzene-ethyl acetate 40:60 mixture. Subsequent elution with methanol drew *cis*-**7**. In this case all these compounds were identified by ir spectroscopy after purity checks carried out by glpc and tlc on Merck silica gel G with various solvent systems.

Quantitative determinations were performed by glpc peak area evaluation using a Perkin-Elmer SIP-1 electronic integrator. Calculation of relative weight percentages required the determination of relative detector (FID) response factors from a THF standard solution of known amounts of **1**, **9**, **5**, and *cis*-**7**. Each reaction was repeated to ascertain quantitative reproducibility, and percentages in the text represent average results. In every case reproducibility was within ±1.5%.

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Registry No.—**1**, 138-86-3; **5**, 10482-56-1; $Hg(OAc)_2$, 1600-27-7.

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Reaction of Terpenes with Diethyl Phosphonate under Free Radical Conditions

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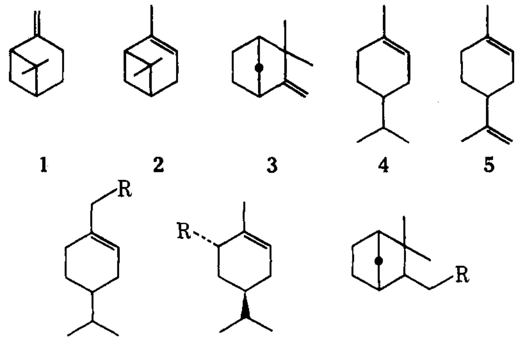
β-Pinene (1), α-pinene (2), camphene (3), carvomenthene (4), and limonene (5) were treated with commercial diethyl hydrogen phosphite to yield phosphonates. The phosphonate addition to the pinenes yielded *p*-menthenyl derivatives, to camphene yielded isocamphanyl derivatives, and to limonene yielded diphosphonates, with a bornyl derivative as a minor product. Structures based on ir and nmr data are discussed.

As part of this laboratory's efforts to produce flame-resistant naval stores derivatives, it was of interest to prepare some terpenyl phosphonic acids or phosphonates.

The preparation of alkyl phosphonates from olefins has been studied to some extent. Pudovik and Konovalona[2] used uv light or benzoyl peroxide to effect 1:1 anti-Markovnikov addition of dialkyl phosphonates to unsaturated hydrocarbons. They noted that telomers and polymers also were formed. Stiles, *et al.*,[3] obtained polymers when peroxides were used to initiate the addition of dialkyl phosphonates to olefins. Recently, Callot and Benezra,[4] using benzoyl peroxide, added dimethyl phosphonate to norbornadiene to yield a norbornene phosphonate, two diphosphonate derivatives, and a nortricyclene derivative.

In this study we treated commercial diethyl hydrogen phosphite (DEHP) with β-pinene (**1**), α-pinene (**2**), camphene (**3**), carvomenthene (**4**), and limonene (**5**) in the presence of di-*tert*-butyl peroxide (DTBP). From **1** a 94% yield of a single product (**6**) was obtained. The elemental analysis established that it was a 1:1 adduct. The presence of a P=O absorption[4] at 1245 cm^{-1} in its infrared spectrum showed that the terpenyl linkage was to the phosphorus, as expected, not to the oxygen. The appearance of a broad olefinic proton peak at 5.53 ppm in the nmr spectrum showed that the addition had been accompanied by ring opening, as in the case of other free radical additions to β-pinene.[5] The other features of the nmr spectrum were in accord with this assignment. It should be noted that the C_7-H_2 resonance at 2.16 ppm was deshielded by only about 0.2 ppm from the normal allylic methylene position[6] by the phosphonate group. As previously reported,[7] the ethoxy methylene was a quintet due to equal coupling to the methyl protons and to phosphorus.



R = $PO(OCH_2CH_3)_2$

A single product (**7**) was also obtained from **2**, but the yield was somewhat lower (56%). As with **6**, elemental analyses and infrared spectrum indicated that it was a ring-opened 1:1 adduct. On steric grounds, the phosphonyl radical should attack **2** trans to C_6 leading to **7**. This configuration was confirmed by the high molecular rotation of