center fraction was a colorless liquid, b.p. 79° (12 mm.), n^{25}_D 1.4420 (reported b.p. 76–77° (17 mm.)[11]; 83–83.5 (20 mm.)[21]; n^{25}_D 1.4390,[11] n^{25}_D 1.4432[21]). This material was twice redistilled, n^{25}_D 1.4414. The infrared spectrum showed a sharp carbonyl maximum at 1739 cm.$^{-1}$ in carbon tetrachloride, and a shoulder at 1730 cm.$^{-1}$.

Anal. Calcd. for C_6H_9FO: C, 62.05; H, 7.81; F, 16.36. Found: C, 61.78; H, 7.90; F, 16.70.

***cis*- and *trans*-2-Fluoro-4-*t*-butylcyclohexanone (II).**—To an ice bath-cooled solution of 4.6 g. (0.200 g.-atom) of sodium dissolved in 300 ml. of absolute ethanol was added 36.4 g. (0.200 mole) of 2-(hydroxymethylene)-4-*t*-butylcyclohexanone with stirring. After several minutes gaseous perchloryl fluoride was passed through the yellow solution at a moderate rate with stirring and ice bath cooling until the *p*H of the mixture reached 7. During this period of time (*ca.* 0.5 hr.) a white solid precipitated. The mixture was poured into water and was extracted twice with ether. The combined ether extracts were washed twice with water and dried over anhydrous magnesium sulfate. The filtered solution was evaporated to dryness under reduced pressure and the residue was rapidly distilled three times under vacuum to yield 29.4 g. of virtually colorless liquid which was fractionally distilled through a 24-in. Podbielniak-type column with a partial reflux head. The initial fractions yielded 3.0 g. (9%) of *trans*-2-fluoro-4-*t*-butylcyclohexanone (IIa) as a colorless liquid, b.p. 67° (3.0 mm.), n^{25}_D 1.4458. A center fraction of this material was rapidly distilled to yield a sample for analysis and dipole moment studies. It showed an infrared carbonyl maximum at 1734 cm.$^{-1}$ (carbon tetrachloride).

Anal. Calcd. for $C_{10}H_{17}FO$: C, 69.73; H, 9.95; F, 11.03. Found: C, 70.02; H, 10.00; F, 11.48.

After the collection of 2.8 g. of material from the intermediate fractions of the Podbielniak distillation, a total of 16.9 g. (49%) of *cis*-2-fluoro-4-*t*-butylcyclohexanone (IIe) was obtained as a virtually colorless liquid, b.p. 100.5–101° (3.2 mm.), n^{25}_D 1.4558, which solidified on standing in the refrigerator. Several crystallizations from dry *n*-pentane with cooling yielded IIe as small white needles, m.p. 39.5–41.5°. It showed an infrared carbonyl maximum at 1743 cm.$^{-1}$ (carbon tetrachloride). In another run a yield of 54% of IIe was obtained.

Anal. Calcd. for $C_{10}H_{17}FO$: C, 69.73; H, 9.95; F, 11.03. Found: C, 69.92; H, 9.85; F, 11.35.

***trans*-2-Fluoro-4-*t*-butylcyclohexanone Hydrate.**—*trans*-2-Fluoro-4-*t*-butylcyclohexanone, 0.30 g. (0.0017 mole), was partially converted to a solid upon exposure to the air for several hours. A total of 0.22 g. (67%) of hydrate was obtained on filtration with dry *n*-pentane, m.p. 74.5–76.5°. It did not show a carbonyl maximum in the infrared but did show a broad O—H band at 2.98 μ (mull).

Anal. Calcd. for $C_{10}H_{19}FO_2$: C, 63.13; H, 10.07; F, 9.99. Found: C, 63.25; H, 9.95; F, 9.79.

Measurements of Dipole Moments.—The dipole moment apparatus used has been previously described.[22] The dipole moments were measured at 25° and the calculations were carried out by essentially the method of Halverstadt and Kumler[23] utilizing an IBM 650 computer programmed as described earlier.[24] Atomic polarization was neglected. The data are summarized in Table III.

Acknowledgment.—The authors are indebted to Miss M. A. DaRooge for determining the dipole moments reported in this paper, and would also like to thank Dr. A. S. Kende and Dr. E. M. Kosower for helpful discussion.

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(21) S. Nakanishi, K. Morita, and E. V. Jensen, *J. Am. Chem. Soc.*, **81**, 5259 (1959).

(22) N. L. Allinger, H. M. Blatter, M. A. DaRooge, and L. A. Freiberg, *J. Org. Chem.*, **26**, 2550 (1961).

(23) I. F. Halverstadt and W. D. Kumler, *J. Am. Chem. Soc.*, **64**, 2988 (1942).

(24) N. L. Allinger and J. Allinger, *J. Org. Chem.*, **24**, 1613 (1959).

Stereospecific Synthesis of *p*-Bornyl- and *p*-Isobornylphenol

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The synthesis of *p*-bornylphenol (I) and *p*-isobornylphenol (II) from camphor is described. Reaction of camphor and *p*-anisylmagnesium bromide afforded *p*-anisylborneol (VI, 26%), which was dehydrated solely to *p*-anisylbornylene (VII, 91%) with 0.3% boron trifluoride etherate in ether. Hydrogenation of VII in the presence of a sponge nickel catalyst afforded isobornylanisole (IX, 72%) exclusively, while chemical reduction with sodium in liquid ammonia gave bornylanisole (VIII, 94%), exclusively. The ethers VIII and IX were converted to the corresponding phenols I and II by fusion with pyridine hydrochloride. The stereochemical configurations of the products were confirmed by an independent unambiguous synthesis of the *endo* isomer I.

The formation in varying proportions of the two epimeric phenols—*p*-bornyl-(I)- or *p*-isobornyl-(II)-phenol from condensation of camphene, pinene, bornene, and related terpenes with phenol has been reported by numerous investigators.[1–9] The *p*-isobornyl- or *p*-bornylphenol structures were

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(1) W. Koenigs, *Ber.*, **24**, 179 (1891).

(2) H. Wuyts, U. S. Patent 1,469,709 (1923) [*Chem. Abstr.*, **17**, 3879 (1923)].

(3) R. Zink, U. S. Patent 2,186,132 (1940) [*Chem. Abstr.*, **34**, 2966 (1940)].

(4) R. O. Roblin, Jr., and I. Hechenbleikner, U. S. Patent 2,311,282 (1943) [*Chem. Abstr.*, **37**, 4526 (1943)].

(5) L. J. Kitchen, *J. Am. Chem. Soc.*, **70**, 3608 (1948).

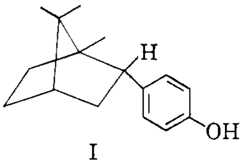
(6) W. C. Sears and L. J. Kitchen, *J. Am. Chem. Soc.*, **71**, 4110 (1949).

(7) L. J. Kitchen, U. S. Patent 2,537,636 (1951) [*Chem. Abstr.*, **45**, 3644 (1951)]; U. S. Patent 2,537,647 (1951) [*Chem. Abstr.*, **45**, 6222 (1951)]; U. S. Patent 2,581,916 (1952) [*Chem. Abstr.*, **46**, 8677 (1952)].

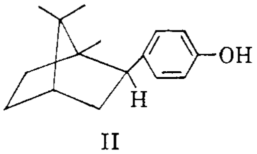
(8) (a) Lech-Chemie Gersthofen, West German Patent 860,946 (1942); West German Patent 876,241 (1953) [*Chem. Abstr.*, **52**, 5759 (1958); *Chem. Zentr.*, **125**, 2930, 6367 (1954)]; (b) Y. Watanabe, *J. Chem. Soc. Japan, Ind. Chem. Sect.*, **63**, 1420 (1960).

(9) (a) L. A. Kheifits, G. I. Moldovanskaya, E. V. Broun, and V. N. Belov, *Zhur. Obshchei. Khim.*, **30**, 1716 (1960) [*Chem. Abstr.*, **55**, 1681 (1961)]; (b) V. N. Belov and L. A. Kheifits, *Zhur. Obshchei. Khim.*, **27**, 1377 (1957) [*Chem. Abstr.*, **52**, 3734 (1958)]; *J. Gen. Chem.* (U.S.S.R.), **27**, 1041 (1957); (c) V. N. Belov and L. A. Kheifits, *Zhur. Obshchei. Khim.*, **27**, 960 (1957) [*Chem. Abstr.*, **52**, 3733 (1958)]; *J. Gen. Chem.* (U.S.S.R.), **27**, 1459 (1957).

assigned to the principal products from reaction mechanism considerations but little chemical or physical evidence accompanied the assignment of structures. The assignment of isobornyl or bornyl structures to condensation products of these terpenes and phenols must, however, remain ambiguous until further confirmation of structure is presented. Pinene derivatives are known to undergo scission to dipentene and related compounds,[10] and an equilibrium between the camphene and bornyl carbonium ion would be expected to exist[11] under the conditions required for C-alkylation of phenols by these compounds. Furthermore, because of the vigorous conditions required for C-alkylation, little stereospecificity for isobornyl compounds would be anticipated in these reactions since isobornyl derivatives are formed under rather stringent conditions and rearrange slowly to the bornyl derivatives under prolonged acid treatment.[12,13]



I

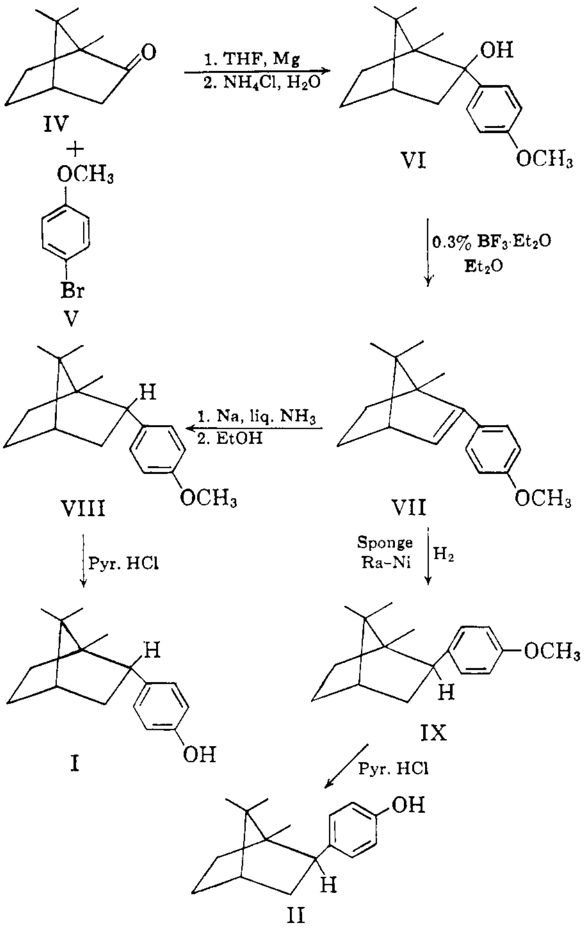


II

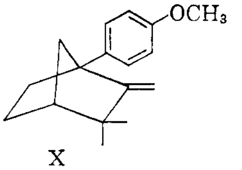
Consequently we synthesized *p*-bornylphenol (I) and *p*-isobornylphenol (II) by unambiguous routes. With the use of these two epimers and other *exo-endo* pairs as model compounds, we have been able to distinguish between certain *exo*- and *endo*-bornane derivatives by the use of proton magnetic resonance. Thus the benzyl protons (6.9–7.3 τ) were resolved completely from the other protons in the molecule so that the difference between the chemical shift and spin coupling constants of *exo*- and *endo*-protons in the bornyl and isobornyl derivatives could be measured easily. The differentiation between *exo* and *endo* epimers in the bornane series by the use of NMR spectroscopy is discussed in detail elsewhere by Flautt and Erman.[14]

Preparation of *p*-bornyl- and *p*-isobornylphenol.—The epimeric phenols I and II were readily accessible by the route outlined in Scheme 1. The exact stereochemistry of the two compounds was subsequently established by an unambiguous synthesis of the *endo* isomer, as will be described. The physical constants of these compounds were strikingly different from those reported by previous authors, suggesting that assignment of the *p*-bornyl or *p*-isobornyl structures to the compounds isolated by these authors was premature.

Scheme 1



The key intermediate in the preparation of the two epimers I and II was *p*-anisylbornylene VII, a compound obtained in 91% yield by treatment of *p*-anisylisoborneol VI with 0.3% boron trifluoride in ether. Under more vigorous acid conditions the alcohol VI underwent rearrangement with formation of lesser amounts of the conjugated olefin VII and increasing amounts of the rearranged structure, 1-*p*-anisyl camphene (X).



X

The structure of the olefin VII was confirmed from the infrared spectrum, which showed no terminal double bond, the ultraviolet spectrum, which was typical of *p*-vinyl substituted anisole

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(10) (a) R. Lombard and A. Kress, *Bull. soc. chim. France*, 1419 (1959); (b) M. S. Kharasch and W. B. Reynolds, *J. Org. Chem.*, **9**, 148 (1944); (c) R. E. Fuguitt and J. E. Hawkins, *J. Am. Chem. Soc.*, **67**, 242 (1945); (d) H. G. Hunt and J. E. Hawkins, *J. Am. Chem. Soc.*, **72**, 5618 (1950); (e) F. Flawitzky, *Ber.*, **12**, 1406, 2354 (1879); *Ber.*, **20**, 1956 (1887); (f) W. A. Mosher, *J. Am. Chem. Soc.*, **69**, 2139 (1947).

(11) P. D. Bartlett and I. Pöchel, *J. Am. Chem. Soc.*, **59**, 820 (1937).

(12) T. P. Nevell, E. de Salas, and C. L. Wilson, *J. Chem. Soc.*, 1188 (1939).

(13) H. Meerwein and K. van Emster, *Ber.*, **53**, 1815 (1920); *Ber.*, **55**, 2500 (1922).

(14) T. J. Flautt and W. F. Erman, Paper presented at the 140th Meeting of the American Chemical Society, Chicago, Ill., Sept. 3, 1961.

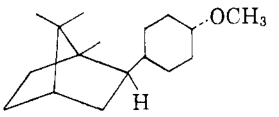
derivatives, and the NMR spectrum.[15] The rearranged product X, which was a high-boiling, gas-chromatographically homogeneous liquid,[16] was shown to be a terminal olefin from the infrared spectrum and the NMR spectrum was consistent with the assigned structure.[15]

The formation of the starting material, *p*-anisylisoborneol (VI) from the Grignard reaction of *p*-bromoanisole and camphor in ether has been reported[17,18] but only low yields (5–10%) of the alcohol VI were obtained even after twenty-four hours reaction time. Substitution of tetrahydrofuran as solvent, however, gave spontaneous reaction and afforded the alcohol VI in 26–33% yields along with varying quantities of dianisyl (XI) (2–7%), 2-*p*-anisylbornylene (VII) (3–5%), and 1-*p*-anisylcamphene (X) (5–12%). Large quantities of camphor were invariably recovered from the reaction, probably due to formation of a stable carbonyl-Grignard complex[19] or to enolization of the keto group.[19b,20] The *exo* structure was assigned to the alcohol VI by analogy to the known stereochemistry of Grignard addition to ketones from the least hindered side.[21,22]

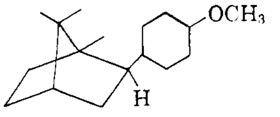
Reduction of the 2-*p*-anisylbornylene (VII) with sodium in liquid ammonia afforded a single gas chromatographically homogeneous[16] dihydro derivative VIII in 89% yield. The addition of sodium to conjugated double bonds or to acetylenes is believed to proceed by *trans* addition; the reduced product is then formed by protonation of the sodium addition compound.[23] The intermediate disodium compound in the reduction of VII could then lead either to the thermodynamically more stable product, or, if protonation resulted from attack by solvent from the least hindered side of the molecule, to the kinetically favored product.

The stereochemistry of catalytic hydrogenation of olefins has been shown to be highly dependent upon catalyst, reaction conditions, and compounds.[24–26] For example, reduction of 1,2-dimethyl-cyclohex-1-ene yields mainly the *trans* isomer when a platinum or palladium catalyst is employed.[25] On the other hand, Arnold[26] has shown that α-pinene is converted exclusively to nopinane, or *cis* addition product, with platinum oxide in acetic acid. We found that when either a platinum or palladium catalyst was employed for reduction of either the benzyl alcohol VI or the conjugated olefin VII, only mixtures of the two isomers VIII and IX were obtained. The two epimers, though separable by gas chromatography on a capillary column, could not be separated by fractional distillation or preparative gas chromatography.

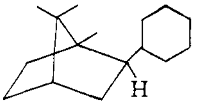
Hydrogenation of VII with a W-5 Raney nickel catalyst led to reduction of the aromatic ring as well as the olefin, but when a sponge nickel catalyst was employed, a single crystalline gas-chromatographically homogeneous[14] dihydro derivative IX, m.p. 41–42.4°, was obtained in 72% yield. Accompanying products were tentatively assigned the structures of *trans*-*p*-isobornylcyclohexanol methyl ether (XII, 16%), *cis*-*p*-isobornylcyclohexanol methyl ether (XIII, 3%), and isobornylcyclohexane (XIV, 8%).



XII



XIII



XIV

Except for the fact that rearrangement could have occurred during hydrogenation or chemical reaction with *p*-anisylbornylene (VII), the two dihydro derivatives VIII and IX must be the two epimeric *p*-anisylbornanes. The NMR spectrum of the two compounds gave further evidence for the anisylbornane structures since both showed multiplets in the 7.0–7.2-τ region typical of benzyl proton spin-spin coupling with two adjacent protons. In the dihydrobornylene VIII, three peaks at 8.99 τ, 9.09 τ, and 9.31 τ, and in the dihydro derivative IX, two peaks at 9.18 τ and 9.27 τ in the approximate ratio 2:1, showed the presence of three angular methyl groups.

To establish conclusively that no rearrangement occurred during hydrogenation, the terminal olefin X was reduced catalytically. The product, obtained in 93% yield, was a mixture of epimers,

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[15] Significant NMR, infrared, and ultraviolet data and interpretations are listed in the Experimental.

[16] In this work "gas-chromatographically homogeneous" infers that a single symmetrical peak was obtained when the material was chromatographed at 210° and 60 ml./min. flow rate of helium through a 10-ft. column containing 30% succinic acid–triethylene glycol polymer on 60/80 mesh Chromasorb and on a 5-ft. column containing 20% GE-silicone on firebrick.

[17] S. Ledric, *Compt. rend.*, **180**, 1502 (1925).

[18] N. C. Deno, P. T. Groves, J. J. Jaruzelski, and M. N. Lugasch, *J. Am. Chem. Soc.*, **82**, 4719 (1960).

[19] (a) M. S. Kharasch and O. Rinmuth, "Grignard Reactions of Nonmetallic Substances," Prentice-Hall, Inc., New York, 1954, p. 140; (b) M. Bredt-Savelsberg, *J. prakt. Chem.* [2], **107**, 65 (1924); (c) J. Leroide, *Compt. rend.*, **148**, 1611 (1909) [*Chem. Zentr.*, **1909**, II, 358 (1909)].

[20] M. S. Kharasch and O. Rinmuth, "Grignard Reactions of Nonmetallic Substances," Prentice-Hall, Inc., New York, 1954, pp. 167–169.

[21] P. D. Bartlett, E. R. Webster, C. E. Dills, and H. G. Richey, Jr., *Ann.*, **623**, 217 (1959).

[22] S. Beckmann, R. Schaber, and R. Bamberger, *Chem. Ber.*, **87**, 997 (1954).

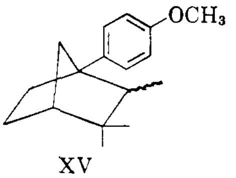
[23] (a) W. S. Johnson *et al.*, *J. Am. Chem. Soc.*, **78**, 6289 (1956); *J. Am. Chem. Soc.*, **78**, 6354 (1956); (b) N. A. Dobson and R. A. Raphael, *J. Chem. Soc.*, 3558 (1955); (c) D. R. Howton and R. H. Davis, *J. Org. Chem.*, **16**, 1405 (1951); (d) B. B. Elsner and P. F. M. Paul, *J. Chem. Soc.*, 3156 (1953).

[24] R. P. Linstead *et al.*, *J. Am. Chem. Soc.*, **64**, 1985 (1942).

[25] S. Siegel and G. V. Smith, *J. Am. Chem. Soc.*, **82**, 6082, 6087, 6090 (1960).

[26] G. W. Eigenmann and R. T. Arnold, *J. Am. Chem. Soc.*, **81**, 3440 (1959).

tentatively assigned the structure 1-*p*-anisyl-2-methyl-3,3-dimethylbicyclo[2.2.1]heptane (XV) on the basis of the NMR spectrum. The product XV was shown to be different from the two bornane epimers VIII and IX by gas chromatography, comparison of infrared and NMR spectra, and physical constants.

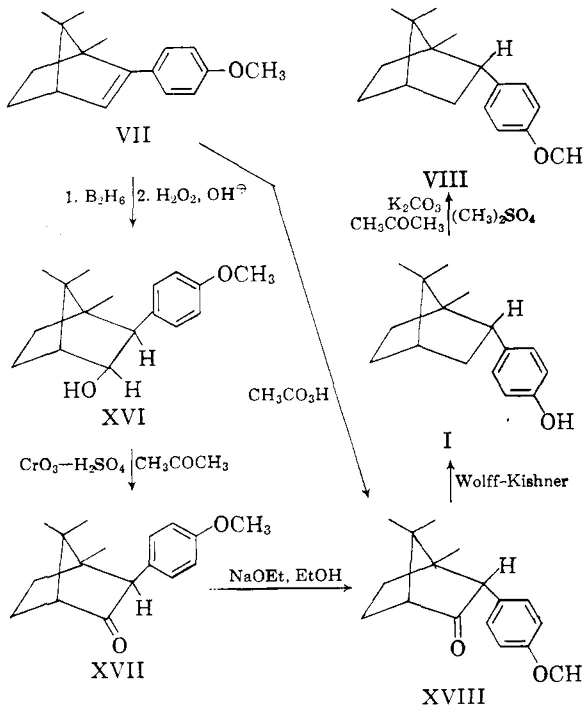


XV

Both methyl ethers VIII and IX were converted by pyridine hydrochloride fusion to the corresponding phenol derivatives I, m.p. 135–136°, and II, m.p. 151–152°, respectively.

Unambiguous Synthesis of *p*-Bornylphenol.—The above evidence clearly establishes that I and II are *p*-hydroxyphenylbornanes but does not determine the stereochemistry. Consequently, a more tedious but unambiguous synthesis of *p*-bornylphenol was carried out as outlined in Scheme 2. In this synthesis we have taken advantage of the high degree of electronic and steric specificity of the addition of diborane to olefins.[27–30] Treatment of the olefin VII with diborane afforded the *endo* alcohol, 2-*exo*-*p*-anisylepiborneol (XVI), in 75% yield after oxidation with alkaline peroxide. Titration of an acetone solution of the alcohol XVI with standard chromate reagent[31] in acetone afforded 2-*exo*-*p*-anisylepicamphor (XVII) in 65% yield. When even a slight excess of chromate reagent was employed, the yield of the ketone XVI was considerably decreased as a result of enolization and epimerization to 2-*endo*-*p*-anisylepicamphor (XVIII). The *exo*-anisyl ketone XVII, in fact, was quite stable in the crystalline form, could be recrystallized from ethanol, but was rapidly epimerized to the *endo* derivative XVIII by acid or base. Surprisingly, a 10% solution of the *exo* ketone XVII in reagent grade carbon tetrachloride was slowly isomerized to the *endo* ketone XVIII. After sixteen hours approximately 50% of the *exo* ketone (XVII) had isomerized and after forty-eight hours a 100% conversion to *endo* ketone was effected. The epimerization could be easily followed by means of the NMR spectrum, the benzyl C-2 proton of the *endo* isomer being shifted 0.21 p.p.m. downfield relative to the *exo* isomer. This observation is a rather well defined example of the fact that the chemical shifts of axial hydrogens of cyclohexane derivatives occur at higher fields than the chemical shifts for equatorial hydrogens.[32] A surprising characteristic of the NMR spectrum of the *endo*-anisyl ketone XVIII was the benzene proton pattern which showed up as a single peak at 3.30 τ while the benzene proton pattern of the *exo* isomer was a quartet centered at 3.25 τ.

Scheme 2



When the *exo*-anisylepicamphor (XVII) was treated with sodium ethoxide in ethanol a 56% yield of the *endo*-anisylepicamphor (XVIII) was obtained, after recrystallization from ethanol. However, the NMR and infrared spectrum showed that the residue from the mother liquors consisted entirely of *endo*-ketone, indicating that the isomerization was complete.

Attempts to reduce the *exo*-ketone XVII with sodium borohydride led to epimerization of the anisyl group with formation of 2-*exo*-*p*-anisylepiborneol (XX) in 63% yield. That epimerization occurred during borohydride treatment was indicated by the fact that the *endo* ketone XVIII was converted to the same alcohol by borohydride.

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[27] (a) H. C. Brown and B. C. Subba Rao, *J. Org. Chem.*, **22**, 1136 (1957); (b) H. C. Brown and G. Zweifel, *J. Am. Chem. Soc.*, **81**, 247 (1959); (c) H. C. Brown and B. C. Subba Rao, *J. Am. Chem. Soc.*, **81**, 6423, 6428, 6434 (1959); (d) H. C. Brown and G. Zweifel, *J. Am. Chem. Soc.*, **82**, 3222 (1960).

[28] S. Winstein, E. L. Allred, and J. Sonnenberg, *J. Am. Chem. Soc.*, **81**, 5833 (1959).

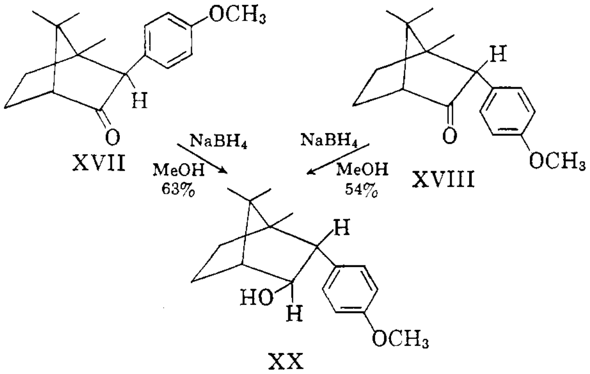
[29] G. A. Wiley, paper presented at the 137th Meeting of the American Chemical Society, Cleveland, Ohio, April 5, 1960.

[30] R. Dulou and Y. Chretien-Bessiere, *Bull. soc. chim. France*, 1362 (1959).

[31] (a) C. Djerassi, R. R. Engle, and A. Bowers, *J. Org. Chem.*, **21**, 1547 (1956); (b) K. Bowden, I. M. Heilbron, E. R. H. Jones, and B. C. Weedon, *J. Chem. Soc.*, 39 (1946); (c) G. J. Kent and E. S. Wallis, *J. Org. Chem.*, **24**, 1235 (1959); (d) R. M. Moriarty and E. S. Wallis, *J. Org. Chem.*, **24**, 1274 (1959).

[32] (a) R. V. Lemieux, R. K. Kullnig, H. J. Bernstein, and W. G. Schneider, *J. Am. Chem. Soc.*, **80**, 6098 (1958); (b) F. R. Jensen, D. S. Noyce, C. H. Sederholm, and A. J. Berlin, *J. Am. Chem. Soc.*, **82**, 1256 (1960); (c) H. C. Brown and K. J. Murray, *J. Org. Chem.*, **26**, 631 (1961).

A model of the ketone XVIII clearly indicates that the carbonyl group is more hindered by the *endo*-anisyl and *endo*-C_5-proton than by the C-8 methyl group on the *exo* side. Since sodium borohydride reduction involves hydride attack from the least hindered side of the carbonyl group,[33] reduction of the ketone XVIII would be expected to lead to the *endo* alcohol XX.



The *endo* ketone XVIII was also prepared by direct oxidation of the olefin VII with peracetic acid. The oxidation of trisubstituted olefins to form ketones has been reported and probably involves formation of the intermediate epoxide followed by acid-catalyzed ring opening *via* the most stable carbonium ion. Other mechanisms for ketone formation by peracid oxidation of trisubstituted olefins have also been postulated.[34]

Examination of a molecular model of the *endo*-*p*-anisyl ketone XVIII indicates considerable steric hindrance about both sides of the carbonyl function. As a result, most methods for removal of the keto group were ineffective. For example, a dithioketal of the ketone could not be formed and ordinary Wolff-Kishner procedures for removal of the keto group gave quantitative recoveries of starting material.[35] However, Barton's variation of the Wolff-Kishner reaction,[36] using anhydrous reagent and solvent for conversion of highly hindered steroidal ketones to the corresponding hydrocarbons, produced *p*-bornylphenol (I) in 60% yield from the ketone XVIII. The methyl ether was cleaved to the phenol by the strong alkaline conditions at the high temperatures employed, a phenomenon well substantiated in the literature.[37,38] Treatment of the phenol with dimethyl sulfate in acetone solution afforded the methyl ether X in 83% yield. The *p*-bornylphenol, prepared *via* the modified Wolff-Kishner reduction of XVIII was shown to be identical with the product from sodium reduction and subsequent pyridine hydrochloride fusion of the olefin VII by comparison of the infrared and NMR spectra, by gas chromatographic comparison, and by the mixture melting point. The methyl ethers were similarly shown to be identical by comparison of the infrared and NMR spectra and gas chromatography retention volumes. The reduction of *p*-anisylbornylene (VII) with sodium therefore proceeded *via trans* addition to the thermodynamically more stable *p*-bornylanisole, while catalytic reduction proceeded *via cis* addition, exclusively, with formation of *p*-isobornylanisole.

Experimental

General.—Melting points were taken in an Ace Glass Hershberg melting point bath using calibrated Anschuetz thermometers. Boiling points were taken on standard thermometers and are uncorrected. Infrared spectra were recorded on a Perkin-Elmer Infracord spectrophotometer; ultraviolet spectra were recorded on a Cary Model 11 spectrophotometer. We are indebted to Dr. W. D. MacMillan and his associates for the microanalyses and to Dr. W. L. Courchene and Mr. Z. T. Pace for infrared and ultraviolet interpretations. The NMR spectra were obtained with a Varian high resolution instrument, Model V4200B, at a frequency of 60 Mc. The samples were run in carbon tetrachloride solution using tetramethylsilane (TMS) as an internal reference. Calibration of the spectrogram abscissa was accomplished by the usual sideband technique with the audio oscillator monitored by a frequency counter. The chemical shift of TMS was taken to be 10.00 p.p.m.[39] Significant peaks of the NMR spectra are listed in Table I. Chemical shifts are accurate to at least ±0.05 p.p.m., coupling constants to ±0.2 c.p.s. Peak areas were measured with a Varian V-3521 electronic integrator.

Grignard Reaction of Camphor and *p*-Bromoanisole. Preparation of *p*-Anisylisoborneol (VI). A. Use of Tetrahydrofuran as Solvent.—A solution of 165 g. (1.07 moles) of *dl*-camphor, m.p. 173–174°, in 250 ml. of anhydrous tetrahydrofuran was added dropwise during a period of 1 hr. to a solution of Grignard reagent prepared from 30.0 g. (1.23 g.-atoms) of magnesium and 200 g. (1.07 moles) of *p*-bromoanisole (V) dissolved in 250 ml. of tetrahydrofuran. The mixture was heated at reflux for 2 hr., cooled to 0–5°, and hydrolyzed by dropwise addition of 120 g. of ammonium chloride dissolved in 350 ml. of water. The magnesium salts which separated were removed by filtration, washed with ether, and the combined ethereal layers washed with water and dried over magnesium sulfate. The solvents were removed under reduced pressure and the bulk of the anisole and *p*-bromoanisole removed by distillation and the camphor removed by sublimation at 5 mm. pressure and at a bath temperature of no greater than 90°. The solid residue was recrystallized from petroleum ether (b.p. 30–60°) to afford 65.5 g. (23% yield) of *p*-anisylisoborneol (VI), m.p. 95–98°. In other runs the alcohol, m.p. 93–98°, was obtained in 20–33% yields. Recrystallization from ethanol afforded rhombic prisms, m.p. 105–107° (lit., m.p. 98–101°[19]). Infrared spectrum: 2.89 μ (hydroxyl).

Anal. Calcd. for $C_{17}H_{24}O_2$: C, 78.42; H, 9.29. Found: C, 78.73; H, 9.17.

Removal of solvent from the mother liquors and recrystallization of the residue from ethanol afforded 5.7 g.

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[35] (a) N. L. Allinger and S. Greenberg, *J. Org. Chem.*, **25**, 1399 (1960); (b) Huang-Minlon, *J. Am. Chem. Soc.*, **68**, 2487 (1946).

[36] D. H. R. Barton, D. A. J. Ives, and B. R. Thomas, *J. Chem. Soc.*, 2056 (1955).

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[38] M. Mottier, *Helv. Chim. Acta*, **18**, 840 (1935).

[39] Following the convention proposed by G. V. D. Tiers, *J. Phys. Chem.*, **62**, 1151 (1958).

TABLE I

NMR SPECTRA OF SUBSTITUTED BORNANES

Compound	Chemical Shift τ Value	Multiplicity^a	Coupling Constant J = c.p.s.	Proton Peak Assignment	Area Ratio
p-Isobornylphenol (II)	3.46	q		Benzene	4.0
	4.61	s		Hydroxyl	1.0
	7.21	t	$J_1 = J_2 = 8.3$	Benzyl	1.0
	7.7–8.7	m		Methylene + C_4	7.3
	9.19	2s			
	9.28	s		Methyl	9.2
p-Bornylphenol (I)	3.23	q		Benzene	3.9
	4.36	s		Hydroxyl	1.0
	7.13	q	$J_1 = 5.5$ $J_2 = 11.4$	Benzyl	1.0
	7.9–8.7	m		Methylene + C_4	6.9
	8.98	s		Methyl	
	9.07	s		Methyl	9.2
	9.30	s		Methyl	
p-Isobornylanisole (IX)	3.20	q		Benzene	3.9
	6.28	s		Methoxyl	3.0
	7.17	t	$J_1 = J_2 = 8.7$	Benzyl	1.3
	7.9–8.7	m		Methylene + C_4	16.0
	9.18	2s^b			
	9.27	s		Methyl	
p-Bornylanisole (VIII)	3.20	q		Benzene	4.2
	6.24	s		Methoxyl	3.0
	7.02	q	$J_1 = 5.8$ $J_2 = 11.4$	Benzyl	0.8
	7.9–8.7	m		Methylene + C	16.4
	8.99	s		Methyl	
	9.09	s			
	9.31	s			
p-Anisylbornylene (VII)	3.26	q		Benzene	4.2
	4.31	d	$J_1 = 3.5$	Vinyl	1.0
	6.40	s		Methoxyl	3.2
	7.76	m		C_4-allyl	1.0
	7.9–8.7	m		Methylene	3.8
	8.97	s		Methyl	9.0
	9.12	s		Methyl	
	9.20	s		Methyl	
1-*p*-Anisylcamphene (X)	3.12	q		Benzene	4.0
	5.51	s		Vinyl	1.2
	5.85	s		Vinyl	1.0
	6.26	s		Methoxyl	3.0
	7.5–8.7	m		Methylene	6.9
	8.89	2s^b		Methyl	5.8
1-*p*-Anisyl-2-*endo*-methyl-3,3-dimethylbicyclo[2.2.1]heptane (XV)	3.15	q		Benzene	3.9
	6.31	s		Methoxyl	3.0
	7.7–8.7	m		Methylene + C	17.0
	9.17	d		Methyl	
	8.99	s		Methyl	
	9.36	s	$J = 7.0$	C_2-methyl	
2-*exo*-*p*-Anisylepiborneol (XVI)	3.20	q		Benzene	4.0
	5.39	m		C_3-proton	0.9
	6.34	s		Methoxyl	3.0
	7.22	s		Hydroxyl	1.2
	7.67	d	$J = 6.4$	C_2-benzyl	0.8
	7.8–8.7	m		Methylene + C_4	12.9
	9.16	2s^b		Methyl	
	9.35	s		Methyl	
2-*exo*-*p*-Anisylepiborneol *p*-toluenesulfonate (XVIa)	2.63	q		Tosyl benzene	7.9
	3.32	q		Anisyl benzene	
	4.74	q	$J_1 = 4.2$ $J_2 = 6.4$	C_3-proton	1.1
	6.33	s		Methoxyl	3.0
	7.38	d	$J = 6.4$	C_2-benzyl	0.8
	7.68	s		Tosyl methyl	17.3
	7.7–8.7	m		Methylene + C_4	
	9.13	2s^b		Methyl	
	9.37	s		Methyl	

TABLE I (*Continued*)

Compounds	Chemical Shift τ Value	Multiplicity[a]	Coupling Constant J = c.p.s.	Proton Peak Assignment	Area Ratio
2-*exo*-*p*-Anisylepicamphor (XVII)	3.25	q		Benzene	3.8
	6.32	s		Methoxyl	2.9
	6.92	s		Benzyl-C_2	1.1
	7.7–8.7	m		Methylene + C_4	14.3
	9.03	s		Methyl	
	9.06	2s[b]		Methyl	
2-*endo*-*p*-Anisylepicamphor (XVIII)	3.30	s		Benzene	3.9
	6.35	s		Methoxyl	3.1
	6.71	s		Benzyl-C_2	1.0
	7.9–8.7	m		Methylene + C_4	14.1
	8.94	s		Methyl	
	8.98	s		Methyl	
	9.06	s		Methyl	
2-*endo*-*p*-Anisylepiborneol *p*-toluene sulfonate (XXa)	2.90	q		Tosyl benzene	7.8
	3.28	q		Anisyl benzene	
	5.03	q	J_1 = 4.2 J_2 = 10.6	C_3-proton	0.9
	6.28	s		Methoxyl	2.9
	7.17	d	J = 10.8	C_2-benzyl	0.9
	7.67	s		Tosyl methyl	17.3
	7.8–8.7	m		Methylene + C_4	
	8.97	s		Methyl	
	9.04	s		Methyl	
	9.45	s		Methyl	

[a] s = singlet; d = doublet; t = triplet; q = quartet; m = multiplet. [b] 2s = two single peaks superimposed.

(2.2% yield) of 2-*p*-anisylbornylene (VII), m.p. 71–72°. The mixture melting point with a sample of 2-*p*-anisylbornylene, m.p. 68–70°, isolated from Grignard reaction in ether solution below was not depressed, m.p. 68–71°.

B. Use of Ether as Solvent.—From 4.56 g. (0.187 g.-atom) of magnesium, 50.0 g. (0.27 mole) of *p*-bromoanisole, and 28.5 g. (0.27 mole) of *dl*-camphor there was obtained, after heating 67 hr. at reflux and hydrolysis with ammonium chloride solution, 51.7 g. of light yellow oil which was dissolved in 200 ml. of petroleum ether and chromatographed over 500 g. of Woelm Activity III alumina. Elution with petroleum ether afforded 16.61 g. of *p*-bromoanisole (V), 4.28 g. of *dl*-camphor (IV), 1.23 g. dianisyl (XI) (6%), m.p. 177–178° (lit., m.p. 171–172° [40]).

Anal. Calcd. for $C_{14}H_{14}O_2$: C, 78.48; H, 6.59. Found: C, 78.53; H, 6.46, and 8.05 g. of an oil.

The oil was sublimed (120°/1 mm.) to afford 1.35 g. (5%) of 2-*p*-anisylbornylene (VII), m.p. 67–69°. The material was recrystallized from ethanol in plates, m.p. 69–71°, for analysis. Ultraviolet spectrum in 95% ethanol: λ_{max} 253 mμ, log ϵ 4.17.

Anal. Calcd. for $C_{17}H_{22}O$: C, 84.25; H, 9.15. Found: C, 84.08; H, 8.94.

Distillation of the residual oil remaining after sublimation yielded 4.59 g. of a mixture of 1-*p*-anisylcamphene (X), 4-*p*-anisylcamphene (tentatively identified by means of the NMR spectrum) and 2-*p*-anisylbornylene in the approximate ratio 5:2:2. The 1-*p*-anisylcamphene was isolated by a tedious fractional distillation through an 18-in. spinning band column, b.p.100.5°/0.2 mm., $n^{25}\text{D}$ 1.5441, followed by recrystallization from methanol in needles, m.p. 44–45°; infrared spectrum: 6.05 μ and 11.3 μ (terminal olefin).

Anal. Calcd. for $C_{17}H_{22}O$: C, 84.25; H, 9.15. Found: C, 84.17; H, 9.03.

Elution with benzene–ether provided 9.88 g. (21%) of *p*-anisylisoborneol (VI), m.p. 98–102°.

1-*p*-Anisylcamphene. (X). A. From Grignard Reaction.—Treatment of a Grignard solution prepared from 30.0 g. (1.23 g.-atoms) of magnesium and 200 g. (1.07 moles) of *p*-bromoanisole with 165 g. (1.07 moles) of *dl*-camphor, hydrolysis with 6 *N* sulfuric acid and subsequent heating with 10.0 g. of boron trifluoride etherate in 200 ml. ether at 50–80° afforded 59.3 g. of a colorless oil which was chromatographed over 200 g. of Woelm Activity III alumina. The residue before column chromatography was analyzed by gas chromatography and shown to consist of 64% 1-*p*-anisylcamphene (X) and 36% of other unidentified products. Total yield of *p*-anisylcamphene was 25%. Elution with petroleum ether gave two compounds, the *p*-anisylcamphene (X) being separated by fractional distillation from a 24-in. spinning band column, b.p. 100.5°/0.3 mm., $n^{25}\text{D}$ 1.5440. Recrystallization from methanol afforded needles, m.p. 41–43°.

Anal. Calcd. for $C_{17}H_{22}O$: C, 84.25; H, 9.15. Found: C, 84.29; H, 9.25.

B. From *p*-Anisylisoborneol.—A solution of 0.87 g. (0.003 mole) of VI in 50 ml. of absolute ethanol and 10 ml. of 6 *N* sulfuric acid was heated at reflux for 20 min., the mixture cooled, the alcohol removed under reduced pressure, and the residue extracted with ether. The ethereal solution was washed with 5% sodium bicarbonate and water and was dried over magnesium sulfate. Evaporation of ether afforded 0.57 g. of colorless oil which was distilled from a modified Hickman still to afford 0.51 g. of colorless liquid. Gas chromatographic analysis indicated that 53% of the distillate was *p*-anisylcamphene (X) (38% yield).

***p*-Anisylbornylene (VII).**—To a solution of 64.3 g. (0.024 mole) of VI dissolved in 1 l. of anhydrous ether was added 2.8 g. of boron trifluoride ethereate dissolved in 350 ml. of ether. After storage at room temperature for 3 hr. the mixture was washed with 5% sodium bicarbonate solution and water, dried over magnesium sulfate, and the ether evaporated to afford 57.0 g. of colorless crystalline material, m.p. 65–67.5°. Recrystallization from ethanol afforded 54.5 g. (91%) of *p*-anisylbornylene as colorless plates, m.p. 68.9–69.4°. Two further recrystallizations gave a constant m.p. 71–72°. There was no depression of melting point upon admixture with a sample of VII isolated from the Grignard reaction of camphor and *p*-bromoanisole above.

Hydrogenation of *p*-Anisylbornylene. Preparation of *p*-Isobornylanisole. A. Sponge Nickel Catalyst.—A mixture of 5.00 g. (0.022 mole) of *p*-anisylbornylene and 6.00 g. of sponge nickel[41] in 75 ml. of ethanol was placed in a

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(40) J. H. Gardner and P. Borgstrom, *J. Am. Chem. Soc.*, **51**, 3376 (1929).

(41) Available from Davison Chemical Co.

glass-lined rocking autoclave and hydrogenated for 24 hr. at 2175 p.s.i. of hydrogen at 110°. The Raney nickel was removed by filtration and the ethanol removed under reduced pressure to afford 4.7 g. of colorless liquid which was fractionated on an 18-in. spinning band column to afford 2.67 g. (53%) of *p*-isobornylanisole (IX), b.p. 75°/0.1 mm., m.p. 34–39°. The product recrystallized from ethanol-water in long needles, m.p. 39.5–41.8°. Further recrystallization gave a constant m.p. 41.0–42.4°. The infrared spectrum showed presence of aromatic (6.25, 6.6 μ) and ether (8.0 μ).

Anal. Calcd. for $C_{17}H_{24}O$: C, 83.55; H, 9.90. Found: C, 83.71; H, 9.83.

Gas chromatographic analysis indicated the original product mixture consisted of *p*-isobornylanisole (IX) (72%), *trans-p*-bornylcyclohexanol methyl ether (XII, 16%), *cis-p*-bornylcyclohexanol methyl ether (XIII, 3%), and *p*-isobornylcyclohexane (XIV, 8%). The peaks were identified by comparison of products isolated from the hydrogenation using W-5 Raney nickel catalyst (see following).

B. W-5 Raney Nickel Catalyst.—Hydrogenation of 5.00 g. of olefin VII with 5.00 g. of W-5 Raney nickel[42] at 2500 p.s.i. and 110° for 19 hr. in glass-lined rocking autoclave afforded 4.82 g. of colorless oil which was fractionated on an 18-in. spinning band column. There was isolated 0.90 g. (19%) *p*-isobornylcyclohexane (XIV), b.p. 63°/0.1 mm., n^{25}D 1.4971. The infrared spectrum showed absence of aromatic and ether bands.

Anal. Calcd. for $C_{16}H_{28}$: C, 87.19; H, 12.81. Found: C, 87.38; H, 12.76.

There was isolated 2.24 g. (46%) of a mixture of *cis*-(XIII) and *trans*-(XII) isobornylcyclohexanol methyl ether, b.p. 85°/0.1 mm., n^{25}D 1.4960. Gas chromatographic analysis indicated the mixture to consist of 23% *cis*- and 77% *trans*-isobornylcyclohexanol methyl ether. The infrared spectrum showed absence of aromatic bands but possessed strong absorption at 9.1 μ (ether).

Anal. Calcd. for $C_{17}H_{28}O$: C, 81.53; H, 12.08. Found: C, 81.52; H, 12.07.

The residue consisted of 0.84 g. (7%) of *p*-isobornylanisole (IX), m.p. 41–42°.

Gas chromatographic analysis of the original product mixture indicated the presence of (XIV) (29%), XIII (14%), XII (48%), and VIII (8%).

C. 10% Palladium-on-Charcoal Catalyst.—A solution of 7.0 g. (0.029 mole) of the olefin VII in ethanol was hydrogenated in the presence of 0.6 g. 10% palladium on charcoal at 50 p.s.i. hydrogen initial pressure and 27° in a Parr hydrogenation apparatus with shaking. Total uptake of hydrogen occurred within the first 10 min. (0.0295 mole, 102%), although shaking was continued for 24 hr. After filtration of catalyst the solvent was evaporated and the residue distilled. There was obtained 6.9 g. of a mixture of 60% *p*-isobornylanisole (IX) and 40% *p*-bornylanisole (VIII), b.p. 95.5°/0.5 mm., n^{25}D 1.5392. The mixture could not be separated by fractional distillation or preparative gas chromatography, but was resolved on a 1000-ft. Apiezon L capillary column at 200° and 50 ml./min. helium flow rate.[43] The infrared spectrum of the mixture showed aromatic (6.25, 6.6 μ), methoxy (8.0 μ) peaks. The NMR spectrum indicated a mixture of bornyl- and isobornylanisole derivatives in the ratio 2:3.

Anal. Calcd. for $C_{17}H_{24}O$: C, 83.55; H, 9.90. Found: C, 83.39; H, 9.61.

Reduction of the olefin in different solvents, *i.e.*, acetic acid, methanol, or ethyl acetate gave similar results. Likewise, Adams catalyst afforded a mixture of *exo* and *endo* products. Reduction of the alcohol VI with 10% palladium on charcoal gave a 50:50 mixture of bornyl and isobornyl derivatives but the rate of reduction of the alcohol was slower than the rate of reduction of olefin VII.

Sodium Reduction of *p*-Anisylbornylene. Preparation of *p*-Bornylanisole.—To a solution of 0.46 g. (0.02 g.-atom) of sodium dissolved in 150 ml. of liquid ammonia was added dropwise with stirring 2.47 g. (0.01 mole) of the olefin VII, m.p. 69–71°, in 100 ml. of anhydrous ether. As the last drop of olefin was added, the blue color of sodium dissolved in liquid ammonia disappeared, a light yellow color persisting. The stirring was continued an additional 10 min. when 50 ml. of ethanol was added dropwise over a period of 10 min. After evaporation of liquid ammonia, the mixture was acidified with 50 ml. of 10% hydrochloric acid, diluted with ether and water, the ethereal layer partitioned and washed with 5% sodium bicarbonate solution and water. The ethereal solution was dried over magnesium sulfate and the ether evaporated to afford 2.36 g. of colorless oil, shown by gas chromatography to consist of 94% *p*-bornylanisole (VIII) and 6% starting olefin VII (yield of VIII, 89%). The oil was distilled from an 18-in. spinning band column to yield 1.8 g. (72%) of VIII as a colorless liquid, b.p. 110°/0.1 mm., n^{25}D 1.5400. Infrared spectrum: presence of aromatic (6.25, 6.6 μ) and ether (8.0 μ).

Anal. Calcd. for $C_{17}H_{24}O$: C, 83.55; H, 9.90. Found: C, 83.76; H, 9.76.

Hydrogenation of 1-*p*-Anisylcamphene (X). Preparation of 1-*p*-Anisyl-2-methyl-3,3-dimethylbicyclo[2.2.1]heptane (XV).—A solution of 5.46 g. (0.02 mole) of 1-*p*-anisylcamphene (X) dissolved in 150 ml. of absolute ethanol was hydrogenated in a Parr hydrogenation apparatus at 41 p.s.i. initial hydrogen pressure and room temperature using 0.2 g. 10% palladium-on-charcoal catalyst. The theoretical quantity of hydrogen was consumed after 14 min. but shaking was continued for 16 hr. After removal of catalyst by filtration the solvent was removed under reduced pressure and the residue distilled to afford 5.36 g. (93%) of 1-*p*-anisyl-2-methyl-3,3-dimethylbicyclo[2.2.1]heptane (XV) as a colorless liquid, b.p. 92°/0.1 mm., n^{25}D 1.5359. The product was gas-chromatographically homogeneous, but the NMR spectrum suggested a mixture of epimers. The *endo*-methyl isomer was isolated in 65% yield by recrystallization from methanol in colorless plates, m.p. 43–44°. Infrared spectrum: absence of terminal olefin bands at 6.05 and 11.3 μ.

Anal. Calcd. for $C_{17}H_{24}O$: C, 83.55; H, 9.90. Found: C, 83.47; H, 9.86.

Pyridine Hydrochloride Fusion of *p*-Isobornylanisole (IX). Preparation of *p*-Isobornylphenol (II).—A mixture of 1.00 g. (0.0041 mole) of *p*-isobornylanisole (IX) and 5.0 g. (0.043 mole) of anhydrous pyridine hydrochloride were heated under a nitrogen atmosphere at 250° for 4 hr. The reaction mixture was cooled, diluted with 50 ml. of water, extracted with ether, and the ethereal layer washed with 10% hydrochloric acid, 5% sodium bicarbonate and water, dried, and evaporated under reduced pressure to yield 0.65 g. (69%) of *p*-isobornylphenol as fine needles, m.p. 151–152°, after recrystallization from benzene–petroleum ether. Infrared spectrum: λ 2.9, 7.9–8.2 μ (phenol).

Anal. Calcd. for $C_{16}H_{22}O$: C, 83.43; H, 9.63. Found: C, 83.49; H, 9.56.

Pyridine Hydrochloride Fusion of *p*-Bornylanisole (VIII). Preparation of *p*-Bornylphenol (I).—The same procedure was followed as for cleavage of the isobornyl isomer. From 1.71 g. (0.007 mole) of VIII and 5.0 g. (0.043 mole) of pyridine hydrochloride there was obtained 1.0 g. (60%) of *p*-bornylphenol as needles, m.p. 135–136°, after recrystallization from benzene–petroleum ether. Infrared spectrum: λ 2.85, 7.9–8.1 μ (phenol).

Anal Calcd. for $C_{16}H_{22}O$: C, 83.43; H, 9.63. Found: C, 83.27; H, 9.40.

Preparation of 2-*exo*-*p*-Anisylepiborneol (XVI).—The general hydroboration procedure of Brown[27a,c] was used for

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[42] H. R. Billica and H. Adkins, *Org. Syn.*, **Coll. Vol. III**, 176 (1953).

[43] The authors are indebted to Dr. C. H. Orr for capillary column gas chromatograms mentioned in this work.

hydroboration of 2-*p*-anisylbornylene (VII). Diborane, generated from 28.5 g. (0.20 mole) of boron trifluoride etherate and 5.1 g. (0.135 mole) of sodium borohydride, was passed into a solution of 5.0 g. (0.02 mole) of *p*-anisylbornylene VII in 200 ml. of tetrahydrofuran (Baker reagent grade, freshly distilled over sodium) over a period of 30 min. After oxidation with alkaline peroxide there was obtained 5.68 g. of colorless oil which was chromatographed over Woelm Activity V alumina. Elution with petroleum ether separated 0.3 g. of olefin VII, m.p. 65–67°. Further elution with petroleum ether afforded 4.28 g. (75%) of 2-*exo*-*p*-anisylepiborneol (XVI) as a colorless oil which could not be induced to crystallize. The NMR spectrum indicated a pure isomer. Infrared spectrum; λ 2.9 μ (hydroxyl).

Anal. Calcd. for $C_{17}H_{24}O_2$: C, 78.42; H, 9.29. Found: C, 77.95; H, 9.17.

Treatment of 5.96 g. (0.023 mole) of the alcohol XVI prepared from a separate run, with 6.2 g. (0.051 mole) of *p*-toluenesulfonyl chloride in 50 ml. of pyridine afforded 4.37 g. (44%) of tosylate (XVIa), m.p. 97–102°. Two more recrystallizations from ethanol gave glistening rhombic prisms, m.p. 102.6–103.6°.

Anal. Calcd. for $C_{24}H_{30}O_4S$: C, 69.54; H, 7.30. Found: C, 69.77; H, 7.42.

Preparation of 2-*exo*-*p*-Anisylepicamphor (XVII).—Essentially the method of Moriarty and Wallis[31d] for the oxidation of A-norcholest-5-en-3-one using the standard chromate reagent described by Kent and Wallis[31c] was employed for oxidation of 2-*exo*-*p*-anisylepiborneol (XVI). A solution of 20.0 g. (0.077 mole) of XVI in 700 ml. of absolute acetone was titrated at 35° (at temperatures significantly below 35° reaction was too slow to allow direct titration) with 31.0 cc. (0.83 mole) of standard chromate reagent over a period of approximately 10 min. The appearance of the red color of chromate indicated the end point. The reaction mixture was poured into 250 ml. of saturated sodium bisulfite solution, 500 ml. of saturated sodium bicarbonate was added, and the mixture extracted with ether. The ethereal layer was washed with water, dried over magnesium sulfate, and evaporated to afford 18.4 g. of colorless crystalline solid, m.p. 105–117°. Recrystallization of 15.6 g. of this material from ethanol afforded 12.3 g. (65%) of 2-*exo*-*p*-anisylepicamphor (XVII) as colorless plates, m.p. 119–122°. Further recrystallization from ethanol gave a constant m.p. 121.2–122.4°. Infrared spectrum: λ 5.78 μ.

Anal. Calcd. for $C_{17}H_{22}O_2$: C, 79.03; H, 8.58. Found: C, 78.96; H, 8.61.

The 2,4-dinitrophenylhydrazone[44] was recrystallized from ethanol in golden yellow needles, m.p. 195.5–196.5.

Anal. Calcd. for $C_{17}H_{26}N_4O_4$: C, 63.00; H, 5.98; N, 12.78. Found: C, 62.81; H, 5.58; N, 12.58.

Preparation of 2-*endo*-*p*-Anisylepicamphor (XVIII). A. By Equilibration of 2-*exo*-*p*-Anisylepicamphor (XVII).—To a solution of 2.0 g. (0.09 g.-atom) of sodium in 90 ml. of absolute ethanol was added 1.79 g. (0.007 mole) of 2-*exo*-*p*-anisylepiborneol dissolved in 25 ml. of ethanol and the solution heated at reflux for 6 hr. The ethanol was removed under reduced pressure and the residue diluted with cold water and extracted with ether to afford 1.63 g. of orange-colored oil which solidified on standing. The solid was recrystallized from ethanol to afford 1.0 g. (56%) of 2-*endo*-*p*-anisylepicamphor (XVIII), as colorless rhombic prisms, m.p. 91–93°. Recrystallization from ethanol gave a constant m.p. 91.5–93°. Infrared spectrum, λ 5.78 μ.

Anal. Calcd. for $C_{17}H_{22}O_2$: C, 79.03; H, 8.58. Found: C, 78.92; H, 8.60.

The 2,4-dinitrophenylhydrazone[44] was recrystallized from ethanol in golden yellow needles, m.p. 195.5–196.5°. There was no depression of melting point when a sample of the 2,4-dinitrophenylhydrazone, m.p. 195.5–196.5°, from the *exo* ketone XVII, was mixed with the above 2,4-dinitrophenylhydrazone. Apparently the acid conditions required for 2,4-dinitrophenylhydrazone formation effected equilibration of XVII before condensation with the hydrazine occurred.

B. By Epoxidation of 2-*p*-Anisylbornylene (VII).—To a solution of 5.0 g. (0.02 mole) of 2-*p*-anisylbornylene in 150 ml. of ether was added at room temperature 6 ml. of peracetic acid solution (Becco 40% in acetic acid) containing 2.32 g. (0.03 mole) of peracetic acid. This mixture was stored 16 hr. at room temperature when it was diluted with ether and water and washed with saturated sodium bicarbonate solution and water. The ethereal solution was dried over magnesium sulfate and evaporated to afford 5.7 g. of a colorless, viscous oil which was subjected to chromatography through 100 g. of Woelm Activity III alumina. Elution with 1:1 petroleum ether–benzene yielded 0.50 g. of starting olefin. Further elution gave 2.24 g. (42%) of 2-*endo*-*p*-anisylepicamphor (XVIII) which was recrystallized in colorless prisms from ligroin, m.p. 88–91°. A sample of the crystals, m.p. 88–91° showed no depression of melting point, 91–92.5°, upon admixture with the 2-*endo* ketone XVIII, m.p. 91.5–93°, prepared by equilibration of the *exo* ketone XVII. The infrared and NMR spectra of the two ketones were identical. Further elution with ether separated an ester, the structure of which was not elucidated. The ester probably resulted from a Baeyer-Villiger oxidation of the ketone with the excess peracetic acid.

Attempts to oxidize the olefin VII with monoperphthalic acid gave an 81% recovery of starting olefin VII after 12 hr.

Preparation of 2-*endo*-*p*-Anisylepiborneol (XX). A. From Sodium Borohydride Reduction of 2-*exo*-*p*-Anisylepicamphor (XVII).—To a solution of 2.0 g. (0.05 mole) of sodium borohydride in 100 ml. of absolute methanol was added 2.41 g. (0.009 mole) of the ketone (XVII) in 100 ml. of absolute methanol. The mixture was stored at room temperature overnight then was heated at reflux for 30 min., cooled to room temperature, and diluted with 10% hydrochloric acid solution. The bulk of the methanol was removed under reduced pressure and the product extracted with ether. The ethereal layer was washed with 5% sodium bicarbonate and water, dried, and evaporated to afford 1.92 g. (80%) of 2-*endo*-*p*-anisylepiborneol (XX) as a colorless oil. Infrared spectrum: λ 2.9 μ; absence of carbonyl band at 5.78 μ. Treatment of the oil with 2.7 g. of *p*-toluenesulfonyl chloride in 100 ml. of pyridine afforded 1.34 g. (63%) of the *p*-toluenesulfonate of XX as colorless prisms, m p. 125.2–126.2° dec., after recrystallization from ethanol. The crystals melted with decomposition and formation of a deep wine-red liquid. Further recrystallization gave a m.p. 135–137°. There was no depression of melting point upon admixture with a sample of XX tosylate prepared from XVIII below. The NMR spectra of the two tosylates were identical.

Anal. Calcd. for $C_{24}H_{30}O_4S$: C, 69.54; H, 7.30. Found: C, 69.55; H, 7.14.

B. From Sodium Borohydride Reduction of 2-*endo*-*p*-Anisylepicamphor (XVIII).—The procedure was the same as employed for reduction of the *exo* ketone XVII. From 1.51 g. (0.006 mole) of XVIII there was obtained an oil which was treated with *p*-toluenesulfonyl chloride in pyridine to afford 0.92 g. (54%) of tosylate XXa, m.p. 135–138°, after recrystallization from ethanol. The material was recrystallized in colorless prisms, m.p. 137.0–138.5°, for analysis.

Anal. Calcd. for $C_{24}H_{30}O_4S$: C, 69.54; H, 7.30. Found: C, 69.33; H, 7.17.

Wolff-Kishner Reduction of 2-*endo*-*p*-Anisylepicamphor (XVIII). Preparation of *p*-Bornylphenol (I).—Essentially the method of Barton[37] was employed for the reduction of

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(44) R. L. Shriner and R. C. Fuson, "The Systematic Identification of Organic Compounds," John Wiley & Sons, Inc., New York, 1948, p. 171.

2-*endo*-*p*-anisylepicamphor (XVIII). To 50 ml. of freshly distilled triethylene glycol placed in a 100 ml. three-necked round-bottomed flask fitted with thermometer, nitrogen system, and reflux condenser connected to a still head from a hydrazine distillation apparatus was added 1.0 g. (0.043 g.-atom) of sodium and the temperature raised to 180° for 3 hr. The ketone (2.64 g., 0.01 mole) was added and the temperature maintained at 180° 2 hr. longer, when 8 ml. (8.1 g., 0.25 mole) of anhydrous hydrazine, prepared according to the method of Barton,[37] was distilled over sodium hydroxide into the flask. The temperature was maintained at 180° for 18 hr., then part of the hydrazine (about 4 cc.) distilled until a temperature of 210° was achieved. The temperature was controlled at 210° for 24 hr., the solution cooled, diluted with water, and extracted with ether. The ethereal layer was washed with water dried over magnesium sulfate, and evaporated to yield 1.4 g. (60%) of *p*-bornylphenol (I) as rhombical prisms, m.p. 133–134.5°, after recrystallization from benzene–petroleum ether. The mixture melting point of the above sample, m.p. 133–134.5°, and a sample of the product from pyridine hydrochloride fusion of *p*-bornylanisole, m.p. 135–136°, obtained from reduction of *p*-anisylbornylene (VII) with liquid ammonia, showed no depression, m.p. 133–135°. The infrared and NMR spectra were identical.

Anal. Calcd. for $C_{16}H_{22}O$: C, 83.43; H, 9.63. Found: C, 82.86; H, 9.55.

To a solution of 0.35 g. (0.01 mole) of the *p*-bornylphenol above, m.p. 133–134.5°, dissolved in 50 ml. of acetone and placed in a 100 ml. three-necked round-bottomed flask fitted with mechanical stirrer, condenser, and nitrogen system, was added 12.0 g. (0.09 mole) of potassium carbonate and 13.87 g. (0.11 mole) of dimethylsulfate. The mixture was stirred vigorously and heated at reflux for 3 hr. when it was cooled to room temperature, the potassium carbonate removed by filtration through Filter-Cel, and the acetone removed under reduced pressure. The excess dimethyl sulfate was decomposed by the careful addition of concd. ammonium hydroxide, the mixture extracted with ether, the ethereal solution washed with water, 10% hydrochloric acid, 5% sodium bicarbonate, and water, dried, and the ether removed under reduced pressure to afford 0.31 g. (83%) of *p*-bornylanisole as a colorless liquid, b.p. 110°/0.1 mm., $n^{25}D$ 1.5397. The product was shown to be identical with the product from sodium reduction of *p*-anisylbornylene by gas chromatography, by comparison of the infrared and NMR spectra and physical constants.

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Geometrical Isomers of 3-Methyl-5-phenyl-2,4-pentadienoic Acid. The Two 4-*cis* Isomers and Their NMR Characteristics

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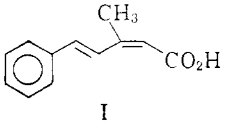
The NMR characteristics of the two unknown geometric isomers (2-*cis*-4-*cis* and 2-*trans*-4-*cis*) of 3-methyl-5-phenylpentadienoic acid and their esters have been obtained from 30% and 95% pure samples of these compounds prepared by partial hydrogenation of the acetylenic esters. The NMR data establish differences in the compounds which have been used to assign the 3-*s*-*trans* structure to the 4-*cis* isomers.

Previous studies[1] of the geometrical isomers of 3-methyl-5-phenyl-2,4-pentadienoic acid have shown that the two known isomers have the 2-*trans*-*4*-*trans* (II), m.p. 160°, and the 2-*cis*-4-*trans* (I), m.p. 158°, configurations. We have now examined the possibility of preparing the two unknown 4-*cis* isomers (III, IV) by partial hydrogenation of the esters of the corresponding 2-*cis* and 2-*trans* isomers of 3-methyl-5-phenylpent-2-en-4-ynoic acids and have, in the course of these studies, shown that their NMR absorption characteristics provide a conclusive basis for structural assignment in the series and establish that the 4-*cis* isomers exist in a preferred 3-*s*-*trans* conformation.



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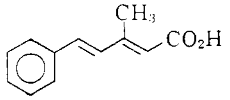

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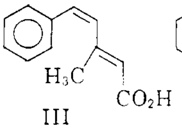

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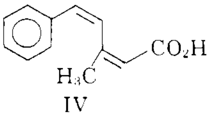

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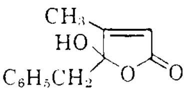

V

The two geometrical isomers of 3-methyl-5-phenylpent-2-en-4-ynoic acid are obtained as a mixture of their methyl esters on dehydration of methyl 3-hydroxy-3-methyl-5-phenyl-4-pentynoate over phosphorus oxychloride–pyridine. The ester of the hydroxy acid is formed in 70–80% yield in the Reformatsky reaction between 4-phenyl-3-butyn-2-one and methyl bromoacetate. Saponification of the *cis*-*trans* mixture of the esters gives a solid acid, m.p. 128°. This acid has NMR characteristics (Table I) which indicate that it is the *trans* acid and that it is at least 95% pure stereochemically. Re-esterification of the acid gives the 2-*trans* ester again 95% pure stereochemically. The *cis* acid has not been separated from the mother liquor from which the *trans* acid was crystallized in a solid form. The liquid acid is approximately 60% *cis* stereochemically, based on its NMR ab-

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[1] Richard H. Wiley, *J. Chem. Soc.*, 3831 (1958).