Dimethyl oxalate was also observed when the polar material obtained from the ozonolysis of 4 (14 mg) was treated in a similar fashion.

Reduction of the Enamides 11 and 12 with Sodium Borohydride. To 2 mg of a 1:1 mixture of 11 and 12 dissolved in 15 mL of ethanol was added 100 mg of sodium borohydride. The solution was stirred at room temperature for 20 h. Excess reagent was destroyed with 1 N hydrochloric acid, and the solution was concentrated and extracted with dichloromethane. The dichloromethane layer was dried over anhydrous sodium sulfate and evaporated to give a mixture of 17 and 18: ^{1}H NMR ($(CD_3)_2SO$) δ 1.0 (m, $(CH_3)_2CH$), 1.7 (m, Leu γ-CH and β-CH_2), 1.78 (s, NHAc), 1.9 (m, Val β-CH), 2.73 (dd, J = 7.5, 15.7 Hz, Trp β-CH_2), 2.90 (dd, J = 6.3, 15.7, Trp β-CH_2), 3.36 (s, OMe), 3.66 (m, β-CH_2), 3.93 (m, Leu α-CH), 4.02 (m, Val α-CH), 4.45 (m, α-CH), 4.73 (m, α-CH), 7.09 (dd, J = 1.6, 8.7 Hz, indole H_5), 7.11 (br s, $CONH_2$), 7.13 (d, J = 2.7 Hz, indole H_2), 7.54 (d, J = 1.6 Hz, indole H_7), 7.56 (d, J = 8.7 Hz, indole H_4), 7.80 (d, J = 8.3 Hz, NH), 7.92 (br s, $CONH_2$), 8.31 (s, PhH), 10.92 (br s, indole H_1).

Isolation with Acetic-d_6 Anhydride. A small-scale isolation procedure (40 g, wet weight of sponge) employing acetic-d_6 anhydride (10 mL, 99+ atom %; Aldrich) as the acetylating agent yielded hexaacetylcelenamide-d_{18} A (5, 12 mg) and hexaacetylcelenamide-d_{18} B (6, 8 mg) which proved to be identical with 3 and 4 (TLC, IR, ^{1}H NMR), respectively, with the exception of the absence of signals in the ^{1}H NMR spectra corresponding to phenol acetate and acetamide.

Acknowledgment. We thank Michael LeBlanc (British Columbia collections) and Dr. D. J. Faulkner (La Jolla collections) for assistance in collecting *Cliona celata*. This work was supported by the Natural Science and Engineering Research Council of Canada. R.J.S. thanks the Natural Science and Engineering Research Council of Canada for a postgraduate scholarship.

Registry No. 3, 74144-16-4; 4, 74144-17-5; 5, 74144-18-6; 6, 74144-19-7; 9, 68857-44-3; 11, 74144-20-0; 12, 74144-21-1; 13, 74144-22-2; 14, 74144-23-3; 15, 74144-24-4; 16, 74144-25-5; 17, 74144-26-6; 18, 74144-27-7; 3,4,5-triacetoxybenzaldlehyde, 71932-18-8; 3,4-diacetoxybenzaldehyde, 67727-64-4; leucine, 61-90-5; valine, 72-18-4; dimethyl oxalate, 553-90-2.

Synthesis of Phosphines Having Chiral Organic Groups Ligated to Chiral Phosphorus

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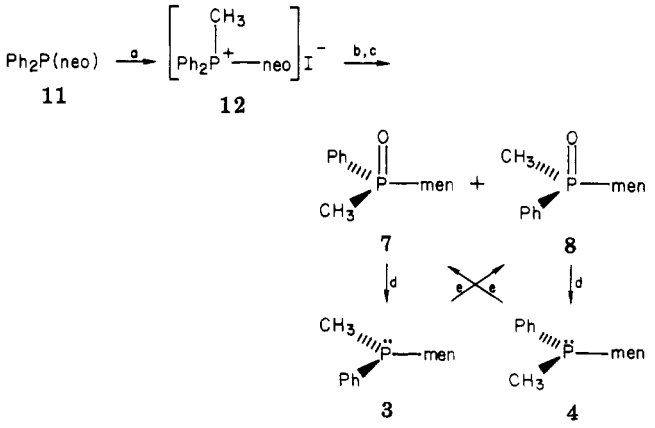
Both *R* and *S* phosphorus epimers of menthylmethylphenylphosphine and its phosphine oxide and of neomenthylmethylphenylphosphine and its phosphine oxide were prepared. The menthylmethylphenylphosphine oxides were prepared from neomenthyldiphenylphosphine by a method which is potentially general for synthesis of phosphines and phosphine oxides having chiral organic groups ligated to chiral phosphorus. Thus, neomenthyldiphenylphosphine was quaternized by methyl iodide to give neomenthylmethyldiphenylphosphonium iodide which was decomposed in boiling aqueous methanolic sodium hydroxide to give a 1:1 mixture of *R* and *S* phosphorus epimers of menthylmethylphenylphosphine oxides. The pure diastereomers were obtained from the mixture by fractional crystallization and reduced to the phosphines by using hexachlorodisilane. Structures of the *R* phosphorus epimers of both menthyl- and neomenthylmethylphenylphosphine oxides are reported. The structure of η^4-(1,5-cyclooctadiene)bis[(*R*)-menthylmethylphenylphosphine]rhodium(I) tetrafluoroborate is also reported.

Chiral phosphines have been widely used to prepare low-valent transition-metal-complex catalysts for enantioselective organic transformations.[1,2] The most commonly used type of chiral phosphine is the chelating diphosphine in which two achiral phosphorus centers are connected by a chiral link, e.g., DIOP (1),[3] or in which two chiral phosphorus centers are linked by an achiral connector, as in DIPAMP (2)[4] (Chart I). Another possibility is ligation of chiral organic groups to chiral phosphorus. Few examples are known of this type, apparently because of a lack of adequate synthetic methods. One exception is the recent description by Fisher and Mosher[5] of the diastereomeric menthylmethylphenylphosphines 3 and 4, which they prepared by condensation of sodium methylphenylphosphide with neomenthylchloride as shown in eq 1. We were also interested in these phosphines for the

$$NaP(Ph)(CH_3) + Cl(neo) \rightarrow 3 + 4 \qquad (1)$$

formation of catalysts for asymmetric hydrogenations of acrylic acids.[6] Phosphines 3 and 4 have been prepared by a convenient and potentially general new method. We have also prepared for the first time the corresponding neomenthylmethylphenylphosphines 5 and 6. This paper

Scheme I. Menthylmethylphenylphosphines and Their Phosphine Oxides[a]



[a] Conditions: a, CH_3I, 23 °C, 18 h, then reflux 2 h (95% yield); b, reflux, NaOH/aqueous CH_3OH, 18 h (88%, 7/8 ratio ~1:1); c, fractional crystallization, see text; d, Si_2Cl_6, 80 °C, 10 min, C_6H_6; e, 30% H_2O_2, 23 °C, 18 h, C_6H_6.

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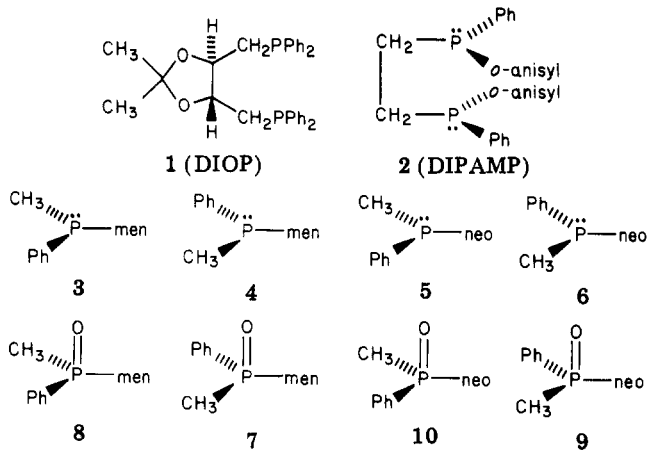
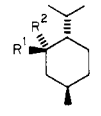
0022-3263/80/1945-3691$01.00/0

Chart I[a]



[a] The abbreviations "men" and "neo" refer to moieties derived from *l*-menthol (natural menthol); i.e.,[7] for "neo", R^1 = H and R^2 = substituent, and for "men", R^1 = substituent and R^2 = H in structure I.



I

describes the preparations and properties of **3–6**, the corresponding phosphine oxides **7–10**, and several related substances. Uses of **3–6** to form rhodium catalysts for asymmetric hydrogenations of acrylic acid derivatives are described in the accompanying paper.[6]

Results

(1) Menthylmethylphenylphosphines and Their Phosphine Oxides. Menthylmethylphenylphosphines **3** and **4** and the corresponding phosphine oxides **7** and **8** were prepared as shown in Scheme I. The method used was based on the well-known alkali hydroxide induced decomposition of quaternary phosphonium cations (eq 2).[8] These decompositions had been little used synthetically, but it was known from many mechanistic studies that yields were good and that product would be formed by loss of the most electronegative group, R^4.

$$[R^1R^2R^3R^4P^+] + OH^- \rightarrow R^1R^2R^3PO + R^4H \quad (2)$$

Neomenthyldiphenylphosphine (**11**), which is readily available,[9] was quaternized by methyl iodide to give neomenthyldiphenylmethylphosphonium iodide (**12**).[10] The epimeric menthyldiphenylphosphine[11] (**13**) was converted to menthyldiphenylmethylphosphonium iodide (**14**) whose

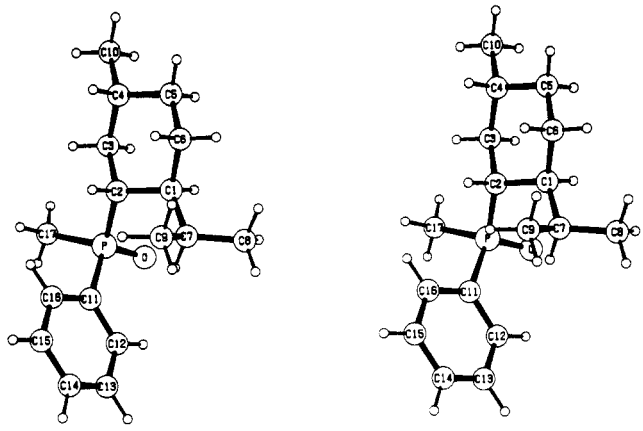


Figure 1. Structure of the *R* epimeric menthylmethylphenylphosphine oxide, **7**.

^1H NMR was clearly distinct from that of **12**. Decomposition of either **12** or **14** in boiling aqueous methanolic sodium hydroxide gave a 85–90% distilled yield of an ca. 1:1 mixture of menthylmethylphenylphosphine oxides **7** and **8** and none of the corresponding neomenthyl systems **9** and **10**. It was found that under the conditions used to decompose **12** it was rapidly epimerized to **14** with the result that the phosphonium salts recovered from incomplete decompositions of **12** contained only the menthyldiphenylmethylphosphonium cation. In synthetic applications, use of **12** rather than **14** was preferred because of the ease of synthesis of **11**.

The 1:1 mixture of **7** and **8** obtained from decomposition of **12** was readily separated. One crystallization of the mixture from 7:1 hexane–benzene gave pure **7** in a 23% yield based on **11**. Evaporation of the mother liquors and crystallization of the residue from diisopropyl ether gave pure **8** in a 10% yield based on **11**.

Structures and relative stereochemistries of **3**, **4**, **7**, and **8** were firmly established. The structure of **7** as determined by X-ray crystallography is shown as Figure 1. The structures of **3**, **4**, and **8** were related to the structure of **7** by the chemical interconversions outlined in Scheme I. Thus, reduction of **7** by Si_2Cl_6 (80 °C, 10 min, C_6H_6), a procedure which is known to convert $R^1R^2R^3PO$ to $R^1R^2R^3P$ with inversion of phosphorus configuration, gave phosphine **3** as a colorless oil in an 83% yield (21% based on **11**).[12,13] Reoxidation of **3** by 30% H_2O_2 in benzene, a process which is known to convert $R^1R^2R^3P$ to $R^1R^2R^3PO$ with retention of phosphorus configuration, gave as crude product **8**,[13,14] which was a pure phosphorus epimer according to ^{31}P NMR. Similarly, reduction of **8** by Si_2Cl_6 (80 °C, 10 min, C_6H_6) gave **4** (56% yield based on **8**; 6% yield based on **11**) as a colorless oil. Reoxidation of **4** by H_2O_2 gave **7**, which was a pure epimer according to ^{31}P NMR.

The chemical interconversions described above unequivocably establish the structures of **3**, **4**, **7**, and **8** and prove further that both the Si_6Cl_6 reductions of **7** and **8** and the H_2O_2 oxidations of **3** and **4** are effectively stereospecific. The latter finding is important to the synthetic utility of Scheme I. In our experience, Si_2Cl_6 is the only useful reagent to reduce **7** and **8**. Use of the less

(1) Review: J. W. Scott and D. Valentine, Jr., *Science*, **184**, 943 (1974).
(2) Review: D. Valentine, Jr. and J. W. Scott, *Synthesis*, 329 (1978).
(3) T.-P. Dang and H. B. Kagan, *J. Am. Chem. Soc.*, **94**, 6429 (1972).
(4) W. S. Knowles, M. J. Sabacky, B. D. Vineyard, and D. J. Weinkauff, *J. Am. Chem. Soc.*, **97**, 2567 (1975).
(5) C. Fisher and H. S. Mosher, *Tetrahedron Lett.*, 2487 (1977).
(6) D. Valentine, Jr., K. K. Johnson, W. Priester, R. C. Sun, K. Toth, and G. Saucy, *J. Org. Chem.*, following paper in this issue.
(7) Among compounds **3–10**, **3**, **5**, **7**, and **9** have the *R* configuration at phosphorus while **4**, **6**, **8**, and **10** have the *S* configuration.
(8) Review: H. R. Hays and D. J. Peterson in "Organic Phosphorus Chemistry", Vol. 3, G. Kosolapoff and L. Maier, Eds., Wiley-Interscience, New York, 1972, p 341.
(9) J. D. Morrison and W. F. Masler, *J. Org. Chem.*, **39**, 270 (1974).
(10) Toxic substance. Exposure to the dust has caused respiratory tract irritation in two of us.
(11) Y. Kiso, K. Yamamoto, K. Tamao, and M. Kumada, *J. Am. Chem. Soc.*, **94**, 4373 (1972).
(12) K. Naumann, G. Zon, and K. Mislow, *J. Am. Chem. Soc.*, **91**, 7012 (1969).
(13) "Inversion" is used in the sense that if O is replaced by an electron pair in $R^1R^2R^3PO$ to give $R^1R^2R^3P$:, the direction of rotation of R^1, R^2, and R^3 is reversed. Similarly, "retention" means that replacing O by electron pair or vice versa does not change the direction of rotation of R^n.
(14) L. Horner, *Pure Appl. Chem.*, **9**, 225 (1964).

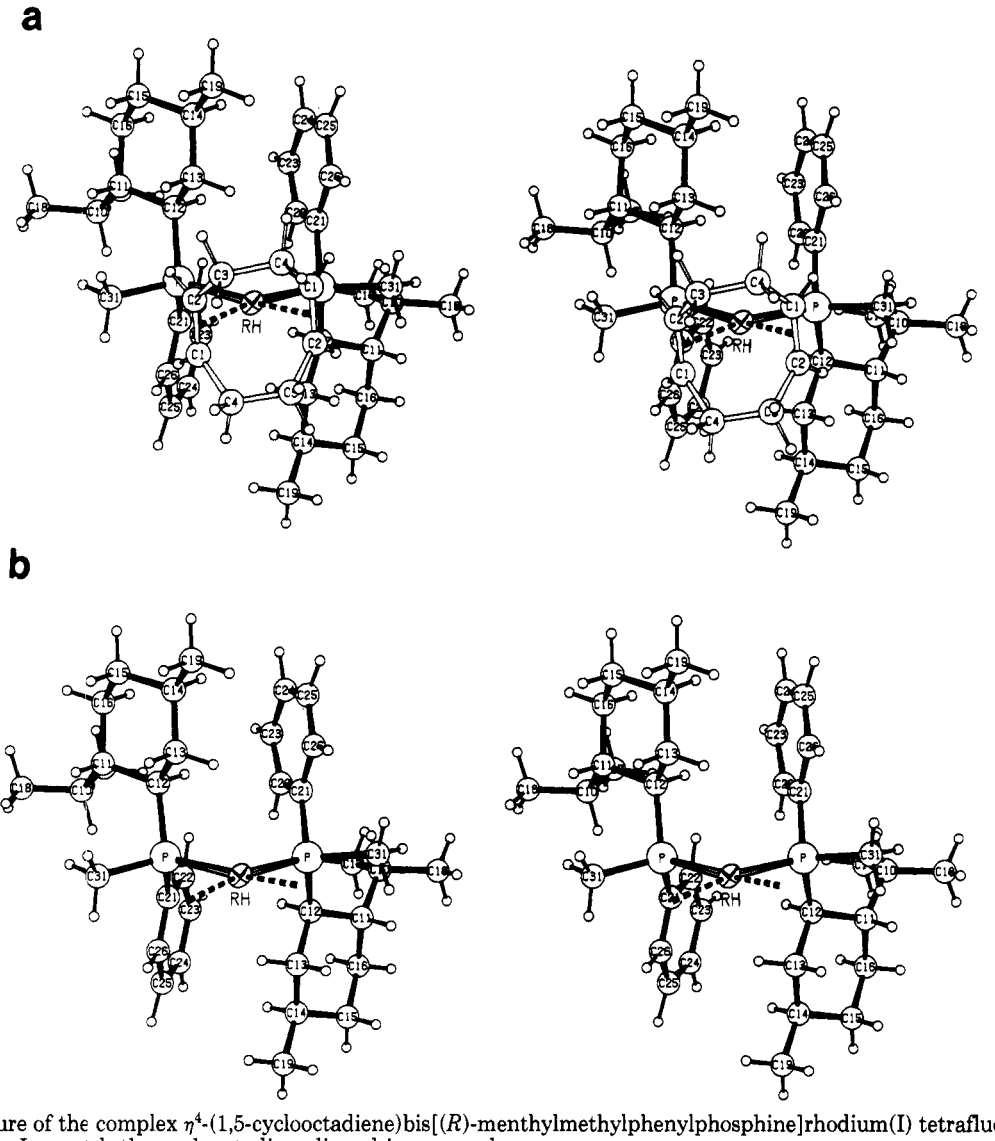
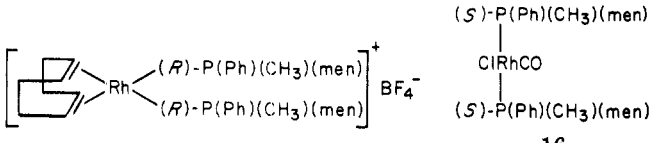


Figure 2. Structure of the complex η^4-(1,5-cyclooctadiene)bis[(*R*)-menthylmethylphenylphosphine]rhodium(I) tetrafluoroborate viewed along the C_2 axis. In part b the cyclooctadiene ligand is removed.

expensive combination reagent $HSiCl_3$–$(C_2H_5)_3N$ (73–75 °C, 90 min, neat)[15] to reduce **7** gave a 4:1 mixture of **3** and **4**. Similarly, treatment of **7** with phenylsilane (93–95 °C, 4 h, neat), a reagent reported to reduce $R^1R^2R^3PO$ to $R^1R^2R^3P$ with retention of phosphorus configuration,[16] gave **4** (retention) contaminated with about 10% of **3**.

Phosphines **3** and **4** were characterized further by converting them to the rhodium complexes **15**[17] and **16**,[18] respectively. The structure of **15** was determined by X-ray crystallography and is shown as Figure 2.



15 **16**

(2) Menthylalkylphenylphosphine Oxides. Quaternization of **11** by iodoethane gave **17**, whose decomposition in boiling aqueous methanol afforded **18** (two diastereomers in a 5:7 ratio).[19] Similarly, **11** reacted with 2-iodopropane to give **19**, which decomposed to **20** (two diastereomers in a 1:1 ratio) (eq 3). The same methods

$$\mathbf{11} \xrightarrow{RI} [Ph_2RP^+neo]I^- \xrightarrow[CH_3OH(aq),\ reflux]{NaOH} \underset{\mathbf{19},\ R = 2\text{-}C_3H_7}{\mathbf{17},\ R = C_2H_5} \quad (Ph)(R)(men)P{=}O \quad \underset{\mathbf{20},\ R = 2\text{-}C_3H_7}{\mathbf{18},\ R = C_2H_5} \qquad (3)$$

could be used to prepare diphosphines. Thus, quaternization of **11** by 1,4-diiodobutane afforded **21** (eq 4) which

$$\mathbf{11} \xrightarrow{I(CH_2)_4I} [(Ph)_2(neo)P^+(CH_2)_4P^+(neo)(Ph)_2]I_2 \xrightarrow[HMPTA,\ 120\ °C,\ 18\ h]{NaOH} \underset{\mathbf{21}}{} (Ph)(men)P(O)(CH_2)_4P(O)(Ph)(men) \quad (4)$$
$$\mathbf{22}$$

was decomposed (120 °C, 18 h, HMPTA) to **22**, which was obtained as a mixture of three diastereomers in an ca. 3:3:1 ratio according to ^{31}P NMR. One of the major components was the meso diastereomer, (*R*,*S*)-**22**, which was isolated as a crystalline solid, mp 180–182 °C. On the basis of the

(15) E.g., ref. 12.
(16) K. L. Marsi, *J. Org. Chem.*, **39**, 265 (1974).
(17) R. R. Schrock and J. A. Osborne, *J. Am. Chem. Soc.*, **93**, 2397 (1971).
(18) J. A. McCleverty and G. Wilkinson, *Inorg. Synth.*, **8**, 214 (1966).
(19) Compounds **18**, **20**, and **22** are presumed by analogy with the similarly prepared **7** and **8** to contain menthyl rather than neomenthyl groups.

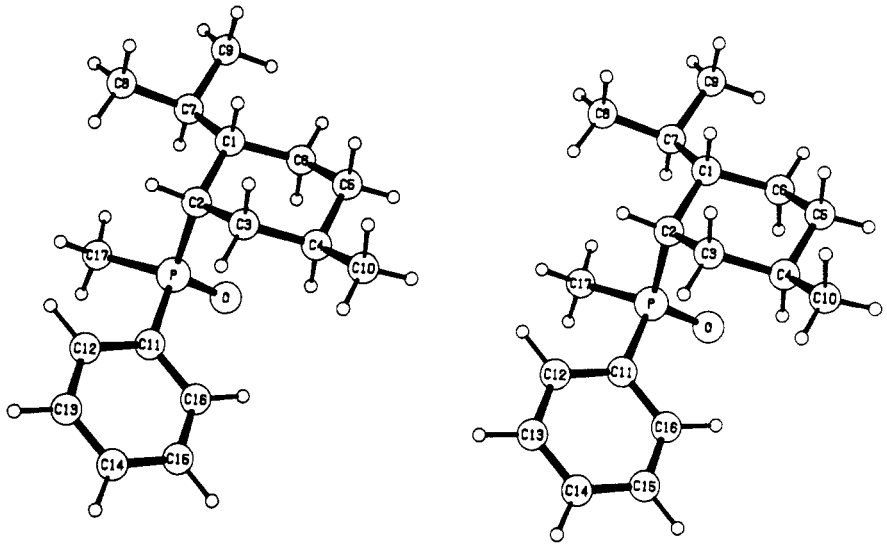
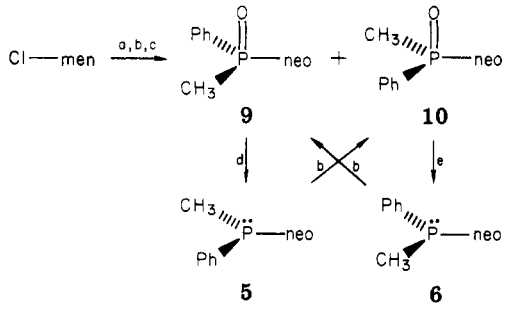


Figure 3. Structure of the *R* epimeric neomenthylmethylphenylphosphine oxide, **9**.

Scheme II. Neomenthylmethylphenylphosphines and Their Phosphine Oxides[a]



[a] Conditions: a, $KP(CH_3)(Ph)$, THF; b, 30% H_2O_2, C_6H_6; c, fractional crystallization; d, Si_2Cl_6, 80 °C, 2 h, C_6H_6; e, Si_2Cl_6, 80 °C, 4 h, C_6H_6.

observed ratio of **22** diastereomers, it was calculated that in decompositions of **21** there was about a 2:1 preference for formation of one epimeric phosphorus configuration compared to the other.

Properties of the menthylalkylphenylphosphine oxides prepared in this work are given in Table I.

(3) Neomenthylmethylphenylphosphines and Their Phosphine Oxides. Diastereomeric neomenthylmethylphenylphosphines **5** and **6** and their phosphine oxides **9** and **10** were obtained from the condensation of potassium methylphenylphosphide with (−)-menthyl chloride in tetrahydrofuran as shown in Scheme II. The best conditions found for this condensation gave a mixture of **3**–**6** which, after H_2O_2 oxidation, was found to contain **7**–**10** in an ca. 1:1:19:19 ratio. Use of either $[NaP(CH_3)(Ph)]$ or $[LiP(CH_3)(Ph)]$ gave more menthyl products, **20** and 33%, respectively. Crystallization from hexane removed the menthyl epimers, and the resulting ca. 1:1 mixture of **9** and **10** was separated by repeated fractional crystallizations (see Experimental Section) to give, from 30 g of 1:1 mixture, 2.7 g of **9** and 0.7 g of **10**.

The structure of **9** was determined by X-ray crystallography (see Figure 3). The conformation of **9** is similar to that adopted by **11** in solution.[20] The cyclohexane ring is in the chair form with the methyl and isopropyl groups equatorial and the phosphinyl substituent axial.

(20) A. M. Aguiar, C. J. Morrow, J. D. Morrison, R. E. Burnett, W. F. Masler, and N. S. Bhacca, *J. Org. Chem.*, 41, 1545 (1976).

Table I. Chiral Menthyl and Neomenthyl Groups Ligated to Chiral Phosphorus

compd	diastereomer ratio	^{31}P NMR[b]	other properties and comments
12			mp 194.5–195 °C; toxic, irritating substance
17		32.37	mp 254–259 °C/dec; toxic, irritating substance
19		35.9	mp 222–224 °C/dec; toxic, irritating substance
18	0.71[a]		from **17** in $NaOH/H_2O/CH_3OH$
18	1.36[a]		from **17** via the ylide made with $Na(CH_2SOCH_3)$ in Me_2SO
20	~1[a]	49.2, 46.1	ν_{PO} 1153, 1168 cm^{-1} ($CHCl_3$)
21			toxic, irritating substance; extremely insoluble
22	*RR/RS/SS* = 1:2:2[c]		observed diastereomer ratios indicate a 6:4 *R/S* center ratio is produced in hydrolysis of **20**
(*R,S*)-**22**	pure		mp 170–172 °C; $[\alpha]^{25}_D$ −32° (*c* 0.95, $CHCl_3$)

[a] According to GLC: HP Model 402B, 1/4 in. × 4 ft glass column, on-column injection, 3.8% UCW 98 on Chromosorb Q, 205 °C. [b] Spectral values for $CHCl_3$ solutions in parts per million relative to 50% H_3PO_4 as external standard. [c] By ^{31}P NMR as in footnote *b*.

The chemical interconversions outlined in Scheme II served to relate the structures of **5**, **6**, **9**, and **10**. The behavior of the neomenthyl systems was similar to that of the menthyl systems. One significant difference was that Si_2Cl_6 reductions of **9** and **10** were about 10–20 times slower than corresponding reductions for **7** and **8**. Despite this, however, both the conversion of **9** to **5** and that of **10** to **6** were highly stereoselective. Phosphine **5** crystallized after workup by distillation and reoxidation of the crystalline material by H_2O_2 gave pure **10**. Phosphine **6** was an oil whose reoxidation by H_2O_2 gave about 98% **9** and 2% **10**. Physical properties of **5**, **6**, **9**, and **10** are listed in Table II.

Because **9** and **10** were difficult to obtain in pure form from their 1:1 mixture, attempts were made to equilibrate

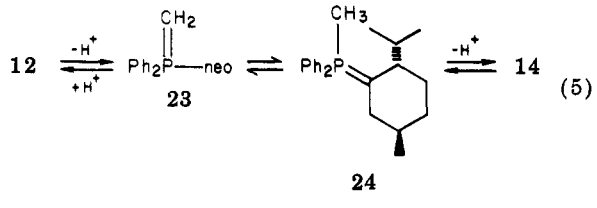
Table II. Properties of Menthyl- and Neomenthylmethylphenylphosphines and Their Phosphine Oxides

compd	confign	mp,[a] °C	$[\alpha]^{25}_D$ (c 2, $CHCl_3$)[f]	^{31}P NMR,[b] δ
3	R	oil, bp 95 (0.03)		
4	S	oil, bp 95 (0.025)		
5	R	30-35		−39.0[d]
6	S	oil, bp 78-80 (0.025)		
7	R	144-144.5	−33.4	40.6
8	S	102-103	−36.6	42.3
9	R	136-137	+58.3	43.2
10	S	149-150	−1.2	40.66
15	R		+85.7[d]	
16[e]	S	135-138		

[a] Boiling points (°C) are for Kugelrohr distillations; pressures in torr are given in parentheses. [b] At 40.5 MHz vs. 50% H_3PO_4 external standard in $CDCl_3$. [c] Some 9 was also present. [d] Measured in 1.0% CH_3OH solution. [e] ν_{CO} 1966 cm^{-1}. [f] Values in degrees.

5 and 6, and 9 and 10, to obtain what we hoped would be mixtures of diastereomers in ratios different from unity. Nothing useful was found. Treatment of 5 and 6 with $SiCl_4$ (80 °C, C_6H_6, varying times), a reagent known to racemize chiral $R^1R^2R^3P$,[21] did epimerize the phosphorus center but led also to epimerization at C_1 with the result that most of the product was the menthylphosphine 3. When a mixture of 5 and 6 was heated at 130 °C for many hours, the 5/6 ratio did not change appreciably, and decomposition was noticeable. Similarly, treatment of a 1:1 mixture of 7 and 8 with lithium aluminum hydride, a reagent reported to racemize chiral $R^1R^2R^3PO$,[22] did not result in useful changes in the phosphorus epimer ratio.

Attempts were also made to decompose 12 without epimerization at C_1. Our reasoning was that epimerization of 12 to 14 probably required formation of ylide 24 while the kinetic deprotonation of 12 should lead mainly to 23 (eq 5). Hydrolysis of ylides is known to proceed analo-



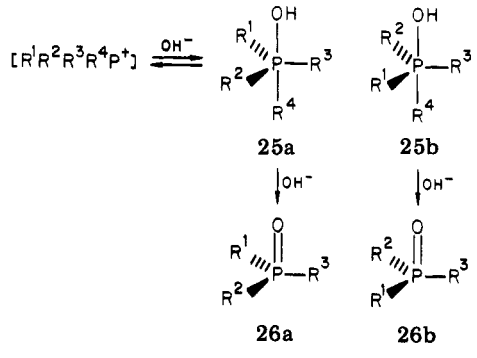
(5)

gously to hydrolysis of phosphonium cations to give tertiary phosphine oxides.[23] Conceivably the hydrolysis of 23 might lead to 9 and 10 instead of 7 and 8. Accordingly, 12 was suspended in tetrahydrofuran, and an ylide solution was generated by treatment with butyllithium and then promptly hydrolyzed with water. Only 7 and 8 were obtained together with some unconverted phosphonium salts. Treatment of 11 with dimethyl sulfoxide anion in Me_2SO[24] and hydrolysis also gave only 7 and 8. We then tried the same experiments on the more soluble phosphonium iodide 17. Treatment of a tetrahydrofuran solution of 17 with butyllithium and prompt hydrolysis gave, in addition to two diastereomers of 18, two new products of similar GLC retention time, which we presume to be the neomenthyl analogues of 18. Deprotonation of 17 by Me_2SO anion/Me_2SO gave only 18. These procedures were not synthetically useful.

Discussion

The phosphonium salt route we used to prepare 7 and 8 from 11 has some potential as a general method to obtain phosphine oxides in which chiral organic groups are ligated to chiral phosphorus. One must be able to prepare R^*Ar_2P and $[R^*R^1Ar_2P^+]$, the various phosphorus ligands must not undergo undesirable reactions when treated with strong base, and it must be possible to separate the mixture of phosphorus epimers, R^*R^1ArPO, which will be obtained from alkali hydroxide induced decompositions of $[R^*R^1Ar_2P^+]$. Separation will usually be easier when unequal amounts of diastereomeric R^*R^1ArPO are obtained. Diastereoselective decompositions of $[R^*R^1Ar_2P^+]$ are, therefore, of interest.

According to mechanistic studies of $[R^1R^2R^3R^4P^+]$ decompositions, attack of hydroxide on the phosphonium cation gives phosphorane 25 which is deprotonated by a second hydroxide and then decomposes to product in the rate-limiting step (eq 6).



(6)

Alkali hydroxide induced decompositions of chiral $[R^1R^2R^3R^4P^+]$ have been found to occur with retention, inversion, or racemization of the configuration, depending both on the nature of R^n and on the reaction conditions.[25] These different stereochemical results appear to reflect both the preferred configurations and the lifetimes, i.e., opportunities for pseudorotation, of the phosphoranes 25. In decompositions of $[R^*R^1Ar_2P^+]$ the configuration of the chiral phosphorus atom which is created will be determined by its formation from either 25a or 25b. When R* was menthyl, the most selective reaction we observed was formation of 22, in which about two-thirds of the new chiral phosphorus atoms had one epimeric configuration. Better diastereoselectivity may be possible in other cases, particularly where R* is very bulky or bifunctional.

That condensation of (−)-menthyl chloride with $MP(CH_3)(Ph)$ yields (3 + 4)/(5 + 6) in ratios dependent on whether M = Li, Na, or K is of some interest. A plausible way to obtain menthyl products from this reaction would be substitution induced by electron transfer (eq 7). Such

$$\begin{aligned} &Cl(men) + [MP(CH_3)(Ph)]_n \rightarrow \\ &\quad [Cl(men)]^-\cdot + [MP(CH_3)(Ph)]_n^{+}\cdot \rightarrow \\ &[MP(CH_3)(Ph)]_{n-1} + Cl^- + (Ph)(CH_3)P\cdot + men\cdot \rightarrow \mathbf{3\text{–}6} \end{aligned} \quad (7)$$

a pathway might operate exclusively or, more likely, in

(21) Reference 12, p 7018, and references therein.
(22) P. D. Henson, K. Naumann, and K. Mislow, *J. Am. Chem. Soc.*, **91**, 5465 (1969).
(23) A. Schnell and J. C. Tebby, *J. Chem. Soc., Perkin Trans. 1*, 1883 (1977), and references therein. See also G. W. Fenton and C. K. Ingold, *J. Chem. Soc.*, 2432 (1929); L. Hey and C. K. Ingold, *ibid.*, 531 (1933).
(24) E. J. Corey and M. J. Chaykovsky, *J. Am. Chem. Soc.*, **84**, 866 (1962); **87**, 1345 (1965).
(25) Cf. R. Luckenbach, *Chem. Ber.*, **108**, 803 (1975); *Phosphorus*, **1**, 223, 229, 293 (1973); **3**, 117 (1973).

competition with a "normal" S_N2 displacement. It is plausible to assume that electron transfer will become relatively more important as n increases. The (3 + 4)/(5 + 6) ratio does increase for M in the order K < Na < Li, which is also the order expected for increasing n.

In this paper, we have described the preparations of the eight diastereomeric menthyl- and neomenthylmethylphenylphosphines and their phosphine oxides which can be derived from natural menthol. Hydrogenation studies using 3–6 to form soluble rhodium asymmetric hydrogenation catalysts will be described elsewhere.[6]

Experimental Section

General Procedures. Melting points were taken on a Thomas-Hoover capillary melting point apparatus and are not corrected. Spectral measurements were taken by members of the physical chemistry department of Hoffmann-La Roche. ^1H NMR spectra were recorded on Varian A-60, HA-100, and XL-100 instruments in the continuous-wave mode. ^{31}P NMR spectra were obtained on a Varian XL-100 spectrometer in the Fourier transform mode at 40.5 MHz. Chemical shifts are reported in parts per million downfield from internal tetramethylsilane for ^1H nuclei and from external phosphoric acid for ^{31}P nuclei. Infrared spectra were obtained on a Beckman IR-9 or a Digilab FTS-14 spectrometer. Ultraviolet spectra were recorded on a Cary Model 14 spectrophotometer. Mass spectra were obtained on a JEOLCO OISG or CEC 21-110 instrument.

Neomenthylmethyldiphenylphosphonium Iodide (12). A solution of 275 g of 11[9] and 357 g of distilled methyl iodide in 1.25 L of benzene and 1.6 L of ether was stirred 18 h at 25 °C, refluxed 2 h, cooled, and filtered. The crude **12** was dissolved in 1.6 L of boiling ethanol and reprecipitated by addition of 1.0 L of ether. The precipitate was collected by filtration, washed with ether (3 × 250 mL), and dried (18 h, 23 °C, 1 mm): yield 406 g (94%); mp 192–193 °C. The analytical sample was crystallized from acetone–ether: mp 194.5–195.0 °C; ^1H NMR ($CDCl_3$) δ 0.83 (t, 6, $(CH_3)_2C$), 2.9 (d, 3, PCH_3, J_{PH} = 13 Hz).

Anal. Calcd for $C_{23}H_{32}IP$: C, 59.28; H, 6.92; I, 27.23; P, 6.64. Found: C, 58.43; H, 6.88; I, 27.14; P, 6.60.

Menthylmethylphenylphosphine Oxides 7 and 8. A solution of 418 g of **12** in 4.9 L of methanol and 1.18 L of 10 M NaOH was refluxed 18 h, cooled, and concentrated under reduced pressure to give ca. 2 L of oily residue. This was diluted with 2 L of benzene and extracted with water (3 × 1 L). The aqueous layers were back extracted with benzene (2 × 500 mL). The combined benzene layers were dried ($MgSO_4$) and concentrated under reduced pressure, giving 256 g of residue which was slurried with 1.5 L of hot ether and filtered to remove 41.5 g of phosphonium salts. The NMR spectra of these salts indicated that they contained the menthylmethyldiphenylphosphonium cation. Evaporation gave 215 g of residue which was distilled in a large Kugelrohr apparatus to give 198 g of an ca. 1:1 mixture of **7** and **8**, bp 135–145 °C (0.045–0.050 mm). Crystallization from 2.7 L of hexane and 400 mL of benzene gave 52.2 g of **7** which was recrystallized from 3:1 hexane–benzene to give (first crop) 42 g of **7** (mp 144.5–145.0 °C) and (second crop) 8.1 g of **7** (mp 143.5–145.0 °C): ^1H NMR ($CDCl_3$) δ 0.43 (d, 3, CH_3CH, $J_{H_aH_b}$ = 7 Hz), 0.84, 0.87 (2 d, 6, $(CH_3)_2CH$), 1.63 (d, 3, CH_3P, J_{PH} = 12 Hz); $[\alpha]^{25}_D$ −33.4° (*c* 1.0, $CHCl_3$).

Anal. Calcd for $C_{17}H_{27}OP$: C, 73.35; H, 9.78; P, 11.13. Found: C, 73.66; H, 9.86; P, 10.93.

The S_P diastereomer **8** was obtained by concentration of the mother liquors from the first crystallization under reduced pressure. The residue, an ca. 1:2 mixture of **7** and **8**, was crystallized several times from disopropyl ether and finally from cyclohexane to give pure **8**: 15.1 g; mp 102–103 °C; IR ($CHCl_3$) ν_{PO} 1160 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.82, 0.84 (m, 9, 3 CH_3CH), 1.76 (d, 3, CH_3P, J_{PH} = 13 Hz), 2.60 (m, 1, CH–P); $[\alpha]^{25}_D$ −36.6° (*c* 1.0, $CHCl_3$).

Anal. Found: C, 73.37; H, 9.98; P, 11.21, 11.35.

(R_P)-Menthylmethylphenylphosphine (3). Freshly distilled hexachlorodisilane [4.38 mL, 7.36 g, of Si_2Cl_6; bp 144–145 °C (746 mm)] was added dropwise at ca. 5 °C to a stirred solution of 5.6 g of **7** in 50 mL of benzene. The mixture was rapidly heated, refluxed 10 min, cooled in an ice–acetone bath, and hydrolyzed by cautious dropwise addition of 5 M NaOH. The organic layer was washed with 20 mL of water, dried over $MgSO_4$, and concentrated under reduced pressure. The residue of 5.3 g was distilled in a Kugelrohr apparatus to give 4.7 g of **3**, which was redistilled to give 4.4 g (83%) of **3** as a colorless oil: bp 95 °C (0.03 mm); ^1H NMR ($CDCl_3$) δ 1.37 (d, 3, CH_3P, J_{PH} = 4 Hz), 2.8 (m, 1, CH–P). A 1.0-g aliquot of **3** in 10 mL of benzene was oxidized by dropwise addition of 1 mL of 30% aqueous hydrogen peroxide. The mixture was stirred 18 h at 23 °C. The phases were then separated, and the organic layer was dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The ^1H-decoupled ^{31}P NMR spectrum of the residue exhibited one signal at δ 42.3, characteristic of **8**.

(S_P)-Menthylmethylphenylphosphine (4). The previous procedure was applied to **8** except that the Kugelrohr distillation was terminated after about 60% of the residue had distilled (avoids epimerization of **4**). A 58% yield of **4** was obtained: bp 95 °C (0.025 mm); ^1H NMR ($CDCl_3$) δ 1.25 (d, 3, CH_3P, J_{PH} = 3.5 Hz), 2.55 (m, 1, CH–P). Oxidation of **4** gave a crude product having a single ^{31}P NMR signal at δ 40.6, characteristic of **7**.

Menthylethylphenylphosphine Oxide (18). A solution of 1.0 g of **11** and 3 mL of ethyl iodide in 20 mL of benzene was refluxed 28 h, cooled, and concentrated under reduced pressure. The residue was triturated with hexane, filtered, and air-dried to give 1.36 g (92%) of **17**. An analytical sample was crystallized from acetone–ether: ^1H NMR ($CHCl_3$) δ 0.61 (d, 3, CH_3CH, $J_{H_aH_b}$ = 8 Hz), 0.92 (d, 3, CH_3CH, $J_{H_aH_b}$ = 6 Hz), 1.08 (d, 3, CH_3CH, $J_{H_aH_b}$ = 6 Hz), 3.16, 3.55 (m, 2, CH_2P), 4.50 (m, 1, CHP); $[\alpha]^{25}_D$ −2.0° (*c* 0.97, $CHCl_3$). In $CDCl_3$ the ^1H-decoupled ^{31}P NMR spectrum consisted of a singlet at δ 30.07.

Anal. Calcd for $C_{24}H_{34}IP$: C, 60.00; H, 7.13; I, 26.41; P, 6.45. Found: C, 59.96; H, 7.22; I, 26.25; P, 6.41.

A solution of 1.0 g of **17** in 1.0 mL of 10 M NaOH and 6.0 mL of methanol was refluxed 24 h, cooled, and concentrated under reduced pressure. The residue was triturated with benzene which was removed by filtration, dried over $MgSO_4$, concentrated under reduced pressure, and distilled in a Kugelrohr apparatus to give 0.507 g (84%) of a mixture of two diastereomers of **18**: bp 145 °C (0.03 mm), an oil which solidified to a waxy solid on cooling; IR (KBr) ν_{PO} 1162 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.37 (d, J = 7 Hz, $^1/_2$ CH_3CH); ^1H-decoupled ^{31}P NMR ($CDCl_3$) δ 44.3, 46.7 (in 9:11 ratio); GLC (HP Model 402B, all glass, on-column injection, $^1/_4$ in. × 4 ft column, UCW 98 on Chromosorb Q, 200 °C) indicated a 5:7 ratio of 2 diastereomers **18**.

Anal. Calcd for $C_{18}H_{29}OP$: C, 73.94; H, 10.01; P, 10.59. Found: C, 73.71; H, 10.01; P, 10.32.

Neomenthylmethylphenylphosphine Oxides 9 and 10. A solution of 45 g of methylphenylphosphine[26] in 300 mL of tetrahydrofuran was added dropwise at −78 °C to a stirred solution prepared from 14.5 g of potassium in 1.48 L of liquid ammonia. The ammonia was allowed to evaporate, and when most was gone the flask was cautiously warmed in a water bath for 30 min. Purified (−)-menthyl chloride[27] ($[\alpha]^{25}_D$ −54.11° (*c* 0.99, C_2H_5OH), 88.5 g) was then added, and the mixture was stirred 18 h at 23 °C. The resulting orange-yellow reaction mixture was hydrolyzed by cautious addition of 5 mL of H_2O, and the solvents were removed under reduced pressure. The residue was mixed with 500 mL of benzene and filtered through Celite which was further washed with benzene (2 × 50 mL). Aqueous 30% H_2O_2 (25 mL) was added dropwise to the combined benzene layers, and the resulting mixture was stirred 18 h at 23 °C. The organic layer was then removed, washed with water (2 × 50 mL), dried ($MgSO_4$), and concentrated under reduced pressure. Distillation of the residue through a short column gave 18.9 g of (−)-menthyl chloride, bp 75 °C (22 mm). The residue was distilled in a large Kugelrohr apparatus. The main fraction was 35.6 g of white solid, bp 135–155 °C (0.015 mm). This was a 19:19:1:1 mixture of **9**, **10**, **7**, and **8** according to ^{31}P NMR. Recrystallization from 150 mL of hexane gave 30.2 g of white solid indicated by NMR to be an ca. 1:1 mixture of **9** and **10**. This mixture was crystallized twice from

(26) L. Horner, H. Hoffmann, and P. Beck, *Chem. Ber.*, **91**, 1583 (1958).

(27) J. G. Smith and G. F. Wright, *J. Org. Chem.*, **17**, 1116 (1952); N. Kursanov, *Justus Liebigs Ann. Chem.*, **318**, 327 (1901).

diisopropyl ether and five times from hexane to give 2.9 g of **9**: mp 136–137 °C; $[\alpha]^{25}_D$ +58.3° (*c* 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 0.57 (d, 3, $CHCH_3$), 1.81 (d, 3, PCH_3, J_{PH} = 12 Hz). There was ca. 1% of δ 0.27 impurity (vide infra).

Anal. Found: C, 73.33; H, 9.87; P, 11.25.

The first hexane mother liquor was evaporated, and the semisolid residue was triturated with hexane and filtered. The solids were recrystallized from diisopropyl ether to give 0.7 g of **10**: mp 149–150 °C; ^1H NMR ($CDCl_3$) δ 0.27 (d, 3, CH_3CH), 0.76 (d, 3, CH_3CH), 0.93 (d, 3, CH_3CH), 1.66 (d, 3, PCH_3, J_{PH} = 12 Hz); $[\alpha]^{25}_D$ −1.2° (*c* 1.0, $CHCl_3$).

Anal. Found: C, 73.34, 73.36; H, 9.77, 9.81.

(R_p)-Neomenthylmethylphenylphosphine (5). A solution of 0.6 g of **9** in 7 mL of benzene was treated with 0.6 mL of hexachlorodisilane, refluxed 4 h, cooled to 0 °C, and hydrolyzed by dropwise addition of 14 mL of 5 M NaOH. The two-phase mixture was stirred 30 min at 23 °C. The organic layer was washed with water, dried over $MgSO_4$, filtered, concentrated under reduced pressure, and vacuum distilled in a Kugelrohr apparatus to give 0.5 g of **5** [bp 78–80 °C (0.025 mm)] as a colorless, foul-smelling oil which soon crystallized (needles): ^1H NMR ($CHCl_3$) δ 0.39 (d, 3, CH_3CH), 1.14 (d, 3, CH_3P, J_{PH} = 5 Hz).

Anal. Calcd for $C_{17}H_{27}P$: C, 77.32; H, 10.37. Found: C, 76.52, 76.42; H, 10.32, 10.27.

Oxidation of the sample with H_2O_2 gave as a crude product epimerically pure **10**, exhibiting a single ^1H-decoupled ^{31}P resonance at δ 40.54.

(S_p)-Neomenthylmethylphenylphosphine (6). The Si_2Cl_6 reduction of 0.3 g of **10** (2 h, 80 °C, C_6H_6) gave 0.2 g of **6**: bp 78–80 °C (0.02 mm), in the Kugelrohr apparatus; ^1H NMR (60-MHz, $CDCl_3$) δ 0.58 (d, 3, CH_3CH), 0.96 (d, 6, 2 CH_3CH), 1.29 (d, 3, CH_3P, J_{PH} = 4.5 Hz). The crude H_2O_2 oxidation product of this phosphine was indicated by ^1H NMR to contain ca. 98% **9** and 2% **10**.

η^4-(1,5-Cyclooctadiene)bis[(R_p)-methylmenthylphenylphosphine]rhodium(I) Tetrafluoroborate (15). Sodium tetrafluoroborate, freshly crystallized from methanol (1.32 g), was dissolved in 100 mL of methanol, and 1.0 g of μ,μ'-dichlorobis(η^4-1,5-cyclooctadiene)rhodium(I)[28] was added, followed by 2.0 g of **3**. The dark orange solution was stirred 1 h at 23 °C, the solvents were removed under vacuum, and the residue was washed with benzene until the washings were colorless. The residue was then dissolved in dichloromethane, and the solution was concentrated on the rotary evaporator to 3–4 mL, when crystals began to form. About 150 mL of ether was then added slowly, and the mixture was allowed to stand 18 h at 23 °C. The complex was recovered by filtration, washed repeatedly with ether, and dried (18 h, 1 mm, 23 °C). The yield was 1.37 g (44%) of an orange, crystalline complex, $[\alpha]^{25}_D$ +86.7° (*c* 1.00, CH_3OH).

Anal. Calcd for $C_{42}H_{66}BF_4P_2Rh$: C, 61.32; H, 8.09. Found: C, 60.14; H, 7.85.

***trans*-Chlorocarbonylbis[(S_p)-menthylmethylphenylphosphine]rhodium(I) (16).** An attempt to prepare an analogue of **15** containing **4** instead of **3** gave no precipitate. The CH_2Cl_2–ether solution was evaporated, and the residue was dissolved in benzene and treated first with hydrogen and then with carbon monoxide. The solution was concentrated to ca. 4 mL, and ca. 25 mL of methanol was added gradually. The precipitate which formed was recrystallized from benzene–methanol, giving, after storage at −5 °C, hard orange crystals of **16**: mp 135–138 °C; IR (KBr) ν_{CO} 1960 cm^{-1}.

Anal. Calcd for $C_{35}H_{54}ClOP_2Rh$: C, 60.83; H, 7.88; Cl, 5.13; P, 8.96. Found: C, 60.85; H, 8.01; Cl, 5.13; P, 8.14.

Preparation of 21 and 22. The mixture of 72.3 g (0.223 mol) of **11** and 34.6 g (0.112 mol) of 1,4-diiodobutane in 180 mL of acetonitrile was refluxed 1.34 h under argon, cooled to 23 °C, and filtered. The diphosphonium salt **21** was washed with ether and dried (air, then 18 h, 1 mm, 23 °C). A total of 106.2 g of **21**, containing a little ether, was obtained. An analytical sample of the very insoluble salt was obtained by repeatedly washing with ether and prolonged drying under vacuum.

Anal. Calcd for $C_{48}H_{66}I_2P_2$: C, 60.13; H, 6.94; I, 26.47; P, 6.46. Found: C, 60.17; H, 6.93; I, 26.46; P, 6.47.

The mixture of 98 g of **21** with 60 g of potassium hydroxide in 350 mL of hexamethylphosphoramide was stirred 36 h at 120 °C under argon, allowed to cool, and poured into 1 L of water. This mixture was extracted with toluene (5 × 300 mL) which was back extracted with water (2 × 500 mL), dried over magnesium sulfate, filtered, and concentrated under reduced pressure. The residue was a mixture of glass and waxy solid which was dissolved in 250 mL of boiling acetone. The solution was allowed to stand at room temperature. A first crop of 10.7 g of product was obtained. Cooling the mother liquors and the acetone (ca. 50 mL) used to wash the first crop to −20 °C for 24 h gave a further 8.7 g of product as a second crop. Stripping of the mother liquors then gave a further 26.5 g of product as a third crop. The total yield of **22** as a mixture of diastereomers in three crops was 45.9 g (78%). These were analyzed by ^1H-decoupled ^{31}P NMR spectroscopy with the results shown below. The assignments of epimeric configuration at P were based on ^{31}P signals, the higher field signals being assigned to the *R* phosphorus compound by analogy with **7** and **8**.

crop	wt, g	% (*R*,*S*)-**22**	% (*S*,*S*)-**22**	% (*R*,*R*)-**22**
1	10.7	70.5	18.4	11.1
2	8.7	43.4	15.8	40.8
3	26.5	26.8	56.5	6.7

Recrystallization of the first crop from acetone gave the meso compound (*R*,*S*)-**22** as a white crystalline solid (needles): mp 170–172 °C; ^1H-decoupled ^{31}P NMR ($CDCl_3$) δ 44.88, 42.53; $[\alpha]^{25}_D$ −32° (*c* 0.945, $CHCl_3$).

Anal. Calcd for $C_{36}H_{56}O_2P_2$: C, 74.19; H, 9.68; P, 10.63. Found: C, 74.00; H, 9.74; P, 10.32.

Crystallography

The crystal data for **7**, **9**, and **15** are given in Table III (supplementary material). Details of the crystallographic analyses are summarized in Table IV (supplementary material). The real and imaginary parts of the anomalous dispersion correction for Rh and P were taken into account in the refinements. The absolute stereochemistries were defined by the known configurations of the menthyl or neomenthyl moieties. The positions of the hydrogen atoms were calculated from the molecular geometry after anisotropic refinement of the heavier atoms.

In **15**, both ions are located on crystallographic twofold axes. Thus the cation possesses twofold symmetry, with the twofold axis passing through the rhodium atom and the center of the cyclooctadiene ligand. The two phosphine ligands are equivalent by symmetry. The atoms of the BF_4^- ion are not well-defined. Although the ion does not have a twofold axis of symmetry, the crystallographic twofold axis passes through the boron atom and one fluorine atom so that the BF_4^- ion is disordered in the crystal. In the final refinement of **15**, the Rh, P, and C atoms had anisotropic thermal parameters and the F, B, and H atoms had isotropic temperature factors. The B and H atoms were included in the structure factor calculations, but their parameters were not refined. The final difference map had several peaks in the range ±(0.5–1.0) eA^{-3}, all located near the Rh atom or the BF_4^- ion.

Acknowledgment. We are grateful to Mr. R. Pitcher for ^{31}P NMR spectra and to Dr. F. Scheidl for microanalyses. We thank Professor G. Whitesides and Dr. G. Saucy for useful discussions.

Registry No. **3**, 65440-74-6; **4**, 65440-73-5; **5**, 74298-24-1; **6**, 74298-25-2; **7**, 65440-75-7; **8**, 65440-76-8; **9**, 74298-26-3; **10**, 74298-27-4; **11**, 43077-29-8; **12**, 74298-28-5; **15**, 74312-43-9; **16**, 74298-06-9; **17**, 74298-29-6; **18** (isomer 1), 74298-30-9; **18** (isomer 2), 74298-31-0; **19**, 74298-32-1; **20** (isomer 1), 74298-33-2; **20** (isomer 2), 74298-34-3; **21**, 74298-35-4; *R*,*R*-**22**, 74298-36-5; *R*,*S*-**22**, 74345-44-1; *S*,*S*-**22**, 74345-45-2; methylphenylphosphine, 6372-48-1; (−)-menthyl chloride, 16052-42-9; μ,μ'-dichlorobis(η^4-1,5-cyclooctadiene)rhodium(I),

(28) J. Chatt and L. Venanzi, *J. Chem. Soc.*, 4735 (1957).

12092-47-6; 1,4-diiodobutane, 628-21-7.

Supplementary Material Available: Table III, crystal data; Table IV, details of crystallographic analyses; Table V, atomic parameters for 7; Table VI, anisotropic thermal parameters for 7; Table VII, bond lengths in 7; Table VIII, bond angles in 7; Table IX, atomic parameters for 9; Table X, anisotropic thermal parameters for 9; Table XI, bond lengths in 9; Table XII, bond angles in 9; Table XIII, atomic parameters for 15; Table XIV, anisotropic thermal parameters for 15; Table XV, bond lengths in 15; Table XVI, bond angles in 15 (15 pages). Ordering information is given on any current masthead page.

Rhodium Chiral Monophosphine Complex Catalyzed Hydrogenations of Terpenic and α-(Acylamino)-Substituted Acrylic Acids

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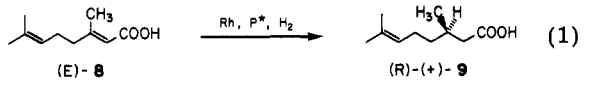
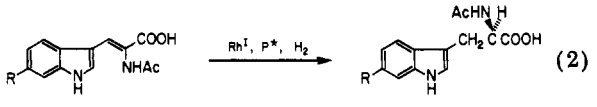
Four phosphines, 1–4, in which chiral menthyl or neomenthyl groups are ligated to chiral phosphorus, menthyldiphenylphosphine (5), neomenthyldiphenylphosphine (6), and (2-phenyl-2-methoxyethyl)diphenylphosphine (14), were used to form soluble rhodium catalysts for the enantioselective hydrogenations of 3,7-dimethylocta-2,6-dienoic acid (geranic acid, 8) and α-(acetylamino)-6-methylindole-3-acrylic acid (10). Under mild conditions (23 °C, 3 atm of H_2), the catalysts Rh-1 (containing (S_P)-menthylmethylphosphine), Rh-6, and Rh-14 catalyzed the hydrogenation of (*E*)-8 to optically active 3,7-dimethyloct-6-enoic acid (citronellic acid) in ca. 65–70% enantiomeric excess (ee). Very modest enantioselectivities were observed in hydrogenations of 10. The mechanism of Rh-6-catalyzed hydrogenations of 8 is discussed, and attempts to optimize this reaction for fast rates are described.

The preceding paper described our synthesis of the phosphines 1–4, which are characterized by ligation of chiral menthyl and neomenthyl moieties to chiral phosphorus.[1] This paper describes the use of these phosphines to form soluble rhodium-complex catalysts for the enantioselective hydrogenation reactions 1 and 2. Our study

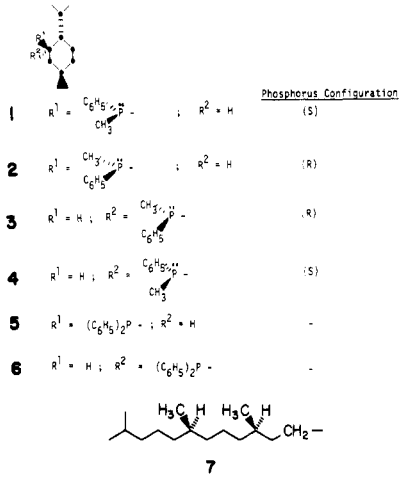


(E)-8 (R)-(+)-9 (1)



(Z)-10 (R=CH3) (R)-(-)-11 (R=CH3)
(Z)-12 (R=Cl) (R)-(-)-13 (R=Cl) (2)

of reaction 1 was part of an effort to find efficient ways to prepare the chiral moiety 7 which is found in several important natural products such as α-tocopherol (vitamin E) and phylloquinone (vitamin K_1).[2] Substrates such as 8 were potentially available as byproducts of existing technical syntheses of vitamins A and E and were considered to be possibly attractive precursors to 7. Hydrogenations of the related substrates, α- and β-methylcinnamic acids, catalyzed by rhodium complexes of 6, had been reported to give chiral carboxylic acid products in as high as 60% ee.[3] Reaction 1 was therefore subjected to detailed study by using both 1–6 and chiral diphosphines to form soluble rhodium hydrogenation catalysts. The results with rhodium catalysts containing 1–6 are presented in this paper. The results obtained by using rhodium diphosphine complex catalysts are described in the following paper.[4]



7

Our interest in reaction 2 was prompted by the potential value of 6-methyltryptophans as nonnutritive sweeteners. In this case also, both 1–6 and chiral diphosphines were studied. The results obtained by using rhodium–diphosphine complex catalysts were much better and have been reported elsewhere in detail.[5]

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(2) Other approaches to the total synthesis of pure diasteromeric tocopherols have recently been reported: (a) Chan, K. K.; Cohen, N.; De Noble, J. P.; Specian, A. C., Jr.; Saucy, G. *J. Org. Chem.* **1976**, *41*, 3497–3404; (b) Cohen, N.; Eichel, W. F.; Lopresti, R. J.; Neukom, C.; Saucy, G. *Ibid.* **1976**, *41*, 3505–3511. (c) *Ibid.* **1976**, *41*, 3512–3515; (d) Chan, K. K.; Specian, A. C., Jr.; Saucy, G. *Ibid* **1978**, *43*, 3435–3440; (e) Leuenberger, H. G. W.; Boguth, W.; Barner, R.; Schmid, M.; Zell, R. *Helv. Chim. Acta* **1979**, *62*, 455–463; (f) Schmid, M.; Barner, R. *Ibid.* **1979**, *62*, 464–473; (g) Zell, R. *Ibid.* **1979**, *62*, 474–480.

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