(m, 2 H), 3.78 (s, 6 H), 4.45–4.92 (m, 1 H). Anal. Calcd for $C_{12}H_{19}NO_5$: C, 56.02; H, 7.44; N, 5.44. Found: C, 55.74; H, 7.52; N, 5.62.

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Registry No. **1a**, 4801-58-5; **1b**, 99687-80-6; **1c**, 54105-63-4; **1d**, 7446-43-7; **1e**, 5904-62-1; **1f**, 5765-63-9; **1g**, 6763-87-7; **2a**, 34418-91-2; **2b**, 55386-67-9; **2c**, 24423-87-8; **2d**, 20135-16-4; **4**, 99687-81-7; **5**, 99745-91-2; **6**, 99687-82-8; **7**, 99687-83-9; NaI, 7681-82-5; KI, 7681-11-0; Et_4NI, 68-05-3; Pr_2NH, 142-84-7; 2-methylpiperidine, 109-05-7; 1,2,3,4-tetrahydroisoquinoline, 91-21-4; dimethyl fumarate, 624-49-7; diethyl fumarate, 623-91-6; pyrrolidine, 123-75-1; morpholine, 110-91-8; hexahydroazepine, 111-49-9.

Preparation of 8-Phenylmenthol and Its Diastereomer, 2-*epi*,*ent*-8-Phenylmenthol. A Caveat

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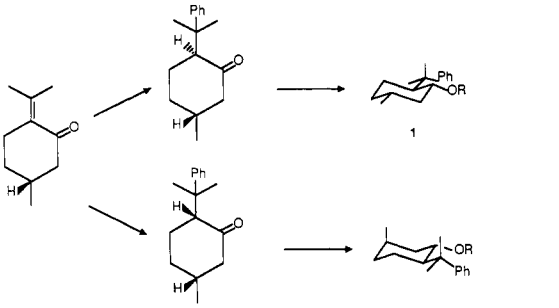
A number of publications[1] that detail the use of 8-phenylmenthol (phenmenthol, **1a**) as a chiral auxiliary for asymmetric induction followed initial publications in this area by Corey[2] and Oppolzer.[3] Our research[4-6] has produced the highest levels of induction with this auxiliary and the observation of diastereomeric excess (de) values of at least 99.9 to 0.1 in the ene reaction of the glyoxylate ester of **1** with hexene probably stands as an all time record in the area of asymmetric induction in carbon–carbon bond formation. The power of this chiral auxiliary as well as the interest demonstrated in its application to a variety of processes prompts us to detail here our experimental findings on its preparation. In particular, we draw attention to the fact that the sequence to be described starting from pulegone results inevitably in phenmenthol (**1a**) admixed with a diastereomer (**2a**) that is epimeric at both C-1 and C-2 (hence our trivial name of epientphenmenthol for **2a** since it is the enantiomer of 8-phenylmenthol save for being epimeric at C-5). Since it is these centers that appear to be solely responsible for the induction of asymmetry, it would be anticipated that this diastereomer would be equally as effective as phenmenthol as a chiral auxiliary in inducing the opposite sense of chirality.[7] We have been able to show that this is indeed the case.

Table I

reaction	auxiliary, de 1	2
1b/2b + $H_2C{=}CHC_4H_9$	99.8	99.8
1c/2c + C_5H_5	90	86
1d/2d + RMgBr	92	68

The procedure used for the synthesis of **1a** (and of **2a**) is that described by Corey[1,5] beginning with pulegone.



Since the degree of induction observed will depend on the purity of the starting material, we have examined the level of enantiomeric purity of **1a** derived from commercial pulegone (Givaudan) through analysis by our published procedure[8] involving the formation of the mandelic acid ester. Using this method, we are able to set a minimum level of enantiomeric excess for phenmenthol (and hence for the pulegone from which it is derived) of 99%. This result corresponds well with an independent analysis by Eliel of the methoxytrifluorophenylacetate ester of menthol prepared by reduction of pulegone.[9] It would thus appear that pulegone derived from natural sources can be considered to be enantiomerically pure.

The conversion of pulegone to **1a** and **2a** involves the copper-catalyzed addition of phenylmagnesium bromide followed by dissolving metal reduction of the derived ketone. The conjugate addition afforded a mixture of diastereomers epimeric at the newly formed stereocenter (C-2) where the ratio varied depending on the method of quenching of the reaction from 60:40 to near the equilibrium value of 85:15. However, since in the next step reduction of the carbonyl is slower than epimerization, the ratio of the epimeric ketones was not reflected in the ratio of phenmenthol to epientphenmenthol which invariably is 85:15. Indeed, we examined a range of reducing agents and reaction conditions in an attempt to improve the overall amount of epientphenmenthol produced. However, with all other reagents either the reduction proceeded to afford predominantly the axial alcohol or the chemical yield was significantly lower than that with the simple dissolving metal conditions.

(1) (a) Roush, W. R.; Gillis, H. R.; Ko, A. I. *J. Am. Chem. Soc.* **1982**, *104*, 2269. (b) Oppolzer, W.; Robbiani, C.; Battig, K. *Tetrahedron* **1984**, *40*, 1391. (c) Yamamoto, Y.; Yatagai, H.; Ishihara, Y.; Maeda, N.; Maruyama, K. *Tetrahedron* **1984**, *40*, 2239. (d) Danishefsky, S.; Bednarski, M.; Izawa, T.; Maring, C. *J. Org. Chem.* **1984**, *49*, 2290. (e) Yamamoto, Y.; Maeda, N.; Maruyama, K. *J. Chem. Soc., Chem. Commun.* **1983**, 774. (f) Little, R. D.; Moeller, K. D. *J. Org. Chem.* **1983**, *48*, 4487. (g) Oppolzer, W.; Moretti, R.; Godel, T.; Meunier, A.; Loher, H. J. *Tetrahedron Lett.* **1983**, *24*, 4971. (h) Quinkert, G.; Stark, H. *Angew. Chem., Int. Ed. Engl.* **1983**, *22*, 637. (i) Binger, P.; Brinkmann, A.; Richter, W. J. *Tetrahedron Lett.* **1983**, *24*, 3599. (j) Koch, H.; Runsink, J.; Scharf, H. D. *Tetrahedron Lett.* **1983**, *24*, 3217. (k) Devos, M. J.; Krief, A. *Tetrahedron Lett.* **1983**, *24*, 103. (l) Quinkert, G.; Adam, F.; Durner, G. *Angew. Chem., Int. Ed. Engl.* **1982**, *21*, 856. (m) Quinkert, G.; Schwartz, U.; Stark, H.; Weber, W. D.; Adam, F.; Baier, H.; Frank, G.; Durner, G. *Liebigs Ann. Chem.* **1982**, *1982*, 1999. (n) Dauben, W. G.; Bunce, R. A. *Tetrahedron Lett.* **1982**, *23*, 4875.

(2) Corey, E. J.; Ensley, H. E. *J. Am. Chem. Soc.* **1975**, *97*, 6908.

(3) Oppolzer, W.; Robbiani, C.; Battig, K. *Helv. Chem. Acta* **1980**, *63*, 2015. Oppolzer, W.; Kurth, M.; Reichlin, D.; Chapuis, C.; Mohnhaupt, M.; Moffatt, F. *Ibid.* **1981**, *64*, 2802. Oppolzer, W.; Loher, H. J. *Ibid.* **1981**, *64*, 2808. Oppolzer, W.; Kurth, M.; Reichlin, D.; Moffatt, F. *Tetrahedron Lett.* **1981**, *22*, 2545.

(4) Whitesell, J. K.; Bhattacharya, A.; Henke, K. *J. Chem. Soc., Chem. Commun.* **1982**, 987.

(5) Whitesell, J. K.; Bhattacharya, A.; Aguilar, D. A.; Henke, K. *J. Chem. Soc., Chem. Commun.* **1982**, 989.

(6) Whitesell, J. K.; Deyo, D.; Bhattacharya, A. *J. Chem. Soc., Chem. Commun.* **1983**, 802.

(7) This possibility was noted by Corey (ref 2).

(8) Whitesell, J. K.; Reynolds, D. *J. Org. Chem.* **1983**, *48*, 3548.

(9) Lynch, J. E.; Eliel, E. L. *J. Am. Chem. Soc.* **1984**, *106*, 2943 (ref 6, supplemental part).

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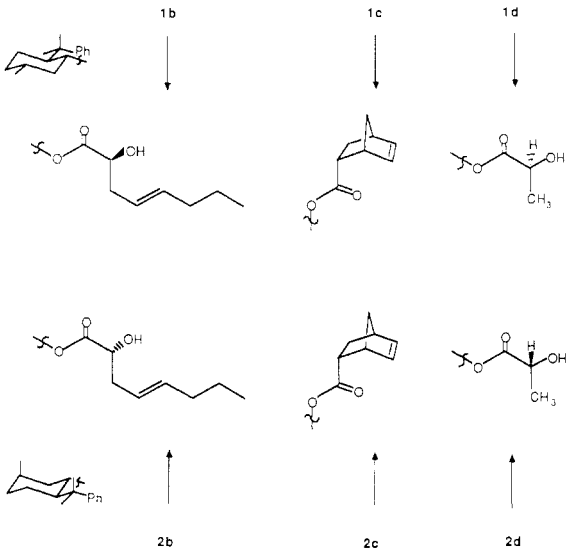
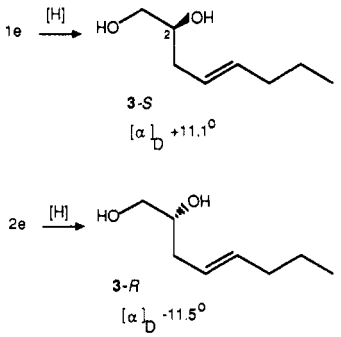
Separation of phenylmenthol and epientphenmenthol can be readily accomplished by using a Waters Prep-500 system in such a fashion that both diastereomers can be obtained with purities in excess of 99.5% as determined by analytical HPLC. During the course of purification of large quantities of phenmenthol we accumulated reasonable amounts of epientphenmenthol and were thus in a position to examine is use as a chiral auxiliary in the Diels–Alder reactions as well as in the ene reactions of and Grignard additions to its glyoxylate ester. In the first two cases we found that the levels of induction were of the same magnitude as with phenmenthol whereas the Grignard reactions led to only moderate levels of induction (Table I).



The levels and sense of induction for the ene reactions of the glyoxylates of **1b** and **2b** and 1-hexene were confirmed by reduction of the products to the known diols **3**.



We have also confirmed that the ene reactions of glyoxylate **2b** with *trans*-2-butene and with 1-(trimethylsilyl)-*cis*-2-butene afford the opposite sense of induction as with **1b** and the same level and sense of *threo*/*erythro* control (15:1 and 1:15, respectively). However, the chemical yields are not as high, with a significant proportion of material diverted to chlorine containing adducts.

While it is clear that that phenmenthol can be a powerful tool for the control of the absolute stereochemical outcome of several synthetically useful transformations, its application is hampered by significant difficulties attending its preparation. An alternative auxiliary, *trans*-2-phenylcyclohexanol, which does not suffer from these problems is described elsewhere.[13]

Experimental Section

Materials. Ether and tetrahydrofuran (THF) were distilled prior to use from a deep-blue solution resulting from benzophenone and sodium. Skelly-B (hexane) was stirred with sulfuric acid and solid sodium carbonate and distilled before use. All other solvents and reagents were used as obtained from commercial sources.

Procedures. Reactions were routinely run under a dry nitrogen atmosphere with magnetic stirring. Organic solutions of products were dried with molecular sieves prior to concentration in vacuo. Crude products were routinely passed through short columns of silica gel with an appropriate mixture of hexane and ethyl acetate. Reference to purification by HPLC refers to the use of a Waters Prep-500 system with two silica gel cartridges and standard recycling techniques.

Spectra. Proton nuclear magnetic resonance spectra (^{1}H NMR) were obtained on either a Varian EM-390 or a Nicolet 200-MHz instrument and values are reported downfield from tetramethylsilane as internal standard. Shifts are provided only for those hydrogens that show distinct absorptions, the remainder exhibited as a broad band from approximately δ 2.2–0.5 representing mainly the cyclohexyl hydrogens of the auxiliary. ^{13}C NMR data were obtained as $CDCl_3$ solutions on either a Brucker WD-90 or a Varian FT-80A instrument. Infrared (IR) spectra were obtained in dilute, dichloromethane solutions on a Perkin-Elmer 237B instrument. High-resolution mass spectra were recorded with a Dupont 21-110B instrument.

(1*S*,2*R*,5*R*)-5-Methyl-2-(1-methyl-1-phenylethyl)cyclohexanol (Epientphenmenthol) (2a). Epientphenmenthol was isolated by preparative HPLC (Waters Prep-500 system, two columns, 20 g per injection; Skelly-B–EtOAc, 15:1) as the minor product from the preparation of phenmenthol in 6% overall yield from pulegone. Efficient and effective purification of phenmenthol could be achieved on this scale in a single pass but recycling techniques were required when simultaneous purification of the less mobile, minor diastereomer **2a** was desired: ^{1}H NMR ($CDCl_3$) 7.58–7.10 (m, 5 H, aromatic CH's), 3.75 (dt, J = 10 Hz, J = 4.5 Hz, 1 H, CHO), 1.43 (s, 3 H, CH_3), 1.3 (s, 3 H, CH_3), 0.92 (d, J = 7 Hz, 3 H, CH_3); ^{13}C NMR ($CDCl_3$) 151.0 (s), 128.2 (d), 125.8 (d), 125.5 (d), 68.5 (d), 54.7 (d), 42.0 (t), 40.2 (s), 31.5 (t), 27.6 (d), 27.3 (q), 26.1 (q), 21.5 (t), 18.8 (q); IR (neat) 3100–3600 (OH), 1600 (aromatic CH) cm^{-1}.

(1*S*,2*R*,5*R*)-5-Methyl-2-(1-methyl-1-phenylethyl)cyclohexyl Glyoxylate (2b) Hydrate. Method A. A mixture of 0.735 g (2.57 mmol) of acrylate ester **2c**, 0.01 g (0.039 mmol) of osmium tetraoxide, 3 mL of water, and 9 mL of dioxane was stirred at room temperature for 5 min during which time the mixt. became dark brown. A total of 1.11 g (5.2 mmol) of sodium periodate was added in portions over a period of 30 min. The color of the mixture changed to pale brown and the mixture was stirred at room temperature for another 2 h. The mixture was then extracted thoroughly with ether and the combined organic extracts were dried (4-Å molecular sieves), concentrated, and filtered through a short column of silica gel (Skelly-B/EtOAc, 4:1) to afford 0.69 g (ca. 90%) of a mixture of the glyoxylate and its hydrate.

Method B. Ozone in oxygen was bubbled into a solution of 5.41 g (18.89 mmol) of **2c** in 200 mL of MeOH and 50 mL of CH_2Cl_2 at −78 °C until the solution turned pale blue. While the solution was still at −78 °C, the system was flushed with nitrogen to remove the excess O_3, and then 2.1 mL of dimethyl sulfide was added dropwise. The mixture was placed in an ice–salt bath (ca. −15 °C) and was allowed to warm up to room temperature over 14 h. The solvents were evaporated and the residue was extracted with ether. The ethereal extract was washed with water, dried (4-Å molecular sieves), and concentrated to afford 6.30 g of crude product. The hydrated glyoxylate ester was purified by preparative HPLC (Skelly-B–EtOAc, 4:1) to give 5.22 g (ca. 90%). This material was used directly without further purification: ^{1}H NMR ($CDCl_3$) 7.45–7.0 (m, 5 H), 5.3–4.7 (m, 1 H), 1.32 (s, 3 H), 1.27 (s, 3 H).

(10) Pappas, J. J.; Keaveney, W. P.; Gancher, E.; Berger, M. *Tetrahedron Lett.* **1966**, 4273.
(11) Pappo, R.; Allen, D. S., Jr.; Lemieux, R. U.; Johnson, W. S. *J. Org. Chem.* **1956**, *21*, 478.
(12) Bartlett, P. A.; Tanzella, D. J.; Barstow, J. F. *J. Org. Chem.* **1982**, *47*, 3941.
(13) Whitesell, J. K.; Chen, H.-H.; Lawrence, R. M. *J. Org. Chem.* **1985**, *50*, 4663.

(1S,2R,5R)-5-Methyl-2-(1-methyl-1-phenylethyl)cyclohexyl Acrylate (2c). To a solution of 2.5 g (10.8 mmol) of alcohol **2a**, 0.19 g (1.52 mmol) of 4-(dimethylamino)pyridine, and 2.19 g (21.6 mmol) of triethylamine in 100 mL of dichloromethane at 0 °C was slowly added 1.96 g (21.6 mmol) of acryloyl chloride. The mixture was stirred at 0 °C for 1.5 h and then 20 mL of saturated $NaHCO_3$ solution was added. The layers were separated and the aqueous layer was extracted with three 40-mL portions of dichloromethane. The organic layers were combined, dried (4-Å molecular sieves), and concentrated. The crude product was filtered through a short column of silica gel (Skelly-B–EtOAc, 50:1) to yield 2.80 g (91%) of acrylate: ^1H NMR ($CDCl_3$) 7.35–6.90 (m, 5 H, aromatic CH's), 6.27-5.40 (m, 3 H, $HC{=}CH_2$), 5.12 (dt, J = 9 Hz, J = 4 Hz, 1 H, CHO), 1.33 (s, 3 H, CH_3), 1.23 (s, 3 H, CH_3), 0.97 (d, J = 7.5 Hz, 3 H, CH_3); ^{13}C NMR ($CDCl_3$) 164.8, 150.8, 129.4, 129.1, 127.9, 125.5, 125.1, 71.1, 50.9, 40.0, 38.3, 31.2, 27.4, 27.1, 26.0, 21.6, 18.6; IR (CH_2Cl_2) 1710 (C=O) cm^{-1}; mass spectrum, m/e calcd for $C_{19}H_{26}O_2$ 286.1933, obsd 286.1941.

(1S,2R,5R)-5-Methyl-2-(1-methyl-1-phenylethyl)cyclohexyl Pyruvate (2d). To a solution of 1.62 g (6.99 mmole of epientphenmenthol (**2a**) in 60 mL of pyridine was slowly added 2.23 g (20.9 mmol) of freshly prepared pyruvyl chloride at −10 °C. The reaction mixture was stirred under nitrogen at room temperature for 16 h. The mixture was then diluted with 75 mL of dichloromethane and washed successively with 2 N HCl, saturated $NaHCO_3$, and brine. The organic layer was dried (4-Å molecular sieves) and concentrated to afford 2.48 g of a mixture of the acetate and pyruvate esters. The desired pyruvate was isolated by preparative HPLC (Skelly-B–EtOAc, 20:1) to give 1.08 g (51%): ^1H NMR ($CDCl_3$) 7.38–6.93 (m, 5 H, aromatic CH's), 5.17 (m, 1 H, CHO), 2.05 (s, 3 H, $CH_3C{=}O$), 1.32 (s, 3 H, CH_3), 1.23 (s, 3 H, CH_3), 0.95 (d, J = 7 Hz, 3 H, CH_3); ^{13}C NMR ($CDCl_3$) 191.1, 159.3, 150.7, 128.1, 125.5, 73.7, 50.7, 39.9, 38.0, 31.0, 28.4, 27.3, 26.3, 24.5, 21.2, 18.6; IR ($CHCl_3$) 1740 (C=O), 1725 (C=O) cm^{-1}.

(1S,2R,5R,2'S)-5-Methyl-2-(1-methyl-1-phenylethyl)-cyclohexyl 2-Hydroxy-4-octenoate (2e). To a solution of 1.991 g (6.5 mmol) of the hydrate of in 30 mL of dichloromethane at −78 °C was added dropwise 2.87 g (11 mmol) of tin tetrachloride. The mixture was stirred at −78 °C (under N_2) for 10 min and the 1.64 g (19.5 mmol) of 1-hexene was then added. After a further 6 h at −78 °C, 1.01 g (10 mmol) of triethylamine was added. The mixture was washed with water, dried (4-Å molecular sieves), and concentrated to yield 6.68 g (88%) of crude ene adduct. Analysis of the crude product by HPLC and showed that it is at least 97% pure. The product was purified by prep HPLC to give 1.58 g of pure compound **2e**: yield 65%; ^1H NMR ($CDCl_3$, 200 MHz) 7.37–7.06 (m, 5 H, aromatic CH's), 5.53–5.17 (m, 2 H, CH=CH), 5.08 (dt, J = 10.5 Hz, J = 4.4 Hz, 1 H, $CHOC{=}O$), 3.37 (q, J = 6 Hz, 1 H, $CHC{=}O$), 2.62 (d, J = 6 Hz, 1 H, OH), 1.33 (s, 3 H, CH_3), 1.22 (s, 3 H, CH_3), 0.97 (d, J = 7.4 Hz, 3 H, CH_3), 0.87 (t, J = 7.4 Hz, 3 H, CH_3); ^{13}C NMR ($CDCl_3$) 173.8, 151.0, 133.9, 128.0, 125.4, 124.2, 72.4, 69.8, 50.9, 39.7, 38.4, 37.2, 34.7, 31.2, 28.4, 27.4, 24.9, 22.5, 21.3, 18.6, 13.6; mass spectrum, m/e calcd for $C_{24}H_{36}O_3$ 372.2664, obsd 372.2671.

(1S,2R,5R,2'S)-5-Methyl-2-(1-methyl-1-phenylethyl)-cyclohexyl *endo*-2-Bicyclo[2.2.1]heptanecarboxylate (2f). To a solution of 0.916 g (3.2 mmol) of acrylate **2c** in 50 mL of dichloromethane at 0 °C was added 0.911 g (4.8 mmol) of titanium tetrachloride followed after 45 min by 1.06 g (16 mmol) of freshly distilled cyclopentadiene. After 4 h the reaction was quenched by the addition of 10 mL of water. The aqueous layer was separated and washed with three 25-mL portions of ether. The organic layers were dried and concentrated to afford 1.10 g of crude adducts. The endo diastereomer **2f** was isolated by preparative HPLC in 81% yield: ^1H NMR ($CDCl_3$, 200 MHz) 7.40–7.08 (m, 5 H, aromatic), 6.13 (d of d, J = 3.2 Hz, 1 H, C=CH), 5.94 (d of d, J = 6.0, 3.2 Hz, 1 H, CH=C), 5.02 (d of t, J = 8.4, 5.0 Hz, 1 H, CH), 3.11 (br s, 1 H, CHCH=C), 2.83 (br s, 1 H, CHC=C), 2.56 (d of t, J = 9.5, 4.2 Hz, 1 H, $CHC{=}O$), 0.93 (d, J = 7.4 Hz, 3 H, CH_3); ^{13}C NMR ($CDCl_3$) 173.8, 150.7, 132.7, 132.1, 127.9, 125.7, 125.3, 71.3, 50.4, 49.5, 45.5, 43.7, 42.5, 40.2, 38.1, 31.1, 29.5, 27.4, 27.2, 27.0, 26.4, 21.7, 19.1; IR ($CHCl_3$) 1720 (C=O) cm^{-1}.

(1S,2R,5R,2'S)-5-Methyl-2-(1-methyl-1-phenylethyl)-cyclohexyl 2-Phenyl-2-hydroxypropionate (2g). To a solution of 0.977 g (3.3 mmol) of the pyruvate **2d** in 20 mL of dry ether at −78 °C was added 1.2 mL of a 3.0 M (3.6 mmol) solution of phenylmagnesium bromide in ether. After the reaction mixture had been stirred under nitrogen at −78 °C for 6 h, it was quenched with 8 mL of saturated NH_4Cl solution. The ethereal layer was separated and the aqueous layer was extracted with three 50-mL portions of ether. The organic layers were combined, dried (4-Å molecular sieves), and concentrated to give 1.19 g of crude material. The Grignard addition products were isolated by preparative HPLC to afford 0.974 g (78%) of a mixture of two diastereoisomers differing in configuration at C2' in a ratio of 86:14.

For the major isomer 2'*R*: ^{13}C NMR ($CDCl_3$) 174.5, 150.0, 143.0, 128.1, 128.0, 127.5, 125.6, 125.5, 125.4, 125.2, 75.6, 74.4, 49.9, 40.1, 37.1, 30.7, 27.3, 26.5, 26.2, 21.5, 19.1.

(2S)- and (2R)-1,2-Dihydroxy-*trans*-4-hexene (3). To a solution of 2.56 g (6.88 mmol) of **1e** in 70 mL of THF at −78 °C was slowly added 27 mL a 1.0 M (27 mmol) hexane solution of diisobutylaluminum hydride. The mixture was allowed to slowly warm up to room temperature over a period of 16 h. The mixture was then cooled to 0 °C and 15 mL of methanol was added to destroy any excess amount of diisobutylaluminum hydride. After 15 mL of water was added, the reaction mixture was filtered through a pad of Celite. The filtrate was concentrated and extracted with three 50-mL portions of ether. The ethereal extracts were combined and washed with saturated sodium chloride solution. The organic layer was separated, dried (4-Å molecular sieves), and concentrated to give 2.20 g of crude product. The desired *S* diol was separated from 8-phenylmenthol by preparative HPLC (Skelly-B/EtOAc = 1:1) to yield 0.415 g (52%) of **3(2S)** that was further purified by simple vacuum distillation: ^1H NMR ($CDCl_3$, 200 MHz) 5.64–5.30 (m, 2 H, CH=CH), 3.80–3.58 (m, 2 H, CH_2O), 3.55–3.37 (m, 1 H, CHO), 3.18 (br s, 2 H, OH), 2.18 (t, J = 6.3 Hz, 2 H, CH_2), 2.0 (q, J = 7.4 Hz, 2 H, CH_2), 1.50–1.28 (m, 2 H, CH_2), 0.9 (t, J = 6.9 Hz, 3 H, CH_3); ^{13}C NMR ($CDCl_3$) 134.4, 125.4, 71.9, 66.3, 36.8, 34.8, 22.6, 13.7; IR (CH_2Cl_2) 3040–3695 (OH) cm^{-1}; $[\alpha]_D$ −11.5° (EtOH).

The enantiomer, **3(2R)**, was obtained in an analogous fashion from 0.914 g of **2e** in 52% yield with ^1H NMR, ^{13}C NMR, and infrared spectra identical with those for **3(2S)**: $[\alpha]_D$ +11.1° (EtOH).

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A Study of the Catalytic Deuteration of Maleic and Fumaric Acids and Derivatives with Palladium on Carbon

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Catalytic deuteration of maleic and fumaric acids and of the corresponding esters with Pd/C is an important and useful method for the stereospecific incorporation of vicinal deuterium.[1-11] Reduction of fumaric and maleic acids and

(1) Childs, C. R., Jr.; Bloch, K. *J. Org. Chem.* **1961**, *26*, 1630.
(2) Chickos, J. S. *J. Org. Chem.* **1979**, *44*, 780.
(3) Chickos, J. S.; Alul, R.; Baush, M. *J. Org. Chem.* **1981**, *46*, 3559. Annamalai, A.; Keiderling, T. A.; Chickos, J. S. *J. Am. Chem. Soc.* **1984**, *106*, 6254.
(4) Field, L. D.; Kovac, C. A.; Stephenson, L. M. *J. Org. Chem.* **1982**, *47*, 1358.
(5) Tchen, T. T.; Van Milligan, H. *J. Am. Chem. Soc.* **1960**, *82*, 4115.
(6) Chickos, J. S.; Al-Nawwar, K. *Tetrahedron Lett.* **1985**, 1127.
(7) Arigoni, D.; Eliel, E. L. In "Topics in Stereochemistry"; Eliel, E. L., Allinger, N. L., Ed.; Wiley-Interscience: New York, 1969; Vol. 4, pp 127–243.
(8) Winter, R. E. K.; Honig, M. L. *J. Am. Chem. Soc.* **1971**, *93*, 4616.
(9) Honig, M. L. Ph.D. Thesis, Polytechnic Institute of Brooklyn, Brooklyn, NY, June 1970; *Diss. Abst. Int., B* **1971**, *31*, 3918B.

0022-3263/86/1951-0553$01.50/0