Pt-Catalyzed Enantioselective Diboration of Terminal Alkene with B₂(pin)₂

Laura T. Kliman, Scott N. Mlynarski, and James P. Morken*

Department of Chemistry, Merkert Chemistry Center, Boston College, Chestnut Hill, MA 02467

Supporting Information

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General Information

^1H NMR spectra were recorded on Varian Unity Inova 500 MHz and Varian Gemini 400 MHz spectrometers. Chemical shifts are reported in ppm with the solvent resonance as the internal standard (CDCl_3 : 7.24 ppm). Data are reported as follows: chemical shift, integration, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, br = broad, m = multiplet), coupling constants (Hz) and assignment. $^{13}\text{C}\{^1\text{H}\}$ NMR spectra were recorded on Varian Unity Inova 500 MHz (125 MHz) and Varian Gemini 400 MHz (100 MHz) spectrometers. Chemical shifts are reported in ppm with the solvent resonance as the internal standard (CDCl_3 : 77.00 ppm). $^{31}\text{P}\{^1\text{H}\}$ NMR (162 MHz) were recorded on a Varian Unity Inova 400 spectrometer. Chemical shifts are reported for ^{31}P NMR spectra using phosphoric acid as an external standard. Infrared (IR) spectra were recorded on a Bruker α -P Spectrometer. Frequencies are reported in wavenumbers (cm^{-1}) as follows: strong (s), broad (br), medium (m), and weak (w). High-resolution mass spectrometry (ESI) was performed at Boston College, Chestnut Hill, MA.

Liquid chromatography was performed using forced flow (flash chromatography) on silica gel (SiO_2 , 230 x 450 Mesh) purchased from Silicycle. Thin layer chromatography was performed on 25 μm silica gel glass backed plates from Silicycle. Visualization was performed using ultraviolet light (254 nm), phosphomolybdic acid (PMA), and potassium permanganate (KMnO_4).

Analytical chiral gas-liquid chromatography (GLC) was performed on a Hewlett-Packard 6890 Series chromatograph equipped with a split mode capillary injection system, a flame ionization detector, and a Supleco β -Dex 120 column with helium as the carrier gas. Analytical chiral supercritical fluid chromatography (SFC) was performed on a Berger Instruments Supercritical Chromatograph equipped with an Alcott auto sampler and a Knauer UV detector with methanol as the modifier. Analytical chiral high-performance liquid chromatography (HPLC) was performed on a Shimadzu SCL-10A liquid chromatograph equipped with a UV detector and a Daicel Chiracel-OD column.

All reactions were conducted in oven- or flame-dried glassware under an inert atmosphere of nitrogen or argon. Tetrahydrofuran, dichloromethane, and diethyl ether were purified using Pure Solv MD-4 solvent purification system, from Innovative Technology, Inc., by passing the solvent through two activated alumina columns after being purged with argon. Ethyl acetate was distilled from calcium hydride and degassed. Triethylamine was distilled from calcium hydride. Potassium tetrachloroplatinate(II) was purchased from Acros Organics. Dibenzylideneacetone was purchased from Oakwood Chemicals. Tetrabutylammonium chloride was purchased from Fluka. Sodium acetate was purchased from Fisher Scientific. Bis(pinacolato)diboron was obtained from Allychem Co., Ltd. and recrystallized from pentane prior to use. Dichlorophenylphosphine was purchased from Strem Chemicals, Inc. and used without further purification. 1-octene, 4,4-dimethyl-1-pentene, 4-phenyl-1-butene, vinyl cyclohexane, 3,3-dimethyl-1-butene, allylbenzene, styrene, *tert*-butyldiphenylsilyl chloride, imidazole, and bromochloromethane were purchased from Aldrich and used without further purification.

Experimental Procedures

I. Preparation of Pt₂(dba)₃.

Tris(dibenzylideneacetone)diplatinum was prepared using the literature procedure¹ with slight modification. To a 3-neck 500-mL round-bottomed flask equipped with a magnetic stir bar and reflux condenser was added dibenzylideneacetone (3.95 g, 16.8 mmol), tetrabutylammonium chloride (2.0 g, 7.2 mmol), and sodium acetate (3.55 g, 43.3 mmol). Salts were dissolved in methanol and the solution was warmed to 70 °C and allowed to stir for 5 min. To a 50-mL pear-shaped flask was added potassium tetrachloroplatinate (1.00 g, 2.41 mmol). The potassium salt was dissolved in water (8 mL) with mild heating. The 3-neck round-bottomed flask was charged with the potassium tetrachloroplatinate solution and the reaction was allowed to stir at 70 °C for 3 h. After 3 h, the reaction was cooled to ambient temperature, transferred to a 500-mL round-bottomed flask and concentrated by rotary evaporation to half the volume. The reaction mixture was filtered on a Büchner funnel; solids were washed with copious amounts of water and methanol until no yellow dibenzylideneacetone crystals were visible. The platinum catalyst was placed under the high vacuum for 24 h to remove residual methanol and water, and tris(dibenzylideneacetone)diplatinum was obtained as a brown solid (923 mg, 70% yield). Spectroscopic characterization of the platinum catalyst was in accord with spectra reported in the literature.²

II. Ligand Synthesis.

Preparation of 3,5-diethylphenylTADDOL.

3,5-DiethylphenylTADDOL was prepared according to the literature procedure² with slight modification. To a flame dried 100 mL 2-neck round bottom flask equipped with magnetic stir bar and reflux condenser was added crushed magnesium turnings (401.0 mg, 16.50 mmol) under N₂. The apparatus was flame-dried again, a single crystal of I₂ was added and the reaction mixture was diluted with tetrahydrofuran (29 mL). To another flame dried 25 mL pear-shaped flask was added 1-bromo-3,5-diethylbenzene (3.91 g, 18.33 mmol) and tetrahydrofuran (12 mL). The solution of 1-bromo-3,5-diethylbenzene in tetrahydrofuran was slowly added to the magnesium mixture at room temperature via syringe. The reaction was allowed to reflux at 80 °C in an oil bath for 2 h, at which time the reaction was cooled to 0 °C, and a solution of (4*R*,5*R*)-2,2-dimethyl-1,3-dioxolane-4,5-dicarboxylic acid in tetrahydrofuran (4 mL) was added slowly via syringe. The reaction was allowed to reflux for 12 h, after which it was cooled to 0 °C and quenched with NH₄Cl (10 mL, sat. aq.). The organic and aqueous layers were separated and the aqueous layer was extracted with ethyl acetate (3 x 30 mL). The combined organics were dried over Na₂SO₄, filtered, and concentrated *in vacuo*. The crude material was purified by silica gel chromatography (1-50% ethyl acetate/hexanes) to afford the title compound as a yellow solid (2.23g, 88% yield).

¹ Lewis, L. N.; Krafft, T. A.; Huffman, J. C. *Inorg. Chem.* **1992**, *31*, 3555.

² Sieber, J. D.; Morken, J. P. *J. Am. Chem. Soc.* **2008**, *130*, 4978.

3,5-DiethylphenylTADDOL. ^1H NMR (400 MHz, CDCl_3): δ 0.94 (6H, s), 1.13 (12H, t, $J = 7.6$ Hz), 1.22 (12H, t, $J = 7.6$ Hz), 2.54 (8H, q, $J = 15.2$ Hz, 7.6 Hz), 2.61 (8H, q, $J = 14.8$ Hz, 7.2 Hz), 3.78 (2H, s), 4.67 (2H, s), 6.91 (2H, s), 6.96 (2H, s), 7.00 (4H, s), 7.20 (4H, s); ^{13}C NMR (CDCl_3): δ 15.51, 15.94, 27.04, 28.94, 29.08, 76.68, 77.00, 77.32, 78.29, 81.00, 109.2, 124.6, 125.8, 126.1, 126.5, 142.6, 142.7, 143.6, 145.9. IR (neat): 3299 (br w), 2962 (s), 2930 (m), 1599 (w), 1457 (m), 1238 (w), 1063 (m) 871 (s), 746 (m) cm^{-1} . $[\alpha]_{\text{D}}^{20} = +8.555$ ($c = 0.522$, CHCl_3 , $l = 50$ mm).

Preparation of (R,R)-3,5-diethylphenylTADDOLPPh.

To a flame dried 100 mL round bottom flask equipped with magnetic stir bar was added 3,5-diethylphenylTADDOL (2.23 g, 3.23 mmol) and tetrahydrofuran (32.3 mL, 0.1 M) under N_2 . Triethylamine (1.53 mL, 10.97 mmol) was added via syringe and the reaction mixture was brought to 0 °C in an ice bath. Dichlorophenylphosphine (0.48 mL, 3.55 mmol) was added dropwise via syringe at 0 °C, the reaction was brought to room temperature and was allowed to stir for 2 h. The reaction was diluted with Et_2O , filtered through celite and concentrated *in vacuo*. The crude material was purified by silica gel chromatography (5% ethyl acetate/hexanes) to afford the title compound as a white solid (2.31 g, 90% yield).

(R,R)-3,5-DiethylphenylTADDOLPPh. ^1H NMR (400 MHz, CDCl_3): δ 0.18 (3H, s), 1.20 (24H, m), 1.55 (3H, s), 2.60 (16H, m), 4.89 (1H, d, $J = 8.4$ Hz), 5.65 (1H, q, $J = 8.4$ Hz, 4.8 Hz), 6.87 (1H, s), 6.93 (2H, s), 6.96 (1H, s), 7.07 (2H, s), 7.16 (2H, s), 7.30 (2H, s), 7.47 (3H, s), 7.55 (2H, s), 7.86 (2H, s); ^{13}C NMR (CDCl_3): δ 15.42, 15.53, 15.73, 15.92, 24.64, 27.95, 28.94, 29.12, 82.53, 82.77, 83.01, 83.52, 83.59, 84.29, 110.9, 124.5, 124.6, 125.9, 126.3, 126.4, 126.5, 126.6, 128.1, 128.2, 129.7, 130.0, 130.3, 141.5, 141.6, 142.6, 142.9, 143.3, 143.5, 146.3, 146.9. ^{31}P NMR (162 MHz, CDCl_3): δ 156.7. IR (neat): 2962 (s), 2931 (m), 2872 (w), 1599 (w), 1458 (m), 1160 (m), 1069 (m), 875 (s), 806 (m) cm^{-1} . $[\alpha]_{\text{D}}^{20} = -59.634$ ($c = 0.660$, CHCl_3 , $l = 50$ mm).

III. Preparation of 1-Alkenes.

A. Preparation of allyloxy(*tert*-butyl)diphenylsilane. To a flame-dried, round bottom flask was added imidazole (3.52 g, 51.65 mmol). The flask was purged with nitrogen and charged with allyl alcohol (1.0 g, 17.23 mmol) and dichloromethane (34.4 mL). *tert*-Butyldiphenylsilyl chloride (13.4 mL, 51.65 mmol) and triethylamine (7.2 mL, 51.65 mmol) were added to the reaction mixture under nitrogen atmosphere and the reaction was allowed to stir at room temperature for 20 h. The reaction was then diluted with dichloromethane (30 mL) and washed with brine (15 mL). The layers were separated and the aqueous layer was extracted with dichloromethane (3 x 30 mL). The combined organics were dried over Na_2SO_4 , filtered, and concentrated by rotary evaporation. The crude product was purified by column chromatography on SiO_2 (100% hexanes) to give the title compound as a clear, colorless liquid (4.39 g, 86% yield).

Allyloxy(*tert*-butyl)diphenylsilane. ¹H NMR (400 MHz, CDCl₃): δ 1.13 (9H, s, SiC(CH₃)₃), 4.26-4.28 (2H, m, SiOCH₂), 5.17 (1H, dd, *J* = 10.8 Hz, 2.0 Hz, HC=CH_{cis}H_{trans}), 5.44 (1H, dd, *J* = 16.8 Hz, 2.8 Hz, HC=CH_{cis}H_{trans}), 5.98 (1H, dddd, *J* = 18.8 Hz, 8.4 Hz, 4.0 Hz, 4.0 Hz, SiOCH₂CH=CH₂), 7.40-7.49 (6H, m, SiAr), 7.71-7.76 (4H, m, SiAr); ¹³C NMR (100 MHz, CDCl₃): δ 19.3, 26.9, 64.6, 113.9, 127.6, 129.6, 133.6, 135.5, 136.9; IR (neat): 2931.3 (w), 2857.5 (m), 1427.5 (m), 1134.0 (m), 1111.4 (s), 1079.1 (m), 823.8 (m), 739.8 (m), 701.1 (s) cm⁻¹; HRMS-(ESI+) for C₁₉H₂₅OSi [M+H]⁺: calculated: 297.1675, found: 297.1669.

B. Preparation of (but-3-enyloxy)(*tert*-butyl)diphenylsilane. To a flame-dried, round bottom flask was added imidazole (2.83 g, 41.60 mmol). The flask was purged with nitrogen and charged with 3-buten-1-ol (1.0 g, 13.87 mmol) and dichloromethane (27.7 mL). *tert*-Butyldiphenylsilyl chloride (10.8 mL, 41.60 mmol) and triethylamine (5.8 mL, 41.60 mmol) were added to the reaction mixture under nitrogen atmosphere and the reaction was allowed to stir at room temperature for 20 h. The reaction was then diluted with dichloromethane (30 mL) and washed with brine (15 mL). The layers were separated and the aqueous layer was extracted with dichloromethane (3 x 30 mL). The combined organics were dried over Na₂SO₄, filtered, and concentrated by rotary evaporation. The crude product was purified by column chromatography on SiO₂ (100% hexanes) to give the title compound as a clear, colorless liquid (3.88 g, 90% yield).

(But-3-enyloxy)(*tert*-butyl)diphenylsilane. ¹H NMR (400 MHz, CDCl₃): δ 1.19 (9H, s, OSiC(CH₃)₃), 2.44 (2H, dd, *J* = 13.2 Hz, 6.4 Hz, SiOCH₂CH₂), 3.84 (2H, t, *J* = 6.4 Hz), 5.11-5.20 (2H, m, CH₂CH=CH₂), 5.95 (1H, dddd, *J* = 16.8 Hz, 10.0 Hz, 6.8 Hz, 6.8 Hz, CH₂CH=CH₂), 7.46-7.53 (6H, m, SiAr), 7.80-7.82 (4H, m, SiAr); ¹³C NMR (100 MHz, CDCl₃): δ 19.3, 26.9, 37.3, 63.5, 116.3, 127.6, 129.5, 133.9, 135.3, 135.5; IR (neat): 2930.5 (w), 2857.5 (w), 1427.4 (m), 1104.9 (s), 1087.7 (s), 910.6 (m), 822.4 (m), 736.3 (m), 698.8 (s) cm⁻¹; HRMS-(ESI+) for C₂₀H₂₇OSi [M+H]⁺: calculated: 311.1831, found: 311.1834.

IV. Representative Procedure for Alkene Diboration/Oxidation.

To an oven-dried 6-dram vial with magnetic stir bar in the dry box was added Pt₂(dba)₃ (18.3 mg, 16.7 μmol), (*R,R*)-3,5-diethylphenyl-TADDOLPPh (**L8**) (32.0 mg, 40.1 μmol), B₂(pin)₂ (178.2 mg, 701.7 μmol) and tetrahydrofuran (6.7 mL, [substrate] = 0.1 M). The vial was sealed with a polypropylene cap, removed from the dry box, and heated to 80 °C in an oil bath for 30 min. The vial was cooled to room temperature, returned to the dry box and charged with 1-octene (75.0 mg, 668.8 μmol). The vial was sealed, removed from the dry box, and stirred at 60 °C for 12 h. The reaction mixture was cooled to 0 °C (ice/water) and charged with 3 M sodium hydroxide (2 mL), and 30% hydrogen peroxide (1 mL). The reaction was gradually warmed to room temperature and allowed to stir for 4 h at which time the vial was cooled to 0 °C (ice/water) and saturated aqueous sodium thiosulfate was added dropwise over 5 min. The reaction mixture was diluted with ethyl acetate and the aqueous and organic layers were separated. The aqueous layer was washed with ethyl acetate (3 x 15 mL). The combined organic layers were dried over Na₂SO₄, filtered, and concentrated by rotary evaporation. The crude

reaction mixture was purified on silica gel (30-70% ethyl acetate/hexanes) to afford a clear, colorless oil (81.1 mg, 83% yield).

V. Full Characterization and Proof of Stereochemistry

(S)-Octane-1,2-diol. The diboration was performed according to the general procedure with 1-octene (75.0 mg, 668.8 μ mol), Pt₂(dba)₃ (18.3 mg, 16.7 μ mol), (*R,R*)-3,5-diethylphenylTADDOLPh (**L8**) (32.0 mg, 40.1 μ mol), and B₂(pin)₂ (178.2 mg, 701.7 μ mol) in tetrahydrofuran (6.7 mL, 0.1 M). The crude reaction mixture was purified on silica gel (30-70% ethyl acetate/hexanes, stain in KMnO₄) to afford a white solid (81.1 mg, 83% yield). Spectral data are in accordance with the literature.³ HRMS-(ESI+) for C₈H₁₉O₂ [M+H]⁺: calculated: 147.1385, found: 147.1380. $[\alpha]_D^{20} = -1.538$ ($c = 0.784$, CHCl₃, $l = 50$ mm).

Proof of Stereochemistry:

The resulting 1,2-diol was treated with 2,2-dimethoxypropane and catalytic *p*-toluenesulfonic acid (below). The resulting ketal was compared to the racemic ketal of octane-1,2-diol prepared from dihydroxylation of 1-octene with osmium tetroxide and 4-methylmorpholine *N*-oxide. The authentic (*S*)-isomer was prepared from the Sharpless asymmetric dihydroxylation of 1-octene utilizing AD-mix- α .⁴

Chiral GLC (β -dex, Supelco, 100 °C, 20 psi) – analysis of the acetonide of octane-1,2-diol.

³ Emmanuvel, L.; Shaikh, T. M. A.; Sudalai, A.; *Org. Lett.*, **2005**, 7, 5071.

⁴ Jacobsen, E.N.; Markd, I; Mungall, W.S.; Schreider, G.; Sharpless, K.B.; *J. Am. Chem. Soc.*, **1988**, 110, 1968.

(S)-4,4-Dimethylpentane-1,2-diol. The diboration was performed according to the general procedure with 4,4-dimethyl-1-pentene (75.0 mg, 763.8 μmol), Pt_2dba_3 (20.8 mg, 19.1 μmol), (*R,R*)-3,5-diethylphenylTADDOLPPh (**L8**) (36.5 mg, 45.8 μmol), and $\text{B}_2(\text{pin})_2$ (203.7 mg, 802.2 μmol) in tetrahydrofuran (7.6 ml, 0.1 M). The crude reaction mixture was purified on silica gel (30-70% ethyl acetate/hexanes, stain in KMnO_4) to afford a clear, colorless oil that could not be separated from pinacol (115.5 mg, 2:1 product:pinacol = 77% yield). Spectral data are in accordance with the literature.⁵ HRMS-(ESI+) for $\text{C}_7\text{H}_{17}\text{O}_2$ [$\text{M}+\text{H}$]: calculated 133.1226, found: 133.1231.

Proof of Stereochemistry:

The resulting 1,2-diol was treated with benzoic anhydride, triethylamine and catalytic 4-(dimethylamino)pyridine (below). The resulting bis(benzoate) was compared to the racemic bis(benzoate) of 4,4-dimethylpentane-1,2-diol prepared from dihydroxylation of 4,4-dimethyl-1-pentene with osmium tetroxide and 4-methylmorpholine *N*-oxide. The authentic (*R*)-isomer was prepared from the Sharpless asymmetric dihydroxylation of 4,4-dimethyl-1-pentene utilizing AD-mix- β .

Chiral SFC (Chiracel OD-H, 0% MeOH, 3 mL/min, 150 bar, 50 °C, 220 nm) – analysis of the bis(benzoate) of 4,4-dimethylpentane-1,2-diol.

⁵ Trudeau, S.; Morgan, J. M.; Shrestha, M.; Morken, J. P.; *J. Org. Chem.*, **2005**, 70, 9538.

(S)-4-Phenylbutane-1,2-diol. The diboration was performed according to the general procedure with 4-phenyl-1-butene (75.0 mg, 571.6 μmol), Pt_2dba_3 (15.6 mg, 14.3 μmol), (*R,R*)-3,5-diethylphenylTADDOLPh (**L8**) (27.3 mg, 34.3 μmol), and $\text{B}_2(\text{pin})_2$ (152.4 mg, 600.2 μmol) in tetrahydrofuran (5.72 mL, 0.1 M). The crude reaction mixture was purified on silica gel (30-70% ethyl acetate/hexanes, stain in KMnO_4) to afford a clear, colorless oil (81.7 mg, 86 % yield). Spectral data are in accordance with the literature.⁶ HRMS-(ESI+) for $\text{C}_{10}\text{H}_{15}\text{O}_2$ $[\text{M}+\text{H}]^+$: calculated: 167.1072, found: 167.1077. $[\alpha]_{\text{D}}^{20} = -16.240$ ($c = 1.143$, CHCl_3 , $l = 50$ mm).

Proof of stereochemistry:

The resulting 1,2-diol was treated with 2,2-dimethoxypropane and catalytic *p*-toluenesulfonic acid. The resulting ketal was compared to the racemic ketal of 4-phenylbutane-1,2-diol prepared from treatment of 4-phenyl-1-butene with osmium tetroxide and 4-methylmorpholine *N*-oxide. The authentic (*R*)-isomer was prepared from the Sharpless asymmetric dihydroxylation of 4-phenyl-1-butene utilizing AD-mix- β .

Chiral GLC (β -dex, Supelco, 100 $^\circ\text{C}$, 20 psi) – analysis of the acetonide of 4-phenylbutane-1,2-diol.

⁶ Stead, D.; O'Brien, P.; Sanderson, A.; *Org. Lett.*, **2008**, *10*, 1409.

(S)-1-Cyclohexylethane-1,2-diol. The diboration was performed according to the general procedure with vinyl cyclohexane (75.0 mg, 680.6 μmol), $\text{Pt}_2(\text{dba})_3$ (18.6 mg, 17.0 μmol), (*R,R*)-3,5-diethylphenylTADDOLPPh (**L8**) (32.5 mg, 40.8 μmol), and $\text{B}_2(\text{pin})_2$ (181.5 mg, 714.6 μmol) in tetrahydrofuran (6.8 mL, 0.1 M). The crude reaction mixture was purified on silica gel (30-70% ethyl acetate/hexanes, stain in KMnO_4) to afford a clear, colorless oil (85.4 mg, 87% yield). Spectral data are in accordance with the literature.⁷ HRMS-(ESI+) for $\text{C}_8\text{H}_{17}\text{O}_2$ $[\text{M}+\text{H}]^+$: calculated: 145.1229, found: 145.1222. $[\alpha]_{\text{D}}^{20} = +3.921$ ($c = 0.510$, CHCl_3 , $l = 50$ mm).

Proof of Stereochemistry:

The resulting 1,2-diol was treated with 2,2-dimethoxypropane and catalytic *p*-toluenesulfonic acid. The resulting ketal was compared to the racemic ketal of 1-cyclohexylethane-1,2-diol prepared from treatment of vinyl cyclohexane with osmium tetroxide and 4-methylmorpholine *N*-oxide. The authentic (*R*)-isomer was prepared from the Sharpless asymmetric dihydroxylation of vinyl cyclohexane utilizing AD-mix- β .

Chiral GLC (Supelco β -dex, 130 $^\circ\text{C}$, 20 psi) – analysis of the acetonide of 1-cyclohexylethane-1,2-diol.

⁷ Miller, S. P.; Morgan, J. B.; Nepveux, F. J.; Morken, J. P.; *Org. Lett.*; **2004**, 6, 131.

(S)-3,3-Dimethylbutane-1,2-diol. The diboration was performed according to the general procedure with 3,3-dimethyl-1-butene (75.0 mg, 891.2 μmol), $\text{Pt}_2(\text{dba})_3$ (24.4 mg, 22.3 μmol), (*R,R*)-3,5-diethylphenylTADDOLPPh (**L8**) (42.6mg, 53.5 μmol), and $\text{B}_2(\text{pin})_2$ (237.6 mg, 935.8 μmol) in tetrahydrofuran (8.9 mL, 0.1 M). The crude reaction mixture was purified on silica gel (40-70% ether/pentane, stain in KMnO_4) to afford a clear, colorless oil that was inseparable from pinacol (193.7 mg, 1:3 product:pinacol = 46% yield). Spectral data are in accordance with the literature.⁸ HRMS-(ESI+) for $\text{C}_6\text{H}_{15}\text{O}_2$ $[\text{M}+\text{H}]$: calculated: 119.1072, found: 119.1074.

Proof of Stereochemistry:

The title compound was compared to racemic 3,3-dimethylbutane-1,2-diol prepared from treatment of 3,3-dimethyl-1-butene with osmium tetroxide and 4-methylmorpholine *N*-oxide. The absolute stereochemistry was assigned by analogy.

Chiral GLC (β -dex, Supelco, 90 °C, 20 psi) – analysis of 3,3-dimethylbutane-1,2-diol.

racemic

diboration product

⁸ Miller, S. P.; Morgan, J. B.; Nepveux, F. J.; Morken, J. P.; *Org. Lett.*; **2004**, 6, 131.

(S)-3,3-Dimethyl-4-*p*-tolylbutane-1,2-diol. The diboration was performed according to the general procedure with 3,3-dimethyl-4-(4-methylphenyl)-1-butene (75.0 mg, 430.3 μmol), Pt_2dba_3 (11.7 mg, 10.8 μmol), (*R,R*)-3,5-diethylphenylTADDOLPPh (**L8**) (20.6 mg, 25.8 μmol) and $\text{B}_2(\text{pin})_2$ (114.6 mg, 451.8 μmol) in tetrahydrofuran (4.3 mL, 0.1 M). The crude reaction mixture was purified on silica gel (30–70% ethyl acetate/hexanes) to afford a clear, colorless oil (46.6 mg, 52% yield). Spectral data are in accordance with the literature.⁹ HRMS- (ESI+) for $\text{C}_{13}\text{H}_{21}\text{O}_2$ $[\text{M}+\text{H}]^+$: calculated: 209.1542, found: 209.1545. $[\alpha]_{\text{D}}^{20} = -4.202$ ($c = 0.691$, CHCl_3 , $l = 50$ mm).

Proof of Stereochemistry:

The title compound was compared to the racemic 1,2-diol prepared from dihydroxylation of 3,3-dimethyl-4-(4-methylphenyl)-1-butene with osmium tetroxide and 4-methylmorpholine *N*-oxide. The authentic (*R*)-isomer was prepared from the Sharpless asymmetric dihydroxylation of 3,3-dimethyl-4-(4-methylphenyl)-1-butene utilizing AD-mix- β .

*Chiral SFC (Chiracel OD-H, 0.7% MeOH, 3 mL/min, 150 psi, 50 °C, 220 nm) – analysis of 3,3-dimethyl-4-*p*-tolylbutane-1,2- diol.*

⁹ Miller, S. P.; Morgan, J. B.; Nepveux, F. J.; Morken, J. P.; *Org. Lett.*, **2004**, *6*, 131.

(S)-3-Phenylpropane-1,2-diol. The diboration was performed according to the general procedure with allylbenzene (75.0 mg, 634.6 μmol), $\text{Pt}_2(\text{dba})_3$ (17.3 mg, 17.9 μmol), (*R,R*)-3,5-diethylphenylTADDOLPh (**L8**) (30.3 mg, 38.1 μmol), and $\text{B}_2(\text{pin})_2$ (169.2 mg, 666.3 μmol) in tetrahydrofuran (6.3 mL, 0.1 M). The crude reaction mixture was purified on silica gel (30-70% ethyl acetate/hexanes, stain in KMnO_4) to afford a white solid (83.8 mg, 87% yield). ^1H NMR (400 MHz, CDCl_3): δ 2.66-2.76 (2H, m, PhCH_2), 2.83 (2H, br s, $\text{OH} \times 2$), 3.44 (1H, dd, $J = 11.2$ Hz, 7.2 Hz, HOCH_AH_B), 3.61 (1H, dd, $J = 11.2$ Hz, 2.8 Hz, HOCH_AH_B), 3.85-3.90 (1H, m, CH_2CHOH), 7.17-7.23 (3H, m, CH_2Ph), 7.26-7.30 (2H, m, CH_2Ph); ^{13}C NMR (100 MHz, CDCl_3): δ 39.8, 65.9, 73.0, 126.5, 128.5, 129.3, 137.7; IR (neat): 3363.1 (br s), 2939.5 (w), 1495.8 (m), 1454.2 (m), 1089.7 (s), 1069.0 (s), 1030.6 (s), 745.3 (m), 699.6 (s) cm^{-1} ; HRMS-(ESI+) for $\text{C}_8\text{H}_9\text{O}_1$ [$\text{M}-\text{H}_2\text{O}+\text{H}$]: calculated: 121.0653, found: 121.0657. $[\alpha]_D^{20} = -17.877$ ($c = 0.576$, CHCl_3 , $l = 50$ mm).

Proof of Stereochemistry:

The title compound was compared to racemic 3-phenylpropane-1,2-diol prepared from treatment of allylbenzene with osmium tetroxide and 4-methylmorpholine *N*-oxide. The authentic (*R*)-isomer was prepared from the Sharpless asymmetric dihydroxylation of allylbenzene utilizing AD-mix- β .

Chiral HPLC (Chiracel OD, 2.0% IPA, 1.5 mL/min, 220 nm)-analysis of 3-phenylpropane-1,2-diol.

(S)-1-Phenylethane-1,2-diol. The diboration was performed according to the general procedure with styrene (75.0 mg, 720.1 μmol), $\text{Pt}_2(\text{dba})_3$ (19.7 mg, 18.0 μmol), (*R,R*)-3,5-diethylphenylTADDOLPPh (**L8**) (34.4 mg, 43.2 μmol), and $\text{B}_2(\text{pin})_2$ (192.0 mg, 756.1 μmol) in tetrahydrofuran (7.2 mL, 0.1 M). The crude reaction mixture was purified on silica gel (30-70% ethyl acetate/hexanes, stain in KMnO_4) to afford a white solid (83.6 mg, 84% yield). Spectral data are in accordance with the literature.¹⁰ HRMS-(ESI+) for $\text{C}_8\text{H}_9\text{O}_1$ [$\text{M}-\text{H}_2\text{O}+\text{H}$]: calculated: 121.0653, found: 121.0656. $[\alpha]_{\text{D}}^{20} = +53.883$ ($c = 1.146$, CHCl_3 , $l = 50$ mm).

Proof of Stereochemistry:

The title compound was treated with 2,2-dimethoxypropane and catalytic *p*-toluenesulfonic acid. The resulting ketal was compared to the racemic ketal of 1-phenylethane-1,2-diol prepared from treatment of styrene with osmium tetroxide and 4-methylmorpholine *N*-oxide. The authentic (*R*)-isomer was prepared from the Sharpless asymmetric dihydroxylation of styrene utilizing AD-mix- β .

Chiral GLC (β -dex, Supelco, 140 $^\circ\text{C}$, 20 psi) – analysis of the acetonide of 1-phenylethane-1,2-diol.

racemic

diboration product

authentic

¹⁰ Miller, S. P.; Morgan, J. B.; Nepveux, F. J.; Morken, J. P.; *Org. Lett.*, **2004**, 6, 131.

(R)-3-(*tert*-Butyldiphenylsilyloxy)propane-1,2-diol. The diboration was performed according to the general procedure with allyloxy(*tert*-butyl)diphenylsilane (75.0 mg, 250.3 μmol), $\text{Pt}_2(\text{dba})_3$ (6.9 mg, 6.3 μmol), (*R,R*)-3,5-diethylphenylTADDOLPPh (**L8**) (12.1 mg, 15.2 μmol), and $\text{B}_2(\text{pin})_2$ (67.5 mg, 265.7 μmol) in tetrahydrofuran (2.5 mL, 0.1 M). The crude reaction mixture was purified on silica gel (20-30% ethyl acetate/hexanes) to afford a white solid (77.7 mg, 93% yield). $R_f = 0.39$ (50% ethyl acetate/hexane, stain in KMnO_4); ^1H NMR (400 MHz, CDCl_3): δ 1.05 (9H, s, $\text{SiCH}(\text{CH}_3)_3$), 1.94 (1H, br s, OH), 2.55 (1H, br s, OH), 3.61-3.74 (4H, m, $\text{SiOCH}_2\text{CHOHCH}_2\text{OH}$), 3.76-3.82 (1H, m, $\text{SiOCH}_2\text{CHOH}$), 7.36-7.45 (6H, m, SiAr), 7.62-7.65 (4H, m, SiAr); ^{13}C NMR (100 MHz, CDCl_3): δ 19.2, 26.9, 63.8, 65.2, 71.9, 127.8, 129.8, 132.8, 135.4; IR (neat): 3375.5 (br s), 2930.6 (m), 2857.8 (w), 1427.6 (m), 1111.7 (s), 823.7 (w), 740.3 (w), 701.6 (s) cm^{-1} ; HRMS- (ESI+) for $\text{C}_{19}\text{H}_{30}\text{NO}_3\text{Si}$ [$\text{M}+\text{NH}_4^+$]: calculated: 348.1995, found: 348.2000. $[\alpha]_D^{20} = +1.836$ ($c = 1.534$, CHCl_3 , $l = 50$ mm).

Proof of Stereochemistry:

Absolute stereochemistry was assigned by analogy.

Chiral HPLC (Chiracel-OD, 2.0 % IPA, 1.5 mL/min, 220 nm) – analysis of the title compound.

(S)-4-(*tert*-Butyldiphenylsilyloxy)butane-1,2-diol. The diboration was performed according to the general procedure with (but-3-enyloxy)(*tert*-butyl)diphenylsilane (100.0 mg, 322.1 μmol), $\text{Pt}_2(\text{dba})_3$ (8.8 mg, 8.1 μmol), (*R,R*)-3,5-diethylphenylTADDOLPh (**L8**) (15.4 mg, 19.3 μmol), and $\text{B}_2(\text{pin})_2$ (85.9 mg, 338.2 μmol) in tetrahydrofuran (3.2 mL, 0.1 M). The crude reaction mixture was purified on silica gel (30-60% ethyl acetate/hexanes) to afford a clear, colorless oil that could not be separated from pinacol (137.1 mg, 1:1 product:pinacol = 92% yield). R_f = 0.26 (50% ethyl acetate/hexane, stain in KMnO_4); ^1H NMR (400 MHz, CDCl_3): δ 1.03 (9H, s, $\text{SiC}(\text{CH}_3)_3$), 1.59-1.66 (1H, m, $\text{SiOCH}_2\text{CH}_A\text{H}_B$), 1.72-1.81 (1H, m, $\text{SiOCH}_2\text{CH}_A\text{H}_B$), 3.50 (1H, dd, J = 11.2 Hz, 6.4 Hz, $\text{OHCHCH}_A\text{H}_B\text{OH}$), 3.62 (1H, dd, J = 11.2 Hz, 3.6 Hz, $\text{OHCHCH}_A\text{H}_B\text{OH}$), 3.85 (2H, t, J = 5.2 Hz, SiOCH_2), 3.97-4.01 (1H, m, $\text{SiOCH}_2\text{CH}_2\text{CHOH}$), 7.35-7.45 (6H, m, SiAr), 7.64-7.66 (4H, m, SiAr); ^{13}C NMR (100 MHz, CDCl_3): δ 19.1, 24.9, 34.9, 62.5, 66.7, 71.6, 127.7, 129.8, 132.9, 135.5; IR (neat): 3380.8 (br s), 2930.1 (w), 2857.6 (w), 1427.6 (m), 1110.2 (s), 822.8 (w), 737.4 (m), 701.5 (s), 688.8 (m) cm^{-1} ; HRMS-(ESI+) for $\text{C}_{20}\text{H}_{29}\text{O}_3\text{Si}$ $[\text{M}+\text{H}]^+$: calculated: 345.1886, found: 345.1878. $[\alpha]_D^{20}$ = +2.224 (c = 1.065, CHCl_3 , l = 50 mm).

Proof of Stereochemistry:

The title compound was compared to racemic 4-(*tert*-butyldiphenylsilyloxy)butane-1,2-diol prepared from treatment of (but-3-enyloxy)(*tert*-butyl)diphenylsilane with osmium tetraoxide and 4-methylmorpholine *N*-oxide. The authentic (*R*)-isomer was prepared from the Sharpless asymmetric dihydroxylation of (but-3-enyloxy)(*tert*-butyl)diphenylsilane utilizing AD-mix- β .

Chiral HPLC (Chiracel-OD, 2.0% IPA, 1.5 mL/min, 220 nm) – analysis of the title compound.

VI. Procedure for Experiment in Scheme 1.

To an oven-dried 6-dram vial with magnetic stir bar in the dry box was added $\text{Pt}_2(\text{dba})_3$ (14.6 mg, 13.4 μmol), (*R,R*)-3,5-diethylphenylTADDOLPPh (**L8**) (25.6 mg, 32.1 μmol), $\text{B}_2(\text{pin})_2$ (712.8 mg, 2.81 mmol) and ethyl acetate (5.3 mL, 0.5 M). The vial was sealed with a polypropylene cap, removed from the dry box, and heated to 80 °C in an oil bath for 30 min. The vial was cooled to room temperature, returned to the dry box and charged with 1-octene (300.0 mg, 2.67 mmol). The vial was sealed, removed from the dry box, and stirred at 60 °C for 12 h. The reaction mixture was cooled to 0 °C (ice/water) and charged with 3 M sodium hydroxide (4 mL), and 30% hydrogen peroxide (2 mL). The reaction was gradually warmed to room temperature and allowed to stir for 4 h at which time the vial was cooled to 0 °C (ice/water) and saturated aqueous sodium thiosulfate was added dropwise over 5 min. The reaction mixture was diluted with ethyl acetate and the aqueous and organic layers were separated. The aqueous layer was washed with ethyl acetate (3 x 20 mL). The combined organic layers were dried over Na_2SO_4 , filtered, and concentrated by rotary evaporation. The crude reaction mixture was purified on silica gel (30-70% ethyl acetate/hexanes) to afford a white solid (340.1 mg, 87% yield).

Chiral GLC (β -dex, Supelco, 100 °C, 20 psi) – analysis of the acetonide of octane-1,2-diol.

racemic

diboration product

authentic

VII. Procedure for Alkene Diboration/Homologation/Oxidation (Scheme 2).

To an oven-dried 6-dram vial with magnetic stir bar in the dry box was added $\text{Pt}_2(\text{dba})_3$ (12.2 mg, 11.1 μmol), (*R,R*)-3,5-diethylphenylTADDOLPh (**L8**) (21.3 mg, 26.7 μmol), $\text{B}_2(\text{pin})_2$ (118.8 mg, 467.9 μmol) and tetrahydrofuran (4.5 mL, 0.1 M). The vial was sealed with a polypropylene cap, removed from the dry box, and heated to 80 °C in an oil bath for 30 min. The vial was cooled to room temperature, returned to the dry box and charged with 1-octene (50.0 mg, 445.6 μmol). The vial was sealed, removed from the dry box, and stirred at 60 °C for 12 h, after which the reaction was cooled to room temperature, fitted with a septum, and placed under nitrogen atmosphere. The crude reaction mixture was then charged with bromochloromethane (7 μL , 980.3 μmol) and cooled to -78 °C. *n*-BuLi (37 μL , 980.3 μmol) was added dropwise under nitrogen atmosphere and the reaction was allowed to stir at -78 °C for 10 min, at which time it was warmed to room temperature and stirred for 12 h. The reaction mixture was cooled to 0 °C (ice/water) and charged with 3 M sodium hydroxide (2 mL), and 30% hydrogen peroxide (1 mL). The reaction was gradually warmed to room temperature and allowed to stir for 4 h, at which time the vial was cooled to 0 °C (ice/water) and saturated aqueous sodium thiosulfate was added dropwise over 5 min. The reaction mixture was diluted with ethyl acetate and the aqueous and organic layers were separated. The aqueous layer was washed with ethyl acetate (3 x 20 mL) and the combined organic layers were dried over Na_2SO_4 , filtered, and concentrated by rotary evaporation. The crude reaction mixture was purified on silica gel (30-70% ethyl acetate/hexanes) to afford the desired 1,4-diol as a clear, colorless oil (64.6 mg, 83% yield).

(S)-2-Hexylbutane-1,4-diol. ^1H (400 MHz, CDCl_3): δ 0.85 (3H, t, $J = 6.8$ Hz, $(\text{CH}_2)_5\text{CH}_3$), 1.19-1.35 (10H, m, $(\text{CH}_2)_5$), 1.52-1.71 (3H, m, $\text{HOCH}_2\text{CHCH}_2\text{CH}_2\text{OH}$), 2.97 (2H, br s, OH x 2), 3.45 (1H, dd, $J = 10.8$ Hz, 6.8 Hz, $\text{CH}_\text{A}\text{H}_\text{B}\text{OH}$), 3.61-3.65 (2H, m, CH_2OH), 3.73-3.78 (1H, m, $\text{CH}_\text{A}\text{H}_\text{B}\text{OH}$); ^{13}C NMR (100 MHz, CDCl_3): δ 14.1, 22.6, 27.0, 29.6, 31.7, 31.8, 35.8, 39.3, 61.2, 66.4; IR (neat): 3318.0 (br s), 2955.6 (m), 2925.0 (s), 2856.5 (m), 1466.2 (w), 1043.9 (w) cm^{-1} ; HRMS-(ESI+) for $\text{C}_{10}\text{H}_{23}\text{O}_2$ $[\text{M}+\text{H}]$: calculated 175.1698, observed: 175.1693. $[\alpha]_\text{D}^{20} = -10.115$ ($c = 0.680$, CHCl_3 , $l = 50$ mm).

Proof of Stereochemistry

The Matteson homologation reaction is known to proceed with retention of stereochemistry.¹¹ The authentic (*R*)-isomer of the title compound was prepared using Evan's alkylation,¹² followed by ozonolysis and reduction as shown below.

¹¹ Sadhu, K. M.; Matteson, D. S.; *Organometallics*, **1985**, 4, 1687.

¹² Evans, D. A.; Ennis, M. D.; Mathre, D. J.; *J. Am. Chem. Soc.*, **1982**, 104, 1737.

Chiral HPLC (Chiracel-OD, 1.0 mL/min, 0.5% IPA, 220 nm) – analysis of the bis(benzoate) of 2-hexylbutane-1,4-diol.

racemic

diboration/homologation
/oxidation product

TBDPSO