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Supporting Information

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Enantioselective alkynylation of ketones catalyzed by Zn(Salen) metal complex

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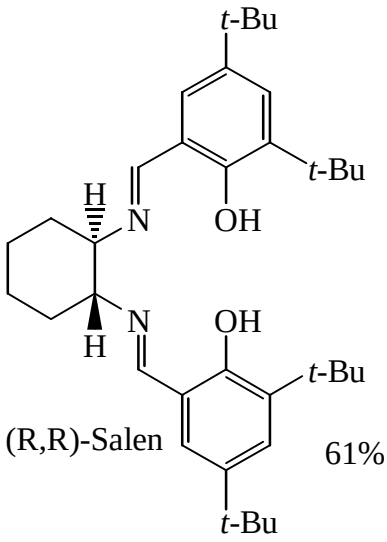
General: ^{1}H NMR spectra were recorded on Varian 200 MHz or Varian 300 MHz spectrometers. Chemical Shifts are reported in ppm from tetramethylsilane with the solvent resonance as the internal standard (deuterochloroform: δ 7.27 ppm). Data are reported as follows: chemical shifts, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, br = broad, m = multiplet), coupling constants (Hz). ^{13}C NMR spectra were recorded on a Varian 50 MHz or Varian 75 MHz spectrometers with complete proton decoupling. Chemical shifts are reported in ppm from tetramethylsilane with the solvent as the internal standard (deuterochloroform: δ 77.0 ppm). Mass spectra were performed at an ionizing voltage of 70 eV. Chromatographic purification was done with 240-400 mesh silica gel. Analytical gas chromatography (GC) was performed on a Hewlett-Packard HP 6890 gas chromatograph with a flame ionization detector and split mode capillary injection system, using a Crosslinked 5% PH ME Siloxane (30 m) column or a Megadex5 chiral (25 m) column. Analytical high performance liquid chromatograph (HPLC) was performed on a HP 1090 liquid chromatograph equipped with a variable wavelength UV detector (deuterium lamp 190-600 nm), using a Daicel Chiralcel^{TM} OD column (0.46 cm I.D. x 25 cm) (Daicel Inc.). HPLC grade isopropanol and hexane were used as the eluting solvents. All the reactions were carried out under a nitrogen atmosphere in flame-dried glassware using standard inert techniques for introducing reagents and solvents. All ketones were distilled prior to use. All the other commercially obtained reagents were used as received. Commercially available Me_2Zn 2M in toluene (Aldrich) was used for all the reactions. Anhydrous toluene was purchased from the Fluka Co. All racemic alcohols were prepared by addition of lithium acetylide to ketones at 0°C.

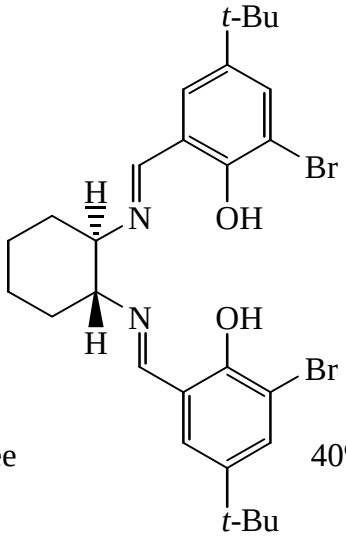
General procedure for the addition of phenyl acetylene to ketone.

A 2M solution of Me_2Zn in toluene (3mmol.), toluene (1mL) and phenylacetylene (3mmol) were added to a reaction flask at room temperature and the resulting solution was stirred during 1 hour, then (R,R)-Salen (0.2mmol.) was added to the mixture at room temperature . Gas immediately was evolving and the resulting yellow solution was stirred 1 hour. The ketone (1mmol.) was added and the reaction mixture was stirred for 48-96 hours. The reaction mixture was quenched by the addition of water (5mL) and the mixture was diluted with Et_2O and stirred for 5 min., then it was filtered through celite. The collected phases were separated and the aqueous phase was extracted with Et_2O (3 x 3mL). The organic phases were reunited and dried over sodium sufate. After removal of the solvent under reduced pressure, the resulting yellow oil was purified by a quickly chromatography on a deactivated SiO_2 [SiO_2 was deactivated by adding Et_3N (1% vol.) to the eluent during the preparation of the column].

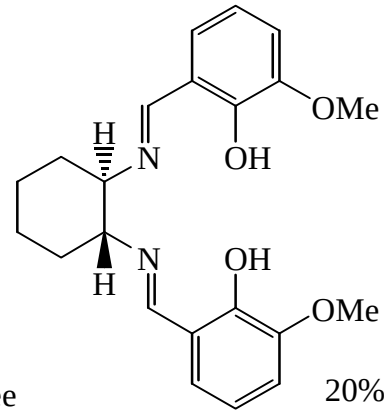
The following Salens were used in the reaction of phenylacetylene to acetophene with the optimized protocol. The enantiomeric excesses recorded are indicated.



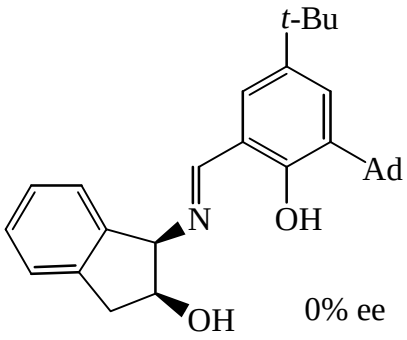
(R,R)-Salen 61% ee



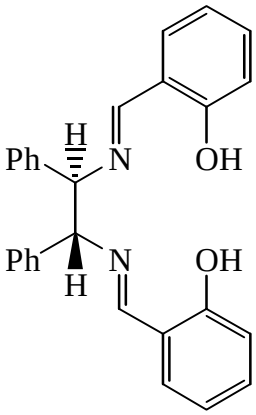
40% ee



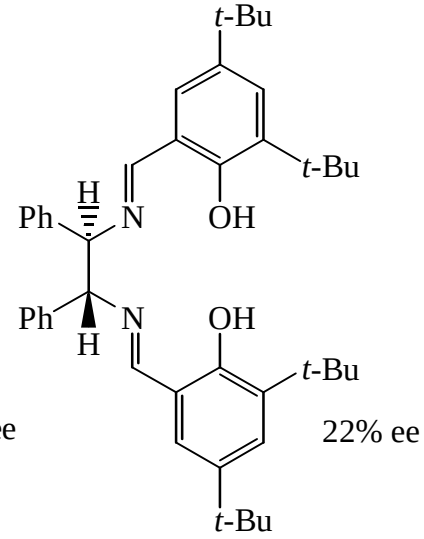
20% ee



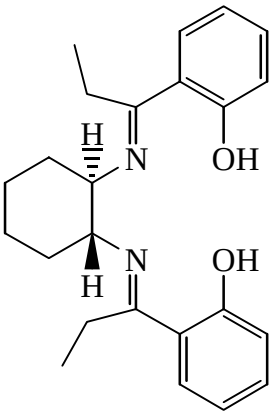
0% ee



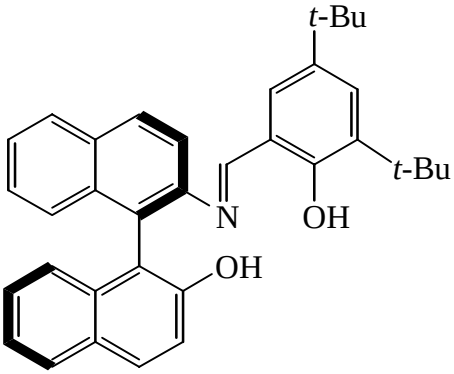
0% ee



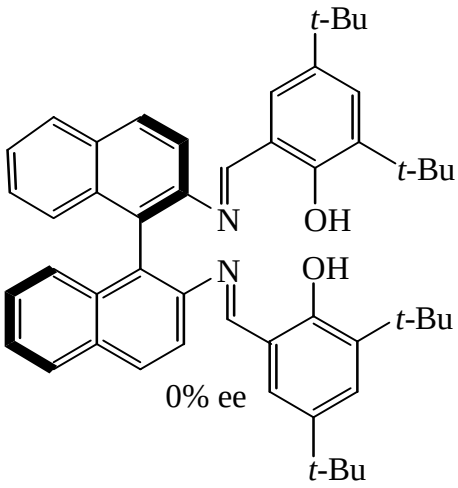
22% ee



30% ee

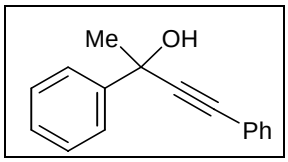


0% ee



0% ee

2,4-Diphenyl-but-3-yn-2-ol



$C_{16}H_{14}O$ Fw = 256.38

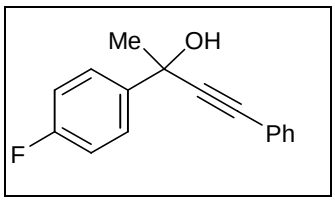
$[\alpha]_D$ = +5.2 (c 2.5, $CHCl_3$)

^{1}H-NMR ($CDCl_3$, 200 MHz) δ : 1.91 (s, 3H); 2.50 (brs, 1H); 7.24-7.6 (m, 8H); 7.76-7.78 (m, 2H).

^{13}C-NMR ($CDCl_3$, 50 MHz) δ: 33.32; 70.35; 84.86; 92.42; 122.46; 128.89; 128.36; 127.60; 128.22; 128.36; 131.60; 140.10.

HPLC analysis OD: isocratic (hexane: *i*-PrOH) 90:10. TM: 9.70 min.; tm: 10.56 min. ee 61%

2-(4-Fluoro-phenyl)-4-phenyl-but-3-yn-2-ol



$C_{16}H_{13}FO$ Fw = 240.27

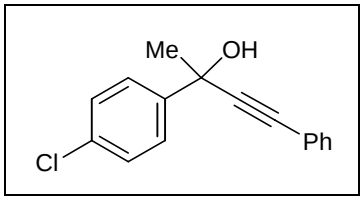
$[\alpha]_D$ = - 10.5 (c 1.68, $CHCl_3$)

^{1}H-NMR ($CDCl_3$, 200 MHz) δ: 1.88(s, 3H); 2.60 (brs, 1H); 7.00.-7.13 (m, 2H); 7.37-7.52 (m, 5H); 7.68-7.76 (m, 2H).

^{13}C-NMR ($CDCl_3$, 50 MHz) δ: 33.34; 69.96; 85.07; 92.11; 114.80 (d, J = 21.3Hz); 128.28; 126.74 (d, J = 8.7Hz); 128.16; 128.27; 128.54.131.62; 141.36.

HPLC analysis OD: isocratic (hexane: *i*-PrOH) 95:5. TM: 14.57 min.; tm: 18.91 min. ee 57%

2-(4-Chloro-phenyl)-4-phenyl-but-3-yn-2-ol



$C_{16}H_{13}ClO$ PM = 256.73

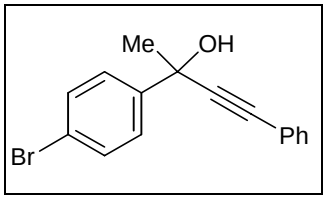
$[\alpha]_D$ = - 2.2 (c 0.9, $CHCl_3$)

^{1}H-NMR ($CDCl_3$, 200 MHz) δ: 1.78(s, 3H); 2.4 (s, 1H); 7.20-7.42 (m, 5H); 7.60 (AA'BB', 2H, J = 8.0Hz); 7.56 (AA'BB', 2H, J = 8.0Hz).

^{13}C-NMR ($CDCl_3$, 50 MHz) δ: 38.38; 69.82; 85.02; 91.93; 122.17; 126.42; 128.21; 128.26; 128.49; 128.72, 129.60; 131.54; 133.31.

HPLC analysis OD: isocratic (hexane: *i*-PrOH) 98:2. TM: 31.14 min. tm: 43.24 min. ee 53%

2-(4-Bromo-phenyl)-4-phenyl-but-3-yn-2-ol



$C_{16}H_{13}BrO$ PM = 301.18

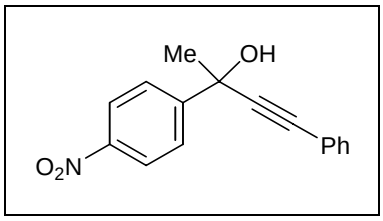
$[\alpha]_D$ = +5.8 (c 0.86, $CHCl_3$)

^{1}H-NMR ($CDCl_3$, 200 MHz) δ: 1.86 (s, 3H); 2.51 (s, 1H); 7.34-7.37 (m, 2H); 7.46-7.55 (m, 5H); 7.60-7.65 (m, 2H).

^{13}C-NMR ($CDCl_3$, 50 MHz) δ: 33.34; 69.93; 85.11; 91.81; 121.55; 122.15; 126.79; 128.54; 131.24; 131.29; 144.62.

HPLC analysis OD: isocratic (hexane: *i*-PrOH) 95:5. TM: 12.30 min.; tm: 19.87 min. ee 53%

2-(4-Nitro-phenyl)-4-phenyl-but-3-yn-2-ol



$C_{16}H_{13}NO_3$ PM = 267.28

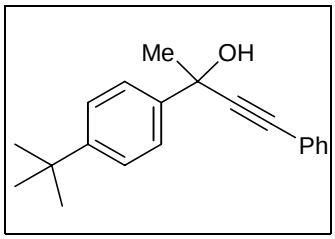
$[\alpha]_D$ = +2.5 (c 1.96, $CHCl_3$)

^{1}H-NMR ($CDCl_3$, 200 MHz) δ: 1.90 (s, 3H); 2.26 (s, 1H); 7.20-7.60 (m, 5H); 7.86-7.93 (m, 2H); 8.21-8.26 (m, 2H).

^{13}C-NMR ($CDCl_3$, 50 MHz) δ: 35.51; 69.85; 85.70; 91.02; 123.47; 125.98; 128.11; 128.29; 128.80; 131.59; 147.18; 152.56.

HPLC analysis OD: isocratic (hexane: *i*-PrOH) 90:10. TM: 19.37 min.; tm: 22.17 min. ee 55%

2-(4-*tert*-Butylphenyl)-4-phenyl-but-3-yn-2-ol



$C_{20}H_{22}O$ Fw = 278.39

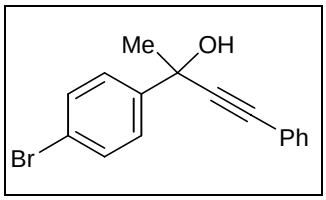
$[\alpha]_D$ = - 10.5 (c 2.01, $CHCl_3$)

^{1}H-NMR ($CDCl_3$, 200 MHz) δ: 1.37 (s, 9H); 1.91 (s, 3H); 2.40 (s, 1H); 7.37-7.55 (m, 7H); 7.69 (AA'BB', 2H, J =8.4Hz).

^{13}C-NMR ($CDCl_3$, 50 MHz) δ: 31.37; 33.09; 70.18; 84.70; 92.61; 122.59; 124.66 ;124.67; 125.16; 128.32; 131.66; 142.57; 150.60.

HPLC analysis OD: isocratic (hexane: *i*-PrOH) 95:5. TM: 8.91 min.; tm: 13.50min. ee 66%

2-(4-Bromo-phenyl)-4-phenyl-but-3-yn-2-ol



$C_{16}H_{13}BrO$ PM = 301.18

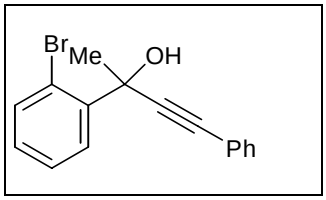
$[\alpha]_D$ = +5.8 (c 0.86, $CHCl_3$)

^{1}H-NMR ($CDCl_3$, 200 MHz) δ: 1.86 (s, 3H); 2.51 (s, 1H); 7.34-7.37 (m, 2H); 7.46-7.55 (m, 5H); 7.60-7.65 (m, 2H).

^{13}C-NMR ($CDCl_3$, 50 MHz) δ: 33.34; 69.93; 85.11; 91.81; 121.55; 122.15; 126.79; 128.54; 131.24; 131.29; 144.62.

HPLC analysis OD: isocratic (hexane: *i*-PrOH) 95:5. TM: 12.30 min.; tm: 19.87 min. ee 53%

2-(2-Bromo phenyl)-4-Phenyl-but-3-yn-2-ol



$C_{16}H_{13}BrO$ PM = 301.18

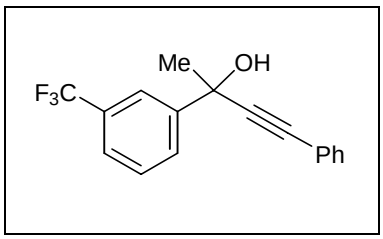
$[\alpha]_D$ = +5.8 (c 0.86, $CHCl_3$)

^{1}H-NMR ($CDCl_3$, 300 MHz) δ 2.11 (s, 3H); 3.20 (s, 1H); 7.35-7.38 (m, 3H); 7.44-7.52 (m, 2H); 7.69-7.74 (m, 2H); 7.91 (dd, 2H, J = 1.8, 8.1Hz).

^{13}C-NMR ($CDCl_3$, 75 MHz) δ: 29.66; 69.85; 84.78; 91.57; 126.81; 127.35; 127.43; 128.16; 128.33; 128.86; 129.08; 131.54; 131.72; 133.75; 134.86; 142.74.

HPLC analysis OD: (hexane :*i*-PrOH) 99:1. 20 min., then hexane: *i*-PrOH 95:5. TM: 32.30 min.; tm: 19.87 min. ee 70%

2-(3-Trifluoromethyl-phenyl)-4-phenyl-but-3-yn-2-ol



$C_{17}H_{13}F_3O$ PM = 290.28

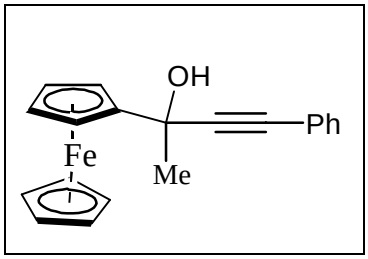
$[\alpha]_D$ = - 7.2 (c 1.25, $CHCl_3$)

^{1}H-NMR ($CDCl_3$, 200 MHz) δ: 1.79 (s, 3H); 2.45 (s, 1H); 7.20-7.60 (m, 7H); 7.86-7.78 (m, 1H); 7.92 (s, 1H).

^{13}C-NMR ($CDCl_3$, 50 MHz) δ: 35.51; 65.77; 69.98; 85.41; 91.62; 121.84 (q, J = 4Hz); 124.40 (q, J = 4Hz); 124.67; 125.16; 128.27; 128.51; 128.63; 128.73; 131.62; 146.71.

HPLC analysis OD: isocratic (hexane: *i*-PrOH) 95:5. TM: 14.74 min.; tm: 17.79 min. ee 61%

2-Ferrocenyl-4-phenyl-but-3-yn-2-ol



$C_{20}H_{18}OFe$ Fw = 330.20

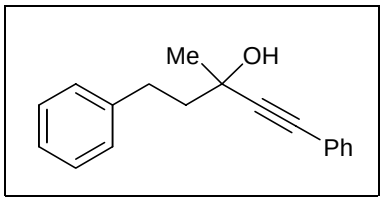
$[\alpha]_D$ = +47.2 (c 2.9, $CHCl_3$)

^{1}H-NMR ($CDCl_3$, 200 MHz) δ: 1.80 (s, 3H); 4.19-4.22 (m, 2H); 4.28 (s, 5H); 4.41-4.46 (m, 2H); 7.29-7.40 (m, 3H); 7.43-7.60 (m, 2H).

^{13}C-NMR ($CDCl_3$, 50 MHz) δ: 31.36; 65.25; 67.06; 67.13; 68.07; 68.14; 68.79; 82.70; 92.88; 96.26; 122.81; 128.19; 128.24; 131.50.

HPLC analysis OD: isocratic (hexane: *i*-PrOH) 95:5. tm: 22.88 min.; TM: 23.73min. ee 62%

3-Methyl-1,5-diphenyl-pent-1-yn-3-ol



$C_{18}H_{18}O$ PM = 250.33

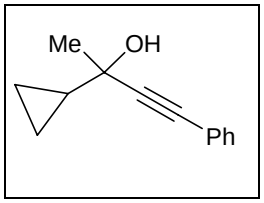
$[\alpha]_D$ = - 4.2 (c 1.42, $CHCl_3$)

^{1}H-NMR ($CDCl_3$, 200 MHz) δ: 1.67 (s, 3H); 2.06-2.15 (m, 3H); 2.93-3.20 (m, 2H); 7.60-7.80 (m, 10H).

^{13}C-NMR ($CDCl_3$, 50 MHz) δ: 30.12; 31.50; 45.46; 68.49; 83.82; 92.41; 122.56; 125.79; 128.19; 128.23; 128.35; 113.58; 141.77.

HPLC analysis OD: isocratic (hexane: *i*-PrOH) 95:5. TM: 13.52 min.; tm: 17.78 min. ee 32%

2-Cyclopropyl-4-phenyl-but-3-yn-2-ol



$C_{13}H_{14}O$ PM = 186.25

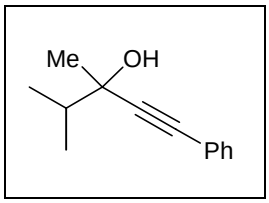
$[\alpha]_D$ = - 28.8 (c 2.0, $CHCl_3$)

^{1}H-NMR ($CDCl_3$, 200 MHz) δ: 0.58-0.73 (m, 4H); 1.22-1.29 (m, 1H); 1.69 (s, 3H); 2.20 (s, 1H); 7.20-7.40 (m, 5H).

^{13}C-NMR ($CDCl_3$, 50 MHz) δ: 1.80; 2.68; 22.11; 29.86; 70.46; 83.71; 89.93; 122.49; 128.13; 128.18; 131.57.

HPLC analysis OD: isocratic (hexane: *i*-PrOH) 95:5. TM: 12.87 min.; tm: 16.81 min. ee 50%.

3,4-Dimethyl-1-phenyl-pent-1-yn-3-ol



$C_{13}H_{16}O$ PM = 188.27

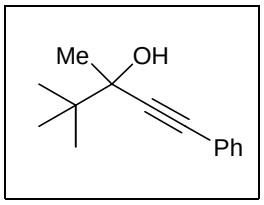
$[\alpha]_D$ = - 7.2 (c 1.25, $CHCl_3$)

^{1}H-NMR ($CDCl_3$, 200 MHz) δ: 1.11 (dt, 6H, J = 1.6, 7.0Hz); 1.56 (s, 3H); 1.75-2.00 (m, 1H); 2.08 (s, 1H); 7.60-7.80 (m, 5H).

^{13}C-NMR ($CDCl_3$, 50 MHz) δ: 17.57; 17.80; 27.18; 39.11; 72.01; 83.88; 92.03; 122.79; 128.03; 128.10; 131.52.

HPLC analysis OD: isocratic (hexane: *i*-PrOH) 95:5. TM: 11.44 min.; tm: 15.47 min. ee 57%.

3,4,4-Trimethy-1-Phenyl-pent-1-yn-3-ol



$C_{14}H_{18}O$ PM = 202.29

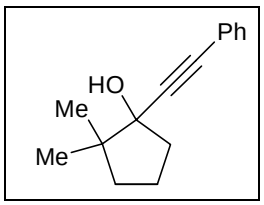
$[\alpha]_D$ = - 14.8 (c 2.16, $CHCl_3$)

^{1}H-NMR ($CDCl_3$, 200 MHz) δ: 1.41(s, 9H); 1.56 (s, 3H); 1.98 (s, 1H); 7.29-7.34 (m, 3H); 7.42-7.46 (m, 2H).

^{13}C-NMR ($CDCl_3$, 50 MHz) δ: 24.85; 25.27; 38.55; 74.36; 83.86; 92.86; 122.95; 128.07; 128.16; 131.52.

HPLC analysis OD: isocratic (hexane: *i*-PrOH) 93:7. TM: 9.31 min.; tm: 13.35 min. ee 80%.

2,2-Dimethyl -1-phenylethynyl-cyclopent-1-ol



$C_{14}H_{18}O$ PM = 202.29

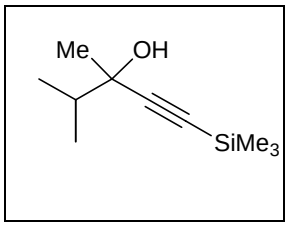
$[\alpha]_D$ = - 6.4 (c 1.19, $CHCl_3$)

^{1}H-NMR ($CDCl_3$, 200 MHz) δ: 1.51 (s, 3H); 1.58-2.32 (m, 6H); 1.95 (s, 1H); 7.30-7.35 (m, 3H); 7.44-7.48 (m, 2H).

^{13}C-NMR ($CDCl_3$, 50 MHz) δ: 19.63; 21.39; 26.00; 39.53; 47.04; 79.93; 84.78; 90.80; 122.84; 127.89, 128.02; 131.43.

HPLC analysis OD: isocratic (hexane: *i*-PrOH) 95:5. TM: 11.03 min.; tm: 20.88 min. ee 69%.

3, 4-Dimethyl-1-trimethylsilyl-pent-1-yn-3-ol



$C_{10}H_{20}OSi$ PM = 184.35

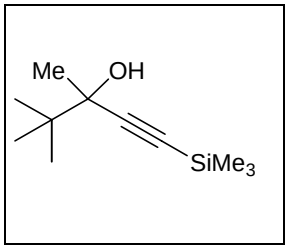
$[\alpha]_D$ = - 13.0 (c 1.61, dioxane)

^{1}H-NMR ($CDCl_3$, 200 MHz) δ: 0.18 (s, 9H); 1.27 (t, 6H, J = 6.6Hz); 1.45 (s, 3H); 1.8 (sept, 1H, J = 6.6Hz); 1.86 (s, 1H).

^{13}C-NMR ($CDCl_3$, 50 MHz) δ: 0.06, 17.42; 17.88; 27.10; 38.86; 71.85; 87.93; 108.70.

GCMS: ramp 50°C to 150°C, 3.0°C/min. t_m: 9.03 min.; TM: 9.26 min. ee 64%

3,4,4-Trimethyl-1-trimethylsilyl-pent-1-yn-3-ol



$C_{11}H_{22}OSi$ Fw = 198.38

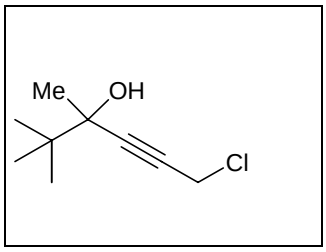
$[\alpha]_D$ = - 26.8 (c 1.61, dioxane)

^{1}H-NMR ($CDCl_3$, 300 MHz) δ: 0.17 (s, 9H); 1.06 (s, 9H); 1.43 (s, 3H); 1.86 (s, 1H).

^{13}C-NMR ($CDCl_3$, 50 MHz) δ: -0.09; 24.62; 25.02; 37.99; 74.00; 88.15; 109.00.

GCMS: ramp 50°C to 150°C, 3.0°C/min. t_m: 9.03 min.; TM: 9.26 min. ee 81%

6-Chloro-2,3,3 -trimethyl-1-hex-4-yn-3-ol



$C_9H_{15}ClO$ PM = 256.38

$[\alpha]_D$ = - 4.1 (c 2.9, $CHCl_3$)

^{1}H-NMR ($CDCl_3$, 200 MHz) δ: 1.07 (s, 9H); 1.47 (s, 3H); 1.80 (brs, 1H); 4.2 (s, 2H).

^{13}C-NMR ($CDCl_3$, 50 MHz) δ: 24.61; 25.08; 30.58; 38.32, 74.00; 78.69; 90.18.

GCMS: 57(72); 65(7); 69(6); 82(100); 91(12); 95(7); 103(10; 117(54); 123(9); 159 (2).

Chiral GC analysis: ramp 50°C to 150°C; 3.0°C/min. tm:16.98 min TM: 17.22 min. ee 80%