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SUPPLEMENTARY MATERIAL

Experimental

Materials

All chemicals were from Aldrich Chemical Company, unless otherwise specified, and were used as received. 3-Hexyn-2-ol and 4-hexyn-3-ol were purchased from Lancaster Synthesis Inc. and used without further purification. Chromium trioxide was purchased from Lancaster synthesis Inc. $Pd(OAc)_2$ was purchased from Alfa Aesar and used without further purification. THF was dried over sodium benzophenone ketyl, distilled and stored over CaH_2 under argon. All other chemicals were of reagent grade. Stock solutions in water of the following composition were prepared: 0.2 M in K_2PdCl_4, and 0.2 M in HCl. Stock solutions in methanol of the following composition were prepared: 0.2 M in Li_2PdCl_4, and 0.2 M in LiCl. Reaction mixtures were prepared by diluting stock solutions.

Physical Measurements

^1H NMR data were recorded on a Varian VXR 300 NMR or 400S NMR spectrometer. GLC analysis were carried out using a GOW-MAC 350 gas chromatograph fitted with Carbowax 10 M on 80-100 mesh Chromosorb W - NAW column. IR spectra were obtained on a ATI Mattson Genesis Series FT-IR or a Perkin Elmer 1310 Infrared spectrometer. All chemical shifts are reported relative to tetramethylsilane as internal standard.

Preparation of Pyridinium Chlorochromate

To 46.0 mL of 6.0 M HCl was added 25.0 g (0.25 mol) of CrO_3 rapidly with stirring. After about 5 min the homogenous solution was cooled to 0°C followed by the careful addition of 16.3 mL pyridine (15.8 g, 0.2 mol) over approximately 10 min. Recooling to 0°C produce a yellow orange solid which was collected by suction filtration

and dried in vacuum.

Preparation of 3-pentyn-2-ol.

A clean oven dried 3-necked one liter flask equipped with a magnetic stirring bar, a dropping funnel, and a reflux condenser connected with a drying tube of anhydrous $CaCl_2$, was used for this experiment. Acetaldehyde (22.0 g, 0.5 mol) in 50 ml anhydrous ether was gradually added to a solution of propenylmagnesium bromide obtained by passing propyne into a solution of ethylmagnesium bromide. After 5 hours of stirring, ice-cold saturated aqueous ammonium chloride (500 mL) was added. The ethereal layer was separated, dried over anhydrous $MgSO_4$ and fractionated, giving 21.9 g (52%) of 3-pentyne-2-ol. bp 117-119 °C ; IR (neat): 3350, 2220.

Preparation of 3-pentyn-2-one.

In a 500-mL round bottomed flask fitted with a reflux condenser and magnetic stir bar was suspended 64.6 g (0.3 mol) of pyridinium chlorochromate in 100 ml CH_2Cl_2. 3-Pentyn-2-ol (19 mL, 16.8 g, 0.2 mol) in 20 mL of CH_2Cl_2 was added in one portion to the stirred solution. After 2 h, 200 mL of ether was added and the supernatant decanted from the black gum. The gum was washed 3 times with 100 mL portions of ether. The combined ether washings were dried over $MgSO_4$ and distilled under reduced pressure to give 12.3 g (0.15 mol) of 3-pentyn-2-one, 75% yield. ^1H NMR ($CDCl_3$) δ: 2.02 (s, 3H), 2.32 (s, 3H).

Preparation of (S)-(+)-3-pentyn-2-ol.

An oven-dried 500 mL 3-necked round bottom flask, equipped with a septum-capped side arm, magnetic stirring bar, reflux condenser, and stopcock adapter connected to a mercury bubbler, was assembled hot and flushed with a stream of Ar. After the apparatus cooled, it was charged, via a double-ended syringe, with 303 mL of a 0.5 M

THF solution of 9-borabicyclo-[3.3.1] nonane (0.15 mol). Then 27 mL (23.2 g, 0.17 mol) of (-)-α-pinene was added. After the solution was refluxed for 4 h, the excess α-pinene and THF was removed first by water aspirator and then by vacuum pump at 40° to provide a thick clear oil. The flask was then cooled in an ice bath and 10.2 mL (8.86 g, 0.108 mol) of 3-pentyn-2-one was added under Ar. Stirring was continued for 8 h, the first 2 h at 0°C. Then 8.4 mL of acetaldehyde was added to the solution and stirring continued for another 1 h. Liberated α-pinene was removed under vacuum. Then 75 mL of THF and 57 mL of 3 M NaOH was added followed by 57 mL of 30% H_2O_2 dropwise. The mixture was stirred for 4 h at 40°C and extracted with Et_2O (3 x 50 mL). The ether layers were combined, dried over $MgSO_4$, filtered and concentrated to give an oil. Distillation under vacuum provided 6.3 g (76 mmol) of 3-pentyn-2-ol, 70% yield. IR (neat) cm^{-1}: 3350, 3005, 2220, 720. ^1H NMR ($CDCl_3$) δ: 4.48 (m, 1H), 2.55(broad, 1H, OH) 1.82 (s, 3H), 1.42 (d, 3H). Examination of the ^{1}HNMR spectrum in the presence of $Eu(hfc)_3$ indicated an enantiomeric mixture containing 92% (**R**),(84% ee).

Preparation of (S)-(-)-(Z)-3-penten-2-ol (3a).

A low pressure hydrogenation apparatus, was charged with 5 mL of hexane, 2.2 mL (2.1 g, 25 mmol) of (S)-(+)-3-pentyn-2-ol, 0.1 g of Pd on $CaCO_3$ with Pb (Lindlar's catalyst) and ten drops of quinoline. The apparatus was evacuated and hydrogen was admitted to give a pressure slightly above 1 atm. The contents of the flask were shaken until absorption of hydrogen stopped. The catalyst was removed by filtration, hexane was distilled off and the residue upon distillation at 50 mm Hg at 61-63°C gave 1.5 g (70%) of colorless liquid. GC analysis of the product indicated it to be 98% pure cis isomer.

IR (neat) cm^{-1}: 3350, 3005, 1605, 720. ^1H NMR ($CDCl_3$) δ: 5.52 (m, 1H), 5.40 (m, 1H), 4.65 (dq, J = 18.6 and 6.28, 1H), 2.15(br, 1H), 1.68 (d, J = 6.5, 3H), 1.25 (d, J =

6.35, 3H). Examination of the ^{1}HNMR spectrum in the presence of Eu(hfc)$_3$ indicated an enantiomeric mixture containing 87% (S),(74% ee).

Preparation of 3-Hexyn-2-one

In a 250-mL round bottomed flask fitted with a reflux condenser and magnetic stirring bar, 12.9 g (0.06 mol) of pyridinium chlorochromate in 50 mL CH_2Cl_2 was suspended. 3-Hexyn-2-ol, 4.4 mL (3.9 g, 0.04 mol), in 10 mL of CH_2Cl_2 was then added in one portion to the stirred mixture. After 2 h, 100 mL of ether was added and the supernatant was decanted from the black gum. Next the black gum was washed three times with 50 mL portions of ether. The combined ether washings were dried over $MgSO_4$ and distilled under reduced pressure to give 3.0 g (0.03 mol) of 3-hexyn-2-one, 77% yield. ^{1}H NMR ($CDCl_3$) δ: 2.31 (q, 2H), 2.26 (s, 3H), 1.15 (t, 3H).

Preparation of (R)-3-Hexyn-2-ol

An oven-dried 500 mL round bottom flask equipped with a septum-capped side arm, magnetic stirring bar, reflux condenser, and stopcock adapter connected to a mercury bubbler, was assembled hot and flushed with a steam of Ar. After the apparatus was cooled, it was charged, via a double-ended syringe, with 309 mL of a 0.5 M THF solution of 9-BBN (0.152 mol). Then 27.0 mL (23.2 g, 0.17 mol) of α-pinene was added . After the solution was refluxed for 4 h, the excess α-pinene and THF was removed first by water aspirator and then by vacuum pump at 40°C to provide a thick clear oil. The flask was then cooled in an ice bath and 12 mL (10.8 g, 0.108 mol) of 3-hexyn-2-one was added under Ar. Stirring was continued for 8 h, being the first 2 h at 0°C. Then 8.4 mL of acetaldehyde was added to the solution and stirring was continued for another 1 h. Next, liberated α-pinene was removed under vacuum. Then 75 mL of THF and 57 mL of 3 M NaOH were added followed by dropwise addition of 57 mL of 30% H_2O_2. The

mixture was stirred for 4 h at 40°C and extracted with Et_2O (3 x 50 mL). The ether layers were combined, dried over $MgSO_4$, filtered and concentrated to yield an oil. Distillation under vacuum provided 7.7 g (0.79 mol) of 3-hexyn-2-ol, 73% yield. IR (neat) cm^{-1} : 3350, 3005, 2220, 720. ^1H NMR ($CDCl_3$) δ: 4.58 (q, 1H), 2.45 (b, 1H, OH), 2.25 (q, 2H), 1.63 (d, 3H), 1.67 (t, 3H). Optical rotation $[\alpha]_D^{24}$ (neat) +18.8. Examination of the ^1H NMR spectrum in the presence of $Eu(hfc)_3$ indicated an enantiomeric mixture containing 84% (**R**) (68% ee).

Preparation of (R)-(-)-(Z)-3-Hexen-2-ol (3b)

A low pressure hydrogenation apparatus was charged with 10 mL of hexane, 3.5 mL (3.2 g, .032 mol) of (**R**)-(+)-3-hexyn-2-ol, 0.2 g of Pd on $CaCO_3$ poisoned with lead (Lindlar's catalyst) and 20 drops of quinoline. The apparatus was evacuated and hydrogen was admitted to a pressure slightly above 1 atm. The contents of the flask was shaken until absorption of hydrogen stopped. The catalyst was removed by filtration, hexane was distilled off and the residue upon distillation under vacuum produced 2.2 g (0.022 mol, 71% yield) of colorless liquid. GLC analysis of the product indicated it to be a 98% pure Z isomer. Optical rotation $[\alpha]_D^{24}$ (neat) -6.20, ^1H NMR ($CDCl_3$) δ: 5.43 (m, 2H), 4.65 (m, 1H), 2.12 (m, 2H), 1.90 (b, 1H, OH), 1.63 (d, 3H), 1.00 (t, 3H). ^1H NMR study of the product in the presence of $Eu(hfc)_3$ indicated the sample was 83% (**R**) (66% ee).

Li_2PdCl_4 Catalyzed Phenylation of (R)-(+)-Z-3-penten-2-ol

To a stirred solution of 0.1 M Li_2PdCl_4 in methanol (15.0 mL) was added 0.5 mL (3.7 mmol) Et_3N, 0. 5 g (3.7 mmol) $CuCl_2$, 1.1 g (3.5 mmol) PhHgCl and 0.35 mL (0.3 g, 3.5 mmol) (R)-Z-3-penten-2-ol (ee = 53%). After stirring for 2 h at room temperature the reaction was diluted with water. The precipitate was removed by filtration and the filtrate and the precipitate were extracted with ether (3 x 30 mL). The ether layers were

combined, dried over $MgSO_4$ and solvent removed under vacuum. The residue was purified twice by column chromatography (silica gel, 8/2 hexane/ether) to give 0.47 g (84% yield) of 4-phenyl-2-pentanone. Lanthanide shift determination showed the presence of 65% **R** (30% ee).

Phenylation of (S)-Z-3-penten-2-ol (ee = 74%) in the Presence of High [LiCl]

A 100-mL 2-necked round bottom flask, containing a magnetic stirring bar and LiCl (1.6 g, 37.7 mmol) fitted with a septum-cap was evacuated on a vacuum line at 100 °C for 2 h. To this was added $PdCl_2$ (0.11 g, 0.6 mmol), $CuCl_2$ (0.67 g, 5 mmol) and 15 mL methanol. After stirring the solution for 30 min PhHgCl (0.70 g, 3.5 mmol) and (S)-Z-3-penten-2-ol (0.35 mL, 0.30 g, 3.5 mmol) were added. The stirring was continued for 48 h at room temperature, then the reaction mixture was diluted with 100 mL CH_2Cl_2 and washed with 30 mL water. The organic layer was dried over anhydrous $MgSO_4$, and concentrated under reduced pressure. Analysis of the residue by GLC and NMR showed the presence of 4-phenyl-Z-2-pentene (**3a''**), Phenylbenzene, and 4-phenyl-2-pentanone (**5a''**) in relative yields of 70%, 25% and 5%, respectively. ^{1}H NMR of **3a''** $CDCl_3$ δ: 7.20 (m, 5H), 5.54 (m, J = 1.6 and 10.8 Hz, 1H), 5.46 (dq, J = 6.6 and 10.8 Hz, 1H) 3.80 (m, 7.0 Hz, 1H), 1.73 (dd, 1.6 and 6.5 Hz, 3 Hz), 1.15 (d, 7.0 Hz, 3H). ^{13}C NMR $CDCl_3$ δ: 146.7, 135.9, 128,4, 126.9, 125.8, 122.8, 36.9, 22.0, 13.0.

The enantiomeric purity of **3a''** and its absolute configuration was determined by converting pure sample of **3a''** obtained by preparative GLC to 4-phenyl-2-pentanone (**5a''**) as described below.

$Pd(OAc)_2$ Catalyzed Oxidation of 4-Phenyl-Z-2-pentene

A 2 mL conical vial fitted with a magnetic stirring bar and a reflux condenser was charged with acetonitrile (0.9 mL), H_2O (0.1 mL), benzoquinone (20 mg, 0.19 mmol),

$HClO_4$ (10 μL), 4 -phenyl-Z-2-pentene (**3a''**) (0.015 g, 0.1 mmol), and $Pd(OAc)_2$ (0.0011g, 0.005 mmol). The resulting solution was stirred at 50 °C for 6 h. Then it was diluted with CH_2Cl_2 (5 mL), washed with water (5 mL) and dried over $MgSO_4$. CH_2Cl_2 was removed under reduced pressure. Analysis of the residue by ^1H NMR showed the presence of one product 4-phenyl-2-pentanone (**5a''**). Its ee was determined by ^1H NMR in the presence of $Eu(hfc)_3$ to be 56%. Its absolute configuration was determined to be to be "S" by comparing its ^1H NMR spectrum with that of an authentic sample both in the presence of $Eu(hfc)_3$. ^1H NMR of **5a''** $CDCl_3$ δ: 7.22 (m, 5H), 3.30 (m, J = 7.0 Hz, 1H), 2.72 (dd, J = 6.7 and 16.3 Hz, 1H), 2.68 (dd, J = 7.9 and 16.2 Hz, 1H) 2.07 (s, 3H), 1.69 (d, J = 7.0 Hz, 3H). ^1C NMR ($CDCl_3$) δ: 207.8, 146.2, 128.5, 126.8, 126.3, 52.0, 35.5, 30.62, 22.0.

Li_2PdCl_4 Catalyzed Methoxylation of (R)-Z-3-penten-2-ol ((R)-(-)-Z-3a)

A solution of 0.1 M Li_2PdCl_4, 0.1 M LiCl, and 0.1 M benzoquinone in 25 mL methanol was prepared. To this solution was added 0.35 mL (0.3 g, 0.35 mmol) of (R)-(-)-Z-**3** (ee = 53%). The system was placed under Ar and stirred for 8 h at room temperature. The mixture was then diluted with water and the aqueous layer was extracted with CH_2Cl_2 (3 x 15 mL). The combined organic phase was dried over $MgSO_4$ and solvent removed by distillation. Analysis of the residue by gas chromatography showed the presence of 4-methoxy-2-pentanone and 3-penten-2-one in 95% and 5% relative yields, respectively. Examination of the ^1H NMR spectrum in the presence of $Eu(hfc)_3$ indicated the 4-methoxy-2-pentanone was an enantiomeric mixture containing 71% (**R**),(42% ee).

Methoxylation of (S)-Z-3-penten-2-ol ((S)-Z-3a)(ee = 74%) in the Presence of High [LiCl]

A 100-mL 2-necked round bottom flask, containing a magnetic stirring bar and LiCl (1.6 g, 37.7 mmol, 2.5 M) fitted with a septum-cap was evacuated on a vacuum line at 100 °C

for 2 h. To this was added $PdCl_2$ (0.11 g, 0.6 mmol), $CuCl_2$ or benzoquinone (5 mmol) and 15 mL methanol. After stirring the solution for 30 min, (S)-Z-3-penten-2-ol (0.35 mL, 0.30 g, 3.5 mmol) were added. The stirring was continued for 48 h at room temperature, then the reaction mixture was diluted with 100 mL CH_2Cl_2 and washed with 30 mL water. The organic layer was dried over anhydrous $MgSO_4$, and distilled to remove the solvent. Analysis of the residue by GLC and NMR showed the presence of only one product which was analyzed by NMR spectroscopy to be 4-methoxy-Z-2-pentene (**3a''**). ^{1}H NMR of **3a''** $CDCl_3$ δ: 5.50 (dq, J = 6.35 and 15.3 Hz, 1H), 5.32 (qdd, J = 1.6 ,7.9 and 15.4 Hz, 1H), 3.80 (m, J = 6.4 Hz, 1H), 1.73 (dd, J = 1.6 and 6.9 Hz, 3H), 1.15 (d, J = 6.4 Hz, 3H). ^{13}C NMR $CDCl_3$ δ:133.0, 127.7, 78.0, 55.6, 21.4, 17.6.

The enantiomeric purity of **3a''** was determined by ^{1}H NMR in the presence of $Eu(hfc)_3$ to be 68%. Its absolute configuration was determined to be "**R**" by converting pure sample of **3a'** obtained by preparative GLC to 4-methoxy-2-pentanone (**5a'**) as shown below.

$Pd(OAc)_2$ Catalyzed Oxidation of 4-Methoxy-Z-2-pentene (Z-3a')

For procedure see $Pd(OAc)_2$ catalyzed oxidation of 4-phenyl-Z-2-pentene. The absolute configuration of **5a'** was determined to be "**R**" by comparing its ^{1}H NMR spectrum with that of an authentic sample both in the presence of $Eu(hfc)_3$. ^{1}H NMR of **5** $CDCl_3$ δ: 3.78 (m, J = 6.35 Hz, 1H), 3.32 (s, 3H), 2.72 (dd, J = 7.3, and 15.9 Hz, 1H), 2.41 (dd, J = 5.1 and 15.7 Hz, 3H), 1.18 (d, J = 6.4 Hz, 3H). ^{13}C NMR $CDCl_3$ δ: 207.2, 73.2, 56.3, 50.6, 31.1, 19.13.

Oxidation of (R)-(-)-(Z)-3-Hexen-2-ol (3b)

The reaction was carried out in an open round bottom flask. The reaction solution (50.0 mL) was 0.1 M in K_2PdCl_4, 0.1 M in HCl, and 0.1 M in benzoquinone. (**R**)-(-)-Z-**3b**(0.65 mL; 0.11 M) was gradually added over a period of 20 min. The solution was stirred for another 20 min, Zn powder was added, and the mixture was stirred for another 10 min followed by extraction with ether (3 x 50 mL). The combined extracts were combined dried

($MgSO_4$, anhydrous). Analysis of the product by GLC and ^1H NMR showed that the product is a mixture of two compounds **5b** and **5c** in relative yields of 57% and 43%, respectively. Pure samples of **5b** and **5c** were obtained by preparative GLC. ^1H NMR ($CDCl_3$) of **5b** δ: 3.95 (m, 1H), 2.97 (bd, 1H, OH) , 2.60 (dd, 2H), 2.19 (s, 3H), 1.50 (m, 2H), 0.95 (t, 3H). ^{13}C NMR ($CDCl_3$) δ: 187.5, 63.9, 50.1, 36.7, 22.4, 7.6. ^1H NMR ($CDCl_3$) of **5c** δ: 4.25 (m, 1H), 3.28 (bd, 1H, OH), 2.55 (dd, 2H), 2.45 (q, 2H), 1.19 (d, 3H), 1.07 (t, 3H). ^{13}C NMR ($CDCl_3$) of **5c** δ: 197.5, 64.2, 50.1, 37.2, 22.4, 7.5. The ee of **5b** and **5c** as determined by ^1H NMR in the presence of the lanthanide shift reagent $Eu(hfc)_3$ to be 42% and 38%, respectively.

Preparation of (R)-(-)-MTPA Derivative of 4-Hydroxy-2-hexanone (5b)

The reagents were injected by a syringe into a 1 mL conical vial fitted with a rubber septum in the following order, dry pyridine (300 µL), carbon tetrachloride (300 µL), (+)-MTPA-Cl (37 µL, 0.15 mmol), and **5c** (11.5 mg, 0.15 mmol). The reaction mixture was stirred at room temperature for about 48 h. Excess 3-dimethylethylamino-2-propylamine 24 µL (20 mg, 0.2 mmol) was added and the mixture was stirred for another 10 min. It was then diluted with ether, washed with cold dilute HCl, cold saturated Na_2CO_3 and saturated NaCl, after drying over $MgSO_4$, the ether was removed under vacuum. The ^1H NMR spectrum of the residue was taken in the presence of $Eu(hfc)_3$.

Preparation of (R)-(+)-MTPA Derivative of 5-Hydroxy-3-hexanone (5c)

See preparation of (R)-(+)-MTPA derivative of 4-hydroxy-2-hexanone.

Isomerization of (R)-(-)-(Z)-4-Hexen-3-ol (3c)

The reaction solution (25.0 mL) was 0.05 M in Li_2PdCl_4, 0.2 M in benzoquinone 2.0 M in LiCl and 0.06 M in (R)-(-)-Z-(**3c**). The reaction mixture was stirred for 30 min at room temperature and CH_2Cl_2 was used to extract the product (3 x 30 mL). The extracts

were combined, dried over $MgSO_4$ and evaporated. A pure sample of the product was collected by preparative gas chromatography. The product was identified by ^1H and ^{13}C NMR to be a mixture of equal amounts of (**R**)-(-)-Z-(**3c**) and (**S**)-(-)-Z-(**3b**) The ee was determined by ^1H NMR in the presence of the chiral shift reagent $Eu(hfc)_3$.