Supporting Materials

Synthesis of a Novel Chiral Binaphthyl Phospholane and its Application in the Highly Enantioselective Hydrogenation of Enamides

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A. General Procedures: All reactions and manipulations were performed in a nitrogen-filled glovebox or using standard Schlenk techniques. THF and toluene were dried and distilled from sodium-benzophenone ketyl under nitrogen. Methylene chloride was distilled from CaH_2. Methanol was distilled from Mg under nitrogen. (*R*, *R*)-binaphane was made a solution of 10mg/ml in toluene before use. Column chromatography was performed using EM silica gel 60 (230~400 mesh). ^1H, ^{13}C and ^{31}P NMR were recorded on Bruker WP-200, AM-300, and AMX-360 spectrometers. Chemical shifts were reported in ppm down field from tetramethylsilane with the solvent resonance as the internal standard. Optical rotation was obtained on a Perkin-Elmer 241 polarimeter. MS spectra were recorded on a KRATOS mass spectrometer MS 9/50 for LR-EI and HR-EI. GC analysis was carried on Helwett-Packard 6890 gas chromatography using chiral capillary columns. HPLC analysis was carried on Waters^{TM} 600 chromatography. Enamides were prepared according to a reported procedure.[10f]

Synthesis of 1,2-Bis{(*R*)-4,5-dihydro-3H-dinaphtho[1,2-c;2',1'-e]phosphepino}benzene:

(*R*)-2,2'-bistriflate-1,1'-binaphthyl (2)[1]: To a solution of (*R*)-BINOL (40.3 g, 140.7 mmol) in 900 mL of CH_2Cl_2 was added pyridine (40 mL) and followed by dropwise addition of triflic anhydride (50.5 mL, 300 mmol) at 0°C. The mixture was stirred at rt for 6h. After removal of the solvent, the residue was diluted with

EtOAc (500 mL) and then washed with 5% aqueous HCl (100 mL), saturated $NaHCO_3$ (100 mL) and brine (100 mL). The organic layer was dried over anhydrous sodium sulfate, concentrated and passed through a silica gel plug (eluted with CH_2Cl_2) to give the (*R*)-bistriflate (**2**) (77 g, 99%).

(*R*)-2,2'-dimethyl-1,1'-binaphthyl (3)[2]: To a solution of (*R*)-bistriflate (**2**) (77 g, 140 mmol) and $NiCl_2$•dppp (3.8 g, 7 mmol) in ether (1000 mL) was added dropwisely the methyl magnesiumbromide (3.0 M, 280 mL) at 0°C. The reaction mixture was heated to refluxing for 24h. The reaction was quenched by addition of water (200 mL) slowly at 0°C and then diluted with 5% aqueous HCl (200 mL). The aqueous layer was extracted with ether (3 × 100 mL). The combined organic layer was washed with $NaHCO_3$(100 mL), dried over anhydrous sodium sulfate and concentrated to afford **3** as light yellow color solid (39.2 g, 99%).

(*R*)-2,2'-dibromomethyl-1,1'-binaphthyl (4)[3]: A mixture of (R)-2,2'-dimethyl-1,1'-binaphthyl (**3**) (39.2 g, 138.8 mmol), *N*-bromosuccinimide (52.4 g, 291.5 mmol) and benzoylperoxide (1.25 g) in tetrachlorocarbon (900 mL) was heated at refluxing and irradiated under a sunlight for three days. The mixture was cooled to rt and filtered. The filtrate was concentrated and passed through a silica gel plug. After removal of the solvent, the residue was recrystallized from CH_2Cl_2/hexanes to afford 2,2'-dibromomethyl-1,1'-dinaphthyl (**4**) (41.1 g, 67.3 %).

(*R*)-2,2'-dichloromethyl-1,1'-binaphthyl (5)[4]: (*R*)-2,2'-Dibromomethyl-1,1'-binaphthyl (**4**, 40 g, 90.8 mmol) and LiCl (30 g, 707 mmol) in DMF (800 mL) was mixed together and stirred at rt for 6h. To this mixture was added carefully 5% aqueous HCl (300 mL) (exothermomic reaction occurred). The mixture was then extracted with ether (4 × 400 mL). The organic layer was dried over sodium sulfate, concentrated and recrystallized from CH_2Cl_2/hexane to gave **5** as white solid (30 g, 93%).

(*R*,*R*)-1,2-bis{(*R*)-4,5-dihydro-3H-dinaphtho[1,2-c:2',1'-e]phosphepino}benzene (1): To a solution of (*R*)-2,2'-dichloromethyl-1,1'-binaphthyl (**5**, 0.57 g, 1.62 mmol) and NaH (0.2 g, 8.3 mmol) in THF (20ml) was added 1,2-bis(phosphino)benzene (109 μl, 0.812 mmol) at -78°C under nitrogen. The mixture was kept stirring at rt for 24 h and was heated at refluxing for 24 h. After the reaction was completed (monitored by ^{31}P NMR), the solvent was removed via vacuum and the residue was washed with ether (3 × 15 mL). The organic phase was filtered through a silica gel plug to give the fairly pure product. Further purification by recrystallization from ether afforded **1** (0.31 g, 55%). $[\alpha]_D^{20}$ = 845 (c = 0.22, $CHCl_3$), ^{1}H NMR ($CDCl_3$) 360MHz δ 7.81-7.76 (8H, m, Ar-H), 7.57-7.54 (4H, m, Ar-H), 7.31-7.13 (10H, m, Ar-H), 7.00-6.90 (2H, m, Ar-H), 6.80-6.70 (2H, m, Ar-H), 6.64-6.62 (2H,d, *J* = 8.34 Hz, Ar-H), 2.97-2.74 (8H, m, $ArCH_2$); ^{13}C NMR ($CDCl_3$) δ 141.70, 134.71, 134.21, 133.40, 133.27, 132.73, 132.54, 132.34, 131.20, 128.83, 128.69, 128.62, 128.08, 127.80, 127.13, 127.10, 126.32, 125.46, 125.26, 32.50, 29.83; ^{31}P NMR($CDCl_3$) δ -6.87. MS m/z: 698 (M^+).

General Procedure for Catalytic Asymmetric Hydrogenation of Enamides: In a glovebox**,** the Rh-phosphine complex was made *in situ* by mixing $Rh(COD)_2PF_6$ (3.7 mg, 0.008 mmol) and **1** (0.8 mL of 10mg/mL ligand in toluene, 0.012 mmol) in 19.2 mL of CH_2Cl_2. The mixture was stirred for 30 min. Then 2.5 mL of this solution was transferred to a 10mL vial with an enamide substrate (0.1 mmol). The hydrogenation was performed at rt under 20 psi of hydrogen pressure for 24 h. The hydrogen was released carefully and the reaction mixture was passed through a silica gel plug eluted with EtOAc. The enantiomeric excess was measured by using GC or HPLC with a chiral GC or HPLC column without further purification. The absolute configuration of products was determined by comparing the sign of optical rotation with the reported data.

References:

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