Synthesis of New Atropisomeric Bisphosphine Ligands Bearing Chiral Phospholane and Their Use in Asymmetric Hydrogenation[1)]

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Novel chiral bisphosphine ligands bearing (2*S*,5*S*)-dimethylphospholano group on a chiral biphenyl backbone were designed and prepared. Asymmetric hydrogenations of a ketone and an olefin with the rhodium(I) complex catalysts prepared *in situ* from $[Rh(COD)Cl]_2$ and (*R*)-2,2′-bis[(2″*S*,5″*S*)-2″,5″-dimethylphospholano]-5,5′-dimethoxy-4,4′,6,6′-tetramethyl-1,1′-biphenyl and (*S*)-2,2′-bis[(2″*S*,5″*S*)-2″,5″-dimethylphospholano]-5,5′-dimethoxy-4,4′,6,6′-tetramethyl-1,1′-biphenyl gave the corresponding alcohol and alkane in high yields. The asymmetric hydrogenations with these ligands showed a different enantioselectivity.

Key words atropisomeric bisphosphine ligand; asymmetric hydrogenation; rhodium(I)-complex

Efficient asymmetric hydrogenation of functionalized olefins and ketones using rhodium(I) complexes with chiral bisphosphine ligands have been studied extensively in the last two decades. In the previous communication, we reported that the chiral positioning array (P/M-chirality)[2)] of four phenyl rings in the rhodium–chiral bisphosphine catalyst played an important role in determining the absolute configuration of the asymmetric hydrogenation product. Recently, Burk and co-workers reported excellent bisphosphine ligands bearing the chiral phospholano groups 1,2-bis((2*S*,5*S*)-2,5-diethylphospholano)ethane (BPE) and 1,2-bis((2*S*,5*S*)-2,5-dimethylphospholano)benzene (DuPHOS) (Chart 1) for asymmetric hydrogenation of some functionalized olefins, ketones, and imines.[3)] We have given much attention to the role of the chiral phospholano group and to identify their electronic and steric effects for enhancing both the enantioselectivity and the reactivity of the catalysts. The absolute configuration of the products resulting from the asymmetric hydrogenation of prochiral olefinic substrates catalyzed by rhodium complexes of DuPHOS and BPE was opposite to that of the authorized mechanism of the asymmetric hydrogenation.[4)] To learn the mechanism of asymmetric hydrogenation with bisphospholane ligands, new bisphosphine ligands (a*R*,*S*,*S*)-**1** and (a*S*,*S*,*S*)-**2** possessing chiral phospholano groups have been designed and prepared. Besides the chirality of the phospholano group, these bisphosphine ligands also possess the chirality of a backbone. Owing to the introduction of the chiral backbone, the new ligands were expected to have higher chiral environment than that of (*S*,*S*)-Me-DuPHOS and (*S*,*S*)-Me-BPE, giving more effective asym-metric induction as shown in Fig. 1.

In this paper, we wish to report the preparation of new multi-chiral bisphosphine ligands, (*R*)-2,2′-bis[(2″*S*,5″*S*)-2″,5″-dimethyl phospholano]-5,5′-dimethoxy-4,4′,6,6′-tetramethyl-1,1′-biphenyl (a*R*,*S*,*S*)-**1** and (*S*)-2,2′-bis[(2″*S*,5″*S*)-2″,5″-dimethylphospholano]-5,5′-dimethoxy-4,4′,6,6′-tetramethyl-1,1′-biphenyl (a*S*,*S*,*S*)-**2** and their application to Rh-catalyzed asymmetric hydrogenation of prochiral olefinic and ketonic substrates.

Previously, we reported a convenient method for the syn-

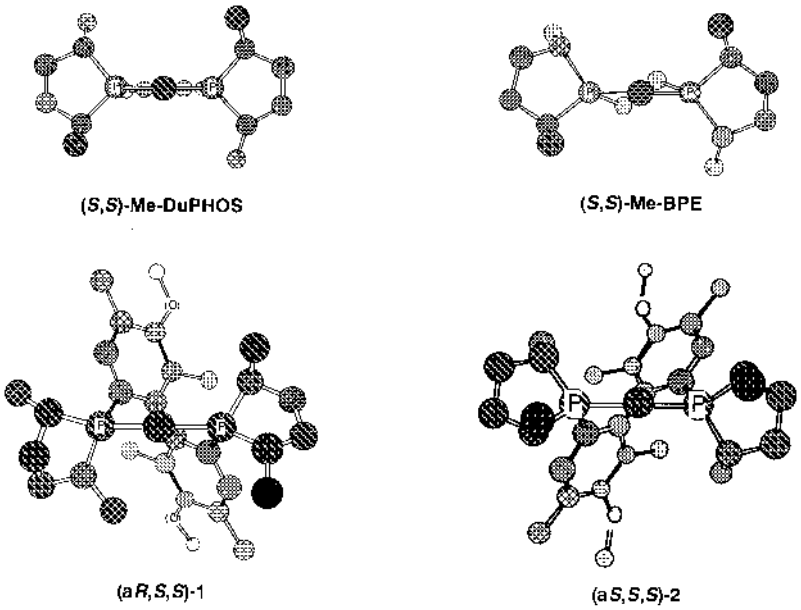

Fig. 1. Three Dimension Views of New Chiral Bisphospholane Ligands Bearing (2*S*,5*S*)-2,5-Dimethylphospholano Groups Rh(I) Complexes (Calculated with CAChe System Using MM2)

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thesis of optically pure (2*R*,5*R*)-2,5-hexanediol **3** from a mixture of the racemic and meso diols using lipase-catalyzed esterification.[5] The optically pure (2*R*,5*R*)-diol **3** was converted to a (2*S*,5*S*)-2,5-dimethylphospholane *via* (2*R*,5*R*)-2,5-hexanediol cyclic sulfate **4**.[3a—d]

Preparation of (a*R*,*S*,*S*)-**1** and (a*S*,*S*,*S*)-**2** starting from 2,6-dimethylanisole is shown in Chart 3. 2,6-Dimethylanisole was converted to the corresponding bromide **5** in 97% yield by treatment with bromine in acetic acid. Phosphonation of **5** with ethyl phosphite in the presence of tetrakis(triphenylphosphine)palladium catalyst[6] afforded the phosphate **6** in 90% yield. Iodination of **6** with iodine and periodic acid in acetic acid gave the compound **7** in 16% yield. Compound **7** was converted to the coupling product **8** in 33% yield by Ullmann reaction. Reduction of product **8** with $LiAlH_4$ in the presence of chlorotrimethylsilane afforded the bisphosphine,[7] which was dilithiated with *n*-BuLi and allowed to react with 2,5-diol cyclic sulfate **4**, followed by a second addition of *n*-BuLi affording the corresponding bisphospholane,[3b,d] which was directly converted to (a*RS*)-**9** in 27% overall yield from **8** by oxidation with hydrogen peroxide. The resulting two diastereomeric phosphine oxides (a*R*)-(*S*,*S*)-**9** and (a*S*)-(*S*,*S*)-**9** were separated by silica gel column chromatography. Repeated recrystallization gave diastereomerically pure (a*R*)-(*S*,*S*)-**9** and (a*S*)-(*S*,*S*)-**9** in 30—35% yield. The phosphinyl groups were reduced by refluxing for 3 h with a large excess of trichlorosilane[8] in benzene to afford optically pure (a*R*,*S*,*S*)-**1** and (a*S*,*S*,*S*)-**2** in 90—92% yield. The absolute configurations of the two diastereomers were determined by comparison of their CD spectra with that of (6,6′-dimethylbiphenyl-2,2′-diyl)bis(diphenylphosphine) (BIPHEMP).[9]

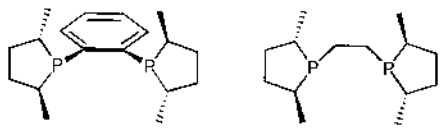


Chart 1

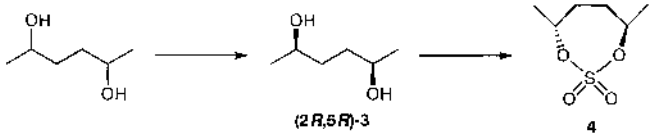


Chart 2

Using these ligands and (*S*,*S*)-Me-DuPHOS, asymmetric hydrogenations of an itaconic acid derivative **10** and an α-aminoketone derivative **12** were carried out. Table 1 summarizes the results of the asymmetric hydrogenation of the itaconic acid derivative **10**. The Rh(I)-complex of (a*S*,*S*,*S*)-**2** was found to have much better enantioselectivity than that of (a*R*,*S*,*S*)-**1**, and less than that of (*S*,*S*)-Me-DuPHOS.

The results of the asymmetric hydrogenation of the α-aminoketone hydrochloride derivative **12** summarized in Table 2 show that (a*R*,*S*,*S*)-**1** has much better enantioselectivity than those of (a*S*,*S*,*S*)-**2** and (*S*,*S*)-Me-DuPHOS.

Thus, we synthesized new chiral ligands (a*R*,*S*,*S*)-**1** and (a*S*,S,*S*)-**2** possessing two chiral phospholano groups with a chiral biphenyl backbone. Unfortunately, they could not retain the high enantioselectivity of the phospholano group in their Rh(I)-complexes-catalyzed asymmetric hydrogenation of the itaconic acid derivative **10**. But, (a*R*,*S*,*S*)-**1** gave better optical yield than that of (*S*,*S*)-Me-DuPHOS with inversion of the absolute configuration of the product in their Rh(I)-complexes-catalyzed asymmetric hydrogenation of the α-aminoketone hydrochloride **12**.

These results may suggest that (a*R*,*S*,*S*)-**1** has the opposite enantioselectivity to that of (*S*,*S*)-Me-DuPHOS in the asymmetric hydrogenation of **12**. Furthermore, (a*R*,*S*,*S*)-**1** gives the (*R*)-product with an instability-controlled mechanism[4] as expected, and (*S*,*S*)-Me-DuPHOS also gives the (*R*)-product with a stablity-controlled mechanism contrary to our expec-

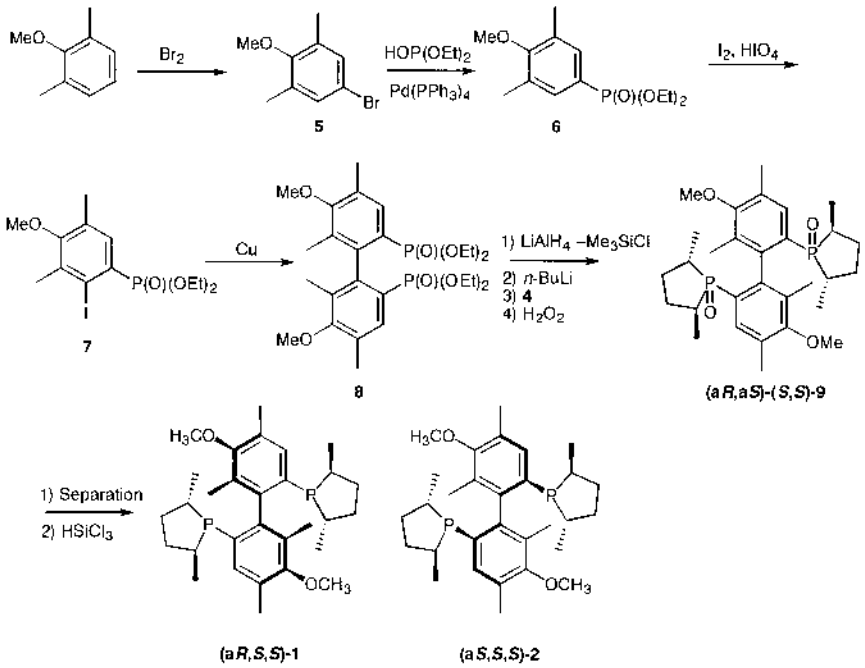
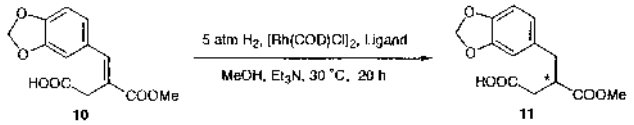


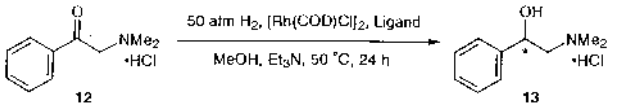
Chart 3

Table 1. Asymmetric Hydrogenation of an Itaconic Acid Derivative



Entry	Ligand	[subst.]/[cat.]	Convn. (%)	e.e. (%)	Confign.
1	(*S*,*S*)-Me-DuPHOS	500	100	80.1	(*R*)
2	(a*S*,*S*,*S*)-**2**	500	100	69.5	(*R*)
3	(a*R*,*S*,*S*)-**1**	500	100	37.2	(*R*)

Table 2. Asymmetric Hydrogenation of an α-Aminoketone Derivative



Entry	Ligand	[subst.]/[cat.]	Convn. (%)	e.e. (%)	Confign.
1	(*S*,*S*)-Me-DuPHOS	500	53.8	4.9	(*S*)
2	(a*R*,*S*,*S*)-**1**	500	100	47.9	(*R*)
3	(a*S*,*S*,*S*)-**2**	500	100	1.3	(*R*)

tation in the asymmetric hydrogenation of **10**.

Experimental

All melting points were determined with micromelting point apparatus (Yanagimoto) and are uncorrected. Optical rotations were measured on a JASCO DIP-140 digital polarimeter. IR spectra were recorded on a JASCO IR-700 spectrometer. ^{1}H-NMR spectra were recorded with a JEOL JNM-EX 270 (270 MHz) spectrometer. ^{1}H chemical shifts are given in ppm relative to tetramethylsilane (δ=0) in $CDCl_3$ as an internal standard at ambient temperature. The abbreviations of signal patterns are as follows: s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet. Column chromatography was carried out on silica gel (Kiesel gel 60, 70—230 mesh, Merck).

4-Bromo-2,6-dimethylanisole (5) Bromine (9.5 ml, 0.22 mol) was added dropwise to a stirred solution of 2,6-dimethylanisole (25 g, 0.18 mol) in acetic acid (180 ml) under ice cooling and then the mixture was stirred for 3 h at room temperature. The reaction mixture was treated with saturated aqueous sodium bisulfite under ice cooling and then the aqueous solution was extracted with CH_2Cl_2. The organic layer was neutralized with saturated aqueous $NaHCO_3$, and then washed with H_2O and saturated brine. The organic layer was dried over anhydrous $MgSO_4$ and evaporated to give **5** (38.5 g, 97%) as a colorless oil.[10] GC-MS: (M^+) 214. ^{1}H-NMR ($CDCl_3$) δ: 2.24 (6H, s, CH_3), 3.68 (3H, s, CH_3O), 7.13 (2H, s, Ar-H).

4-Diethylphosphono-2,6-dimethylanisole (6) Under an argon atmosphere, a mixture of **5** (36.5 g, 0.17 mol), ethyl phosphite (25.8 g, 0.187 mol), tetrakis(triphenylphosphine)palladium (9.8 g, 8.5 mmol) and triethylamine (18.9 g, 0.187 mol) was stirred and heated under reflux for 12 h in dry, degassed toluene (40 ml). After cooling to room temperature, the mixture was diluted with H_2O (200 ml) and extracted with ether. The organic layer was dried over anhydrous $MgSO_4$ and evaporated. The residue was chromatographed on silica gel with AcOEt as an eluent to give **6** (41.7 g, 90%) as a colorless oil. GC-MS: (M^+) 272. IR (KBr) cm^{-1}: 1220 (P=O), 1120, 1019 (P–O–C). ^{1}H-NMR ($CDCl_3$) δ: 1.33 (6H, t, J=6.9 Hz, CH_3CH_2O), 2.31 (6H, s, CH_3), 3.75 (3H, s, CH_3O), 4.05 (4H, m, $CH_3C\underline{H}_2O$), 7.47 (2H, d, J=13.5 Hz, Ar-H). *Anal*. Calcd for $C_{13}H_{21}O_4P$: C, 57.35; H, 7.77. Found: C, 57.21; H, 7.70.

4-Diethylphosphono-2,6-dimethyl-3-iodoanisole (7) A mixture of the compound **6** (22.5 g, 82.7 mmol), iodine (8.39 g, 33 mmol), periodic acid dihydrate (17 g, 74 mmol), H_2O (25 ml), conc. H_2SO_4 (5 ml) and acetic acid (80 ml) was stirred at 70 °C for 3 d. After cooling to room temperature, the reaction mixture was diluted with H_2O and neutralized with saturated aqueous $NaHCO_3$. The mixture was extracted with ether and then the organic layer was washed with saturated brine, dried over anhydrous $MgSO_4$, and evaporated. The residue was purified by column chromatography on silica gel with CH_2Cl_2–methanol (20 : 1) as an eluent to give **7** (5.27 g, 16%) as a pale yellow oil. GC-MS: (M^+) 398. IR (KBr) cm^{-1}: 1243 (P=O), 1149, 1026 (P–O–C). ^{1}H-NMR ($CDCl_3$) δ: 1.37 (6H, t, J=6.9 Hz, CH_3CH_2O), 2.27 (3H, s, CH_3), 2.48 (3H, s, CH_3), 3.71 (3H, s, CH_3O), 4.09—4.26 (4H, m, CH_3CH_2O), 7.76 (1H, d, J=14.5 Hz, Ar-H).

2,2′-Bis(diethylphosphono)-5,5′-dimethoxy-4,4′,6,6′-tetramethylbiphenyl (8) Under an argon atmosphere, a mixture of the compound **7** (5.84 g, 14.7 mmol) and copper powder (20 g, 315 mmol) in dimethylformamide (DMF) (300 ml) was stirred and refluxed for 12 h. After cooling to room temperature, the reaction mixture was filtered through Celite and concentrated *in vacuo*. The residue was dissolved in ethyl acetate (300 ml) and then washed with saturated brine, dried over anhydrous $MgSO_4$, and evaporated. The residue was purified by column chromatography on silica gel with AcOEt as an eluent to give **8** (1.65 g, 33%) as a pale yellow viscous oil. FAB-MS: $(M+H)^+$ 543. IR (KBr) cm^{-1}: 1242 (P=O), 1153, 1053 (P–O–C). ^{1}H-NMR ($CDCl_3$) δ: 1.13 (6H, t, J=7.3 Hz, $C\underline{H}_3CH_2O$), 1.16 (6H, t, J=7.3 Hz, $C\underline{H}_3CH_2O$), 1.88 (6H, s, CH_3), 2.36 (6H, s, CH_3), 3.75 (6H, s, CH_3O), 3.80—3.99 (8H, m, $CH_3C\underline{H}_2O$), 7.67 (2H, d, J=14.6 Hz, Ar-H). *Anal*. Calcd for $C_{26}H_{40}O_8P_2$: C, 57.56; H, 7.43. Found: C,57.29; H, 7.41.

(*RS*)-2,2′-Bis[(2″*S*,5″*S*)-2″,5″-dimethylphospholano]-5,5′-dimethoxy-4,4′,6,6′-tetramethyl-1,1′-biphenyl Oxide ((a*RS*)-(*S*,*S*)-9) Under an argon atmosphere, chlorotrimethylsilane (8.43 ml, 66.4 mmol) was added to a stirred solution of lithium aluminium hydride in THF (1.0 M; 66.4 ml) at −78 °C. The mixture was allowed to warm to room temperature and was stirred for 2 h and then a solution of **8** (3 g, 5.53 mmol) in THF (10 ml) was added at −78 °C. After the reaction mixture was warmed to room temperature and stirred for a further 12 h, degassed water (17 ml) and degassed aqueous potassium hydroxide (1 N; 20 ml) were added. The mixture was extracted with degassed *n*-pentane and the combined organic extracts were dried over anhydrous $MgSO_4$ and evaporated. The residue was dissolved in THF (70 ml) under an argon atmosphere and cooled to −30 °C. To the solution was added dropwise a 1.47 M solution of *n*-butyllithium (7.53 ml, 11.07 mmol) in *n*-hexane, and the reaction mixture was stirred for 1.5 h at room temperature. To the resulting mixture was added (2*R*,5*R*)-2,5-hexanediol cyclic sulfate **4** (2.09 g, 11.61 mmol) in THF (10 ml). After stirring for 2 h, *n*-butyllithium (1.47 M) (8.28 ml, 12.17 mmol) in *n*-hexane was added dropwise. The reaction mixture was allowed to stir for 3 h. After evaporation of the solvent, the residue was extracted with toluene. The extracts were dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The residue was dissolved in CH_2Cl_2 (40 ml)–H_2O (10 ml). Hydrogen peroxide (30%) (12.5 ml, 110.6 mmol) was added to the stirred and ice-cooled solution and the mixture was stirred at room temperature for 3 h. After concentration under reduced pressure, water was added to the residue and the organic layer was extracted with AcOEt. The combined extracts were washed with saturated aqueous NaCl, dried over anhydrous $MgSO_4$, and evaporated. The residue was purified by column chromatography on silica gel with AcOEt as the eluent to give (a*RS*)-(*S*,*S*)-**9** (800 mg, 27%) as an amorphous powder. FAB-MS: $(M+H)^+$ 531.

(*S*)-2,2′-Bis[(2″*S*,5″*S*)-2″,5″-dimethylphospholano]-5,5′-dimethoxy-4,4′,6,6′-tetramethyl-1,1′-biphenyl Oxide ((a*S*)-(*S*,*S*)-9) and (*R*)-2,2′-Bis[(2″*S*,5″*S*)-2″,5″-dimethylphospholano]-5,5′-dimethoxy-4,4′,6,6′-tetramethyl-1,1′-biphenyl Oxide ((a*R*)-(*S*,*S*)-9) The separation of (a*RS*)-(*S*,*S*)-**9** was effected by column chromatography on silica gel with AcOEt–ethanol (9 : 1) as the eluent. Repeated recrystallization of crude (a*S*)-(*S*,*S*)-**9** from diisopropyl ether (IPE) and crude (a*R*)-(*S*,*S*)-**9** from AcOEt–hexane gave diastereomerically pure (a*S*)-(*S*,*S*)-**9** and (a*R*)-(*S*,*S*)-**9** in 30—35% yield, respectively. The purity of (a*S*)-(*S*,*S*)-**9** and (a*R*)-(*S*,*S*)-**9** was confirmed by HPLC (a chiral stationary column: Chiralpack AD) using a mixed solvent of hexane–isopropyl alcohol (20 : 1).

(a*R*)-(*S*,*S*)-**9**: Colorless needles. mp 184—185 °C. $[\alpha]_D^{23}$ +141.1° (c=0.90, $CHCl_3$). FAB-MS: $(M+H)^+$ 531. IR (KBr) cm^{-1}: 1151 (P=O). ^{1}H-NMR ($CDCl_3$) δ: 0.92 (6H, dd, J=7.3, 15.5 Hz, CH_3×2), 1.12 (6H, dd, J=7.3, 14.9 Hz, CH_3×2), 1.37—1.61 (4H, m, CH_2×2), 1.87 (6H, s, CH_3×2), 1.93—2.24 (8H, m, CH_2×2, CH×4), 2.34 (6H, s, CH_3×2), 3.75 (6H, s, CH_3O×2), 7.03 (2H, d, J=12.2 Hz, Ar-H). *Anal*. Calcd for $C_{30}H_{44}O_4P_2$: C, 67.91; H, 8.36. Found: C,67.95; H, 8.37.

(a*S*)-(*S*,*S*)-**9**: Colorless prism. mp 242—244 °C. $[\alpha]_D^{23}$ +48.9° (c=0.64, $CHCl_3$). FAB-MS: $(M+H)^+$ 531. IR (KBr) cm^{-1}: 1150 (P=O). ^{1}H-NMR ($CDCl_3$) δ: 1.11 (6H, t, J=7.3 Hz, CH_3×2), 1.17 (6H, t, J=7.6 Hz, CH_3×2), 1.29—1.43 (4H, m, CH_2×2), 1.86 (6H, s, CH_3×2), 1.91—2.18 (8H, m, CH_2×2, CH×4), 2.33 (6H, s, CH_3×2), 3.74 (6H, s, CH_3O×2), 6.82 (2H, d, J=12.5 Hz, Ar-H). *Anal*. Calcd for $C_{30}H_{44}O_4P_2$: C, 67.91; H, 8.36. Found: C, 67.89; H, 8.33.

(*S*)-2,2′-Bis[(2″*S*,5″*S*)-2″,5″-dimethylphospholano]-5,5′-dimethoxy-4,4′,6,6′-tetramethyl-1,1′-biphenyl ((a*S*,*S*,*S*)-2) and (*R*)-2,2′-Bis[(2″*S*,5″*S*)-

2″,5″-dimethylphospholano]-5,5′-dimethoxy-4,4′,6,6′-tetramethyl-1,1′-biphenyl ((a*R*,*S*,*S*)-1) Trichlorosilane (2.06 g, 15.2 mmol) was added to a stirred mixture of (a*S*)-(*S*,*S*)-**9** (200 mg, 0.38 mmol), triethylamine (1.85 g, 18.24 mmol) and degassed benzene (10 ml) in an argon atmosphere under ice cooling. The reaction mixture was refluxed for 3 h. After cooling with ice, degassed 30% aqueous NaOH (10 ml) was added to the mixture and then the whole was heated to 60 °C with stirring under an argon atmosphere for 30 min. After cooling to room temperature, the organic layer was separated and further extraction of the aqueous layer with degassed toluene was carried out. The combined extracts were washed with degassed H_2O, degassed saturated aqueous NaCl and then dried over anhydrous $MgSO_4$ in an argon atmosphere. The organic layer was evaporated and the residue was chromatographed on silica gel with toluene as an eluent to provide colorless powder (a*S*,*S*,*S*)-**2** (172 mg, 91%). (a*R*,*S*,*S*)-**1** was prepared in a similar manner as (a*S*,*S*,*S*)-**2**.

(a*R*,*S*,*S*)-**1**: Viscous oil. $[\alpha]_D^{23}$ +152.5° (c=0.64, $CHCl_3$). FAB-MS: $(M+H)^+$ 499. ^{1}H-NMR ($CDCl_3$) δ: 0.75 (6H, dd, J=6.9, 9.2 Hz, $CH_3\times2$), 1.29 (6H, dd, J=6.9, 17.8 Hz, $CH_3\times2$), 1.41—1.66 (4H, m, $CH_2\times2$), 1.84 (6H, s, $CH_3\times2$), 1.86—2.30 (8H, m, $CH_2\times2$, CH×4), 2.36 (6H, s, $CH_3\times2$), 3.73 (6H, s, $CH_3O\times2$), 7.20 (2H, s, Ar-H). *Anal*. Calcd for $C_{30}H_{44}O_2P_2$: C, 72.26; H, 8.89. Found: C, 72.46; H, 8.93.

(a*R*,*S*,*S*)-**2**: Colorless powders. mp 212—214°C. $[\alpha]_D^{23}$ +37.8° (c=0.58, $CHCl_3$). FAB-MS: $(M+H)^+$ 499. ^{1}H-NMR ($CDCl_3$) δ: 1.04 (6H, dd, J=6.9, 9.2 Hz, $CH_3\times2$), 1.17 (6H, dd, J=6.9, 17.5 Hz, $CH_3\times2$), 1.56—1.72 (4H, m, $CH_2\times2$), 1.76 (6H, s, $CH_3\times2$), 2.10—2.45 (8H, m, $CH_2\times2$, CH×4), 2.35 (6H, s, $CH_3\times2$), 3.73 (6H, s, $CH_3O\times2$), 7.31 (2H, s, Ar-H). *Anal*. Calcd for $C_{30}H_{44}O_2P_2$: C, 72.26; H, 8.89. Found: C, 72.14; H, 8.95.

Asymmetric Hydrogenation of 2-*N*,*N*-Dimethylaminoacetophenone Hydrochloride (General Procedure) A mixture of $[Rh(COD)Cl]_2$ (chloro-(1,5-cyclooctadiene) rhodium(I) dimer, 0.7 mg, 1.3×10^{-3} mmol), chiral bisphosphine ligand (a*R*,*S*,*S*)-**1** (1.4 mg, 2.8×10^{-3} mmol), and degassed methanol (2 ml) was stirred at room temperature under argon atmosphere for 15 min. This solution, together with 2-*N*,*N*-dimethylaminoacetophenone hydrochloride (223 mg, 1.3 mmol ([subst.]/[cat.]=500)), triethylamine (1.3 mg, 1.3×10^{-2} mmol) and degassed methanol (3 ml) was placed in an autoclave, pressurized with hydrogen to 50 atm, and stirred at 50 °C for 24 h. The reaction mixture was brought to ambient temperature, and active carbon powder (150 mg) was added. The mixture was stirred for 1 h and filtered. The filtrate was evaporated to give 2-*N*,*N*-dimethylamino-1-phenylethanol hydrochloride. The conversion was measured by ^{1}H-NMR analysis. The optical yield was calculated on the basis of the specific rotation value of the pure (*S*)-enantiomer. $[\alpha]_D^{20}$ +55.5° (c=0.9 H_2O).[11]

Asymmetric Hydrogenation of 1-(3,4-Methylenedioxyphenyl)-2-methoxycarbonylbutenoic Acid (General Procedure) A mixture of $[Rh(COD)Cl]_2$ (chloro(1,5-cyclooctadiene)rhodium(I) dimer, 0.7 mg, 1.3×10^{-3} mmol), chiral bisphosphine ligand (a*R*,*S*,*S*)-**1** (1.4 mg, 2.8×10^{-3} mmol), and degassed methanol (2 ml) was stirred at room temperature under argon atmosphere for 15 min. This solution, together with 1-(3,4-methylenedioxyphenyl)-2-methoxycarbonylbutenoic acid (344 mg, 1.3 mmol ([subst.]/[cat.]=500)), triethylamine (13 mg, 1.3×10^{-1} mmol) and degassed methanol (3 ml) was placed in an autoclave, pressurized with hydrogen to 5 atm, and stirred at 30 °C for 20 h. The reaction mixture was evaporated *in vacuo*. The conversion rate was determined by ^{1}H-NMR analysis. After the evaporation, the residue was dissolved in aqueous NaOH (0.5 M, 2.6 ml), and extracted with CH_2Cl_2 to remove the catalyst. The aqueous layer was acidified with dil. HCl, extracted with ether and the combined extracts were dried over anhydrous $MgSO_4$. Evaporation of the solvent gave the hydrogenation product. The optical yield was calculated on the basis of the maximum optical rotation value of the pure (*S*)-enantiomer. $[\alpha]_D^{20}$ −30.5° (c=1.35 MeOH).[12]

References and Notes

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