BIPNOR: A New, Efficient Bisphosphine Having Two Chiral, Nonracemizable, Bridgehead Phosphorus Centers for Use in Asymmetric Catalysis

Frédéric Robin, François Mercier, Louis Ricard, François Mathey,* and Michel Spagnol

Abstract: Optically active phosphorus ligands are widely used in homogeneous asymmetric catalysis. However, among the numerous available structures of this type, the subclass of optically active bisphosphines with at least one chiral phosphorus atom is rather underdeveloped. A bisphosphine with two chiral, nonracemizable bridgehead phosphorus centers, (*meso*,*d*/*l*)-2,2′,3,3′-tetraphenyl-4,4′,5,5′-tetramethyl-6,6′-**bis**-1-**phosphanor**borna-2,5-dienyl (BIPNOR), can be obtained by thermolysis of 1,1′-bisphospholyl with diphenylacetylene. Here, we report the resolution of the *d*/*l* isomer by means of a chiral palladium complex to give the two optically active forms of BIPNOR. We then investigate the catalytic properties of BIPNOR, incorporated in Rh^{I} and Ru^{II} catalysts for the hydrogenation of olefins and ketones and in a Pd^{II} catalyst for asymmetric alkylation reactions. BIPNOR is shown to give good results in these catalytic reactions.

Keywords
asymmetric catalysis · hydrogenations · palladium · phosphorus ligands · rhodium

Introduction

Currently, the most effective catalysts for enantioselective hydrogenation and related reactions incorporate chelating diphosphines such as BINAP[1] and DuPHOS,[2] whose chiral centers are localized on the carbon backbone. It seems reasonable to assume that homochiral phosphines with the chirality directly located at the phosphorus atoms should also have an enormous potential in enantioselective catalysis. Although such compounds are well known,[3] they have found few applications; only DIPAMP[4] has been employed successfully to any significant extent. Thus, the development of new, efficient enantioselective catalysts based on ligands with chirality at phosphorus remains an intuitively desirable and exciting goal.

Some time ago, we developed a versatile synthesis of 1-phosphanorbornadienes.[5, 6] Subsequently, we and others have been able to show that very high turnover frequencies can be achieved when using these novel phosphines as ligands in rhodium-catalyzed hydrogenations and hydroformylations of alkenes.[7–10] These rigid bicyclic phosphines contain nonracemizable phosphorus centers, whose geometry precludes any loss of enantiomeric purity during catalysis or the associated recycling processes.[11] This rigidity suggested a potential in asymmetric catalysis for such homochiral monodentate phosphines, but preliminary screenings gave low *ee*'s in the hydrogenation of dehydroaminoacids.[12] More recently, we have prepared the chelating bisphosphine **1** (BIPNOR) as a mixture of *meso* and *d*,*l* isomers.[13] Here, we report the separation of the *d* and *l* enantiomers and the evaluation of their potential in asymmetric catalysis.

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Results and Discussion

BIPNOR (**1**) can be easily prepared from 3,4-dimethyl-1-phenylphosphole. The P–Ph bond is first cleaved by lithium metal. The resulting phospholide is then coupled by means of iodine, and the 1,1′-biphospholyl thus formed is heated at 140 °C in the presence of diphenylacetylene to yield **1**.[13] The separation of the *d*,*l* (**1a**) and *meso* (**1b**) components of BIPNOR was achieved by converting the ligand **1** into its Pd complex **2** according to the sequence described in Scheme 1. The *d*,*l* mixture of **2** eluted first from silica gel (eluent: dichloromethane/ethyl acetate 19:1).

meso-BIPNOR was unequivocally characterized by X-ray analysis of its *P*,*P*-disulfide **3**. This disulfide has two inequivalent phosphorus nuclei (^{31}P NMR: $\delta = +54.5$ and $+51.9$ in $CDCl_3$ at RT); this demonstrates that the rotation of the two phosphanorbornadiene units about the C2–C2′ axis is slow on the NMR timescale. Racemic BIPNOR was resolved with one equivalent of **4**,[14] by following the scheme proposed by Roberts and Wild for the resolution of chiral phosphines (Scheme 2).[15]

The mode of complexation of *d*,*l*-BIPNOR is noteworthy: the formation of a dinuclear species rather than the expected palladium chelate suggests that BIPNOR has a lower chelating abil-

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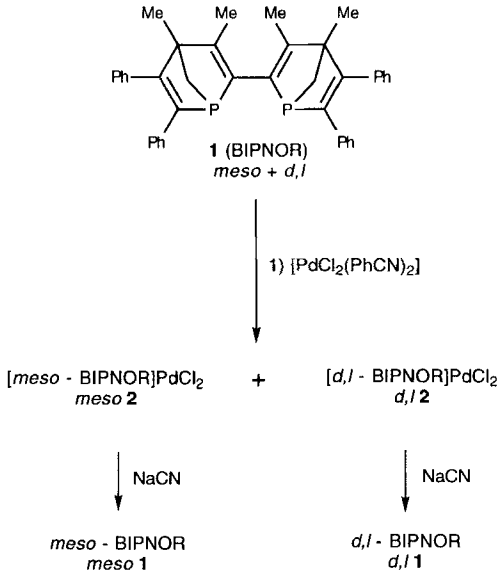
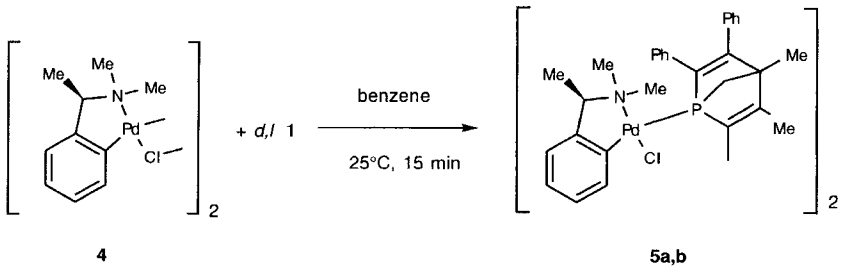


Scheme 1. Separation of the two diastereomers of **1**.



Scheme 2. Resolution of *d,l*-**1**.

ity than BINAP.[23] The diastereomeric palladium complexes **5a** (^{31}P NMR: $\delta = +56.9$, C_6D_6) and **5b** (^{31}P NMR: $\delta = +54.3$, C_6D_6) were separated by chromatography. Complex **5a** eluted first from silica gel (eluent: toluene/AcOEt 4:1) and was recrystallized from Et_2O/CH_2Cl_2. According to the X-ray crystal structure analysis (Figure 1), the BIPNOR ligand in **5a** has an (*R,R*) configuration.

Classical decomplexation reactions of **5a** and **5b** by NaCN in CH_2Cl_2/H_2O (N_2 atmosphere, 25 °C, 30 min stirring) yielded

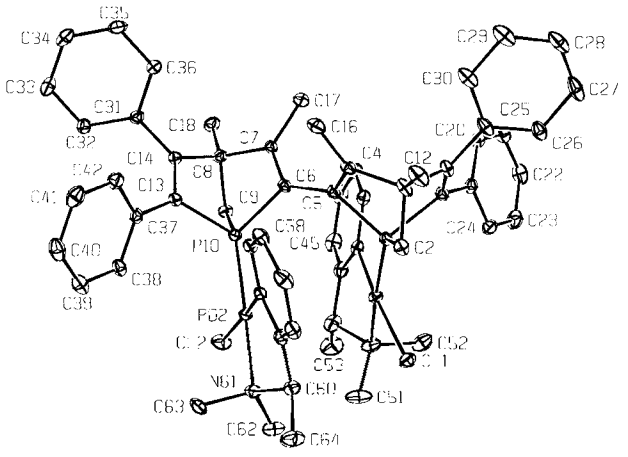


Figure 1. Molecular structure of **5a**.

(*R,R*)-(+)-BIPNOR [(+)-**1a**] and (*S,S*)-(−)-BIPNOR [(−)-**1a**], respectively, with an $[\alpha]_D^{25}$ of ±215 ($c = 0.7$ in CH_2Cl_2).

Preliminary asymmetric hydrogenation experiments were performed on olefins and ketones **6**–**10** to compare the properties of BIPNOR with BINAP, DIOP,[16] and BICHEP.[21] The results are summarized in Table 1. Apparently, BIPNOR performs similarly to BINAP and BICHEP, even though its structure is very different.

In a further comparison, a $[PdCl_2(PhCN)_2]$/(−)-BIPNOR catalyst (1%) was employed in the asymmetric alkylation of 1,3-diphenyl-2-propenyl acetate by sodium dimethyl malonate (24 h at 25 °C in THF). The (*R*) alkylation product was obtained in 60% yield, with an enantiomeric excess of 84%. A similar experiment with an (*S*)-BINAP-based catalyst gave the same product in 80% yield, but in only 34% *ee* (44 h).[22] To obtain a high degree of asymmetric induction with BINAP, a tertiary carbanion derived from acetamidomalonate ester was required as the nucleophile.

Conclusion

The substitution pattern in the 1-phosphanorbornadiene skeleton can easily be varied: simply changing the substituents of the alkyne undergoing the [2+4] cycloaddition with the 2*H*-phosphole precursor provides a method for fine-tuning the BIPNOR structure. Hence, it can be optimized for reaction with any given substrate, provided that the resolution technique is adapted to the new phosphine. We feel that a promising new series of bisphosphines is now available for asymmetric catalysis.

Experimental Section

***meso*- and *d,l*-2:** $[PdCl_2(PhCN)_2]$ (2.7 g, 7.1 mmol) in CH_2Cl_2 (100 mL) was added dropwise to a mixture of *meso*- and *d,l*-**1** (4 g, 6.9 mmol) in CH_2Cl_2 (100 mL). After stirring under dry nitrogen at room temperature for 15 min, the solvent was evaporated and the residue washed twice with diethyl ether. The *meso* and *d,l* diastereomers of **2** were then separated by chromatography on silica gel. The *d,l* complex eluted first with dichloromethane/ethyl acetate (95:5) ($R_f = 0.45$) and the *meso* complex second with dichloromethane/ethyl acetate (80:20) ($R_f = 0.32$). Overall yield of **2**: 4.6 g (90%); *meso*-**2**: 3.2 g and *d,l*-**2**: 1.4 g.

meso-**2**: ^{31}P NMR (CD_2Cl_2): $\delta = 88.12$; ^{1}H NMR (CD_2Cl_2): $\delta = 1.41$ (s, 6H, CH_3), 2.47 (s, 6H, CH_3), 2.80 (d, ^2J(H,H) = 10 Hz, 2H, CH_2 bridge), 3.10 (q, ^2J(H,H) = 10 Hz, ^2J(H,P) = 1 Hz, 2H, CH_2 bridge), 6.79–7.44 (m, 20H, Ph); ^{13}C NMR (CD_2Cl_2): $\delta = 19.05$ (s, CH_3), 20.79 (s, CH_3), 68.62–69.94 (m, CH_2 bridge and C sp_3), 127.88–165.10 (m, C sp_2).

d,l-**2**: ^{31}P NMR (CD_2Cl_2): $\delta = 82.5$; ^{1}H NMR (CD_2Cl_2): $\delta = 1.41$ (s, 6H, CH_3), 2.28 (s, 6H, CH_3), 2.65 (d, ^2J(H,H) = 10.2 Hz, 2H, CH_2 bridge), 3.05 (q, ^2J(H,H) = 10.2 Hz, ^2J(H,P) = 1 Hz, 2H, CH_2 bridge), 6.98–7.46 (m, 20H, Ph); ^{13}C NMR (CD_2Cl_2): $\delta = 18.48$ (s, CH_3), 20.69 (s, CH_3), 68.59–70.10 (m, CH_2 bridge and C sp_3), 127.88–165.10 (C sp_2).

***meso*-1 (1b):** NaCN (0.5 g, 10 mmol) and few milliliters of distilled, degassed water were added to *meso*-**2** (1 g, 1.32 mmol) in CH_2Cl_2 (30 mL). After vigourous stirring at room temperature under dry nitrogen for 20 min, water (20 mL) was added. The mixture was then allowed to settle for decantation, and the two phases were separated. The organic phase was washed twice with brine and once with water, and the aqueous layer with dichloromethane. The

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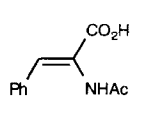
Table 1. Asymmetric hydrogenation of substrates **7**–**10** using BIPNOR complexes [a].



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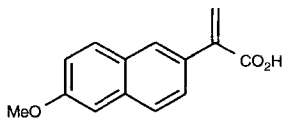

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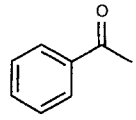

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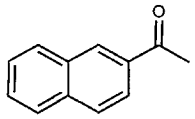

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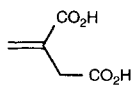

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	Catalyst	Data from present paper Conditions	% *ee* (conv.)	Catalyst	Comparative data Conditions [b]	% *ee* (conv.)	Ref.
6	[Rh(cod)((−)-L)]$^+$PF$_6^-$ (1%)	EtOH, H_2 3 atm 25 °C, 2 h	>98% [c] (*S*) (100%)	[Rh(nbd)(P*P)]$^+$ClO$_4^-$ P*P = (*S*)-BINAP	48 h	84% [d] (99%)	[1]
7	[Rh(cod)((−)-L)]$^+$PF$_6^-$ (1%)	MeOH, H_2 4 atm 25 °C, 2 h	98% (*S*) (30%)	[Rh(cod)(P*P)]$^+$BF$_4^-$ (0.1%), P*P = (−)-DIOP	16 h	73% (100%)	[18]
8	[RuBr$_2$((+)-L)] (0.5%)	MeOH, H_2 60 atm 50 °C, 48 h	60% (*R*) (30%)	[RuBr$_2$(P*P)] (0.1%) P*P = (*R*)-BINAP	100 atm, 25 °C, 62 h	74% [e] (1%)	[19]
9	[RuBr$_2$((+)-L)] (0.2%), N*N [f]/KOH	*i*PrOH, H_2 5 atm 28 °C, 10 h	81% [g] (*R*) (65%)	[RuBr$_2$(P*P)] (0.2%) N*N/KOH, P*P = (*S*)-BINAP	5 atm, 28 °C, 6 h	95% (99%)	[20]
10	[Rh(cod)((+)-L)]$^+$PF$_6^-$ (0.5%)	MeOH, H_2 3 atm 25 °C, 40 min	93% (*S*) (100%)	[Rh(nbd)(P*P)]$^+$ClO$_4^-$ (0.2%), P*P = (*R*)-BICHEP	1 atm, 15 min	93% (*R*) (100%)	[21]

[a] (−)-L = (−)-BIPNOR, (+)-L = (+)-BIPNOR; all *ee*'s measured by HPLC, except when noted otherwise. [b] Under similar conditions to those used with BIPNOR, except where noted. [c] With the (+)-L catalyst, the (*R*) product is obtained with the same *ee*. [d] *ee* is 100% under similar conditions when using (*Z*)-α-(benzamido)cinnamic acid [23]. [e] Better conditions found more recently, resulting in higher *ee* (97%) [20], but they have not been tested with BIPNOR on acetophenone. [f] N*N = (*S*,*S*)-1,2-diamino-1,2-diphenylethane. [g] Measured by ^{1}H NMR on the MTPA (α-methoxy-α-trifluoromethylphenylacetic acid) ester.

combined organic fractions were dried over magnesium sulfate, and the solvent evaporated to yield pure *meso*-**1**. Yield: 0.7 g (90%). ^{31}P NMR ($CDCl_3$): $\delta = -13.24$; ^{1}H NMR ($CDCl_3$): $\delta = 1.31$ (s, 6H, CH_3), 1.69 (s, 6H, CH_3), 2.02–2.24 (m, 4H, CH_2 bridge), 6.86–7.29 (m, 20H, Ph); ^{13}C ($CDCl_3$): $\delta = 16.99$ (s, CH_3), 21.40 (s, CH_3), 64.78 (s, C sp_3), 71.97 (d, ^1J(C,P) = 2,6 Hz, CH_2 bridge), 126.88–161.96 (sp_2 carbons).

***d,l*-1 (1a)**: Same procedure as for *meso*-**1** from *d,l*-**2**. Yield of *d,l*-**1**: 0.7 g (90%). Same spectroscopic data as for (±)-**1a** (see below).

3: S_8 (1 g, 3.9 mmol) was added in small portions to *meso*-**1** (1 g, 1.73 mmol) in toluene (100 mL). After stirring under dry nitrogen at 80 °C for 2 h, the mixture was allowed to cool to room temperature. The insoluble material (excess sulfur) was filtered off, the solvent was evaporated, and the residue was purified by chromatography on silica gel, first with toluene to elute the remaining sulfur and then with ethyl acetate. Yield of **3**: 1 g (89%). Crystals of **3** were grown from a dichloromethane/*n*-hexane solution of the compound. ^{31}P NMR ($CDCl_3$): (AB) $\delta_A = 51.92$, $\delta_B = 54.52$, $J_{AB} = 10.15$ Hz; ^{1}H NMR ($CDCl_3$): $\delta = 1.28$ (s, 3H, CH_3), 1.39 (s, 3H, CH_3), 1.62 (pseudo-t, $\sum|^4J(C,P) + {}^5J(C,P)| = 5.2$ Hz, 3H, CH_3), 2.28 (pseudo-t, $\sum|^4J(C,P) + {}^5J(C,P)| = 5.6$ Hz, 3H, CH_3), 2.57–2.92 (m, 4H, CH_2 bridge), 6.93–7.31 (m, 20H, Ph); ^{13}C NMR ($CDCl_3$): $\delta = 17.08$ (d, $^3J(C,P) = 12.8$ Hz, CH_3), 18.22 (d, $^3J(C,P) = 12.8$ Hz, CH_3), 19.26 (d, $^3J(C,P) = 16.3$ Hz, 2 CH_3), 55.78 (d, $^2J(C,P) = 7.74$ Hz, C sp_3), 56.17 (d, $^2J(C,P) = 7.4$ Hz, C sp_3), 71.68 (d, $^1J(C,P) = 59.4$ Hz, C bridge), 73.65 (d, $^1J(C,P) = 57.3$ Hz, C bridge), 127.1–166.7 (sp_2 carbons); MS (70 eV): *m/z*(%): 642 (23) [M^+], 464 (36) [M^+ − PhCCPh], 286 (100) [M^+ − 2PhCCPh]; $C_{40}H_{36}P_2S_2$ (642.8): calcd C 74.74, H 5.64, P 9.64; found C 74.56, H 5.61, P 9.43

Crystal structure determination of 3 (see also Table 2):[27] $C_{41}H_{38}Cl_2P_2S_2$, $M_r = 727.74$; space group: $P2_1/c$ (no. 14); $a = 13.081(1)$, $b = 17.903(2)$, $c = 16.469(2)$ Å; $\beta = 108.31(1)°$; $V = 3661.48(1.3)$ Å^3; $Z = 4$; $\rho_{calcd} = 1.320$ g cm^{-3}; radiation: $Cu_{K\alpha}$ ($\lambda = 1.54184$ Å); $\mu = 37.3$ cm^{-1}; $F(000) = 1520$; $T = -150 \pm 0.5$ °C; final $R = 0.035$.

Table 2. Crystallographic data for **3** and **5a** [a].

	3	**5a**
color, habit	colorless, cube	colorless, cube
dimensions	0.32 × 0.32 × 0.32	0.30 × 0.30 × 0.30
max 2θ	0.0	60.0
h,k,l ranges	$0 \le h \le 12$, $0 \le k \le 17$ $-16 \le l \le 15$	$0 \le h \le 20$, $0 \le k \le 21$ $0 \le l \le 33$
no. refl. measured	4124 total, 3742 unique	8451 total, 8437 unique
refl. incl. $F_o^2 > 3.0\sigma(F_o^2)$	3457	6979
least-squares details [b]:		
parameters refined	424	613
unweighted agreement factor	0.035	0.029
weighted agreement factor	0.064	0.041
GOF	1.53	1.08
convergence, largest shift/error	0.00	0.00
instrument instability factor, *p*	0.08	0.06
high/low peak in final diff. map, e Å^{-3}	0.24(6)/0.00(6)	0.94(8)/0.00(8)

[a] Details in common: instrument: Enraf-Nonius CAD4 diffractometer; corrections: Lorentz polarization; solution: direct methods. [b] Details in common: hydrogen atoms included as fixed contributions to the structure factors; minimization function: $w(|F_o| - |F_c|)^2$, where $w = 4F^2/\sigma^2(F^2)$; least-squares weights: $4F_o^2/\sigma^2(F_o^2)$, with $\sigma^2(F^2) = \sigma^2(I) + (pF^2)^2$.

5a and 5b: Complex **4** (1 g, 1.75 mmol) was added to *d,l*-**1** (1 g, 1.73 mmol) in benzene (50 mL). After stirring under dry nitrogen for 15 min at room temperature, the solvent was evaporated. The diastereomers **5a** and **5b** were separated by chromatography on silica gel. With toluene/ethyl acetate (80:20) **5a** was eluted first ($R_f = 0.33$) and **5b** second ($R_f = 0.13$). Overall yield of **5**: 1.8 g (91%); 0.9 g of each diastereomer. Crystals of **5a** were grown from a dichloromethane/diethyl ether solution of the compound. **5a**: ^{31}P NMR (C_6D_6): $\delta = 56.9$. **5b**: ^{31}P NMR (C_6D_6): $\delta = 54.3$.

Crystal structure determination of 5a (see also Table 2):[27] $C_{60}H_{64}Cl_2N_2P_2Pd_2$, $M_r = 1158.85$; space group: $P2_12_12_1$ (no. 19); $a = 14.881(1)$, $b = 14.985(1)$, $c = 23.811(2)$ Å; $V = 5309.56(1.2)$ Å^3; $Z = 4$; $\rho_{calcd} = 1.450\ g\,cm^{-3}$; radiation: $Mo_{K\alpha}$ ($\lambda = 0.71073$ Å); $\mu = 8.7\ cm^{-1}$; $F(000) = 2376$; $T = -150 \pm 0.5$ °C; final $R = 0.029$; $R_\omega = 0.041$; GOF = 1.08; for the enantiomeric structure: $R = 0.03305$; $R_\omega = 0.04632$; GOF = 1.227.

(+)-1a: Same procedure from **5a** as for decomplexation of **2**. The organic phase was washed twice with a 1 M HCl solution and once with water. After evaporation of the solvent, the solid residue was purified by flash chromatography on silica gel with dichloromethane. From 0.85 g of **5a** and 0.4 g of NaCN 0.35 g of (+)-**1a** (85%) was recovered. ^{31}P NMR ($CDCl_3$): $\delta = -13.00$; ^1H NMR ($CDCl_3$): $\delta = 1.27$ (s, 6H, CH_3), 1.71 (s, 6H, CH_3), 2.05-2.19 (m, 4H, CH_2 bridge), 6.95-7.29 (m, 20H, Ph); ^{13}C NMR ($CDCl_3$): $\delta = 16.98$ (s, CH_3), 21.43 (s, CH_3), 66.02 (s, C sp_3), 71.75 (s, C bridge), 126.88-162.32 (sp_2 carbons); $C_{40}H_{36}P_2$ (578.7): calcd C 83.02, H 6.27, P 10.70; found C 83.39, H 6.23, P 10.35; $[\alpha]_D^{20} = +215$ ($c = 0.7$ in CH_2Cl_2); MS (70 eV): m/z (%): 578 (14) [M^+], 400 (68) [$M^+ - PhCCPh$], 222 (100) [$M^+ - 2PhCCPh$].

(−)-1a: Same procedure as for (+)-**1a**. From 0.85 g of **5b** and 0.4 g of NaCN, 0.35 g of (−)-**1a** (85%) was recovered. Same spectroscopic data as for (+)-**1a**; $[\alpha]_D^{20} = -218$ ($c = 0.7$ in CH_2Cl_2)

Rhodium-Catalyzed Hydrogenation of α-Acetamidocinnamic Acid (6): The substrate (1 mmol) in 25 mL of ethanol containing the rhodium complex (0.01 mmol) (prepared by mixing 1 equiv of $[Rh(cod)_2][PF_6]$ and 1 equiv of (+)- or (−)-BIPNOR in acetone) was introduced by means of a syringe into a 100 mL autoclave previously purged with argon. The solution was stirred under 3 atm of H_2 (initial pressure) for 2 h at room temperature. Complete conversion to product was indicated by ^1H NMR analysis of the crude material after evaporation of the solvent. Enantiomeric excess was determined by HPLC analysis of the purified product[123] using a Shandon column HSA (phosphate solution pH 6, 0.02 M; 1 mL min^{-1} flow). Retention time (*N*-acetyl-(*S*)-phenylalanine) = 8.5 min. Retention time (*N*-acetyl-(*R*)-phenylalanine) = 13.0 min. The absolute configuration was assigned by determination of the sign of the optical rotation of the pure product and according to ref. [1].

Rhodium-Catalyzed Hydrogenation of 2-(6′-Methoxy-2′-naphthyl)propenoic Acid (7): The substrate (1 mmol) in 25 mL of ethanol containing the rhodium complex (0.01 mmol) (prepared by mixing 1 equiv of $[Rh(cod)_2][PF_6]$ and 1 equiv of (+)- or (−)-BIPNOR in acetone) was introduced by means of a syringe into a 100 mL autoclave previously purged with argon. The solution was stirred under 4 atm of H_2 (initial pressure) for 2 h at room temperature. The conversion was calculated from the crude solution by ^1H NMR after evaporation of solvent. Enantiomeric excess was determined by HPLC analysis of crude product using a Regis column whelk-01 (RR) (80/20/0.5 hexane/ethanol/acetic acid; 1 mL min^{-1} flow). Retention time ((*S*)-naproxen) = 10.3 min. Retention time ((*R*)-naproxen) = 17.6 min.

Rhodium-Catalyzed Hydrogenation of Itaconic Acid (10): The substrate (1 mmol) in 25 mL of ethanol containing the rhodium complex (0.01 mmol) (prepared by mixing 1 equiv of $[Rh(cod)_2][PF_6]$ and 1 equiv of (+)- or (−)-BIPNOR in acetone) was introduced by means of a syringe into a 100 mL autoclave previously purged with argon. The solution was stirred under 3 atm of H_2 (initial pressure) for 40 min at room temperature. Complete conversion to product was indicated by ^1H NMR analysis of the crude material after evaporation of the solvent. In order to purify the product, the crude material was dissolved in 10 mL of 10 M HCl. After filtration of the insoluble material, the product was extracted with ether and recovered as a white powder after evaporation of the solvent. Enantiomeric excess was determined by HPLC analysis of purified product using a Daicel column chiralcel OD (90/10/0.1 hexane/2-propanol/TFA; 0.75 mL min^{-1} flow). Retention time ((*R*)-methylsuccinic acid) = 6.0 min. Retention time ((*S*)-methylsuccinic acid) = 8.3 min. The absolute configuration was attributed by determination of the sign of the optical rotation of the pure product and according to ref. [21].

Ruthenium-Catalyzed Hydrogenation of Acetophenone (8): The substrate (2.5 mmol) in 7 mL of methanol containing the ruthenium complex (0.013 mmol) (prepared by mixing 1 equiv of $[Ru(Me\text{-}allyl)_2(cod)]$, 1 equiv of (+)- or (−)-BIPNOR and 2 equiv of HBr (0.29 M in MeOH) in acetone[24]) was introduced by means of a syringe into a 100 mL autoclave previously purged with argon. The solution was stirred under 60 atm of H_2 at 50 °C for 48 h. The conversion was calculated from the crude solution by ^1H NMR after evaporation of solvent. Enantiomeric excess was determined by HPLC analysis of the crude product using a Daicel column chiralcel OD (95/5 hexane/ethanol; 0.5 mL min^{-1} flow). Retention time ((*R*)-*sec*-phenethyl alcohol) = 6.0 min. Retention time ((*S*)-*sec*-phenethyl alcohol) = 8.3 min. The absolute configuration was assigned by determination of the sign of the optical rotation of the pure product and according to ref. [25].

Palladium-Catalyzed Allylic Substitution Reaction of 1,3-Diphenylprop-2-enyl acetate with $NaCH(CO_2Me)_2$ in THF: A mineral oil dispersion of NaH (60% NaH, 1.25 mmol) was washed free of oil with dry pentane (2 × 5 mL). The oil-free NaH was suspended in THF (4 mL) and cooled to 0 °C, and dimethyl malonate (1.2 equiv) was added dropwise to the stirred suspension. After the reaction was complete, the resulting solution was cannulated into a 50 mL flask containing 1,3-diphenyl-2-propenyl acetate (1.2 mmol), and the catalytic precursor $[PdCl_2\{(+)$ or $(-)$-BIPNOR$\}]$ (prepared by mixing 1 equiv of $[PdCl_2(PhCN)_2]$ and 1 equiv of (+)- or (−)-BIPNOR in CH_2Cl_2). The solution was stirred at room temperature for 24 h. The reaction mixture was then worked up to give the product as a yellow oil (dilution in AcOH, extraction with Et_2O, and washing with brine). The conversion was calculated from the crude product by ^1H NMR. Alumina gel chromatography using hexane/ethyl acetate (80/20) afforded the pure allylation product. Enantiomeric excess was determined by HPLC analysis of the purified material using a Daicel column chiralcel OD (200/1 hexane/2-propanol; 1 mL min^{-1} flow). Retention time ((*R*)-1,3-diphenyl-2-propenyl dimethylmalonate) = 25.1 min. Retention time ((*S*)-1,3-diphenyl-2-propenyl dimethylmalonate) = 27.7 min. The absolute configuration was assigned by determination of the sign of the optical rotation of the pure product and according to ref. [26].

Ruthenium-Catalyzed Hydrogenation of 1′-Acetonaphthone (9): The substrate (6.5 mmol) in 7 mL of 2-propanol containing the ruthenium complex (0.013 mmol) (prepared by mixing 1 equiv of $[Ru(Me\text{-}allyl)_2(cod)]$, 1 equiv of (+)- or (−)-BIPNOR and 2 equiv of HBr (0.29 M in MeOH) in acetone[124]), KOH (2 equiv/Ru), and (1*S*,2*S*)-(−)-1,2-diamino-1,2-diphenylethane (1 equiv/Ru) was introduced by means of a syringe into a 100 mL autoclave previously purged with argon. The solution was stirred for 10 h under 5 atm of H_2 at room temperature. The conversion was calculated from the purified product (obtained by Kugelrohr distillation) by ^1H NMR.

CH_2Cl_2 (4 mL) was added to a mixture of 1-(1-naphthyl)ethanol (50 mg), (*R*)-(+)-α-methoxy-α-trifluoromethylphenylacetic acid (70 mg, MTPA), *N*,*N*′-dicyclohexylcarbodiimide in CH_2Cl_2 (0.3 mL, 1.0 M), and a small amount of 4-dimethylaminopyridine. After stirring the mixture overnight at room temperature, the solvent was removed by vaccum distillation. Ether (4 mL) was then added to the solid residue formed, and the dissolved portion was recovered to provide the MTPA ester of 1-(1-naphthyl)ethanol. Enantiomeric excess of the hydrogenated product was then determined by ^1H NMR analysis of its MTPA ester. The absolute configuration was assigned by determination of the sign of the optical rotation of the pure product and according to ref. [20].

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