Asymmetric Hydrogenation of isobutrophenone using a [(diphosphine)-$RuCl_2$-(1,4-diamine) catalyst

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General procedure for preparation of [(*S*)-Binap $RuCl_2$ (*R*)-**1**]: A solution of (*S*)-Binap (0.1 mmol) and $RuCl_2$(benzene) dimer (0.05 mmol) in DMF (1 ml) was heated at 100 ^oC for 15 mins. The DMF was removed and a solution of diamine **1** (0.1 mmol) in DCM was added and the mixture stirred at rt for 1hr. The solvent was removed in vacuo to give the catalyst as a golden brown solid which was used without further purification for the hydrogenation reactions. ^{31}P NMR (102 MHz, $CDCl_3$) δ 44.57 (s). Crystal data: $C_{51}H_{48}Cl_2N_2O_2P_2Ru,C_4H_{10}O$, M = 1028.94, orthorhombic, a = 12.12220(10), b = 12.9432(2), c = 31.4025(4) Å, U = 4927.05(11) $Å^3$, T = 180 K, space group $P2_12_12_1$, Z = 4, μ(Mo-K_α) = 0.538 mm^{-1}, 8252 reflections measured, 7981 unique (R_{int} = 0.0325) which were used in all calculations. The final $wR(F^2)$ was 0.0818 (all data).

The method was repeated using and TolBinap and XylBinap ligands. The analyses of the resulting products were as follows;

(*R*)-TolBinap $RuCl_2$(*R*)-**1**. ^{31}P NMR (102 MHz, $CDCl_3$) δ45.5 (s).
(*S*)-TolBinap $RuCl_2$ (*R*)-**1**. ^{31}P NMR (102 MHz, $CDCl_3$) δ44.8 (s).

(*R*)-XylBinap $RuCl_2$ (*R*)-**1**. ^{31}P NMR (102 MHz, $CDCl_3$) δ45.0 (s).
(*S*)-XylBinap $RuCl_2$ (*R*)-**1**. ^{31}P NMR (102 MHz, $CDCl_3$) δ45.2 (s).

General Procedure for Preparation of (*R*/*S*)-Xyl-P-Phos $RuCl_2$ (*R*/*S*)-**1** Catalysts.

Representative Example: A solution of (S)-Xyl-P-Phos (100 mg, 0.132 mmol) and [$RuCl_2$(benzene)] dimer (31.5 mg, 0.063 mmol) in Dimethylformamide (1 ml) was heated at 100 ^oC for 2.5 hrs under N_2. The dark red reaction mixture was cooled to room temperature. To this crude complex was added a solution of the (*R*)-**1** (0.138 mmol) in dichloromethane (1 ml) under nitrogen. The brown solution was stirred at room temperature overnight after which the solvent was removed in vacuo to yield the crude complex as a brown solid.

(*R*)-Xyl-P-Phos $RuCl_2$ (*R*)-**1**. ^{31}P NMR (102 MHz, $CDCl_3$) δ 43.7 (s).

(*S*)-Xyl-P-Phos $RuCl_2$ (*R*)-**1**. ^{31}P NMR (102 MHz, $CDCl_3$) δ 43.4 (s).

The method was repeated using (*R*)- and (*S*)-P-Phos. The analyses of the resulting products were as follows:

(*R*)-P-Phos $RuCl_2$ (*R*)-**1**. ^{31}P NMR (102 MHz, $CDCl_3$) δ 45.4 (s).

(*S*)-P-Phos $RuCl_2$ (*R*)-**1**. ^{31}P NMR (102 MHz, $CDCl_3$) δ 44.8 (s).

(*S*)-P-Phos $RuCl_2$ (*rac*)-**1**. ^{31}P NMR (102 MHz, $CDCl_3$) δ 44.8 and 45.5 (d).

Representative example of Hydrogenation using catalysts derived from Diamine 1

Hydrogenation of isobutyrophenone at s/c 1000: To a 50 ml Parr autoclave was added (*S*)-P-Phos $RuCl_2$ (*rac*)-**1** (1.9 mg, 2 μmol). To this was added isobutyrophenone (2 mmol), tBuOK (1M in tBuOH, b/c 25) and 2-propanol (2 ml). The mixture was pressurised with H_2 (10 bar) and left until hydrogen consumption

had ceased (3 hrs). The pressure was released and a sample analysed by chiral GC (Chrompack Chirasil-DEX CB column).

Preparation of (*R*/*S*)-TolBINAP $RuCl_2$ (*S*)-2 Catalysts

A solution of (S)-TolBinap (100 mg, 0.147 mmol) and [$RuCl_2$(benzene)] dimer (37 mg, 0.0737 mmol) in DMF (1 ml) was heated at 110^{o}C for 15 mins under N_2. The dark red reaction mixture was cooled and the DMF removed in vacuo. To this crude complex was added a solution of the Diamine (*S*)-**2** (34 mg, 0.147 mmol) in dichloromethane (5 ml) under nitrogen. The yellowish solution was stirred at room temperature for 1 hr after which the solvent was removed in vacuo. The complex was extracted from the crude solid by addition of hexane:MTBE (1:1, 10 ml), filtration and removal of the solvent which resulted in the precipitation of a yellow solid. The solvent was completely removed and to give the complex as a yellow solid.

(*S*)-Tol-BINAP $RuCl_2$ (*R*)-**2**: ^{31}P NMR ($CDCl_3$, 102 MHz) δ 44.8

(*R*)-Tol-BINAP $RuCl_2$ (*R*)-**2**: ^{31}P NMR ($CDCl_3$, 102 MHz) δ 45.4

Preparation of Catalysts using Diamine 3

Preparation of (*R*/*S*)-Xyl-P-Phos $RuCl_2$ (*S*)-**3**

A solution of (R)- or (S)-Xyl-P-Phos (51 mg, 0.066 mmol) and [$RuCl_2$(benzene)] dimer (16.8 mg, 0.0315 mmol) in Dimethylformamide (1 ml) was heated at 100°C for 2.5 hrs under nitrogen. The dark red reaction mixture was cooled to room temperature. To this crude complex was added a solution of the (*S*)-**3** (0.067 mmol) in dichloromethane (1 ml) under nitrogen. The brown solution was stirred at room

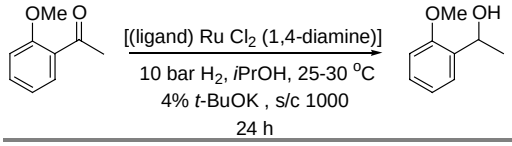
temperature overnight after which the solvent was removed in vacuo to yield the crude complex as a brown solid.

(*R*)-Xyl-P-Phos $RuCl_2$ (*S*)-**3**: ^{31}P NMR ($CDCl_3$, 102 MHz) δ 45.2 (d, J 37) and δ 41.3 (d, J 30)

(*S*)-Xyl-P-Phos $RuCl_2$ (*S*)-**3**: ^{31}P NMR ($CDCl_3$, 102 MHz) δ 44.6 (d, J 37) and δ 41.7 (d, J 37)

Further Examples of the Hydrogenation of Aromatic Ketones

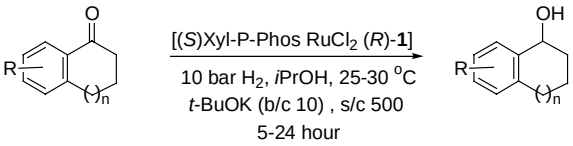
Table 1. Hydrogenation of *o*-OMe-acetophenone using [(diphosphine) $RuCl_2$ (1,4 diamine)] catalysts



Entry	Catalyst	Conv	ee
1	(*R*)-P-Phos $RuCl_2$ (*R*)-**1**	> 99	85 (*R*)
2	(*S*)-P-Phos $RuCl_2$ (*R*)-**1**	> 99	93 (*S*)
3	(*R*)-Xyl-P-Phos $RuCl_2$ (*R*)-**1**	18	23 (*S*)
4	(*S*)-Xyl-P-Phos $RuCl_2$ (*R*)-**1**	76	32 (*R*)
5	(*R*)-TolBinap $RuCl_2$ (*R*)-**1**	> 99	80 (*R*)
6	(*S*)-TolBinap $RuCl_2$ (*R*)-**1**	> 99	92 (*S*)
7	(*R*)-XylBinap $RuCl_2$ (*R*)-**1**	21	14 (*S*)
8	(*S*)-XylBinap $RuCl_2$ (*R*)-**1**	35	33 (*R*)

[a] The conversion and ee determined by chiral GC (Chrompack Chirasil DEX-CB column).

Table 2. Hydrogenation of cyclic ketones using [(*S*)Xyl-P-Phos $RuCl_2$ (*R*)-1] catalysts



Entry	n	R	Conv. (%)	ee (%)
1	0	H	> 99	82
2	1	H	> 99	96
3	1	*m*-OMe	> 90	91
4	1	*p*-OMe	> 99	98
5	2	H	> 99	69

[a] The conversion and ee determined by chiral GC (Chrompack Chirasil DEX-CB column).