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Novel sterically congested chiral tripodal phosphite ligands: catalytic asymmetric hydrosilylation of ketones with a Rh(I)–TRISPHOS catalyst

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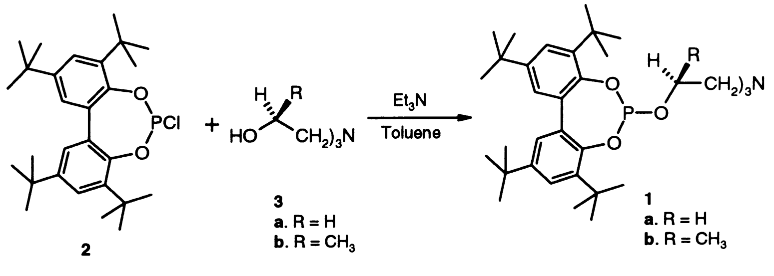
Abstract

A new chiral trisphosphite ligand, (*S,S,S*)-2,2′,2′′-tris(2,4,8,10-tetra-*tert*-butyl-dibenzo[*d,f*][1,3,2]dioxaphosphepin-6-yl-6-oxy)tri-2-propylamine, (*S,S,S*)-TRISPHOS, was synthesized and coordination chemistry investigated. The Rh(I)–(*S,S,S*)-TRISPHOS complexes were found to be effective catalysts for the enantioselective hydrosilylation of ketones. © 1998 Elsevier Science Ltd. All rights reserved.

Rationally designed sterically hindered phosphite ligands are a recent tool in the synthetic chemists arsenal for achieving novel stereoselectivity in transition metal catalyzed reactions.[1–8] Relatively little attention, however, has been paid to the synthesis of tripodal ligands with phosphite functionality.[9,10]

The phosphite ligand **1a** was prepared by the reaction of the seven-membered phosphorochloridite **2**[11] with triethanolamine (**3a**) using triethylamine as an acid acceptor. Although three stereoaxes are present in a molecule of **1a**, rotation about the stereoaxis in the seven-membered ring is known to be rapid at room temperature.[1a,11a,12,13] In the $^{31}P\{^1H\}$ NMR (CD_2Cl_2) spectrum of **1a** at 26°C, a singlet was observed at δ 140.6, which was assigned to three equivalent phosphorus atoms. In the VT $^{31}P\{^1H\}$ NMR spectrum of **1a** below −55°C, the coalescence temperature, signals were observed that were assigned to the (*M*,M*,M**)- and (*M*,M*,P**)-diastereoisomers of **1a**.



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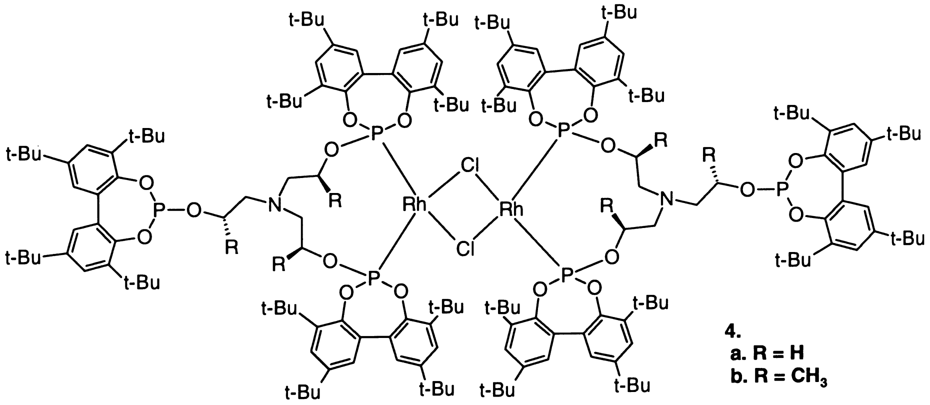
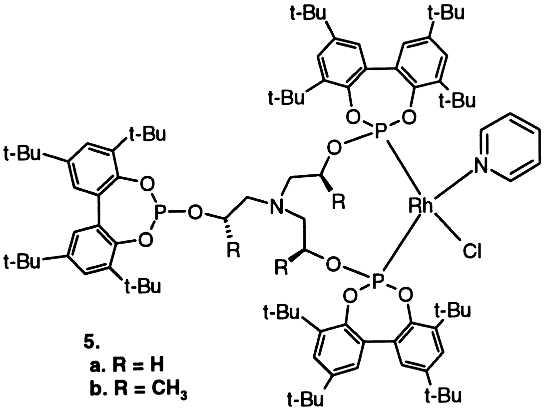
In an analogous manner, the chiral ligand **1b**, (*S*,*S*,*S*)-TRISPHOS,[14] was prepared by the reaction of **2** with (*S*,*S*,*S*)-triisopropanolamine (**3b**).[15] In the $^{31}P\{^1H\}$ NMR ($CDCl_3$) spectrum of (*S*,*S*,*S*)-TRISPHOS, a singlet was observed at δ 145.2 that is consistent with the C_3 symmetry of the molecule.

Quite interestingly, the Rh(I) complex formed by the reaction of either **1a** or **1b** with chloro(1,5-cyclooctadiene)Rh(I) dimer showed evidence for the formation of the dimeric Rh(I) complexes **4ab** illustrated with coordination of only two of the phosphorus atoms of the ligand to rhodium.[16] For example, in the $^{31}P\{^1H\}$ NMR ($CDCl_3$) spectrum of complex **4b** formed by the reaction of (*S*,*S*,*S*)-TRISPHOS with chloro(1,5-cyclooctadiene)Rh(I) dimer, a singlet and a doublet were observed at δ 146.6 and δ 125.5 ($^1J_{PRh}$=323 Hz), respectively, whose peak areas integrated to a 1:2 ratio, respectively.



4.
a. R = H
b. R = CH_3

Consistent with this interpretation, the addition of pyridine to **4b** resulted in the formation of the monomeric Rh(I) complex **5b** with three nonequivalent phosphorus atoms in the $^{31}P\{^1H\}$ NMR spectrum.[16] Similarly, the coordination of only two phosphorus atoms of (*S*,*S*,*S*)-TRISPHOS to Rh(I) were observed both in the neutral complex formed with (bicyclo[2.2.1]hepta-2,5-diene)(2,4-pentanedionato)Rh(I) and the cationic complex formed with bis(bicyclo[2.2.1]hepta-2,5-diene)Rh(I) perchlorate.[16]



5.
a. R = H
b. R = CH_3

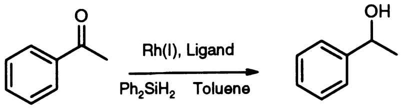
Although Rh-catalyzed hydrosilylations of acetophenone with chiral amine and phosphine[17,18] ligands have been reported to give the corresponding alcohol with high enantioselectivity, the use of chiral phosphites in this reaction gave the corresponding alcohol in only 60% ee.[3b,19] The Rh(I)-catalyzed hydrosilylation of acetophenone with the achiral ligand **4a** prepared in situ followed by hydrolysis gave *sec*-phenethyl alcohol in 60% isolated yield. The asymmetric hydrosilylation of acetophenone using (*S*,*S*,*S*)-TRISPHOS was investigated using dimeric, monomeric, and cationic catalyst precursors (Table 1). All three catalyst precursors gave the same sense of chiral induction. The highest rate

Table 1
Rh(I)-catalyzed hydrosilylation of acetophenone with TRISPHOS ligand

Run#	Catalyst Precursor	Ligand	Rh:Ligand	Mole % Rh	% Yield Isolated	% ee (GLC) (*R*)-alcohol
1	$[(1,5\text{-COD})Rh(I)Cl]_2$	**1a**	1:2	0.2	60	0
2	$[(1,5\text{-COD})Rh(I)Cl]_2$	**1b**	1:2	2.0	38	81[a]
3	$[(1,5\text{-COD})Rh(I)Cl]_2$	**1b**	1:3	2.0	53	75
4	$[(1,5\text{-COD})Rh(I)Cl]_2$	**1b**	1:2	5.0	-	75
5	[(NBD)Rh(I)AcAc]	**1b**	1:1	2.0	67	58
6	$[(NBD)Rh(I)ClO_4]$	**1b**	1:1	2.0	65	81[b]

a. % Ee by ^{1}H NMR using a chiral solvating agent. b. The solvent was benzene.

and conversion were obtained using a cationic Rh(I) catalyst and an unprecedented 81% ee of (*R*)-*sec*-phenethyl alcohol was obtained for a catalyst prepared from a chiral phosphite ligand. As noted previously by van Leeuwen[20] for hydroformylation reactions using chiral seven-membered phosphite ligands, the high reaction stereoselectivity observed suggests that that there is a cooperative effect between the stereocenters and stereoaxes in the coordinated ligand, a manifestation of the concept of chiral cooperativity.[21]



In a typical procedure for the determination of reaction enantioselectivity a catalyst solution prepared in situ from 300 mg (0.20 mmol) of (*S*,*S*,*S*)-TRISPHOS and 49 mg (0.20 mmol) of bis(bicyclo[2.2.1]hepta-2,5-diene)Rh(I) perchlorate in 10 mL of benzene was added to a solution of 1.2 mL (10 mmol) of acetophenone and 1.9 mL (10 mmol) of diphenylsilane in 11 mL of benzene. After stirring for 16 h at room temperature (complete disappearance of acetophenone), a mixture of 5 mL of 2.5 N aqueous sodium hydroxide and 7 mL of methanol was added to the reaction mixture. After stirring for 10 min, the reaction mixture was extracted with diethyl ether (3×3 mL) and the combined organic extracts were dried over anhydrous sodium sulfate. The volatiles were removed in vacuo and the ee of the resultant *sec*-phenethyl alcohol was determined both by ^{1}H NMR spectroscopy using the chiral solvating agent (*R*)-(−)-2,2,2-trifluoro-1-(9-anthryl)ethanol and GLC using a Chiraldex™ β-PM chiral column (30 m×0.25 mm). The crude alcohol was purified by dissolution in 3 mL of hexane and filtration of any precipitate formed followed by flash chromatography (silica gel; hexane eluent) to give 1.0 g (65%) of (*R*)-*sec*-phenethyl alcohol.

The scope of hydrosilylation reactions using the (*S*,*S*,*S*)-TRISPHOS ligand and the extension to other transition metal catalyzed reactions is currently being pursued.

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