The design of new chiral ligands is the key in the development of transition metal catalyzed asymmetric synthesis. Many chiral diphosphine ligands have been prepared and applied in asymmetric catalytic reactions with excellent enantioselectivities. Among the chiral diphosphine ligands that have been reported, the atropisomeric C2-symmetric phosphines with a biaryl scaffold initiated by Noyori and co-workers with BINAP were found to have the widest application in the transition metal catalyzed reactions. Planar chiral diphosphines based on ferrocene or paracyclophane backbones have also been applied to a number of reactions with a remarkable degree of success. However, the spiro diphosphine compounds, another type of axially chiral ligands, have not been synthesized until now. Recently, we designed chiral phosphoramidite ligands (SIPHOS) containing a 1,1'-spirobiindane backbone and demonstrated that these ligands can be highly efficient for the Rh-catalyzed asymmetric hydrogenation of functionalized olefins. Especially, in the case of asymmetric hydrogenation of α-arylethenylamines, the spiro monophosphoramidite ligands provided a significantly higher level of enantiocontrol compared to that of the monophosphoramidite ligands derived from BINOL. We now describe the application in the transition metal catalyzed reactions. Planar chiral diphosphine ligands have been prepared and applied in asymmetric catalytic reactions with excellent enantioselectivities. Among the diphosphine ligands, PhanePhos and P-Phos, have been reported to approach high activity and excellent enantioselectivity of their ruthenium complexes as catalysts for the asymmetric hydrogenation of ketones. The catalysts 7 (Figure 1) were prepared by reacting ligands 6 with [C2H4RuCl2]2 in DMF at 100 °C, followed by the treatment of the resulting reddish brown solution with 1 equiv of DPEN at room temperature. The complexes, thus obtained, were used directly in the catalytic reactions. Initial tests with catalyst [(S)-SDP]Ru-((R,R)-DPEN)Cl2 ([S,R]-7a) in the asymmetric hydrogenation of acetoephone in 2-propanol in the presence of t-BuOK (S/C = 70) at room temperature provided (S)-1-phenylethanol in quantitative yield and 90% ee over 1.5 h at S/C = 5000 (Table 1, entry 1). This result is slightly better than that obtained with [(R)-BINAP]Ru-((R,R)-DPEN)Cl2 (87% ee). A systematical investigation on the effect of substituents in the ligands 6 indicated that the introduction of 3.5-dimethyl groups to P-pheny rings, ([S,R]-7d, dramatically increased the enantioselectivity to 99% ee (entry 4). The enantioselectivity remained to be 98% ee even when the ratio of substrate to catalyst (S/C) was increased to 100 000 (entry 5).

A variety of aromatic, heteroaromatic, and α,β-unsaturated ketones can be hydrogenated by catalyst ([S,R]-7d with excellent enantioselectivities. The results summarized in Table 1 are better than or comparable to those achieved with Xyl-BINAP-Ru-DAIPEN, Xyl-PhanePhos-Ru-DPEN, and Xyl-P-Phos-Ru-DPEN systems. It deserves commendation that the hydrogenation of acetylfenrocene with ([S,R]-7d produced (S)-1-ferrocenylethanol in 98% ee at S/C = 5000. The enantioselectically enriched 1-ferrocenylethanol is a crucial starting material in the synthesis of many chiral ferrocene compounds such as ferrocenylethylamines and ferrocenolphosphines. Our study provides a practical method to the synthesis of ferrocenylethanol and related compounds.

In conclusion, we have developed novel chiral diphosphine ligands with spiro biindane as a new chiral scaffold, which are highly effective for the asymmetric hydrogenation of ketones. The extremely high activity and enantioselectivity of their ruthenium hydrogenation of aromatic, heteroaromatic, and α,β-unsaturated ketones.
Catalytic Asymmetric Synthesis

Preparations and properties of compounds 2–6 and 7, procedures for asymmetric hydrogenation of ketones, GC behavior of chiral alcohols (PDF). This material is available free of charge via the Internet at http://pubs.acs.org.

**References**


(10) For experimental details, see the Supporting Information.


(14) Xylyl-BINAP = 2,2′-bis(diphenylphosphino)-1,1′-binaphthyl. Tol-BINAP = 2,2′-bis(diphenylphosphino)-1,1′-biphenyl. DIAPEN = 1,1-diisopropyl-2,2′-ethylidenediamine. DPEN = 1,2-diphenylethylenediamine.


(17) The R,R′-Bis(diphenylphosphino)tetraphenylporphyrin (BICP) was also tested in this reaction, providing the enantioselectivities which are lower than those obtained with Noyori’s BINAP—Ru—diamine system. (18) With the catalyst [(SS)-7d], which shows a mismatch in chirality between SDP and DPEP, (SS)-1-phenylethanol was produced in 28% ee. (19) [(S,Tol-BINAP)(R,S)-DAIPENCl] (87% ee) and [(S)-(R)XYl-Phenolphos(R),(R)-DPENCl] (92% ee) were also used in the hydrogenation of acetophenone, see refs. 13f and 15.