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Catalytic Asymmetric Hydroboration with Heterotopic P-N Ligands: Trends in Enantioselectivity with Increased Steric Demand.

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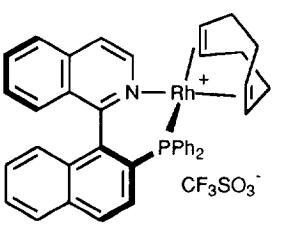
Abstract: The rhodium complexes 1 and 3 catalyse asymmetric hydroboration with differing selectivity originating in the disparate steric environments of the catalysts.

Much recent effort in catalytic asymmetric synthesis has been directed to reactions of simple prochiral alkenes. Among the conspicuous successes obtained, oxygen addition via epoxidation[1] or dihydroxylation[2] are prominent, and the formal hydration of alkenes has been achieved by hydroboration[3] or hydrosilylation.[4] A previous contribution described the catalytic asymmetric hydroboration of alkenes with e.e.s of up to 94% at ambient temperature[5] using the Rh complex **1** derived from 1-(2-diphenylphosphino-1-naphthyl)isoquinoline (QUINAP). In parallel work Pd complexes of the same ligand were shown to be highly effective in asymmetric allylic alkylation,[6] and an analysis of the intermediates involved indicates that the 3-H region of the isoquinoline plays an important role in the ligand-reactant complex interactions leading to enantioselection. The origin of enantioselectivity in catalytic asymmetric hydroboration is as yet unknown, but may be governed by similar factors. With the availability of the phenanthridine analogue of QUINAP **2** of 98% enantiomeric purity[7] this postulate could be tested.



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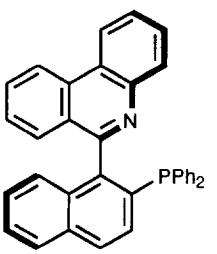
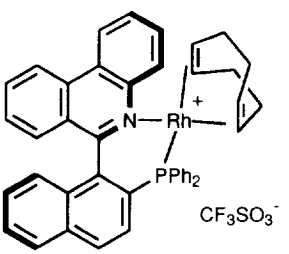


(*R*)-**2**



3

Dedicated to the memory of Professor Hidemasa Takaya, deceased on 5 October 1995

The Rh complex **3** from R-ligand was prepared by the standard method,[8] [δ_P 27.3 ppm, J_{RhP} 127 Hz] and proved to be much more stable than the parent complex **1** being storable at -20°C under Ar for long periods. Its initial application to the catalytic asymmetric hydroboration of phenylethene **4** followed previous practice [catecholborane, 1 mol% catalyst, 0.5 cm^3 thf, 20°C, 1 h., 0.375 mmolar scale, then H_2O_2/NaOH workup under Ar.]. Analysis by GC [CYDEX, 100°C] gave the R-secondary alcohol **5** in 66% e.e., but accompanied by 10% of hydrocarbon and 4% of the primary alcohol. Unlike the previous observations,[5] the enantioselectivity was insensitive to temperature change over the region between 0°C and 40°C. The pattern of lower enantioselectivity in hydroborations catalysed by complex **3** was followed for indene **6** and 1-phenylpropene **8** (Table). For completeness, results obtained with Rh-BINAP are incorporated in the Table,[9] as are some more recent results with the original P-N ligand **1**. It is notable that E-**8** and Z-**8** gave essentially similar results, and also that the hydroboration of Z-stilbene occurred with concomitant isomerisation to the less reactive E-isomer; this implies that the Rh-H addition step in the catalytic cycle is reversible, or that a species capable of reversible Rh-H addition coexists with the catalyst.

For complex **3** the most interesting hydroborations are two in which the QUINAP complex **1** gave poor results, presumably because the steric demand of substituents in the region of the alkene double bond frustrated productive complexation. With 1,2-dihydronaphthalene **10**, the e.e. was 84% rather than 37%, and with chromene **12** the e.e was 74% rather than 52%, with far more satisfactory regioselectivity.

These results demonstrate that steric effects in the reactant and ligand play an important part in determining the stereoselectivity of catalytic asymmetric hydroboration. Since Rh BINAP complexes are only effective for monosubstituted vinylarenes (and only at low temperatures) the reduced steric demand in the space around the isoquinoline nitrogen of complex **1**, when compared to the aryl residues of the biphosphine, must play a part. This is underscored by the satisfactory result obtained with 2-vinylnaphthalene **14**.[10] The difference between indene and 1,2-dihydronaphthalene is marked, and the fact that two P-N catalysts show opposing trends indicates that rather subtle effects are involved.

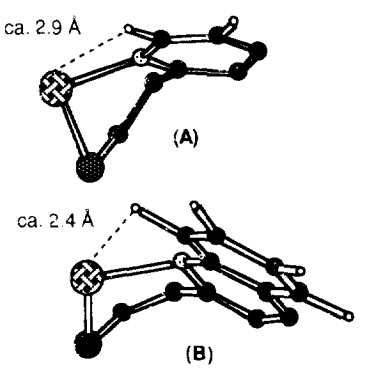


Figure 1. Comparative interaction of the 3-H of isoquinoline (**A**) and the 4-H of phenanthridine (**B**) with a coordinated metal in the respective ligand complexes.

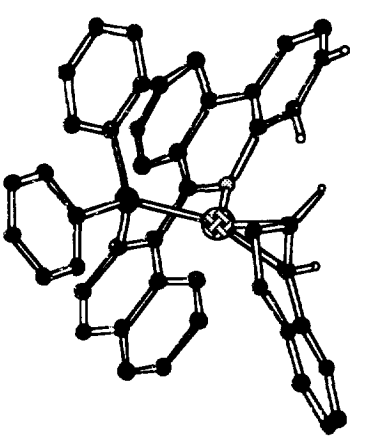
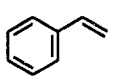
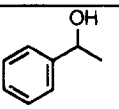
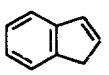
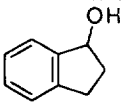
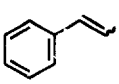
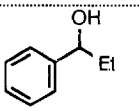
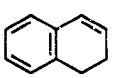
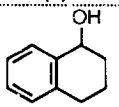
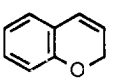
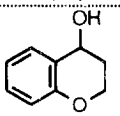
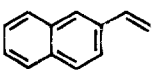
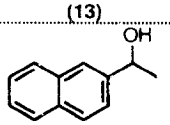


Figure 2. A model for alkene coordination in asymmetric hydroboration based on the ligand X-ray data, with C=C trans to P. This correctly predicts the stereochemical course of dihydronaphthalene addition on steric grounds.

Ligands **1**, **3** and BINAP all catalyse the reaction with the same sense of relative asymmetric induction. The striking differences between the two P-N Rh complexes indicates that the phenanthridine moiety participates to control the diastereoselectivity of alkene coordination, or more strictly in the stereochemically defining transition-state for hydride transfer from rhodium to carbon. This is most readily rationalised when the alkene is bound *trans* to phosphorus so that it lies in the vicinity of the 4-H of phenanthridine, the likely steric environment being shown in Figure 1 which is based on X-ray crystal structures of Pd complexes of the ligands. At this stage (and in the absence of detailed mechanistic and spectroscopic studies) a speculative model is shown in Figure 2.

Table. Hydroboration of arylalkenes with catecholborane catalysed by complexes **1** or **3**[a], in comparison to Rh BINAP.

Reactant	Product	Catalyst	E.e.% (yield[b])
 (4)	 (5)	**S-1** **R-3** **Rh-BINAP**	**91 S**[c] (71) **67 R**[c] (70) **96**
 (6)	 (7)	**S-1** **R-3** **Rh-BINAP**	**91S**[d] (58)[5] **64 R**[e] (59) **13**
 (8)	 (9)	**S-1** **R-3** **S-1** **Rh-BINAP**	**E-8 - 95 S**[c] (64) **E-8 - 91 R**[c] (60) **Z-8 - 93 S**[c](60) **E-8 - 42**
 (10)	 (11)	**S-1** **R-3**	**37 S**[d] (68)[5] **84 R**[c] (69)
 (12)	 (13)	**S-1** **R-3**	**52 S**[e] (21) +3-OH **74 R**[e] (57)
 (14)	 (15)	**S-1** **Rh-BINAP**	**89 S**[c] (64) **13**

[a] Reactions were carried out on 0.375 mmolar scale with 1 mol% catalyst in THF at ambient temperature for 2h, followed by oxidation with H_2O_2, OH^-, save that the styrene reaction was with 0.2 mol% catalyst on a 1 g. scale (8h.); the e.e. with E-**8** supersedes that reported earlier.[5] [b] Isolated yield of pure product after preparative tlc or silica gel flash chromatography. [c] E.e. determined by chiral GC on a 20m CYDEX column. [d] E.e. determined by ^{1}H NMR using the oxazaborolidine method.[11] [e] E.e. determined by ^{1}H NMR using the chiral shift reagent Eu(hfc)$_3$.

Acknowledgments

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