ChemPubSoc Europe

DOI: 10.1002/cctc.201402687

P-Aryl-Diphenylphospholanes and their Phospholanium Salts as Efficient Monodentate Ligands for Asymmetric Rhodium-Catalyzed Hydrogenation

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Enantiopure P-aryl-2,5-diphenylphospholanes and its corresponding P-aryl-phospholanium salt appear as very efficient ligands for rhodium-catalyzed asymmetric hydrogenation reaction with similar activities and enantioselectivities. The hydrogenation product was obtained in good enantiomeric excesses (up to 93% *ee*) in only few minutes under an atmospheric pressure of dihydrogen. The excellent activity of the catalyst can be explained by a constant and high TOF value during the reaction.

Introduction

The elaboration of new chiral phosphanes is of importance, as they play a major role as ligands in transition-metal-based asymmetric catalysis. Particularly, a large number a chiral diphosphines have been developed for enantioselective transformations.[1] However, a rich chemistry of monophosphanes as ligands or organocatalysts has been developed recently. This has extended the organic chemist's toolbox and contributed to the development of new reactions.[1,2] The design of novel, useful, and efficient chiral phosphorus ligands still remains a challenge. Therefore, it appears of interest to synthesize new chiral dialkylaryl- and trialkylphosphanes in order to modulate their electronic properties. Indeed, the dialkyl or trialkyl substitution of the phosphorus atom provides an electron-rich environment which could influence the reactivity and selectivity of transition metal center in particular.[3] These electron-rich, basic ligands differ from the usual chiral phosphines which usually possess two or three aryl substituents on phosphorus. The inherent nature of monophosphane and the functionalization of the phosphorus atom is likely to lead to interesting results in terms of enantioselectivity, as well as activity in a catalytic process. More precisely, the turnover frequency (TOF) in enantioselective processes is an important parameter for the chemical and pharmaceutical industry.[4]

It is well established that chiral diphosphanes offer excellent enantioselectivities and TOF values for the Rh-catalyzed asymmetric hydrogenation of functionalized alkenes. This is why chiral diphosphanes have concentrated the attention of the scientific community during several decades,[1,4,5] in contrast to chiral monophosphanes, which were thought to be "unsuitable" for applications in highly enantioselective hydrogenation reactions. This relative lack of interest in these compounds was reported at the beginning of the 20th century.[6,7] This was followed by the emergence of the synthesis and the use of new monodentate phosphorus ligands. Phosphinites, phosphites, and phosphoramidites became the best sellers of monophosphorous ligands for asymmetric hydrogenation reactions.[8] In comparison, the studies dealing with the rhodium catalyzed hydrogenation of functionalized enamides in the presence of chiral monophosphanes are scarce during the last decade.[8,9] As a consequence, the turnover frequency value of monophosphane activity is poorly available in the literature. This prompted us to develop chiral monophosphines as ligands for efficient applications in rhodium-catalyzed asymmetric hydrogenation reaction of enamides. The development of efficient chiral monophosphane for such process requires: 1) To have a chiral environment close to the phosphorus atom to ensure good enantioselectivity; 2) To have a sufficiently electron rich phosphorus atom which should improve the catalytic activity.

The efficiency of electron-rich phosphane in asymmetric hydrogenation of alkenes was recently reported by Chen and coworkers.[10] With this in mind, we propose to develop monophosphane ligands and more precisely, 2,5-diphenylphospholane ligands that offer an interesting structure and provides the desired features: 1) A monodentate phosphorus nature which presents a trialkyl or dialkylaryl substitution on phosphorus. The relative electronic richness of the phosphorus atom is likely to offer efficient catalytic activity; 2) A non stereogenic phosphorus atom, which should avoid all problem of stereochemical integrity; 3) The chiral environment is close to the phosphorus and provided by the 2,5-substitution of the five-membered cyclic chain.

In previous works, we reported the preparation of chiral enantiopure 1-*r*,2-*c*,5-*t*-triphenylphospholane **3a**[9b] and its corresponding salt **4a**[11] (Scheme 1). The monodentate phosphane **3a** can be classified as dialkylarylphosphane (P-arylphospholane) and shows high activity and selectivity (93% *ee*) in rhodium-catalyzed hydrogenation of (*Z*)-methyl dehydrocin-

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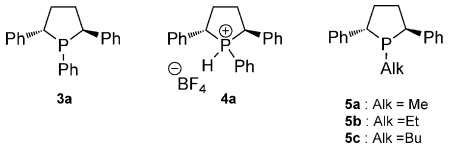
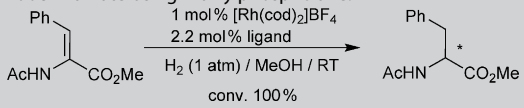
Supporting Information for this article is available on the WWW under http://dx.doi.org/10.1002/cctc.201402687.



Scheme 1. (*S*,*S*)-1-*r*,2-*c*,5-*t*-triphenylphospholane **3 a** and (*S*,*S*)-P-alkyl-*r*,2-*c*,5-*t*-diphenylphospholane **5 a**–**c**.

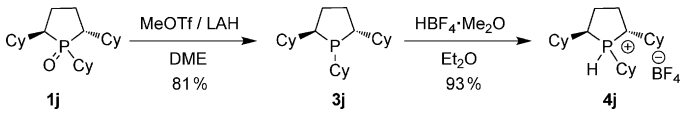
Table 1. Rh-Catalyzed enantioselective hydrogenation of methyl (*Z*)-2-acetamidocinnamate using P-alkylphospholane.[a]



Ligand	Reaction time [min]	*ee*[b] [%]	Conformer[b]
3 a	8	93	*R*
5 a	30	34	*S*
5 b	60	47	*R*
5 c	60	62	*R*

[a] All reactions were performed under one hydrogen atmosphere at room temperature. [b] Determined by chiral HPLC analysis on a Chiralcel OD-H column, with hexane/isopropanol 9:1 as eluent.

namate with a short reaction time (8 min) and under an atmospheric pressure of dihydrogen (Table 1). We noticed that the trialkyl-substitution on phosphorus atom diminished the efficiency of the catalyst as the use of P-alkylphosphane ligands **5 a**–**c** required longer reaction time to reach full conversion as ligands.[12] Furthermore, we observed modest asymmetric inductions, compared to P-arylphospholane **3 a**.[13] This observation was subsequently confirmed by the use of the more electron-rich ligand **3 j** and its precursor **4 j** prepared from oxide **1 j** (Scheme 2). **3 j** and **4 j** were both ineffective for the Rh-catalyzed hydrogenation of methyl-(*Z*)-2-acetamidocinnamate since no reaction took place after 10 h.



Scheme 2. Preparation of (*R*, *R*)-1-*r*,2-*c*,5-*t*-triphenylphospholane **3 j** and its phospholanium salt **4 j**.

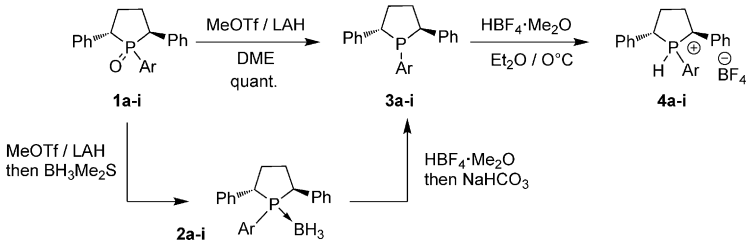
Despite the good activities of P-alkylphospholane as ligand in Rh-catalyzed hydrogenation of olefins, these ligands are not as effective as the P-arylphospholane **3 a**. So it appears that the best activity and enantioselectivity are closely linked to the adequate electronic richness of the phosphorus atom. We conclude that P-arylphospholanes should, therefore, offer better activities and enantioselectivities than their P-alkylphospholane homologues.

This observation is in agreement with the interesting results obtained by Beller et al.[8] Rhodium-catalyzed asymmetric hydrogenation of various acetamides was studied in the presence of P-substituted phosphepine under pressure of hydrogen. The authors stated that: "for obtaining good enantioselectivity, aryl-substituted phosphepine ligands are necessary, while alkyl-substituted ligands showed significantly lower selectivity". This encouraged us to develop more P-arylphospholane ligands in order to investigate the influence of the nature of the P-aryl substituent in catalysis. In the presence of rhodium metal, we propose that the phospholane structure and the well-balanced richness of phosphorus atom in these ligands should give an efficient catalytic system with a good activity (TOF) in asymmetric hydrogenation reaction.

Previously we described the preparation of enantiopure substituted P-aryl-2-*c*,5-*t*-diphenylphospholane oxides **1 a**–**i**.[14] In this paper, we describe the preparation of a range of P-aryl-2-c,5-t-diphenylphospholane **3 a**–**i** and their corresponding phospholanium salts **4 a**–**i** from the oxides **1 a**–**i**. Preliminary evaluation as ligands in Rh-catalyzed asymmetric hydrogenation has been investigated to estimate the enantioselectivity, as well as their efficiency.

Results and Discussion

P-aryl-2,5-diphenylphospholanes **3 a**–**i** were obtained via direct reduction of phosphine oxides **1 a**–**i** (Scheme 3).[6] Treatment of the oxide with methyl triflate followed by $LiAlH_4$ offers the



Scheme 3. preparation of free phospholane ligands **3 a**–**i** and phospholanium salts **4 a**–**i** from **1 a**–**i**.

enantiomerically pure phosphine **3 a**–**i** in quantitative yields. Nevertheless, these electron-rich phosphines are air-sensitive, particularly in solution. It is important to isolate these ligands as an air-stable form before purification of the crude product. In first instance, we have isolated the corresponding phosphine-borane complexes **2 a**–**i**. These intermediates offer stable materials for identification and analysis.[15] Deprotection of the borane-complexes offers the free phosphanes in satisfying yields (Table 2). To circumvent the problem of oxidation, we prepared the corresponding stable phospholanium salts **4 a**–**i** from the free phosphanes. Preparation of phosphonium salts **4 a**–**i** is performed by direct treatment of the corresponding free phosphine **3 a**–**i** with tetrafluoroboric acid dimethyl ether complex (HBF_4·Me_2O) in diethyl ether at 0 °C. After few minutes, the salt precipitates in solution and filtration gives the phosphonium as a white powder in good yield (Table 2).

Table 2. Preparation of phosphines **3a–i** and their corresponding salts **4a–i**.

Compound	R	Yield of **3**[a]	Yield of **4**[b]
a	Ph	70	90
b	*p*-tolyl	56	94
c	*o*-tolyl	86	98
d	3,5-$(Me)_2$-C_6H_4	70	96
e	3,5-$(tBu)_2$-C_6H_4	61	86
f	2-naphthyl	85	70
g	1-naphthyl	80	65
h	4-MeO-C_6H_4	73	80
i	2-MeO-C_6H_4	69	77

[a] Isolated yield calculated from phosphine-borane **2a–i**. [b] Isolated yield calculated from phosphoniums **3a–i**.

The resulting salts **4a–i** are air-stable and can be stored in air for months without oxidation. The salt easily liberates the free phospholane ligands **3a–i** in MeOH to form the active catalytic specie in the presence of $Rh(COD)BF_4$ complex and without the presence of a base.[9a] Furthermore, the use of phosphonium salt offers additional advantages concerning handling. Indeed, phosphane **3i** is a sticky semi-solid, difficult to manipulate, whereas the corresponding phosphonium salt **4i** is an easy-to-handle white solid.[16]

The asymmetric Rh-catalyzed hydrogenation of methyl-(*Z*)-2-acetamidocinnamate was investigated with complexes prepared by mixing the phospholaniums **4a–i** and the cationic $Rh(COD)_2$-BF_4 complex (Table 3). More particularly, we were interested in evaluating phosphoniums activities and enantioselectivities compared to the corresponding free phosphines **3a–i**. Methyl-(*Z*)-2-acetamidocinnamate appears as a substrate of choice for our study, owing to the wide use of this compound as a test compound.

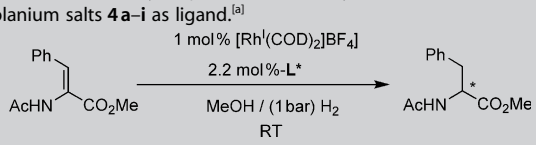
The conversion was calculated by direct measurement of consumption of dihydrogen by using graduated glassware. ^1H NMR analysis confirmed the complete conversion of substrate to the hydrogenated product only. Satisfactorily, the consumption of dihydrogen is fast. Thus, complete conversions were obtained in few minutes ($t_{1/2} \leq 8$ min) at room temperature under the atmospheric pressure of dihydrogen (1 atm.). The product is obtained with excellent enantiomeric excess in most cases (for a monophosphane ligand) and quantitative yield.[17] The reaction does not require heating or high dihydrogen pressure, thus proving the efficiency of the phospholane structure as ligand for the hydrogenation reaction rate.

We observed that *ortho*-substitution of the P-aryl group appears detrimental to the good reactivity (ligands **3–4c**, **3–4g** and **4i**; entries 5–6; 13–14; 17) and particularly for ligands **3–4c** and **3–4g** for which low reactivity and enantiomeric excesses were obtained despite the total conversion after several hours.[18]

Conversely, an excellent reaction rate when a more electron-rich phosphine is used such as ligands **3–4d** and **3–4h**. Indeed, in the presence of ligand **3h**, total conversion is obtained in only 6 min. and the TOF is 1000 h^{-1}. The $TOF_{1/2}$ is 1000 h^{-1} at half conversion suggesting a real efficiency of the catalytic system over the whole reaction period. The corresponding phosphonium salt **4h** offers slightly longer reaction time (6.5 min.) and the TOF is 920 h^{-1}. The $TOF_{1/2}$ is 860 h^{-1} at half conversion and confirms the general real efficiency of the catalytic system.

To the best of our knowledge, there is only one report dealing with the measurement of the turnover frequency in rhodium-catalyzed asymmetric hydrogenation of simple enamides in the presence of chiral monophosphane as ligand.[8] In that report, Beller et al. described the rhodium-catalyzed hydrogenation of *N*-acyl enamides at 50 °C under a pressure of 2.5 bars in dihydrogen gas. The activity of phosphepine ligand was

Table 3. Rh-catalyzed enantioselective hydrogenation of methyl (*Z*)-2-acetamidocinnamate using free phosphines **3a–i** or phospholanium salts **4a–i** as ligand.[a]



Entry	Ligand	Aryl	Time [min][b] $t_{1/2}$	Time [min][b] t_R	*ee*[c] [%]	Conformer	TOF [h^{-1}] $TOF_{1/2}$[d]	TOF [h^{-1}] TOF[e]
1	(*S*, *S*)-**3a**	Ph	8	20	93	*R*	375	300
2	(*S*, *S*)-**4a**		8	20	90	*R*	375	300
3	(*R*, *R*)-**3b**	*p*-tolyl	12	30	79	*S*	250	200
4	(*R*, *R*)-**4b**		6	14	86	*S*	500	430
5	(*R*, *R*)-**3c**	*o*-tolyl	n.d.[f]	2 h	16	*S*	n.d.[c]	50
6	(*R*, *R*)-**4c**		n.d.	4 h	18	*S*	n.d.	25
7	(*S*, *S*)-**3d**	3,5-$(Me)_2$-C_6H_4	3.5	7	90	*R*	860	860
8	(*S*, *S*)-**4d**		4.5	10	91	*R*	670	630
9	(*R*, *R*)-**3e**	3,5-$(tBu)_2$-C_6H_4	5	11	81	*S*	600	550
10	(*S*, *S*)-**4e**		7	15	82	*R*	430	400
11	(*S*, *S*)-**3f**	2-naphthyl	3.5	7	83	*R*	860	860
12	(*S*, *S*)-**4f**		7	16	88	*R*	430	380
13	(*S*, *S*)-**3g**	1-naphthyl	n.d.[f]	10 h	35	*R*	n.d.[c]	10
14	(*S*, *S*)-**4g**		n.d.[f]	10 h	36	*R*	n.d.[c]	10
15	(*S*, *S*)-**3h**	4-(MeO)-C_6H_4	3	6	86	*R*	1000	1000
16	(*S*, *S*)-**4h**		3.5	6.5	87	*R*	860	920
17	(*S*, *S*)-**4i**	2-(MeO)-C_6H_4	n.d.[f]	10 h	85	*S*	n.d.[c]	10

[a] All reactions were performed under one hydrogen atmosphere at room temperature in MeOH in the presence of 1 mol% of $[Rh(COD)_2]BF_4$. [b] $t_{1/2}$ reaction time determined at 50% conversion of substrate in a minute unless otherwise noted; $t_{(R)}$ reaction time for complete conversion. [c] Determined by chiral HPLC analysis on a Chiralcel OD-H column, with hexane/isopropanol as eluent. [d] $TOF_{1/2}$ is calculated for 50% conversion of starting material. [e] TOF is calculated for a complete conversion of starting material. [f] Not determined, due to the long reaction time.

studied with a substrate/catalyst ratio from 100:1 to 2000:1 which corresponds to a TOF up to 2000 h^{-1} under optimized conditions. The similarity of these results with our data confirms the excellent activities of P-arylphospholanes and phospholaniums, which do not require heating or pressure of dihydrogen gas, to attain complete substrate conversion with satisfying TOF values.[19]

We were able to gather some interesting information by comparing the activity data for phosphonium salts **4a–i** with that of free phosphanes **3a–i**. We observed only an usual but very slight slowdown of the catalyst activity when the reaction was performed in the presence of phosphonium as ligand precursor. This could be explained by a short latency time before the beginning of the consumption of dihydrogen. It probably corresponds to the time necessary to liberate the free phosphine and form the active complex. However, the $TOF_{1/2}$ values are very close to the values at complete conversion for each ligand. This provides further evidence of the high effectiveness and stability of the catalytic system during the entire reaction duration. Moreover, the enantiomeric excesses recorded using as ligands free phosphanes **3a–i** are very similar with those observed by utilizing the corresponding phosphonium salts **4a–i**.

Overall, these results confirm that the rhodium complex is formed by the coordination of the rhodium precursor with the phosphane obtained from of the dissociation of the salt in polar solvent in absence of any base.[9a]

Conclusion

P-aryl-2,5-diphenylphospholaniums salts **4a–i** are useful precursors ligands of enantiopure P-aryl-2,5-diphenylphospholanes. These air-stable salts were conveniently used in rhodium-catalyzed enantioselective hydrogenation: Methyl-(*Z*)-2-acetamidocinnamate is hydrogenated to provide methyl-*N*-acetyl-phenylalaninate in very short reaction time, and good enantiomeric excesses for a monophosphine ligand (up to 93% *ee*). We also demonstrated that by using the phosphonium salts as ligands, same yields and enantioselectivities as for the use of free phosphanes are obtained. The salt can be used in the absence of base. TOF calculations show that the P-aryl phospholane ligand offers an efficient and stable rhodium-catalytic system during all the advancement of reaction without significant loss of activity.

Experimental Section

Data for compounds **3a** and **4a** were already described in References [9b] and [9a] respectively. Data for compounds P-aryl-1-oxo-2,5-diphenylphospholane **1a–j** were already described in our previous paper.[14] The experimental procedure for the preparation of phosphane-borane complex **2a–j** is described in Ref. [14]. Data for compounds **3b–i** and **4b–i** were collected in the Supporting Information.

Preparation of enantiopure P-aryl-2,5-diphenylphospholane (3a–i)

Method A (from direct reduction of phosphine oxide **1a–j**): To the appropriate P-aryl-phospholane oxide **1a–j** (1 mmol) dissolved in distilled DME (10 mL), were added methyl trifluoromethanesulfonate (1.1 mmol) under argon atmosphere. After 2 h the mixture is cooled down to 0 °C and lithium aluminum hydride (1.5 mmol) were added. The mixture was allowed to warm to room temperature and stirred for additional 15 h. After hydrolysis with a minimum of water, the mixture was filtered under argon through Celite via cannula. DME was evaporated under vacuum to give the free P-aryl-phospholane **3a–j**.

Method B (from deprotection of borane complex **2a–j**): To a solution of phosphane-borane complex **2a–j** (1 mmol) in freshly degassed dichloromethane was added tetrafluoroboric acid dimethyl ether complex (4 mmol) at 0 °C. The mixture was allowed to warm to room temperature and stirred overnight at ambient temperature. The mixture is cooled down to 0 °C and a solution of saturated $NaHCO_3$ was added carefully under argon atmosphere until the effervescence ceased. The aqueous phase was extracted three times with degassed dichloromethane under argon via cannula. The organic layers were combined and washed with brine. The aqueous phase was eliminated via cannula and the organic layer died over magnesium sulfate, filtrated under argon. The solvent was evaporated by vacuum to give the free P-aryl-phospholane **3a–j**.

Preparation of P-aryl-2,5-diphenylphospholanium tetrafluoroborate salt (4a–i)

To a solution of enantiopure P-aryl-2,5-diphenylphospholane **3a–i** (1 mmol) in dry degassed diethyl ether (5 mL) were added three equivalents of HBF_4·Me_2O complex at 0 °C. After a few minutes the precipitate was collected by filtration, washed with diethyl ether (3×10 mL) and dried, to give the phospholanium salt as a white powder.

Rhodium-catalyzed asymmetric hydrogenation

General method: A Schlenk tube was charged with free P-aryl-phospholane **3a–i** or phospholanium salt **4a–i** (0.024 mmol) and bis(1,5-cyclooctadiene) rhodium(I)tetrafluoroborate (10 μmol). The tube was purged with argon and degassed, anhydrous methanol (5 mL) was added. The solution was stirred for 10 min, and the yellow solution obtained was cannulated into a Schlenk tube containing methyl-(*Z*)-α-acetamidocinnamate (1 mmol) under a hydrogen atmosphere. The uptake of hydrogen began immediately upon stirring. The conversion was calculated by direct measurement of consumption of dihydrogen by using graduated glassware. After completion of the reaction (no further hydrogen uptake), the resulting solution was concentrated in vacuo, taken up in dichloromethane (10 mL) and stirred with activated carbon for 1.5 h. Filtration over celite and removal of the solvent afforded the hydrogenated product. The conversion was evaluated by ^1H NMR analysis. Enantiomeric excesses were determined by chiral HPLC on a Chiralcel OD-H column, with hexane/*i*PrOH (9:1) as eluent.

Keywords: asymmetric catalysis · homogeneous catalysis · hydrogenation · P-ligands · turnover frequency

[1] a) *Phosphorus Ligands in Asymmetric Catalysis, Vols. 1, 2 and 3* (Ed.: A. Börner), Wiley-VCH, Weinheim, **2008**; b) L. Kollár, G. Keglevich, *Chem. Rev.* **2010**, *110*, 4257 – 4302.
[2] a) L. Methot, W. R. Roush, *Science of Synthesis "Applications of Tricoordinated Phosphorus Compounds in Organocatalysis", Vol. 42, chapt. 11* (Ed.: F. Mathey), Thieme, Stuttgart, **2009**, pp. 469 – 501; b) P. I. Dalko, *Enantioselective Organocatalysis*, Wiley-VCH, Weinheim, **2007**; c) A. Marinetti, A. Voituriez, *Synlett* **2010**, 174 – 194; d) C. Gomez, J.-F. Betzer, A. Voituriez, A. Marinetti, *ChemCatChem* **2013**, *5*, 1055 – 1065; e) N. Pinto, M. Neel, A. Panossian, P. Retailleau, G. Frison, A. Voituriez, A. Marinetti, *Chem. Eur. J.* **2010**, *16*, 1033 – 1045; f) Y. Wei, M. Shi, *Acc. Chem. Res.* **2010**, *43*, 1005 – 1018; g) A. Voituriez, N. Pinto, M. Neel, P. Retailleau, A. Marinetti, *Chem. Eur. J.* **2010**, *16*, 12541 – 12544; h) L.-W. Xu, *ChemCatChem* **2013**, *5*, 2775 – 2784.
[3] R. H. Crabtree, *The Organometallic Chemistry of Transition Metals*, Wiley, New York, **2001**.
[4] N. Arai, T. Ohkuma, *Chem. Rec.* **2012**, *12*, 284 – 289.
[5] a) P. Etayo, A. Vidal-Ferran, *Chem. Soc. Rev.* **2013**, *42*, 728 – 754; b) K. Tamura, M. Sugiya, K. Yoshida, A. Yanagisawa, T. Imamoto, *Org. Lett.* **2010**, *12*, 4400 – 4403.
[6] I. V. Komarov, A. Börner, *Angew. Chem. Int. Ed.* **2001**, *40*, 1197 – 1200; *Angew. Chem.* **2001**, *113*, 1237 – 1240.
[7] F. Lagasse, H. B. Kagan, *Chem. Pharm. Bull.* **2000**, *48*, 315 – 324.
[8] S. Enthaler, B. Hagemann, K. Junge, G. Erre, M. Beller, *Eur. J. Org. Chem.* **2006**, 2912 – 2917.
[9] a) C. Dobrota, M. Toffano, J.-C. Fiaud, *Tetrahedron Lett.* **2004**, *45*, 8153 – 8156; b) F. Guillen, M. Rivard, M. Toffano, J.-Y. Legros, J.-C. Daran, J.-C. Fiaud, *Tetrahedron* **2002**, *58*, 5895 – 5904; c) Z. Pakulski, O. M. Demchuk, J. Frelek, R. Luboradzki, K. M. Pietrusiewicz, *Eur. J. Org. Chem.* **2004**, 3913 – 3918; d) M. T. Reetz, G. Mehler, A. Meiswinkel, *Tetrahedron: Asymmetry* **2004**, *15*, 2165 – 2167; e) S. Enthaler, G. Erre, F. Marras, K. Junge, S. Gladiali, D. Michalik, A. Spannenberg, M. Beller, *Tetrahedron: Asymmetry* **2007**, *18*, 1288 – 1298; f) E. Alberico, S. Karandikar, S. Gladiali, *ChemCatChem* **2010**, *2*, 1395 – 1398; g) H. Ibrahim, C. Bournaud, R. Guillot, M. Toffano, G. Vo-Thanh, *Tetrahedron Lett.* **2012**, *53*, 4900 – 4902.
[10] For representative examples of efficient electron-rich phosphanes in asymmetric hydrogenation see the following reference and references cited therein: W. Chen, F. Spindler, B. Pugin, U. Nettekoven, *Angew. Chem. Int. Ed.* **2013**, *52*, 8652 – 8656; *Angew. Chem.* **2013**, *125*, 8814 – 8818.
[11] Phosphane **3a** can be generated from phospholanium **4a** in reaction mixture. See Ref. [9a].
[12] P-alkylphospholanes **5a**–**c** were generated from their corresponding phosphonium salts in reaction mixture.
[13] C. Dobrota, A. Duraud, M. Toffano, J.-C. Fiaud, *Eur. J. Org. Chem.* **2008**, 2439 – 2445.
[14] M. Toffano, C. Dobrota, J.-C. Fiaud, *Eur. J. Org. Chem.* **2006**, 650 – 656.
[15] Preparation of phosphine boranes **2a**–**j** was described in our previous paper. See Ref. [14].
[16] Ligand **4i** provides reproducible results in asymmetric hydrogenation while **4h** offers the hydrogenation product with an enantiomeric excess from 76 to 88%ee.
[17] A slight decrease of asymmetric induction and lower activity were observed for **3b**. This might be related to a slight contamination of the ligands **3b** with boron salts. The good activity is recovered with **4b** which is prepared from **3b**. This might be explained by the purification of the salt during its preparation.
[18] In the case of ligand **4i**, we observe an inversion of asymmetric induction of that obtained with other ligand which has the same configuration. In this case, we suppose that the presence of anisyl substituent might participate in the coordination of the ligand to rhodium, thus establishing a different chiral environment around the metal. See I. D. Gridnev, T. Imamoto, *Acc. Chem. Res.* **2004**, *37*, 633 – 644.
[19] Because of the lack of data concerning the activity of rhodium-monophosphane catalyst (TOF) in hydrogenation reaction of enamide, it is difficult to compare the activity of our ligands with those reported in the literature.

Received: August 27, 2014
Revised: October 9, 2014
Published online on ■■ ▮▮, 0000

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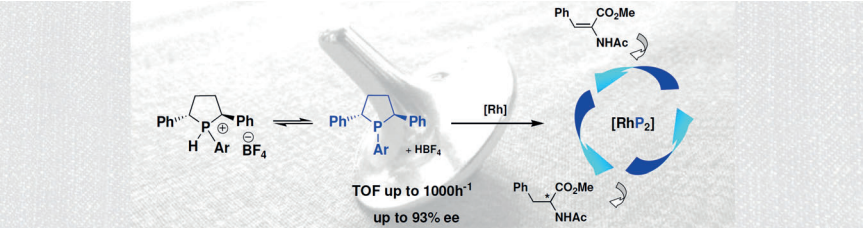
P-Aryl-Diphenylphospholanes and their Phospholanium Salts as Efficient Monodentate Ligands for Asymmetric Rhodium-Catalyzed Hydrogenation



Would you like a phospholanium with that? A family of enantiopure monodentate ligands based on P-aryl-2, 5-diphenylphospholane has been developed. The phospholanes and their corresponding phospholanium salt are very efficient ligands for the rhodium-catalyzed asymmetric hydrogenation reaction and show similar activities and enantioselectivities (up to 93% *ee*).