A Novel Synthesis of Atropisomeric *P,N* Ligands by Catalytic Phosphination Using Triarylphosphines

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The novel palladium-catalyzed phosphination using triarylphosphines as the phosphinating agents was developed and applied to the synthesis of atropisomeric *P,N* ligands from their corresponding *O,N* triflates. Various *P,N* ligands that possessed different dihedral angles and electronic properties were prepared from corresponding *O,N* triflates and triarylphosphines, respectively. The Pd-Ar/P-Ar′ exchange reactions were found to occur in this phosphination as the key step. The brief mechanistic studies concerning the rate of reactions and the coordination mode of *O,N* triflates to the palladium center are discussed.

Introduction

Mixed donor ligands, especially *P,N* type ligands, are a class of hemilabile ligands that possess a combination of hard and soft donor atoms and have different features associated with each donor atom that provide unique reactivity to their metal complexes.[1] The hard ends weakly coordinate to soft metal centers and easily dissociate in solution to afford a vacant site whenever demanded.[2] The versatility of *P,N* donor ligands was demonstrated in many asymmetric reactions, such as asymmetric allylic substitution,[3−15] hydrogenation,[16−20] hydrosilylation,[21−23] hydroboration,[24−28] hydroformylation,[29] Diels−Alder reaction,[30,31] Grignard cross-coupling,[32,33] Heck coupling,[34−36] conjugate addition,[37−39] copolymerization,[40] and terpolymerization.[41] Moreover, the wide scope of the application of *P,N* mixed donor ligands is also examplified in the catalytic amination[2a,3c,42] and cross-coupling reactions.[3c,42,43]

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The major structural features constituting the *N* coordinating skeletons of *P,N* ligands are oxazoline, quinoline, amine, pyridine, pyrazole, etc., which are readily available or simple to prepare. The phosphorus sites of these ligands are usually the phosphine moiety (PAr_2). Classical methods for the synthesis of tertiary aryl phosphine are the reaction between aryl halides with organometallic phosphide, e.g., K/Na/LiPPh_2,[44] or Grignard/organolithium reagents with chlorophosphines.[45] Alternatively, the C−P bond formation is achieved by the reaction of a Grignard reagent with $Ph_2P(O)Cl$, and the resultant phosphine oxide is then reduced by trichlorosilane to afford the phosphine.[46] These organometallic methodologies are limited to compounds that are not base sensitive and not applicable to aryl triflates. The recent method for introduction of a diphenylphosphino group to aryl halides/triflates is transition metal catalyzed phosphination. However, some drawbacks still exist. The phosphination using Pd/$Ph_2P(O)H$ requires a subsequent reduction step by trichlorosilane;[47] the phosphination using Pd/Ph_2PH-BH_3 phosphinating agent is incompatible with amine- or pyridine-containing functional groups and requires an extra deprotection step;[48] the Pd/Ph_2P(TMS) methodology is mainly limited to aryl iodides.[49] Recently, the nickel-catalyzed phosphination of BINOL ditriflates (2,2′-bis(trifluoromethanesulfonyloxyl)-1,1′-binaphthyl) using Ph_2PH[50] or Ph_2PCl/Zn[51] reagents has been found to be a direct synthesis of tertiary aryl phosphines. However, these methods required air- and moisture-sensitive secondary phosphinating agents, and

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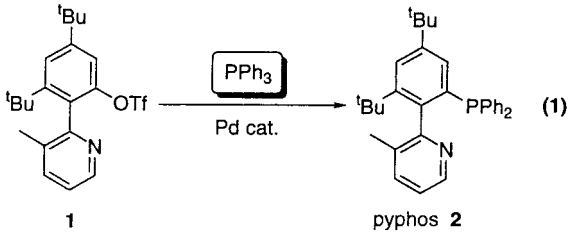
Table 1. Optimization of Catalytic Phosphination for the Synthesis of *P,N* Ligand 2 from *O,N* Triflate 1 Using Triphenylphosphine

entry	catalyst, mol %	solvent	equiv of PPh_3	temp/°C	time/days	$ArPPh_2$:ArH[b]	% yield[c]
1	$Pd(PPh_3)_4$, 10%	DMF	2.3	110	4.5	7:1	64
2	$Pd(dba)_2$, 10%	DMF	2.3	110	4	28:1	61
3	$Pd(OAc)_2$, 10%	DMF	2.3	110	4.5	28:1	68
4	$PdCl_2(L)_2$,[a] 10%	DMF	2.3	110	7	nd[d]	no rxn.[e]
5	$Pt(PPh_3)_4$, 10%	DMF	2.3	110	7	nd[d]	no rxn.[e]
6	$Ni(OAc)_2$, 10%	DMF	2.3	110	7	nd[d]	no rxn.[e]
7	$Pd(OAc)_2$, 5%	DMF	2.3	110	7	3:1	32
8	$Pd(OAc)_2$, 15%	DMF	2.3	110	4	30:1	64
9	$Pd(OAc)_2$, 20%	DMF	2.3	110	4	30:1	60
10	$Pd(OAc)_2$, 10%	NMP	2.3	110	5	12:1	47
11	$Pd(OAc)_2$, 10%	HMPA	2.3	110	5	22:1	40
12	$Pd(OAc)_2$, 10%	DMSO	2.3	110	4	2:1	41
13	$Pd(OAc)_2$, 10%	THF	2.3	110	7	nd[d]	no rxn.[e]
14	$Pd(OAc)_2$, 10%	DMF	1.0	110	5	26:1	21[f]
15	$Pd(OAc)_2$, 10%	DMF	1.5	110	5	26:1	28[f]
16	$Pd(OAc)_2$, 10%	DMF	2.0	110	5	30:1	40[f]
17	$Pd(OAc)_2$, 10%	DMF	2.2	110	5	30:1	64
18	$Pd(OAc)_2$, 10%	DMF	2.5	110	5	30:1	67
19	$Pd(OAc)_2$, 10%	DMF	3.0	110	5	30:1	18[f]
20	$Pd(OAc)_2$, 10%	DMF	4.0	110	5	28:1	5[f]
21	$Pd(OAc)_2$, 10%	DMF	2.3	125	3.5	27:1	65
22	$Pd(OAc)_2$, 10%	DMF	2.3	100	7	nd[d]	trace[g]
23	$Pd(OAc)_2$, 10%	DMF	2.3	90	7	nd[d]	no rxn.[e]

[a] L = MeCN (acetonitrile), PPh_3 (triphenylphosphine), dppf (bis-1,1′-(diphenylphosphino)ferrocene). [b] The ratios were determined by ^1H NMR integration of the crude reaction mixture. [c] Isolated yield. [d] Not determined. [e] Starting material was recovered quantitatively. [f] Incomplete conversion was observed by TLC. [g] Monitored by TLC.

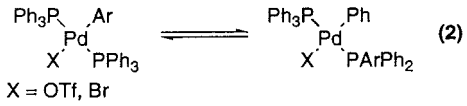
the latter method is not tolerant of easily reducible functional groups since Zn metal is used. We herein report a novel palladium-catalyzed phosphination using tertiary phosphines as the diarylphosphinating agents for the synthesis of biaryl *P,N* ligands (eq 1).[52]



1 pyphos **2** (1)

Results and Discussion

The facile aryl/aryl exchange between the palladium-bound Ar with phosphorus-bound Ar′ (eq 2) was found to be the key step in the catalytic phosphination. In the past decade, the aryl/aryl exchange was an undesirable reaction leading to the formation of scrambled side products of Stille coupling,[53] Suzuki coupling,[54] Heck reaction,[55] C−S coupling,[56] and arylation of ketone enolates.[57] The synthetic potential of these palladium-catalyzed aryl/aryl exchange reactions has been recognized and applied in the synthesis of atropisomeric *P,N* ligands from their corresponding aryl *O,N* triflates recently (eq 2).[52]



(2)

Palladium-Catalyzed Phosphination. The *O,N* triflate **1**, prepared by the trifluoromethanesulfonation[58] of 2-(3′-methylpyridyl)-3,5-di-*tert*-butylphenol,[59a] was used as the prototype substrate for the screening and optimization of catalytic phosphination. $Pd(OAc)_2$, $Pd(PPh_3)_4$, and $Pd(dba)_2$ complexes were found to be active catalysts for the catalytic phosphination (Table 1, entries 1−3). However, $Pd(OAc)_2$ was the best choice because it is an air-stable complex and allows the use of other triarylphosphines as phosphinating agents instead of triphenylphosphine only (Table 1, entry 3). $Pd(dba)_2$ was not preferred since dba (*trans*-dibenzylideneacetone) dissociated from the palladium complex during the course of reaction and gave similar chromatographic R_f values with the desired products, making purification difficult. Other complexes, such as $PdCl_2$, $Pd(MeCN)_2Cl_2$, $Pd(PPh_3)_2Cl_2$, $Pd(dppf)Cl_2$, $PtCl_2$, $Pt(PPh_3)_4$, and $Ni(OAc)_2$ did not show any catalytic activity (Table 1, entries 4−6). Presumably the $PdCl_2(L)_2$ complexes were not reduced by triphenylphosphine to generate the catalytically active palladium(0) species.[60] The rate and the yield of the reaction increased when the catalyst loading increased from 5 to 10 mol % (Table 1, entries 3 and 7). Further increase of the

(52) Kwong, F. Y.; Chan, K. S. *Organometallics* **2000**, *19*, 2058−2060.
(53) Segelstein, B. E.; Butler, T. W.; Chenard, B. L. *J. Org. Chem.* **1995**, *60*, 12−13.
(54) O'Keefe, D. F.; Dannock, M. C.; Maruccio, S. M. *Tetrahedron Lett.* **1992**, *33*, 6679−6680.
(55) Hunt, A. R.; Stewart, S. K.; Whiting, A. *Tetrahedron Lett.* **1993**, *34*, 3599−3602.
(56) Barañano, D.; Hartwig, J. F. *J. Am. Chem. Soc.* **1995**, *117*, 2937−2938.
(57) For arylation of ketone enolates, some side products, α-phenylated ketones and α-(*p*-tolyl) ketones, were observed when BINAP and Tol-BINAP were used as the catalysts, respectively. Åhman, J.; Wolfe, J.. P.; Troutman, M. V.; Palucki, M.; Buchwald, S. L. *J. Am. Chem. Soc.* **1998**, *120*, 1918−1919.
(58) (a) Kawashima, M.; Hirata, R. *Bull. Chem. Soc. Jpn.* **1993**, *66*, 2002−2005. (b) Vondenhof, M.; Mattay, J. *Tetrahedron Lett.* **1990**, *31*, 985−988. (c) Stang, P. J.; Hanack, M.; Subramanian, L. R. *Synthesis* **1982**, 85−126.
(59) (a) Zhang, H. C.; Kwong, F. Y.; Tian, Y.; Chan, K. S. *J. Org. Chem.* **1998**, *63*, 6886−6890. (b) Kwong, F. Y.; Chan, A. S. C.; Chan, K. S. *Tetrahedron* **2000**, *56*, 8893−8899.

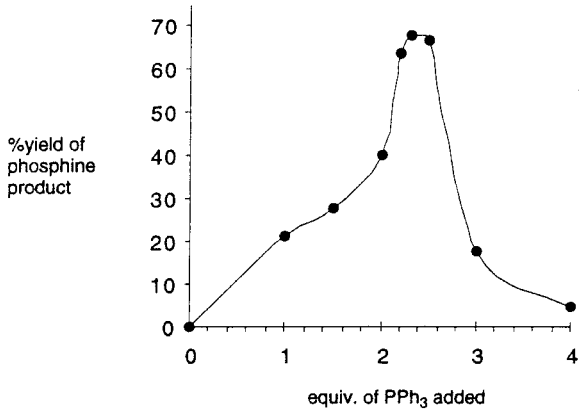


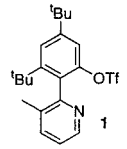
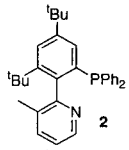
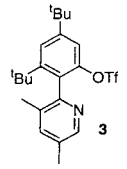
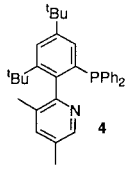
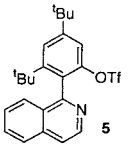
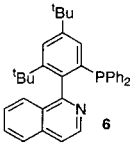
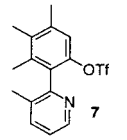
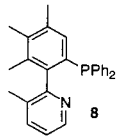
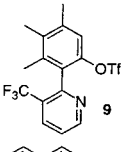
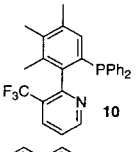
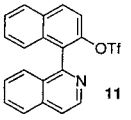
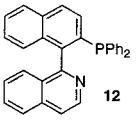
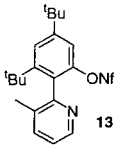
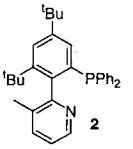
Figure 1. Effect of triphenylphosphine in phosphination.

amount of catalyst did not change the product yield substantially (Table 1, entries 8 and 9).

The effects of solvent were examined, and polar aprotic solvents were found to be most suitable. DMF was the best solvent, while NMP, HMPA, and DMSO gave lower phosphine product ($ArPPh_2$) to reduction product (ArH) ratio (Table 1, entries 3 and 10−12). The reduction side product was probably formed from the competitive protonolysis of the Pd−aryl intermediate.[61] The much less polar solvent[62] THF was found to be inferior, even with extended reaction time, and the starting material **1** was recovered quantitatively (Table 1, entry 13). The amount of triphenylphosphine used was critical. When 1 equiv of triphenylphosphine was added, only about 10% conversion of **1** to **2** was observed (Table 1, entry 14).[63] The optimal range of the quantity of triphenylphosphine added was between 2.3 and 2.5 equiv (Figure 1; Table 1, entries 15−18). When more than 2.5 equiv of triphenylphosphine was used, the yield of *P,N* product **2** rapidly dropped, and finally almost no reaction occurred when 4 equiv of triphenylphosphine was added (Figure 1; Table 1, entries 19 and 20). Since triphenylphosphine acts as a ligand to stabilize the palladium catalyst and the diphenylphosphinating agent, the optimal amount of triphenylphosphine used was found to be 2.3−2.5 equiv with respect to the triflates used (Figure 1). Larger amounts of tertiary phosphine ligands likely decrease the catalytic activity by forming coordinatively saturated and catalytically less active palladium species.

The effect of temperature was also investigated. No reaction occurred below 100 °C (Table 1, entry 23). Only a trace amount of product formed at 100 °C by TLC analysis (Table 1, entry 22). When the temperature was increased from 110 °C to 125 °C, the rate of reaction slightly increased and the yield remained practically the same (Table 1, entries 3 and 21). Further increase of the reaction temperature to 150 °C afforded a black reaction mixture, which probably was the palladium black formation due to the decomposition of catalyst. The reaction did not proceed further with most of the starting material unreacted.

Table 2. Palladium-Catalyzed Phosphination of Biaryl *O,N* Triflates

Entry	Substrates	Products	Time / d	% yield[a]
1	 **1**	 **2**	4.5	68
2	 **3**	 **4**	4.5	60
3	 **5**	 **6**	4.5	58
4	 **7**	 **8**	4.0	53
5	 **9**	 **10**	4.0	57
6	 **11**	 **12**	4.5	53
7	 **13**	 **2**	4.0	61

[a] Isolated yield.

Syntheses of Atropisomeric *P,N* Ligands. The pyridylphenyl triflate **1** was reacted with 2.3 equiv of triphenylphosphine and 10 mol % of palladium(II) acetate in DMF at 110 °C for about 4.5 days at the optimized reaction conditions to give pyphos **2** in 68% yield (Table 2, entry 1). These optimized conditions were further applied to the synthesis of other atropisomeric *P,N* ligands **4**, **6**, **8**, and **10** from their corresponding *O,N* triflates **3**, **5**, **7**, and **9**, respectively (Table 2, entries 2−5). Moreover, this phosphination was also applicable to the synthesis of well-known *P,N* ligand QUINAP[25] **12** in 53% yield (Table 2, entry 6). Various *P,N* ligands possessing different dihedral angles (**2**, 72°; **4**, 72°; **6**, 76°; **8**, 62°; **10**, 62°)[64] and electronic properties were prepared in similar yield and reaction time. The triflate alternative, nonaflate **13**, which was prepared by the

(60) (a) Amatore, C.; Jutand, A.; M'Barki, M. A. *Organometallic* **1992**, *11*, 3009−3013. (b) Jutand, A.; Mosleh, A. *Organometallics* **1995**, *14*, 1810−1817. (c) Amatore, C.; Jutand, A.; Khalil, F.; M'Barki, M. A. Mottier, L. *Organometallics* **1993**, *12*, 3168−3173.

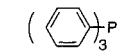
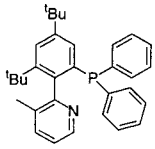
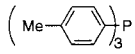
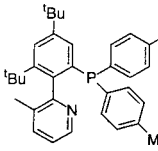
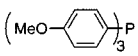
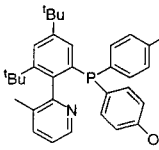
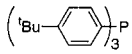
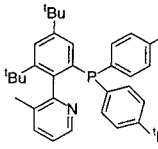
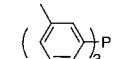
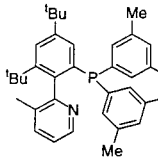
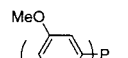
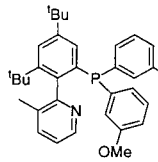
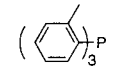
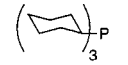
(61) Pedersen, J. R. *Acta Chem. Scand.* **1972**, *26*, 929−932.

(62) The dielectric constants for DMF, NMP, DMSO, and THF are 36.7, 35.8, 46.7, and 7.6, respectively. Cowdrey, W. A.; Hughes, E. D.; Ingold, C. K.; Masterman, S.; Scott, A. D. *J. Chem. Soc.* **1937**, 1252−1253.

(63) Percentage conversion was determined by ^1H NMR integration from the crude reaction mixture.

(64) Dihedral angle for pyphos **2** was found to be 72° from X-ray crystallography and ChemDraw 3D calculations. Dihedral angles for *P,N* ligands **4**, **6**, **8**, and **10** were estimated by the ChemDraw 3D program (ChemOffice 2000 ver. 5.0).

Table 3. Palladium-Catalyzed Phosphination with Different Triarylphosphines

Entry	triarylphosphines	Products	Time / d	% yield
1		 **2**	4.5	68
2		 **14**	4.5	60
3		 **15**	3.5	60
4		 **16**	4.0	55
5		 **17**	4.0	58
6		 **18**	5.0	55
7		/	7.0	no rxn[a]
8		/	7.0	no rxn[a]

[a] Starting material was recovered.

nonafluorobutanesulfonation[65] of 2-(3′-methylpyridyl)-3,4-di-*tert*-butylphenol,[59a] was also found to be reactive in this palladium-catalyzed phosphination to yield pyphos **2** in 61% yield (Table 2, entry 7).

Synthesis of Diarylphosphino Atropisomeric *P,N* Ligands. The substituted atropisomeric *P,N* ligands were synthesized by the palladium-catalyzed phosphination using different triarylphosphines (eq 3). Employing the optimized palladium-catalyzed phosphination using 10 mol % of $Pd(OAc)_2$ and 2.3 equiv of triarylphosphines in dry DMF at 110 °C, the corresponding phenyl-substituted atropisomeric *P,N* ligands **14**−**18** were obtained in 55%−68% yield (Table 3). The substitutents on the phenyl ring of the *P,N* ligands **2**, **14**−**16**, and **18** exerted different electronic effect on the phosphorus donor of the ligands. The Hammett plot of the ^{31}P NMR chemical shift with Hammett constants[66] showed that a linear relationship with $R^2 = 0.99$ was followed (Figure 2).

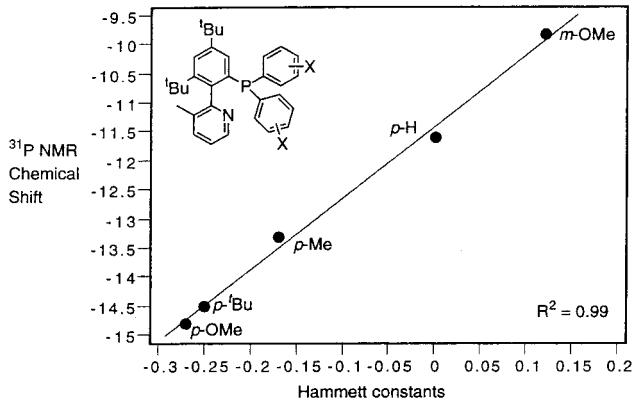
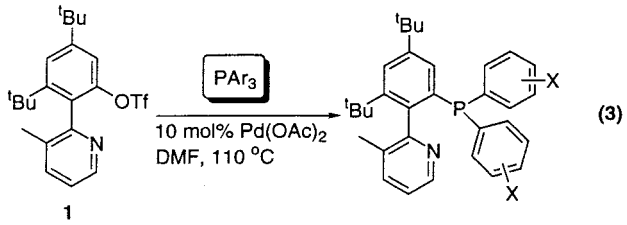


Figure 2. Electronic properties of the phosphorus donor atom of X-substituted *P,N* ligands.



The rate of phosphination was found to be dependent on the electronic properties of the phosphinating reagents. Monitoring the phosphination by performing ^1H NMR analysis of the aliquots revealed that the electron-rich tri(*p*-methoxyphenyl)phosphine exerted a slightly faster rate of phosphination when compared with tri(*p*-tolyl)phosphine and triphenylphosphine (Table 3, entries 1−3). The starting material *O,N* triflate **1** was consumed gradually and no product was observed from TLC during the first 30 h of reaction, probably indicating that an induction period was needed. This period may be due to the generation of phosphonium salt intermediates (see mechanistic studies).

Sterically more hindered tri(*o*-tolyl)phosphine did not yield any substituted *P,N* ligand, with the substrate **1** being recovered almost quantitatively (Table 3, entry 7). This sterically hindered *ortho*-substituted triarylphosphine likely retarded aryl/aryl exchange, and similar steric effects have been reported in the palladium-catalyzed preparation of phosphonium salt from triphenylphosphine and aryl halides.[67]

Tricyclohexylphosphine did not undergo any phosphination (Table 3, entry 8). Likely the alkyl/aryl exchange is difficult, as Stille and Norton reported that no migration of alkyl groups from the phosphine to the palladium center was observed.[68] The evidence for the selective aryl-P/aryl-Pd exchange instead of alkyl-P/aryl-Pd exchange (Scheme 1) was also noted in the reaction of quinolyl triflate **19** with Ph_2PMe (Scheme 1). Only the quinolyl phosphine **20** was observed by GC−MS without any **21** formed. Therefore, C_{aryl}−P bond cleav-

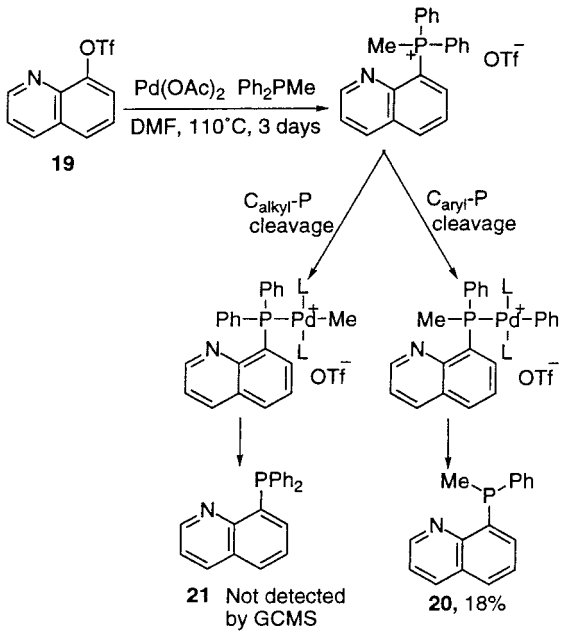
(65) Nonaflate = ^{n}nonafluorobutanesulfonate. (a) Subramanian, L. R.; Bentz, H.; Hanack, M. *Synthesis* **1973**, 293−294. (b) Niederprüm, H.; Voss, P.; Beyl, V. *Liebigs. Ann. Chem*. **1973**, 20−32. For review, see: (c) ref 58c.

(66) Gordon, A. J.; Ford, R. A. *The Chemist's Campanion*; John Wiley: New York, 1972.

(67) Migita, T.; Nagai, T.; Kiuchi, K.; Kosugi, M. *Bull. Chem. Soc. Jpn*. **1983**, *56*, 2869−2870.

(68) Morita, D. K.; Stille, J. K.; Norton, J. R. *J. Am. Chem. Soc*. **1995**, *117*, 8576−8581.

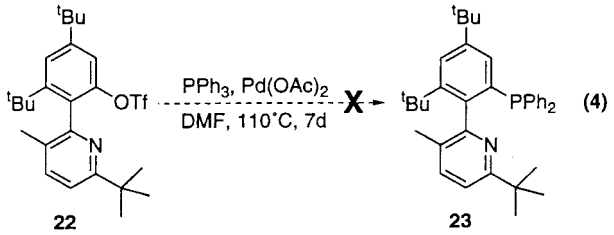
Scheme 1. Selective Pd-Ar/P-Ar′ Exchange Reaction in Palladium-Catalyzed Phosphination



age was more facile (Scheme 1). The poor isolated yield of the product **20** was likely due to the fast oxidation of the product to the corresponding quinolyl *P*-chiral phosphine oxide.

Mechanism of Palladium-Catalyzed Phosphination. Scheme 2 illustrates a plausible mechanism for the reaction involving both Pd(0)/Pd(II) and Pd(II)/Pd(IV) cycles. Palladium acetate is in situ reduced by triphenylphosphine to PdL_2 (L = triphenylphosphine).[60a] This Pd(0) species then undergoes oxidative addition with pyridylphenyl triflate **1** to afford complex **A** (Pd(II) species).

Complex **A** subsequently undergoes reductive elimination with triphenylphosphine to produce a phosphonium salt, complex **B**. Such Pd-catalyzed phosphonium salt formation for *meta*- and *para*- but not *ortho*-substituted aryl bromides has been reported.[67] This Pd(0) complex **B** undergoes oxidative addition by carbon−phosphorus bond activation of the phosphonium salt to generate the coordinated *P,N* product complex **C** (Scheme 2).[69,70,71] Finally, ligand substitution of complex **C** by triphenylphosphine to the Pd(II) complex gives the *P,N* product and Pd−phenyl complex **D**. The PdL_2 species is regenerated by reductive elimination from complex **D** between triphenylphosphine and the Pd-bound phenyl group to yield the tetraphenylphosphonium triflate coproduct (Scheme 2). The formation of tetraphenylphosphonium triflate was detected by ^{31}P NMR (δ = 24.3 ppm)[72] in the reaction mixture and was isolated in 78%. Therefore, 2 equiv of PPh_3 was required. The first one serves as the diphenylphosphinating agent, and the second one yields the phosphonium salt.



Since the palladium-catalyzed formation of phosphonium salt[67] and aryl/aryl exchange reaction[69b] at the palladium center are limited to sterically nonhindered *para*- or *meta*-substituted aryl compounds, the successful *ortho*-substituted aryl/aryl exchange which contributed to the phosphination of *O,N* triflates is rather unique. To investigate the possibility that the reaction is templated by the coordination of the pyridyl nitrogen, the sterically hindered substrate **22** was subjected to palladium-catalyzed phosphination. The *O,N* triflate **22** bears the *tert*-butyl group adjacent to the pyridine-nitrogen, which prevents the coordination to the palladium center.[73] When **22** was subjected to palladium-catalyzed phosphination (eq 4), no phosphination product **23** was formed, and the starting material was recovered almost quantitatively. The complete recovery of starting material **22** showed that even the oxidative addition of the carbon−oxygen bond ($C-OSO_2CF_3$) did not occur. Therefore, the coordination of the pyridine-nitrogen may facilitate the catalytic phosphination of sterically demanding *ortho*-substituted aryl triflates.

Conclusion

In conclusion, the palladium-catalyzed phosphination using triarylphosphines as the phosphinating reagents was developed and optimized. This method was applied to the synthesis of atropisomeric *P,N* ligands from their corresponding *O,N* triflates. An array of *P,N* ligands that possessed different dihedral angles and electronic properties were prepared. Sterically hindered *ortho*-substituted aryl triflates underwent successful catalytic aryl/aryl exchange reaction and phosphination likely facilitated by the coordinating pyridine-nitrogen.

Experimental Section

General Considerations. Unless otherwise noted, all reagents were purchased from commercial suppliers and used without purification. Tetrahydrofuran (THF) and diethyl ether were distilled from sodium and benzophenone ketyl prior to use, and toluene was distilled from sodium. Dichloromethane and hexane for reaction were distilled from calcium hydride. Hexane for chromatography was distilled from anhydrous calcium chloride. *N,N*-Dimethylformamide and *N*-methylpyrrolidinone were distilled from magnesium sulfate under reduced pressure.[74] $Pd(MeCN)Cl_2$,[75] $Pd(PPh_3)_2Cl_2$,[75] Pd(dppf)-

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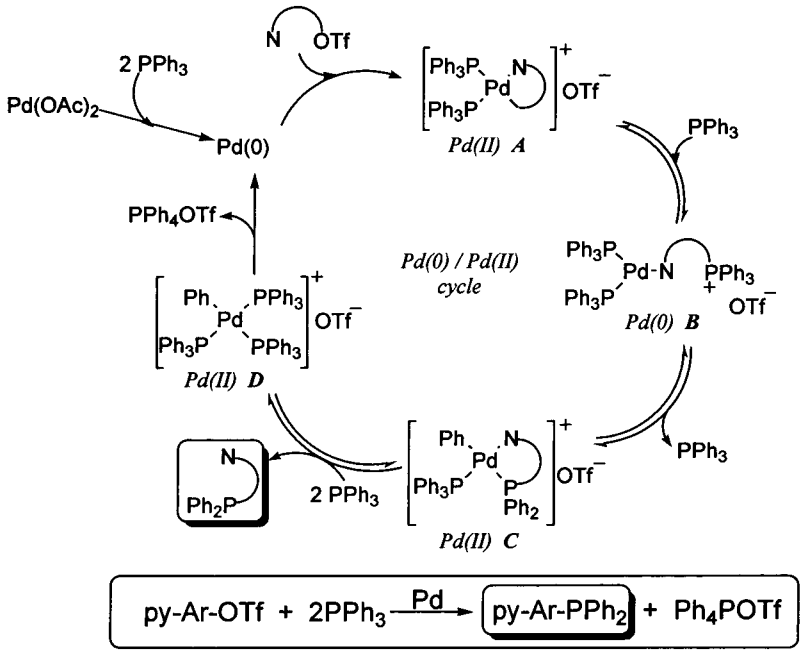
Scheme 2. Suggested Mechanism for Palladium-Catalyzed Phosphination



Cl_2,[75] $Pt(PPh_3)_4$,[75] tri(*p*-*tert*-butylphenyl)phosphine,[76] tri(3,5-dimethylphenyl)phosphine,[76] tri(*m*-methoxyphenyl)phosphine,[77] and tri(*o*-tolyl)phosphine[77] were prepared according to the literature method without modification. Thin-layer chromatography was performed on Merck precoated silica gel 60 F_{254} plates. Silica gel (Merck, 70−230 and 230−400 mesh) was used for column chromatography. ^{1}H NMR spectra were recorded on a Brüker DPX 300 (300 MHz) spectrometer. Spectra were referenced internally to the residual proton resonance in $CDCl_3$ (δ 7.26 ppm) or with tetramethylsilane (TMS, δ 0.00 ppm) as the internal standard. Chemical shifts (δ) were reported as parts per million (ppm) in δ scale downfield from TMS. ^{13}C NMR spectra were recorded on a Brüker DPX 300 (75 MHz) spectrometer and referenced to $CDCl_3$ (δ 77.00 ppm). ^{31}P NMR spectra were recorded on a Varian 400 (162 MHz) and referenced to 85% H_3PO_4 externally. Coupling constants (J) were reported in hertz (Hz). Mass spectra (EIMS and FABMS) were recorded on a HP 5989B mass spectrometer. High-resolution mass spectra (HRMS) were obtained on a Brüker APEX 47e FT-ICR mass spectrometer (ESIMS). GC−MS analysis was conducted on a HP G1800C GCD system using a HP5MS column (30 m × 0.25 mm). Mac-curve Fit program ver. 1.1 (Machintoch version) was used for curve fitting.

General Procedure for Palladium-Catalyzed Phosphination. 2-(2′-Diphenylphosphino-4′,6′-di-*tert*-butyl-1′-phenyl)-3-methylpyridine (pyphos) (2). 3,5-Di-*tert*-butyl-2-(3′-methyl-2′-pyridyl)phenyl trifluoromethanesulfonate (**1**) (1.07 g, 2.5 mmol), palladium(II) acetate (56 mg, 0.25 mmol), and triphenylphosphine (1.51 g, 5.8 mmol) were dissolved in dry DMF (10 mL) under nitrogen. The solution was heated to 110−115 °C for 4.5 days, and the color of the solution changed from yellow to red. The reaction was cooled and DMF was removed under reduced pressure. The residue was purified by column chromatography on silica gel using a solvent mixture of (hexane/ethyl acetate = 6:1, R_f = 0.6) as eluent to obtain the crude product. This crude product was then purified by column chromatography on silica gel with eluent (toluene/ethyl acetate = 20:1) to afford the pure 2-(2′-diphenylphosphino-4′,6′-di-*tert*-butyl-1′-phenyl)-3-methylpyridine (pyphos) (**2**) (790 mg, 68%) as a white solid: mp 135−136 °C; R_f = 0.6 (toluene/ethyl acetate = 15:1); ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.13 (s, 9 H), 1.17 (s, 9 H), 1.94 (s, 3 H), 7.04−7.30 (m, 13 H), 7.60 (d, 1 H, J = 2.0 Hz), 8.34 (d, 1 H, J = 4.3 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 19.9, 31.1, 32.4, 34.8, 37.2, 125.8, 127.9, 128 (d, J_{CP} = 8.0 Hz), 128.2 (d, J_{CP} = 4.6 Hz), 130.1, 131.2 (d, J_{CP} = 7.6 Hz), 131.1 (d, J_{CP} = 7.5 Hz), 133.4 (d, J_{CP} = 19.3 Hz), 134.0 (d, J_{CP} = 20.0 Hz), 137.1 (d, J_{CP} = 8.7), 138.0 (d, J_{CP} = 9.3 Hz), 138.2, 145.1, 147.1 (d, J_{CP} = 5.6 Hz), 149.7; ^{31}P NMR (162 MHz, $CDCl_3$) δ −11.60; MS (EI) *m*/*z* (relative intensity) 465 (M^+, 80), 450 (88), 408 (100), 388 (82), 374 (22), 358 (35), 342 (23); HRMS (ESIMS) calcd for $C_{32}H_{36}NPH^+$ 466.2658, found 466.2622.

2-(2′-Diphenylphosphino-4′,6′-di-*tert*-butyl-1′-phenyl)-3,5-dimethylpyridine (4). The general procedure of palladium-catalyzed phosphination for **2** was used. 3,5-Di-*tert*-butyl-2-(3′,5′-dimethyl-2′-pyridyl)phenyl trifluoromethanesulfonate (**3**) (400 mg, 0.9 mmol), palladium(II) acetate (20 mg, 0.09 mmol), triphenylphosphine (544 mg, 2.1 mmol), and dry DMF (3.5 mL) were used to obtain 2-(2′-diphenylphosphino-4′,6′-di-*tert*-butyl-1′-phenyl)-3,5-dimethylpyridine (**4**) (259 mg, 60%) as a light yellow solid: mp 111−112 °C; R_f = 0.6 (toluene/ethyl acetate = 15:1); ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.13 (s, 9 H), 1.17 (s, 9 H), 1.89 (s, 3 H), 2.35 (s, 3 H), 7.05−7.29 (m, 12 H), 7.59 (d, 1 H, J = 2.0 Hz), 8.18 (s, 1 H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 18.2, 19.9, 31.1, 32.4, 34.8, 37.2, 125.8, 127.9, 128.0 (d, J_{CP} = 8.0 Hz), 128.2 (d, J_{CP} = 4.6 Hz), 130.1, 131.2 (d, J_{CP} = 7.6 Hz), 132.1 (d, J_{CP} = 7.5 Hz), 133.4 (d, J_{CP} = 19.3 Hz), 134.0 (d, J_{CP} = 20.0 Hz), 137.1 (d, J_{CP} = 8.7 Hz), 138.0 (d, J_{CP} = 9.3 Hz), 138.1, 145.1, 147.1 (d, J_{CP} = 5.6 Hz), 149.6; ^{31}P NMR (162 MHz, $CDCl_3$) δ −11.78; MS (EI) *m*/*z* (relative intensity) 479 (M^+, 5), 464 (5), 444 (17), 428 (54), 310 (13), 295 (76), 280 (100); HRMS (ESIMS) calcd for $C_{33}H_{38}NPH^+$ 480.2814, found 480.2807.

1-(2′-Diphenylphosphino-4′,6′-di-*tert*-butyl-1′-phenyl)-isoquinoline (6). The general procedure of palladium-catalyzed phosphination for **2** was used. 3,5-Di-*tert*-butyl-2-(2′-isoquinolyl)phenyl trifluoromethanesulfonate (**5**) (500 mg, 1.07 mmol), palladium(II) acetate (24 mg, 0.11 mmol), triphenylphosphine (648 mg, 2.47 mmol), and dry DMF (5 mL) was used to obtain 1-(2′-diphenylphosphino-4′,6′-di-*tert*-butyl-1′-phenyl)isoquinoline (**6**) (311 mg, 58%) as a white solid: mp

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144−147 °C; R_f = 0.5 (toluene/ethyl acetate = 15:1); ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.04 (s, 9 H), 1.23 (s, 9 H), 6.94 (t, 1 H, J = 8.2 Hz), 7.06−7.27 (m, 11 H), 7.49 (t, 1 H, J = 8.0 Hz), 7.64 (d, 1 H, J = 5.7 Hz), 7.68 (d, 1 H, J = 1.9 Hz), 7.78 (d, 1 H, J = 8.2 Hz), 8.51 (d, 1 H, J = 5.7 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 31.2, 32.7, 34.9, 37.3, 120.0, 125.6, 126.1, 126.4, 127.9 (d, J_{CP} = 18.0 Hz), 128.0, 128.2 (d, J_{CP} = 18.2 Hz), 129.5, 130.2, 130.4 (d, J_{CP} = 5.0 Hz), 133.1 (d, J_{CP} = 18.9 Hz), 133.7 (d, J_{CP} = 20.6 Hz), 135.8, 137.9 (d, J_{CP} = 15.0 Hz), 138.4 (d, J_{CP} = 15.0 Hz), 141.2, 147.8 (d, J_{CP} = 5.9 Hz), 150.0, 163.6 (d, J_{CP} = 6.6 Hz); ^{31}P NMR (162 MHz, $CDCl_3$) δ −12.78; MS (EI) *m/z* (relative intensity) 501 (M^+, 70), 474 (7), 460 (11), 424 (100), 407 (23), 392 (21), 375 (10); HRMS (ESIMS) calcd for $C_{35}H_{37}NPH^+$ 502.2658, found 502.2646.

2-(2′-Diphenylphosphino-4′,5′,6′-trimethyl-1′-phenyl)-3-methylpyridine (8). The general procedure of palladium-catalyzed phosphination for **2** was used. 3,4,5-Trimethyl-2-(3′-methyl-2′-pyridyl)phenyl trifluoromethanesulfonate (**7**) (45 mg, 0.13 mmol), palladium(II) acetate (3 mg, 13 μmol), triphenylphosphine (75 mg, 0.29 mmol), and DMF (0.5 mL) were used to afford 2-(2′-diphenylphosphino-4′,5′,6′-trimethyl-1′-phenyl)-3-methylpyridine (**8**) (26 mg, 53%) as a white solid: mp 78−80 °C; R_f = 0.4 (toluene/ethyl acetate = 15:1); ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.90 (s, 3 H), 1.97 (s, 3 H), 2.20 (s, 3 H), 2.21 (s, 3 H), 6.79 (d, 1 H, J = 4.0 Hz), 7.12−7.28 (m, 11 H), 7.51 (d, 1 H, J = 7.6 Hz), 8.32 (d, 1 H, J = 4.1 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 15.9, 16.9, 19.0, 20.9, 122.2, 128.0 (d, J_{CP} = 7.1 Hz), 128.2 (d, J_{CP} = 7.2 Hz), 132.2 (d, J_{CP} = 9.3 Hz), 132.7 (d, J_{CP} = 13.4 Hz), 132.8, 133.4 (d, J_{CP} = 19.1 Hz), 133.8 (d, J_{CP} = 20.0 Hz), 136.2, 136.9, 137.2 (d, J_{CP} = 10.8 Hz), 137.4, 137.7 (d, J_{CP} = 11.6 Hz), 146.1, 159.6 (d, J_{CP} = 5.6 Hz); ^{31}P NMR (162 MHz, $CDCl_3$) δ −11.53; MS (EI) *m/z* (relative intensity) 395 (M^+, 100), 379 (25), 334 (9), 318 (66); HRMS (ESIMS) calcd for $C_{27}H_{26}NPH^+$ 396.1876, found 396.1886.

2-(2′-Diphenylphosphino-4′,5′,6′-trimethyl-1′-phenyl)-3-trifluoromethylpyridine (10). The general procedure of palladium-catalyzed phosphination for **2** was used. 2-(3′-Trifluoromethyl-2′-pyridyl)-3,4,5-trimethylphenyl trifluoromethanesulfonate (**9**) (52 mg, 0.13 mmol), palladium(II) acetate (3 mg, 0.013 mmol), triphenylphosphine (78 mg, 0.29 mmol), and dry DMF (0.5 mL) were used to obtain the 2-(2′-diphenylphosphino-4′,5′,6′-trimethyl-1′-phenyl)-3-trifluoromethylpyridine (**10**) (32 mg, 57%) as light yellow solid: mp 45−47 °C; R_f = 0.5 (toluene/ethyl acetate = 10:1); ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.92 (s, 3 H), 2.21 (s, 6 H), 6.87 (d, 1 H, J = 4.0 Hz), 7.16−7.22 (m, 10 H), 7.35−7.42 (m, 1 H), 8.11 (dd, 1 H, J = 1.2, 8.0 Hz), 8.63 (d, 1 H, J = 8.4 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 15.8, 16.2, 17.7, 19.5 (q, J_{CF} = 245.9 Hz), 122.2, 123.6, 128.0−128.5 (m), 131.7, 132.2 (d, J_{CP} = 10.3 Hz), 133.2 (d, J_{CP} = 20.0 Hz), 133.6 (d, J_{CP} = 21.1 Hz), 135.1, 137.2, 137.7, 137.8, 150.6; ^{31}P NMR (162 MHz, $CDCl_3$) δ −10.9; MS (EI) *m/z* (relative intensity) 450 (M^+ + 1, 80), 395 (10), 379 (100), 371 (30), 352 (9); HRMS (ESIMS) calcd for $C_{27}H_{23}F_3NPH^+$ 450.1593, found 450.1585.

3,5-Di-*tert*-butyl-2-(3′-methyl-2′-pyridyl)phenyl Nonafluorobutanesulfonate (13). 3,5-Di-*tert*-butyl-2-(3′-methyl-2′-pyridyl)phenol[59a] (594 mg, 2.0 mmol) in anhydrous ether (3 mL) was added to the NaH (120 mg, 2.7 mmol) in anhydrous ether (7 mL) at 0 °C. Nonafluorobutanesulfonyl fluoride (1.2 g, 4.0 mmol) was then added under nitrogen at 0 °C. After complete addition, the reaction mixture was heated to reflux for 2 h. The reaction was cooled, followed by the addition of water (20 mL). The aqueous phase was extracted by diethyl ether (50 mL × 2). The combined organic phase was washed by water and brine and dried over $MgSO_4$. The solvent was removed by rotary evaporation, and the residue was purified by column chromatography on silica gel using a solvent mixture (hexane/ethyl acetate = 5:1) as the eluent to yield the 3,5-di-*tert*-butyl-2-(3′-methyl-2′-pyridyl)phenyl nonafluorobutanesulfonate (**13**) (984 mg, 85%) as a light yellow solid: R_f = 0.6 (hexane/ethyl acetate = 5:1); mp 48−50 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.16 (s, 9 H), 1.36 (s, 9 H), 2.11 (s, 3 H), 7.22 (d, 1 H, J = 0.9 Hz), 7.24 (dd, 1 H, J = 3.8 Hz, 7.4 Hz), 7.55 (d, 1 H, J = 7.5 Hz), 7.63 (d, 1 H, J = 1.6 Hz), 8.52 (d, 1 H, J = 3.9 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 19.2, 31.1, 32.3, 35.1, 37.1, 109.2−118.9 (m), 115.1, 123.1, 124.5, 129.3, 133.9, 137.6, 146.0, 148.0, 150.4, 152.7, 155.2; MS (FAB) *m/z* (relative intensity) 580 (M^+ + 1, 60), 564 (10), 297 (30), 282 (100), 266 (33); HRMS (ESIMS) calcd for $C_{24}H_{26}F_9NO_3SH^+$ 580.1562, found 580.1536.

2-(2′-Di(4-tolyl)phosphino-4′,6′-di-*tert*-butyl-1′-phenyl)-3-methylpyridine (14). The general procedure of palladium-catalyzed phosphination for **2** was used. 3,5-Di-*tert*-butyl-2-(3′-methyl-2′-pyridyl)phenyl trifluoromethanesulfonate (**1**) (858 mg, 2.0 mmol), palladium(II) acetate (45 mg, 0.2 mmol), tri(4-tolyl)phosphine (1.4 g, 4.6 mmol), and dry DMF (8 mL) were used to yield the 2-(2′-di(4-tolyl)phosphino-4′,6′-di-*tert*-butyl-1′-phenyl)-3-methylpyridine (**14**) (592 mg, 60%) as a white solid: R_f = 0.4 (toluene/ethyl acetate = 20:1); mp 123−125 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.12 (s, 9 H), 1.18 (s, 9 H), 1.94 (s, 3 H), 2.28 (s, 3 H), 2.32 (s, 3 H), 6.95−7.03 (m, 4 H), 7.07−7.11 (m, 5 H), 7.18 (t, 1 H, J = 7.2 Hz), 7.45 (d, 1 H, J = 7.2 Hz), 7.58 (d, 1 H, J = 1.9 Hz), 8.33 (d, 1 H, J = 4.2 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 20.1, 21.5, 31.1, 32.4, 34.8, 37.2, 122.5, 125.7, 128.7−128.9 (m), 129.9, 133.3 (d, J_{PC} = 20.2 Hz), 133.7 (d, J_{PC} = 21.1 Hz), 137.5 (d, J_{PC} = 10.2 Hz), 137.9, 144.9, 146.6, 149.5, 160.8; ^{31}P NMR (162 MHz, $CDCl_3$) δ −13.31; MS (EI) *m/z* (relative intensity) 493 (M^+, 60), 478 (95), 452 (10), 436 (100), 401 (50), 371 (40), 355 (35); HRMS (ESIMS) calcd for $C_{34}H_{40}NPH^+$ 494.2971, found 494.2951.

2-(2′-Di(4-methoxyphenyl)phosphino-4′,6′-di-*tert*-butyl-1′-phenyl)-3-methylpyridine (15). The general procedure of palladium-catalyzed phosphination for **2** was used. 3,5-Di-*tert*-butyl-2-(3′-methyl-2′-pyridyl)phenyl trifluoromethanesulfonate (**1**) (540 mg, 1.25 mmol), palladium(II) acetate (30 mg, 0.13 mmol), tri(4-methoxyphenyl)phosphine (1.01 g, 2.88 mmol), and dry DMF (5 mL) were used to yield the 2-(2′-di(4-methoxyphenyl)phosphino-4′,6′-di-*tert*-butyl-1′-phenyl)-3-methylpyridine (**15**) (394 mg, 60%) as a white solid: R_f = 0.4 (toluene/ethyl acetate = 10:1); mp 116−118 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.12 (s, 9 H), 1.19 (s, 9 H), 1.91 (s, 3 H), 3.76 (s, 3 H), 3.79 (s, 3 H), 6.76−6.85 (m, 4 H), 6.99−7.14 (m, 5 H), 7.20 (t, 1 H, J = 7.2 Hz), 7.45 (d, 1 H, J = 7.2 Hz), 7.58 (d, 1 H, J = 1.9 Hz), 8.33 (d, 1 H, J = 4.1 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 20.1, 31.2, 32.4, 34.8, 37.2, 55.1, 133.6−133.9 (m), 122.5, 125.6, 129.5, 134.8 (d, J_{PC} = 20.8 Hz), 135.3 (d, J_{PC} = 21.5 Hz), 137.1, 137.7 (d, J_{PC} = 10.4 Hz), 144.8, 146.6, 149.6, 159.7 (d, J_{PC} = 21.1 Hz); ^{31}P NMR (162 MHz, $CDCl_3$) δ −14.79; MS (FAB) *m/z* (relative intensity) 525 (M^+, 70), 511 (72), 494 (10), 469 (50), 435 (10), 419 (100), 402 (44), 388 (62); HRMS (ESIMS) calcd for $C_{34}H_{40}NO_2PH^+$ 526.2869, found 526.2855.

2-(2′-Di(4-*tert*-butylphenyl)phosphino-4′,6′-di-*tert*-butyl-1′-phenyl)-3-methylpyridine (16). The general procedure of palladium-catalyzed phosphination for **2** was used. 3,5-Di-*tert*-butyl-2-(3′-methyl-2′-pyridyl)phenyl trifluoromethanesulfonate (**1**) (214 mg, 0.5 mmol), palladium(II) acetate (11.2 mg, 0.05 mmol), tri(4-*tert*-butylphenyl)phosphine (495 mg, 1.15 mmol), and dry DMF (2 mL) were used to obtain 2-(2′-di(4-*tert*-butylphenyl)phosphino-4′,6′-di-*tert*-butyl-1′-phenyl)-3-methylpyridine (**16**) (159 mg, 55%) as a white solid: R_f = 0.5 (toluene/ethyl acetate = 15:1); mp 173−176 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.13 (s, 9 H), 1.17 (s, 9 H), 1.29 (s, 9 H), 1.32 (s, 9 H), 1.91 (s, 3 H), 7.00−7.03 (m, 1 H), 7.03−7.16 (m, 4 H), 7.23−7.30 (m, 5 H), 7.41 (d, 1 H, J = 7.2 Hz), 7.57 (d, 1 H, J = 1.8 Hz), 8.33 (d, 1 H, J = 4.2 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 20.3, 31.0, 31.2, 31.8, 32.4, 34.4, 34.5, 34.7, 37.2, 122.4, 124.8−125.0 (m), 125.5, 130.0, 133.1 (d, J_{PC} = 19.4 Hz), 133.3 (d, J_{PC} = 20.0 Hz), 134.2 (d, J_{PC} = 10.5 Hz), 134.9 (d, J_{PC} = 11.3 Hz), 136.9, 137.6 (d, J_{PC} = 10.1 Hz), 145.0, 146.4 (d, J_{PC} = 5.6 Hz), 149.3, 150.7, 151.2, 160.9 (d, J_{PC} = 5.5 Hz); ^{31}P NMR (162 MHz, $CDCl_3$) δ −14.50; MS (FAB) *m/z* (relative intensity) 578 (M^+ + 1, 70), 563 (100), 547 (12), 521 (98), 455 (38), 431

(45), 415 (41); HRMS (ESIMS) calcd for $C_{40}H_{52}NPH^+$ 578.3910, found 578.3920.

2-(2′-Di(3,5-dimethylphenyl)phosphino-4′,6′-di-*tert*-butyl-1′-phenyl)-3-methylpyridine (17). The general procedure of palladium-catalyzed phosphination for **2** was used. 3,5-Di-*tert*-butyl-2-(3′-methyl-2′-pyridyl)phenyl trifluoromethanesulfonate (**1**) (429 mg, 1.0 mmol), palladium(II) acetate (22 mg, 0.1 mmol), trixylylphosphine (796 mg, 2.3 mmol), and dry DMF (4 mL) were used to obtain the 2-(2′-di(3,5-dimethylphenyl)-phosphino-4′,6′-di-*tert*-butyl-1′-phenyl)-3-methylpyridine (**17**) (302 mg, 58%) as a white solid: $R_f = 0.5$ (toluene/ethyl acetate = 15:1); mp 89−91 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.14 (s, 9 H), 1.22 (s, 9 H), 1.86 (s, 3 H), 2.17 (s, 6 H), 2.21 (s, 6 H), 6.72 (s, 1 H), 6.74 (s, 1 H), 6.80 (s, 1 H), 6.82 (s, 2 H), 6.86 (s, 1 H), 7.16 (dd, 1 H, $J = 4.8, 7.6$ Hz), 7.28 (dd, 1 H, $J = 1.9$ Hz, $J_{PH} = 3.6$ Hz), 7.38 (dd, 1 H, $J = 7.5$ Hz, 0.8 Hz), 7.58 (d, 1 H, $J = 1.9$ Hz), 8.39 (dd, 1 H, $J = 4.7$ Hz, 1.1 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 20.1, 21.3, 31.1, 32.3, 34.8, 37.2, 122.2, 125.4, 129.7 (d, $J_{PC} = 5.2$ Hz), 130.4, 131.1−131.6 (m), 134.2 (d, $J_{PC} = 4.4$ Hz), 136.5, 136.9 (d, $J_{PC} = 6.8$ Hz), 137.2 (d, $J_{PC} = 6.8$ Hz), 137.4 (d, $J_{PC} = 10.3$ Hz), 137.9 (d, $J_{PC} = 12.1$ Hz), 138.3 (d, $J_{PC} = 12.8$ Hz), 142.1 (d, $J_{PC} = 32.4$ Hz), 145.3, 146.4 (d, $J_{PC} = 5.9$ Hz), 149.0, 161.4 (d, $J_{PC} = 6.7$ Hz); ^{31}P NMR (162 MHz, $CDCl_3$) δ −12.24; MS (EI) *m*/*z* (relative intensity) 522 ($M^+ + 1$, 45), 507 (100), 465 (82), 449 (11), 418 (40), 385 (27); HRMS (ESIMS) calcd for $C_{36}H_{44}NPH^+$ 522.3290, found 522.3288.

2-(2′-Di(3-methoxyphenyl)phosphino-4′,6′-di-*tert*-butyl-1′-phenyl)-3-methylpyridine (18). The general procedure of palladium-catalyzed phosphination for **2** was used. 3,5-Di-*tert*-butyl-2-(3′-methyl-2′-pyridyl)phenyl trifluoromethanesulfonate (**1**) (429 mg, 1.0 mmol), palladium(II) acetate (22 mg, 0.1 mmol), tri(3-methoxyphenyl)phosphine (810 mg, 2.3 mmol), and dry DMF (4 mL) were used to yield the 2-(2′-di(3-methoxyphenyl)phosphino-4′,6′-di-*tert*-butyl-1′-phenyl)-3-methylpyridine (**18**) (289 mg, 55%) as a white solid: $R_f = 0.5$ (toluene/ethyl acetate = 15:1); mp 90−92 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.13 (s, 9 H), 1.20 (s, 9 H), 1.88 (s, 3 H), 3.67 (s, 3 H), 3.69 (s, 3 H), 6.66−6.85 (m), 7.13−7.23 (m), 7.46 (d, 1 H, $J = 6.9$ Hz), 7.61 (d, 1 H, $J = 1.9$ Hz), 8.38 (d, 1 H, $J = 4.2$ Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 19.9, 31.0, 32.3, 34.8, 37.2, 55.1, 114.2 (d, $J_{PC} = 24.5$ Hz), 118.0 (d, $J_{PC} = 21.8$ Hz), 119.0 (d, $J_{PC} = 21.8$ Hz), 122.6, 125.7−125.9 (m), 126.3 (d, $J_{PC} = 19.9$ Hz), 128.9−129.2 (m), 130.0, 134.8, 136.9 (d, $J_{PC} = 9.8$ Hz), 137.4, 139.0 (d, $J_{PC} = 12.6$ Hz), 144.7, 146.8 (d, $J_{PC} = 5.5$ Hz), 149.8, 159.0 (d, $J_{PC} = 8.0$ Hz), 159.2 (d, $J_{PC} = 8.0$ Hz); ^{31}P NMR (162 MHz, $CDCl_3$) δ −9.84; MS (FAB) *m*/*z* (relative intensity) 525 (M^+, 70), 511 (78), 435 (20), 419 (100), 402 (45), 388 (62); HRMS (ESIMS) calcd for $C_{34}H_{40}NO_2PH^+$ 526.2820, found 526.2855.

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