Palladium-Catalyzed Amination of Aryl Triflates and Importance of Triflate Addition Rate

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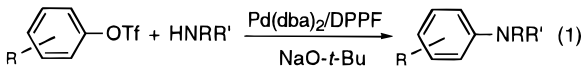
We report that a combination of DPPF (1,1-bis(diphenylphosphino)ferrocene) and $Pd(dba)_2$ leads to the amination of aryl triflates, a reaction that allows for the conversion of phenols to arylamines. A combination of BINAP and $Pd(dba)_2$ also catalyzes the amination of aryl triflates, but $P(o\text{-tolyl})_3$ complexes were not effective catalysts. In some cases, slow addition of the aryl triflate was necessary to prevent cleavage of the triflate and generation of phenol. We found that added halide, necessary in some cross-coupling chemistry of aryl sulfonates, was an unnecessary additive and even inhibited the amination chemistry.

Introduction

New reaction procedures and catalysts based on chelating ligands have made catalytic amination of aryl halides a convenient method for the preparation of a wide variety of arylamines.[1−8] For example, $P(o\text{-tolyl})_3$-ligated catalysts produce arylamines from aryl bromides and secondary amines in the presence of base.[3,7] Reactions of aryl iodides, however, gave lower yields.[9] Most recently, palladium complexes containing the chelating DPPF and BINAP have been shown to catalyze the formation of arylamines from aryl bromides and both primary and secondary amines.[2,6] DPPF-ligated catalysts are effective for such aminations with aryl bromides or iodides. BINAP-ligated catalysts lead to amination of either electron rich or electron poor aryl bromides with alkylamines.

The diversity of available phenols, the directed aromatic chemistry of protected phenols,[10] the simple conversion of phenols to aryl triflates,[11] and the demonstrated value of aryl triflates in Stille and Suzuki couplings[12−14] make it clear that the amination of aryl triflates will have significant synthetic value. Although the most activated aryl triflates are known to react slowly with secondary amines in the absence of catalyst in polar solvents or under high pressure,[15] the reaction times for uncatalyzed processes are on the order of days unless high pressure is used. In addition, the less activated aryl triflates are not suitable substrates for direct reaction with amines. Further, copper-mediated additions of amines to aryl halides that occur at high temperatures and in variable yields[16,17] have not been effectively extended to aryl triflates. We report that a combination of $Pd(dba)_2$ and a chelating ligand such as DPPF is an effective catalyst for the addition of amines to aryl triflates. In contrast, $P(o\text{-tolyl})_3$-ligated complexes that were first shown to catalyze addition of tin amides[5,18,19] and amines[3,7] to aryl halides do not catalyze the amination of aryl triflates.



(1)

Results and Discussion

We investigated the ability of DPPF-ligated palladium complexes to catalyze the amination of a variety of aryl triflates with anilines and alkylamines (eq 1). Our results are presented in Tables 1 and 2. Table 1 shows our results for aminations using aniline. Reaction of electron rich or electron poor aryl triflates with aniline in the presence of NaO-*t*-Bu and a combination of $Pd(dba)_2$ (dba = dibenzylideneacetone) and DPPF (DPPF = 1,1′-bis(diphenylphosphino)ferrocene) (catalyst **1**) in toluene solvent gave high yields of mixed diarylamines. The use of a combination of $Pd(dba)_2$ and BINAP (bis(diphenylphosphino)binaphthyl) (catalyst **2**) for aminations using aniline (Table 1, entry 7) gave yields that were similar to those obtained with DPPF. Reactions of *N*-alkyl anilines with aryl triflates catalyzed by $Pd(dba)_2$/DPPF gave yields that were lower than those obtained for the analogous aryl bromides (entry 4). The reduced arene benzophenone (11% isolated) was a major byproduct in these reactions.

Reaction yields were higher for the combination of $Pd(dba)_2$ and DPPF than for the catalyst precursor (DPPF)$PdCl_2$. For example, 4-hydroxybiphenyl, resulting from O−S bond cleavage of the triflate, was the dominant product formed from (DPPF)$PdCl_2$-catalyzed reactions of 4-*t*-Bu-aniline with 4-phenylphenyl triflate. In contrast to the amination of aryl halides, amination of aryl

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(8) Guram, A. S.; Buchwald, S. L. *J. Am. Chem. Soc.* **1994**, *116*, 7901.
(9) Wolfe, J. P.; Buchwald, S. L. *J. Org. Chem.* **1996**, *61*, 1133−1135.
(10) Snieckus, V. *Chem. Rev.* **1990**, *90*, 879−933.
(11) Stang, P. J.; Hanack, H.; Subramanian, L. R. *Synthesis* **1982**, 85−126.
(12) Echavarren, A. M.; Stille, J. K. *J. Am. Chem. Soc.* **1987**, *109*, 5478−5486.
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(15) Kotsuki, H.; Kobayashi, S.; Suenaga, H.; Nishizawa, H. *Synthesis* **1990**, 1145.
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(18) Kosugi, M.; Kameyama, M.; Migita, T. *Chem. Lett.* **1983**, 927−928.
(19) Kosugi, M.; Kameyama, M.; Sano, H.; Migita, T. *Nippon Kagaku Kaishi* **1985**, *3*, 547−551.

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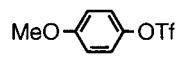
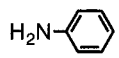
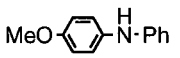
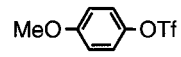
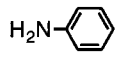
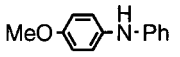
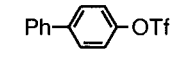
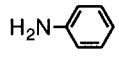
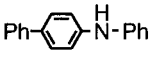
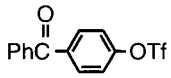
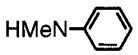
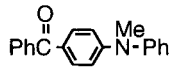
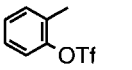
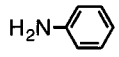
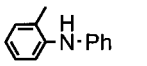
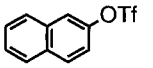
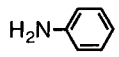
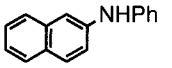
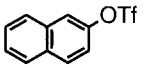
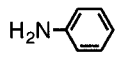
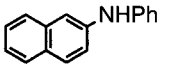
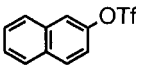
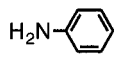
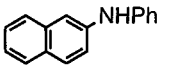
Table 1. Addition of Anilines to Aryl Triflates Catalyzed by a Combination of Pd(dba)$_2$ and Phosphine[a]

	Aryl Triflate	Amine	Product	Cat.[b]	Procedure[c]	Yield[d]
1				1.5% **1**	A	92%
2				5% **3**	A	< 5%
3				1.5% **1**	A	96%
4				5% **1**	B	59%
5				1.5% **1**	A	96%
6				1.5% **1**	A	97%
7				1.5% **2**	A	96%
8				1.5% **1**	A	53%[e]

[a]Reactions were conducted with 1.0 mol % catalyst, 3 mol % ligand, 1.5 equiv of amine, and 1.5 equiv of NaO-*t*-Bu in toluene solvent (except entry 8) at 85 °C for 8 h. [b]Catalysts: **1**, Pd(dba)$_2$/DPPF; **2**, Pd(dba)$_2$/BINAP; **3**, Pd(dba)$_2$/P(*o*-tolyl)$_3$. [c]Procedure A: arylamine isolated by sublimation; B: arylamine isolated by column chromatography using a gradient between 10:1 and 20:1 hexanes/EtOAc. See experimental section for details. [d]Except for entry 2, yields are an average of at least two runs and are reported for pure isolated material after chromatography or sublimation. Entry 2 was analyzed by GC. [e]Reaction run in THF solvent.

triflates gave higher yields in toluene solvent than in THF (entry 8), although modest yields were still obtained in THF solvent.

Results from reaction of alkyl amines with aryl triflates catalyzed by a combination of Pd(dba)$_2$ and DPPF are shown in Table 2. The reaction conditions were similar to those for amination of aryl halides and gave good to excellent yields of mixed *N*-alkyl anilines for most aryl triflates. As shown by entry 5, improved yields for amination of electron neutral aryl triflates with primary alkylamines were observed in reactions catalyzed by a combination of Pd(dba)$_2$ and BINAP (BINAP = 1,1′-bis-(diphenylphosphino)-2,2′-binaphthyl). Improved yields with the BINAP ligand have been observed previously for a similar combination of aryl halide and primary alkylamine.[2,6] Cyclic secondary amines gave excellent yields of tertiary amines with DPPF as ligand. Acyclic secondary amines, however, gave low yields and were not investigated extensively. We observed no reaction of the *p*-CN- or *p*-C(O)Ph-substituted aryl triflates in toluene solvent in the absence of palladium catalyst.

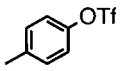
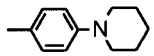
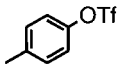
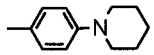
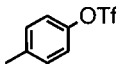
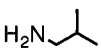
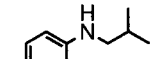
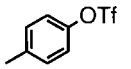
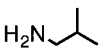
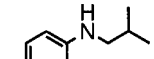
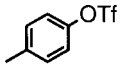
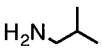
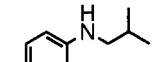
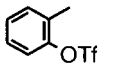
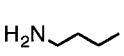
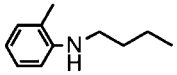
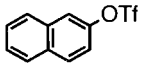
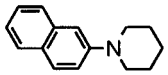
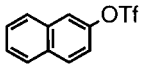
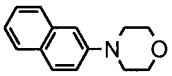
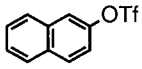
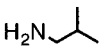
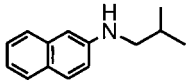
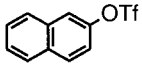
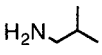
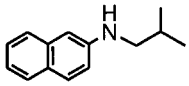
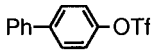
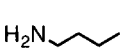
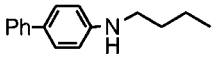
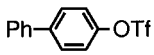
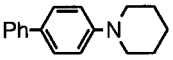
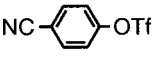
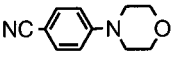
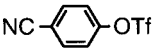
These most electron deficient aryl triflates were sensitive to formation of phenol under the basic reaction conditions. This triflate cleavage process appeared to occur primarily during the early stages of the reactions. Further, this cleavage was observed in the presence of amine and alkoxide in the absence of palladium. We were able to overcome this problem by slowly adding the aryl triflate to a solution of palladium catalyst, amine, and alkoxide base. By this procedure, yields for the reaction between alkylamines and electron poor aryl triflates were reproducibly higher than those for reactions conducted by heating a mixture of all components. For example, yields for reaction of naphthyl triflate and isobutylamine obtained by slow addition of triflate were 88%, about 15% higher than those obtained by the standard procedure. Further, yields for reactions of the triflate derived from 4-hydroxybenzonitrile and the triflate derived from 4-hydroxybenzophenone obtained from slow addition of the triflate were reproducibly higher than similar reactions reported in the accompanying paper in this journal issue by Buchwald. The yields were also more reproducible than the variable and often lower yields of arylamines obtained for reaction of these electron poor aryl triflates under the standard conditions in our hands. Yields for the reaction of *p*-tolyl triflate were not affected greatly by the rate of triflate addition, but *p*-cresol was not a major byproduct in this case.

One rationalization for the improved yields upon slow addition is straightforward. The cleavage of aryl triflate by alkoxide or alkoxide and amine is likely to be first order in aryl triflate. In contrast, the catalytic cycle is likely to have a resting state that is an aryl−palladium complex. Such a resting state has been observed for the amination of aryl halides.[3,4] In this case, the reaction would be zero order in aryl triflate. As a result, reducing the concentration of aryl triflate would not affect the rate of the amination process, but would decrease the rate of phenol formation. The selectivity for amination vs triflate cleavage would be improved.

Added halide is often necessary to obtain high yields of coupled products with aryl triflates in Stille chemistry, although this effect depends on the identity of the halide and is poorly understood.[20] In the case of our aryl triflate aminations, added LiCl, LiBr, or LiI was not necessary

(20) Farina, V.; Krishnan, B.; Marshall, D. R.; Roth, G. P. *J. Org. Chem.* **1993**, *58*, 5434 and references therein.

Table 2. Addition of Alkylamines to Aryl Triflates Catalyzed by a Combination of $Pd(dba)_2$ and Phosphine[a]

	Aryl Triflate	Amine	Product	Cat.[b]	Procedure[c]	Yield[d]
1				**1**	B	75%
2				**3**	B	<5%
3				**1**	B	45%[e]
4				**1**	C	42%[e]
5				**2**	B	80%
6				**1**	B	68%
7				**1**	A	90%
8				**1**	A	90%
9				**1**	B	68%
10				**1**	C	88%
11				**1**	B	50%
12				**1**	A	67%
13				**1**	A	60%[f]
14				**1**	C	63%
15				**1**	B	51%[f]
16				**1**	C	67%
17				**1**	B	57%[f]
18				**1**	C	83%

[a]Reactions were conducted with 5 mol % catalyst, 10 mol % ligand, 1.5 equiv of amine and 1.5 equiv of NaO-*t*-Bu in toluene solvent at 100 °C for 5 h, except for reactions involving slow addition of triflate that were complete with 1.5 mol % catalyst and 3-4 mol % ligand at 85 °C. [b]Catalysts: **1**, $Pd(dba)_2$/DPPF; **2**, $Pd(dba)_2$/BINAP; **3**, $Pd(dba)_2$/P(*o*-tolyl)$_3$. [c]Procedure A: arylamine isolated by sublimation; B: arylamine isolated by silica column chromatography using either a combination of hexanes/EtOAc or hexanes/ether; Procedure C: triflate added slowly to a mixture of the other reaction components at 85 °C. Product isolated by chromatography. See experimental section for details. [d]Except for entry 2, yields are the average of at least two runs for pure isolated material after chromatography or sublimation. Entry 2 was analyzed by GC. [e]Single experiment. [f]As discussed in the text, these yields were highly variable.

to observe high yields of amination products. In THF solvent, the presence of LiCl led to reduced yields, LiBr had little effect, and the presence of LiI led to complete inhibition of catalyst activity. It has been stated that

halide inhibits the amination of aryl halides.[4,8] Although the origins of the halide effects in the amination of aryl triflates are unclear at this time, the NaO-*t*-Bu base can presumably replace added halide in converting the potential palladium aryl triflate complex to a more stable intermediate or in inducing oxidative addition of the aryl triflate.

Our attempts to observe amination chemistry of aryl triflates with P(*o*-tolyl)$_3$-ligated palladium catalysts were unsuccessful, demonstrating the importance of our and Buchwald's recent discovery that palladium complexes with chelating ligands can catalyze amination chemistry. As shown in entry 2 of Tables 1 and 2, essentially no product was formed for reactions catalyzed by a combination of Pd(dba)$_2$ and P(*o*-tolyl)$_3$ (**3**). It appears that oxidative addition of the aryl triflate by the Pd(0) species is unfavorable and prohibits catalysis. In contrast to aryl bromides and iodides, which react rapidly with Pd[(P-*o*-tolyl)$_3$]$_2$ at room temperature,[5,21,22] phenyl triflate is unreactive toward Pd[(P-*o*-tolyl)$_3$]$_2$ at room temperature. Further, heating of the mixture for 3 h at 100 °C led to no clean reaction products and left unreacted Pd[P(*o*-tolyl)$_3$]$_2$. It is likely that the bent geometry of the (chelate)Pd(0) fragment, instead of the linear geometry of Pd[(P-*o*-tolyl)$_3$]$_2$,[21] accounts for its greater reactivity toward oxidative addition of aryl triflates.

In conclusion, it appears that many of the same factors that control the reaction yields for amination of aryl halides with DPPF- and BINAP-ligated palladium catalysts also control reaction yields of aryl triflates, with the exception of aryl triflates with strongly electron-accepting substituents. A stark contrast exists between catalysts containing chelating ligands and catalysts containing P(*o*-tolyl)$_3$ in their ability to catalyze the amination of aryl triflates. Added halide that is often beneficial in Stille coupling chemistry is detrimental to the amination of aryl triflates.

Experimental Section

General. Unless otherwise specified, all reagents were purchased from commercial suppliers and used without further purification. NaO-*t*-Bu was prepared by reaction of NaH and HO-*t*-Bu, which was dried over CaH_2. THF and toluene were distilled from sodium benzophenone ketyl under nitrogen. (DPPF)$PdCl_2$ was prepared by standard addition of phosphine to $(CH_3CN)_2PdCl_2$ formed by refluxing $PdCl_2$ in CH_3CN. Pd(dba)$_2$ was prepared by literature procedures.[23] The aryl triflates were prepared according to the methods of Stille[12] and have been prepared previously: 4-methoxyphenyl,[12] 2-naphthyl,[11] 4-cyanophenyl[24] , 4-benzoylphenyl,[15] 4-phenylphenyl,[25] 2-methylphenyl,[26] and 4-methylphenyl.[11]

Reactions were set-up in an inert atmosphere glove box, although it is equally effective to simply degas solvents before conducting the reactions under a nitrogen atmosphere. Amines were added by syringe without degassing the amine, with the exception of aniline, which had been distilled under N_2. Samples for elemental analysis were submitted to Atlantic Microlab, Inc. GC analyses were conducted on a Hewlett Packard 5890 instrument connected to a 3395 integrator.

Representative Example of Procedure A. *N*-(2-Naphthyl)piperidine[27] **(Table 2, entry 7).** Into a screw-capped test tube were weighed 15.1 mg (0.0272 mmol) of Pd(dba)$_2$, 30.6 mg (0.0545 mmol) of DPPF, and 78.2 mg (0.815 mmol) of NaO-*t*-Bu. The solid materials were suspended in 8 mL of toluene. 2-Naphthyl triflate (150 mg, 0.545 mmol) was dissolved in 1 mL of toluene and added to the test tube. The test tube was sealed with a cap containing a Teflon-lined septum and removed from the dry box. Piperidine (80.6 μL, 0.815 mmol) was added to the test tube by syringe. The reaction mixture was heated at 100 °C for 5 h. A TLC of the reaction mixture indicated complete consumption of the naphthyl triflate. The reaction mixture was cooled to room temperature, and the volatile materials were removed by rotary evaporation. Sublimation (120 °C, 0.1 Torr) of the resulting residue afforded the product as a white solid (109 mg, 95% yield). ^{1}H NMR: ($CDCl_3$) δ 1.65−1.68 (m, 2H), 1.74−1.80 (m, 4H), 3.26−3.30 (m, 4H), 7.20 (s, 1H), 7.28 −7.31 (m, 2H), 7.34 (t, 2.4 Hz, 1H), 7.70−7.80 (m, 3H); ^{13}C{^{1}H} NMR: ($CDCl_3$) δ 24.39, 25.90, 51.29, 110.73, 120.23, 123.31, 126.22, 126.79, 127.47, 128.52, 128.63, 134.72, 149.26.

Representative Example of Procedure B: 1-(4-Methylphenyl)piperidine[9] **(Table 2, entry 1).** Into a screw-capped test tube were weighed 29 mg (0.052 mmol) Pd(dba)$_2$, 55 mg (0.10 mmol) of DPPF, and 144 mg (1.5 mmol) of NaO-*t*-Bu. The solid materials were suspended in 7 mL of toluene. A solution of 4-Methylphenyl triflate (240 mg, 1.0 mmol) in 1 mL of toluene was added to the test tube. The test tube was sealed with a cap containing a Teflon-lined septum and removed from the dry box. Piperidine (148 μL, 1.5 mmol) was added to the test tube by syringe. The reaction mixture was heated at 100 °C for 5 h. A TLC of the reaction mixture indicated complete consumption of the starting triflate. The reaction mixture was cooled to room temperature, and the mixture was absorbed onto silica gel. Chromatography on a silica gel column using 50:1 hexanes:Et_2O afforded the product as a clear oil (135 mg, 77% yield). ^{1}H NMR: ($CDCl_3$) δ 1.62 (m, 2H), 1.78 (m, 4H), 2.33 (s, 3H), 3.15 (m, 4H), 6.93 (d, 8.5 Hz, 2H), 7.12 (d, 8.4 Hz, 2H); ^{13}C{^{1}H} NMR: ($CDCl_3$) δ 20.35, 24.25, 25.91, 51.25, 116.88, 128.62, 129.45, 150.23.

Representative Example of Procedure C: *N*-Isobutyl-2-naphthylamine (Table 2, entry 10). Into a screw-capped test tube were weighed 1.9 mg (0.0033 mmol) of Pd(dba)$_2$, 6.3 mg (0.011 mmol) of DPPF, and 77.4 mg (0.805 mmol) of NaO-*t*-Bu. The solid materials were suspended in 7 mL of toluene. The test tube was sealed with a cap containing a Teflon-lined septum and removed from the dry box. Isobutylamine (62.0 μL, 0.624 mmol) was added to the test tube by syringe. The reaction mixture was heated at 80 °C for 5−10 min. A solution of 2-naphthyl triflate (122 mg, 0.442 mmol) in 1 mL of toluene was added dropwise by syringe to the test tube over a 30 min period. A TLC of the reaction mixture indicated complete consumption of the starting triflate. The reaction mixture was cooled to room temperature, and the mixture was adsorbed onto silica gel. Chromatography on a silica gel eluting with 30:1 hexanes:Et_2O afforded the product as a pale yellow oil (77.6 mg, 88%). ^{1}H NMR: ($CDCl_3$) δ 1.04 (d, 6.6 Hz, 6H), 2.00 (m, 1H), 3.06 (d, 7.0 Hz, 2H), 6.90 (s, 1H), 6.94 (dd, 8.9, 2.2 Hz, 1H), 7.20 (dd, 7.7, 6.9 Hz, 1H), 7.62 (d, 9.0 Hz, 2H), 7.66 (d, 8.1 Hz, 1H); ^{13}C{^{1}H} NMR: ($CDCl_3$) δ 20.54, 27.91, 51.92, 104.33, 117.94, 121.76, 125.81, 126.24, 127.37, 127.57, 128.82, 135.23, 145.99.

Representative Example for Aminations with Aniline: 4-Methoxydiphenylamine[28] **(Table 1, entry 1).** Into a screw-capped test tube were weighed 2.0 mg (0.0038 mmol) of Pd(dba)$_2$, 6.0 mg (0.011 mmol) of DPPF, and 33.6 mg (0.350 mmol) of NaO-*t*-Bu. The solid materials were suspended in 8 mL of toluene. 4-Methoxyphenyl triflate (56.7 mg, 0.221 mmol) was dissolved in 1 mL of toluene and added to the test tube. Aniline (30.0 μL, 0.329 mmol) was added, and the test tube was sealed with a cap containing a Teflon-lined septum. The reactions were stirred in an 85 °C oil bath for 8 h. After this time, the volatile materials were removed under vacuum,

(21) Paul, F.; Patt, J.; Hartwig, J. F. *Organometallics* **1995**, *14*, 3030.
(22) Hartwig, J. F.; Paul, F. *J. Am. Chem. Soc.* **1995**, *117*, 5373.
(23) Rettig, M. F.; Maitlis, P. M. *Inorg. Synth.* **1992**, *28*, 110.
(24) Cabri, W.; Candiani, I.; Bedeschi, A.; Penco, S.; Santi, R. *J. Org. Chem.* **1992**, *57*, 1481−1486.
(25) Badone, D.; Cardamone, R.; Guzzi, U. *Tetrahedron Lett.* **1994**, *30*, 5477−5480.
(26) Reuter, H. K.; Scott, W. J. *J. Org. Chem.* **1993**, *58*, 4722−4726.
(27) Carmack, M.; Behforouz, M.; Berchtold, G. A.; Berkowitz, S. M.; Wiesler, D.; Barone, R. *J. Heterocycl. Chem.* **1989**, *26*, 1305−1318.
(28) King, F. E.; King, T. J.; Muir, I. H. M. *J. Chem. Soc.* **1946**, 5.

and the product was collected by sublimation (110 °C, 0.05 Torr) as a white solid (41.3 mg, 94%). ^{1}H NMR ($CDCl_3$) δ 3.82 (s, 3H), 5.51 (s, 1H), 6.86 (tt, 7.3, 1.0 Hz, 1H), 6.89 (dt, 8.9, 2.2 Hz, 2H), 6.93 (dd, 8.5, 1.0 Hz, 2H), 7.09 (dt, 8.9, 2.2 Hz, 2H), 7.24 (td, 7.4, 2.0 Hz, 2H); ^{13}C{^{1}H} NMR: ($CDCl_3$) δ 155.48, 145.38, 135.93, 129.50, 122.41, 119.77, 115.77, 114.87, 55.77.

Reaction of 4-Methoxyphenyl triflate with Aniline Using Pd(dba)$_2$ and P(*o*-tolyl)$_3$ (Table 1, entry 2). 4-Methoxyphenyl triflate (15.0 mg, 0.0586 mmol), Pd(dba)$_2$ (1.5 mg, 0.0030 mmol), P(*o*-tolyl)$_3$ (2.0 mg, 0.0066 mmol), and NaO-*t*-Bu (8.0 mg, 0.083 mmol) were suspended in 2 mL of toluene in a small screw-capped vial. The vial was sealed with a cap containing a Teflon-lined septum and removed from the dry box. Aniline (8.0 L, 0.083 mmol) was added to the reaction mixture by syringe. The vial was heated at 105 °C for 6 h. A GC/MS of the reaction mixture showed less than 5% conversion to product, 4-methoxydiphenylamine.

4-Phenyldiphenylamine[2] **(Table 1, entry 3).** Using the general procedure for anilines with 68.4 mg (0.226 mmol) of 4-biphenylyl triflate and 30.0 L (0.329 mmol) of aniline yielded the product as a white solid (55.4 mg, 99%). ^{1}H NMR: ($CDCl_3$) δ 5.80 (s, 1H), 7.00 (t, 7.3 Hz, 1H), 7.16 (d, 7.3 Hz, 2H), 7.18 (d, 8.5 Hz, 2H), 7.32−7.38 (m, 3H), 7.46 (dd, 7.8, 7.3 Hz, 2H), 7.56 (d, 8.5 Hz, 2H), 7.62 (d, 7.3 Hz, 2H); ^{13}C{^{1}H} NMR: ($CDCl_3$) δ 117.91, 118.28, 121.33, 126.61, 126.65, 128.04, 128.80, 129.46, 133.86, 140.94, 142.69, 142.99.

***N*-Methyl-*N*-phenyl-4-aminobenzophenone**[2] **(Table 1, entry 4).** The general procedure B using 200 mg (0.606 mmol) of 4-benzophenone triflate and 98.0 μL (0.989 mmol) of *N*-methylaniline gave 62% yield after silica gel chromatography using 5% EtOAc in hexanes. ^{1}H NMR: ($CDCl_3$) δ 3.41 (s, 3H), 6.80 (d, 8.9 Hz, 2H), 7.25−7.28 (m, 3H), 7.38−7.54 (m, 5H), 7.73−7.78 (m, 4H); ^{13}C{^{1}H} NMR: ($CDCl_3$) δ 40.43, 113.68, 125.84, 126.29, 127.06, 128.24, 129.71, 130.07, 131.50, 132.53, 139.24, 147.53, 152.78, 196.80.

***N*-(2-Methylphenyl)aniline**[29] **(Table 1, entry 5).** The general procedure B using 51.7 mg (0.215 mmol) of *o*-tolyl triflate and 29.4 μL (0.323 mmol) of aniline gave 96% yield of *N*-(2-methylphenyl)aniline after sublimation (130 °C, 0.1 Torr). ^{1}H NMR: ($CDCl_3$) δ 2.29 (s, 3H), 5.40 (br s, 1H), 7.00−6.90 (m, 4H), 7.17 (dd, 8.0, 7.0 Hz, 1H), 7.30−7.20 (m, 4H); ^{13}C-{^{1}H} NMR: ($CDCl_3$) δ 17.86, 117.39, 118.73, 120.41, 121.93, 126.71, 128.25, 129.25, 130.89, 141.16, 143.93.

***N*-Phenyl-2-naphthylamine (Table 1, entry 6).** Using the general procedure for anilines with 66.8 mg (0.242 mmol) of 2-naphthyl triflate and 30.0 μL (0.329 mmol) of aniline yielded the product as a white solid (52.3 mg, 99%), whose NMR spectra were identical to commercial material available from Aldrich.

***N*-Phenyl-2-naphthylamine Using Pd(dba)$_2$ and BINAP (Table 1, entry 7).** Into a screw-capped test tube were weighed 2.2 mg (0.0038 mmol) of Pd(dba)$_2$, 4.0 mg (0.0064 mmol) of BINAP, 34.7 mg (0.361 mmol) of NaO-*t*-Bu, and 70.0 mg (0.253 mmol) of 2-naphthyl triflate. The solid materials were suspended in 8 mL of toluene. Aniline (33.0 μL, 0.362 mmol) was added to the mixture, and the test tube was sealed with a cap containing a Teflon-lined septum. The reaction was stirred at 85 °C for 6 h. The volatile materials were removed under vacuum, and the product was collected by sublimation (110 °C, 0.05 Torr) as a white solid (53.4 mg, 96%).

***N*-Phenyl-2-naphthylamine Using Pd(dba)$_2$ and DPPF in THF Solvent (Table 1, entry 8).** The general procedure for anilines with 113.4 mg (0.411 mmol) of 2-naphthyl triflate and 62 μL (0.680 mmol) of aniline, but in 8 mL of THF solvent, gave 45.8 mg (51%) of *N*-phenyl-2-naphthylamine.

1-(4-Methylphenyl)piperidine Using Pd(dba)$_2$ and P(*o*-tolyl)$_3$ (Table 2, entry 2). 4-Methylphenyl triflate (15.0 mg, 0.0625 mmol), Pd(dba)$_2$ (1.5 mg, 0.003 mmol), P(*o*-tolyl)$_3$ (2.0 mg, 0.0066 mmol), and NaO-*t*-Bu (8.0 mg, 0.083 mmol) were suspended in 2 mL of toluene in a small screw-capped vial. The vial was sealed with a cap containing a Teflon-lined septum and removed from the dry box. Piperidine (9.0 μL, 0.090 mmol) was added to the reaction mixture by syringe. The vial was heated at 105 °C for 6 h. A GC/MS of the reaction mixture showed less than 5% conversion to product.

***N*-Isobutyl-4-methylaniline**[30] **Using Pd(dba)$_2$ and DPPF (Table 2, entry 3).** General procedure B with 120 mg (0.50 mmol) of 4-methylphenyl triflate and 75 μL (0.75 mmol) of isobutylamine gave the product as a pale yellow oil (37 mg, 45%). ^{1}H NMR ($CDCl_3$): δ 1.04 (d, 6.7 Hz, 6H), 1.97 (m, 1H), 2.03 (s, 3H), 2.97 (m, 2H), 3.63 (broad s, 1H), 6.66 (d, 8.0 Hz, 2H), 7.05 (d, 8.0 Hz, 2H); ^{13}C{^{1}H} NMR ($CDCl_3$): 20.45, 20.31, 27.95, 52.15, 112.78, 126.06, 129.64, 146.28.

***N*-Isobutyl-4-methylaniline**[30] **by Slow Triflate Addition (Table 2, entry 4).** General procedure C with 107.0 mg (0.469 mmol) of 4-methylphenyl triflate and 75 μL (0.76 mmol) isobutylamine gave *N*-isobutyl-4-methylaniline (34.8 mg, 42%).

***N*-Isobutyl-4-methylaniline Using Pd(dba)$_2$ and BINAP (Table 2, entry 5).** Into a screw-capped test tube were weighed 23 mg (0.042 mmol) of Pd(dba)$_2$, 51.7 mg (0.083 mmol) of BINAP, and 120 mg (1.25 mmol) of NaO-*t*-Bu. The solid materials were suspended in 7 mL of toluene. 4-Methylphenyl triflate (200 mg, 0.833 mmol) was dissolved in 1 mL of toluene and added to the test tube. The test tube was sealed with a cap containing a Teflon-lined septum and removed from the dry box. Isobutylamine (126 μL, 1.25 mmol) was added to the test tube by syringe. The reaction mixture was heated at 100 °C for 3 h. A TLC of the reaction mixture indicated complete consumption of the starting triflate. The reaction mixture was cooled to room temperature, and the mixture was absorbed onto silica gel. Chromatography on a silica gel column using 30:1 hexanes:Et_2O afforded the product as a pale yellow oil (112 mg, 82%).

***N*-Butyl-2-methylaniline**[31] **(Table 2, entry 6).** General procedure B using 55.1 mg (0.229 mmol) of *o*-tolyl triflate and 34.0 μL (0.344 mmol) of *n*-butylamine gave 68% yield after silica gel chromatography using 5% EtOAc in hexanes. ^{1}H NMR: ($CDCl_3$) δ 1.00 (t, 7.4 Hz, 3H), 1.48 (m, 2H), 1.68 (m, 2H), 2.15 (s, 3H), 3.18 (t, 7.1 Hz, 2H), 3.44 (bs, 1H), 6.60−6.70 (m, 2H) , 7.02 (d, 7.6 Hz, 1H), 7.14 (dd, 8.0, 7.5 Hz, 1H); ^{13}C-{^{1}H} NMR: ($CDCl_3$) δ 13.90, 17.40, 20.34, 31.69, 43.59, 109.54, 116.55, 121.60, 127.08, 129.94, 146.36.

4-(2-Naphthyl)morpholine[27] **(Table 2, entry 8).** General procedure A with 150.0 mg (0.545 mmol) of 2-naphthyl triflate and 70.9 μL (0.815 mmol) of morpholine gave the product as a white solid (103.5 mg, 90% yield). ^{1}H NMR: ($CDCl_3$) δ 3.28 (m, 4H), 3.94 (m, 4H), 7.14 (d, 2.4 Hz, 1H), 7.30−7.42 (m, 2H), 7.45 (dt, 7.7, 1.1 Hz, 1H), 7.70−7.77 (m, 3H); ^{13}C{^{1}H} NMR: ($CDCl_3$) δ 49.89, 67.03, 110.17, 118.99, 123.63, 126.43, 126.85, 127.53, 128.74, 128.90, 134.58, 149.16.

***N*-Isobutyl-2-naphthylamine (Table 2, entry 9).** General procedure B with 23.0 mg (0.083 mmol) of 2-naphthyl triflate and 9.9 μL (0.10 mmol) of isobutylamine gave 72% yield after silica gel chromatograph using 5% EtOAc in hexanes. ^{1}H NMR: ($CDCl_3$) δ 1.04 (d, 6.6 Hz, 6H), 2.00 (m, 1H), 3.06 (d, 7.0 Hz, 2H), 6.90 (s, 1H), 6.94 (dd, 8.9, 2.2 Hz, 1H), 7.20 (dd, 7.7, 6.9 Hz, 1H), 7.62 (d, 9.0 Hz, 2H), 7.66 (d, 8.1 Hz, 1H); ^{13}C{^{1}H} NMR: ($CDCl_3$) δ 20.54, 27.91, 51.92, 104.33, 117.94, 121.76, 125.81, 126.24, 127.37, 127.57, 128.82, 135.23, 145.99. HRMS calcd for $C_{14}H_{17}N$ (M^+) 199.1361. Found: 199.1361 Anal. Calcd for $C_{14}H_{17}N$: C, 84.37; H, 8.60; N, 7.03. Found: C, 84.13; H, 8.40; N, 6.85.

***N*-(4-Biphenylyl)butylamine (Table 2, entry 11).** General procedure B with 50.0 mg (0.166 mmol) of 4-biphenylyl triflate and 24.5 μL (0.249 mmol) of butylamine gave the product as a pale yellow oil (19.2 mg, 50% yield). ^{1}H NMR: ($CDCl_3$) δ 1.00 (t, 7.3 Hz, 3H), 1.47 (hex, 7.3 Hz, 2H), 1.66 (quin, 7.3 Hz, 2H), 3.21 (t, 7.0 Hz, 2H), 3.72 (s, 1H), 6.70 (d, 8.4 Hz, 2H), 7.28 (t, 7.3 Hz, 1H), 7.40−7.48 (m, 4H), 7.57 (d, 7.8 Hz, 2H); ^{13}C{^{1}H} NMR: ($CDCl_3$) δ 14.02, 20.40, 31.75, 43.76, 112.96, 126.04, 126.33, 127.99, 128.70, 130.00, 141.44, 148.04. HRMS calcd for $C_{16}H_{19}N$ (M^+) 225.1518. Found: 225.1516 Anal. Calcd for $C_{16}H_{19}N$: C, 85.29; H, 8.5; N, 6.22. Found: C, 85.14, H, 8.66, N, 5.99.

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***N*-(4-Biphenylyl)piperidine (Table 2, entry 12).** General procedure B with 150 mg (0.50 mmol) of 4-biphenylyl triflate and 79.0 μL (0.75 mmol) of piperidine gave the product as a white solid (78.8 mg, 67% yield). ^{1}H NMR: ($CDCl_3$) δ 1.61−1.68 (m, 2H), 1.72−1.82 (m, 4H), 3.25−3.33 (m, 4H), 7.00 (d, 8.5 Hz, 2H), 7.27 (d, 7.5 Hz, 1H), 7.42 (t, 7.5 Hz, 2H), 7.50 (d, 8.5 Hz, 2H), 7.56 (d, 7.5 Hz, 2H); ^{13}C{^{1}H} NMR: ($CDCl_3$) δ 24.34, 25.78, 50.82, 115.86, 116.81, 126.58, 126.68, 126.77, 128.37, 128.78. 141.04. HRMS calcd for $C_{17}H_{19}N$ (M^+) 237.1518. Found: 237.1517. Anal. Calcd for $C_{17}H_{19}N$: C, 86.03; H, 8.07; N, 5.9. Found: C, 85.94, H, 8.27, N, 5.75.

***N*-(4-Cyanophenyl)morpholine[15] (Table 2, entry 13).** General procedure A with 150.0 mg (0.598 mmol) of 4-cyanophenyl triflate and 78.0 μL (0.896 mmol) of morpholine gave the product as a white solid (67.5 mg, 60% yield). ^{1}H NMR: ($CDCl_3$) δ 3.26−3.29 (m, 4H), 3.83−3.86 (m, 4H), 6.86 (d, 8.8 Hz, 2H), 7.51 (d, 8.8 Hz, 2H); ^{13}C{^{1}H} NMR: ($CDCl_3$) δ 47.31, 66.52, 114.13, 116.35, 133.60, 134.31, 153.56.

***N*-(4-Cyanophenyl)morpholine[15] by Slow Addition of Triflate (Table 2, entry 14).** General procedure C with 158 mg (0.628 mmol) of 4-cyanophenyl triflate and 82.2 μL (0.942 mmol) of morpholine gave the product as a white solid (73.8 mg, 62% yield) after silica gel chromatography using a gradient of 10 to 20% EtOAc in hexanes.

***N*-Butyl-4-aminobenzonitrile[2] (Table 2, entry 15).** General procedure B using 248 mg (0.986 mmol) of 4-cyanophenyl triflate and 146 μL (1.48mmol) of *n*-butylamine gave 46% yield after silica gel chromatography using a gradient of 10 to 20% EtOAc in hexanes. ^{1}H NMR: ($CDCl_3$) δ 0.97 (t, 7.2 Hz, 3H), 1.43 (hex, 7.2 Hz, 2H), 1.62 (quin, 7.2 Hz, 2H), 3.14 (q, 7.2 Hz, 2H), 4.29 (s, 1H), 6.55 (d, 8.6 Hz, 2H), 7.40 (d, 8.6 Hz, 2H); ^{13}C{^{1}H} NMR: ($CDCl_3$) δ 13.91, 20.28, 31.33, 43.02, 98.29, 112.15, 120.71, 133.75, 151.67.

***N*-Butyl-4-aminobenzonitrile[2] by Slow Addition of Triflate (Table 2, entry 16).** General procedure C using 155 mg (0.617 mmol) of 4-cyanophenyl triflate and 91.0 μL (0.926 mmol) of *n*-butylamine gave 72.8 mg of product (68% yield) after silica gel chromatography using a gradient of 10 to 20% EtOAc in hexanes.

***N*-Butyl-4-aminobenzophenone[2] (Table 2, entry 17).** The general procedure B using 126 mg (0.381 mmol) of 4-benzophenone triflate and 56.5 μL (0.572 mmol) of *n*-butylamine gave 44% yield after silica gel chromatography using a gradient 5 to 10% EtOAc in hexanes. ^{1}H NMR: ($CDCl_3$) δ 0.97 (t, 7.3 Hz, 3H), 1.43 (hex, 7.4 Hz, 2H), 1.63 (quin, 7.3 Hz, 2H), 3.19 (t, 7.1 Hz, 2H), 4.28 (bs, 1H), 6.57 (d, 9.1 Hz, 2H), 7.44 (dd, 8.1, 7.0 Hz, 2H), 7.52 (t, 7.3 Hz, 1H), 7.72 (d, 7.2 Hz, 2H), 7.74 (d, 8.2 Hz, 2H); ^{13}C{^{1}H} NMR: ($CDCl_3$) δ 13.80, 20.15, 31.27, 43.04, 111.22, 125.81, 127.96, 129.37, 131.09, 132.97, 139.15, 152.11, 195.06.

***N*-Butyl-4-aminobenzophenone[2] (Table 2, entry 18).** The general procedure C using 149 mg (0.450 mmol) of 4-benzophenone triflate and 66.7 μL (0.675 mmol) of *n*-butylamine gave 99.6 mg of product (87% yield) after silica gel chromatography using 10% EtOAc in hexanes.

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