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Cu(II)-Mediated C−H Amidation and Amination of Arenes: Exceptional Compatibility with Heterocycles

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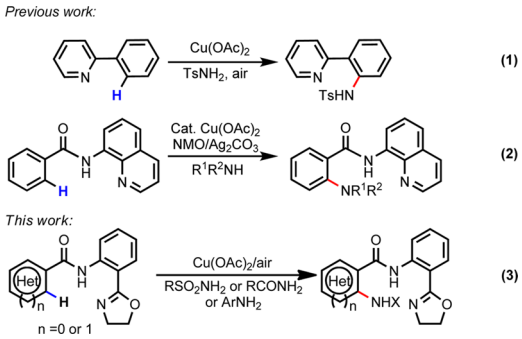
Supporting Information

ABSTRACT: A $Cu(OAc)_2$-mediated C−H amidation and amination of arenes and heteroarenes has been developed using a readily removable directing group. A wide range of sulfonamides, amides, and anilines function as amine donors in this reaction. Heterocycles present in both reactants are tolerated, making this a broadly applicable method for the synthesis of a family of inhibitors including 2-benzamidobenzoic acids and *N*-phenylaminobenzoates.

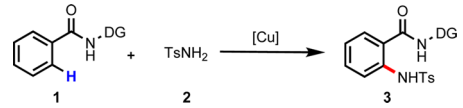
Diverse carbon−carbon and carbon−heteroatom bond-forming reactions have been developed using directed C−H functionalizations catalyzed by various transition metals.[1] Notably, Pd catalysts have demonstrated extraordinary versatility by participating in various redox catalysis including Pd(0)/Pd(II),[2a−c] Pd(II)/Pd(0),[2d,e] Pd(II)/Pd(IV),[2f] and Pd(II)/Pd(II)[2g] manifolds. It is highly desirable to develop analogous reactions using inexpensive metals such as copper[3−6] and iron.[7]



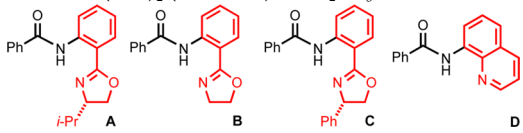
Significant progress has been made on both the development[5] and mechanistic studies[8] of Cu-catalyzed C−H functionalizations. We previously reported a diverse range of Cu-catalyzed or -mediated C−H activation/carbon−heteroatom-forming reactions of 2-phenylpyridine.[4a] It is likely that the diverse reactions we disclosed in that report proceed through different redox manifolds depending on the oxidants employed.[8] For example, Cu(III) species may be involved in C−H activation in the presence of highly oxidizing chacogenide-like oxidants,[4a,8] whereas a single-electron-transfer pathway may be operative in the presence of O_2 or a Ag^+ oxidant.[4a,8]

In light of the broadly encountered heteroatom poisoning effect in Pd-catalyzed C−H aminations, we became particularly intrigued by a single example of Cu-mediated amidation of 2-phenylpyridine with $TsNH_2$ under aerobic conditions.[4a] We wondered whether Cu-catalyzed or -mediated C−H amination could overcome these detrimental heteroatom effects. Here we report Cu-mediated amidation and amination of arenes and heteroarenes with a broad range of sulfonamides, amides, and

Table 1. Reaction Optimization[a]



entry	DG	[Cu]	base	temp, °C	yield, %[b]
1	**A**	$Cu(OAc)_2$	K_2CO_3	rt	8
2	**A**	$Cu(OAc)_2$	K_2CO_3	50	26
3	**A**	$Cu(OAc)_2$	K_2CO_3	80	64
4	**A**	$Cu(OAc)_2$	K_2CO_3	100	60
5	**A**	CuI	K_2CO_3	80	36
6	**A**	$CuCl_2$	K_2CO_3	80	34
7	**A**	$Cu(OTf)_2$	K_2CO_3	80	10
8	**A**	$Cu(acac)_2$	K_2CO_3	80	trace
9	**A**	$Cu(OAc)_2{\cdot}H_2O$	K_2CO_3	80	63
10	**A**	$Cu(OAc)_2$	Li_2CO_3	80	68
11	**A**	$Cu(OAc)_2$	Na_2CO_3	80	70
12	**B**	$Cu(OAc)_2$	Na_2CO_3	80	76
13	**C**	$Cu(OAc)_2$	Na_2CO_3	80	66
14	**D**	$Cu(OAc)_2$	Na_2CO_3	80	n.d.
15[c]	**B**	$Cu(OAc)_2$	Na_2CO_3	80	85
16[d]	**B**	$Cu(OAc)_2$	Na_2CO_3	80	65
17[c,e]	**B**	$Cu(OAc)_2$	Na_2CO_3	80	78
18[c,f]	***B***	***$Cu(OAc)_2$***	***Na_2CO_3***	***80***	***89 (87)***[g]
19[c,f]	**B**	$Cu(OAc)_2$ (0.05 mmol)	Na_2CO_3	80	40
20[c,f]	**B**	$Cu(OAc)_2$ (0.02 mmol)	Na_2CO_3	80	20



[a]Conditions: **1** (0.1 mmol), **2** (0.3 mmol), $Cu(OAc)_2$ (0.0 mmol), base (0.2 mmol), DMSO(1.0 mL), air, 8 h. [b]Yield determined by ^1H NMR analysis of crude reaction mixture using CH_2Br_2 as an internal standard. [c]**2** (0.2 mmol). [d]**2** (0.1 mmol). [e]4 h. [f]6 h. [g]Isolated yield is given in parentheses.

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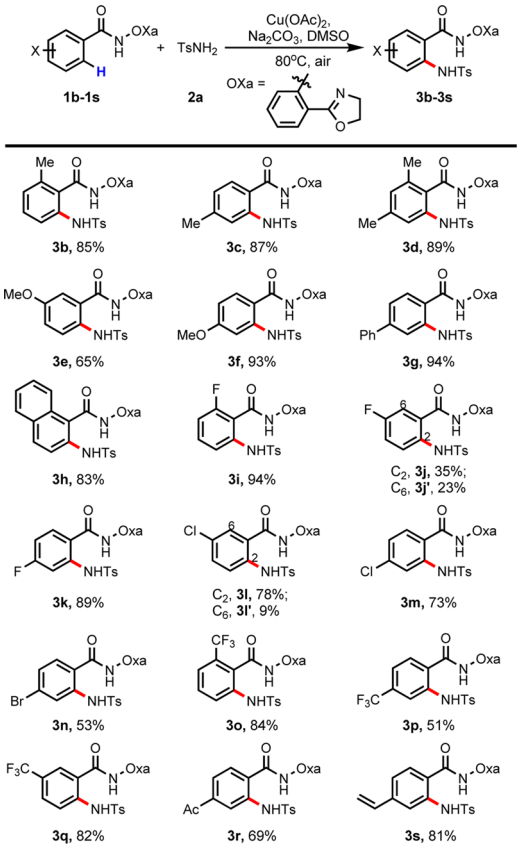
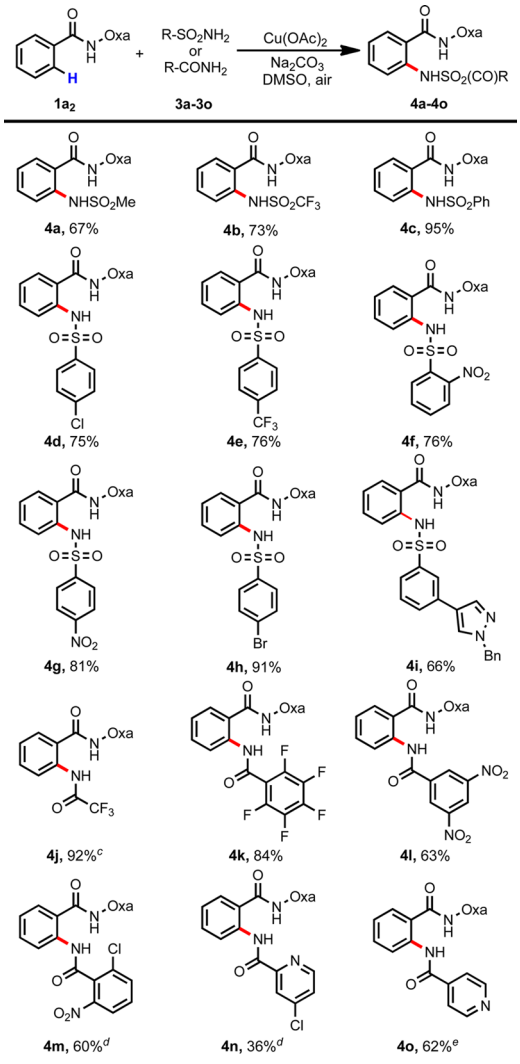
Table 2. Scope of Arenes[a,b]



[a]Conditions: **1b−1s** (0.1 mmol), **2** (0.2 mmol), $Cu(OAc)_2$ (0.1 mmol), Na_2CO_3 (0.2 mmol), DMSO (1.0 mL), 80 °C, air, 6 h. [b]Isolated yield.

Table 3. Scope of Amide Partners[a,b]



[a]Conditions: **1a** (0.1 mmol), **3a−3o** (0.2 mmol), $Cu(OAc)_2$ (0.1 mmol). Na_2CO_3 (0.2 mmol), DMSO (1.0 mL), 80 °C, air, 6 h. [b]Isolated yield. [c]O_2. [d]$Cu(OAc)_2$ (0.3 mmol), Ar, DMSO (2.0 mL). [e]$Cu(OAc)_2$ (0.2 mmol), Ar.

anilines under aerobic conditions. The reactivity hinges upon use of an amide-tethered oxazoline as a directing group (DG). Both oxidants and amine donors used are distinct from a recent important example reported by Daugulis (eq 2).[9] While the reaction remains substoichiometric in copper at this stage, the unprecedented level of compatibility of this reaction with heterocyclic arenes and amine donors is a practical and important feature attractive to medicinal chemists. Notably, coupling of heteroarenes with heterocyclic amines has not been demonstrated.[9] These amination and amidation products are structurally related to a family of inhibitors including *N*-phenylaminobenzozates.

Based on the Cu(II)-mediated C−H amination of 2-phenylpyridine, we tested various removable DGs for benzoic acids under these conditions but without success. In light of the well-known coordinating ability of oxazoline with Cu(II) catalysts, we decided to focus on an amide-tethered oxazoline DG and searched for suitable reaction conditions. We have previously shown in a Pd-catalyzed dehydrogenation that this DG forms a six-membered bis-dentate complex with Pd(II).[10] In our hands, the amide-oxazoline DG has displayed reactivity different from that of the Daugulis amide-quinoline DG, which forms a five-membered bis-dentate complex with a Pd(II) center.[11] Encouragingly, we found that C−H amidation of *N*-arylbenzamide substrate $\mathbf{1a_1}$ with 3 equiv of $TsNH_2$ proceeded in the presence of 1 equiv of $Cu(OAc)_2$ and 2 equiv of K_2CO_3 in DMSO at room temperature to give the desired amidation product $\mathbf{3a_1}$ in 8% yield (Table 1, entry 1). This yield was dramatically improved (64%) when we increased the reaction temperature to 80 °C. Among various copper catalysts that we screened, $Cu(OAc)_2$ gave the highest yield (entries 4−9). A small improvement was observed when K_2CO_3 was replaced by Li_2CO_3 or Na_2CO_3 to afford the amidation products in 68% and 70% yield, respectively (entries 10, 11).

With these conditions in hand, we subsequently investigated the influence of the DG (Table 1, entries 12−14) on the efficiency of our amination reaction. We found that the use of substrate $\mathbf{1a_2}$ containing less-hindered oxazoline DG **B** afforded amination product $\mathbf{3a_2}$ in 76% yield (entry 12). Interestingly, use of Daugulis's 8-aminoquinoline DG under the same conditions did not provide any desired product (entry 14). This result is consistent with our early observation[10] and suggests that the less rigid six-membered ring chelation and the electronic nature of the oxazoline confer a significant impact on the reactivity. We subsequently found that decreasing the quantity of $TsNH_2$ to 2 equiv is optimal, affording the amidation product in 85% yield (entries 15, 16). The reaction time can also be reduced to 6 h without affecting the yield (entries 17, 18). Unfortunately,

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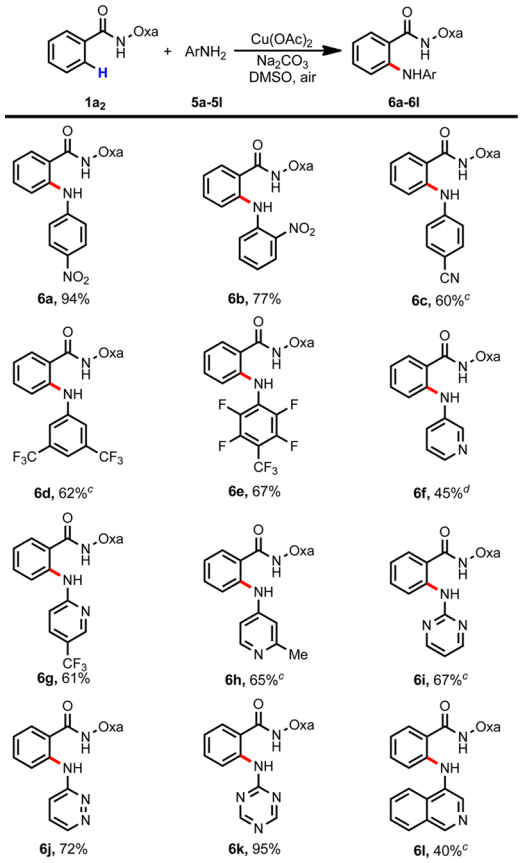
Table 4. Scope of Anilines[a,b]



[a]Conditions: **1a** (0.1 mmol), **5a–5l** (0.2 mmol), $Cu(OAc)_2$ (0.1 mmol), Na_2CO_3 (0.2 mmol), DMSO (1.0 mL), 80 °C, air, 6 h. [b]Isolated yield. [c]$Cu(OAc)_2$ (0.3 mmol), Ar, DMSO (2.0 mL). [d]$Cu(OAc)_2$ (0.2 mmol), Ar.

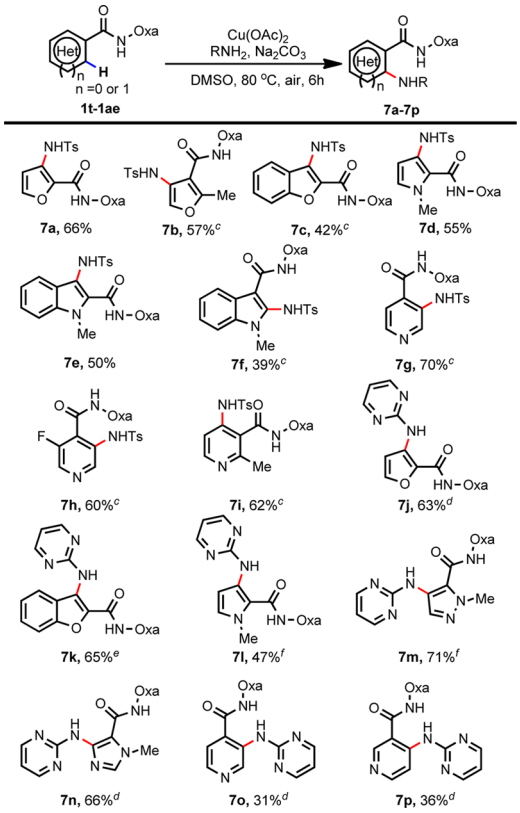
decreasing the amount of $Cu(OAc)_2$ in an attempt to render this reaction catalytic significantly lowered the yields (entries 19, 20).

As shown in Table 2, a variety of aryl substrates are compatible with this transformation. Electron-donating (**3b–3h**) and -withdrawing (**3i–3r**) functional groups are all tolerated in this transformation. The compatibility of a vinyl group is a valuable feature that remains problematic for Pd-catalyzed C–H activations (**3s**). It is also practically important that mono-amidated products were exclusively obtained in all cases. We also reacted $\mathbf{1a_2}$ in 1.0 g scale, and the desired product $\mathbf{3a_2}$ was obtained in 75% yield (see Supporting Information).

In addition to $TsNH_2$, a wide range of other sulfonamides are compatible with this transformation (Table 3). Notably, amidation with a heterocyclic sulfonamide affords the medicinally important precursor **4i** in 66% yield. Subsequent removal of the DG would lead to a concise synthesis of the allosteric inhibitor of dengue viral polymerase.[12] Similarly, a variety of electron-deficient amides are also effective coupling partners (**4j–4m**). Amidation with electron-neutral carboximides under current conditions, however, gave the desired products in <10% yields.

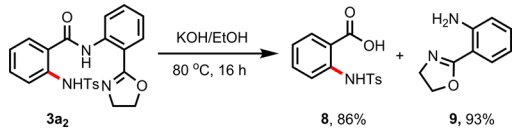
To our surprise, the pyridyl-containing amide also undergoes amidation to give the desired product **4o** in 62% yield, further indicating the potential of this reaction in circumventing poisoning by Lewis basic heterocycles. Notably, a family of PqsD inhibitors is structurally based on 2-benzamidobenzoic acids.[13]

Table 5. Exceptional Compatibility with Heterocycles[a,b]



[a]Conditions: **1t–1k** (0.1 mmol), RNH_2 (0.2 mmol), $Cu(OAc)_2$ (0.1 mmol), Na_2CO_3 (0.2 mmol), DMSO (1.0 mL), 80 °C, air, 6 h. [b]Isolated yield. [c]$Cu(OAc)_2$ (0.2 mmol), 50 °C, air, 24 h. [d]$Cu(OAc)_2$ (0.2 mmol), 2 h. [e]$Cu(OAc)_2$ (0.2 mmol), 1 h. [f]$Cu(OAc)_2$ (0.2 mmol).

Scheme 1. Directing Group Removal



In light of the importance of *N*-phenylaminobenzoates as therapeutic agents for neurodegenerative diseases,[14] we examined the use of anilines as coupling partners (Table 4). We found benzoic-acid-derived amide substrate $\mathbf{1a_2}$ is aminated with a wide range of electron-deficient anilines to give the *ortho*-aminated products in good to excellent yields (**6a–6e**). Although anilines that do not contain electron-withdrawing substituents are poor amine donors, affording the desired products in <10% yields, various heteroanilines are well tolerated in this reaction. The use of aminopyridines and aminoquinoline provides moderate yields of the desired products (**6f–6h**, 40–65%). 2-Aminopyrimidine, 3-aminopyridazine, and 2-amino-1,3,5-triazine are effective coupling partners, affording the corresponding products in good to excellent yields (67–95%, **6i–6k**).

The successful use of heterocyclic amine donors prompted us to examine the compatibility of this reaction with heteroaryl substrates (Table 5). A recent example of Cu-catalyzed directed C–H amination uses a single pyridine substrate containing a methyl group at the 2-position (56% yield).[9] Directed arylation of a pyridine substrate at 135 °C with 3 equiv of $Cu(OAc)_2$ was also reported (34% yield).[5u] We were pleased to find that amidation of a wide range of heteroarenes including furan,

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benzofuran, pyrole, indole, and pyridine proceeds smoothly to give the corresponding amidation products in moderate to good yields (**7a**−**7i**). Unfortunately, thiophene-based substrates decompose under these conditions. Considering the frequent presence of multiple heterocycles within drug molecules, we tested the coupling of heteroarenes with heteroanilines. Again, amination of heteroarenes such as furan, benzofuran, pyrole, pyrazole, and imidazole gave the desired products in moderate to good yields (**7j**−**7n**) except for a single example (**7o**), making this method broadly useful for synthesis of a family of biologically active 2-benzamidobenzoic acids and *N*-phenylaminobenzoates.[12−14] Interestingly, amination of pyridine substrate **1ae** occurs predominantly at the 4-position to give **7p** selectively in 36% yield. In most cases, the remaining heterocyclic starting materials decomposed. Removal of this amide−oxazoline DG was demonstrated by treating product $\mathbf{3a}_2$ with 2 N KOH/EtOH at 80 °C to release the corresponding carboxylic acid and oxazolyamide DG in good yields (Scheme 1).

In summary, we have developed a copper(II)-mediated C−H amidation and amination with a variety of sulfonamides, amides, and anilines. The exceptional compatibility of this amination with multiple heteroatoms present in both reactants renders this reaction highly valuable for the synthesis of medicinally important compounds using readily available benzoic acids.

■ ASSOCIATED CONTENT

Supporting Information

Experimental procedures and spectral data. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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■ REFERENCES

(1) Selected reviews on C−H functionalization using transition metals: (a) Kakiuchi, F.; Sekine, S.; Tanaka, Y.; Kamatani, A.; Sonoda, M.; Chatani, N.; Murai, S. *Bull. Chem. Soc. Jpn.* **1995**, *68*, 62. (b) Daugulis, O.; Do, H.-Q.; Shabashov, D. *Acc. Chem. Res.* **2009**, *42*, 1074. (c) Chen, X.; Engle, K. M.; Wang, D.-H.; Yu, J.-Q. *Angew. Chem., Int. Ed.* **2009**, *48*, 5094. (d) Giri, R.; Shi, B.-F.; Engle, K. M.; Maugel, N.; Yu, J.-Q. *Chem. Soc. Rev.* **2009**, *38*, 3242. (e) Lyons, T. W.; Sanford, M. S. *Chem. Rev.* **2010**, *110*, 1147. (f) Colby, D. A.; Bergman, R. G.; Ellman, J. A. *Chem. Rev.* **2010**, *110*, 624. (g) Wencel-Delord, J.; Dröge, T.; Liu, F.; Glorius, F. *Chem. Soc. Rev.* **2011**, *40*, 4740. (h) Arockiam, P. B.; Bruneau, C.; Dixneuf, P. H. *Chem. Rev.* **2012**, *112*, 5879. (i) Ackermann, L. *Acc. Chem. Res.* **2014**, *47*, 281−295.

(2) Pd-catalyzed C−H functionalizations via various redox manifolds: (a) Baudoin, O.; Herrbach, A.; Guéritte, F. *Angew. Chem., Int. Ed.* **2003**, *42*, 5736. (b) Campeau, L. S.; Rousseaux, S.; Fagnou, K. *J. Am. Chem. Soc.* **2005**, *127*, 18020. (c) Wasa, M.; Engle, K. M.; Yu, J.-Q. *J. Am. Chem. Soc.* **2009**, *131*, 9886. (d) Jia, C.; Piao, D.; Oyamada, J.; Lu, W.; Kitamura, T.; Fujiwara, Y. *Science* **2000**, *287*, 1992. (e) Chen, X.; Goodhue, C. E.; Yu, J.-Q. *J. Am. Chem. Soc.* **2006**, *128*, 12634. (f) Ball, N. D.; Kampf, J. W.; Sanford, M. S. *J. Am. Chem. Soc.* **2010**, *132*, 2878. (g) Ma, S.; Villa, G.; Thuy-Boun, P. S.; Homs, A.; Yu, J.-Q. *Angew. Chem., Int. Ed.* **2014**, *53*, 734.

(3) (a) Stoichiometric hydroxylation of *N*-benzoyl-2-methylalanine using Cu(0)/trimethylamine *N*-oxide: Reinaud, O.; Capdevielle, P.; Maumy, M. *J. Chem. Soc., Chem. Commun.* **1990**, 566. (b) Stoichiometric acetoxylation of *p*-methoxyphenol using $Cu(OAc)_2$: Takizawa, Y.; Tateishi, A.; Sugiyama, J.; Yoshida, H.; Yoshihara, N. *J. Chem. Soc., Chem. Commun.* **1991**, 104.

(4) (a) Chen, X.; Hao, X.-S.; Goodhue, C. E.; Yu, J.-Q. *J. Am. Chem. Soc.* **2006**, *128*, 6790. (b) Uemura, T.; Imoto, S.; Chatani, N. *Chem. Lett.* **2006**, *35*, 842. (c) Chen, X.; Dobereiner, G.; Hao, X.-S.; Giri, R.; Maugel, N.; Yu, J.-Q. *Tetrahedron* **2009**, *65*, 3085. (d) John, A.; Nicholas, K. M. *J. Org. Chem.* **2011**, *76*, 4158.

(5) Development of Cu-catalyzed C−H functionalizations toward synthetic applications: (a) Brasche, G.; Buchwald, S. L. *Angew. Chem., Int. Ed.* **2008**, *47*, 1932. (b) Ueda, S.; Nagasawa, H. *Angew. Chem., Int. Ed.* **2008**, *47*, 6411. (c) Phipps, R. J.; Grimster, N. P.; Gaunt, M. J. *J. Am. Chem. Soc.* **2008**, *130*, 8172. (d) Ban, I.; Sudo, T.; Taniguchi, T.; Itami, K. *Org. Lett.* **2008**, *10*, 3607. (e) Mizuhara, T.; Inuki, S.; Oishi, S.; Fujii, N.; Ohno, H. *Chem. Commun.* **2009**, 3413. (f) Monguchi, D.; Fujiwara, T.; Furukawa, H.; Mori, A. *Org. Lett.* **2009**, *11*, 1607. (g) Wang, Q.; Schreiber, S. L. *Org. Lett.* **2009**, *11*, 5178. (h) Huffman, L. M.; Stahl, S. S. *J. Am. Chem. Soc.* **2008**, *130*, 9196. (i) Yang, L.; Lu, Z.; Stahl, S. S. *Chem. Commun.* **2009**, 6460. (j) Klein, J. E. M. N.; Perry, A.; Pugh, D. S.; Taylor, R. J. K. *Org. Lett.* **2010**, *12*, 3446. (k) Shuai, Q.; Deng, G.; Chua, Z.; Bohle, D. S.; Li, C.-J. *Adv. Synth. Catal.* **2010**, *352*, 632. (l) Casitas, A.; King, A. E.; Parella, T.; Costas, M.; Stahl, S. S.; Ribas, X. *Chem. Sci.* **2010**, *1*, 326. (m) Neumann, J. J.; Suri, M.; Glorius, F. *Angew. Chem., Int. Ed.* **2010**, *49*, 7790. (n) Miyasaka, M.; Hirano, K.; Satoh, T.; Kowalczyk, R.; Bolm, C.; Miura, M. *Org. Lett.* **2011**, *13*, 359. (o) Parsons, A. T.; Buchwald, S. L. *Angew. Chem., Int. Ed.* **2011**, *50*, 9120. (p) Tran, L. D.; Popov, I.; Daugulis, O. *J. Am. Chem. Soc.* **2012**, *134*, 18237. (q) Ni, Z.-K.; Zhang, Q.; Xiong, T.; Zheng, Y.-Y.; Li, Y.; Zhang, H.-W.; Zhang, J.-P.; Liu, Q. *Angew. Chem., Int. Ed.* **2012**, *51*, 1244. (r) Roane, J.; Daugulis, O. *Org. Lett.* **2013**, *15*, 5842. (s) Gallardo-Donaire, J.; Martin, R. *J. Am. Chem. Soc.* **2013**, *135*, 9350. (t) Bhadra, S.; Dzik, W. I.; Goosßen, L. J. *Angew. Chem., Int. Ed.* **2013**, *52*, 2959. (u) Nishino, M.; Hirano, K.; Satoh, T.; Miura, M. *Angew. Chem., Int. Ed.* **2013**, *52*, 4457.

(6) Seminal work on Cu-catalyzed carbon−heteroatom bond formation from aryl halides or aryl borons: (a) Kiyomori, A.; Marcoux, J.-F.; Buchwald, S. L. *Tetrahedron Lett.* **1999**, *40*, 2657. (b) Maiti, D.; Buchwald, S. L. *J. Am. Chem. Soc.* **2009**, *131*, 17423. (c) Ma, D.; Cai, Q. *Acc. Chem. Res.* **2008**, *41*, 1450. (d) Chan, D. M. T.; Monaco, K. L.; Wang, R.-P.; Winters, M. P. *Tetrahedron Lett.* **1998**, *39*, 2933. (e) Lam, P. Y. S.; Clark, C. G.; Saubern, S.; Adams, J.; Winters, M. P.; Chan, D. M. T.; Combs, A. *Tetrahedron Lett.* **1998**, *39*, 2941. (f) Evans, D. A.; Katz, J. L.; West, T. R. *Tetrahedron Lett.* **1998**, *39*, 2937.

(7) (a) Matsumoto, A.; Ilies, L.; Nakamura, E. *J. Am. Chem. Soc.* **2011**, *133*, 6557. (b) Asako, S.; Ilies, L.; Nakamura, E. *J. Am. Chem. Soc.* **2013**, *135*, 17755. (c) Shang, R.; Ilies, L.; Matsumoto, A.; Nakamura, E. *J. Am. Chem. Soc.* **2013**, *135*, 6030. (d) Matsubara, T.; Asako, S.; Ilies, L.; Nakamura, E. *J. Am. Chem. Soc.* **2014**, *136*, 646.

(8) (a) Wendlandt, A. E.; Suess, A. M.; Stahl, S. S. *Angew. Chem., Int. Ed.* **2011**, *50*, 11062. (b) Huffman, L. M.; Casitas, A.; Font, M.; Canta, M.; Costas, M.; Ribas, X.; Stahl, S. S. *Chem.—Eur. J.* **2011**, *17*, 10643. (c) Suess, A. M.; Ertem, M. Z.; Cramer, C. J.; Stahl, S. S. *J. Am. Chem. Soc.* **2013**, *135*, 9797.

(9) Tran, L. D.; Roane, J.; Daugulis, O. *Angew. Chem., Int. Ed.* **2013**, *52*, 6043.

(10) Giri, R.; Maugel, N. L.; Foxman, B. M.; Yu, J.-Q. *Organometallics* **2008**, *27*, 1667.

(11) (a) Zaitsev, V. G.; Shabashov, D.; Daugulis, O. *J. Am. Chem. Soc.* **2005**, *127*, 13154. (b) Shabashov, D.; Daugulis, O. *J. Am. Chem. Soc.* **2010**, *132*, 3965.

(12) Yin, Z.; et al. *J. Med. Chem.* **2009**, *52*, 7934.

(13) Weidel, E.; et al. *J. Med. Chem.* **2013**, *56*, 6146.

(14) (a) Adeniji, A. O.; et al. *J. Med. Chem.* **2012**, *55*, 2311. (b) Lawrence, H. R.; et al. *J. Med. Chem.* **2012**, *55*, 7392. (c) Suzuki, T.; et al. *J. Med. Chem.* **2012**, *55*, 5760.