Suzuki-Miyaura Cross-Coupling Reactions of Unactivated Alkyl Halides Catalyzed by a Nickel Pincer Complex

Thomas Di Franco, Nicolas Boutin, Xile Hu*

Laboratory of Inorganic Synthesis and Catalysis, Institute of Chemical Sciences and Engineering, Ecole Polytechnique Fédérale de Lausanne (EPFL), ISIC-LSCI, BCH 3305, Lausanne, CH 1015, Switzerland

Fax: +41 (0)21 693 93 05

E-mail: xile.hu@epfl.ch

Received: The date will be inserted once the manuscript is accepted.

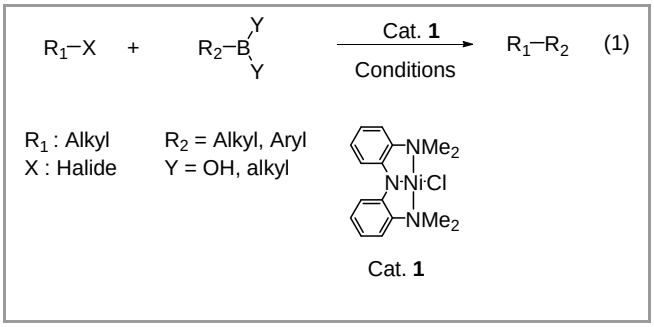
Abstract: A nickel (II) pincer complex, [($^{Me}N_2N$)Ni-Cl], was used to catalyze alkyl-alkyl and alkyl-aryl Suzuki-Miyaura coupling reactions of unactivated alkyl halides. The coupling of alkyl-(9-borabicyclononane) and phenyl-(9-borabicyclononane) reagents with alkyl halides was achieved in modest to good yields. The reactions tolerated a variety of useful functional groups including ester, ether, furan, thioether, acetal, boc groups.

Key words: cross-coupling, nickel, alkyl halides, pincer complex, Suzuki-Miyaura coupling

Carbon-carbon bond-formation reactions are powerful and important synthetic tools in chemistry.[1] These reactions can play a key role in the synthesis of pharmaceuticals, agrochemicals and organic materials. Metal-catalyzed cross-coupling between organoboron derivatives and carbon electrophiles, known as Suzuki-Miyaura coupling,[2] is one of the most advantageous reactions for C-C bond formation. Its wide use is owing to the abundance of commercially available boron reactants, their relative stability, non-toxic nature and functional-group tolerance. Compared with aryl, vinyl and alkynyl halides and pseudo-halides, unactivated alkyl halides represent a more difficult class of electrophiles for the Suzuki-Miyaura coupling. That is due to their slow rate of oxidative addition and their tendency to participate in competitive side reactions such as β-hydride elimination or hydrodehalogenation. Therefore, the development of cross-coupling of unactivated alkyl halides was hindered compared with those of aryl and vinyl electrophiles. In 1992, Suzuki and coworkers described the first palladium-catalyzed alkyl-alkyl cross-coupling of non-activated alkyl halide.[3] However, the reactions occurred only with primary alkyl iodides; neither secondary alkyl iodides nor alkyl bromides react under these conditions and significant hydrodehalogenation of the electrophile was observed. In 2001 the first efficient method for Suzuki-Miyaura coupling of non-activated alkyl electrophiles was reported by Fu and coworkers.[4] Coupling of alkyl-(9-BBN) reagents with unactivated alkyl bromides was achieved with a $Pd(OAc)_2/PCy_3$ catalyst system. Since then, the majority of the reported sp^3-sp^3 Suzuki-Miyaura cross-coupling reactions have been done using palladium catalysts, with phosphine ligands[5] or N-heterocyclic carbene ligands.[6] There are only a few methods for base metal-catalyzed Suzuki-Miyaura couplings with non-activated electrophiles. Fu and coworkers successfully developed systems using nickel catalysts to perform cross-coupling of alkyl electrophiles such as unactivated secondary alkyl halides,[7] unactivated homobenzylic halides[8] or unactivated secondary alkyl chlorides.[9] Liu and coworkers reported in 2011 a copper-catalyzed cross-coupling of primary non-activated alkyl electrophiles with organoboron reagents.[10] In the presence of LiO*t*-Bu as a base, CuI could efficiently catalyze the cross-coupling of primary alkyl tosylates and bromides in moderate yields. One year later, the first iron-catalyzed alkyl-alkyl Suzuki-Miyaura coupling reaction was reported by Nakamura and coworkers.[11] The use of a $[Fe(acac)_3]$/Xantphos catalyst and *i*-PrMgCl as an activator for trialkylboranes afforded the coupling of primary and secondary alkyl halides in a highly chemoselective manner.

Our group has developed a Nickel (II) complex with an amidobis(amine) pincer ligand, [($^{Me}N_2N$)Ni-Cl] (**1**),[12] which has shown a high efficiency in Kumada-Corriu-Tamao coupling[13,14] and C-H functionalization reactions[15,16] using unactivated alkyl halides as electrophiles. This well-defined Nickel complex affords broad substrate scope and high functional group tolerance. Moreover, it was shown that β-hydride elimination of [($^{Me}N_2N$)Ni-alkyl] complexes is kinetically accessible but thermodynamically unfavorable.[17]

Due to the versatility of the [($^{Me}N_2N$)Ni-Cl] pincer complex **1**, it is interesting to continue exploring its reactivity in other cross-coupling reactions. The aim of this work was to develop conditions to use complex **1** in Suzuki-Miyaura cross-coupling reactions of unactivated alkyl halides (eq. 1).

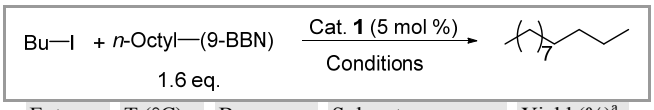


The 9-borabicyclononane (9-BBN) reagents are the most reactive boron species and are often used despite

their limited stability and their high air and moisture sensibility. Due to their high reactivity, they are good partners for Suzuki-Miyaura coupling with the less reactive alkyl electrophiles.

After a large screening of reaction conditions, it was established that complex **1** was efficient for the alkyl-alkyl cross-coupling of *n*-butyl iodide with octyl-(9-BBN). Dodecane was formed as the major product. The best results were obtained using 5 mol % of catalyst **1**, 1.6 equivalent of NaOH as a base and 1,4-dioxane as solvent. The reactions were heated for 24h at 80°C (Table 1, Entry 2).

Table 1 Optimization of Alkyl-Alkyl Suzuki Cross-Coupling Reaction between Octyl-(9-BBN) and *n*-Butyl Iodide



Entry	T (°C)	Base	Solvent	Yield (%)[a]
1	r.t.	NaOH	1,4-Dioxane	10
2	80	NaOH	1,4-Dioxane	66[b]
3	100	NaOH	1,4-Dioxane	0
4	80	KOH	1,4-Dioxane	33
5	80	LiOH	1,4-Dioxane	20
6	80	NaOMe	1,4-Dioxane	36
7	80	LiOEt	1,4-Dioxane	37
8	80	NaO*i*-Pr	1,4-Dioxane	29
9	80	NaOH	DMF	22
10	80	NaOH	*Tert*-butanol	28
11	80	NaOH	Butan-1-ol	5
12	80	NaOH	*Tert*-amyl alcohol	41
13	80	NaOH	*Iso*-propanol	21

[a] GC-MS Yield relative to the alkyl halide
[b] Yield was 50% after 15h, and 64 % after 48h (separate experiments)

Trial reactions at room temperature showed sodium hydroxide as the best base (Table 1, Entry 1). When temperature was increased to 80°C, the yield increased to 66% (Table 1, Entry 2). If the reaction was heated at 100°C no product was obtained (Table 1, Entry 3). This result could be explained by the previous studies on the thermal stability of nickel alkyl complex [($^{Me}N_2N$)Ni-Et]. That complex is stable up to 80°C but undergoes decomposition when heated at 100°C in benzene. [13a] In general, a strong base such as hydroxide or alkoxide is required to produce some product (Table 1, Entries 4-8). With a weaker base commonly used in the Suzuki-Miyaura cross-coupling, K_3PO_4, [2,3] no cross-coupling occurred. As already reported in the literature, the counter ion is very important during the catalysis.[18] With KOH or LiOH instead of NaOH as base, the yields were reduced by a factor of two and three, respectively (Table 1, Entries 4, 5).

A complete conversion was not achieved with reaction time shorter than 24h, and with longer time the yields were not improved (a separate trial at 80°C for 48h yielded 64% of cross-coupling product). With solvents other than 1,4-dioxane, the yields were worse. The yield was divided by three with DMF or *tert*-butanol as solvent (Table 1, Entries 9, 10). Use of a primary alcohol resulted in a dramatic reduction in yield (5%; Table 1, Entry 11). When reaction was carried out in *tert*-amyl alcohol or *iso*-propanol (*i*-PrOH), the yields were lower (Table 1, Entries 12,13).

Fu has observed the quantitative formation of a tetravalent -ate complex by ^{11}B NMR spectroscopy when an organoborane, KO*t*-Bu and *i*-BuOH are mixed.[8b] These species are presumed to activate the alkylborane reagents for transmetalation by making the organic group more nucleophilic. This report prompted us to use *iso*-propanol and sodium iodide as additives (Figure 1). Addition of 2 equivalents of *i*-PrOH and 50 mol % of NaI had no effect on the reaction with *n*-butyl iodide, but the yield was improved with other substrates like *n*-octyl iodide, *n*-butyl bromide and *n*-octyl bromide (from 40%, 59% and 55% to 79%, 68% and 80%, respectively). Addition of only *iso*-propanol as an additive was not efficient for *n*-butyl iodide and *n*-butyl bromide (yields decreased from 66% and 59% without any additive to 30% and 40%, respectively). Interestingly, the addition of only *iso*-propanol was helpful for the reaction with *n*-butyl chloride. The yield increased from 42% without any additive to 69% with 2 equivalent of *iso*-propanol. In contrast, yield decreased to 32% with the combination *i*-PrOH/NaI.

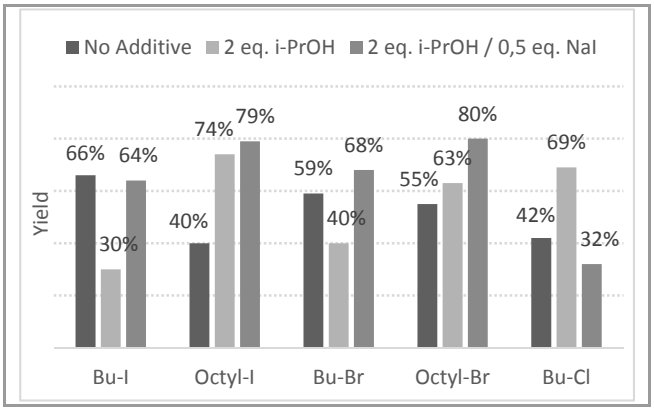
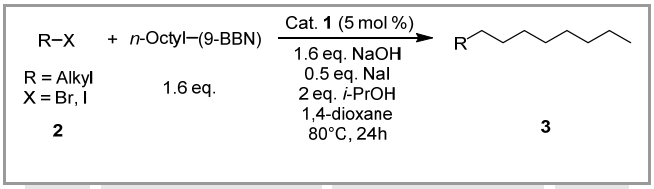


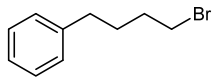
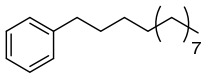
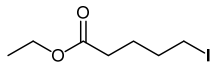
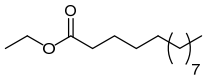
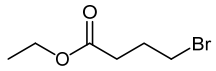
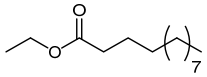
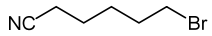
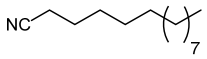
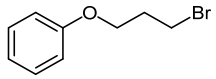
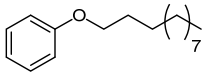
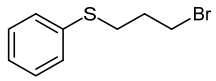
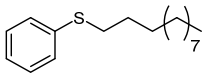
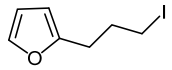
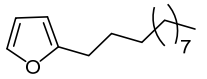
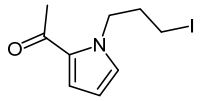
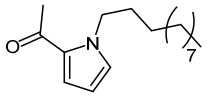
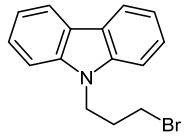
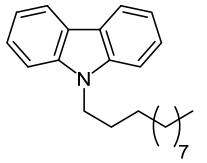
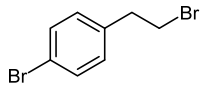
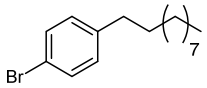
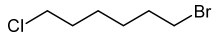
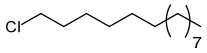
Figure 1 Additive Effect on the Cross-Coupling of Unactivated Alkyl Halides

With the optimized conditions in hand, the scope of the reaction was extended to different alkyl bromides and iodides with various functional groups (Table 2).

Table 2 Alkyl-Alkyl Suzuki Cross-Coupling Reaction between Alkyl-(9-BBN) and Unactivated Alkyl Halides



Entry	Halide	Product	Yield (%)[a]

1	 **2a**	 **3a**	68
2	 **2b**	 **3b**	59
3	 **2c**	 **3c**	58
4	 **2d**	 **3d**	67
5	 **2e**	 **3e**	68
6	 **2f**	 **3f**	54
7	 **2g**	 **3g**	52
8	 **2h**	 **3h**	49
9	 **2i**	 **3i**	71
10	 **2j**	 **3j**	65
11	 **2k**	 **3k**	58

[a] Isolated Yield relative to the Alkyl Halide

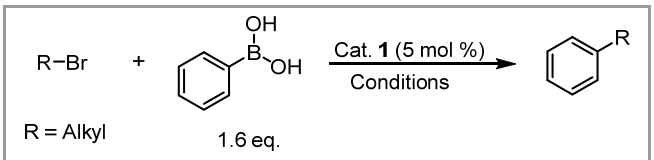
Cross-coupling occurred with a broad range of substrates. 1-bromo-4-phenylbutane (**2a**) reacted with the *n*-octyl-(9-BBN) to give 68% yield of **3a** (Table 2, Entry 1). For ester iodide and bromide, coupling products were obtained in 59% and 58% yield respectively (Table 2, Entries 2, 3). Bromides carrying nitrile (Table 2, Entry 4), ether (Table 2, Entry 5), thiother (Table 2, Entry 6) and carbazole (Table 2, Entry 9) were coupled in good yields of coupling product, from 54% to 71%. Iodides reacted to afford similar cross-coupling yields, with tolerance on functional groups such as furan (Table 2, Entry 7) and pyrrole (Table 2, Entry 8).

Sp^2-hybridized carbon electrophiles were unreactive under the given conditions. Reaction of the 1-bromo-4-(2-bromoethyl)benzene (**2j**) gave only the 1-bromo-4-decylbenzene (**3j**) as coupling product (Table 2, Entry 10). Bromides are more reactive than chlorides: reaction of the 1-bromo-6-chlorohexane (**2k**) gave only the 1-chlorotetradecane (**3k**) as product (Table 2, Entry 11).

Our experiments with other alkylboron reagents such as alkylboronic acids, alkylboronates or potassium alkyltrifluoroborates were not successful, so we decided then to focus on alkyl-aryl Suzuki cross-coupling reactions. Boronic acids present many advantages. They are relatively cheap, air-stable and commercially available reagents with a high functional group tolerance. Most of reported alkyl-aryl Suzuki-Miyaura coupling used alkylboronic acid and aryl halide as reaction partners, in order to avoid the β-hydride elimination when an alkyl halide is used as electrophile. As β-hydride elimination is thermodynamically uphill with the pincer complex **1**, our idea was to couple alkyl halides with arylboronic acids to achieve alkyl-aryl coupling.

Our initial studies showed potassium *tert*-butoxide as the most effective base. With most of the common organic solvents, including 1,4-dioxane, no cross-coupling occurred. With *tert*-amyl alcohol used as solvent and a reaction temperature of 120°C, 42% of coupling product was obtained for the reaction of phenylboronic acid and *n*-butyl bromide (Table 3, Entry 1). The importance of the counter ion in the reaction was demonstrated by using bis[2-(N,N-dimethylamino)ethyl] ether (OTMEDA) as an additive. Without OTMEDA, yields were 42% when KO*t*-Bu was used as a base, and 2 % when NaO*t*-Bu was used as a base (Table 3, Entries 1, 2). With 3 equivalent of OTMEDA as additive, the yields were 34% and 21%, respectively (Table 3, Entries 3, 4). An interaction between OTMEDA and the cation might explain these results.

Table 3 Optimization of Alkyl-Aryl Suzuki Cross-Coupling Reaction between Phenylboronic Acid and Alkyl Halide



Entry	Halide	T (°C)	Base	Additive	Yield (%)[a]
1	Bu-Br	120	KO*t*-Bu	-	42
2	Bu-Br	120	NaO*t*-Bu	-	2
3	Bu-Br	120	KO*t*-Bu	OTMEDA	34
4	Bu-Br	120	NaO*t*-Bu	OTMEDA	21
5	Bu-Br	120	NaOH	OTMEDA	51[b]

6	Bu-Br	120	NaOH	-	0
7	Bu-Br	120	NaOH	NaI	6
8	Bu-Br	120	NaOH	NaI / OTMEDA	35
9	Bu-Br	80	NaOH	NaI / OTMEDA	57
10	Octyl-Br	80	NaOH	OTMEDA	46
11	Octyl-Br	80	NaOH	NaI / OTMEDA	66[c]
12	Octyl-Br	80	NaOH	$MgBr_2$ / OTMEDA	61[d]
13	Octyl-Br	80	NaOH	NaI / 2-MME[e]	2

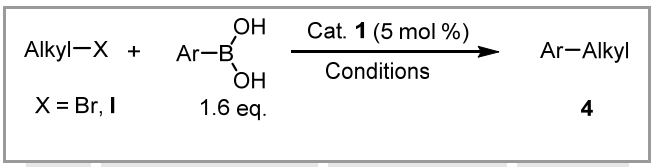
[a] GC-MS Yield relative to the Alkyl Halide
[b] With KOH, Yield was 12%
[c] With no NaI, Yield was 44%
[d] With 3 eq. OTMEDA and 0,5 eq. MgI_2, yield was 47%
[e] 2-MME = 2-Methoxyethylether

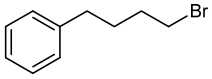
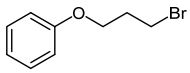
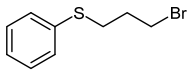
A better result was obtained (51% yield) using NaOH as base in the presence of 3 equivalent of OTMEDA (Table 3, Entry 5). Without OTMEDA, no cross-coupling product was formed (Table 3, Entry 6). With 50 mol % of NaI but without OTMEDA, only 6% of coupling product was formed (Table 3, Entry 7). The combination NaI/OTMEDA as additives was not beneficial at 120°C (Table 3, Entry 8). But by decreasing the temperature to 80°C, yield was improved to 57% (Table 3, Entry 9).

It appeared that the presence of an anionic halide allowed a better coupling. For the coupling of *n*-octyl-Br with phenylboronic acid, the yield was 46% with only OTMEDA used as additive (Table 3, Entry 10).With sodium iodide (50 mol %) as a further additive, the yield was 66% (Table 3, Entry 11). With magnesium bromide (50 mol %) as a further additive, the yield was 63% (Table 3, Entry 12). Additive other than OTMEDA gave lower yield, or almost no product (2% of yield when 2-methoxyethylether was used instead of OTMEDA; Table 3, Entry 13).

These optimized conditions were tested for the coupling of different substrates carrying functional groups (Table 4). But the yields were quite low, around 20%. Reaction of the 4-methoxyphenylboronic acid was tested with the *n*-octyl bromide and *n*-octyl iodide. Coupling product **4o** was obtained in the same range of yield (16% and 19%, respectively, Table 4, Entries 4, 5).

Table 4 Alkyl-Aryl Suzuki Cross-Coupling between Phenylboronic Acid and Unactivated Alkyl Halides

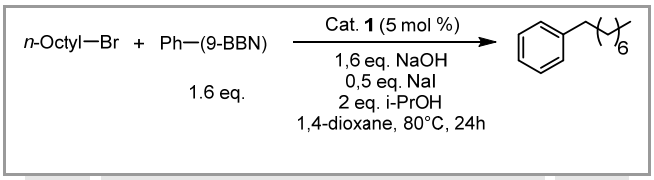


Entry	Halide	Boronic Acid	Yield (%)[a] of **4**
1		$PhB(OH)_2$	21 (**4a**)
2		$PhB(OH)_2$	19 (**4e**)
3		$PhB(OH)_2$	20 (**4f**)
4	Octyl-Br	4-MeO-$PhB(OH)_2$	16 (**4o**)
5	Octyl-I	4-MeO-$PhB(OH)_2$	19 (**4o**)

[a] Isolated Yield relative to the Alkyl Halide

Due to the low efficiency in the coupling of phenylboronic acid with alkyl electrophiles using **1** as catalyst, we decided to use the phenyl-9-borabyclo[3.3.1]nonane as arylboron reagent. The same conditions used in the alkyl-alkyl coupling with octyl-(9-BBN) reagent were successfully applied with this reagent (Table 5).

Table 5 Optimization of Alkyl-Aryl Suzuki Cross-Coupling Reaction between Phenyl-(9-BBN) and *n*-Octyl Bromide



Entry	Modification from the "standard" conditions	Yield (%)[a]
1	None	91
2	No catalyst	0
3	$NiCl_2$ instead of Cat. **1**	0
4	$PdCl_2$ instead of Cat. **1**	0
5	KOH instead of NaOH	37
6	No *i*-PrOH	82
7	3 eq. *i*-PrOH	93[b]
8	*i*-PrOH used as solvent	73
9	No NaI	83
10	Bu_4NI instead of NaI	25
11	At r.t.	51[c]
12	2 eq. *tert*-amyl alcohol instead of *i*-PrOH	81
13	*Tert*-amyl used as solvent	98
14	$NiCl_2$ (5 mol %) and ligand (10 mol %)	0

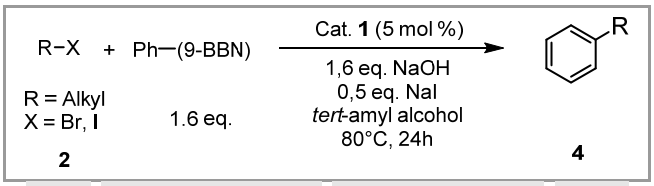
[a] GC-MS Yield relative to the Alkyl Halide
[b] With 1 eq. *i*-PrOH, yield was 84%, with 4 eq., yield was 82%
[c] Conversion was 64%

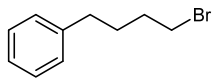
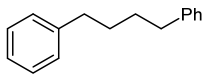
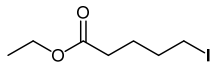
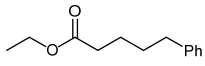
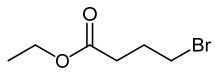
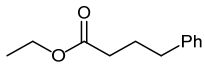
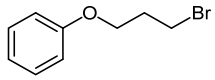
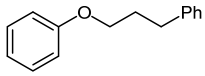
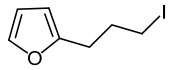
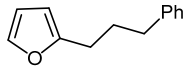
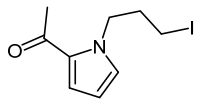
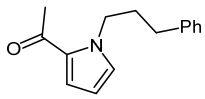
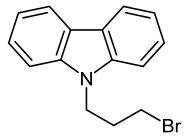
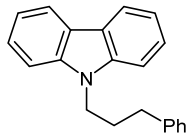
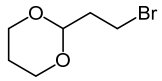
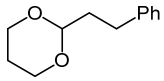
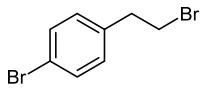
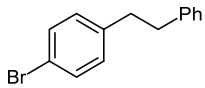
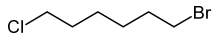
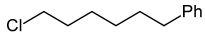
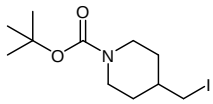
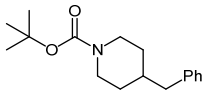
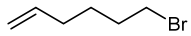
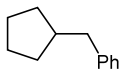
91% of coupling yield was reached when no modifications were brought to the conditions previously established for the alkyl-alkyl Suzuki-Miyaura cross-coupling catalyzed by complex **1** (Table 5, Entry 1). With no catalyst or with $NiCl_2$ used as a nickel source, no cross-coupling occurred (Table 5, Entries 2, 3). No product was formed with $PdCl_2$ as catalyst (Table 5, Entry 4). Addition of $NiCl_2$ with the free ligand afforded no product neither (Table 5, Entry 14). Thus, the possible Ni or Pd contamination in the catalysis could be ruled out. Replacement of the base by KOH afforded only 37% of product (Table 5, Entry 5). Thus, the counter cation of the base played an important role. When one of the additive is missing, the yield was about 10% lower (Table 5, Entry 6, 9), as when 2 equivalent of *tert*-amyl alcohol were used instead of *i*-PrOH (Table 5, Entry 12). With 3 equivalent of *i*-PrOH, the yield was slightly increased

to 93%, while with 1 or 4 equivalent of *i*-PrOH, it was 84% and 82%, respectively (Table 5, Entry 7). Use of another I^- donor, tetrabutylammonium iodide, afforded a decrease in the yield, from 91% to 25% (Table 5, Entry 10). At room temperature, the reaction required longer time to proceed; the conversion after 24h was 64% and the yield was only 51% (Table 5, Entry 11). Replacing 1,4-dioxane by *iso*-propanol as solvent decreased the yield to 73% (Table 5, Entry 8). But replacing 1,4-dioxane by *tert*-amyl alcohol as solvent increased the yield to 98% (Table 5, Entry 13). Consequently, we decided to perform these alkyl-aryl Suzuki reactions in *tert*-amyl alcohol.

Scope of the reaction is reported in Table 6.

Table 6 Alkyl-Aryl Suzuki Cross-Coupling between Phenyl-(9-BBN) and Unactivated Alkyl Halides



Entry	Halide	Product	Yield (%)[a]
1	 **2a**	 **4a**	76
2	 **2b**	 **4b**	59
3	 **2c**	 **4c**	76
4	 **2e**	 **4e**	87
5	 **2g**	 **4g**	83
6	 **2h**	 **4h**	60
7	 **2i**	 **4i**	87
8	 **2l**	 **4l**	73
9	 **2j**	 **4j**	56
10	 **2k**	 **4k**	82
11	 **2m**	 **4m**	51
12	 **2n**	 **4n**	70

[a] Isolated Yield relative to the Alkyl Halide

1-bromo-4-phenylbutane (**2a**) reacted with phenyl-(9-BBN) to afford 1,4-diphenylbutane (**4a**) in 76% yield (Table 6, Entry 1). Several functional groups tolerated the conditions of the reaction: esters (Table 6, Entries 2,3), ether (Table 6, Entry 4), furan (Table 6, Entry 5), pyrrole (Table 6, Entry 6), carbazole (Table 6, Entry 7), acetal (Table 6, Entry 8), and boc-protected amine (Table 6, Entry 11). Yields are similar between ester iodide **2b** and ester bromide **2c** (59% and 76%, respectively; Table 6, Entries 2, 3).

Csp^3-halides are more reactive than Csp^2-halides for this coupling. Reaction of the 1-bromo-4-(2-bromoethyl)benzene gave the 1-bromo-4-phenethylbenzene (**4j**) as the major coupling product (56%; Table 6, Entry 9). Conversion was complete and 4-phenethyl-1,1'-biphenyl was the only by-product (23 % yield). Bromides are more reactive than chlorides. Reaction of the 1-bromo-6-chlorohexane gave the (6-chlorohexyl)benzene (**4k**) as the major product (82%, Table 6, Entry 10).

It was reported that activation of alkyl halides using complex **1** in Kumada-type coupling reactions occurred via a radical mechanism.[19] Coupling reaction with a radical clock, 6-bromohex-1-ene (**2n**) yielded the ring-closed product, (cyclopentylmethyl)benzene (**4n**), in 70% yield (Table 6, Entry 12). The direct coupling product, hex-5-en-1-ylbenzene, was produced in traces. These results are consistent with the fact that the activation of primary alkyl halides takes place via an alkyl radical intermediate. The recombination of this acyclic primary carbon radical with the catalyst is slower than the ring-closing rearrangement of the hex-5-en-1-radical.

Thioether, benzylether, alcohol, carboxylic acid, indole and amides seemed not suitable functional groups under these conditions. No cross-coupling product was formed when substrates carrying these groups were used.

In summary, complex **1** was able to catalyze Suzuki-Miyaura cross-coupling reactions of unactivated alkyl

halides. The system is effective enough for a wide range of alkyl bromides and iodides. The conditions tolerate a variety of useful functional groups including ester, nitrile, furan, pyrrole, acetal, boc protecting group. Alkyl- and aryl-(9-BBN) reagents are applicable reaction partners. Further studies of coupling reactions employing other boron reagents and secondary alkyl halides are under way.

All manipulations were carried out under an N_2 atmosphere using standard Schlenk or glovebox techniques. Solvent was purified using a two-column solid-state purification system (Innovative Technology, NJ, USA) and transferred to the glovebox without exposure to air by the aid of a Straus flask. Deuterated solvents were purchased from Cambridge Isotope Laboratories, Inc., and stored over activated 3 Å molecular sieves, after degassing by Freeze-Pump-Thaw method. Arylboronic acids, 9-borabicyclo[3.3.1]nonane dimer and OTMEDA (Bis[2-(N,N-dimethylamino)ethyl]ether) were used as purchased, without further purification. Compound [($^{Me}N_2N$)Ni-Cl] was prepared according to the procedure developed by Hu and coworkers.[20] The catalyst is also commercially available from Sigma-Aldrich bearing a short name – *Nickamine*. The list of the references and procedures for the synthesis of the following starting materials can be found in our previous publications:[13,14] ethyl 5-iodopentanoate, (3-bromopropoxy)benzene, 2-(3-iodopropyl)furan, (3-bromopropyl)(phenyl)sulfane, 9-(3-bromopropyl)-9*H*-carbazole, 1-(1-(3-iodopropyl)-1H-pyrrol-2-yl)ethan-1-one and tert-butyl 4-(iodomethyl)piperidine-1-carboxylate. Physical methods ^{1}H and ^{13}C{^{1}H} NMR spectra were recorded at ambient temperature on a Bruker Avance 400 spectrometer. ^{1}H NMR and ^{13}C{^{1}H} chemical shifts were referenced to residual solvent as determined relative to TMS (δ = 0.00 ppm). GC-MS measurements were conducted on a Perkin-Elmer Clarus 600 GC equipped with Clarus 600T MS. HRCI-MS measurements were conducted at the EPFL ISIC Mass Spectrometry Service at Micro Mass QTOF Ultima. Elemental analyses were performed on a Carlo Erba EA 1110 CHN instrument at EPFL. All the cross-coupling products were purified with a flash purification system, the Biotage Isolera One.

Octyl-9-borabyclo[3.3.1]nonane; Typical Procedure

Under dry N_2, 9-borabyclo[3.3.1]nonane (9-BBN-H) dimer (5 mmol, 1.22 g) and 1-octene (12 mmol, 1.34 g) were dissolved in 1,4-dioxane (20 mL) to deliver a final concentration of 0.5 M based on the alkyl-(9-BBN). The reaction mixture was stirred overnight at room temperature. The solution was filtered and used without further purification.

Phenyl-9-borabyclo[3.3.1]nonane; Typical Procedure

Under a dry nitrogen atmosphere, the B-methoxy-(9-BBN) (1.0 M in hexane, 20 mmol, 20 mL) was introduced in a Schlenk flask and hexane was removed under reduced pressure. The boronic ester was then redissolved in 40 mL anhydrous Et_2O. To this solution were added phenylmagnesium chloride (2.0 M in THF, 20 mmol, 10 mL) at -50°C. The reaction mixture was stirred overnight at room temperature. The solvent was removed under reduced pressure to obtain a white solid. 20 mL of pentane were introduced to crack the -ate complex and the mixture was vigorously stirred for 3h. The slurry mixture was then allowed to settle. The supernatant was transferred into another Schlenk flask. The solid was extracted two more times with 20 mL of pentane. After evaporation of all the supernatant fractions, a slightly white oil was collected (3.22 g, Yield 81%) and used in the catalysis without further purification.

Alkyl-Alkyl Coupling reactions; General Procedure

To a solution of sodium hydroxide (1.6 eq., 0.8 mmol, 32 mg), catalyst **1** (5 mol %, 0.025 mmol, 8.4 mg), sodium iodide (0.5 eq., 0.25 mmol, 37 mg), *iso*-propanol (2 eq., 1 mmol, 76 µL) in 2.4 mL of dry 1,4-dioxane, were added alkyl halide (0.5 mmol) and the alkyl-(9-BBN) (1.6 eq., 0.8 mmol, 1.6 mL) under a nitrogen atmosphere. The reaction mixture was stirred at 80°C for 24h. The solution was diluted in Et_2O (10 mL), filtered on a short pad of silica, washed with Et_2O (3 x 10 mL) and concentrated to dryness under reduced pressure. The residue was purified with a flash purification system to give the coupling product (Tables 1, 2).

Aryl-Alkyl Coupling reactions; General Procedure with $ArB(OH)_2$

To a solution of sodium hydroxide (1.6 eq., 0.8 mmol, 32 mg), catalyst **1** (5 mol %, 0.025 mmol, 8.4 mg), sodium iodide (0.5 eq., 0.25 mmol, 37 mg), OTMEDA (3 eq., 1.5 mmol, 241 mg) in 4 mL of dry *tert*-amyl alcohol, were added alkyl halide (0.5 mmol) and the phenylboronic acid (1.6 eq., 0.8 mmol, 98 mg) under a nitrogen atmosphere. The reaction mixture was stirred at 80°C for 24h. The solution was diluted in Et_2O (10 mL), filtered on a short pad of silica, washed with Et_2O (3 x 10 mL) and concentrated to dryness under reduced pressure. The residue was purified with a flash purification system to give the coupling product (Tables 3, 4).

Aryl-Alkyl Coupling reactions; General Procedure with Ph-(9-BBN)

To a solution of sodium hydroxide (1.6 eq., 0.8 mmol, 32 mg), catalyst **1** (5 mol %, 0.025 mmol, 8.4 mg), sodium iodide (0.5 eq., 0.25 mmol, 37 mg), *iso*-propanol (2 eq., 1 mmol, 76 µL) in 4 mL of dry 1,4-dioxane, were added alkyl halide (0.5 mmol) and the phenyl-(9-BBN) (1.6 eq., 0.8 mmol, 1.6 mL) under a nitrogen atmosphere. The reaction mixture was stirred at 80°C for 24h. The solution was diluted in Et_2O (10 mL), filtered on a short pad of silica, washed with Et_2O (3 x 10 mL) and concentrated to dryness under reduced pressure. The residue was purified with a flash purification system to give the coupling product (Tables 5, 6).

Dodecylbenzene (3a)

Yield: 84 mg (68%); colorless oil.

^{1}H NMR (400MHz, $CDCl_3$): δ = 7.39-7.22 (m, 2 H), 7.18 (d, *J* = 7.1 Hz, 3 H), 2.61 (t, *J* = 7.6 Hz, 2 H), 1.76-1.56 (m, 2 H), 1.40-1.18 (m, 18 H), 0.89 (t, *J* = 6.3 Hz, 3 H).

$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 143.1, 128.5, 128.4, 125.7, 36.2, 32.1, 31.7, 29.82, 29.80, 29.75, 29.7, 29.5, 22.9, 14.3.

HRMS (APCI): *m/z* $[M]^+$ calcd for $C_{18}H_{30}$: 246.2348. Found, 246.2337.

Anal. Calcd for $C_{18}H_{30}$: C, 87.73; H, 12.27. Found: C, 87.67; H, 12.26.

Ethyl tridecanoate (3b)

Yield: 71 mg (59%); colorless oil.

^1H NMR (400MHz, $CDCl_3$): δ = 4.12 (q, *J* = 7.1 Hz, 2 H), 2.28 (t, *J* = 7.6 Hz, 2 H), 1.71-1.57 (m, 2 H), 1.36-1.15 (d, *J* = 8.3 Hz, 21 H), 0.88 (t, *J* = 6.9 Hz, 3 H).

$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 174.1, 60.3, 44.1, 34.6, 32.1, 29.8, 29.7, 29.6, 29.5, 29.4, 29.3, 25.2, 22.8, 14.4, 14.3.

HRMS (ESI): *m/z* $[M + H]^+$ calcd for $C_{15}H_{31}O_2$: 243.2324. Found, 243.2322.

Anal. Calcd for $C_{15}H_{30}O_2$: C, 74.32; H, 12.48. Found: C, 74.32; H, 12.41.

Ethyl dodecanoate (3c)

Yield: 66 mg (58%); colorless oil.

^1H NMR (400MHz, $CDCl_3$): δ = 4.12 (q, *J* = 7.0 Hz, 2 H), 2.28 (t, *J* = 7.4 Hz, 2 H), 1.77-1.50 (m, 2 H), 1.50-1.05 (m, 19 H), 0.88 (t, *J* = 6.3 Hz, 3 H).

$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 123.8, 60.3, 44.1, 34.6, 32.1, 29.8, 29.6, 29.5, 29.4, 29.3, 25.2, 22.8, 14.4, 14.3.

HRMS (ESI): *m/z* $[M + H]^+$ calcd for $C_{14}H_{29}O_2$: 229.2168. Found, 229.2166.

Anal. Calcd for $C_{14}H_{28}O_2$: C, 73.63; H, 12.36. Found: C, 73.56; H, 12.27.

Tetradecanenitrile (3d)

Yield: 70 mg (67%); colorless oil.

^1H NMR (400MHz, $CDCl_3$): δ = 2.33 (t, *J* = 7.1 Hz, 2 H), 1.66 (dt, *J* = 14.8, 7.2 Hz, 2 H), 1.50-1.36 (m, 2 H), 1.39-1.18 (m, 18 H), 0.88 (t, *J* = 6.8 Hz, 3 H).

$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 123.7, 44.1, 32.1, 29.8, 29.7, 29.6, 29.5, 29.4, 28.9, 28.8, 25.5, 22.8, 17.3, 14.3.

HRMS (ESI): *m/z* $[M + Na]^+$ calcd for $C_{14}H_{27}NNa$: 232.2041. Found, 232.2037.

Anal. Calcd for $C_{14}H_{27}N$: C, 80.31; H, 13.00; N, 6.69. Found: C, 80.23; H, 12.74; N, 7.25.

(Undecyloxy)benzene (3e)

Yield: 84 mg (68%); colorless oil.

^1H NMR (400MHz, $CDCl_3$): δ = 7.45-7.15 (m, 2 H), 7.09-6.76 (m, 3 H), 3.98 (t, *J* = 6.6 Hz, 2 H), 1.81 (dt, *J* = 14.6, 6.6 Hz, 2 H), 1.67-1.41 (m, 4 H), 1.41-1.12 (m, 12 H), 0.91 (t, *J* = 6.9 Hz, 3 H).

$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 159.3, 129.5, 120.6, 114.6, 68.0, 32.1, 29.8, 29.7, 29.6, 29.50, 29.47, 26.2, 22.9, 14.3.

HRMS (APCI): *m/z* $[M]^+$ calcd for $C_{17}H_{28}O$: 248.2140. Found, 248.2148.

Anal. Calcd for $C_{17}H_{28}O$: C, 82.20; H, 11.36. Found: C, 82.34; H, 11.56.

Phenyl(undecyl)sulfane (3f)

Yield: 71 mg (54%); white solid; mp 29-30 °C.

^1H NMR (400MHz, $CDCl_3$): δ = 7.31 (t, *J* = 7.9 Hz, 2 H), 7.27 (d, *J* = 4.2 Hz, 2 H), 7.16 (t, *J* = 6.9 Hz, 1 H), 2.92 (t, *J* = 7.3 Hz, 2 H), 1.76-1.59 (m, 2 H), 1.48-1.37 (m, 2 H), 1.37-1.16 (m, 14 H), 0.88 (t, *J* = 6.3 Hz, 3 H).

$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 129.0, 128.9, 125.8, 33.7, 32.1, 29.8, 29.7, 29.6, 29.5, 29.32, 29.31, 29.0, 22.8, 14.3.

HRMS (APCI): *m/z* $[M]^+$ calcd for $C_{17}H_{28}S$: 264.1912. Found, 264.1904.

Anal. Calcd for $C_{17}H_{28}S$: C, 77.21; H, 10.67. Found: C, 77.35; H, 10.69.

2-Undecylfuran (3g)

Yield: 58 mg (52%); colorless oil.

^1H NMR (400MHz, $CDCl_3$): δ = 7.44-7.11 (m, 1 H), 6.27 (s, 1 H), 5.96 (s, 1 H), 2.80-2.38 (m, 2 H), 1.79-1.56 (m, 2 H), 1.48-0.98 (m, 16 H), 0.96-0.71 (m, 3 H).

$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 156.8, 140.7, 110.2, 104.6, 32.1, 29.79, 29.78, 29.71, 29.53, 29.50, 29.4, 28.2, 28.1, 22.9, 14.3.

HRMS (APCI): *m/z* $[M]^+$ calcd for $C_{15}H_{26}O$: 222.1984. Found, 222.1990.

Anal. Calcd for $C_{15}H_{26}O$: C, 81.02; H, 11.79. Found: C, 81.05; H, 11.85.

1-(1-Undecyl-1*H*-pyrrol-2-yl)ethan-1-one (3h)

Yield: 65 mg (49%); yellow oil.

^1H NMR (400MHz, $CDCl_3$): δ = 7.04-6.95 (m, 1 H), 6.95-6.82 (m, 1 H), 6.19-6.06 (m, 1 H), 4.32 (t, *J* = 7.2 Hz, 2 H), 2.45 (s, 3 H), 1.83-1.67 (m, 2 H), 1.48-1.08 (m, 16 H), 0.90 (t, *J* = 6.4 Hz, 3 H).

$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 188.3, 130.3, 123.7, 120.3, 107.9, 50.0, 44.1, 32.1, 31.6, 29.74, 29.72, 29.5, 29.4, 27.5, 26.8, 22.8, 14.3.

HRMS (ESI): *m/z* $[M + H]^+$ calcd for $C_{17}H_{30}NO$: 264.2327. Found, 264.2329.

Anal. Calcd for $C_{17}H_{29}NO$: C, 77.51; H, 11.10; N, 5.32. Found: C, 77.44; H, 11.05; N, 5.61.

9-Undecyl-9*H*-carbazole (3i)

Yield: 114 mg (71%); colorless oil.

^{1}H NMR (400MHz, $CDCl_3$): δ = 8.12 (d, *J* = 7.6 Hz, 2 H), 7.47 (d, *J* = 7.2 Hz, 2 H), 7.46-7.35 (m, 2 H), 7.30-7.18 (m, 2 H), 4.31 (m, 7.2 Hz, 2 H), 2.01-1.79 (m, 2 H), 1.50-1.12 (m, 16 H), 0.89 (t, *J* = 6.5 Hz, 3 H).

^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 140.6, 125.7, 123.0, 120.5, 118.8, 108.8, 43.2, 32.0, 29.7, 29.65, 29.57, 29.45, 29.1, 27.5, 22.8, 14.3.

HRMS (APCI): *m/z* $[M]^+$ calcd for $C_{23}H_{31}N$: 321.2457. Found, 321.2450.

Anal. Calcd for $C_{23}H_{31}N$: C, 85.92; H, 9.72; N, 4.36. Found: C, 86.23; H, 9.71; N, 4.51.

1-Bromo-4-decylbenzene (3j)

Yield: 97 mg (65%); colorless oil.

^{1}H NMR (400MHz, $CDCl_3$): δ = 7.38 (d, *J* = 8.0 Hz, 2 H), 7.06 (t, *J* = 9.6 Hz, 2 H), 2.55 (t, *J* = 7.5 Hz, 2 H), 1.71-1.48 (m, 2 H), 1.48-1.13 (m, 14 H), 1.03-0.70 (m, 3 H).

^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 142.0, 131.4, 128.4, 119.4, 35.5, 32.1, 31.5, 29.9, 29.8, 29.7, 29.6, 29.5, 29.3, 22.8, 14.3.

HRMS (APCI): *m/z* $[M]^+$ calcd for $C_{16}H_{25}Br$: 296.1140. Found, 296.1149.

Anal. Calcd for $C_{16}H_{25}Br$: C, 64.64; H, 8.48. Found: C, 67.35; H, 9.14.

1-Chlorotetradecane (3k)

Yield: 67 mg (58%); colorless oil.

^{1}H NMR (400MHz, $CDCl_3$): δ = 3.53 (t, *J* = 6.6 Hz, 2 H), 1.91-1.66 (m, 2 H), 1.64-1.12 (m, 22 H), 0.88 (t, *J* = 6.0 Hz, 3 H).

^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 45.4, 32.8, 32.1, 29.83, 29.81, 29.7, 29.6, 29.5, 29.1, 27.1, 22.9, 14.3.

Anal. Calcd for $C_{14}H_{29}Cl$: C, 72.22; H, 12.55. Found: C, 72.19; H, 12.56.

1,4-Diphenylbutane (4a)

Yield: 80 mg (76%); colorless liquid.

^{1}H NMR (400MHz, $CDCl_3$): δ = 7.32 (t, *J* = 7.2 Hz, 4 H), 7.26 – 7.06 (m, 6 H), 2.69 (m, 4 H), 1.73 (m, 4 H).

^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 142.7, 128.5, 128.4, 36.0, 31.2.

HRMS (APCI): *m/z* $[M]^+$ calcd for $C_{16}H_{18}$: 210.1409. Found, 210.1411.

Anal. Calcd for $C_{16}H_{18}$: C, 91.37; H, 8.63. Found: C, 90.28; H, 8.61.

(3-Phenoxypropyl)benzene (4e)

Yield: 92 mg (87%); yellow oil.

^{1}H NMR (400MHz, $CDCl_3$): δ = 7.34–7.33 (m, 4 H), 7.28–7.26 (m, 3 H), 7.01-6.94 (m, 3 H), 4.01 (t, *J* = 6.0 Hz, 2 H), 2.87 (t, *J* = 7.2 Hz, 2 H), 2.18-2.14 (m, 2 H).

^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 159.2, 141.7, 129.6, 128.7, 128.5, 126.1, 120.7, 114.67, 66.9, 32.3, 31.0.

HRMS (APCI): *m/z* $[M]^+$ calcd for $C_{15}H_{16}O$: 212.1201. Found, 212.1207.

Anal. Calcd for $C_{15}H_{16}O$: C, 84.87; H, 7.60. Found: C, 82.73; H, 7.59.

Phenyl(3-phenylpropyl)sulfane (4f)

Yield: 23 mg (20%); yellow oil.

^{1}H NMR (400MHz, $CDCl_3$): δ = 7.46–7.26 (m, 6 H), 7.26–7.07 (m, 4 H), 2.96 (t, *J* = 7.1 Hz, 2 H), 2.80 (t, *J* = 7.3 Hz, 2 H), 2.01 (p, *J* = 7.1 Hz, 2 H).

^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 141.4, 136.7, 129.3, 129.0, 128.6, 128.5, 126.0, 34.8, 33.1, 30.8.

HRMS (APCI): *m/z* $[M]^+$ calcd for $C_{15}H_{16}S$: 228.0973. Found, 228.0980.

Anal. Calcd for $C_{15}H_{16}S$: C, 78.90; H, 7.06. Found: C, 78.96; H, 7.03.

1-Methoxy-4-octylbenzene (4o)

Yield: 21 mg (19%); colorless oil.

^{1}H NMR (400MHz, $CDCl_3$): δ = 7.09 (d, *J* = 8.0 Hz, 2 H), 6.82 (d, *J* = 8.1 Hz, 2 H), 3.79 (s, 3 H), 2.54 (t, *J* = 7.7 Hz, 2 H), 1.59 (m, 2 H), 1.29-1.26 (m, 10 H), 0.87 (t, *J* = 10.8 Hz, 3 H).

^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 157.7, 135.2, 113.8, 55.4, 35.2, 32.1, 31.9, 29.7, 29.4, 22.8, 14.3.

HRMS (APCI): *m/z* $[M]^+$ calcd for $C_{15}H_{24}O$: 220.1827. Found, 220.1833.

Anal. Calcd for $C_{15}H_{24}O$: C, 81.76; H, 10.98. Found: C, 82.04; H, 11.05.

Ethyl 5-phenylpentanoate (4b)

Yield: 61 mg (59%); yellow oil.

^{1}H NMR (400MHz, $CDCl_3$): δ = 7.35-7.26 (m, 2 H), 7.26-7.16 (m, 3 H), 4.15 (q, *J* = 7.0 Hz, 2 H), 2.70-2.56 (m, 2 H), 2.40-2.27 (m, 2 H), 1.80-1.59 (m, 4 H), 1.35-1.21 (m, 3 H).

^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 137.8,.142.3, 128.9, 128.4, 125.9, 60.3, 35.7, 34.3, 31.0, 24.7, 14.4.

HRMS (ESI): *m/z* $[M + Na]^+$ calcd for $C_{13}H_{18}NaO_2$: 229.1205. Found, 229.1203.

Anal. Calcd for $C_{13}H_{18}O_2$: C, 75.69; H, 8.80. Found: C, 76.48; H, 8.86.

Ethyl 4-phenylbutanoate (4c)

Yield: 73 mg (76%); yellow oil.

^{1}H NMR (400MHz, $CDCl_3$): δ = 7.43 (t, *J* = 7.3 Hz, 1 H), 7.32-7.22 (m, 2 H), 7.17 (d, *J* = 7.4 Hz, 2 H), 4.11 (q, *J* = 7.0 Hz, 2 H), 2.84-2.50 (m, 2 H), 2.31 (t, *J* = 7.4 Hz, 2 H), 2.12-1.77 (m, 2 H), 1.24 (t, *J* = 7.0 Hz, 3 H).

$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 173.7, 141.6, 128.9, 128.6, 128.5, 127.3, 126.1, 60.4, 35.3, 33.9, 26.7, 14.4.

HRMS (ESI): *m/z* $[M + Na]^+$ calcd for $C_{12}H_{16}NaO_2$: 215.1048. Found, 215.1047.

Anal. Calcd for $C_{12}H_{16}O_2$: C, 74.97; H, 8.39. Found: C, 76.64; H, 8.51.

2-(3-Phenylpropyl)furan (4g)

Yield: 78 mg (83%); yellow oil.

^1H NMR (400MHz, $CDCl_3$): δ = 7.39-7.32 (m, 1 H), 7.32-7.25 (m, 2 H), 7.22 (d, *J* = 6.3 Hz, 2 H), 6.31 (s, 1 H), 6.02 (s, 1 H), 2.93-2.47 (m, 4 H), 2.14-1.82 (m, 2 H).

$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 156.1, 142.1, 140.9, 128.6, 128.5, 126.0, 110.2, 105.0, 35.4, 29.8, 27.6.

HRMS (APCI): *m/z* $[M]^+$ calcd for $C_{13}H_{14}O$: 186.1045. Found, 186.1050.

Anal. Calcd for $C_{13}H_{14}O$: C, 83.83; H, 7.58. Found: C, 83.54; H, 7.59.

1-(1-(3-Phenylpropyl)-1*H*-pyrrol-2-yl)ethan-1-one (4h)

Yield: 68 mg (60%); yellow oil.

^1H NMR (400MHz, $CDCl_3$): δ = 7.54 (d, *J* = 7.4 Hz, 1 H), 7.38 (t, *J* = 7.4 Hz, 1 H), 7.21 (d, *J* = 7.3 Hz, 2 H), 7.12 (d, *J* = 7.1 Hz, 2 H), 6.76 (s, 1 H), 6.06 (s, 1 H), 4.28 (t, *J* = 7.1 Hz, 2 H), 2.56 (t, *J* = 7.7 Hz, 2 H), 2.38 (s, 3 H), 2.14- 1.92 (m, 2 H).

$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 188.4, 141.4, 130.3, 128.9, 128.5, 128.4, 127.4, 127.3, 126.1, 120.5, 108.1, 49.5, 44.1, 32.9, 27.5.

HRMS (ESI): *m/z* $[M + H]^+$ calcd for $C_{15}H_{18}NO$: 228.1388. Found, 228.1392.

Anal. Calcd for $C_{15}H_{17}NO$: C, 79.26; H, 7.54; N, 6.16. Found: C, 79.68; H, 7.87; N, 5.84.

9-(3-Phenylpropyl)-9*H*-carbazole (4i)

Yield: 125 mg (87%); white solid; mp 102-104 °C.

^1H NMR (400MHz, $CDCl_3$): δ = 8.14 (d, *J* = 7.6 Hz, 2 H), 7.58-7.40 (m, 2 H), 7.40-7.29 (m, 4 H), 7.29-6.99 (m, 5 H), 4.37 (t, *J* = 7.1 Hz, 2 H), 2.76 (t, *J* = 7.5 Hz, 2 H), 2.26 (p, *J* = 7.2 Hz, 2 H).

$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 141.2, 140.5, 128.6, 128.5, 126.3, 125.8, 123.0, 120.5, 119.0, 42.6, 33.5, 30.3.

HRMS (APCI): *m/z* $[M]^+$ calcd for $C_{21}H_{19}N$: 285.1517. Found, 285.1526.

Anal. Calcd for $C_{21}H_{19}N$: C, 88.38; H, 6.71; N, 4.91. Found: C, 86.34; H, 6.54; N, 4.83.

2-Phenethyl-1,3-dioxane (4l)

Yield: 70 mg (73%); yellow oil.

^1H NMR (400MHz, $CDCl_3$): δ = 7.41-7.26 (m, 2 H), 7.26-7.06 (m, 3 H), 4.55 (t, *J* = 5.2 Hz, 1 H), 4.15 (dd, *J* = 11.1, 4.4 Hz, 2 H), 3.91-3.55 (m, 2 H), 2.76 (t, *J* = 8.0 Hz, 2 H), 2.23-2.03 (m, 1 H), 2.03-1.80 (m, 2 H), 1.37 (d, *J* =13,2 Hz, 1 H).

$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 141.8, 128.6, 128.5, 125.9, 101.6, 67.0, 36.8, 30.2, 26.0.

HRMS (APCI): *m/z* $[M]^+$ calcd for $C_{12}H_{16}O_2$: 192.1150. Found, 191.1065.

Anal. Calcd for $C_{12}H_{16}O_2$: C, 74.97; H, 8.39. Found: C, 74.88; H, 8.37.

1-Bromo-4-phenethylbenzene (4j)

Yield: 74 mg (56%); slightly yellow oil.

^1H NMR (400MHz, $CDCl_3$): δ = 7.38 (d, *J* = 7.7 Hz, 2 H), 7.26 (d, *J* = 7.5 Hz, 2 H), 7.20 (d, *J* = 6.8 Hz, 1 H), 7.14 (d, *J* = 7.0 Hz, 2 H), 7.02 (d, *J* = 7.7 Hz, 2 H), 3.05-2.71 (m, 4 H).

$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 141.4, 140.8, 131.5, 130.4, 128.5, 126.2, 119.8, 37.8, 37.4.

HRMS (APCI): *m/z* $[M]^+$ calcd for $C_{14}H_{13}Br$: 260.0201. Found, 260.0209.

Anal. Calcd for $C_{14}H_{13}Br$: C, 64.39; H, 5.02. Found: C, 64.30; H, 5.02.

(6-Chlorohexyl)benzene (4k)

Yield: 80 mg (82%); colorless oil.

^1H NMR (400MHz, $CDCl_3$): δ = 7.46-7.26 (m, 2 H), 7.26-7.13 (m, 3 H), 3.55 (t, *J* = 6.4 Hz, 2 H), 2.64 (t, *J* = 7.4 Hz, 2 H), 1.88-1.74 (m, 2 H), 1.74-1.61 (m, 2 H), 1.58-1.44 (m, 2 H), 1.44-1.23 (m, 2 H).

$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 142.7, 128.5, 128.4, 45.3, 36.0, 32.7, 31.4, 28.7, 26.9.

HRMS (APCI): *m/z* $[M]^+$ calcd for $C_{12}H_{17}Cl$: 196.1019. Found, 196.1022.

Anal. Calcd for $C_{12}H_{17}Cl$: C, 73.27; H, 8.71. Found: C, 73.04; H, 8.78.

***Tert*-butyl 4-benzylpiperidine-1-carboxylate (4m)**

Yield: 71 mg (51%); yellow oil.

^1H NMR (400MHz, $CDCl_3$): δ = 7.30 (t, *J* = 7.2 Hz, 2 H), 7.23 (d, *J* = 7.0 Hz, 1 H), 7.16 (d, *J* = 7.1 Hz, 2 H), 4.09 (s, 2 H), 2.66 (s, 2 H), 2.56 (d, *J* = 6.7 Hz, 1 H), 1.78-1.55 (m, 4 H), 1.47 (s, 9 H), 1.17 (d, *J* = 10.2 Hz, 2 H).

$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 155.0, 140.3, 129.2, 128.4, 126.1, 79.4, 44.1, 43.3, 38.3, 32.1, 28.6.

HRMS (ESI): *m/z* $[M + Na]^+$ calcd for $C_{17}H_{25}NNaO_2$: 298.1783. Found, 298.1779.

Anal. Calcd for $C_{17}H_{25}NO_2$: C, 74.14; H, 9.15; N, 5.09. Found: C, 73.10; H, 9.16; N, 4.93.

(Cyclopentylmethyl)benzene (4n)

Yield: 56 mg (70%); yellow oil.

^1H NMR (400MHz, $CDCl_3$): δ = 7.28 (d, *J* = 9.3 Hz, 2 H), 7.24-7.01 (m, 3 H), 2.62 (d, *J* = 7.3 Hz, 2 H), 2.22-1.94 (m, 1

H), 1.68 (dd, J = 21.0, 8.5 Hz, 4 H), 1.55 (d, J = 11.9 Hz, 2 H), 1.41-1.07 (m, 2 H).

$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 142.5, 128.9, 128.3, 125.7, 42.3, 42.2, 32.6, 25.1.

HRMS (APCI): *m/z* $[M]^+$ calcd for $C_{12}H_{16}$: 160.1252. Found, 160.1243.

Anal. Calcd for $C_{12}H_{16}$: C, 89.94; H, 10.06. Found: C, 89.96; H, 9.97.

Acknowledgment

This work is supported by Swiss National Science Foundation (no. 200020_144393/1).

Supporting Information for this article is available online at http://www.thieme-connect.com/ejournals/toc/synthesis.

References

(1) De Meijere, A.; Diederich, F, *Metal-Catalyzed Cross-Coupling Reactions, 2nd Edition*; Wiley-VCH: Weinheim, **2004**.

(2) For reviews of the Suzuki reaction, see: (a) Miyaura, N.; Suzuki, A. *Chem. Rev.* **1995**, *95*, 2457-2483. (b) Suzuki, A. *J. Organomet. Chem.* **1999**, *576*, 147-168. (c) Suzuki, A. *In Metal-Catalyzed Cross-Coupling Reactions*; Diederich, F., Stang, P. J., Eds.; Wiley-VCH: New York, **1998**; Chapter 2.

(3) Ishiyama,T.; Abe, S.; Miyaura, N.; Suzuki, A. *Chem. Lett.* **1992**, 691-694.

(4) Netherton, M. R.; Dai, C.; Neuschütz, K.; Fu, G. C. *J. Am. Chem. Soc.* **2001**, *123*, 10099-10100.

(5) (a) Brenstrum, T.; Gerristma, D. A.; Adjabeng, G. M.; Frampton, C. S.; Britten, J.; Robertson, A. J.; McNulty, J.; Capretta, A. *J. Org. Chem.* **2004**, *69*, 7635-7639. (b) Kirchhoff, J. H.; Dai, C.; Fu, G. C. *Angew. Chem. Int. Ed.* **2002**, *41*, 1945-1947. (c) Netherton, M. R.; Fu, G. C. *Angew. Chem. Int. Ed.* **2002**, *41*, 3910-3912.

(6) (a) Arentsen, K.; Caddick, S.; Cloke, F. G. N.; Herring, A. P.; Hitchcock, P.B. *Tetrahedron Lett.* **2004**, *45*, 3511-3515 (b) Valente, C.; Baglione, S.; Candito, D.; O'Brien, C. J.; Organ, M. G. *Chem. Commun.* **2008**, 735-737.

(7) (a) Zhu, J.; Fu, G. C. *J. Am. Chem. Soc.* **2004**, *126*, 1340-1341. (b) Saito, B.; Fu, G. C. *J. Am. Chem. Soc.* **2007**, *129*, 9602-9603.

(8) Saito, B.; Fu, G. C. *J. Am. Chem. Soc.* **2008**, *130*, 6694-6695.

(9) Lu, Z.; Fu, G. C. *Angew. Chem. Int. Ed.* **2010**, *49*, 6676-6678.

(10) Yang, C.-T.; Zhang, Z.-Q.; Liu, Y.-C.; Liu, L. *Angew. Chem. Int. Ed.* **2011**, *50*, 3904-3907.

(11) Hatakeyama, T.; Hashimoto, T.; Kathriarachchi, K. K. A. D. S.; Zenmyo, T.; Seike, H.; Nakamura, M. *Angew. Chem. Int. Ed.* **2012**, *51*, 8834 –8837.

(12) Csok, Z.; Vechorkin, O.; Harkins, S. B.; Scopelliti, R.; Hu, X. L. *J. Am. Chem. Soc.* **2008**, *130*, 8156-8157.

(13) (a) Vechorkin, O.; Csok, Z.; Scopelliti, R.; Hu, X. L. *Chem. Eur. J.* **2009**, *15*, 3889-3899. (b) Vechorkin, O.; Proust, V.; Hu, X. L. *J. Am. Chem. Soc.* **2009**, *131*, 9756-9766. (c) Perez Garcia, P. M.; Di Franco, T.; Orsino, A.; Ren, P.; Hu, X. L. *Org. Lett.* **2012**, *14*, 4286-4289.

(14) Vechorkin, O.; Godinat, A.; Scopelliti, R.; Hu, X. L. *Angew. Chem. Int. Ed.* **2011**, *50*, 11777-11781.

(15) Vechorkin, O.; Proust, V.; Hu, X. L. *Angew. Chem. Int. Ed.* **2010**, *49*, 3061-3064.

(16) Vechorkin, O.; Barmaz, D.; Proust, V.; Hu, X. L. *J. Am. Chem. Soc.* **2009**, *131*, 12078-12079.

(17) Breitenfeld, J.; Vechorkin, O.; Corminboeuf, C.; Scopelliti, R.; Hu, X. L. *Organometallics* **2010**, *29*, 3686-3689

(18) (a) In *Metal-Catalyzed Cross-Coupling Reactions, 2nd Edition*; de Meijere, A.; Diederich, F.; Wiley-VCH: Weinheim, **2004**; Chapter 2, PP 71-73. (b) Amatore,C.; Le Duc, G.; Jutand, J. *Chem. Eur. J.* **2013**, *19*, 10082-10093.

(19) Breitenfeld, J.; Ruiz, J.; Wodrich, M. D.; Hu, X. L. *J. Am. Chem. Soc.* **2013**, *135*, 12004-12012.

(20) Ren, P.; Vechorkin, O.; Csok, Z.; Salihu, I.; Scopelliti, R.; Hu, X. L. *Dalton Trans.* **2011**, *40*, 8906-8911.

Biography of Hu:

Xile Hu was born in 1978 in Putian, China. He received a B.S. degree from Peking University (2000) and a Ph.D. degree from the University of California, San Diego (2004; advisor: Prof. Karsten Meyer). He then carried out a postdoctoral study at the California Institute of Technology (advisor: Prof. Jonas Peters) before joining the faculty of the École Polytechnique Fédérale de Lausanne (EPFL) as a tenure-track assistant professor in 2007. He is currently associate professor at the same institute. His research interests span from organometallic chemistry, synthetic methodology, and reaction mechanism to bio-mimetic and bio-speculated coordination chemistry to electrocatalysis and artificial photosynthesis.

Biography of Di Franco:

Thomas Di Franco was born in 1988 in Briançon, France. He obtained his diplôme d'ingénieur from the Ecole Supérieure de Chimie Physique Electronique de Lyon (CPE Lyon) in 2012. During his studies, he worked for one year at Origenis (Munich area, Germany), synthetizing potentially bioactive molecules for important ophthalmic targets. He also received a Master Degree from the Université Claude Bernard Lyon 1. In 2012, he joined the group of Prof. Xile Hu. His research includes cross-couplings of non-activated halides catalyzed by well-defined Ni-based complexes.

Biography of Boutin:

Nicolas Boutin was born in 1994 in Paris, France. He is currently pursuing his apprenticeship of Chemistry Lab Technician at the Ecole Polytechnique Fédérale de Lausanne (EPFL) and he will complete his degree in 2014. In 2013, he joined the research group of Prof. Hu for a one-year training.

Photo of Hu:

Photo of Di Franco:

Photo of Boutin:

Suzuki-Miyaura Cross-Coupling Reactions of Unactivated Alkyl Halides Catalyzed by a Nickel Pincer Complex