Reusable Copper-Catalyzed Cross-Coupling Reactions of Aryl Halides with Organotins in Inexpensive Ionic Liquids

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(A) Remarks:

NMR spectroscopy was performed on an INOVA-400 (Varian), an INOVA-500 (Varian) or an AMX-300 (Bruker) spectrometer operating at 400 MHz (^1H NMR) and 100 MHz (^{13}C NMR), 500 MHz (^1H NMR) and 125 MHz (^{13}C NMR), or 300 MHz (^1H NMR) and 75 MHz (^{13}C NMR). TMS (tetramethylsilane) was used as an internal standard and CDCl_3 was used as the solvent.

(B) Typical experimental procedure

Typical Experimental Procedure for the Copper-Catalyzed Stille cross-coupling reaction in TBAB. A mixture of aryl halide **1** (0.3 mmol), organotin **2** (0.4 mmol), Cu_2O (nanoparticles; 10 mol %), $\text{P}(o\text{-tol})_3$ (**L**₇; 6 mol%), $\text{KF}\cdot 2\text{H}_2\text{O}$ (2 equiv) and TBAB (1.5 g) was stirred at 125-130 °C for desired time until complete consumption of starting material as monitored by TLC. After the reaction was finished, diethyl ether was poured into the mixture, then washed with water, extracted with diethyl ether, dried by anhydrous Na_2SO_4 and evaporated under vacuum, the residue was purified by flash column chromatography (hexane or hexane/ethyl acetate) to afford the desired coupled product.

After initial experimentation, the residue Cu_2O nanoparticles/ $\text{P}(o\text{-tol})_3$ /TBAB system) were then solidified (evaporated in vacuo and cooled) and subjected to a second run of the Stille reaction by charging with the same substrates (aryl halide, organotin and $\text{KF}\cdot 2\text{H}_2\text{O}$).

(C) Analytical data for 3–13

4-Nitro-biphenyl (3)¹

Yellow solid; ¹H NMR (500 MHz, CDCl₃) δ: 8.32 (d, *J* = 8.8 Hz, 2H), 7.76 (d, *J* = 8.8 Hz, 2H), 7.65 (d, *J* = 6.9 Hz, 2H), 7.55–7.48 (m, 3H); ¹³C NMR (125 MHz, CDCl₃) δ: 147.6, 147.1, 138.8, 129.2, 128.9, 127.8, 127.4, 124.1. LRMS (EI, 20 eV) *m/z* (%): 199 (M⁺, 100).

1-Nitro-4-vinylbenzene (4)²

Yellow oil; ¹H NMR (400 MHz, CDCl₃) δ: 8.19 (d, *J* = 9.2 Hz, 2H), 7.54 (d, *J* = 8.8 Hz, 2H), 6.81, 6.76 (dd, *J* = 10.8 Hz, 10.8 Hz, 1H), 5.94 (d, *J* = 17.6 Hz, 1H), 5.50 (d, *J* = 11.2 Hz, 1H); ¹³C NMR (100 MHz, CDCl₃) δ: 147.2, 143.8, 135.0, 126.8, 123.9, 118.6. LRMS (EI, 20 eV) *m/z* (%): 149 (M⁺, 100).

1-(2-(4-Nitrophenyl)ethynyl)benzene (5)³

slight yellow solid; ¹H NMR (500 MHz, CDCl₃) δ: 8.25 (d, *J* = 8.8 Hz, 2H), 7.60 (d, *J* = 8.8 Hz, 2H), 7.60–7.58 (m, 2H), 7.43–7.41 (m, 3H); ¹³C NMR (125 MHz, CDCl₃) δ: 147.1, 132.2, 131.8, 130.3, 129.3, 128.5, 123.6, 122.2, 94.7, 87.5. LRMS (EI, 20 eV) *m/z* (%): 223 (M⁺, 100).

1-Biphenyl-4-yl-ethanone (6)¹

White solid; ¹H NMR (300 MHz, CDCl₃) δ: 8.04 (d, *J* = 8.4 Hz, 2H), 7.69 (d, *J* = 8.4 Hz, 2H), 7.64 (d, *J* = 7.6 Hz, 2H), 7.50–7.40 (m, 3H), 2.64 (m, 3H); ¹³C NMR (75 MHz, CDCl₃): δ 197.8, 145.8, 139.9, 135.8, 128.9, 128.9, 128.2, 127.3, 127.2, 26.7. LRMS (EI, 20 eV) *m/z* (%): 196 (M⁺, 100).

4-Methoxy-biphenyl (7)¹

White solid; ¹H NMR (500 MHz, CDCl₃) δ: 7.60–7.56 (m, 4H), 7.46 (t, *J* = 7.8 Hz, 2H), 7.34 (t, *J* = 7.5, 1H), 7.02 (d, *J* = 9.0, 2H), 3.89 (s, 3H); ¹³C NMR (125 MHz, CDCl₃) δ: 159.2, 140.9, 133.8, 128.7, 128.2, 126.8, 126.7, 114.2, 55.4. LRMS (EI, 20 eV) *m/z* (%): 184 (M⁺, 100).

1-(2-(4-Methoxyphenyl)ethynyl)benzene (8)³

White solid; ¹H NMR (400 MHz, CDCl₃) δ: 7.52–7.51 (m, 2H), 7.48 (d, *J* = 9.0 Hz, 2H), 7.34–7.32 (m, 3H), 6.88 (d, *J* = 8.8 Hz, 2H), 3.83 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ: 159.6, 133.0, 131.4, 128.3, 127.9, 123.6, 115.4, 114.0, 89.4, 88.1, 55.3; LRMS (EI, 20 eV) *m/z* (%): 208 (M⁺, 100).

1-(4-(2-Phenylethynyl)phenyl)ethanone (9)³

White solid; ¹H NMR (400 MHz, CDCl₃) δ: 7.95 (d, *J* = 8.8 Hz, 2H), 7.61 (d, *J* = 8.8 Hz, 2H), 7.57–7.55 (m, 2H), 7.38 (t, *J* = 3.2 Hz, 3H), 2.63 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ: 197.4, 136.1, 131.8, 131.7, 128.8, 128.4, 128.3, 122.6, 92.7, 88.6, 26.7; LRMS (EI, 20 eV) *m/z* (%): 220 (M⁺, 100).

Biphenyl (10)⁴

White solid; ¹H NMR (300 MHz, CDCl₃) δ: 7.59 (d, *J* = 8.4 Hz, 4H), 7.43 (t, *J* = 7.2 Hz, 4H), 7.36 (t, *J* = 7.8 Hz, 2H); ¹³C NMR (75 MHz, CDCl₃) δ: 141.6, 129.1, 127.6, 127.5. LRMS (EI, 20 eV) *m/z* (%): 154 (M⁺, 100).

1,2-Diphenylethyne (11)³

White solid; ¹H NMR (300 MHz, CDCl₃) δ: 7.60–7.51 (m, 4H), 7.39–7.26 (m, 6H); ¹³C NMR (75 MHz, CDCl₃) δ: 132.0, 128.7, 128.6, 123.7, 89.7; LRMS (EI, 20 eV) *m/z* (%): 178 (M⁺, 100).

4-Methyl-biphenyl (12)¹

White solid; ¹H NMR (400 MHz, CDCl₃) δ: 7.58 (t, *J* = 7.6 Hz, 2H), 7.49 (d, *J* = 8.0 Hz, 2H), 7.42 (t, *J* = 7.6 Hz, 2H), 7.31 (t, *J* = 7.6 Hz, 1H), 7.24 (d, *J* = 8.0 Hz, 2H), 2.38 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ: 141.1, 138.3, 137.0, 129.5, 128.7, 127.3, 127.2, 127.0, 21.1. LRMS (EI, 20 eV) *m/z* (%): 168 (M⁺, 100).

3,5-Dimethyl-biphenyl (13)⁵

Colorless oil; ¹H NMR (400 MHz, CDCl₃) δ: 7.59 (d, *J* = 8.4 Hz, 2H), 7.44–7.40 (m, 2H), 7.31–7.28 (m, 1H), 7.19 (d, *J* = 8.4 Hz, 2H), 6.98 (d, *J* = 9.2 Hz, 1H), 2.35 (s, 3H), 2.37 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ: 141.5, 138.1, 128.9, 128.7, 127.9, 127.2, 127.1, 125.1, 21.4. LRMS (EI, 20 eV) *m/z* (%): 182 (M⁺, 100).

(D) References

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(E) Synthesis of Cu₂O Nanoparticles⁶

Experimental Procedure for the Synthesis of Cu₂O Nanoparticles. A mixture of PEG-6000 (300 mg), Cu(OAc)₂·H₂O (399 mg) and D-(+)-glucose (1800 mg) was dissolved in water (100 mL). The mixture was stirred at 50 °C to ensure them dissolved completely, followed by dropwise addition of NaOH (5 M, 2 mL) into the solution. After the solution was stirred at 50 °C for 40 min, the Cu₂O precipitate was isolated by centrifuge, then washed with distilled water, ethanol and acetone in turn, and dried in a vacuum oven at 40 °C to offer Cu₂O nanoparticles (110 mg).

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Figure 1. TEM picture showing Cu₂O nanoparticles.

Figure 2. Histogram of the Cu₂O nanoparticles' size distribution

Figure 3. XRD pattern of the Cu₂O nanoparticles

[Cu-2.raw]

Peak Search Report

SCAN: 15.0/90.0/0.02/0.075(sec), Cu(40kV,300mA), I(cps)=156099, 06/07/06 16:45

PEAK: 41-pts/Parabolic Filter, Threshold=3.0, Cutoff=0.1%, BG=3/1.0, Peak-Top=Summit

NOTE: Intensity = CPS, 2T(0)=0.0(°), Wavelength to Compute d-Spacing = 1.54056A(Cu/K-alpha1)

#	2-Theta	d(A)	BG	Height	I%	Area	I% FWHM	XS(A)
1	29.559	3.0195	2796	13684	9.2	3565.8	8.3 0.208	417
2	36.438	2.4637	4894	148465	100.0	42925.4	100.0 0.231	375
3	42.321	2.1339	3652	58608	39.5	16996.9	39.6 0.232	379
4	52.521	1.7409	2379	2664	1.8	799.3	1.9 0.240	379
5	61.441	1.5078	3408	40546	27.3	14052.0	32.7 0.277	340
6	73.715	1.2842	3424	20091	13.5	6362.5	14.8 0.253	403
7	77.520	1.2304	2661	5747	3.9	2176.3	5.1 0.303	344

(F) Spectra

4-Nitro-biphenyl (3)

1-Nitro-4-vinylbenzene (4)

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1-(2-(4-Nitrophenyl)ethynyl)benzene (5)

1-(2-(4-Nitrophenyl)ethynyl)benzene (5)

1-Biphenyl-4-yl-ethanone (6)

1-Biphenyl-4-yl-ethanone (6)

4-Methoxy-biphenyl (7)

4-Methoxy-biphenyl (7)

¹H NMR spectrum of compound 10a in CDCl₃. The spectrum shows peaks at 7.522, 7.517, 7.516, 7.506, 7.502, 7.498, 7.482, 7.460, 7.322, 7.318, 7.255, 6.889, and 6.867 ppm. Integration values are 3.9095, 2.8488, 1.9539, and 2.9937. A reference peak is at 0.0002 ppm.

1-(2-(4-Methoxyphenyl)ethynyl)benzene (8)

1-(4-(2-Phenylethynyl)phenyl)ethanone (9)

1-(4-(2-Phenylethynyl)phenyl)ethanone (9)

Biphenyl (10)

Biphenyl (10)

1,2-Diphenylethyn (11)

1,2-Diphenylethyn (11)

4-Methyl-biphenyl (12)

4-Methyl-biphenyl (12)

3,5-Dimethyl-biphenyl (13)

3,5-Dimethyl-biphenyl (13)