

## **Supporting Information**

### **Hydrodehalogenation of aryl chlorides and aryl bromides using a microwave-assisted, copper-catalyzed concurrent tandem catalysis methodology**

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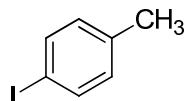
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**General Considerations.** All manipulations were carried out using standard nitrogen drybox techniques. Anhydrous acetonitrile and copper(I) iodide were purchased from Acros and used as received. *trans*-*N,N'*-dimethylcyclohexane-1,2-diamine was purchased from Aldrich and used as received. Microwave reactions were performed in a CEM Discover microwave reactor. GC/MS analysis was performed on a Shimadzu GCMS-QP5050A with a Restek Rxi-5ms capillary column (30 m, 0.25 mm ID, 0.25  $\mu$ m film thickness, 5% diphenyl / 95% dimethylpolysiloxane) or Varian Saturn 2900 GC/3100 GC/MS/MS with a Varian VF-5ms Factor Four capillary column (30 m, 0.25 mm ID, 0.25  $\mu$ m film thickness, 5% diphenyl / 95% dimethylpolysiloxane).  $^1\text{H}$  and  $^{13}\text{C}$  NMR spectra were recorded on a JEOL ECX-400 spectrometer and were referenced to residual protio solvent peaks. Melting points were measured on an Electrothermal Mel-temp melting point device.

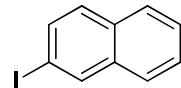
## Experimental Procedures.

**General Procedure for the Copper-Catalyzed Conversion of Aryl Bromides into Aryl Iodides.** In a nitrogen-filled glove box, CuI (15 mg, 0.079 mmol, 5 mol%), NaI (450 mg, 3.00 mmol), and an aryl bromide (1.5 mmol) were weighed into an oven-dried microwave tube containing a small stir bar. Acetonitrile (0.6 mL) was added by syringe and then *trans*-*N,N'*-dimethylcyclohexane-1,2-diamine (23.7  $\mu$ L, 0.1 mmol, 10 mol%) was added by positive displacement pipet, the sample was stirred, and a septum-lined cap was added. The initial reaction mixture appeared as a yellow or yellow-green liquid over a white solid. After removing the tube from the box, the reaction was performed in a CEM Discover microwave reactor for 30-120 minutes at 100 °C and 250 W (with power

adjustments to maintain temperature), with a 2 minute ramp time. After cooling, the reaction mixture contained a turquoise-blue liquid over a solid. The product mixture was purified by column chromatography on silica. The yields reported did not take into account the trace amount of aryl bromide present in the isolated products.

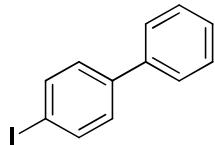


**4-Iodotoluene (Table 1, entry 1).** Following the general procedure, 4-bromotoluene (187  $\mu$ L, 1.5 mmol) was converted to 4-iodotoluene in 60 minutes. The product was purified by column chromatography on silica gel (10:90 v/v EtOAc : hexanes) to provide the desired product as a clear liquid that was further purified by rotary evaporation into white crystals (90% yield, 96% purity). Mp: 34 – 37 °C (lit: 33-35 °C).  $^1$ H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.56 (d, *J* = 7.8 Hz, 2H), 6.92 (d, *J* = 8.3 Hz, 2H), 2.29 (s, 3H).  $^{13}$ C NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  137.44, 137.19, 131.18, 90.18, 21.02.<sup>1</sup>

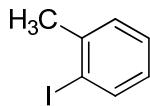


**2-Iodonaphthalene (Table 1, entry 2).** Following the general procedure, 2-bromonaphthalene (311 mg, 1.5 mmol) was converted to 2-iodonaphthalene in 60 minutes. Purification of the crude product was accomplished by column chromatography on silica gel (100% hexanes), which provided the desired product as a clear liquid that was further purified by rotary evaporation into white crystals (97% yield, 96% purity). Mp: 50.5 – 51.5 °C (lit: 53-54 °C).  $^1$ H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  8.24 (s, 1H), 7.81-7.77 (m, 1H),

7.73-7.69 (m, 2H), 7.57 (d,  $J$  = 8.7 Hz, 1H), 7.51-7.47 (m 2H).  $^{13}\text{C}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  136.73, 135.08, 134.47, 132.19, 129.60, 127.97, 126.90, 126.80, 126.58, 91.63.<sup>2</sup>



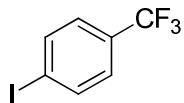
**4-Iodobiphenyl (Table 1, entry 3).** Following the general procedure, 4-bromobiphenyl (351 mg, 1.51 mmol) was converted to 4-iodobiphenyl in 60 minutes. Purification of the crude product by column chromatography on silica gel (10:90 v/v EtOAc : hexanes) provided the desired product as a clear liquid that was further purified by rotary evaporation into white crystals (96% yield, 98% purity). Mp: 113.0 – 115.0 °C (lit: 112.5 – 113.5 °C).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.76 (d,  $J$  = 6.9 Hz, 2H), 7.55 (d,  $J$  = 7.8 Hz, 2H), 7.44 (t,  $J$  = 7.3 Hz, 2H), 7.39 – 7.28 (m, 3H).  $^{13}\text{C}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  140.81, 140.15, 137.94, 129.12, 129.01, 127.80, 127.00, 93.15.<sup>3,4</sup>



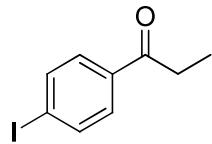
**2-Iodotoluene (Table 1, entry 4).** Following the general procedure, 2-bromotoluene (184  $\mu\text{L}$ , 1.5 mmol) was converted to 2-iodotoluene in 60 minutes at 150 °C. The product was purified by column chromatography on silica gel (10:90 v/v EtOAc : hexanes) to provide the desired product as a clear liquid that was further purified by rotary evaporation into a colorless oil (89% yield, 95% purity).  $^1\text{H}$  NMR (400 MHz,

CDCl<sub>3</sub>) δ 7.84 (d, *J* = 7.4 Hz, 1H), 7.28-7.24 (m, 2H), 6.90-6.88 (m, 1H), 2.46 (s, 3H);

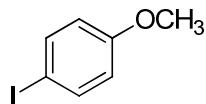
<sup>13</sup>C NMR (400 MHz, CDCl<sub>3</sub>) δ 141.3, 138.8, 129.7, 128.1, 127.3, 101.2, 28.1.<sup>1</sup>



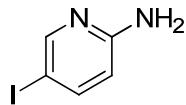
**4-Iodobenzotrifluoride (Table 1, entry 5).** Following the general procedure, 4-bromobenzotrifluoride (210.9 μL, 1.5 mmol) was converted to 4-iodobenzotrifluoride in 60 minutes. The product was purified by column chromatography on silica gel (10:90 v/v EtOAc : hexanes) to provide the desired product as a clear liquid that was further purified by rotary evaporation (84% yield, 96% purity). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.83 (d, *J* = 8.3 Hz, 2H), 7.34 (d, *J* = 8.2 Hz, 2H). <sup>19</sup>F NMR (400 MHz, CDCl<sub>3</sub>) δ -62.93 (s).<sup>5</sup>



**4-Iodopropiophenone (Table 1, entry 6).** Following the general procedure, 4-bromopropiophenone (320 mg, 1.5 mmol) was converted to 4-iodopropiophenone in 30 minutes. Purification of the crude product was accomplished by column chromatography on silica gel (10:90 v/v EtOAc : hexanes), which provided the desired product as a clear liquid that was further purified by rotary evaporation into white crystals (94% yield, 98% purity). Mp: 62.0 – 64.0 °C (lit: 57-58 °C). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.81 (d, *J* = 8.3 Hz, 2H), 7.66 (d, *J* = 8.7 Hz, 2H), 2.95 (q, *J* = 7.3 Hz, 2H), 1.20 (t, *J* = 6.8 Hz, 3H). <sup>13</sup>C NMR (400 MHz, CDCl<sub>3</sub>) δ 200.16, 137.96, 136.19, 129.52, 100.88, 31.83, 8.21.<sup>6</sup>



**4-Iodoanisole (Table 1, entry 7).** Following the general procedure, 4-bromoanisole (187  $\mu$ L, 1.5 mmol) was converted to 4-iodoanisole in 75 minutes. The product was purified by column chromatography on silica gel (10:90 v/v EtOAc : hexanes) to provide the desired product as a clear liquid that was further purified by rotary evaporation into white crystals (95% yield, 98% purity). Mp: 51.0 – 53.0  $^{\circ}$ C (lit: 51 - 53  $^{\circ}$ C).  $^1$ H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.55 (d, *J* = 8.7 Hz, 2H), 6.68 (d, *J* = 8.7 Hz, 2H), 3.77 (s, 3H).  $^{13}$ C NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  159.52, 138.28, 116.44, 82.80, 55.42.<sup>7</sup>



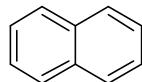
**2-Amino-5-iodopyridine (Table 1, entry 8).** Following the general procedure, 2-amino-5-bromopyridine (261 mg, 1.5 mmol) was converted to 2-amino-5-iodopyridine in 120 minutes. The product was purified by column chromatography on silica gel using 3:2 v/v EtOAc:hexanes as eluent to provide the desired product as a white solid (94% yield, 99% purity).  $^1$ H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  8.20 (s, 1H), 7.61 (dd, *J* = 1.8, 8.7 Hz, 1H), 6.35 (d, *J*=8.7 Hz, 1H), 4.45 (br s, 2H);  $^{13}$ C NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  157.17, 153.38, 145.38, 110.96, 77.32.<sup>4</sup>

**General Procedure for the Copper-Catalyzed Conversion of Aryl Chlorides into Aryl Iodides.** In a nitrogen-filled glove box, CuI (10 mg, 0.047 mmol, 5 mol%), NaI (300 mg, 2.00 mmol), and an aryl chloride (1.0 mmol) were weighed into an oven-dried

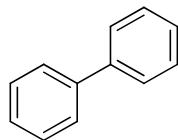
microwave tube containing a small stir bar. Acetonitrile (0.5 mL) was added by syringe and then *trans*-*N,N'*-dimethylcyclohexane-1,2-diamine (23.7  $\mu$ L, 0.1 mmol, 10 mol%) was added by positive displacement pipet, the sample was stirred, and a septum-lined cap was added. The initial reaction mixture appeared as a yellow or greenish liquid over a white solid. After removing the tube from the box, the reaction was performed in a CEM Discover microwave reactor for 30-120 minutes at 100 °C and 250 W (with power adjustments to maintain temperature), with a 2 minute ramp time. After cooling, the crude reaction mixture appeared as a yellow or brown solution. An equimolar amount (versus ArCl) of either hexadecane or decane was added to the solution. The solution was then quenched with 2 mL water and 2 mL EtOAc. The resulting solution was a dark brown, cloudy organic layer over a purple aqueous layer. A drop was removed from the organic layer and diluted with 10 drops of EtOAc in order to determine the GC yield.

**General Procedure for the Copper-Catalyzed Conversion of Aryl Bromides and Aryl Chlorides into Arenes.** In a nitrogen-filled glove box, CuI (40 mg, 0.21 mmol, 20 mol%), NaI (300 mg, 2.00 mmol, 2 equiv), and an aryl bromide or aryl chloride (1.0 mmol) were weighed into an oven-dried microwave tube containing a small stir bar. Acetonitrile (0.5 mL) was added by syringe and then *trans*-*N,N'*-dimethylcyclohexane-1,2-diamine (237  $\mu$ L, 1.5 mmol, 1.5 equiv) was added by positive displacement pipet, the sample was stirred, and a septum-lined cap was added. The initial reaction mixture appeared as a yellow or greenish liquid over a white solid. After removing the tube from the dry box, the reaction was performed in a CEM Discover microwave reactor for 1-2 hours at 200 °C and 250-300 W (with power adjustments to maintain temperature), with a

5-10 minute ramp time. Most reactions reached 200 °C after ~2 minutes. After the desired reaction time was reached and the tube cooled, the crude reaction mixture appeared as a dark brown liquid over some solids. The product mixture was either spiked with ~1.0 mmol decane for GC yield determination or purified by column chromatography on silica gel. Products purified by column chromatography routinely contained a small percentage of the corresponding aryl iodide and reported yields were adjusted to account for this impurity.

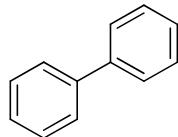


**Naphthalene (Table 4, entry 2).** Following the general procedure, 2-bromonaphthalene (207 mg, 1.0 mmol) was converted to naphthalene in 2 hours at 200 °C. The product was purified by column chromatography on silica gel (hexanes, loaded crude product by dissolving in a minimum of CH<sub>2</sub>Cl<sub>2</sub>) to provide the desired product as a crystalline white solid (87% yield, adjusted for the presence of ~4 mol % 2-iodonaphthalene). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.91-7.83 (m, 4H), 7.54-7.46 (m, 4H); <sup>13</sup>C NMR (400 MHz, CDCl<sub>3</sub>) δ 133.42, 127.88, 125.82. <sup>8</sup>

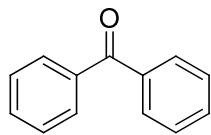


**Biphenyl (Table 4, entry 3).** Following the general procedure, 4-bromobiphenyl (233 mg, 1.0 mmol) was converted to biphenyl in 2 hours at 200 °C. The product was purified by column chromatography on silica gel (hexanes, loaded crude product by dissolving in

a minimum of  $\text{CH}_2\text{Cl}_2$ ) to provide the desired product as a white crystalline solid (77% yield, adjusted for the presence of ~10 mol % 4-iodobiphenyl).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.63-7.57 (m, 4H), 7.48-7.41 (m, 4H), 7.38-7.32 (m, 2H);  $^{13}\text{C}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  141.32, 128.85, 127.35, 127.27.<sup>9</sup>



**Biphenyl (Table 4, entry 4).** CuI (80 mg, 0.42 mmol, 40 mol%), NaI (600 mg, 4.00 mmol, 4 equiv), and 4, 4'-dibromobiphenyl (312 mg, 1.0 mmol) were weighed into an oven-dried microwave tube containing a small stir bar. *trans*-*N,N'*-Dimethylcyclohexane-1,2-diamine (474  $\mu\text{L}$ , 3.0 mmol, 3.0 equiv) and acetonitrile (0.5 mL) were added. The general procedure was then followed to produce biphenyl in 2 hours at 200 °C. The product was purified by column chromatography on silica gel (hexanes, loaded crude product by dissolving in a minimum of  $\text{CH}_2\text{Cl}_2$ ) to provide the desired product as a white solid (72% yield, adjusted for the presence of ~8 mol % 4-iodobiphenyl). Spectral data was consistent with the biphenyl product produced from 4-bromobiphenyl.<sup>9</sup>



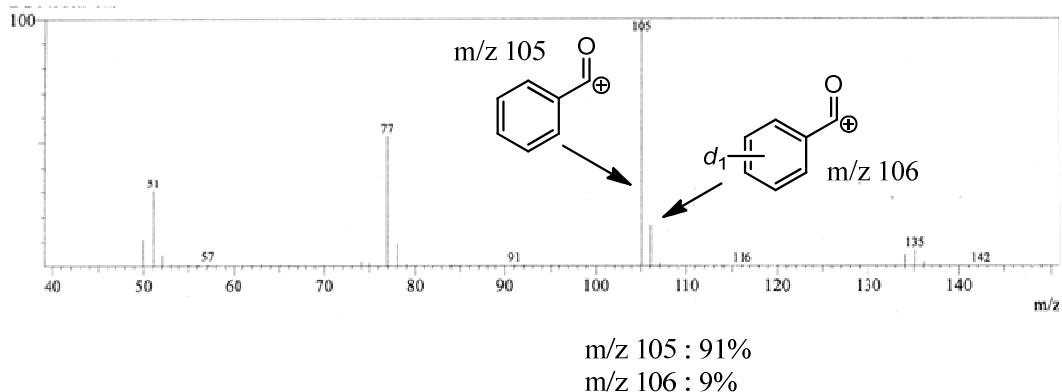
**Benzophenone (Table 4, entry 6).** Following the general procedure, but with only 20 mg CuI (0.10 mmol, 10 mol%), 4-bromobenzophenone (261 mg, 1.0 mmol) was converted to benzophenone in 2 hours at 200 °C. The product was purified by column

chromatography on silica gel (1:10 v/v EtOAc : hexanes, loaded column by adsorbing crude product onto silica gel) to provide the desired product as a yellow oil (77% yield, adjusted for the presence of ~4 mol % 4-iodobenzophenone).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.82-7.77 (m, 4H), 7.61-7.54 (m, 2H), 7.51-7.45 (m, 4H);  $^{13}\text{C}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  196.90, 137.66, 132.53, 130.18, 128.37.<sup>10</sup>

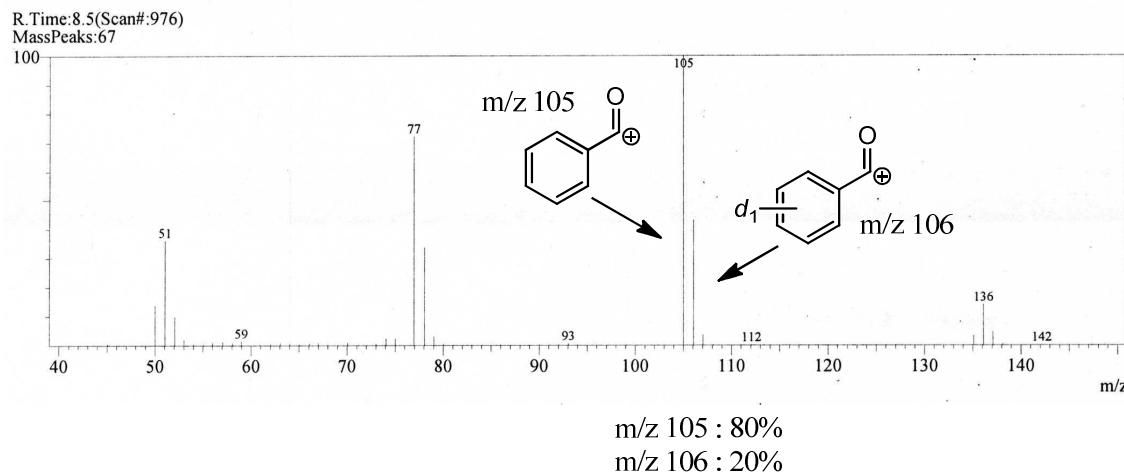
### **Procedure for the Deuterium-Labeling Experiments:**

In a nitrogen-filled glove box, CuI (10 mg, 0.05 mmol, 10 mol%), NaI (150 mg, 1.00 mmol, 2 equiv), and 4-chloropropiophenone (88 mg, 0.5 mmol) were weighed into an oven-dried microwave tube containing a small stir bar. Acetonitrile- $d_3$  (0.25 mL) was added by syringe and then *trans*-*N,N'*-dimethylcyclohexane-1,2-diamine (118.5  $\mu\text{L}$ , 0.75 mmol, 1.5 equiv) was added by positive displacement pipet, the sample was stirred, and a septum-lined cap was added. After removing the tube from the dry box, the reaction was performed in a CEM Discover microwave reactor for 1 hour at 200 °C and 250-300 W (with power adjustments to maintain temperature), with a 10 minute ramp time. Most reactions reached 200 °C after ~3-4 minutes. After the desired reaction time was reached and the tube cooled, the product mixture was diluted in ethylacetate and analyzed by GC-MS.

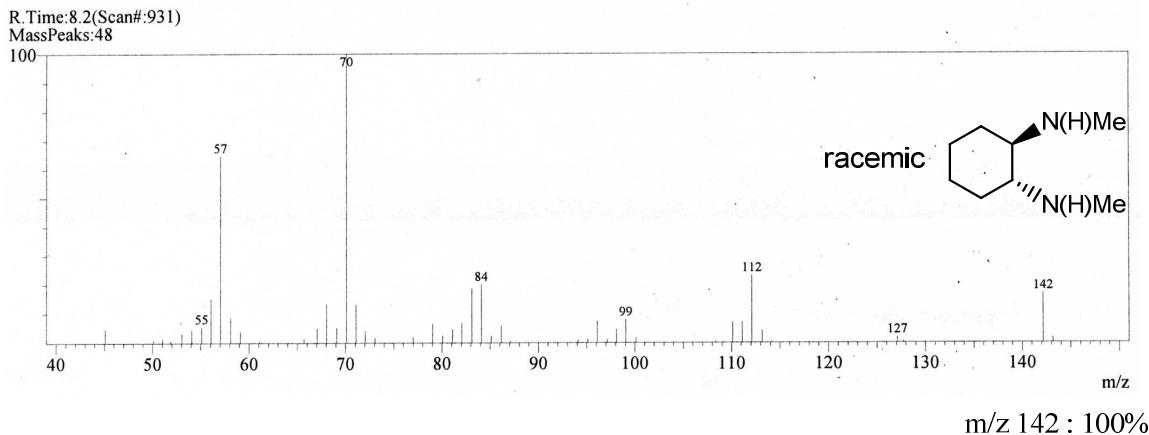
Mass spectra from GC-MS analysis:  
Arene peak after 5 min:



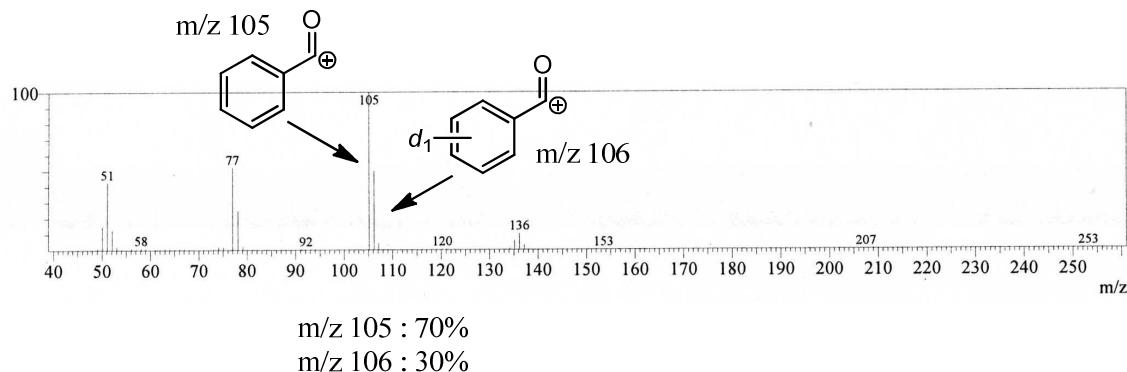
Arene peak, after 10 min:



Ligand peak, after 10 min:



Arene peak after 2 hours:



## References

- (1) Zhou, C. Y.; Li, J.; Peddibhotla, S.; Romo, D. *Org. Lett.* **2010**, *12*, 2104-2107.
- (2) Jean, M.; Renault, J.; Uriac, P.; Capet, M.; van de Weghe, P. *Org. Lett.* **2007**, *9*, 3623-3625. Suzuki, H.; Kondo, A.; Inouye, M.; Ogawa, T. *Synthesis* **1986**, *2*, 121-122.
- (3) Dektar, J. L.; Hacker, N. P. *J. Org. Chem.* **1990**, *55*, 639-647.
- (4) Klapars, A.; Buchwald, S. L. *J. Am. Chem. Soc.* **2002**, *124*, 14844-14845.
- (5) Naka, H.; Uchiyama, M.; Matsumoto, Y.; Wheatley, A. E. H.; McPartlin, M.; Morey, J. V.; Kondo, Y. *J. Am. Chem. Soc.* **2007**, *129*, 1921-1930. Naumann, D.; Kischkowitz, J. *J. Fluorine Chem.* **1990**, *47*, 283-299.
- (6) Legrand, L.; Lozach, N. *Bull. Soc. Chim. Fr.* **1959**, 1686-1688.
- (7) Kuivila, H. G.; Benjamin, L. E.; Murphy, C. J.; Price, A. D.; Polevy, J. H. *J. Org. Chem.* **1962**, *27*, 825-829. Malet-Sanz, L.; Madrzak, J.; Holvey, R. S.; Underwood, T. *Tetrahedron Lett.* **2009**, *50*, 7263-7267.
- (8) Murphy, J. A.; Zhou, S.-z.; Thomson, D. W.; Schoenebeck, F.; Mahesh, M.; Park, S. R.; Tuttle, T.; Berlouis, L. E. A. *Angew. Chem. Int. Ed.* **2007**, *46*, 5178-5183.
- (9) Nising, C. F.; Schmid, U. K.; Nieger, M.; Bräse, S. *J. Org. Chem.* **2004**, *69*, 6830-6833.
- (10) Xing, D.; Guan, B.; Cai, G.; Fang, Z.; Yang, L.; Shi, Z. *Org. Lett.* **2006**, *8*, 693-696.