Copper catalyzed trifluoromethylation of aryl- and vinylboronic acids with generation of CF₃-radicals

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Table S1 Copper-catalyzed trifluoromethylation of 4-methoxyphenylboronic acid: Variation of reaction conditions^a

MeO-	B(OH) ₂ + 0	F ₃ SO ₂ Na +	TBHP -	20 mol% 2,4,6-coll DCM, ⊢	[Cu] idine ₂O → MeO{		
	1a	2	3	rt, air, 6	ĥ	4a	
Entry	[Cu]	CF ₃ SO ₂ Na (equiv)	TBHP ^b (equiv)	NH₄C I (equiv)	2,4,6-collidine (equiv)	Yie l d(%) ^c	
1	Cu(OAc) ₂	5.0	10.0	2.5	2.0	53	
2	_	5.0	10.0	2.5	2.0	<5	
3	CuOAc	5.0	10.0	2.5	2.0	40	
4	Cu(CF3CO2)2+H2O	5.0	10.0	2.5	2.0	44	
5	CuBr	5.0	10.0	2.5	2.0	40	
6	Cul	5.0	10.0	2.5	2.0	38	
7	Cu(CH ₃ CN) ₄ BF ₄	5.0	10.0	2.5	2.0	36	
8	Cu(CH ₃ CN) ₄ OTf	5.0	10.0	2.5	2.0	44	
9	Cu(OAc) ₂	5.0	10.0	3.0	2.0	36	
10	Cu(OAc) ₂	5.0	10.0	2.0	2.0	39	
11	Cu(OAc) ₂	5.0	10.0	2.5		22	
12	Cu(OAc) ₂	5.0	10.0	2.5	1.0	46	
13	Cu(OAc) ₂	5.0	10.0	2.5	1.5	49	
14	Cu(OAc) ₂	5.0	10.0	2.5	2.5	49	
15	Cu(OAc) ₂	5.0	10.0	2.5	3.0	28	
16	Cu(OAc) ₂	6.0	12.0	2.5	2.0	55	
17	Cu(OAc) ₂	7.0	14.0	2.5	2.0	64	
18	Cu(OAc) ₂	7.0	16.1	2.5	2.0	66	
19	Cu(OAc) ₂	7.0	16.1	2.5	2.0	74 ^d	
^a All the reactions were performed on 0.25 mmol scale in DCM (4 mL) and H ₂ O (1.5 mL).							
^b TBHP (tert-butyl hydroperoxide) was used as 70% solution in water. ^c GC yield is shown							
and dodecane was used as internal standard. ^d 0.24 equiv of imidazole was added.							

General information: ¹H NMR Spectra were recorded on Bruker 400 MHz or 300 MHz, ¹⁹F NMR Spectra were recorded on 282 MHz, ¹³C NMR Spectra were recorded on 100 MHz or 75 MHz in the solvents indicated; chemical shifts are reported in units (ppm) by assigning CDCl₃ resonance in the ¹H spectrum as 7.26 ppm and CDCl₃ resonance in the ¹³C spectrum as 77.0 ppm. ¹⁹F NMR chemical shifts were determined relative to CFCl₃ as internal standard. All coupling constants (*J* values) were reported in Hertz (Hz). Column chromatography was performed on silica gel 200-300 mesh. HRMS were performed on Agilent ESI-TOF/MS. (*Z*)-potassium styryltrifluoroborate was synthesized according to the reported procedure (Ref: Molander, G. A., Ellis, N. M. *J. Org. Chem*, **2008**, 73, 6841).

If no special indicated, all the solvents and regents were used as commercial sources and without further purification.

General procedure for the synthesis of compounds 4 and 6.

In a reaction tube (40 mL), the boronic acid (0.25 mmol), NaSO₂CF₃ (1.75 mmol, 273.1 mg), imidazole (0.06 mmol, 4.1 mg), Cu(OAc)₂ solution in water (250 μ L, 0.20 M), NH₄Cl solution in water (200 μ L, 3.12 mmol), 2,4,6-collidine (66 μ L, 0.50 mmol), DCM (4 .0 mL), H₂O (1.05 mL) were added in sequence. Under a vigorous stirring, TBHP (557 μ L, 70% solution in water) was added at rt and the stirring was continued for 6 h at rt.

For the compounds reported as isolated yields, the organic phase was separated; the water phase was extracted with DCM (3 x 10 mL). The combined organic layer was dried by anhydrous Na_2SO_4 , the solvent was removed at 1 atm and the residue was purified on silica gel chromatography with pentane to afford compounds **4** or **6**.

Because some CF_3 compounds are easy to evaporate, the yields of them were detected by GC and ${}^{19}F$ NMR.

For the compounds reported as GC yields, the internal standard [dodecane (57 μ L, 0.25 mmol) or anisole (27 μ L, 0.25 mmol)] was added to the reaction mixture, after stirring for another 5 min, the sample was taken from DCM phase and detected by GC.

For the compounds reported as ¹⁹F NMR yields, the internal standard 3-fluoroanisole (29 μ L, 0.25 mmol) was added to the reaction mixture, after stirring for another 5 min, the sample of DCM phase was detected by ¹⁹F NMR.

The pure samples used as the standard of the crude ¹⁹F NMR, they were also synthesized by our method.



The yield of 4c was determined by ¹⁹F NMR.

¹H NMR (CDCl₃, 300 M Hz): δ 7.16-7.13 (m, 1H), 7.04 (d, J = 1.8 Hz, 1H), 6.86 (d, J = 8.1 Hz, 1H), 6.04 (s, 2H); ¹⁹F NMR (CDCl₃, 282 M Hz): δ -61.1; ¹³C NMR (CDCl₃, 75 M Hz): δ 150.3, 147.9, 124.2 (q, J = 32.6 Hz), 124.0 (q, J = 269.7 Hz), 119.8 (q, J = 4.4 Hz), 108.2, 105.8 (q, J = 3.7 Hz), 101.9. MS (EI): m/z, 190.

Ref: Chu, L.; Qing, F.- L. Org. Lett. 2010, 12, 5060.



According to the general procedure, compound 4d was obtained in 73% (45.7 mg) yield.

¹H NMR (CDCl₃, 300 M Hz): δ 7.56 (d, J = 8.4 Hz, 2H), 7.46-7.34 (m, 5H), 7.05 (d, J = 8.4 Hz, 2H), 5.12 (s, 2H); ¹⁹F NMR (CDCl₃, 282 M Hz): δ -61.1. ¹³CNMR (CDCl₃, 75 M Hz): δ 161.1, 136.2, 128.7 (2C), 128.2, 127.4 (2C), 126.9 (q, J = 3.7 Hz, 2C), 124.4 (q, J = 269.5 Hz), 123.1(q, J = 32.5 Hz), 114.8 (2C), 70.1. MS (EI): m/z, 252.

Ref: Liu, T.; Shen, Q. Org. Lett. 2011, 13, 2342.



According to the general procedure, compound 4e was obtained in 65% (45.1 mg) yield. And 69% yield was determined by ¹⁹F NMR.

¹H NMR (CDCl₃, 300 M Hz): δ 7.50 (d, *J* = 8.4 Hz, 2H), 6.91 (d, *J* = 8.4 Hz, 2H), 1.00 (s, 9H), 0.23 (s, 6H); ¹³CNMR (CDCl₃, 75 M Hz): δ 158.6, 126.8 (q, *J* = 3.7 Hz, 2C), 124.5 (q, *J* = 269.3 Hz), 123.4 (q, *J* = 32.4 Hz), 120.1 (2C), 25.6 (3C), 18.2, -4.5 (2C); ¹⁹F (CDCl₃, 282 M Hz): δ -61.2. MS (EI): m/z, 276. Ref: Sykora, J.; Blechta, V.; Sychrovsky, V.; Hetflejs, J.; Sabata, S.; Soukupova, L.; Schraml, *J. Magn. Reson. Chem.* **2006**, 44, 669.



The yield of 4f was determined by ¹⁹F NMR.

¹H NMR (CDCl₃, 300 M Hz): δ 7.52 (d, J = 8.1 Hz, 2H), 7.30 (d, J = 8.1 Hz, 2H), 2.51 (s, 3H); ¹⁹F (CDCl₃, 282 M Hz): δ -61.9; ¹³C NMR (CDCl₃, 100 M Hz): δ 143.8, 126.8 (q, J = 32.6 Hz), 125.6 (2C), 125.5 (q, J = 3.7 Hz, 2C), 124.2 (q, J = 269.7 Hz), 15.0. MS (EI): m/z, 192.

Ref: Cabiddu, M.; Cabiddu, S.; Cadoni, E.; Corrias, R.; Fattuoni, C. Floris, C. Melis, S. J. Organomet. Chem. **1997**, *531*, 125.



According to the general procedure, compound 4g was obtained in 39% (18.6 mg) yield.

¹H NMR (CDCl₃, 300 M Hz): δ 7.46 (d, *J* = 8.4 Hz, 2H), 6.71 (d, *J* = 8.7 Hz, 2H), 3.01 (s, 6H); ¹⁹F NMR (CDCl₃, 282 M Hz): δ -60.4. ¹³CNMR (CDCl₃, 75 M Hz): δ 152.2, 126.3 (q, *J* = 3.8 Hz, 2C), 125.2 (q, *J* = 278.5 Hz), 117.5 (q, *J* = 32.0 Hz), 111.2 (2C), 40.1 (2C). MS (EI): m/z, 189.

Ref: Yagupolskii, L. M.; Matsnev, A. V.; Orlova, R. K.; Deryabkin, B. G.; Yagupolskii, Y. L. J. Fluor. Chem. 2008, 129, 131.



According to the general procedure, compound **4h** was obtained in 60% (31.0 mg) yield. And 68% yield was determined by 19 F NMR.

¹H NMR (CDCl₃, 300 M Hz): δ 7.48 (d, J = 8.4 Hz, 1H), 6.51-6.47 (m, 2H), 3.87 (s, 3H), 3.84 (s, 3H); ¹⁹F NMR (CDCl₃, 282 M Hz): δ -60.9; ¹³C NMR (CDCl₃, 75 M Hz): δ 163.6, 158.8, 128.2 (q, J = 5.2 Hz), 124.0 (q, J = 269.3 H), 111.5 (q, J = 31.0 H), 103.7, 99.3, 55.8, 55.5. MS: m/z, 206. Ref: Ye, Y.; Lee, S. H.; Sanford, M. S. *Org. Lett.* **2011**, *13*, 5464.



According to the general procedure, compound 4i was obtained in 53% (31.4 mg) yield.

¹H NMR (CDCl₃, 300 M Hz): δ 8.12 (d, J = 7.8 Hz, 1H), 7.98 (dq, J = 7.5 Hz, 0.6 Hz, 1H), 7.71-7.65 (m, 2H), 7.56-7.50 (m, 1H), 7.45-7.37 (m, 2H); ¹⁹F (CDCl₃, 282 M Hz): δ -60.7; ¹³C NMR (CDCl₃, 75 M Hz): δ 156.4, 152.1, 128.1, 126.0, 124.3, 123.3 (q, J = 270.3 Hz), 123.9 (q, J = 4.5 Hz), 123.4, 122.9, 122.3, 120.7, 115.0 (q, J = 33.9 Hz), 112.1. MS: m/z, 236.

Ref: Xu, J.; Luo, D.-F.; Xiao, B.; Liu, Z.-J.; Gong, T.-J.; Fu, Y.; Liu, L. Chem. Commun. 2011, 47, 4300.



According to the general procedure, compound 4l was obtained in 58% (32.2 mg) yield.

¹HNMR (CDCl₃, 300 M Hz): δ 7.70 (br, 4H), 7.62-7.58 (m, 2H), 7.51-7.39 (m, 3H); ¹⁹F (CDCl₃, 282 M Hz): δ -62.0. ¹³CNMR (CDCl₃, 75 M Hz): δ 144.7, 139.7, 129.3 (q, J = 32.3 Hz), 129.0 (2C), 128.2, 127.4 (2C), 127.3 (2C), 125.7 (q, J = 3.8 Hz, 2C), 124.3 (q, J = 270.2 Hz). MS: m/z, 222.

Ref: Xu, J.; Luo, D.-F.; Xiao, B.; Liu, Z.-J.; Gong, T.-J.; Fu, Y.; Liu, L. Chem. Commun. 2011, 47, 4300.



The yield of 4p was determined by ¹⁹F NMR.

¹H NMR (CDCl₃, 300 M Hz): δ 7.68 (d, J = 7.8 Hz, 1H), 7.58 (dq, J = 8.4 Hz, 0.9 Hz, 1H), 7.48-7.42 (m, 1H), 7.36-7.31 (m, 1H), 7.18-7.17 (m, 1H); ¹⁹F NMR (CDCl₃, 282 M Hz): δ -64.4. ¹³C NMR (CDCl₃, 75 M Hz): δ 155.1, 143.5 (q, J = 41.8 Hz), 126.9, 126.0, 124.0, 122.5, 119.3 (q, J = 266.2 Hz), 112.1, 108.1 (q, J = 2.9 Hz). MS: m/z, 186.

Ref: Liu, T.; Shen, Q. Org. Lett. 2011, 13, 2342.



According to the general procedure, compound 4q was obtained in 34% (26.4 mg) yield.

¹H NMR (CDCl₃, 300 M Hz): δ 7.46 (d, J = 9.0 Hz, 1H), 7.08-7.03 (m, 3H), 3.86 (s, 3H), 1.66 (3, 9H); ¹⁹F NMR (CDCl₃, 282 M Hz): δ -57.8. ¹³C NMR (CDCl₃, 75 M Hz): δ 156.2, 148.5, 132.4, 127.2 (q, J = 39.0 Hz), 127.2, 117.0, 116.5, 120.7 (q, J = 265.9 Hz), 113.1 (q, J = 5.2 Hz), 103.4, 85.3, 55.6, 27.8 (3C). HRMS, m/z: [M+H]⁺ calculated for C₁₅H₁₇F₃NO₃:316.1155, found 316.1153.



The yield of **6a** was determined by 19 F NMR.

¹H NMR (CDCl₃, 300 M Hz): δ 7.42-7.38 (m, 2H), 7.10 (dq, J = 16.2 Hz, 2.1 Hz, 1H), 6.94-6.89 (m, 2H), 6.07 (dq, J = 16.2 Hz, 6.6 Hz, 1H), 3.84 (s, 3H); ¹⁹F NMR(CDCl₃, 282 M Hz): δ -62.4 (d, J = 6.5 Hz); ¹³C NMR (CDCl₃, 75 M Hz): δ 161.0, 137.1 (q, J = 6.8 Hz), 129.0 (2C), 126.0, 123.9 (q, J = 266.8 Hz), 114.3 (2C), 113.4 (q, J = 33.5 Hz), 55.3. MS, m/z, 202.

Ref: Liu, T.; Shen, Q. Org. Lett. 2011, 13, 2342.



The yield of **6b** was determinated by ¹⁹F NMR.

¹HNMR (CDCl₃, 300 M Hz): δ 7.35 (d, *J* = 8.1 Hz, 2H), 7.20 (d, *J* = 8.1 Hz, 2H), 7.12 (dq, *J* = 16.2 Hz, 2.1 Hz, 1H), 6.16 (dq, *J* = 16.2 Hz, 6.6 Hz, 1H), 2.38 (s, 3H); ¹⁹F (CDCl₃, 282 M Hz): δ -62.7 (d, *J* = 6.5 Hz); ¹³CNMR (CDCl₃, 75 M Hz): δ 140.3, 137.5 (d, *J* = 6.8 Hz), 130.6, 129.6 (2C), 127.5 (2C), 123.8 (q, *J* = 267.0 Hz), 114.7 (q, *J* = 33.5 Hz), 21.4. MS, m/z, 186.

Ref: Liu, T.; Shen, Q. Org. Lett. 2011, 13, 2342.



The yield of **6c** was determined by 19 F NMR.

¹H NMR (CDCl₃, 300 M Hz): δ 7.48-7.37 (m, 5H), 7.16 (dq, J = 16.2 Hz, 2.1 Hz, 1H), 6.21 (dq, J = 16.2 Hz, 6.6 Hz, 1H); ¹⁹F NMR (CDCl₃, 282 M Hz): δ -62.9 (d, J = 5.6 Hz); ¹³C NMR (CDCl₃, 75 M Hz): δ 137.6 (q, J = 6.7 Hz), 133.4, 130.0, 128.9 (2C), 127.5 (2C), 123.6 (q, J = 267.2 Hz), 115.8 (q, J = 33.5 Hz). MS, m/z, 172.

Ref: Prakash, G. K. S.; Krishnan, H. S.; Jog, P. V.; Lyer, A. P.; Olah, G. A. Org. Lett. 2012, 14, 1146.



According to the general procedure, compound 6d was obtained in 56% (35.1 mg) yield.

¹H NMR (CDCl₃, 300 M Hz): δ 7.66-7.60 (m, 4H), 7.55-7.52 (m, 2H), 7.50-7.44 (m, 2H), 7.42-7.36 (m, 1H), 7.25 (dq, J = 16.2 Hz, 2.1 Hz), 6.25 (dq, J = 16.2 Hz, 6.6 Hz); ¹⁹F NMR (CDCl₃, 282 M Hz): δ -62.8 (d, J = 6.2 Hz); ¹³C NMR (CDCl₃, 75 M Hz): 142.7, 140.0, 137.2 (q, J = 6.8 Hz), 132.3, 128.9 (2C), 128.0 (2C), 127.8, 127.5 (2C), 127.0 (2C), 123.7 (q, J = 267.2), 115.6 (q, J = 33.6). MS, m/z, 248. Ref: Liu, T.; Shen, Q. *Org. Lett.* **2011**, 13, 2342.



The yield of **6e** was determined by ¹⁹F NMR.

¹H NMR (CDCl₃, 400 M Hz): δ 7.41-7.36 (m, 4H), 7.11 (dq, J = 16.0 Hz, 2.0 Hz 1H), 6.18 (dq, J = 16.0 Hz, 4.8 Hz, 1H); ¹⁹F NMR (CDCl₃, 282 M Hz): δ -63.0 (d, J = 5.9 Hz); ¹³C NMR (CDCl₃, 100 M Hz): δ 136.4 (q, J = 6.6 Hz), 136.0, 131.9, 129.2 (2C), 128.7 (2C), 123.4 (q, J = 267.7 Hz), 116.5 (q, J = 33.7 Hz). MS, m/z, 206.

Ref: Liu, T.; Shen, Q. Org. Lett. 2011, 13, 2342.



The yield of **6f** was determined by 19 F NMR.

¹H NMR (CDCl₃, 300 M Hz): δ 7.47-7.41 (m, 2H), 7.16-7.06 (m, 3H), 6.14 (dq, J = 16.2 Hz, 6.3 Hz, 1H); ¹⁹F NMR (CDCl₃, 282 M Hz): δ -62.9 (d, J = 5.9 Hz), -109.9 (d, J = 4.8 Hz); ¹³C NMR (CDCl₃, 100 M Hz): δ 163.7 (d, J = 249.1 Hz), 136.5 (d, J = 6.8 Hz), 129.6 (d, J = 3.4 Hz), 129.4 (d, J = 8.4 Hz, 2C), 123.5 (q, J = 267.2 Hz), 116.1 (d, J = 21.8 Hz, 2C), 115.7 (qd, J = 33.7 and 2.1 Hz); MS, m/z, 190. Ref: Prakash, G. K. S.; Krishnan, H. S.; Jog, P. V.; Lyer, A. P.; Olah, G. A. *Org. Lett.* **2012**, *14*, 1146.



The yield of 6g was determined by ¹⁹F NMR.

¹H NMR (CDCl₃, 300 M Hz): δ 7.66 (d, *J* = 8.4 Hz, 2H), 7.56 (d, *J* = 8.1 Hz, 2H), 7.19 (dq, *J* = 16.2 Hz, 2.1 Hz, 1H); 6.30 (dq, *J* = 16.2 Hz, 6.3 Hz, 1H); ¹⁹F NMR (CDCl₃, 282 M Hz): δ -62.5, -63.4 (d, *J* = 5.9 Hz); ¹³C NMR (CDCl₃, 75 M Hz): δ 136.8, 136.2 (q, *J* = 6.7 Hz), 131.8 (q, *J* = 32.6 Hz), 127.8 (2C), 125.9 (q, *J* = 3.8 Hz, 2C), 123.8 (q, *J* = 270.5 Hz), 123.1 (q, *J* = 267.6 Hz), 118.4 (q, *J* = 34.0 Hz); MS, m/z, 240.

Ref: Hanamoto, T.; Morita, N.; Shindo, K. Eur. J. Org. Chem. 2003, 2003, 4279.



The yield of **6h** was determined by ¹⁹F NMR

¹H NMR (CDCl₃, 300 M Hz): δ 7.70-7.31 (m, mixed signal of *Z* and *E* isomer), 7.16 (dq, J = 15.9, 2.1 Hz, *E*-isomer), 6.94 (d, J = 12.6 Hz, 1H, *Z*-isomer), 6.21 (dq, J = 15.9, 6.6 Hz, *E*-isomer), 5.77 (dq, J = 12.6, 9.0 Hz, *Z* isomer); ¹⁹F NMR (CDCl₃, 282 M Hz): δ -57.1 (d, J = 9.0 Hz, *Z*-isomer), -62.9 (d, J = 8.5 Hz, *E*-isomer); MS, m/z, 172..

Ref: Duan, J.; Dolbier, W. R., Jr.; Chen, Q.-Y. J. Org. Chem. 1998, 63, 9486.



















¹⁹F in DCM



 19 F NMR yield spectrum: 2.07/(1x3)x100% = 69%







¹⁹F NMR in DCM



 19 F NMR yield spectrum: 1.40/(1x3)x100% = 47%









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¹⁹F NMR in DCM:















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 19 F NMR yield spectrum: 2.10/(1x3)x100% = 70%







 19 F NMR yield spectrum: 1.99/(1x3)x100% = 65%





