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Synthesis of Aryl Fluorides from Potassium Aryltrifluoroborates and Selectfluor® Mediated by Iron(III) Chloride

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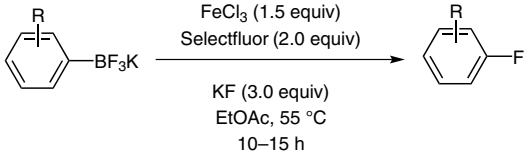
Dedicated to Prof. Paul Knochel on the occasion of his 59th birthday



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Abstract The synthesis of fluorinated arenes by the iron-mediated fluorination of potassium aryltrifluoroborates with Selectfluor® and potassium fluoride is described. The fluorination reaction uses commercially available reagents and without requiring the addition of exogenous ligands. Fluorinated compounds were obtained in moderate to good yields under mild reaction conditions.

Key words fluorination, aryl fluorides, potassium aryltrifluoroborates, iron, Selectfluor®, potassium fluoride

Interest in pharmaceuticals and agrochemicals containing fluorinated aromatic groups lies in the fact that they often display substantially enhanced pharmacological properties, such as increased solubility, bioavailability, and metabolic stability, when compared with their nonfluorinated analogues.[2] Moreover fluorinated aryl and heteroaryl motifs are extensively used in specialty materials and positron emission tomography (PET).[3] The development of efficient methods for the preparation fluorinated arenes has been a topic of increasing importance in organic synthesis.[4] Traditional approaches to incorporate a fluorine atom into aromatic moieties usually require harsh reaction conditions that are incompatible with sensitive functional groups. Direct fluorination,[5] the conversion of anilines via the arenediazonium salt with tetrafluoroboric acid (Balz–Schiemann reaction),[6] the nucleophilic substitution of electron-poor haloarenes with potassium fluoride (Halex reaction)[7] or fluorine,[8] as well as the transformation of aryl iodides with copper(II) fluoride are currently utilized methods.[9] Methods of direct fluorination of aromatic compounds, for example using electrolysis,[10] have limitations such as poor selectivity.

The development of milder, safer, and more general fluorination alternatives has attracted greater attention recently. Reaction of aryl triflates with cesium fluoride in the presence of a palladium catalyst results in aryl fluorides, however isomeric products are obtained in some cases.[11] Arylsilver,[12,13] arylpalladium,[14] and arylnickel[15] complexes have been reported to form aryl fluorides. The active transmetalated intermediates prepared from the corresponding arylstannanes, arylboronic acids, arylsilanes (Ag, Pd), or aryl bromides (Ni) have to be isolated. Hartwig et al. reported the transformation of aryl iodides to the corresponding aryl fluorides with bis(*tert*-butyl cyanide)copper(I) triflate [(*t*-BuCN)$_2$CuOTf] and silver(I) fluoride.[16] The research groups of Knochel and Beller simultaneously reported the electrophilic fluorination of aryl and heteroaryl Grignard reagents.[17] Ritter and co-workers employed phenols in an *ipso* substitution of the OH group to aryl fluorides with a difluoroimidazoline reagent.[18]

Arylboron reagents are exceptionally appealing starting materials for fluorinations, because of their synthetic accessibility, and stability.[19] Olah[20a] and Lemaire[20b] published a direct conversion of electron-rich alkenyl- and arylboronic acids/trifluoroborates into the corresponding alkenyl fluorides and fluoroarenes. Recently, Rozen et al. reported the fluorination of arylboronic acids using in situ generated acetyl hypofluorite.[21]

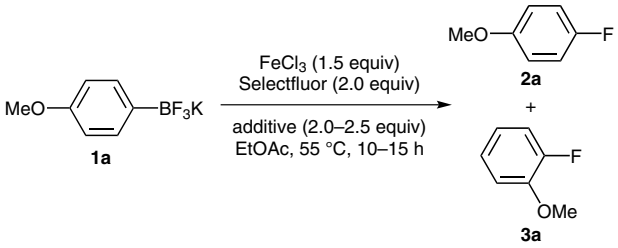
Organoboron compounds have been extensively transformed into their fluoro analogues by either transition-metal-mediated (Pd,[22] Ag,[23] or Cu,[24]) or -catalyzed (Pd) reactions.[25] To the best of our knowledge, there has been no report on the fluorination of potassium aryltrifluoroborates under iron-mediated conditions. In this paper, we report a method for the synthesis of fluorinated arenes in moderate yields from the potassium aryltrifluoroborates with Selectfluor® and potassium fluoride, mediated by iron(III) chloride.

In our initial search for the optimal reaction conditions, we explored the fluorination of potassium trifluoro(4-methoxyphenyl)borate (**1a**) with Selectfluor (2.0 equiv) and iron(III) chloride (1.5 equiv) at room temperature in acetonitrile. This resulted in the formation of a mixture of 1-fluoro-4-methoxybenzene (**2a**) and 1-fluoro-2-methoxybenzene (**3a**) in 10% and 5% yields, respectively, as determined by ^{19}F NMR. In an attempt to improve the yield we first screened various solvents including tetrahydrofuran, toluene, dichloromethane, acetone, heptane, 1,2-dimethoxyethane, *N*,*N*-dimethylformamide, *tert*-butyl methyl ether, ethyl acetate, and others (Supporting Information, Table S1[27]) at room temperature. We found that ethyl acetate was more suitable for this transformation. Furthermore at an elevated temperature (55 °C), the starting material was consumed within 15 hours. After the solvent screening, we were able to obtain 1-fluoro-4-methoxybenzene (**2a**) and 1-fluoro-2-methoxybenzene (**3a**) in 21% and 4% yields, respectively, in ethyl acetate at 55 °C. We then examined various commercial electrophilic fluorinating reagents (Supporting Information, Table S2[27]). Selectfluor gave comparatively better results than the other five reagents. We therefore chose Selectfluor for further optimizations.

We explored the use of reaction additives (inorganic and organic bases; Table 1) with potassium trifluoro(4-methoxyphenyl)borate (**1a**) as the substrate. From various inorganic bases, we found that sodium hydrogen carbonate produced a significant improvement in the yield (entry 8), whereas organic bases gave no product (entries 1–12 vs 13–15). We extended our investigation to examine fluoride sources having various polarizability and size (LiF, NaF, KF, CsF, and AgF). Potassium fluoride was found to be the best fluoride source for trifluoroborate **1a** under the reaction conditions (entry 18). Most of reaction additive with **1a** provided a mixture of *para* **2a** and *ortho* **3a** fluorinated products (Table 1).

We then screened various iron(II) and iron(III) salts (Table 2). Various iron salts (entries 3–14) were tested under our reaction conditions with comparison to iron(III) chloride (entry 1). Without any iron salts (entry 2) only a 5% yield of **2a**/**3a** was observed. Iron(II) chloride (entry 3) and iron powder (entry 4) gave **2a**/**3a** in only 60% and 40% yields, respectively. Whereas iron(III) acetylacetonate (entry 5), ferrocene (entry 6), iron(II) bromide (entry 7), iron(III) bromide (entry 8), iron(III) triflate (entry 9), and iron(III) perchlorate monohydrate (entry 10) did not give the desired products **2a** and **3a**. However, it is worthy of note that organic-solvent-soluble iron salts iron(II) oxalate dihydrate (entry 11) and iron(III) oxalate hexahydrate (entry 12) and water-soluble iron salts ammonium iron(III) sulfate dodecahydrate (entry 13) and iron(III) nitrate nonahydrate (entry 14) gave moderate yields of fluorinated products **2a** and **3a**.

Table 1 Screening of Additives for Fluorination[a,b]

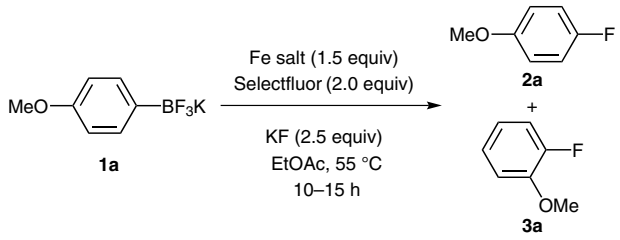


Entry	Additive	Yield[b] (%) (**2a** + **3a**)
1	Li_2CO_3	20 (20 + 0)
2	Na_2CO_3	16 (16 + 0)
3	K_2CO_3	19 (19 + 0)
4	LiOAc	12 (12 + 0)
5	NaOAc	43 (32 + 11)
6	KOAc	50 (40 + 10)
7	NH_4OAc	40 (33 + 7)
8	**$NaHCO_3$**	**60 (48 + 12)**
9	**$KHCO_3$**	**53 (41 + 12)**
10	**NH_4HCO_3**	**42 (41 + 1)**
11	K_3PO_4	9 (8 + 1)
12	Na_2HPO_4	16 (15 + 1)
13	Et_3N	0 (0 + 0)
14	pyridine	0 (0 + 0)
15	*sym*-collidine	0 (0 + 0)
16	LiF	5 (5 + 0)
17	**NaF**	**62 (37 + 25)**
18	**KF**	**70 (55 + 15)**
19	CsF	28 (27 + 1)
20	AgF	15 (14 + 1)

[a] Reaction conditions: **1a** (0.10 mmol, 1.0 equiv), $FeCl_3$ (1.5 equiv), Selectfluor (2.0 equiv), additive (2.5 equiv), EtOAc, 55 °C, 10–15 h.
[b] Combined yield of **2a** and **3a** determined by ^{19}F NMR with 4-fluorobenzonitrile as an internal standard added after the reaction.

Next we examined the optimal proportions of potassium fluoride, Selectfluor, and iron(III) chloride (see Supporting Information, Tables S3–S5[27]) and arrived at the optimized reaction conditions for this transformation; these are trifluoroborate (1.0 equiv, 0.25 mmol), iron(III) chloride (1.5 equiv), Selectfluor (2.0 equiv), potassium fluoride (3.0 equiv) in ethyl acetate at 55 °C for 10–15 hours. Furthermore, addition of oxidant did not improve the yield (Supporting Information, Table S6[27]). The use of a catalytic amount of iron was investigated along with ligands, but this gave only low yields (Supporting Information, Table S7[27]). Finally, we tested various 4-$MeOC_6H_4BX_2$ derivatives. Neither the corresponding boronic acid **1aa**, pinacol ester **1ab**, or MIDA ester **1ac** gave the desired fluorinated product (Supporting Information, Table S8[27]).

Table 2 Screening of Iron Salts for Fluorination[a,b]



Entry	Iron salts	Yield[b] (%) (**2a** + **3a**)
1	$FeCl_3$	70 (55 + 15)
2	none	5 (5 + 0)
3	$FeCl_2$	60 (50 + 10)
4	Fe powder	40 (40 + 0)
5	$Fe(acac)_3$	0 (0 + 0)
6	$FeCp_2$	0 (0 + 0)
7	$FeBr_2$	0 (0 + 0)
8	$FeBr_3$	0 (0 + 0)
9	$Fe(OTf)_3$	0 (0 + 0)
10	$Fe(ClO_4)_3{\cdot}H_2O$	0 (0 + 0)
11	$Fe(C_2O_4){\cdot}2\ H_2O$	40 (40 + 0)
12	$Fe_2(C_2O_4)_3{\cdot}6\ H_2O$	30 (30 + 0)
13	$NH_4Fe(SO_4)_2{\cdot}12\ H_2O$	40 (25 + 15)
14	$Fe(NO_3)_3{\cdot}9\ H_2O$	10 (10 + 0)

[a] Reaction conditions: **1a** (0.10 mmol, 1.0 equiv), Fe salts (1.5 equiv), Selectfluor (2.0 equiv), KF (2.5 equiv), EtOAc, 55 °C, 10–15 h.
[b] Combined yield of **2a** and **3a** determined by ^{19}F NMR with 4-fluorobenzonitrile as an internal standard added after the reaction.

We then re-examined optimized reaction conditions with various commercial electrophilic fluorinating reagents (Figure 1) that differ in their reactivity, solubility, and stability (Table 3). There was no desired fluorinated product observed without Selectfluor (entry 2). Selectfluor II (entry 3), and Accufluor™ NFTh (entry 4) gave moderate to low yields. Where as, the reaction of **1a** with electron-deficient F^+ reagent *N*-fluorobenzenesulfonimide (NFSI, entry 5) or electron-rich F^+ reagent 1-fluoro-2,4,6-trimethylpyridinium (Me_3pyF^+) gave only traces of the products (entries 6 and 7).

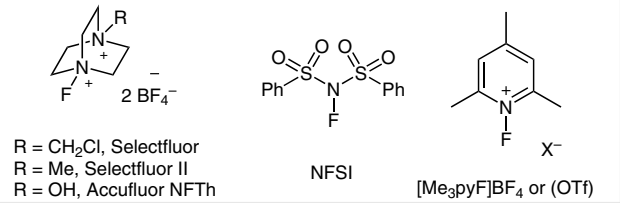
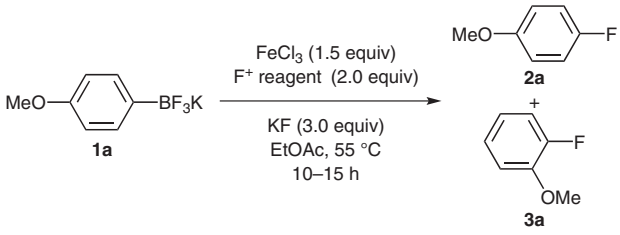


Figure 1 Electrophilic fluorine (F^+) reagents

Table 3 Screening of F^+ Reagents for Fluorination with Iron(III) Chloride and Potassium Fluoride[a]

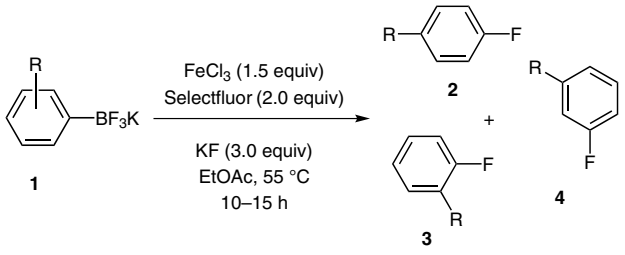


Entry	F^+ Reagent	Yield[b] (%) (**2a** + **3a**)
1	Selectfluor	70 (55 + 15)
2	none	0 (0 + 0)
3	Selectfluor II	55 (45 + 10
4	Accufluor NFTh	31 (25 + 6)
5	NFSI	<1 (1 + 0)
6	$[Me_3pyF]BF_4$	<1 (1 + 0)
7	[Me3pyF]OTf	0 (0 + 0)

[a] Reaction conditions: **1a** (0.10 mmol, 1.0 equiv), $FeCl_3$ (1.5 equiv), F^+ reagent (2.0 equiv), KF (3.0 equiv), EtOAc, 55 °C, 15 h.
[b] Combined yield of **2a** and **3a** determined by ^{19}F NMR with 4-fluorobenzonitrile as an internal standard added after the reaction.

With the optimized reaction condition in hand, the substrate scope was then investigated. A wide range of electronically and structurally diverse aryl- and heteroaryl-substituted trifluoroborates were selected. We found that electron-rich and electron-neutral substrates gave moderate to good yields in most cases (Table 4). The yields are moderate in some cases due to the protodeborylation product, which is a common problem for fluorination reaction of arylboronic acid derivatives[24] whereas electron-deficient substrates gave only poor or no yields. Aryltrifluoroborates with a strong electron-donating *para*-substituent (methoxy, ethoxy, butoxy, and benzyloxy) underwent fluorination in good yields to give the combined *para*- and *ortho*-fluorinated products (entries 1–4). Aryltrifluoroborates with weaker electron-donating *para*-substituents (methyl, *tert*-butyl, phenyl) underwent fluorination in moderate yields with giving only *para*-fluorinated products (by *ipso* substitution) (entries 5–7). Aryltrifluoroborates with electron-donating *meta* substituent (methoxy, ethoxy, methyl, isopropyl) underwent fluorination at the *ortho* and *para* positions (entries 8–11) and no *meta*-fluorinated products were formed. An aryltrifluoroborate with a strong electron-donating *ortho* substituent (methoxy) gave a moderate yield with to give the major *ipso*-fluorinated product (entry 12), whereas the weak electron-donating substituent (methyl) afforded solely the *ipso* product (entry 13).

Table 4 Iron-Mediated Fluorination of Potassium Aryltrifluoroborates[a]



Entry	Substrate (R)	Yield (%)			Total yield[b,c] (%) (**2** + **3**)
		para **2**	*ortho* **3**	*meta* **4**	
1	4-OMe (**1a**)	55	15	0	70
2	4-OEt (**1b**)	50	20	0	70 (60)[d]
3	4-OBu (**1c**)	50	25	0	75
4	4-OBn (**1d**)	60	5	0	65 (62)[d]
5	4-Me (**1e**)	40	0	0	40
6	4-*t*-Bu (**1f**)	40	0	0	40 (36)[d]
7	4-Ph (**1g**)	54	0	0	54 (50)[d]
8	3-OMe (**1h**)	25	15	0	40
9	3-OEt (**1i**)	40	11	0	53
10	3-Me (**1j**)	39	21	0	60
11	3-*i*-Pr (**1k**)	29	36	0	65
12	2-OMe (**1l**)	2	40	0	42
13	2-Me (**1m**)	0	60	0	60 (50)[d]
14	H (**1n**)	–	–	–	40
15	1-naphthyl (**1o**)	–	–	–	75 (70)[d]
16	2-naphthyl (**1p**)	–	–	–	60[e]
17	4-F (**1q**)	60	0	0	60
18	4-CN (**1r**)	10	0	0	10[f]
19	4-CF_3 (**1s**)	0	0	0	0

[a] Reaction conditions: potassium aryltrifluoroborate (0.25 mmol, 1.0 equiv), $FeCl_3$ (1.5 equiv), Selectfluor (2.0 equiv), KF (3.0 equiv), EtOAc, 55 °C, 10–15 h.
[b] Combined yield of *para* and *ortho* products determined by ^{19}F NMR with 4-fluorobenzonitrile as an internal standard added after the reaction.
[c] Some reactions were carried out in duplicate and the average of individual and combined yields was determined by ^{19}F NMR.
[d] Isolated yield; contains ca. 3% impurities.
[e] Combined yield of α/β-fluorination product (5:1 ratio).
[f] 3-Fluorotoluene as an internal standard added.

As *meta*-substituted potassium aryltrifluoroborates gave *para*- and *ortho*-fluorinated products only,[28,29] we examined if these products arise from protodeboronated substrates or potassium aryltrifluoroborates. To test this hypothesis we performed the reaction with anisole and toluene (protodeboronated) substrates under our optimized conditions and found that *para*- and *ortho*-fluorinated products were formed in 15% yield (2:3 ratio) from anisole and 7% yield (3:1 ratio) from toluene. Comparing this data with Table 4, entries 1, 5, 8, 10, 12, and 13 shows that fluorinated products possibly arise from potassium aryltrifluoroborates rather than protodeboronated substrates.[30] Under our reaction conditions, potassium trifluoro(1-naphthyl)borate (**1o**) was converted into the corresponding 1-naphthyl fluorinated product **2o** in 75% yield (entry 15), whereas potassium trifluoro(2-naphthyl)borate (**1p**) gave a mixture of the α/β-fluorination products (5:1) in a combined yield of 60% (entry 16). Potassium trifluoro(4-fluorophenyl)borate (**1q**) containing a weak electron-withdrawing fluoro substituent at the *para* position gave 1,4-difluorobenzene (60%, entry 17) and the protodeborylated product (15%; by ^{19}F NMR). A *para*-substituted electron-deficient substrate produced the desired fluorinated product in only poor yield (entry 18). No desired product was observed when strong electron-withdrawing trifluoro[4-(trifluoromethyl)phenyl]borate was used (entry 19).

In conclusion, we report a convenient iron(III) chloride mediated fluorination of potassium aryltrifluoroborates, using Selectfluor and potassium fluoride. Our protocol uses an inexpensive, commercially available, and environmentally friendly metal mediator. Potassium aryltrifluoroborates with strong electron-donating *para* or *meta* substituents gave isomerized *para* and *ortho* products, whereas those with weak electron-donating *para* substituents afforded *para*-fluorinated products. Currently we are exploring the mechanism of the reaction as well as optimizing the conditions for *ipso*-fluorinated products.

^1H and ^{19}F NMR spectra were recorded on Bruker 400 MHz or 300 MHz in the solvents indicated; referenced to the $CDCl_3$ resonance in the ^1H spectrum (δ = 7.26 ppm). ^{19}F NMR are referenced to $CFCl_3$ as internal standard and are measured proton decoupled. GC-MS spectra were measured on Shimadzu GSMS-QP2010S. Column chromatography was performed on silica gel 200–300 mesh on Combiflash®. If not specially mentioned, all the solvents and reagents were used as purchased from Combi-Blocks, Tokyo chemical industry (TCI), Fluorochem, and Aldrich and without further purification.

Iron-Mediated Fluorination of Potassium Aryltrifluoroborates with Selectfluor (Table 4); General Procedure

$FeCl_3$ (60.8 mg, 0.375 mmol, 1.5 equiv), Selectfluor (177 mg, 0.5 mmol, 2.0 equiv), and KF (43.6 mg, 0.75 mmol, 3.0 equiv) were weighed into a 10-mL microwave vial. EtOAc (2.5 mL) was added, and the vial was sealed with a septum. The mixture stirred at 25 °C for 5 min. Then, potassium aryltrifluoroborate (0.25 mmol, 1.0 equiv) was added to the mixture, and the vial was sealed with microwave cap and the mixture stirred at 55 °C for 10–15 h. The resulting solution was cooled to r.t.

The volatile products were not isolated and their yields were determined only by ^{19}F NMR of the reaction mixture. For the compounds reported with ^{19}F NMR yields, 4-fluorobenzonitrile (0.25 mmol) was added as reference to the mixture, stirred for 5 min, and then diluted with *t*-BuOMe or hexane (2.5 mL) and H_2O (3.0 mL). The layers were separated and an organic aliquot was withdrawn for the ^{19}F NMR measurement in either in $CDCl_3$ or DMSO-d_6. The ^{19}F NMR spectroscopic data were identical to those reported previously in the literature. The identity of the product was further confirmed by GC-MS analysis.

For the compounds reported as isolated yields, the mixture was diluted with *t*-BuOMe or hexane (2.5 mL) and H_2O (4.0 mL). Then organic phase was separated, the aqueous phase was extracted with *t*-BuOMe (2 × 5 mL). The combined organic phases were dried (anhyd Na_2SO_4), the solvent was removed at 1.0 bar and the residue was purified by column chromatography (Combiflash, hexanes) to afford the desired compounds. The identity of the product was confirmed by ^{1}H NMR and GC-MS analyses.

1-Fluoro-4-methoxybenzene (2a) and 1-Fluoro-2-methoxybenzene (3a) (Table 4, Entry 1)[31]

The reaction was performed using potassium trifluoro(4-methoxyphenyl)borate (**1a**, 53.5 mg, 0.25 mmol, 1 equiv) to give **2a**/**3a** (55:15); yield: 70% (^{19}F NMR analysis of the crude reaction mixture). The ^{19}F NMR spectroscopic data were identical to that reported in the literature.[31] The identity of the product was further confirmed by GC-MS analysis.

^{19}F NMR (376 MHz, DMSO-d_6): δ = –125.41 (s, F) (**2a**) and –136.35 (s, F) (**3a**).

GC-MS: *m*/*z* = 126 (M^+).

1-Ethoxy-4-fluorobenzene (2b) and 1-Ethoxy-2-fluorobenzene (3b) (Table 4, Entry 2)[32]

The reaction was performed using potassium (4-ethoxyphenyl)trifluoroborate (**1b**, 57.0 mg, 0.25 mmol, 1 equiv) to give **2b**/**3b** (50:20); yield: 70% (^{19}F NMR analysis of the crude reaction mixture); isolated yield of **2b** and **3b**: 21.0 mg (60%). NMR data were read overlapping with those pure **2b** and **3b** compounds.

^{1}H NMR (300 MHz, $CDCl_3$): δ = **2b**: 6.96 (t, *J* = 6.9 Hz, 2 H), 6.82 (dd, *J* = 6.8 Hz, *J* = 6.9 Hz, 1 H), 3.99 (q, *J* = 7.0 Hz, 2 H), 1.39 (q, *J* = 7.2 Hz, 3 H); **3b**: 6.71–7.21 (m, 4 H), 4.10 (q, *J* = 7.0 Hz, 2 H), 1.25 (q, *J* = 7.2 Hz, 3 H).

^{19}F NMR (376 MHz, DMSO-d_6): δ = –125.45 (s, F) (**2b**), –135.94 (s, F) (**3b**).

GC-MS: *m*/*z* = 140 (M^+).

1-Butoxy-4-fluorobenzene (2c) and 1-Butoxy-4-fluorobenzene (3c) (Table 4, Entry 3)[33]

The reaction was performed using potassium (4-butoxyphenyl)trifluoroborate (**1c**, 64.0 mg, 0.25 mmol, 1 equiv) to give **2c**/**3c** (50:25); yield: 75% (^{19}F NMR analysis of the crude reaction mixture).

^{19}F NMR (376 MHz, DMSO-d_6): δ = –125.46 (s, F) (**2c**), –135.94 (s, F) (**3c**).

GC-MS: *m*/*z* = 168 (M^+).

1-(Benzyloxy)-4-fluorobenzene (2d) and 1-(Benzyloxy)-2-fluorobenzene (3d) (Table 4, Entry 4)[34]

The reaction was performed using potassium [4-(benzyloxy)phenyl]trifluoroborate (**1d**, 72.5 mg, 0.25 mmol, 1 equiv) to give **2d**/**3d** (60:5) yield: 65% (^{19}F NMR analysis of the crude reaction mixture); total isolated yield (**2d**/**3d**): 31.3 mg (62%). NMR data were read by overlapping with those pure **2d** and **3d** compounds.

^{1}H NMR (400 MHz, $CDCl_3$): δ = **2d**: 7.32–7.46 (m, 5 H), 6.90–7.02 (m, 4 H), 5.05 (s, 2 H); **3d**: 7.29–7.46 (m, 5 H), 6.86–7.12 (m, 4 H), 5.14 (s, 2 H).

^{19}F NMR (376 MHz, DMSO-d_6): δ = –124.93 (s, F) (**2d**), –135.54 (s, F) (**3d**).

GC-MS: *m*/*z* = 202 (M^+).

1-Fluoro-4-methylbenzene (2e) (Table 4, Entry 5)[24c]

The reaction was performed using potassium trifluoro(4-methylphenyl)borate (**1e**, 49.5 mg, 0.25 mmol, 1 equiv) to give **2e**; yield: 40% (^{19}F NMR analysis of the crude reaction mixture).

^{19}F NMR (376 MHz, DMSO-d_6): δ = –120.43 (s, F).

GC-MS: *m*/*z* = 110 (M^+).

1-*tert*-Butyl-4-fluorobenzene (2f) (Table 4, Entry 6)[13a]

The reaction was performed using potassium (4-*tert*-butylphenyl)trifluoroborate (**1f**, 49.5 mg, 0.25 mmol, 1 equiv) to give **2f**; yield: 40% (^{19}F NMR analysis of the crude reaction mixture); isolated yield: 13.7 mg (36%).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.33 (dd, *J* = 9.0, 8.8 Hz, 2 H), 6.96 (t, *J* = 8.8 Hz, 2 H), 1.31 (s, 9 H).

^{19}F NMR (282 MHz, $CDCl_3$): δ = –119.73 (s, F).

GC-MS: *m*/*z* = 152 (M^+).

4-Fluoro-1,1′-biphenyl (2g) (Table 4, Entry 7)[13a]

The reaction was performed using potassium (1,1′-biphenyl-4-yl)trifluoroborate (**1g**, 65.0 mg, 0.25 mmol, 1 equiv) to give **2g**; yield: 54% (^{19}F NMR analysis of the crude reaction mixture); isolated yield: 21.5 mg (50%).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.58–7.52 (m, 4 H), 7.46–7.41 (m, 2 H), 7.33 (t, *J* = 7.5 Hz, 1 H), 7.13 (dd, *J* = 8.0, 7.5 Hz, 2 H).

^{19}F NMR ($CDCl_3$, 282 M Hz): δ = –116.32 (s, F).

GC-MS: *m*/*z* = 172 (M^+).

1-Fluoro-4-methoxybenzene (2a) and 1-Fluoro-2-methoxybenzene (3a) (Table 4, Entry 8)[31]

The reaction was performed using potassium trifluoro(3-methoxyphenyl)borate (**1h**, 53.5 mg, 0.25 mmol, 1 equiv) to give **2a**/**3a** (25:15); yield: 40% (^{19}F NMR analysis of the crude reaction mixture).

^{19}F NMR (376 MHz, DMSO-d_6): δ = –125.41 (s, F) (**2a**), –136.35 (s, F) (**3a**).

GC-MS: *m*/*z* = 126 (M^+).

1-Ethoxy-4-fluorobenzene (2b) and 1-Ethoxy-2-fluorobenzene (3b) (Table 4, Entry 9)[32]

The reaction was performed using potassium (3-ethoxyphenyl)trifluoroborate (**1i**, 57.0 mg, 0.25 mmol, 1 equiv) to give **2b**/**3b** (40:11); yield: 53% (^{19}F NMR analysis of the crude reaction mixture).

^{19}F NMR (376 MHz, DMSO-d_6): δ = –125.79 (s, F) (**2b**), –136.33 (s, F) (**3b**).

GC-MS: *m*/*z* = 140 (M^+).

1-Fluoro-4-methylbenzene (2e) and 1-Fluoro-2-methylbenzene (3e) (Table 4, Entry 10)[24c]

The reaction was performed using potassium trifluoro(3-methylphenyl)borate (**1j**, 49.5 mg, 0.25 mmol, 1 equiv) to give **2e**/**3e** (39:21); yield: 60% (^{19}F NMR analysis of the crude reaction mixture).

^{19}F NMR (376 MHz, DMSO-d_6): δ = –119.20 (s, F) (**2e**), –119.87 (s, F) (**3e**).

GC-MS: *m*/*z* = 110 (M^+).

1-Fluoro-4-isopropylbenzene (2k) and 1-Fluoro-2-isopropylbenzene (3k) (Table 4, Entry 11)[35]

The reaction was performed using potassium trifluoro(3-isopropylphenyl)borate (**1k**, 56.5 mg, 0.25 mmol, 1 equiv) to give **2k**/**3k** (29:36); yield: 65% (^{19}F NMR analysis of the crude reaction mixture).

^{19}F NMR (376 MHz, DMSO-d_6): δ = –119.05 (s, F) (**2k**), –121.79 (s, F) (**3k**).

GC-MS: m/z = 226 (M^+).

1-Fluoro-4-methoxybenzene (2a) and 1-Fluoro-2-methoxybenzene (3a) (Table 4, Entry 12)[31]

The reaction was performed using potassium trifluoro(2-methoxyphenyl)borate (**1l**, 53.5 mg, 0.25 mmol, 1 equiv) to give **2a**/**3a** (2:40); yield: 42% (^{19}F NMR analysis of the crude reaction mixture).

^{19}F NMR (376 MHz, DMSO-d_6): δ = –125.41 (s, F) (**2a**), –136.35 (s, F) (**3a**).

GC-MS: m/z = 126 (M^+).

1-Fluoro-2-methylbenzene (3m) (Table 4, Entry 13)[24c]

The reaction was performed using potassium trifluoro(2-methylphenyl)borate (**1m**, 49.5 mg, 0.25 mmol, 1 equiv) to give **3m**; yield: 60% (^{19}F NMR analysis of the crude reaction mixture); isolated yield: 13.7 mg (50%).

^{19}F NMR (376 MHz, DMSO-d_6): δ = –119.07 (s, F).

GC-MS: m/z = 110 (M^+).

Fluorobenzene (2n) (Table 4, Entry 14)

The reaction was performed using potassium trifluoro(phenyl)borate (**1n**, 46.0 mg, 0.25 mmol, 1 equiv) to give **2n**; yield: 40% (^{19}F NMR analysis of the crude reaction mixture). ^{19}F NMR spectral data for **2n** matched that of an authentic sample (δ = –114.01, s).

^{19}F NMR (376 MHz, $CDCl_3$): δ = –113.53 (s, F).

GC-MS: m/z = 96 (M^+).

1-Fluoronaphthalene (2o) (Table 4, Entry 15)[31]

The reaction was performed using potassium trifluoro(1-naphthyl)borate (**1o**, 58.5 mg, 0.25 mmol, 1 equiv) to give **2o**; yield: 75% (^{19}F NMR analysis of the crude reaction mixture); isolated yield: 25.5 mg (70%).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.14–8.09 (m, 1 H), 7.89–7.84 (m, 1 H), 7.63 (d, J = 8.0 Hz, 1 H), 7.58–7.52 (m, 2 H), 7.40 (ddd, J = 8.8, 8.8, 4.8 Hz, 1 H), 7.15 (dd, J = 11.2, 8.0 Hz, 1 H).

^{19}F NMR (282 MHz, $CDCl_3$): δ = –123.96 (s, F).

GC-MS: m/z = 146 (M^+).

1-Fluoronaphthalene (2o) and 2-Fluoronaphthalene (2p) (Table 4, Entry 16)[24]

The reaction was performed using potassium trifluoro(2-naphthyl)borate (**1p**, 58.5 mg, 0.25 mmol, 1 equiv) to give **2o**/**2p** (50:10); yield: 60% (^{19}F NMR analysis of the crude reaction mixture).

^{19}F NMR (376 MHz, $CDCl_3$): δ = –124.09 (s, F) (**2o**), –115.51 (s, F) (**2p**).

GC-MS: m/z = 146 (M^+).

1,4-Difluorobenzene (2q) (Table 4, Entry 17)[36]

The reaction was performed using potassium trifluoro(4-fluorophenyl)borate (**1q**, 50.5 mg, 0.25 mmol, 1 equiv) to give **2q**; yield: 60% (^{19}F NMR analysis of the crude reaction mixture).

^{19}F NMR ($CDCl_3$, 376 M Hz): δ = –120.16 (s, F).

GC-MS: m/z = 114 (M^+).

4-Fluorobenzonitrile (2r) (Table 4, Entry 18)

The reaction was performed using potassium (4-cyanophenyl)trifluoroborate (**1r**, 52.3 mg, 0.25 mmol, 1 equiv) to give **2r**; yield: 10% (^{19}F NMR analysis of the crude reaction mixture with 3-fluorotoluene as an internal standard). The ^{19}F NMR spectral data for **2r** matched that of an authentic sample (δ = –104.01, s).

^{19}F NMR (376 MHz, $CDCl_3$): δ = –104.13 (s, F).

GC-MS: m/z = 121 (M^+).

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Supporting Information

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