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BrØsted acid-catalyzed electrophilic trifluoromethylthiolation of indoles using thermally stable trifluoromethylthiolating reagent

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ABSTRACT

A BrØsted acid-catalyzed electrophilic trifluoromethylthiolation of indoles under mild conditions is described. The reaction was insensitive to moisture and oxygen, that should allow for easy handling. In addition, the reaction is compatible with a variety of functional groups.

1. Introduction

Indole is among one of the privileged structural motif in biological systems and biologically active natural products such as amino acids and alkaloids [1]. Development of new methods for functionalization of indole is, therefore, of great current interests. In particular, the incorporation of fluoroalkyl groups such as trifluoromethylthio group into indoles represents an attractive strategy since it is well-known that the introduction of trifluoromethylthio group often leads to drug molecules with enhanced transmembrane permeability, reduced toxicity or improved affinity for the target receptor [2].

Significant progresses have been achieved recently in the synthesis of trifluoromethylthio-arylethers [3]. The trifluoromethylthiolated arenes or heteroarenes could be accessed easily by a transition metal-catalyzed cross-coupling reaction of an aryl halide with a nucleophilic trifluoromethylthio reagent such as $AgSCF_3$, Me_4NSCF_3 or with sulfur and $TMSCF_3$ as the trifluoromethylthio source [4]. Alternatively, direct coupling of nucleophilic aryl boronic acid with an electrophilic trifluoromethylthiolating reagent could afford the desired trifluoromethylthiolated arene or heteroarene [5]. In this regard, in recent years, there have been considerable efforts in the direct trifluoromethylthiolation of indoles. Notably, Billard and Langlois first reported BrØsted acid-mediated electrophilic trifluoromethylthiolation of indoles under mild conditions (Scheme 1, Eq. (1)) [6]. In 2013, Shibata described a copper-catalyzed trifluoromethylthiolating of indoles with an electrophilic trifluoromethanesulfonyl hypervalent iodonium ylide **2** (Scheme 1, Eq. (2)) [7]. The reactions were proposed to proceed *via* an *in situ* reduction of the CF_3SO_2 group to form a trifluoromethylthiolated ammonia salt that was responsible for the trifluoromethylthiolation.

We recently developed a powerful trifluoromethylthiolating reagent **3** that was allowed to trifluoromethylthiolate a variety of nucleophiles such as aryl boronic acids, alkynes, β-ketoesters, aldehydes and amides [8]. Inspired by the above-mentioned process, we expected to extend scope of reagent **3** to electrophilic aromatic substitution reactions. Herein, we report an efficient BrØsted acid-catalyzed electrophilic trifluoromethylthiolation of indoles under mild conditions (Scheme 1, Eq. (3)).

2. Results and discussion

The electrophilic trifluoromethylthiolating reagent **3** was previously synthesized by mixing $AgSCF_3$[4b] with hypervalent iodine precursor **4** in THF at 50 °C for 1 h. The preparation was conducted at 0.2 M concentration and it required large amount of solvents when the preparation was scaled up. After some careful investigation, we now discovered that mixing $AgSCF_3$ with hypervalent iodine precursor **4** in solvent-free conditions at 50 °C for 1.0 h was equally efficient for the preparation of the electrophilic trifluoromethylthiolating reagent **3.** The reaction was conducted at a 3.5 g scale of $AgSCF_3$ and afforded 2.6 g of the reagent **3** (43% yield) (Eq. (1)).

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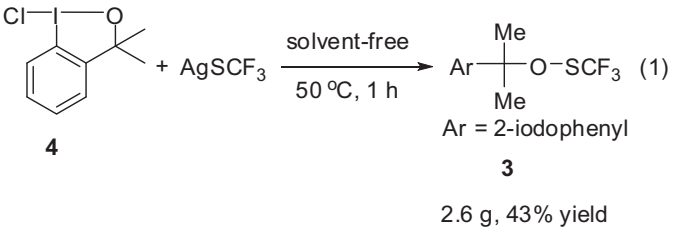
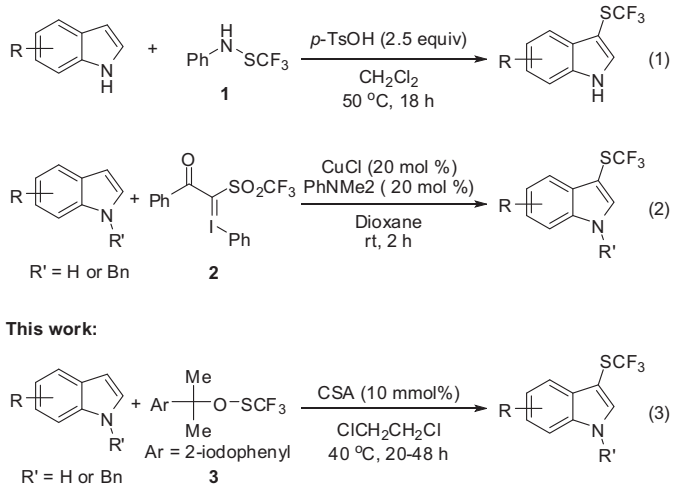


One concerning about the electrophilic trifluoromethylthiolating reagent is its stability. To probe the stability of reagent **3**, differential scanning calorimetry (DSC) analysis and thernogravimetric analysis (TGA) was conducted. DSC analysis on the pure compound showed endotherms that correspond to its boiling point at 150.6 °C. No sharp exothermic signal was observed that indicated no explosive behavior for reagent **3**. The conclusion from DSC analysis is in good agreement with thernogravimetric analysis (TGA) that showed the boiling point at 159.2 °C. These analyses indicate that electrophilic trifluoromethylthiolating reagent **3** is thermally stable.

The reaction of indole with the electrophilic trifluoromethylthiolating reagent **3** in the presence of different transition metal catalyst was initially chosen to optimize the reaction conditions. Reactions using a variety of Cu(I), Cu(II) or Fe(III) salts such as $CuCl_2$, $Cu(OTf)_2$, CuCl, Cu(OAc), $Fe(NO_3)_3{\cdot}9H_2O$ or $FeCl_3$ as the catalyst at 70 °C for 20 h occurred to low to moderate yields (Table 1, entries 1–7). Interestingly, when $CuCl_2{\cdot}2NH_4Cl{\cdot}2H_2O$ was used as the catalyst, the yield increased significantly to 91% (Table 1, entry 8). Reaction in other solvents such as $CHCl_3$, dioxane or THF resulted in much lower yields (Table 1, entries 9–11). To distinguish if the real catalyst was the copper salt or NH_4Cl, we conducted a control experiment using NH_4Cl as the catalyst. The reaction occurred smoothly to full conversion after 20 h when 10 or 20 mol% of NH_4Cl was used to give the trifluoromethylthiolated compound in 51% and 85% yield, respectively (Table 1, entries 12–13). Other BrØsted acids were then evaluated and it was found that reactions using *p*-toluenesulfonic acid or acetic acid as the catalyst occurred in higher yields, while reactions using camphorsulfonic acid or triflic acid as the catalyst occurred in almost quantitative yields (Table 1, entries 14–17). No significant decreasing in yield was observed when the temperature was decrease to 40 °C but required much longer time to full conversion at 25 °C (Table 1, entry 18). Finally, lowering the catalyst loading to 5 mol% led to slower reaction and 84% conversion was observed after 20 h at 70 °C (Table 1, entry 19).



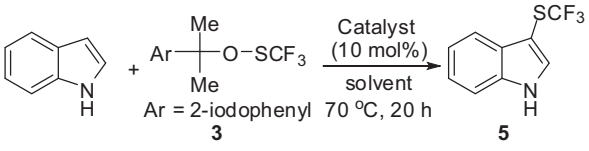
Scheme 1. Trifluoromethylthiolation of indoles.

With the optimized conditions in hand, the scope of the reaction with a variety of indoles was investigated, and the results were summarized in Table 2. Reactions of a variety of indoles with electron-donating or withdrawing groups with the electrophilic trifluoromethylthiolating reagent **3** occurred in good to excellent yields. The reaction was compatible with a variety of functional groups such as chloride, bromide, fluoride, ester, nitrile and nitro group. *N*-methyl indole also reacted under the optimized conditions to give the corresponding product in 92% yield (Table 2, entry 5). Reaction of 3-methyl-indole formed the corresponding trifluoromethylthiolated compounds in 68% yield (Table 2, entry 7). Likewise, reaction of 2-methyl-5-methoxy-indole occurred in 79% yield (Table 2, entry 9). As a comparison, reaction of 5-methoxy-indole with Billard's or Shibata's reagent generated the trifluoromethylthiolated products in much lower yields [6,7].

3. Discussion

Based on the experiment results, we proposed a plausible mechanisn for the current a BrØsted acid-catalyzed electrophilic trifluoromethylthiolation of indoles. In the presence of BrØsted acid, the oxygen of the trifluoromethylthiolating reagent **3** was

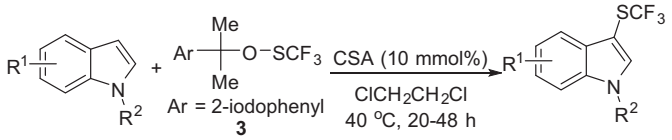
Table 1
Optimization conditions for acid-catalyzed trifluoromethylthio-lation of indole[a].

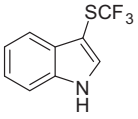
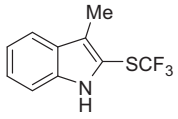
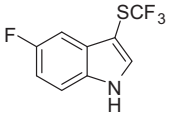
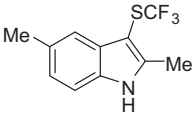
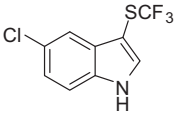
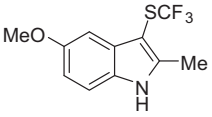
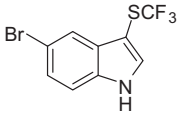
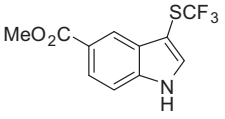
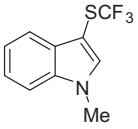
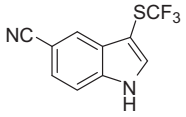
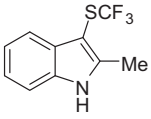
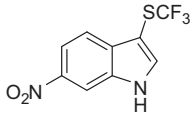


Entry	catalyst	Solvent	Yield (%)[b]
1	$CuCl_2$	$ClCH_2CH_2Cl$	49
2	$CuCl_2{\cdot}2H_2O$	$ClCH_2CH_2Cl$	55
3	$Cu(OTf)_2$	$ClCH_2CH_2Cl$	44
4	CuCl	$ClCH_2CH_2Cl$	21
5	CuOAc	$ClCH_2CH_2Cl$	<2
6	$Fe(NO_3)_3{\cdot}9H_2O$	$ClCH_2CH_2Cl$	23
7	$FeCl_3$	$ClCH_2CH_2Cl$	13
8	$CuCl_2{\cdot}2NH_4Cl{\cdot}2H_2O$	$ClCH_2CH_2Cl$	91
9	$CuCl_2{\cdot}2NH_4Cl{\cdot}2H_2O$	$CHCl_3$	49
10	$CuCl_2{\cdot}2NH_4Cl{\cdot}2H_2O$	dioxane	44
11	$CuCl_2{\cdot}2NH_4Cl{\cdot}2H_2O$	THF	21
12	NH_4Cl	$ClCH_2CH_2Cl$	51
13	NH_4Cl	$ClCH_2CH_2Cl$	85[f]
14	$TsOH{\cdot}H_2O$	$ClCH_2CH_2Cl$	65
15	CSA[c]	$ClCH_2CH_2Cl$	>99
16	CF_3CO_2H	$ClCH_2CH_2Cl$	98
17	CH_3CO_2H	$ClCH_2CH_2Cl$	89
18	CSA	$ClCH_2CH_2Cl$	>99[d]
19	CSA	$ClCH_2CH_2Cl$	84[e]
20	-	$ClCH_2CH_2Cl$	25

[a] Reaction conditions: indole (0.1 mmol), reagent **1** (0.11 mmol), catalyst (10 mol%) in 0.5 mL of solvent for 20 h.
[b] Yields were determined by ^{19}F NMR analysis of the crude reaction mixture with an internal standard.
[c] Camphorsulfonic acid.
[d] Reaction conducted at 40 °C.
[e] 5 mol% of CSA was used.
[f] 20 mol% of NH_4Cl was used for 40 h.

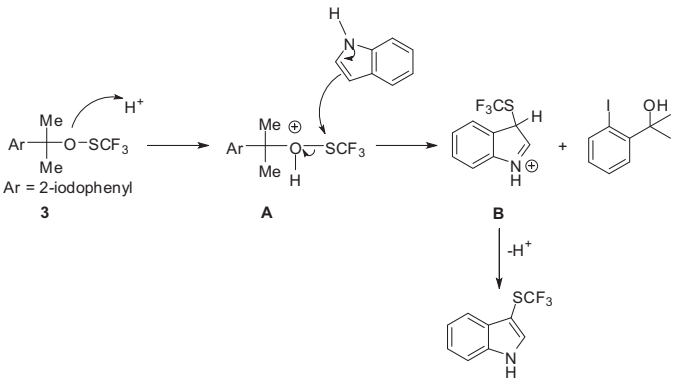
Table 2
Scope of CSA-catalyzed trifluoromethylthiolation of indoles[a,b].



Entry	Product	Yield (%)	Entry	Product	Yield (%)
1		92	7		68
2		99	8		85
3		90	9		79
4		95	10		60
5		92	11		78
6		96	12		85

[a] Reaction conditions: indole (0.5 mmol), reagent **1** (0.55 mmol), catalyst (10 mol%) in 2.5 mL of solvent for 20 h.
[b] Isolated yields.

protonated to form a highly electrophilic intermediate **A**, which was nucleophilically attacked by indole to generate intermediate **B**. **B** was then depronated to form the corresponding product (Scheme 2).



Scheme 2. Proposed mechanism for trifluoromethylthiolating of indoles.

4. Conclusion

We developed an improved method for the synthesis of the electrophilic trifluoromethylthiolating reagent which is thermally stable as determined by DSC and TGA analysis. We further developed a BrØsted acid-catalyzed electrophilic trifluoromethylthiolation of indoles under mild conditions. The reaction was insensitive to moisture and oxygen that should allow for easy handling. In addition, the reaction is compatible with a variety of functional groups. Investigation of the reaction of the electrophilic trifluoromethylthiolating reagent **3** with other arenes and hetereoarenes which are much more difficult than those of indoles, are undergoing currently in our laboratory.

5. Experiment

5.1. General information

All solvents were purified by standard method. ^{1}H, ^{19}F NMR spectra and ^{13}C NMR were recorded on 400 MHz, 376 MHz and 100 MHz spectrometer, respectively. ^{1}H NMR and ^{13}C NMR chemical shifts were determined relative to internal standard TMS at δ 0.0 ppm and ^{19}F NMR chemical shifts were determined relative to $CFCl_3$ as inter standard. Chemical shifts (δ) are reported in ppm, and coupling constants (J) are in Hertz (Hz). The following abbreviations were used to explain the multiplicities: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br = broad. All reactions were monitored by TLC or ^{19}F NMR. Flash column chromatograph was carried out using 300–400 mesh silica gel at medium pressure.

5.2. General procedure for the preparation of reagent **3**

$AgSCF_3$ (3.5 g, 16.8 mmol), 1 chloro-1,3-dihydro-3,3-dimethyl-1,2-benziodoxole (5.0 g, 16.8 mmol) were placed into an oven-dried 100 mL Schlenk tube that is equipped with a stirring bar under Ar. The tube was quickly sealed with a rubber stopper and the reaction was stirred at 50 °C for 1.0 h. Then 100 mL of petroleum ether was added, Filtration of the precipitated AgCl, followed by removal of the solvent gave a pale yellow oil. The residue was purified by flash chromatography on silica gel (R_f = 0.95, petroleum ether) to give reagent **3** (2.6 g, 43% yield) as a colorless oil.

5.3. General procedure for trifluoromethylthiolation of indole derivatives

Camphorsulfonic acid (CSA) (6.9 mg, 0.03 mmol), the indole derivative (0.30 mmol) and hypervalent iodine reagent (119.4 mg, 0.33 mmol) were placed into an oven-dried sealed bomb equipped with a stirring bar under Ar. Under a positive flow of argon, 1.5 mL of freshly distilled 1,2-dichloroethane was added. The reaction was stirred at 40 °C and monitored by ^{19}F NMR spectroscopy until the disappearance of the electrophilic trifluoromethylthiolating reagent **3** (typically 24 h). 15 mL of brine and 10 mL of CH_2Cl_2 was added and the organic phase was separated. The aqueous phase was extracted with CH_2Cl_2 (3 × 10 mL) and the combined organic extracts were dried over anhydrous Na_2SO_4, and concentrated *in vacuo*. The product was purified by flash chromatography on silica gel (*e.g.* Et_2O/petroleum ether) to give 2-methyl-3-(trifluoromethylthio)-1*H*-indole as a yellow oil.

3-(Trifluoromethylthio)-1*H*-indole [6,7] (Table 2, entry 1). Yield 92%, yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$, 293 K, TMS) δ 8.39 (s, 1*H*), 7.88–7.86 (m, 1*H*), 7.48 (d, J = 2.8 Hz, 1*H*), 7.44–7.37 (m, 1*H*), 7.37–7.30 (m, 2*H*) ppm; ^{19}F NMR (376.4 MHz, $CDCl_3$) δ −44.48 (s, 3F) ppm; ^{13}C NMR (100.7 MHz, $CDCl_3$, 293 K, TMS) δ 136.03, 132.87,

129.51 (q, J = 310.4 Hz), 129.45, 123.44, 121.65, 119.31, 111.75, 95.45 (q, J = 2.1 Hz) ppm. MS (EI): m/z (%) 217, 148 (1 0 0). HRMS: Calculated for $C_9H_6NSF_4$: 217.0173; Found: 217.0175.

5-Fluoro-3-(trifluoromethylthio)-1*H*-indole (Table 2, entry 2). Yield 99%, yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$, 293 K, TMS) δ 8.53 (s, 1*H*), 7.56 (d, J = 2.8 Hz, 1*H*), 7.45 (dd, J = 9.0, 2.4 Hz, 1*H*), 7.34 (dd, J = 9.0, 4.2 Hz, 1*H*), 7.04 (td, J = 9.0, 2.4 Hz, 1*H*) ppm; ^{19}F NMR (376.4 MHz, $CDCl_3$) δ −44.62 (s, 3F), −121.68 (td, J = 9.0, 4.2 Hz, 1F) ppm; ^{13}C NMR (100.7 MHz, $CDCl_3$, 293 K, TMS) δ 159.05 (d, J = 238.05 Hz), 134.31, 132.42, 129.32 (q, J = 310.6 Hz), 130.33 (d, J = 10.4 Hz), 112.59 (d, J = 9.6 Hz), 112.08 (d J = 26.7 Hz), 104.47 (d, J = 24.7 Hz), 95.71 (q, J = 2.1 Hz) ppm. MS (EI): m/z (%) 235, 166 (1 0 0). HRMS: Calculated for $C_9H_5NSF_4$: 235.0079; Found: 235.0080.

5-Chloro-3-(trifluoromethylthio)-1*H*-indole [7] (Table 2, entry 3). Yield 90%, yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$, 293 K, TMS) δ 8.58 (s, 1*H*), 7.76 (s, 1*H*), 7.51 (d, J = 2.8 Hz, 1*H*), 7.30 (d, J = 8.8 Hz, 1*H*), 7.22 (dd, J = 8.8, 1.8 Hz, 1*H*) ppm; ^{19}F NMR (376.4 MHz, $CDCl_3$) δ −44.71 (s, 3F) ppm; ^{13}C NMR (100.7 MHz, $CDCl_3$, 293 K, TMS) δ 134.37, 134.04, 130.62, 129.29 (q, J = 310.6 Hz), 127.61, 123.90, 118.83, 112.84, 95.32 (q, J = 2.5 Hz) ppm. MS (EI): m/z (%) 251, 184 (36.64), 182 (1 0 0). HRMS: Calculated for $C_9H_5NF_3SCl$: 250.9783; Found: 250.9781.

5-Bromo-3-(trifluoromethylthio)-1*H*-indole [6,7] (Table 2, entry 4). Yield 95%, white solid. ^{1}H NMR (400 MHz, $CDCl_3$, 293 K, TMS) δ 8.62 (s, 1*H*), 7.93 (s, 1*H*), 7.53 (d, J = 2.4 Hz, 1*H*), 7.38 (d, J = 8.8 Hz, 1*H*), 7.30 (d, J = 8.8 Hz, 1*H*) ppm; ^{19}F NMR (376.4 MHz, $CDCl_3$) δ −44.60 (s, 3F) ppm; ^{13}C NMR (100.7 MHz, $CDCl_3$, 293 K, TMS) δ 134.65, 133.82, 131.16, 129.22 (q, J = 310.2 Hz), 126.46, 121.93, 115.14, 113.20, 95.25 (q, J = 2.5 Hz) ppm. MS (EI): m/z (%) 295, 228 (99.17), 226 (1 0 0). HRMS: Calculated for $C_9H_5NF_3SBr$: 294.9278; Found: 294.9277.

1-Methyl-3-(trifluoromethylthio)-1*H*-indole (Table 2, entry 5). Yield 89%, white solid, m.p. 59–60 °C. ^{1}H NMR (400 MHz, $CDCl_3$, 293 K, TMS) δ 7.83 (d, J = 7.6 Hz, 1*H*), 7.39–7.29 (m, 4*H*), 3.82 (s, 3*H*) ppm; ^{19}F NMR (376.4 MHz, $CDCl_3$) δ −44.94 (s, 3F) ppm; ^{13}C NMR (100.7 MHz, $CDCl_3$, 293 K, TMS) δ 137.20, 136.92, 130.21, 129.44 (q, J = 311.2 Hz), 122.92, 121.27, 119.37, 109.87, 92.98 (q, J = 2.5 Hz), 33.21 ppm. MS (EI): m/z (%) 231, 162 (1 0 0), 106. HRMS: Calculated for $C_{10}H_8NF_3S$: 231.0330; Found: 231.0327.

2-Methyl-3-(trifluoromethylthio)-1*H*-indole (Table 2, entry 6). Yield 96%, white solid, m.p.61–62 °C. ^{1}H NMR (400 MHz, ACETONE-D6, 293 K, TMS) δ ·7.48 (dd, J = 5.6, 2.8 Hz, 1*H*), 7.26 (dd, J = 6.0, 3.2 Hz, 1*H*), 7.04–7.00 (m, 2*H*), 2.44 (s, 3*H*) ppm; ^{19}F NMR (376.4 MHz, ACETONE-D6) δ −45.71 (s, 3F) ppm; ^{13}C NMR (100.7 MHz, ACETONE-D6, 293 K, TMS) δ 144.48, 135.59, 130.48, 130.07 (q, J = 310.4 Hz), 122.09, 120.82, 117.78, 111.26, 89.98 (q, J = 2.1 Hz), 10.93 ppm. MS (EI): m/z (%) 232, 163 (1 0 0). HRMS: Calculated for $C_{10}H_8NF_3S$: 231.0330; Found: 231.0332.

2-Methyl-3-(trifluoromethylthio)-1*H*-indole [6] (Table 2, entry 7). Yield 68%, white solid, m.p.103-104 °C. ^{1}H NMR (400 MHz, $CDCl_3$, 293 K, TMS) δ 8˙06 (s, 1*H*), 7.60 (d, J = 8.0 Hz, 1*H*), 7.34–7.28 (m, 2*H*), 7.16 (t, J = 7.2 Hz, 1*H*), 2.44 (s, 3*H*) ppm; ^{19}F NMR (376.4 MHz, $CDCl_3$) δ·−42.38 (s, 3F) ppm; ^{13}C NMR (100.7 MHz, $CDCl_3$, 293 K, TMS) δ·136.42, 127.71 (q, J = 312.2 Hz), 126.89, 123.72, 122.62, 118.96, 118.90, 111.98 (q, J = 2.3 Hz), 110.08, 8.36 ppm. MS (EI): m/z (%) 231, 162 (1 0 0). HRMS: Calculated for $C_{10}H_8NF_3S$: 231.0330; Found: 231.0332.

2,5-Dimethyl-3-(trifluoromethylthio)-1*H*-indole (Table 2, entry 8). Yield 85%, white solid, m.p.: 80–81 °C. ^{1}H NMR (400 MHz, $CDCl_3$, 293 K, TMS) δ 8˙03 (s, 1*H*), 7.57 (d, J = 4.0 Hz, 1*H*), 7.00 (d, J = 8.0 Hz, 1*H*), 7.93 (dd, J = 7.6, 2.8 Hz, 1*H*), 2.37 (d, J = 4.4 Hz, 3*H*), 2.34 (s, 3*H*) ppm; ^{19}F NMR (376.4 MHz, $CDCl_3$) δ −44.40 (s, 3F) ppm; ^{13}C NMR (100.7 MHz, $CDCl_3$, 293 K, TMS) δ 143.76, 133.34, 130.89, 130.86, 129.96 (q, J = 311.4 Hz), 124.12, 118.39, 110.60, 91.75 (q, J = 2.6 Hz), 21.52, 11.87 ppm. MS (EI): m/z (%) 245, 176 (1 0 0). HRMS: Calculated for $C_{11}H_{10}NSF_3$: 245.0486; Found: 245.0490.

5-Methoxy-2-methyl-3-(trifluoromethylthio)-1*H*-indole (Table 2, entry 9). Yield 79%, white solid. ^{1}H NMR (400 MHz, $CDCl_3$, 293 K, TMS) δ 8˙33 (s, 1*H*), 7.18 (d, J = 2.0 Hz, 1*H*), 7.15 (d, J = 8.8 Hz, 1*H*), 6.86 (dd, J = 8.8, 2.4 Hz, 1*H*), 3.90 (s, 3*H*), 2.50 (s, 3*H*) ppm; ^{19}F NMR (376.4 MHz, $CDCl_3$) δ −44.52 (s, 3F) ppm; ^{13}C NMR (100.7 MHz, $CDCl_3$, 293 K, TMS) δ 155.29, 144.29, 131.48, 129.96, 129.89 (q, J = 311.5 Hz), 112.41, 111.72, 100.66, 91.96 (q, J = 2.2 Hz), 55.88, 11.98 ppm. MS (EI): m/z (%) 261, 192 (1 0 0). HRMS: Calculated for $C_{11}H_{10}NOF_3S$: 261.0435; Found: 261.0439.

Methyl 3-(trifluoromethylthio)-1*H*-indole-5-carboxylate [6,7] (Table 2, entry 10). Yield 60%, white solid, m.p. 178–180 °C. ^{1}H NMR (400 MHz, ACETONE-D6, 293 K, TMS) δ 11.26 (s, 1*H*), 8.31 (s, 1*H*), 7.85 (d, J = 2.8 Hz, 1*H*), 7.80 (dd, J = 8.8, 1.6 Hz, 1*H*), 7.50 (dd, J = 8.8, 0.6 Hz, 1*H*), 3.77 (s, 3*H*) ppm; ^{19}F NMR (376.4 MHz, ACETONE-D6) δ −40.57 (s, 3F) ppm; ^{13}C NMR (100.7 MHz, ACETONE-D6, 293 K, TMS) δ 166.88, 139.34, 136.31, 129.58 (q, J = 309.6 Hz), 129.11, 123.90, 123.48, 120.90, 112.41, 94.44 (q, J = 2.4 Hz), 51.28 ppm. MS (EI): m/z (%) 275, 244, 206 (1 0 0). HRMS: Calculated for $C_{11}H_8NO_2F_3S$: 275.0228; Found: 275.0232.

3-(Trifluoromethylthio)-1*H*-indole-5-carbonitrile (Table 2, entry 11). Yield 78%, yellow solid, m.p. 156–158 °C. ^{1}H NMR (400 MHz, ACETONE-D6, 293 K, TMS) δ ·11.43 (s, 1*H*), 7.98 (s, 1*H*), 7.93 (d, J = 2.8 Hz, 1*H*), 7.61 (dd, J = 8.4, 0.8 Hz, 1*H*), 7.44 (dd, J = 8.4, 1.6 Hz, 1*H*) ppm; ^{19}F NMR (376.4 MHz, ACETONE-D6) δ −45.70 (s, 3F) ppm; ^{13}C NMR (100.7 MHz, ACETONE-D6, 293 K, TMS) δ 138.53, 137.14, 131.01 (q, J = 309.6 Hz), 129.39, 125.61, 123.74, 119.51, 113.87, 104.60, 94.22 (q, J = 2.5 Hz) ppm. MS (EI): m/z (%) 242, 173 (1 0 0). HRMS: Calculated for $C_{10}H_5N_2F_3S$: 242.0126; Found: 242.0128.

6-Nitro-3-(trifluoromethylthio)-1*H*-indole (Table 2, entry 12). Yield 85%, yellow solid, m.p.159-161 °C. ^{1}H NMR (400 MHz, ACETONE-D6, 293 K, TMS) δ 11.73 (s, 1*H*), 8.53 (d, J = 2.0 Hz, 1*H*), 8.22 (d, J = 2.8 Hz, 1*H*), 8.13 (dd, J = 8.8, 2.0 Hz, 1*H*), 7.87 (d, J = 8.8 Hz, 1*H*) ppm; ^{19}F NMR (376.4 MHz, ACETONE-D6) δ −45.69 (s, 3F) ppm; ^{13}C NMR (100.7 MHz, ACETONE-D6, 293 K, TMS) δ ·144.07, 139.88, 135.18, 132.58 (q, J = 310.4 Hz), 127.97, 118.86, 116.19, 109.24, 94.43 (q, J = 2.2 Hz) ppm. MS (EI): m/z (%) 262, 193 (1 0 0), 147. HRMS: Calculated for $C_9H_5N_2O_2F_3S$: 262.0024; Found: 262.0029.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jfluchem.2014.09.011.

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