Flow Synthesis of Iodonium Trifluoroacetates through Direct Oxidation of Iodoarenes by Oxone®

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Abstract: Flow chemistry is considered to be a versatile and complementary methodology for the preparation of valuable organic compounds. We describe a straightforward approach for the synthesis of iodonium trifluoroacetates through the direct oxidation of iodoarenes in a simple flow reactor using an Oxone-filled cartridge. Optimization has been carried out using the Nelder-Mead algorithm. The procedure allows a wide range of iodonium salts to be prepared from simple starting materials.

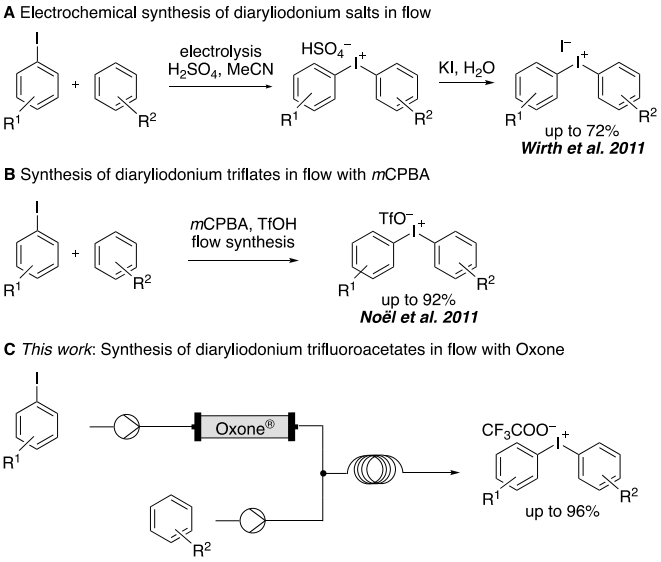
Introduction

In last decades, hypervalent iodine compounds have found wide application as mild, efficient and environmentally friendly reagents in the modern toolbox of synthesis.[1] In particular, diaryliodonium salts have become essential instruments for arylation of different nucleophiles with or without metal catalysts.[2] Moreover, iodonium salts are found as reagents for the surface modification of carbon materials and noble metals.[3]

Traditional procedures for the preparation of iodonium salts include the reaction of electrophilic iodine(III) species with electron-rich arenes.[4] Nowadays, the preliminary stage of the preparation of iodanes can be excluded and reactive iodine(III) species can be generated *in situ*. Such procedures have been investigated by Olofsson and co-workers[5] and successfully applied for the preparation of diaryliodonium tosylates, triflates and tetrafluoroborates.[6] Common oxidants for this reaction are $K_2S_2O_8$, $NaBO_3$, AcOOH and H_2O_2•urea.[7] Nevertheless, one of the most used oxidants for the preparation of iodonium salts is *meta*-chloroperbenzoic acid (*m*CPBA).[8] Recently, we reported other methods for the preparation of iodonium salts utilizing Oxone® as a cheap and alternative oxidant to *m*CPBA.[9]

However, the known approaches for the preparation of iodonium salts do not align with the modern requirements on industrial processes. For instance, *m*CPBA is considered to be a hazardous reagent requiring specific operation and storage conditions[10] as well as the disposal of *m*CPBA-containing by-products. The preparation of iodonium trifluoroacetates through oxidation with Oxone is accompanied by a long reaction time.[9b] Therefore, the development of novel approaches for the preparation of iodonium salts is required for further simplification of the synthetic protocols.

Flow chemistry is considered to be a straightforward method for the synthesis of various organic compounds and intermediates. Flow methodology provides a range of advantages over batch protocols, such as easy scale-up and optimization, effective mass- and energy transfer, reduction of waste and reaction time, safe *in situ* generation of toxic or hazardous compounds.[11] Moreover, flow methodology allows an easy use of optimization algorithms in manual or automatic mode, which improve the fast search for optimal reaction conditions.[12] The flow synthesis of hypervalent iodine compounds is little explored and only a few contributions can be found in the literature. Noël and coauthors developed a synthesis of diaryliodonium salts in flow with *m*CPBA as oxidant[13] while we reported the use of electricity as a reagent for the synthesis of iodine(III) reagents.[14] Nevertheless, the method proposed by Noël uses *m*CPBA with the aforementioned disadvantages. The electrochemical synthesis is free from reagent waste but allows the synthesis of diaryliodonium salts only from electron-rich substrates (Scheme 1).



Scheme 1. Flow synthesis of diaryliodonium salts.

Herein we report on the development of a flow synthesis of diaryliodonium trifluoroacetates using the Oxone® as the oxidant. Reaction conditions have been optimized using the Nelder-Mead algorithm for the synthesis of [bis(trifluoroacetoxy)iodo]benzene in flow and the subsequent reaction with arenes and arylboronic acids for the preparation of diaryliodonium salts.

Results and Discussion

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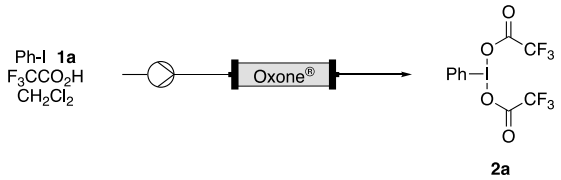
Preliminary studies began with the preparation of [bis(trifluoroacetoxy)iodo]benzene under flow conditions based on our previous findings.[15] As reported earlier, Oxone® can be used as an effective oxidant for the preparation of iodine(III) derivatives and appropriate diaryliodonium trifluoroacetates. We proposed that a simple cartridge filled by powdered Oxone® can be the key part of the flow setup for the synthesis of iodine(III) derivatives. The flow setup is shown in Scheme 2 and proceeds by pumping a 0.1 M solution of iodobenzene **1a** in dichloromethane containing 10% trifluoroacetic acid (TFA) through the Oxone® cartridge.



2a

Scheme 2. Flow synthesis of [bis(trifluoroacetoxy)iodo]benzene **2a**.

Different factors affect the yield of product and the reaction rate.[16] For the proposed setup, the concentration of reagents, the residence time and flow rate are the most important for the flow process. Even the optimization of a synthetic procedure with few variables can be performed by the Nelder-Mead Simplex method, its efficiency for flow protocols has been demonstrated previously.[17] We investigated the residence time, the concentration of iodobenzene, and the concentration of TFA. The results of the optimization are graphically shown in Figure 1, details are in Table S1 (supporting information). The amount of Oxone has been constant for the all experiments, the reaction time varied between 15 and 28.3 minutes, the amount of TFA between 7.7 and 17.4 vol% and the concentration of iodobenzene from 0.082 to 0.12 mmol mL^{-1}. After the end of each reaction, the syringe with the mixture of reagents was replaced by a syringe with dichloromethane and the Oxone column was washed. Based on the selected parameters to optimize the yield of the product, we built the first simplex and run the reaction (reactions 1-4). After the new simplex has been generated, the reactions have been carried out under the new conditions until the termination criterion was reached (reactions 5-10).

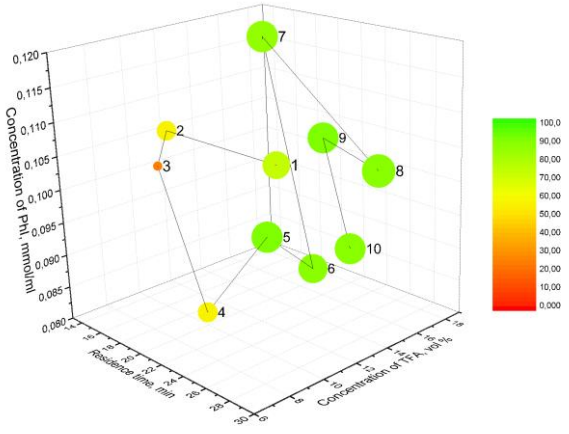


Figure 1. Graphic representation of the optimization of the synthesis of **2a**.

Best results were obtained in reactions 5 and 9 where **2a** has been isolated in 90% yield but reactions 5 required an increased amount of CF_3COOH without any influence on the yield of the desired product. The conditions of reaction 5 (0.09 M PhI, 13.9 vol% TFA, 20 min) have then also been used to successfully prepare [bis(trifluoroacetoxy)iodo]toluene **2b** in 86% yield and [bis(trifluoroacetoxy)iodo]-3-trifluoromethylbenzene **2c** (59% yield).

During the optimization we found that the amount of TFA is crucial for obtaining good yields of [bis(trifluoroacetoxy)iodo]benzene **2a**. From the point of view of reducing the amount of trifluoroacetic acid, best results were obtained in the run 8. However, the residence time there increased significantly leading to a potential clogging of the Oxone cartridge, which was also observed when the cartridge was washed at the high flow rates. The reaction is most likely to proceed at the border between the liquid and solid phase. The interaction between Oxone® and TFA leads to the generation of peroxosulfuric acids and the amount of TFA determines the effective concentration of oxidant and increases its solubility.

The optimization study has been carried out using a freshly filled Oxone® column for each experiment. One advantage of a reagent-filled column is the possibility for a repeated use. We therefore determined the number of runs for the one loading of Oxone® using the preparation of **2a** as an example. The yield of **2a** did not changed during the first 3 runs (Figure 2). Clogging issues after the 3rd run was overcome by re-loading the column with the same Oxone® after drying and crushing allowing to retain the same efficiency (Figure 2). Re-loading after every 3rd run kept the efficiency to 11 runs, which corresponds to 1.4 equivalents of Oxone® for the oxidation of iodobenzene. As reloading is not ideal, we applied ultrasonication to the Oxone®-filled column after the 3rd run which regenerates the column with same efficiency as the reloading procedure (Figure S2, supporting information). The dramatic decrease of yields after run 12 is associated with the depletion of potassium peroxymonosulfate in the solid phase.

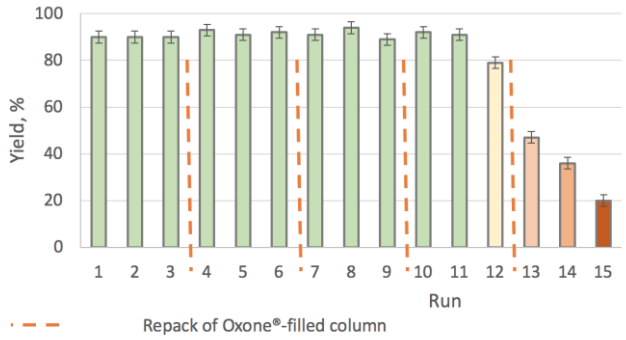
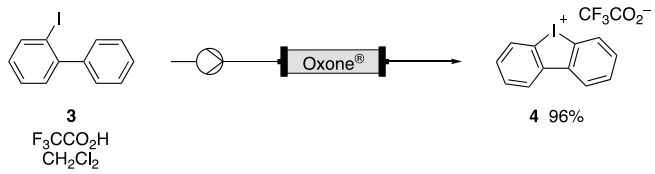


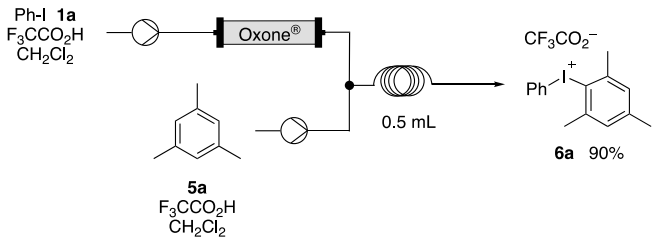
Figure 2. Repeated synthesis of **2a** using the same Oxone cartridge.

The optimized procedure for the preparation of iodine(III) derivatives was then extended to the synthesis of diaryliodonium salts by adding an arene as the second substrate. The intramolecular version of the process leads to dibenziodolium trifluoroacetate as an example for a cyclic iodonium salt[18] in almost quantitative yields as shown in Scheme 3.



Scheme 3. Synthesis of dibenziodolium trifluoroacetate **4**.

Initial efforts to prepare acyclic diaryliodonium trifluoroacetates in flow were less successful when a mixture of mesitylene and iodobenzene were pumped through the Oxone cartridge. We observed the overoxidation of the mesitylene and the desired mesityl(phenyl)iodonium trifluoroacetate was obtained in only 68% yield. Addition of the arene to the flow stream after the iodine(III) formation as shown in Scheme 4 is leading to higher yields.



Scheme 4. Synthesis of iodonium salt **6a**.

Initial experiments have been carried out using mesitylene **5a** as an arene and iodobenzene **1a**. The addition of mesitylene in pure dichloromethane has been unsuccessful due to sedimentation of in the tubing reactor and clogging issues. Therefore, mesitylene was added in the same TFA-dichloromethane mixture, which allowed the isolation of mesityl(phenyl)iodonium trifluoroacetate **6a** in 90% yield. An increase of the reactor volume from 0.5 mL to 1 mL did not change the yield of product **6a**.

The flow setup shown in Scheme 3 has then been applied to different arenes and iodoarenes leading to iodonium salts displayed in Figure 3.

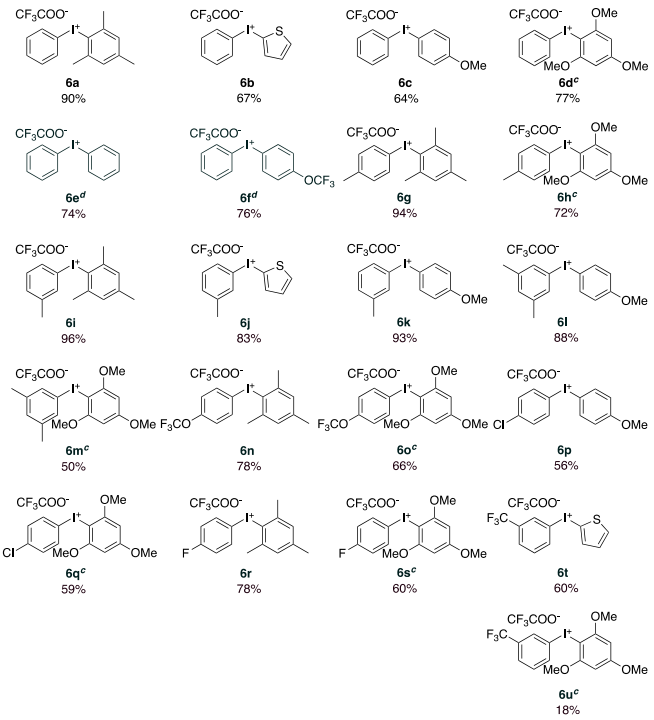


Figure 3. Synthesis of iodonium salts. [a]Reaction conditions: 10 mL reagent mixture 1: **1** (0.9 mmol) and TFA (1.39 mL) in CH_2Cl_2, flow rate: 0.11 mL/min; 11 ml reagent mixture 2: **5** (1.09 mmol), flow rate: 0.11 mL/min; Oxone-filled cartidge (5 g), room temperature; [c]1.04 mmol of arene was used; [d]Phenylboronic acid was used instead arene; [e]4-Trifluoromethoxyboronic acid was used instead of arene.

Iodobenzene **1a** smoothly reacted with electron-rich arenes **5a-d** with the formation of desired iodonium salts **6a-d** in good yields. Similar reactivities have been found in the reaction of methyl-substituted iodoarenes **1b**,**1d**, **1e** and **1f** with arenes **5a-d**. The corresponding iodonium salts have been isolated in excellent yields. Only (3,5-dimethylphenyl)(2,4,6-trimethoxyphenyl) iodonium trifluoroacetate **6m** was accessible in only 50% yield, probably due to steric hindrance. We successfully applied the method to the preparation of iodonium salts from electron-poor iodoarenes **1c**, **1g** and **1h**. In these cases, the yields of target compounds **6p-u** have been slightly lower than for electron-rich arenes. This fact can be explained by the lower reactivity of appropriate iodoarenes in the oxidation process.[9b] Nevertheless, the flow approach provides a much shorter reaction time in comparison with batch procedures.[9a] We successfully prepared a range of 1,3,5-trimethoxyphenyl-substituted iodonium salts,

which are considered to be most valuable compounds for further substitution.[8a,19]

Finally, we investigated to obtain the iodonium salts from electron-poor arenes such as benzene and toluene. The application of flow method did not change the reactivity of hypervalent iodine(III) species, and our efforts to involve benzene were unsuccessful. But the desired iodonium salts **6e** and **6f** could be obtained in the same setup using appropriate boronic acids as reagents in high yields. To the best our knowledge, these is the first example of the preparation of iodonium salts from boronic acids in a flow approach.

Conclusions

In conclusion, the synthesis of diaryliodonium trifluoroacetates in flow was demonstrated using an Oxone®-packed reactor. The Nelder-Mead algorithm for the optimization of the synthesis of bis(trifluoroacetoxy)iodobenzene enabled an increase of efficiency and speeded up the optimization process. Under optimized flow conditions a wide range of diaryliodonium trifluoroacetates including a cyclic derivative and some derivatives of [bis(trifluoroacetoxy)iodo]benzene with yields up to 96% were accessible. The flow approach to the synthesis of diaryliodonium trifluoroacetates simplifies their formation with sensitive to strong oxidants electron-rich arenes with good yields. Successful examples of utilizing arylboronic acids to replace electron-poor arenes expands the applications of this method.

Experimental Section

General information

All aromatic precursors, and other reagents and solvents were from commercial sources and used without further purification from freshly opened containers, NMR spectra were recorded at 300, 400 and 500 MHz (^{1}H NMR), 75, 100 MHz (^{13}C NMR), 376 and 471 MHz (^{19}F NMR). Chemical shifts (δ) are reported in parts per million. Mass spectrometric measurements were performed by Laboratory of Physical–Chemical Analytical Methods of Tomsk State University or the EPSRC Mass Spectrometry Service Centre, Swansea University and ions were generated by the atmospheric pressure Electrospray Ionization (ESI).

Preparation of the Oxone® cartridge:

An Omnifit column 150 mm (6.6 mm ID) was packed with fine powdered Oxone (5.0 g, 8.1 mmol) occupying a volume of approx. 2.2 ml, and the column was washed with CH_2Cl_2 (10 mL) at a flow rate of 0.5 mL/min.

General Procedure for the synthesis of [bis(trifluoro-acetoxy)iodo]benzene derivatives 2a-b

Iodoarene (0.898 mmol) and TFA (1.39 mL) were dissolved in CH_2Cl_2 to achieve a total volume of 10 mL. The reagent mixture was pumped through the Oxone-filled cartridge using a syringe pump at a flow rate of 0.11 mL/min. After the end of the reagent addition, the syringe with the mixture of reagents was immediately replaced with a syringe containing CH_2Cl_2 (10 mL) and CH_2Cl_2 was pumped with 0.11 mL/min flow rate for 30 min after which the flow rate was increased to 0.5 mL/min. The solvent was removed from the reaction mixture in vacuo and the residue was dried in vacuo (7 mbar) for 30 min. The crude mixture was dissolved in CH_2Cl_2 (5 mL) and any precipitate was removed through filtration. The solvent was removed in vacuo, the residue was washed with hexane (3 x 2 mL) and dried in vacuo.

[Bis(trifluoroacetoxy)iodo]benzene (2a) [15]

The reaction of iodobenzene **1a** (0.898 mmol, 183 mg, 100 µL) and TFA (1.39 mL) according to the general procedure afforded 344-363mg (89-94%) of [bis(trifluoroacetoxy)iodo]benzene **2a** as a white crystalline solid; mp: 119-121 ºC (lit 118-120 ºC [15]). ^{1}H NMR (400 MHz, $CDCl_3$:CF_3COOH 25:1): δ 8.21 (d, *J* = 8.4 Hz, 2H), 7.76 (t, *J* = 7.6 Hz, 1H), 7.63 (t, *J* = 7.6 Hz, 2H) ppm.

1-Bis(trifluoroacetoxy)iodo-4-methylbenzene (2b) [20]

The reaction of 4-iodotoluene **1b** (0.898 mmol, 196 mg) and TFA (1.39 mL) according to the general procedure afforded 343 mg (86%) of 1-[bis(trifluoroacetoxy)iodo]-4-methylbenzene **2b** as a pale yellow crystalline solid; mp: 114-116 ºC (lit 113-115 ºC [20]). ^{1}H NMR (400 MHz, $CDCl_3$:CF_3COOH 25:1): δ 8.10 (d, *J* = 8.4 Hz, 2H), 7.41 (d, *J* = 8.4 Hz, 2H), 2.51 (s, 3H) ppm.

1-[Bis(trifluoroacetoxy)iodo]-3-(trifluoromethyl)benzene (2c) [21]

The reaction of 3-iodobenzotrifluoride **1c** (0.898 mmol, 244 mg) and TFA (1.39 mL) according to the general procedure afforded 262 mg (59%) of 3-[bis(trifluoroacetoxy)iodo]-1-(trifluoromethyl)benzene **2c** as a white crystalline solid; mp: 96-98 ºC (lit 96-97 ºC [21]). ^{1}H NMR (400 MHz, $CDCl_3$:CF_3COOH 25:1): δ 8.44 (s, 1H), 8.39 (d, *J* = 8.4 Hz, 1H), 8.00 (d, *J* = 7.6 Hz, 1H), 7.79 (t, *J* = 8.0 Hz, 1H) ppm. ^{19}F NMR (376 MHz, $CDCl_3$:CF_3COOH 25:1): δ -62.98, -75.70 ppm.

Synthesis of dibenzo[b,d]iodoniumtrifluoroacetate (4)

2-Iodobiphenyl 3 (0.898 mmol, 251 mg) and TFA (1.39 mL) was dissolved in CH_2Cl_2 (5 mL) and the volume of mixture was brought to 10 mL by adding CH_2Cl_2. Then the reagent mixture was pumped through Oxone-filled column with syringe pump. Flow rate was 0.11 mL/min. After the end of the reagent addition, the syringe with a mixture of reagents was immediately replaced with a syringe with CH_2Cl_2 (10 mL) and CH_2Cl_2 was pumped with 0.11 mL/min flow rate for 30 min. Then flow rate was increased to 0.5 mL/min and addition continued until the end of the CH_2Cl_2 in the syringe. The solvent was removed from the resulting solution in vacuo and obtained residue was diluted with 5 mL of water. Product was extracted with CH_2Cl_2 (3 x 5 mL). The organic layer was dried over Na_2SO_4 and solvent was removed in vacuo. Then diethyl ether (5 mL) was added to residue and formation of precipitate was observed. The suspension was stirred for 10 minutes and product was filtrated and washed with diethyl ether (5 mL) and hexane (2 x 5 mL). The product was dried in vacuo. Dibenzo[b,d]iodoniumtrifluoroacetate 4 was obtained in 96% yield (379 mg) as a beige crystalline solid; mp: 108-110 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.46 (d, *J* = 8.4 Hz, 2H), 8.10 (dd, *J* = 8.0, 1.2 Hz, 2H), 7.76 (t, *J* = 8.0 Hz, 2H), 7.61 (t, *J* = 8.4 Hz, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 161.3 (q, *J* = 38 Hz), 142.1, 131.4, 131.4, 131.0, 126.5, 122.0, 115.7 (q, *J* = 287 Hz) ppm. ^{19}F NMR (376 MHz, $CDCl_3$): δ -75.52 ppm. HRMS (ESI): *m/z* calcd for $C_{12}H_8I^+$: 278.9665; found: 278.9665.

General Procedure for the synthesis of diaryliodonium trifluoroacetates 6a-u

Reagent mixture 1: Iodoarene **1a-h** (0.898 mmol, 183 mg, 100 µL) and TFA (1.39 mL) were dissolved CH_2Cl_2 to achieve a total volume of 10 mL. Reagent mixture 2: Arene **5a-d** (1.037-1.087 mmol) or boronic acid **5e, f** (1.087 mmol) and TFA (1.53 mL) were dissolved CH_2Cl_2 to achieve a total volume of 11 mL.

Reagent mixture 1 was pumped through the Oxone-filled cartridge using a syringe pump at a flow rate of 0.11 mL/min. After 15.5 minutes, reagent mixture **2** was started to pump with a second syringe pump with 0.11 mL/min. After the end of the reagent mixture **1** addition, the syringe with a mixture of reagents was immediately replaced with a syringe with CH_2Cl_2 (10 ml) and DC CH_2Cl_2 M was pumped with 0.11 ml/min until the end of the pumping reagent mixture **2**. Then flow rate was increased to 0.22 mL/min for 5 min, then and addition continued until the end of the CH_2Cl_2 in the syringe with 0.5 mL/min flow rate. Solvent was removed from the resulting solution in vacuo and the residue was diluted with water (5 mL). The product was extracted with CH_2Cl_2 (3 x 5 mL). The organic layer was dried over Na_2SO_4 and the solvent was removed in vacuo. Then diethyl ether (5 mL) was added to the residue and a precipitate was formed, the suspension was stirred for 10 min, then the product was filtered off and washed with diethyl ether (5 mL) and hexane (10 mL). The obtained product was dried in vacuo.

Mesityl(phenyl)iodonium trifluoroacetate (6a)

The reaction of iodobenzene **1a** (0.898 mmol, 183 mg, 100 µL), mesitylene **5a** (1.087 mmol, 130 mg) and TFA (2.92 mL) according to the general procedure afforded 352 mg (90%) of mesityl(phenyl)iodonium trifluoroacetate **6a** as a white crystalline solid; mp: 142-144 ºC (lit 137-138 ºC [9a]). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.68 (d, *J* = 7.7 Hz, 2H), 7.49 (t, *J* = 7.4 Hz, 1H), 7.37 (t, *J* = 7.8 Hz, 2H), 7.08 (s, 2H), 2.62 (s, 6H), 2.34 (s,3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ161.0 (q, *J* = 37Hz, CF_3COO^-), 144.4, 142.4, 132.9, 132.2, 131.7, 130.4, 121.3, 115.9 (q, *J* = 289Hz, CF_3COO^-), 113.3, 27.1, 21.2 ppm. ^{19}F NMR (376 MHz, $CDCl_3$): δ -75.67 ppm. HRMS (ESI): *m/z* calcd for $C_{15}H_{16}I^+$: 323.0297; found: 323.0299.

Phenyl(thiophen-2-yl)iodonium trifluoroacetate (6b)

The reaction of iodobenzene**1a** (0.898 mmol, 183 mg, 100 µL), thiophene**5b**(1.087 mmol, 91 mg) and TFA (2.92 mL) according to the general procedure afforded 242 mg (67%) of phenyl(thiophen-2-yl)iodonium trifluoroacetate **6b** as a beige crystalline solid; mp 152-154 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.97 (d, *J* = 7.6 Hz, 2H), 7.72 (dd, *J* = 4.0, 1.2 Hz, 1H), 7.59 (dd, *J* = 5.2, 1.2 Hz, 1H), 7.52 (t, *J* = 7.6 Hz, 1H), 7.39 (t, *J* = 7.6 Hz, 2H), 7.06 (dd, *J* = 5.2, 3.6 Hz, 1H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ 160.9 (q, *J* = 38 Hz), 141.1, 137.4, 133.9, 132.5, 132.3, 130.2, 118.3, 115.6 (q, *J* = 287Hz), 97.0 ppm. ^{19}F NMR (376 MHz, $CDCl_3$) δ -75.30 ppm. HRMS (ESI): *m/z* calcd for $C_{10}H_8IS^+$: 286.9391; found: 286.9389.

(4-Methoxyphenyl)(phenyl)iodonium trifluoroacetate (6c)

The reaction of iodobenzene **1a** (0.898 mmol, 183 mg, 100 µL), anisole **5c** (1.087 mmol, 117 mg) and TFA (2.92 mL) according to the general procedure afforded 247 mg (64%) of (4-methoxyphenyl)(phenyl)iodonium trifluoroacetate **6c** as a beige crystalline solid; mp: 162-164 ºC (lit 137-138 ºC [22]). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.90 (d, *J* = 7.6 Hz, 2H), 7.86 (d, *J* = 8.8 Hz, 2H), 7.52 (t, *J* = 7.6 Hz, 1H), 7.38 (t, *J* = 7.6 Hz,2H), 6.89 (d, *J* = 8.8 Hz, 2H), 3.81 (s,3H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ 162.9, 161.0 (q, *J* = 37 Hz), 137.3, 134.3, 132.2, 132.1, 118.0,115.9 (q, *J* = 290 Hz),115.4, 102.9, 55.8 ppm. ^{19}F NMR (376 MHz, $CDCl_3$): δ -75.32 ppm. HRMS (ESI): *m/z* calcd for $C_{13}H_{12}IO^+$: 310.9933; found: 310.9930.

Phenyl(2,4,6-trimethoxyphenyl)iodonium trifluoroacetate (6d)

The reaction of iodobenzene **1a** (0.898 mmol, 183 mg, 100 µL), 1,3,5-trimethoxybenzene **5d** (1.037 mmol, 174 mg) and TFA (2.92 mL) according to the general procedure afforded 336 mg (77%) of phenyl(2,4,6-trimethoxyphenyl)iodoniumtrifluoroacetate **6d** as a pale yellow crystalline solid; mp: 153-155 ºC (lit 160-165 ºC [8d]). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.88 (d, *J* = 8.0 Hz, 2H), 7.46 (t, *J* = 7.4 Hz, 1H), 7.32 (t, *J* = 8.0 Hz, 2H), 6.16 (s, 2H), 3.86 (s, 6H), 3.85 (s, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 166.8,161.7 (q, *J* = 34 Hz), 160.6, 133.9, 131.4, 131.3, 117.0, 116.5 (q, *J* = 293 Hz), 91.5, 85.8, 56.9, 56.0 ppm. ^{19}F NMR (376 MHz, $CDCl_3$): δ -75.31 ppm. HRMS (ESI): *m/z* calcd for $C_{15}H_{16}IO_3^+$: 371.0139; found: 371.0139.

Diphenyliodoniumtrifluoroacetate (6e)

The reaction of iodobenzene **1a** (0.898 mmol, 183 mg, 100 µL), phenylboronic acid **5e** (1.087 mmol, 133 mg) and TFA (2.92 mL) according to the general procedure afforded 261 mg (74%) of diphenyliodoniumtrifluoroacetate **6e** as a white crystalline solid; mp: 202-203 ºC (lit 197-198 ºC [7b]). ^{1}H NMR (400 MHz, DMSO-d_6): δ 8.25 (d, *J* = 7.2 Hz, 4H), 7.66 (t, *J* = 7.6 Hz, 2H), 7.52 (t, *J* = 7.6 Hz, 4H) ppm. ^{13}C NMR (100 MHz, DMSO-d_6): δ 157.9 (q, *J* = 37 Hz), 135.2, 132.0, 131.7,117.3 (q, *J* = 295 Hz), 116.8 ppm. ^{19}F NMR (376 MHz, DMSO-d_6): δ -73.42 ppm. HRMS (ESI): *m/z* calcd for $C_{12}H_{10}I^+$: 280.9822; found: 280.9822.

Phenyl(4-(trifluoromethoxy)phenyl)iodoniumtrifluoroacetate (6f)

The reaction of iodobenzene **1a** (0.898 mmol, 183 mg, 100 µL), 4-trifluoromethoxyphenylboronic acid **5f** (1.087 mmol, 204 mg) and TFA (2.92 mL) according to the general procedure afforded 325 mg (76%) of phenyl(4-(trifluoromethoxy)phenyl)iodonium trifluoroacetate **6f** as a white crystalline solid; mp: 192-194 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.01 – 7.96 (m, 4H), 7.56 (t, *J* = 7.6 Hz, 1H), 7.40 (t, *J* = 7.6 Hz, 2H), 7.19 (d, *J* = 8.4 Hz, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 161.5 (q, *J* = 36 Hz), 151.7, 136.8, 135.1, 132.1, 132.0, 123.7,120.3 (q, *J* = 258 Hz), 117.5, 116.0 (q, *J* = 290 Hz), 113.9 ppm. ^{19}F NMR (376 MHz, $CDCl_3$): δ -57.84, -75.53 ppm. HRMS (ESI): *m/z* calcd for $C_{13}H_9F_3IO^+$: 364.9645; found: 364.9645.

Mesityl(p-tolyl)iodoniumtrifluoroacetate (6g)

The reaction of 4-iodotoluene **1b** (0.898 mmol, 194 mg), mesitylene **5a** (1.087 mmol, 130 mg) and TFA (2.92 mL) according to the general procedure afforded 380 mg (94%) of mesityl(p-tolyl)iodoniumtrifluoro-acetate **6g** as a white crystalline solid; mp: 155-156 ºC. ^{1}H NMR (400 MHz,$CDCl_3$): δ 7.57 (d, *J* = 8.4 Hz, 2H), 7.15 (d, *J* = 8.4 Hz, 2H), 7.04 (s, 2H), 2.62 (s, 6H), 2.33 (s, 3H), 2.32 (s, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 161.2 (q, *J* = 36 Hz), 143.7, 142.1, 132.9, 132.7, 130.2, 123.1, 166.8, 116.1 (q, *J* = 290 Hz), 111.5, 27.1, 21.4, 21.2 ppm. ^{19}F NMR (376 MHz, $CDCl_3$): δ -75.52 ppm. HRMS (ESI): *m/z* calcd for $C_{16}H_{18}I^+$: 337.0448; found: 337.0447.

***p*-Tolyl(2,4,6-trimethoxyphenyl)iodonium trifluoroacetate (6h)**

The reaction of 4-iodotoluene **1b** (0.898 mmol, 196 mg), 1,3,5-trimethoxybenzene **5d** (1.037 mmol, 174 mg) and TFA (2.92 mL) according to the general procedure afforded 320 mg (72%) of *p*-tolyl(2,4,6-trimethoxyphenyl)iodonium trifluoroacetate **6h** as a beige crystalline solid;

mp 161-163 ºC (lit 163-165 ºC [8d]). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.76 (d,*J* = 8.4 Hz, 2H), 7.11 (d, *J* = 8.4 Hz, 2H), 6.15 (s, 2H), 3.86 (s, 6H), 3.84 (s, 3H), 2.32 (s, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 166.8, 161.0 (q, *J* = 33 Hz), 160.5, 142.2, 134.0, 132.3, 116.2 (q, *J* = 290 Hz), 113.5, 91.5, 86.3, 56.9, 56.0, 21.4 ppm. ^{19}F NMR (376 MHz, $CDCl_3$): δ -75.38 ppm. HRMS (ESI): *m/z* calcd for $C_{16}H_{18}IO_3^+$: 385.0295; found: 385.0295.

Mesityl(m-tolyl)iodoniumtrifluoroacetate (6i)

The reaction of 3-iodotoluene **1d** (0.898 mmol, 196 mg), mesitylene **5a** (1.087 mmol, 130 mg) and TFA (2.92 mL) according to the general procedure afforded 388 mg (96%) of mesityl(m-tolyl)iodoniumtrifluoroacetate **6i** as a yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.53 (s, 1H), 7.39 (d, *J* = 8.0 Hz, 1H), 7.34 (d, *J* = 7.2 Hz, 1H), 7.27 (t, *J* = 7.6 Hz, 1H), 7.11 (s, 2H), 2.61 (s, 6H), 2.36 (s, 3H), 2.35 (s, 3H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ 160.8 (q, *J* = 36 Hz), 144.7, 143.3, 142.6, 133.4, 133.0, 132.1, 130.6, 129.8, 119.9, 115.8 (q, *J* = 288 Hz), 112.0, 27.1, 21.5, 21.2 ppm. ^{19}F NMR (376 MHz, $CDCl_3$): δ -75.80 ppm. HRMS (ESI): *m/z* calcd for $C_{16}H_{18}I^+$: 337.0453; found: 337.0456.

Thiophen-2-yl(m-tolyl)iodoniumtrifluoroacetate (6j)

The reaction of 3-iodotoluene **1d** (0.898 mmol, 196 mg), thiophene **5b** (1.087 mmol, 91 mg) and TFA (2.92 mL) according to the general procedure afforded 308 mg (83%) of thiophen-2-yl(m-tolyl)iodoniumtrifluoroacetate **6j** as a yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.79 – 7.78 (m, 2H), 7.74 (d, *J* = 8.0 Hz, 1H), 7.66 (dd, *J* = 5.2, 1.2 Hz, 1H), 7.37 (d, *J* = 7.6 Hz, 1H), 7.30 (t, *J* = 8.0 Hz, 1H), 7.11 (dd, *J* = 5.6, 4.0 Hz, 1H), 2.37 (s, 3H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ 161.0(q, *J* = 38 Hz), 143.1, 140.8, 137.1, 134.2, 133.3, 131.9, 130.9, 130.1, 118.5, 115.7(q, *J* = 287 Hz), 97.7, 21.5 ppm. ^{19}F NMR (376 MHz, $CDCl_3$): δ -75.72 ppm. HRMS (ESI): *m/z* calcd for $C_{11}H_{10}SI^+$: 300.9548; found: 300.9548.

(4-Methoxyphenyl)(m-tolyl)iodoniumtrifluoroacetate (6k)

The reaction of 3-iodotoluene **1d** (0.898 mmol, 196 mg), anisole **5c** (1.087 mmol, 117 mg) and TFA (2.92 mL) according to the general procedure afforded 365 mg (93%) of (4-methoxyphenyl)(m-tolyl)iodoniumtrifluoroacetate **6k** as a yellow oil. ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.87 (d, *J* = 9.0 Hz, 2H), 7.72 (s, 1H), 7.67 (d, *J* = 8.5 Hz, 2H), 7.38 (d, *J* = 7.5 Hz, 1H), 7.31 (t, *J* = 8.0 Hz, 1H), 6.95 (d, *J* = 9.5 Hz, 2H), 3.83 (s, 3H), 2.37 (s, 3H) ppm ^{13}C NMR (75 MHz, $CDCl_3$): δ 163.1, 160.3 (q, *J* = 38 Hz), 143.2, 137.3, 134.7, 133.4, 132.0, 131.3, 118.2,115.8 (q, *J* = 288 Hz), 114.5, 101.9, 55.9, 21.5 ppm. ^{19}F NMR (471 MHz, $CDCl_3$) δ -75.80 ppm. HRMS (ESI): *m/z* calcd for $C_{14}H_{14}OI^+$: 325.0089; found: 325.0094.

(3,5-Dimethylphenyl)(4-methoxyphenyl)iodoniumtrifluoroacetate (6l)

The reaction of 3,5-dimethyliodobenzene**1e** (0.898 mmol, 208 mg), anisole **5c**(1.087 mmol, 117 mg) and TFA (2.92 mL) according to the general procedure afforded 369 mg (88%) of (3,5-dimethylphenyl)(4-methoxyphenyl)iodonium trifluoroacetate**6l**as a beige crystalline solid; mp 160-162 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.85 (d,*J* = 8.0 Hz, 2H), 7.51 (s, 2H), 7.12 (s, 1H), 6.89 (d, *J* = 8.4 Hz, 2H), 3.81 (s, 3H), 2.29 (s, 6H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.4,161.3 (q, *J* = 36 Hz), 142.1, 136.8, 133.7, 131.8, 117.6, 116.8, 116.1 (q,*J* = 290 Hz), 105.1, 55.7, 21.4 ppm. ^{19}F NMR (376 MHz, $CDCl_3$): δ -75.50 ppm. HRMS (ESI): *m/z* calcd for $C_{15}H_{16}IO^+$: 339.0240; found: 339.0240.

(3,5-Dimethylphenyl)(2,4,6-trimethoxyphenyl)iodonium trifluoroacetate (6m)

The reaction of 3,5-dimethyliodobenzene **1e** (0.898 mmol, 208 mg), 1,3,5-trimethoxybenzene **5d** (1.037 mmol, 174 mg) and TFA (2.92 mL) according to the general procedure afforded 232 mg (50%) of (3,5-dimethylphenyl)(2,4,6-trimethoxyphenyl)iodonium trifluoroacetate **6m** as a pale yellow crystalline solid; mp: 187-189 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.51 (s, 2H), 7.07 (s, 1H), 6.16 (s, 2H), 3.88 (s, 6H), 3.86 (s, 3H), 2.28 (s, 6H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 166.8, 160.5, 160.5 (q, *J* = 35 Hz), 141.7, 133.4, 131.5, 116.8, 115.9 (q, *J* = 289 Hz), 91.6, 86.1, 56.9, 56.0, 21.4 ppm. ^{19}F NMR (376 MHz, $CDCl_3$): δ -75.79 ppm. HRMS (ESI): *m/z* calcd for $C_{17}H_{20}IO_3^+$: 399.0452; found: 399.0453.

Mesityl(4-(trifluoromethoxy)phenyl)iodonium trifluoroacetate (6n)

The reaction of 4-trifluorometoxyiodobenzene **1f** (0.898 mmol, 257mg), mesitylene **5a** (1.087 mmol, 130 mg) and TFA (2.92 mL) according to the general procedure afforded 364 mg (78%) of mesityl(4-(trifluoromethoxy)phenyl)iodonium trifluoroacetate **6n** as a white crystalline solid; mp: 167-169 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.73 (d, *J* = 9.2 Hz, 2H), 7.18 (d, *J* = 8.4 Hz, 2H), 7.07 (s, 2H), 2.62 (s, 6H), 2.33 (s, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 161.7 (q, *J* = 35 Hz), 151.3(q, *J* = 2 Hz), 143.9, 142.0, 134.7, 130.2, 123.8, 123.3, 120.3 (q, *J* = 258 Hz), 116.2 (q, *J* = 291 Hz), 111.7, 27.1, 21.2 ppm. ^{19}F NMR (376 MHz, $CDCl_3$): δ -57.89, -75.47 ppm. HRMS (ESI): *m/z* calcd for $C_{16}H_{15}F_3IO^+$: 407.0114; found: 407.0113.

(4-(Trifluoromethoxy)phenyl)(2,4,6-trimethoxyphenyl)iodonium trifluoroacetate (6o)

The reaction of 4-trifluorometoxyiodobenzene **1f** (0.898 mmol, 257mg), 1,3,5-trimethoxybenzene **5d** (1.037 mmol, 174 mg) and TFA (2.92 mL) according to the general procedure afforded 338 mg (66%) of (4-(trifluoromethoxy)phenyl)(2,4,6-trimethoxyphenyl)iodonium trifluoroacetate **6o** as a pale yellow crystalline solid; mp: 177-179 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.95 (d, *J* = 8.8 Hz, 2H), 7.15 (d, *J* = 8.2 Hz, 2H), 6.17 (s, 2H), 3.89 (s, 6H), 3.85 (s, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 167.0, 161.3 (q, *J* = 36 Hz), 160.5, 151.2 (q, *J* = 2 Hz), 135.8, 123.4, 120.3 (q, *J* = 258 Hz), 116.2 (q, *J* = 290 Hz), 113.6, 91.6, 86.8, 57.0, 56.0 ppm. ^{19}F NMR (376 MHz, $CDCl_3$): δ -57.84, -75.59 ppm. HRMS (ESI): *m/z* calcd for $C_{16}H_{15}F_3IO_4^+$: 454.9962; found: 454.9963.

(4-Chlorophenyl)(4-methoxyphenyl)iodoniumtrifluoroacetate (6p)

The reaction of 4-chloroiodobenzene **1g** (0.898 mmol, 214 mg), anisole **5c** (1.087 mmol, 117 mg) and TFA (2.92 mL) according to the general procedure afforded 230 mg (56%) of (4-chlorophenyl)(4-methoxyphenyl)iodonium trifluoroacetate **6p** as a white crystalline solid; mp: 162-164 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.87 – 7.83 (m, 4H), 7.31 (d, *J* = 8.4 Hz, 2H), 6.88 (d, *J* = 8.8 Hz, 2H), 3.81 (s, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 162.6, 161.4(q, *J* = 36 Hz), 138.5, 137.1, 135.7, 131.9, 117.7, 116.2(q, *J* = 291 Hz), 114.7, 105.7, 55.8 ppm. ^{19}F NMR (376 MHz, $CDCl_3$) δ -75.41 ppm. HRMS (ESI): *m/z* calcd for $C_{13}H_{11}ClIO^+$: 344.9538; found: 344.9539.

(4-Chlorophenyl)(2,4,6-trimethoxyphenyl)iodonium trifluoroacetate (6q)

The reaction of 4-chloroiodobenzene **1g** (0.898 mmol, 214 mg), 1,3,5-trimethoxybenzene **5d** (1.037 mmol, 174 mg) and TFA (2.92 mL) according to the general procedure afforded 276 mg (59%) of (4-chlorophenyl)(2,4,6-trimethoxyphenyl)iodonium trifluoroacetate **6q** as a pale yellow crystalline solid; mp: 167-169 ºC (lit 168-172 ºC [8d]). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.85 (d, *J* = 8.4 Hz, 2H), 7.30 (d, *J* = 8.8 Hz, 2H), 6.18 (s, 2H), 3.90 (s, 6H), 3.87 (s, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ

166.9, 161.5 (q, *J* = 35 Hz),160.5, 137.9, 135.2, 131.5, 116.4 (q, *J* = 292 Hz), 114.3, 91.5, 86.5, 56.9, 56.0 ppm. ^{19}F NMR (376 MHz, $CDCl_3$): δ -75.49 ppm. HRMS (ESI): *m/z* calcd for $C_{15}H_{15}ClIO_3^+$: 404.9749; found: 404.9748.

(4-Fluorophenyl)(mesityl)iodonium trifluoroacetate (6r)

The reaction of 4-fluoroiodobenzene **1h** (0.898 mmol, 199 mg), mesitylene **5a** (1.087 mmol, 130 mg) and TFA (2.92 mL) according to the general procedure afforded 318 mg (78%) of (4-fluorophenyl) (mesityl)iodonium trifluoroacetate **6r** as a white crystalline solid; mp: 146-148 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.69 (dd, *J* = 8.8, 4.8 Hz, 4H), 7.08 – 7.03 (m, 4H), 2.62 (s, 6H), 2.32 (s, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 164.3 (d, *J* = 252 Hz), 161.7 (q, *J* = 35 Hz), 143.8, 141.9, 135.3 (d, *J* = 9 Hz), 130.2, 123.4, 119.3 (d, *J* = 23 Hz), 116.3 (q, *J* = 292 Hz), 108.6 (d, *J* = 3 Hz), 27.1, 21.2 ppm. ^{19}F NMR (376 MHz, $CDCl_3$): δ -75.43, -107.25 ppm. HRMS (ESI): *m/z* calcd for $C_{15}H_{15}FI^+$: 341.0197; found: 341.0196.

(4-Fluorophenyl)(2,4,6-trimethoxyphenyl)iodonium trifluoroacetate (6s)

The reaction of 4-fluoroiodobenzene **1h** (0.898 mmol, 199 mg), 1,3,5-trimethoxybenzene **5d** (1.037 mmol, 174 mg) and TFA (2.92 mL) according to the general procedure afforded 269 mg (60%) of (4-fluorophenyl)(2,4,6-trimethoxyphenyl)iodonium trifluoroacetate **6s** as a pale yellow crystalline solid; mp: 169-171 ºC (lit 165-169 ºC [8d]). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.90 (dd,*J* = 9.2, 5.2 Hz, 2H), 7.03 – 6.99 (m, 2H), 6.15 (s, 2H), 3.87 (s, 6H), 3.84 (s, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 166.8, 164.3 (d, *J* = 252 Hz), 161.6 (q, *J* = 35 Hz), 160.5, 136.4 (d, *J* = 9 Hz), 118.8 (d, *J* = 23 Hz), 116.4 (q, *J* = 292 Hz), 110.6 (d, *J* = 3 Hz), 91.5, 86.6, 56.9, 56.0 ppm. ^{19}F NMR (376 MHz, $CDCl_3$): δ -75.40, -107.20 ppm. HRMS (ESI): *m/z* calcd for $C_{15}H_{15}FIO_3^+$: 389.0044; found: 389.0044.

Thiophen-2-yl(3-(trifluoromethyl)phenyl)iodoniumtrifluoroacetate (6t)

The reaction of 3-iodobenzotrifluoride **1c** (0.898 mmol, 244 mg), thiophene **5b** (1.087 mmol, 91 mg) and TFA (2.92 mL) according to the general procedure afforded 253 mg (60%) of thiophen-2-yl(3-(trifluoromethyl)phenyl)iodonium trifluoroacetate **6t** as a grey crystalline solid; mp: 102-104 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.20 – 8.19 (m, 2H), 7.80 – 7.77 (m, 2H), 7.64 (dd, *J* = 5.2, 1.2 Hz, 1H), 7.54 (t, *J* = 8.4 Hz, 1H), 7.10 (dd, *J* = 5.2, 4.0 Hz, 1H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 162.0 (q, *J* = 36 Hz), 140.4, 137.1, 136.5, 133.6 (q, *J* = 34 Hz), 132.0, 130.6 (q, *J* = 4 Hz), 129.9, 128.5 (q, *J* = 4 Hz),122.3 (q, *J* = 272 Hz), 120.0, 116.0 (q, *J* = 291 Hz), 102.1 ppm. ^{19}F NMR (376 MHz, $CDCl_3$): δ -62.89, -75.59 ppm. HRMS (ESI): *m/z* calcd for $C_{11}H_7F_3IS^+$: 354.9260; found: 354.9259.

(3-(Trifluoromethyl)phenyl)(2,4,6-trimethoxyphenyl)iodoniumtrifluoroacetate (6u)

The reaction of 3-iodobenzotrifluoride **1c** (0.898 mmol, 196 mg), 1,3,5-trimethoxybenzene **5d** (1.037 mmol, 174 mg) and TFA (2.92 mL) according to the general procedure afforded 89 mg (18%) of (3-(trifluoromethyl)phenyl)(2,4,6-trimethoxyphenyl)iodoniumtrifluoroacetate **6u** as a pale yellow crystalline solid; mp: 142-144 ºC. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.19 (d, *J* = 8.0 Hz, 1H), 8.14 (s, 1H), 7.71 (d, *J* = 8.0 Hz, 1H), 7.47 (t, *J* = 8.0 Hz, 1H), 6.17 (s, 2H), 3.89 (s, 6H), 3.85 (s, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 167.0, 160.9 (q, *J* = 38 Hz), 160.5, 137.5,133.2 (q, *J* = 33 Hz), 131.6, 130.7 (q, *J* = 4 Hz), 128.0 (q, *J* = 4 Hz),122.8 (q, *J* = 272 Hz), 117.4, 116.0 (q, *J* = 289 Hz), 91.7, 87.3, 57.0, 56.0 ppm. ^{19}F NMR (376 MHz, $CDCl_3$): δ -62.86, -75.79 ppm. HRMS (ESI): *m/z* calcd for $C_{16}H_{15}F_3IO_3^+$: 439.0012; found: 439.0013.

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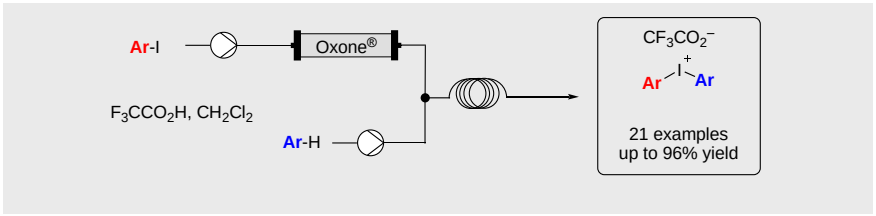

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