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Transition metal- and organophotocatalyst-free perfluoroalkylation reaction of amino(hetero)aromatics initiated by the complex [(TMEDA)I·I_3] and visible light†

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Radical initiation for the perfluoroalkylation reaction of amino(hetero)aromatics has been accomplished employing the complex [(TMEDA)I·I_3] and visible light. This methodology circumvents the use of metal(organo)catalysts and biologically-relevant substrates are easily substituted with R_F moieties employing a mild and environmentally benign radical strategy starting from readily-available perfluoroalkyl iodides R_FI.

Introduction

Aminoaromatic compounds such as aniline derivatives can be perfluoroalkylated with ease[1,2] by radical reactions due to the electrophilic nature of the fluoroalkyl radical[3,4] and the high electron density of the aromatic ring. Even more so, fluoroalkylation can be attempted under visible light through the homolytic cleavage of the R_F–I bond upon irradiation (*ca.* 201 kJ mol^{-1}, 590 nm), albeit, in poor yields. Reports on visible-light photocatalytic perfluoroalkylations utilizing photoorganocatalysts[4,6] have provided alternative routes to better-yielding perfluoroalkyl-substituted compounds (Scheme 1).

Motivated by the results of Noel and collaborators[5] for the RS–H photosubstitution of cysteine derivatives employing TMEDA, R_F–I and a transition metal photoorganocatalyst (POC) in MeCN, we replaced our reported strategy for the radical perfluoroalkylation reactions of anilines that employed Cs_2CO_3/POC[5] for TMEDA and used a commercial fluorescent light CFL in the absence of organophotocatalyst to attempt the visible-light perfluoroalkylation of amino aromatic compounds in the presence of TMEDA. In this work, we will show that radical initiation can take place from visible light-irradiation of TMEDA/I_2 complex and that organophotocatalysts are not necessary for improved substitution yields.

Results and discussion

At start of our studies it was not clear the species responsible for the visible-light absorption, in the absence of photoorganocatalyst POC Rose Bengal[5] (RB), since product formation seemed to improve substantially upon illumination (*cf.* entries 2 & 5, Table 1), and none of the reagents alone (*i.e.*: *n*-C_4F_9I, aniline, or TMEDA) showed enough optical density at the irradiation wavelengths.

When aniline was subjected to the visible-light irradiation in the presence of *n*-C_4F_9I and TMEDA in MeCN as solvent, in the absence of photocatalyst, 62% yield of substitution product was obtained (entry 2, Table 1). By irradiating at 370 nm (with a black fluorescent light lamp), a 64% yield of substitution product was obtained (entry 4, Table 1). The dark reaction (entry 5, Table 1) afforded only 11% yield of product, whereas the absence of TMEDA reduced the yield significantly (entry 6, Table 1).

When we inspected the UV-vis spectrum of the solution mixture of aniline and *n*-C_4F_9I to be irradiated at the working concentrations, we noticed an absorption band at λ_{max} = 458 nm, corresponding to the absorption of iodine in MeCN (Fig. S1, ESI†), with enough optical density to initiate the radical reaction through the production of iodine atoms.[8,9] Concerned about this absorption, we excluded iodine from the reagent *n*-C_4F_9I, passing the neat liquid through a neutral alumina column, and subjected the mixture of aniline, iodine-free *n*-C_4F_9I, and TMEDA to the photoreaction under visible-light (CFL) in MeCN as solvent. Under these latter reaction conditions, we obtained only 23% yield of substitution product, indicating that an iodine-containing species is intervening in the initiation process (entry 7, Table 1). However, when we purposely added tetra butyl ammonium iodide (TBAI) and iodine (entry 8, Table 1) to a solution of purified *n*-C_4F_9I (I_2-free), a low yield of substitution product was again obtained (36%), indicating that I_3^- (λ_{max} = 291 nm and 364 nm in MeCN) was not responsible for the photoinitiation. Conducting the irradiation of aniline with a medium pressure Hg lamp (employing

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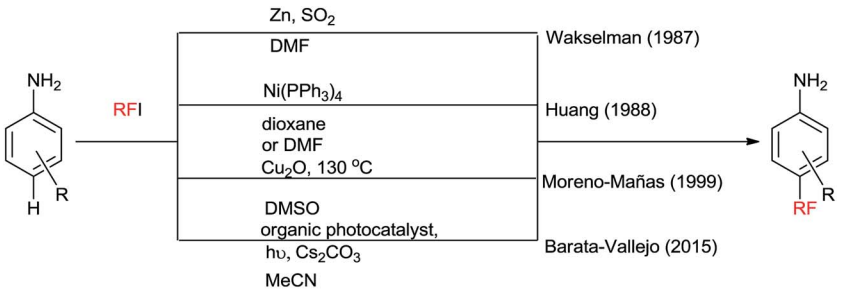
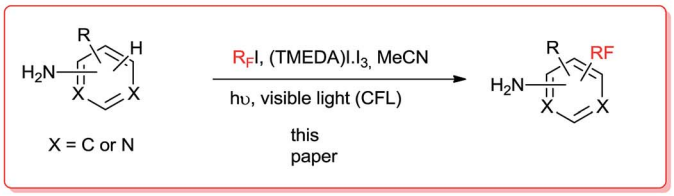




Scheme 1 Methods for radical perfluoroalkylation of aniline derivatives.

Table 1 Substitution yields (%) of aniline (0.6 mmol) with *n*-C_4F_9I (3 equiv.), *N,N,N′,N′*-tetramethylethylene diamine (TMEDA) (3 equiv.) under visible light irradiation (65 watt CFL or otherwise noted) in MeCN (3 mL) as solvent, under Ar atmosphere (20 h reaction)

Entry	Product yield (%)	Isomer ratio (*o* : *p*)
1	76[a]	1 : 1
2	62	0.9 : 1.1
3	—[b]	—
4	64[c]	0.9 : 1.2
5	11[d]	1 : 3
6	3[e]	[h]
7	23[f]	0.8 : 1.2
8	36[g,f]	1 : 1.5
9	65[i]	1 : 1
10	—[e,f,k]	—
11	—[e,f]	—

[a] In the presence of Rose bengal RB, 0.1 equiv. [b] $\lambda_{irradiation}$ = 550–680 nm (λ_{max} = 585 nm). BDE C_4F_9I = 201 kJ mol^{-1} corresponds to λ_{max} = 590 nm. [c] $\lambda_{irradiation}$ = 370 nm (black fluorescent light bulb, 40 watt). [d] Dark reaction. [e] In the absence of TMEDA. [f] I_2 was removed from the reagent *n*-C_4F_9I by neutral alumina column chromatography. [g] 0.5 equiv. TBAI + 0.5 equiv. I_2. [h] Only para-product observed. [i] I_2 was thoroughly removed from the reagent C_4F_9I by neutral alumina column chromatography and then additional 0.5 mM of I_2 to the reaction mixture was added. [j] 3 equiv of iodine added. [k] $\lambda_{irradiation}$ = 410–490 nm (λ_{max} = 425 nm).

a $NaNO_2/CuSO_4$ filter for allowing a light band path range of 410–490 nm – where I_2 absorbs), in the presence of I_2-free *n*-C_4F_9I and 3 additional equiv. of I_2 *in the absence* of TMEDA, no product was obtained (entry 10, Table 1), indicating that iodine alone is not responsible for the initiation. When the same reaction was conducted with I_2-free *n*-C_4F_9I, 3 additional equiv. of I_2, but this time with TMEDA under visible light irradiation (CFL), a 65% yield of substitution product was obtained (entry 9, Table 1).

A complex between TMEDA and I_2 (*i.e.*: [(TMEDA)I·I_3]) has been informed by Adam and colleagues,[10] with λ_{max} = 360 nm in MeCN, ($\varepsilon = 4 \times 10^4$ M^{-1} cm^{-1}, a complex formation constant *ca.* 4.7×10^7 M^{-1} and E_{CT} = 4.35 eV). Due to the traces of I_2 present in the neat starting *n*-C_4F_9I, we deem proper to investigate whether complexation of these trace amounts of I_2 present in *n*-C_4F_9I with TMEDA could trigger the radical initiation process. Fig. S2 and S3,† show the UV-vis spectra of mixtures of TMEDA and I_2, corroborating the remarkable increase in the absorptivity at 360 nm, responsible for the absorption of light. This charge transfer complex would be responsible, upon visible light absorption (λ_{max} = 360 nm from a commercial fluorescent light CFL or λ_{max} = 370 nm from a black fluorescent light bulb), of the initiation process, producing excited iodine atoms, as in eqn (1).[9]

$$[(\text{TMEDA})\text{I}]\text{I}_3 \xrightarrow{h\upsilon} \text{TMEDA} + \text{I}^{*\bullet} + \text{I}_2 + \text{I}^{\bullet} \quad \lambda_{max} = 360\ \text{nm} \quad \varepsilon = 46694\ \text{M}^{-1}\ \text{cm}^{-1} \tag{1}$$

The iodine atoms thus produced (eqn (1)) could then abstract I atoms from perfluoroalkyl (and alkyl) iodides such as *n*-C_4F_9I,[10] thus initiating the chain reaction with the production of $C_4F_9^{\bullet}$ radicals (eqn (2)).

$$\text{C}_4\text{F}_9\text{I} + \text{I}^{\bullet} \underset{k_{-2}}{\overset{k_2}{\rightleftharpoons}} \text{C}_4\text{F}_9^{\bullet} + \text{I}_2 \tag{2}$$

Rate constant k_2 is a very exothermic process with very low activation energy[10] provided abstraction of iodine is carried out by excited iodine atoms,[11–13] which has been demonstrated to be the case when irradiation wavelengths lower than 500 nm (ref. 11) are employed.[14]

In order to corroborate that the complex [(TMEDA)I·I_3] does produce $I^{\bullet}$ atoms upon 370 nm irradiation, we attempted the iodine atom-induced *cis/trans* radical isomerization of oleic fatty acid methyl ester.[16] However, elaidic acid methyl ester was not obtained, indicating that the complex [(TMEDA)I·I_3] does not produce iodine atoms upon irradiation at 370 nm, as in eqn (1), responsible for the *cis/trans* isomerization process.

The dark reaction (TMEDA, n-C_4F_9I and substrate) excluding iodine, does not yield any substitution product, purporting that also the dark component accounting for product formation (entry 11, Table 1) arises from a thermal ET initiation within the complex [(TMEDA)I·I_3] when present.

UV-vis spectra of mixtures of n-C_4F_9I and TMEDA do not show a distinct change in absorption or extinction coefficients. The TMEDA·2-CF_3I complex has been postulated by Ritter[15,17] and colleagues, based on calculations, X-ray crystallographic analysis, and spectroscopic data (^{1}H, ^{19}F, ^{13}C NMR). A complex between a nitrogen base and R_F–I has very recently been postulated to generate R_F radicals upon visible light irradiation.[18–20] We have also observed the same trends for the formation of a complex TMEDA·2C_4F_9I based on NMR data (^{19}F, ^{13}C NMR), where spectral changes are observed when going from free reagents to the complexed mixture, as indicated in Table S1.†

The ^{19}F NMR upfield shifts observed in the I–**CF_2**–C_3F_7 are indicative of a debilitated I–C bond in n-C_4F_9I when TMEDA is present, being the largest shift when a stoichiometry of the complex TMEDA : 2C_4F_9I is reached (Table S1†). Also, from Table S1,† there seems to be the presence of complexes between perfluoroalkyl iodides and aminoaromatic compounds,[16] the existence of which result in chemical shift changes of the signal from **ICF_2**–R_F in the ^{19}F NMR spectra when n-C_4F_9I is in the presence of the amino substrate as compared with the innate chemical shift value of **ICF_2**–R_F signal, interpreted as halogen bonding to the nitrogen atom of the substrate.[17] The –**CF_2**I signals in the ^{19}F NMR spectra of n-C_4F_9I in mixtures with amino aromatics (2,4,6-triaminopyrimidine, 2,4-dihydroxy-6-methylpyrimidine, 2,4-diamino-6-hydroxypyrimidine, respectively) are reported in Table S1,† where the similar upfield chemical shifts of the **ICF_2**–R_F can be observed. Analysis of the data presented in Table S1,† also reveals that the substituent amino group in amino aromatic compounds exerts a more favored halogen-bonding interaction with I–C_4F_9 than the ring-nitrogen does, based on the magnitude of the upfield shifts. Also, this effect is increased when TMEDA is present in the mixture. This is consistent with electron lone pair availability on the nitrogen atom. We therefore could postulate a more facile iodine atom abstraction from TMEDA : 2n-C_4F_9I complex, as depicted in eqn (3).

$$\text{TMEDA}\cdot 2n\text{-}C_4F_9I + I^{\bullet} \underset{k^{-3}}{\overset{k_3}{\rightleftharpoons}} n\text{-}C_4F_9{}^{\bullet} + n\text{-}C_4F_9I + \text{TMEDA} + I_2 \quad (3)$$

With these reaction conditions in hand, we undertook the perfluoroalkylation reactions of a series of aniline derivatives employing the [(TMEDA)I·I_3] complex (*ca.* 0.25 mM) as initiator. The reaction of 2-anisidine afforded 57% yield of substitution products **1** (4-perfluorobutyl-2-methoxy aniline and 2-perfluorobutyl-2-methoxy aniline, 1 : 5) (Table 2), leading predominantly to the *para* isomer. 2,5-Dimethoxy aniline afforded 63% yield of product **2** (*i.e.*: 4-perfluorobutyl-2,5-dimethoxyaniline). By using other perfluoroalkyl iodides, such as I–$(CF_2)_4$–I, I–$(CF_2)_6$–I, and n-$C_{10}F_{21}I$, the corresponding substituted products **3–5** were obtained in 18, 76, and 10% yields, respectively, as indicated in Table 2. 2,3-Dimethylaniline afforded 35% yield of substitution products **6** (o : p isomer ratio = 1 : 2); whereas the yields for the substituted products derived from 2,3-dimethylaniline with n-$C_8F_{17}I$, I–$(CF_2)_6$–I, and I–$(CF_2)_4$–I, and n-$C_{10}F_{21}I$ (*i.e.*: products **6–10**, respectively), are 79, 71, 53, and 6% respectively, as indicated in Table 2. The less activated anilines, *i.e.*: 2,5-difluoroaniline, 2,5-dibromoaniline, 2-chloro-6-methylaniline, and 2,5-dichloroaniline, afforded products **11–14** in 9%, 15%, 15% and 16% yields respectively, as shown in Table 2. The low yields isolated from these products, *i.e.*: **11–14**, are attributed to volatility during the work-up/purification process.

Benzocaine,[4] a local anesthetic, affords 12% yield of the C_4F_9 substitution product **15** (Table 2). Starting from 2-mercaptoaniline, under the reaction conditions of Table 2, 2-((perfluorobutyl)thio)aniline **16** is obtained in almost quantitative yield (>95%) in 2 hour reaction.

We have attempted a large scale reaction of 2-anisidine (see Experimental) and obtained a 36% yield of purified **1** (1.474 g), indicating that a scale-up process is applicable with this methodology.

Taking into account the presence of dissolved iodine in commercial R_FI, the use of TMEDA can aid in the initiation process through the [(TMEDA)I·I_3] complex formation. This is likely the case in many studies[7,21,22] where a combination of R_FI, TMEDA, and visible light is employed.

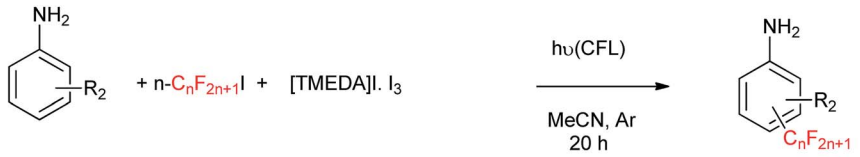
The reactions of 2-anisidine in the presence of DBTN (di-*tert*-butylnitroxide, a well-known radical scavenger) as well as in the presence of 1,4-dinitrobenzene afford no substitution products, indicating the presence of radicals. The reaction of 2-anisidine in the presence of *p*-cresol (0.4 equiv.) affords only 20% yield of products **1**.

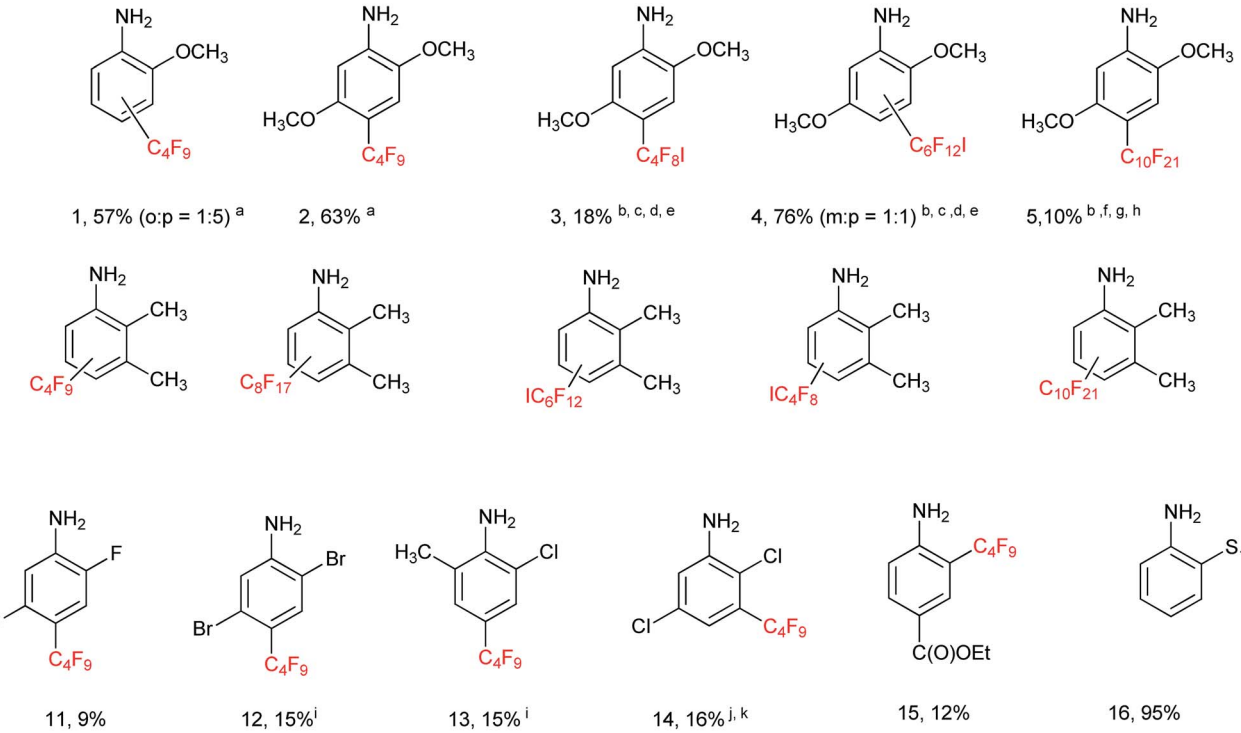
From Table 3, the C_4F_9-substitution yields of a series of aminopyrimidines and aminopyridines is illustrated. 2,4,6-Triaminopyrimidine affords 5-perfluorobutyl-2,4,6-triaminopyrimidine **17** in 48% yield. 2,5-Diamino-6-hydroxy-pyrimidine affords 5-perfluorobutyl-2,4-diamino-6-hydroxypyrimidine **18** in 64% yield. 2-Aminopyridine affords a mixture of 5-perfluorobutyl-2-aminopyridine **19** in 34% yield and 3-perfluorobutyl-2-aminopyridine **20** in 23% yield. 4-Aminopyridine affords 3-perfluorobutyl-4-aminopyridine **21** in 25% yield, whereas 2,3-diaminopyridine affords 4-perfluorobutyl-2,3-diaminopyridine **22** in 12% yield. 5-Methyl-2-aminopyridine and 5-bromo-2-aminopyridine afford 4-perfluorobutyl-5-methyl-2-aminopyridine **23** and 3-perfluorobutyl-5-bromo-2-aminopyridine **24** in 47 and 50% yields, respectively. The low substitution yields encountered for compounds **19–22** is due to volatility, as these products evaporate in the rotary evaporator during the extraction and purification processes.

A large-scale reaction of 5-bromo-2-aminopyridine with n-C_4F_9I was attempted under the protocol proposed (see Experimental), and a 45% yield of purified product **24** (2.111 g) was isolated.

A proposed reaction mechanism is illustrated in Scheme 2. The complex formed by I_2 and TMEDA (*i.e.*: [(TMEDA)I·I_3], absorbs light from either a commercial fluorescent light bulb

Table 2 Substitution product yields (%) of aniline derivatives (0.6 mmol) with *n*-$C_nF_{2n+1}I$ (3 equiv.), and TMEDA (1.8 mmol) ([(TMEDA)I·I_3] complex *ca.* 0.25 mM) promoted by visible light irradiation (CFL, 65 watts) in MeCN (3 mL) as solvent, under Ar atmosphere (20 h) or otherwise noted





[a] In the presence of 0.1 equiv. RB. [b] In the presence of I_2 0.55 mM. [c] Aniline derivative 1.8 mmol. [d] *n*-$C_nF_{2n+1}I$ 0.17 equiv. [e] TMEDA 0.33 equiv. [f] Aniline derivative 0.3 mmol. [g] *n*-$C_nF_{2n+1}I$ 2 equiv. [h] TMEDA 1 equiv. [i] 72 h-reaction. [j] 96 h-reaction.

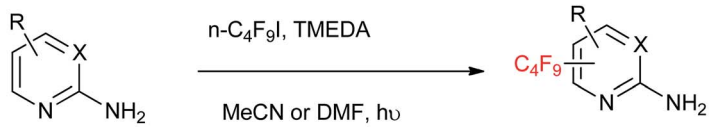
CFL, or black light fluorescent bulb, $\lambda_{max} = 370$ nm) populating an excited state, which collapses into the excited iodine radicals (and ground state iodine radicals and I_2).[11,12] Then, an iodine atom abstraction from *n*-C_4F_9I takes place (as in eqn (3)), generating *n*-$C_4F_9^{\bullet}$ radicals, which enter the electron-catalyzed cycle (Scheme 2) and substitute the amino-substrate, to generate a radical intermediate such as **B**, which by ET to *n*-C_4F_9I produces more *n*-$C_4F_9^{\bullet}$ radicals and the final product **C**. Interestingly, [(TMEDA)I·I_3] complex could be *in situ* regenerated through recombination of two molecules of iodine, one arising from the very decomposition of the complex, the other from *n*-C_4F_9I by iodine atom abstraction. This photocatalytic initiation accounts for the increased yield of product upon visible light illumination.

Radical adduct **B** (Scheme 2) acts as a reductant to *n*-C_4F_9I, generating *n*-$C_4F_9^{\bullet}$ radicals and a cyclohexadienyl-type substituted cation (not shown) which gets deprotonated by TMEDA to afford **C**. To supply more evidence in favor of the mechanism proposed in Scheme 2, we monitored the absorbance of the complex [(TMEDA)I·I_3] through irradiation time, and did not observe any decrease in absorbance, purporting that the complex concentration is not depleted with irradiation time in the presence of *n*-C_4F_9I through regeneration of cycles **E** and **F** (Scheme 2).

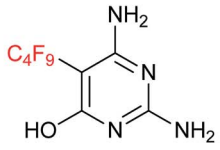
Alternatively, we could also postulate that vertical excitation of the [(TMEDA)I·I_3] complex would produce an internal ET giving iodine atom radical $I^{\bullet}$, triiodide I_3^-, and the radical cation of TMEDA, which would promptly deprotonate giving the radical of TMEDA, according to Scheme 3. TMEDA radical **G** could act as an electron reductant to *n*-C_4F_9I, generating *n*-$C_4F_9^{\bullet}$ radicals and the iminium ion **H** (Scheme 3). We did not observe any product derived from decomposition of TMEDA, through attempts of trapping any carbonyl intermediate with 2,4-dinitrophenylhydrazine/HPLC, indicating that ET from TMEDA radical **G** (Scheme 3) is not a major contributor to product formation.

The role of TMEDA is relevant in the complexation with iodine, and the deprotonation (path **D**, Scheme 2). In the

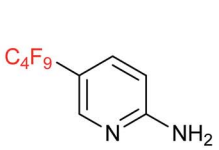
Table 3 Product yields (%) of amino-substituted heteroaromatics (0.6 mmol) with *n*-C_4F_9I (3 equiv.), and TMEDA (1.8 mmol) ([(TMEDA)I·I_3] complex *ca.* 0.25 mM) promoted by visible light irradiation (CFL, 65 watts) in MeCN (3 mL) as solvent or otherwise indicated, under Ar atmosphere (20 h)



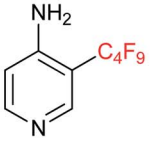
17, 48%[a]



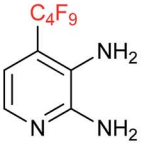
18, 64%[b]



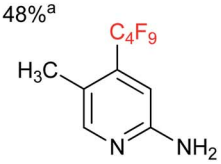
19, 5-C_4F_9-, 34%[c]
20, 3-C_4F_9-, 23%[c]



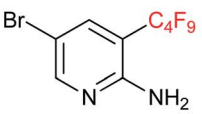
21, 25%[c]



22, 12%[d]

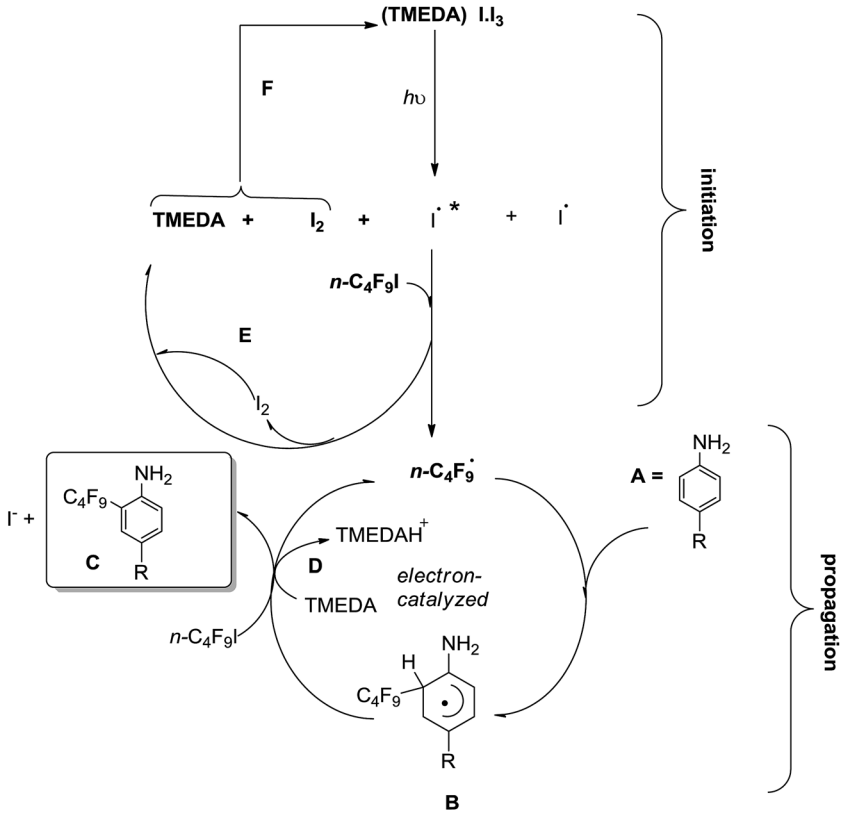


23, 47%[c]

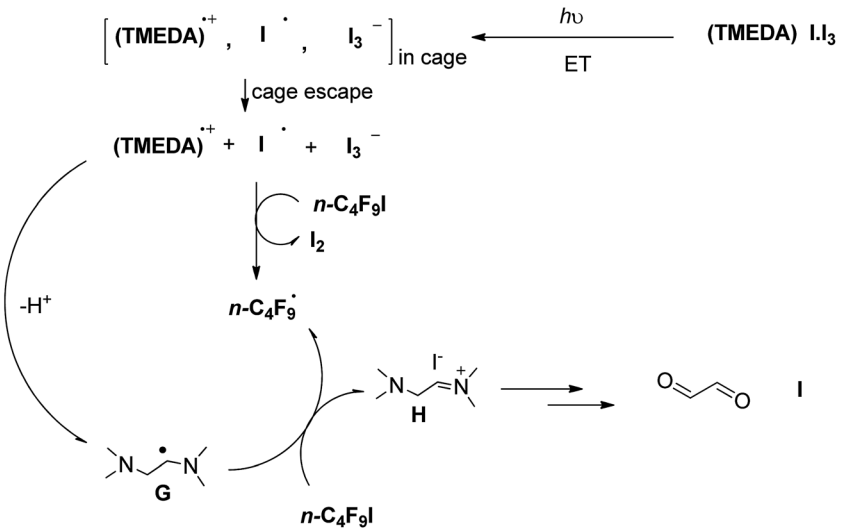


24, 50%

[a] MeOH. [b] Cs_2CO_3 used instead of TMEDA, and Rose bengal as photocatalyst/DMF. [c] Rose bengal as photocatalyst. [d] MeCN : MeOH 5 : 1.



Scheme 2 Proposed electron-catalyzed HAS of amino-substrates in the presence of TMEDA.



Scheme 3 Alternative proposed mechanism where the excited complex [(TMEDA)I·I_3] undergoes inner-sphere ET.

presence of catalyst (POC), Noel and colleagues[23] found that TMEDA acts as an electron donor to the catalyst, involved in a reductive quenching pathway. Being the mechanism still under investigation, a third possibility should be considered: the outer-sphere ET from [(TMEDA)I·I_3] to *n*-C_4F_9I, generating *n*-C_4F_9 radicals (and iodide anion) in conjunction with the radical cation of TMEDA, which could act as an oxidant to intermediate **B** in Scheme 2 to re-generate thermoneutral TMEDA. Iodine could also intervene in the oxidation of intermediate **B**. These mechanistic alternatives are being studied at the moment.

Conclusions

A simple and metal-/photoorganocatalyst-free strategy has been presented for the perfluoroalkylation of aminoaromatics employing a complex [(TMEDA)I·I_3] that upon visible light illumination produces I atoms that generate $R_F^{\bullet}$ radicals from R_F–I sources. These $R_F^{\bullet}$ radicals are capable of substituting biologically-relevant targets such as local anesthetic benzocaine, *etc.* This convenient, high-yielding and metal/photoorganocatalyst-free strategy outperforms traditional near-UV photocatalytic methods while operating under visible light and in the presence of only an additive (TMEDA).

Caution has to be exercised when employing R_FI and TMEDA, since traces of iodine in the reagents (*i.e.*: R_FI) can form a stable complex with TMEDA which could be responsible for the radical initiation process upon visible light irradiation. Moreover, given the high extinction coefficient of the complex [(TMEDA)I·I_3] at the visible light wavelengths (>365 nm), iodine atom production is a key element in the radical process.

Experimental

General procedure for the ((TMEDA·I)·I_3)-initiated reactions

In a 4 mL screw-cap vial provided with a micro stir bar, TMEDA (1.8 mmol, (TMEDA)I·I_3 complex, *ca.* 0.25 mM), substrate (0.6 mmol, aniline derivative or aminoheteroaromatic compound), or photocatalyst (PC) Rose bengal where needed (0.05 equiv.) and 3 mL of acetonitrile were introduced. The mixture was de-oxygenated with a stream of Ar for 15 min and *n*-C_4F_9I or other R_FI (3 equiv.) was introduced by microliter syringe, and the vial sealed. The closed reaction vessel was placed in front of a 60 watt household fluorescent light bulb (or 20 watt fluorescent black light, $\lambda_{max} = 370$ nm) and illuminated, under constant vigorous stirring, for 24 h or otherwise noted. After the reaction time was completed, the mixture was extracted thrice with CH_2Cl_2/water/brine. The organic layers were gathered and dried over anhydrous Na_2SO_4, filtered and evaporated under *vacuo*. The crude reaction mixture was purified by silica-gel (60 mesh) column chromatography, with the eluants indicated in the TLC conditions (*vide infra*, spectral data). When a PC was used, the polarity of the dye did not introduce any particular difficulty in the separation and purification protocol, as the several CH_2Cl_2 extractions eliminated the PC. The eluants employed are referred to in the TLC conditions of each compound.

Large scale reactions

In a 60 mL Schlenk-type tube 2-anisidine (12 mmol), TMEDA (36 mmol), and a stir bar were placed and a volume of 60 mL of MeCN was introduced by syringe through a septum. The mixture was de-oxygenated with a stream of dry Ar for 30 min, and 36 mmol of *n*-C_4F_9I were added to the mixture. The set-up was placed on a stir plate, and vigorously stirred throughout the reaction time. The vessel was placed in front (1 cm) of a 60 watt CFL, and irradiated for 40 hours. The crude reaction mixture was purified by silica-gel (60 mesh) column chromatography, with the eluants indicated in the TLC conditions (*vide infra*, spectral data). The large-scale reaction afforded 36% yield (1.474 g) of combined purified products **1**.

In a 60 mL Schlenk-type tube 5-bromo-2-aminopyridine (12 mmol), TMEDA (36 mmol), and a stir bar were placed. A

volume of 60 mL of MeCN was introduced by 50 mL syringe. The mixture was de-oxygenated with a stream of dry Ar for 30 min, and 36 mmol of *n*-C_4F_9I were added to the mixture by syringe through a septum. The set-up was placed on a stir plate, and vigorously stirred throughout the reaction time. The vessel was placed in front (1 cm) of a 60 watt CFL, and irradiated for 40 hours. The crude reaction mixture was purified by silica-gel (60 mesh) column chromatography, with the eluants indicated in the TLC conditions (*vide infra*, spectral data). The large-scale reaction afforded 45% yield (2.111 g) of purified product **24**.

Characterization of compounds

All compounds are unknown chemicals, unless otherwise noted, and are reported as % yields obtained by NMR integration (from ^{1}H and ^{19}F NMR integration) of the crude reaction mixtures. Isolated purified masses of compounds are expressed in gram units. Characterizations employ ^{1}H, ^{13}C, ^{19}F 1D-NMR techniques, and 2D NMR spectroscopic techniques (HSQC, HMBC, COSY experiments, and DEPT-135), and HRMS measurements (see ESI†).

2-Methoxy-4-(perfluorobutyl)aniline (1) (ref. 4). Yellow oil, 95%. Isolated and purified mass obtained: 67 mg. **TLC** (CH_2Cl_2/iso-octane 1 : 1 v/v): $R_f = 0.5$; ^{1}H NMR (600 MHz, $CDCl_3$) δ: 7.01 (d, $J = 10$ Hz, 1H), 6.92 (s, 1H), 6.73 (d, $J = 10$ Hz, 1H), 4.15 (b s, 2H), 3.90 (s, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ: 146.5, 139.7, 120.4 (t, CF_2), 118.7 (m, CF_2), 118.1 (t, CF_3), 116.7 (m), 113.5, 112.5, 109.7, 108.4, 55.6. ^{19}F NMR (564.603 MHz $CDCl_3$) δ: −81.11 (t, 3F), −109.32 (t, 2F), −122.78 (m, 2F), −125.68 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_{11}H_9F_9NO$: 342.05349; found, 342.05388.

2,5-Dimethoxy-4-(perfluorobutyl)aniline (2). Yellow oil. Yield = 63%. Isolated and purified mass obtained: 27 mg. **TLC** (CH_2Cl_2 : iso-octane 7 : 3 v/v): $R_f = 0.69$; ^{1}H NMR (600 MHz, $CDCl_3$) δ: 6.82 (s, 1H), 6.35 (s, 1H), 4.15 (b s, 2H), 3.83 (s, 3H), 3.76 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ: 154.1, 141.2, 140.6, 116.8 (CF_2), 110.9, 104.9, 99.8, 56.7, 56.3. ^{19}F NMR (564.63 MHz, $CDCl_3$) δ: −81.00 (t, 3F), −106.20 (t, 2F), −122.25 (m, 2F), −126.06 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_{12}H_{10}F_9NO_2$: 372.05678; found, 372.05670.

2,5-Dimethoxy-4-(1,1,2,2,3,3,4,4-octafluoro-4-iodobutyl)aniline (3). Pale yellow oil. Yield = 18%. Isolated and purified mass obtained: 21 mg. **TLC** (CH_2Cl_2 : *n*-hexane 8 : 2 v/v): $R_f = 0.62$; ^{1}H NMR (600 MHz, $CDCl_3$) δ: 6.82 (s, 1H), 6.35 (s, 1H), 4.13 (b s, 2H), 3.83 (s, 3H), 3.76 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ: 154.1, 141.0, 140.6, 111.0, 100.1, 99.9, 56.8, 56.3. ^{19}F NMR (564.63 MHz, $CDCl_3$) δ: −57.55 (t, 2F), −106.07 (t, 2F), −112.78 (m, 2F), −120.43 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_{12}H_{10}F_8INO_2$: 479.96285; found, 479.96280.

2,5-Dimethoxy-4-(1,1,2,2,3,3,4,4,5,5,6,6-dodecafluoro-6-iodohexyl)aniline (4a). Pale yellow oil. Yield = 39%. **TLC** (CH_2Cl_2 : *n*-hexane 8 : 2 v/v): $R_f = 0.52$; ^{1}H NMR (600 MHz, $CDCl_3$) δ: 6.85 (s, 1H), 6.14 (s, 1H), 3.99 (b s, 2H), 3.70 (s, 3H), 3.63 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ: 152.3, 142.7, 139.9, 112.7, 108.5, 98.1, 56.7, 56.6. ^{19}F NMR (564.63 MHz, $CDCl_3$) δ: −58.70 (t, 2F), −107.16 (t, 2F), −113.07 (m, 2F), −119.97 (m, 2F), −120.88 (m, 2F), −121.74 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_{14}H_{10}F_{12}INO_2$: 579.95646; found, 579.95635.

2,5-Dimethoxy-3-(1,1,2,2,3,3,4,4,5,5,6,6-dodecafluoro-6-iodohexyl)aniline (4b). Pale yellow oil. Yield = 37%. **TLC** (CH_2Cl_2 : *n*-hexane 8 : 2 v/v): $R_f = 0.55$; ^{1}H NMR (600 MHz, $CDCl_3$) δ: 6.45 (s, 1H), 6.31 (s, 1H), 3.99 (b s, 2H), 3.66 (s, 3H), 3.57 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ: 153.1, 142.6, 140.6, 112.8, 111.2, 105.3, 56.2, 55.7. ^{19}F NMR (564.63 MHz, $CDCl_3$) δ: −58.39 (t, 2F), −107.16 (t, 2F), −113.07 (m, 2F), −120.13 (m, 2F), −120.88 (m, 2F), −121.48 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_{14}H_{10}F_{12}INO_2$: 579.95646; found, 579.95640.

2,5-Dimethoxy-4-(perfluorodecyl)aniline (5). Pink solid. Yield = 10%. Isolated and purified mass obtained: 6 mg. **TLC** (ethyl acetate : *n*-hexane 4 : 6 v/v): $R_f = 0.70$; ^{1}H NMR (600 MHz, $CDCl_3$) δ: 6.82 (s, 1H), 6.35 (s, 1H), 4.13 (b s, 2H), 3.83 (s, 3H), 3.77 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ: 154.1, 141.1, 140.6, 110.9, 102.1, 99.8, 56.8, 56.3. ^{19}F NMR (564.63 MHz, $CDCl_3$) δ: −80.74 (t, 3F), −105.98 (m, 2F), −121.33 (m, 2F), −121.78 (m, 10F), −122.67 (m, 2F), −126.08 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_{18}H_{10}F_{21}NO_2$: 672.03762; found, 672.03741.

2,3-Dimethyl-4-(perfluorobutyl)aniline (6). Dark amber oil. Yield = 24%. Isolated and purified mass obtained: 30 mg. **TLC** (CH_2Cl_2 : iso-octane 7 : 3 v/v): $R_f = 0.57$; ^{1}H NMR (600 MHz, $CDCl_3$) δ: 7.21 (d, $J = 8.6$ Hz, 1H), 6.61 (d, $J = 8.6$ Hz, 1H), 3.88 (b s, 2H), 2.33 (s, 3H), 2.10 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ: 147.6, 137.6, 127.0, 121.9, 117.0, 112.3, 17.0, 13.1. ^{19}F NMR (564.63 MHz, $CDCl_3$) δ: −80.98 (t, 3F), −102.89 (t, 2F), −121.33 (m, 2F), −125.79 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_{12}H_{10}F_9N$ 340.06695; found, 340.06690.

2,3-Dimethyl-4-(perfluorooctyl)aniline (7). Pale yellow solid. Yield = 58%. Isolated and purified mass obtained: 26 mg. **TLC** (CH_2Cl_2 : *n*-hexane 1 : 1 v/v): $R_f = 0.67$; ^{1}H NMR (600 MHz, $CDCl_3$) δ: 7.21 (d, $J = 8.6$ Hz, 1H), 6.61 (d, $J = 8.6$ Hz, 1H), 3.88 (b s, 2H), 2.33 (s, 3H), 2.10 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ: 147.6, 137.7, 127.0, 121.9, 117.2, 112.3, 17.0, 13.1. ^{19}F NMR (564.63 MHz, $CDCl_3$) δ: −80.81 (t, 3F), −102.72 (t, 2F), −120.40 (m, 2F), −121.49 (m, 2F), −121.87 (m, 4F), −122.73 (m, 2F), −126.13 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_{16}H_{10}F_{17}N$: 540.05418; found, 540.05420.

2,3-Dimethyl-4-(1,1,2,2,3,3,4,4,5,5,6,6-dodecafluoro-6-iodohexyl)aniline (8). Pale yellow oil. Yield = 54%. Isolated and purified mass obtained: 13 mg. **TLC** (CH_2Cl_2 : *n*-hexane 6 : 4 v/v): $R_f = 0.66$; ^{1}H NMR (600 MHz, $CDCl_3$) δ: 7.21 (d, $J = 8.6$ Hz, 1H), 6.60 (d, $J = 8.6$ Hz, 1H), 3.87 (b s, 2H), 2.33 (s, 3H), 2.10 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ: 147.6, 137.7, 127.1, 121.9, 117.3, 112.3, 17.1, 13.1. ^{19}F NMR (564.63 MHz, $CDCl_3$) δ: −58.58 (t, 2F), −102.70 (t, 2F), −112.99 (m, 2F), −120.36 (m, 2F), −120.87 (m, 2F), −121.48 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_{14}H_{10}F_{12}IN$: 547.96663; found, 547.96651.

2,3-Dimethyl-4-(1,1,2,2,3,3,4,4-octafluoro-4-iodobutyl) aniline (9). Yellow oil. Yield = 37%. Isolated and purified mass obtained: 68 mg. **TLC** (CH_2Cl_2 : *n*-hexane 8 : 2 v/v): $R_f = 0.77$; ^{1}H NMR (600 MHz, $CDCl_3$) δ: 7.20 (d, $J = 8.6$ Hz, 1H), 6.60 (d, $J = 8.6$ Hz, 1H), 3.85 (b s, 2H), 2.32 (s, 3H), 2.10 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ: 147.6, 137.6, 127.1, 121.8, 117.1, 112.3, 17.0, 13.1. ^{19}F NMR (564.63 MHz, $CDCl_3$) δ: −57.77 (t, 2F),

−102.74 (t, 2F), −112.56 (m, 2F), −119.42 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_{12}H_{10}F_8IN$: 447.97302; found, 447.96999.

2,3-Dimethyl-6-(perfluorodecyl)aniline (10a). White solid. Yield = 2%. **TLC** (CH_2Cl_2 : *n*-hexane 1 : 1 v/v): $R_f = 0.88$; ^1H NMR (600 MHz, $CDCl_3$) δ: 7.10 (d, $J = 8.0$ Hz, 1H), 6.66 (d, $J = 8.0$ Hz, 1H), 3.49 (b s, 2H), 2.31 (s, 3H), 2.09 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ: 143.9, 141.2, 125.9, 122.0, 119.6, 109.8, 20.9, 12.6. ^{19}F NMR (564.63 MHz, $CDCl_3$) δ: −59.21 (t, 2F), −81.03 (t, 3F), −113.20 (m, 2F), −121.02 (m, 2F), −121.98 (m, 8F), −122.89 (m, 2F), −126.32 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_{18}H_{10}F_{21}N$: 640.04779; found, 640.04771.

2,3-Dimethyl-4-(perfluorodecyl)aniline (10b). Pale yellow solid. Yield = 4%. Isolated and purified mass obtained: 4.6 mg. **TLC** (CH_2Cl_2 : *n*-hexane 1 : 1 v/v): $R_f = 0.60$; ^1H NMR (600 MHz, $CDCl_3$) δ: 7.21 (d, $J = 8.6$ Hz, 1H), 6.61 (d, $J = 8.6$ Hz, 1H), 3.88 (b s, 2H), 2.33 (s, 3H), 2.10 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ: 147.6, 137.7, 127.1, 121.9, 117.2, 112.3, 17.0, 13.1. ^{19}F NMR (564.63 MHz, $CDCl_3$) δ: −80.73 (t, 3F), −102.69 (t, 2F), −120.37 (m, 2F), −121.79 (m, 10F), −122.67 (m, 2F), −126.08 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_{18}H_{10}F_{21}N$: 640.04779; found, 640.04758.

2,5-Difluoro-4-(perfluorobutyl)aniline (11). Yellow oil. Yield = 9%. Isolated and purified mass obtained: 2.5 mg. **TLC** (CH_2Cl_2 : iso-octane 6 : 4 v/v): $R_f = 0.58$; ^1H NMR (600 MHz, $CDCl_3$) δ: 7.11 (dd, $J = 4.6$ Hz, $J = 11$ Hz, 1H), 6.53 (dd, $J = 4.5$ Hz, $J = 11.6$ Hz, 1H), 4.20 (b s, 2H). ^{13}C NMR (151 MHz, $CDCl_3$) δ: 156.6, 147.5, 139.9, 115.0 (m), 108.2, 103.8 (dd). ^{19}F NMR (564.63 MHz, $CDCl_3$) δ: −81.01 (t, 3F), −108.30 (m, 2F), −116.62 (td, 1F), −123.00 (m, 2F), −125.93 (m, 2F), −140.51 (d, 1F). HRMS-EI+ (M + 1): calcd. For $C_{10}H_4F_{11}N$ 348.01681; found, 348.01690.

2,5-Dibromo-4-(perfluorobutyl)aniline (12). Yellow oil. Yield = 15%. Isolated and purified mass obtained: 53.4 mg. **TLC** (CH_2Cl_2 : petroleum ether 4 : 6 v/v): $R_f = 0.60$; ^1H NMR (600 MHz, $CDCl_3$) δ: 7.58 (s, 1H), 7.05 (s, 1H), 4.49 (b s, 2H). ^{13}C NMR (151 MHz, $CDCl_3$) δ: 147.9, 134.2, 120.7, 120.5, 117.6, 106.9. ^{19}F NMR (564.63 MHz, $CDCl_3$) δ: −80.95 (t, 3F), −105.73 (t, 2F), −120.58 (m, 2F), −125.81 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_{10}H_4F_9Br_2N$: 467.85668; found, 467.85669.

2-Chloro-6-methyl-4-(perfluorobutyl)aniline (13). Dark amber oil. Yield = 15%. Isolated and purified mass obtained: 13.7 mg. **TLC** (CH_2Cl_2 : iso-octane 4 : 6 v/v): $R_f = 0.56$; ^1H NMR (600 MHz, $CDCl_3$) δ: 7.36 (s, 1H), 7.15 (s, 1H), 4.36 (b s, 2H), 2.24 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ = 144.5, 127.2, 126.0, 123.0, 118.6, 117.9, 18.1. ^{19}F NMR (564.63 MHz, $CDCl_3$) δ: −81.09 (t, 3F), −109.72 (t, 2F), −122.71 (m, 2F), −125.64 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_{11}H_7F_9ClN$: 360.01233; found, 360.01241.

2,5-Dichloro-3-(perfluorobutyl)aniline (14). Dark amber oil. Yield = 16%. Isolated and purified mass obtained: 58 mg. **TLC** (CH_2Cl_2 : iso-octane 3 : 7 v/v): $R_f = 0.73$; ^1H NMR (600 MHz, $CDCl_3$) δ: 7.45 (d, $J = 2.3$ Hz, 1H), 7.24 (d, $J = 2.3$ Hz, 1H), 4.75 (b s, 2H). ^{13}C NMR (151 MHz, $CDCl_3$) δ: 142.6, 141.2, 132.9, 127.6, 121.9. ^{19}F NMR (564.63 MHz, $CDCl_3$) δ: −80.89 (t, 3F), −109.07 (t, 2F), −122.49 (m, 2F), −125.78 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_{10}H_4Cl_2F_9N$: 379.95771; found, 379.95784.

Ethyl-4-amino-3-(1,1,2,3,3,4,4,4-octafluoro-2-methylbutyl)-benzoate (ref. 4), (15). White solid, mp 89–90 °C. **TLC** (CH_2Cl_2/iso-octane 1 : 1 v/v): $R_f = 0.6$; ^1H NMR (600 MHz, $CDCl_3$) δ: 8.03 (d, $J = 2$ Hz, 1H), 7.94 (dd, $J = 10$ Hz, $J = 5$ Hz, 1H), 6.70 (d, $J = 10$ Hz, 1H), 4.66 (b s, 2H), 4.33 (q, $J = 7$ Hz, 2H), 1.37 (t, $J = 7$ Hz, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ: 165.6, 149.5, 134.2, 131.6 (t, CF_2), 119.8, 118.4, 117.4, 116.9, 110.0 (t, CF_2), 60.8, 14.3. ^{19}F NMR (564.603 MHz $CDCl_3$) δ: −81.00 (t, 3F), −109.06 (t, 2F), −122.74 (m, 2F), −125.83 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_{13}H_{11}F_9NO_2$: 384.06406; found, 384.06535.

2-((Perfluorobutyl)thio)aniline (16). Pale yellow oil. Yield > 95%. Isolated and purified mass obtained: 66.2 mg. **TLC** (CH_2Cl_2 : iso-octane 1 : 1 v/v): R_f = 0.63; ^1H NMR (600 MHz, $CDCl_3$) δ: 7.47 (d, $J = 7.8$ Hz, 1H), 7.28 (t, $J = 7.3$ Hz, $J = 8.2$ Hz, 1H), 6.77 (d, $J = 8.2$ Hz, 1H), 6.74 (t, $J = 7.3$ Hz, $J = 7.8$ Hz, 1H), 4.45 (b s, 2H). ^{13}C NMR (151 MHz, $CDCl_3$) δ: 151.1, 140.0, 133.4, 118.8, 115.8, 104.5. ^{19}F NMR (564.63 MHz, $CDCl_3$) δ: −81.05 (t, 3F), −87.05 (t, 2F), −120.37 (m, 2F), −125.54 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_{10}H_6F_9NS$: 344.00772; found, 344.00801.

5-(Perfluorobutyl)pyrimidine-2,4,6-triamine (17). Pale yellow oil. Yield > 48%. Isolated and purified mass obtained: 56.2 mg. ^1H NMR (600 MHz, DMSO-d_6) δ: –^{13}C NMR (151 MHz, DMSO-d_6) δ: 162.4, 162.5. ^{19}F NMR (564.63 MHz, DMSO-d_6) δ: −80.41 (t, 3F), −101.47 (m, 2F), −122.77 (m, 2F), −125.35 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_8H_6F_9N_5$: 344.04795; found, 344.04799.

2,6-Diamino-5-(perfluorobutyl)pyrimidin-4-ol (18). Pale yellow oil. Yield > 64%. Isolated and purified mass obtained: 39.8 mg. ^1H NMR (600 MHz, DMSO-d_6) δ: 5.74 (s). ^{13}C NMR (151 MHz, DMSO-d_6) δ: 206.5 (C=O from tautomer), 167.3 (from oxo tautomer), 163.1 (from oxo tautomer), 160.6, 160.3, 157.5, 156.3, 155.0 (from oxo tautomer). ^{19}F NMR (564.63 MHz, DMSO-d_6) δ: −79.10 (t, 3F) (from oxo tautomer), −80.45 (t, 3F), −102.34 (m, 2F) (from oxo tautomer), −111.83 (m, 2F), −121.54 (m, 4F), −122.38 (m, 2F), −125.35 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_8H_5F_9N_4O$: 345.03196; found 345.03205.

5-(Perfluorobutyl)pyridin-2-amine (19). Pale yellow oil. Yield > 23%. Isolated and purified mass obtained: 19.8 mg. ^1H NMR (600 MHz, $CDCl_3$) δ: 8.26 (s, 1H), 7.56 (1H, d, $J = 3$ Hz), 6.53 (d, 1H, $J = 3$ Hz), 4.86 (broad s, 2H). ^{13}C NMR (151 MHz, $CDCl_3$) δ: 160.6, 147.7, 136.3, 114.8, 107.8. ^{19}F NMR (564.63 MHz, $CDCl_3$) δ: −81.07 (t, 3F), −110.57 (m, 2F), −123.02 (m, 2F), −125.59 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_9H_5F_9N_2$: 313.03090; found 313.03081.

3-(Perfluorobutyl)pyridin-4-amine (21). Yield > 25%. Isolated and purified mass obtained: 19.9 mg. ^1H NMR (600 MHz, $CDCl_3$) δ: 8.37 (s, 1H), 8.27 (d, 1H, $J = 3$ Hz), 6.57 (d, 1H, $J = 3$ Hz), 4.78 (broad s, 2H). ^{13}C NMR (151 MHz, $CDCl_3$) δ: 152.6, 151.6, 150.2, 150.0, 111.4. ^{19}F NMR (564.63 MHz, $CDCl_3$) δ: −80.96 (t, 3F), −109.48 (broad s, 2F), −123.05 (broad s, 2F), −125.74 (brad s, 2F). HRMS-EI+ (M + 1): calcd. For $C_9H_5F_9N_2$: 313.03090; found 313.03099.

4-(Perfluorobutyl)pyridine-2,3-diamine (22). Yield > 12%. Isolated and purified mass obtained: 10 mg. ^1H NMR (600 MHz, $CDCl_3$) δ: 7.01 (d, 1H, $J = 2$ Hz), 6.94 (d, 1H, $J = 2$ Hz), 4.38 (broad s, 2H), 3.60 (broad s, 2H), 3.82 (s, =NH), 3.75 (s, =NH). ^{13}C NMR (151 MHz, $CDCl_3$) δ: 148.6, 135.6, 132.1, 120.9, 115.1.

^{19}F NMR (564.63 MHz, $CDCl_3$) δ: −80.99 (t, 3F), −113.22 (m, 2F), −122.75 (m, 2F), −125.76 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_9H_6F_9N_3$: 328.04180; found 328.04210.

5-Methyl-4-(perfluorobutyl)pyridin-2-amine (23). Yield > 47%. Isolated and purified mass obtained: 51 mg. ^{1}H NMR (600 MHz, DMSO-d_6) δ: 8.07 (s, 1H), 7.47 (s, 1H), 6.07 (broad s, 2H), 3.33 (s, 3H). ^{13}C NMR (151 MHz, DMSO-d_6) δ: 154.6, 152.9, 142.3, 137.7, 120.6, 16.4. ^{19}F NMR (564.63 MHz, DMSO-d_6) δ: −80.5 (t, 3F), −108.86 (m, 2F), −122.23 (m, 2F), −125.34 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_{10}H_7F_9N_2$: 327.04655; found 327.04669.

5-Bromo-3-(perfluorobutyl)pyridin-2-amine (24). Yield > 50%. Isolated and purified mass obtained: 53 mg. ^{1}H NMR (600 MHz, DMSO-d_6) δ: 8.31 (s, 1H), 7.79 (s, H), 6.65 (broad s, 2H). ^{13}C NMR (151 MHz, DMSO-d_6) δ: 155.2, 153.3, 139.2, 104.1, 99.5. ^{19}F NMR (564.63 MHz, DMSO-d_6) δ: −80.49 (t, 3F), −109.39 (m, 2F), −122.21 (m, 2F), −125.27 (m, 2F). HRMS-EI+ (M + 1): calcd. For $C_9H_4BrF_9N_2$: 390.94141; found 390.94151.

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