Supporting Information

A General and Practical Ni-Catalyzed C-H Perfluoroalkylation of (Hetero)Arenes

Shaoke Zhang, Nicolas Rotta-Loria, Florian Weniger, Jabor Rabeah, Helfried Neumann, Christoph Taeschler, and Matthias Beller*

Leibniz-Institut für Katalyse e. V. an der Universität Rostock,
Albert-Einstein Straße 29a, Rostock, 18059, Germany
Matthias.Beller@catalysis.de
Table of contents:

1. General comments .................................................. S3
2. General methods ................................................... S3
3. General procedures ............................................... S3
4. Other tested substrates ........................................ S5
5. Selected experiments on the investigation and isolation of 5-(perfluorodecyl)-2,3-dihydro-1,4-dioxine in the presence of dioxane .................................................. S7
6. EPR spectra .......................................................... S8
7. Kinetic study in the presence of Ni2 ................................ S8
8. Control experiments with the addition of reductant ........ S9
9. Control experiments with two or three out of four components .................................................. S9
10. Intermediates study ............................................... S9
11. Characterization data of the perfluoroalkylated arenes .................................................. S12
12. Spectra of the perfluoroalkylated arenes ............... S18
13. References ......................................................... S39
1. General comments

All reactions were carried out under an atmosphere of dry argon using standard Schlenk technique or Ace pressure tube. Chemicals were purchased from Sigma-Aldrich, TCI, Alfa Aesar, Fluka, or ABCR. Pyridine, anisole, o-xylene, toluene, perfluorobenzene, MeOH, EtOH, THF and benzene were dried and degassed and stored in Aldrich Sure/Stor flasks under argon. Other chemicals were used as received. Multiplets of NMR were assigned as s (singlet), d (doublet), t (triplet), dd (doublet of doublet), dt (doublet of triplet), td (triplet of doublet), m (multiplet), and br. s (broad singlet).

2. General methods

NMR data were recorded on Bruker Avance 300 or Bruker ARX 400 spectrometers at room temperature. $^{13}$C and $^1$H NMR spectra were referenced to signals of deuterio solvents and residual protiated solvents, respectively. EPR spectra were measured on an ERS 300 cw spectrometer (ZWG/Magnettech GmbH, Berlin-Adlershof, Germany). High resolution mass spectra (HRMS) were recorded on Agilent 6210. The data are given as mass units per charge (m/z).

3. General procedures

The synthesis of Ni (II) pre-catalysts, in the case of cis-(dppf)Ni(o-tol)Cl: The pre-catalysts was synthesized according to a former literature.\textsuperscript{[11]}

\[
\text{Fe} \quad \text{Ph} \\ \text{P} \quad \text{Ph} \\ \text{Fe} \quad \text{P} \quad \text{Ph} \\ \text{dppf} + \text{NiCl}_2 \cdot 6\text{H}_2\text{O} \quad \rightarrow \quad \text{Fe} \quad \text{Ph} \\ \text{P} \quad \text{Ph} \\ \text{Fe} \quad \text{P} \quad \text{Ph} \\ \text{Ni} \quad \text{Cl} \quad \text{Cl} \\ \text{Ni1} \quad \text{Ni} \quad \text{Cl} \\ \text{MgCl} \quad \text{Fe} \quad \text{Ph} \\ \text{P} \quad \text{Ph} \\ \text{Fe} \quad \text{Ph} \\ \text{Ph} \quad \text{Ni} \\ \text{Ni2}
\]

Step 1: NiCl$_2$·6H$_2$O (8.5 mmol, 2.02 g) and EtOH (25 mL) were placed in an argon flushed 100 mL round Schlenk. Then the septum was removed, and dppf (8.5 mmol, 4.712 g) was added in one portion. The flask was fitted with a reflux condenser, and the mixture was refluxed for 30 min with an 80 °C oil bath and then cooled to room temperature. Once cool, the flask was chilled to 0 °C with an ice bath for 10 min, after which the solid was collected by vacuum filtration, washed twice with EtOH (20 mL) and twice with ether (20 mL). Drying under vacuum yielded
Ni1 (4.98 g, 85 %) as a deep green powder.

Step 2: Ni1 (6.81 mmol, 4.658 g) and 180 mL CH$_2$Cl$_2$ were placed in an argon flushed 100 mL round Schlenk. The solution was cooled to 0 °C with an ice bath, and o-tolylmagnesium chloride (6.81 mmol, 0.945 M in THF, 7.21 mL) was added dropwise with vigorous stirring. Near the end of the addition, the solution began to change in color from green to orange. The solution was stirred for 15 min at 0 °C, after which the solution was evaporated to dryness under reduced pressure. MeOH (25 mL) was added and the mixture was stirred for 5 min to form a suspension. After the suspension was cooled to 0 °C, the solvent was filtered out. The residue was washed with two portions of cold MeOH (10 mL), and dried under high vacuum to yield Ni2 (4.63 g, 92 %) as a fine, bright yellow powder.

Ni2: $^1$H NMR (400 MHz, CD$_2$Cl$_2$) δ = 8.23 – 8.12 (m, 4H), 8.02 – 7.93 (m, 2H), 7.51 – 7.38 (m, 7H), 7.27 (td, $J = 8.3$, 2.0 Hz, 2H), 7.21 – 7.15 (m, 1H), 6.99 (t, $J = 7.4$ Hz, 1H), 6.76 (td, $J = 8.2$, 2.6 Hz, 2H), 6.66 – 6.54 (t, 2H), 6.43 (t, $J = 7.4$ Hz, 1H), 6.30 (t, $J = 6.8$ Hz, 1H), 6.10 (d, $J = 7.1$ Hz, 1H), 5.15 (s, 1H), 4.54 (m, 1H), 4.25 (s, 1H), 4.19 (s, 1H), 4.02 (d, $J = 10.1$ Hz, 2H), 3.52 (m, 1H), 3.33 (m, 1H), 2.44 (s, 3H).

$^{31}$P NMR (162 MHz, CD$_2$Cl$_2$) δ = 29.51 (d, $J = 25.9$ Hz, 1P), 12.12 (d, $J = 25.9$ Hz, 1P).

The synthesis of perfluoroalkylated (hetero)arenes:

Perfluorodecylolation of (hetero)arenes with C$_{10}$F$_{21}$I: 0.2 mmol C$_{10}$F$_{21}$I, 5 mol% Ni2, 1.5 eq. Cs$_2$CO$_3$ and 10 eq. (hetero)arenes (only for the cases of solid substrates) were placed in an Ace pressure tube. After flushed with argon, 0.5 mL (hetero)arenes (only for the cases of liquid substrates) was added. Then the tube was sealed and heated for 16 – 30 h at the temperature specified in the table 2. After cooling to room temperature, the products were isolated. Otherwise, after cooling to room temperature, 20 µL 1,4-difluorobenzene and 4 mL acetone were added to the reaction mixture. Then 250 µL of the acetone solution was taken to measure the conversion and yield by $^{19}$F NMR.

The synthesis of trifluoromethylated N-methylpyrrole:

In a representative procedure, the reaction was carried out in a Parr Instruments 4560 series 300 mL autoclave containing an alloy plate with wells for five 10 mL glass vials. Under argon atmosphere, N-methylpyrrole (0.5 mmol, 44 µL), Ni2 (5 mol%, 18.5 mg), Cs$_2$CO$_3$ (1.5 eq., 244.4 mg), perfluorobenzene (1 mL), phenylboronic acid (10 mol%, 6.1 mg) and a magnetic stirring bar
were placed in the vial, which were then capped with a septum equipped with an inlet needle and flushed with argon. The vial was placed in an alloy plate, which was then placed in the autoclave. Once sealed, the autoclave was purged three times with 15 bar nitrogen and then pressurized with 5 bar CF$_3$Br and 40 bar N$_2$ at room temperature and heated at 60 °C for 16 h. It was then cooled to room temperature and vented to discharge the excess gas. 20 µL 1,4-difluorobenzene and 4 mL acetone were then added to the reaction mixture. And 250 µL of the acetone solution was taken and mixed with 350 µL CDCl$_3$ to measure the conversion and yield by $^{19}$F NMR.

The isolation of perfluoroalkylated arenes:

Firstly, the reaction mixture was pre-purified by pipette column using silica gel 60, 0.063-0.2 mm, 70-230 mesh (Merck), eluting with 10 mL heptane, giving a crude product. Then, one more pipette column was made using FluoroFlash® reverse phase silica gel, eluting with a gradient of 4:1 MeOH : H$_2$O (10 mL) – MeOH (10 mL) – acetone (10 mL). The MeOH and acetone fractions were collected and concentrated under vacuum affording the pure product.

4. Other tested substrates

Apart from the substrates listed in the manuscript, we also tested some other compounds, e.g. nitrile and carbonyl group substituted substrates as well as oxygen-containing heteroarenes. However, as shown in Scheme S1, they only gave moderate or low yield of the desired products according to the $^{19}$F NMR.
Conversion (yield) are given based on $^{19}$F NMR

**Scheme S1.** Other tested substrates
5. Selected experiments on the investigation and isolation of 5-(perfluorodecyl)-2,3-dihydro-1,4-dioxine in the presence of dioxane

Table S1. Selected results in the presence of dioxane.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Catalyst</th>
<th>Base</th>
<th>T / °C</th>
<th>Conversion / %</th>
<th>Yield of S2 / %</th>
<th>Yield of R-FH / %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ni₂</td>
<td>Cs₂CO₃</td>
<td>120</td>
<td>100</td>
<td>23</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>Ni₂</td>
<td>NaOrBu</td>
<td>120</td>
<td>85</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>Ni₂</td>
<td>NaH</td>
<td>120</td>
<td>100</td>
<td>29</td>
<td>39</td>
</tr>
<tr>
<td>4</td>
<td>Ni₂</td>
<td>Na₂CO₃</td>
<td>120</td>
<td>100</td>
<td>27</td>
<td>36</td>
</tr>
<tr>
<td>5</td>
<td>Ni₂</td>
<td>NaOH</td>
<td>120</td>
<td>100</td>
<td>20</td>
<td>48</td>
</tr>
<tr>
<td>6</td>
<td>Ni₂</td>
<td>Na₂CO₃</td>
<td>80</td>
<td>100</td>
<td>25</td>
<td>34</td>
</tr>
<tr>
<td>7</td>
<td>(DME)NiCl₂</td>
<td>Na₂CO₃</td>
<td>80</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>NiCl₂ + 5 mol% dppf</td>
<td>Na₂CO₃</td>
<td>80</td>
<td>63</td>
<td>14</td>
<td>27</td>
</tr>
<tr>
<td>9</td>
<td>NiCl₂ + 5 mol% dppb</td>
<td>Na₂CO₃</td>
<td>80</td>
<td>82</td>
<td>19</td>
<td>30</td>
</tr>
<tr>
<td>10</td>
<td>CuCl + 5 mol% dppb</td>
<td>Na₂CO₃</td>
<td>80</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>PdCl₂ + 5 mol% dppb</td>
<td>Na₂CO₃</td>
<td>80</td>
<td>18</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

Reaction conditions: 0.2 mmol C₁₀F₂₁I, 0.5 mL dioxane, 16 h, argon atmosphere. Yields and conversions were determined by ¹⁹F NMR with 1,4-difluorobenzene as standard.

Isolation of product S₂: After cooling to room temperature, the reaction mixture was transferred to a silica gel contained round flask and dried and evaporated to dryness. Then, the resulting powder was purified by column chromatography using COMBIFLASH RF 210B20092 with a 12 g flash column eluting with pentane to yield S₂ as a white powder.

S₂: ¹H NMR (300 MHz, CDCl₃):  δ = 6.55 (t, J = 0.8 Hz, 1H), 4.08 (s, 4H).

¹⁹F NMR (282 MHz, CDCl₃):  δ = -80.85 (t, J = 10.0 Hz, 3F, CF₃), -117.93 (t, J = 12.7 Hz, 2F, -vinyl-CF₂), -122.01 (10F, CF₂), -122.87 (4F, CF₂), -126.18 (s, 2F, CF₂).
6. EPR spectra

Figure S1. EPR spectra. Reaction conditions: 0.2 mmol C_{10}F_{21}I, 0.5 mL benzene, 5 mol% Ni2, 1.5 eq. Cs_{2}CO_{3}, argon atmosphere in EPR tube.

7. Kinetic study in the presence of Ni2

Figure S2. Kinetic study in the presence of Ni2. Reaction conditions: 0.2 mmol C_{10}F_{21}I, 0.5 mL benzene, 5 mol% Ni2, 1.5 equiv. Cs_{2}CO_{3}, argon atmosphere. Yields and conversions were determined by ^{19}F NMR with 1,4-difluorobenzene as standard.
8. Control experiments with the addition of reductant

Table S2. Control experiments with the addition of reductant.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Reductant</th>
<th>Time / h</th>
<th>Conversion / %</th>
<th>Yield / %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Phenylboronic acid</td>
<td>2</td>
<td>93</td>
<td>68</td>
</tr>
<tr>
<td>2</td>
<td>Phenylboronic acid</td>
<td>5</td>
<td>100</td>
<td>76</td>
</tr>
<tr>
<td>3</td>
<td>Ammonium formate</td>
<td>2</td>
<td>65</td>
<td>48</td>
</tr>
<tr>
<td>4</td>
<td>Ammonium formate</td>
<td>5</td>
<td>93</td>
<td>66</td>
</tr>
<tr>
<td>5</td>
<td>Sodium formate</td>
<td>2</td>
<td>59</td>
<td>40</td>
</tr>
<tr>
<td>6</td>
<td>Sodium formate</td>
<td>5</td>
<td>69</td>
<td>48</td>
</tr>
</tbody>
</table>

Reaction conditions: 0.2 mmol C_{10}F_{21}I, 0.5 mL benzene, argon atmosphere, yields and conversions were determined by $^{19}$F NMR with 1,4-difluorobenzene as standard.

9. Control experiments with two or three out of four components

Table S3. Control experiments with any of two or three components

<table>
<thead>
<tr>
<th>Entry</th>
<th>components</th>
<th>31P NMR signal change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.001 mmol Ni2 + 0.3 mmol Cs$_2$CO$_3$</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>0.001 mmol Ni2 + 0.5 mL benzene</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>0.001 mmol Ni2 + 0.2 mmol C$<em>{10}$F$</em>{21}$I</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>0.001 mmol Ni2 + 0.2 mmol C$<em>{10}$F$</em>{21}$I + 0.5 mL benzene</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>0.001 mmol Ni2 + 0.2 mmol C$<em>{10}$F$</em>{21}$I + 0.3 mmol Cs$_2$CO$_3$</td>
<td>Yes</td>
</tr>
<tr>
<td>6</td>
<td>0.001 mmol Ni2 + 0.5 mL benzene + 0.3 mmol Cs$_2$CO$_3$</td>
<td>No</td>
</tr>
</tbody>
</table>

Reaction conditions: 100 °C, 16 h, argon atmosphere.

10. Intermediates study

Synthesis of the intermediates (Scheme S2):

Ni2 (0.05 mmol, 37.0 mg) and C$_{10}$F$_{21}$I (0.2 mmol, 129.2 mg) were added to a 10 mL Schlenk tube. After flushed with argon, 2 mL perfluorobenzene was added as a solvent. Then, the mixture was stirred at 100 °C for 16 h. During the stirring, the color of the solution changed from
colorless to yellow, then to brown. After cooling to room temperature, the solvent was removed under reduced vacuum to give a brown powder which was then washed by heptane (4 mL, 3 times) yielding the potential reaction intermediates as a brown powder (I1).

**NMR data of I1 (Figure S3):**

- $^1$H NMR (300 MHz, CDCl$_3$): $\delta = 7.49$ (m), 4.78 (m), 4.25(m).
- $^{19}$F NMR (282 MHz, CDCl$_3$): $\delta = -80.73, -121.67, -122.68, -126.08, -161.69$.
- $^{31}$P NMR (122 MHz, CDCl$_3$): $\delta = 28.07$.

**Elementary analysis:**

Calcd (%): C 41.97, H 2.24, Ni 4.66, Fe, 4.44, I 10.08, F 31.69, Cl 0.

Found (%): C 42.17, H 2.45, Ni 3.65, Fe, 3.70, I 8.96, F 19.84, Cl 0.

The $^1$H NMR of I1 proved it contains dppf unit. And as only one signal appeared in $^{31}$P NMR, we assume the structure changed geometrically from *cis* to *trans*. However, it was unfortunately could not structurally resolved due to its extremely low solubility in all of the tested solvents, e.g. benzene, CH$_3$CN, CDCl$_3$, DMSO, *et al.*. Nevertheless, the kinetic study in the presence of I1 showed the reaction started almost immediately (yield 42% of the product within 4 h) (Figure S3). Furthermore, product was detected in the absence of C$_{10}$F$_{21}$I using I1 as the catalyst as well as the perfluoro source, which proved I1 contains -C$_{10}$F$_{21}$ unit (Scheme S3). Additionally, I1 could also catalyze the perfluorodecylation of benzene giving 82% of desired product (Scheme S4). Herein, we suggested the structure of I1 as shown in Scheme S2.

![Scheme S2. Synthesis of the intermediates.](image)

*Scheme S2. Synthesis of the intermediates.*
**Figure S3.** NMR spectra of I1

**Figure S4.** Kinetic study in the presence of I1. Reaction conditions: 0.2 mmol C_{10}F_{21}I, 0.5 mL benzene, 5 mol% I1, 1.5 eq. Cs_{2}CO_{3}, in an argon atmosphere, conversions and yields were determined by ^{19}F NMR with 1,4-difluorobenzene as standard.
Scheme S3. Control experiment using I1 as the catalyst as well as the perfluoro source. Yield was determined by $^19$F NMR with 1,4-difluorobenzene as standard.

Scheme S4. Control experiment using I1 as the catalyst. Yield was determined by $^19$F NMR with 1,4-difluorobenzene as standard.

11. Characterization data of the perfluoroalkylated arenes

Notes: For the $^{13}$C NMR (F coupled), peaks for the C of perfluoroalkyl chain and C adjacent to perfluoroalkyl chain (in most cases) are too broad to be assigned (not shown in the following data).

4a, $\text{C}_{10}F_{21}$

$^19$F NMR (282 MHz, CDCl$_3$) $\delta$ = -81.48 (3F, C$_F$$_3$), -111.21 (2F, -aryl-C$_F$$_2$), -121.07 – -123.93 (14F, -C$_F$$_2$), -126.72 (2F, -C$_F$$_2$).

4b, mixture of 2-, 3-, 4-perfluoroalkyl isomers (39%, 17%, 44%), a brown solid.

$^1$H NMR (300 MHz, CDCl$_3$) $\delta$ = 7.46 – 6.90 (4H, -aryl-H), 3.79 – 3.77 (3H, CH$_3$).
$^{19}$F NMR (282 MHz, CDCl$_3$) $\delta$ = -80.86 (3F, CF$_3$), -107.74 (-aryl-CF$_2$, 4-perfluoroalkyl isomer), -109.77 (-aryl-CF$_2$, 2-perfluoroalkyl isomer), -110.63 (-aryl-CF$_2$, 3-perfluoroalkyl isomer), 121.26 – -122.77 (14F, CF$_2$), -126.19 (2F, CF$_2$).

HRMS (EI): [M]+ calcd for C$_{17}$H$_7$F$_{21}$O, 626.01561; found, 626.01376.

4b, mixture of 2-, 3-, 4-perfluoroalkyl isomers (45%, 16%, 39%)

$^{19}$F NMR (282 MHz, CDCl$_3$) $\delta$ = -81.41 (3F, CF$_3$), -102.63 (-aryl-CF$_2$, 4-perfluoroalkyl isomer), -111.32 (-aryl-CF$_2$, 3-perfluoroalkyl isomer), -111.60 (-aryl-CF$_2$, 2-perfluoroalkyl isomer), -121.09 – -123.87 (14F, CF$_2$), -126.71 (2F, CF$_2$).

$^1$H NMR (300 MHz, CDCl$_3$) $\delta$ = 7.33 (d, $J$ = 8.5 Hz, 1H, -aryl-H), 6.51 – 6.43 (m, 2H, -aryl-H), 3.77 (d, $J$ = 4.7 Hz, 6H, CH$_3$).

$^{19}$F NMR (282 MHz, CDCl$_3$) $\delta$ = -80.74 (t, $J$ = 10.0 Hz, 3F, CF$_3$), -106.81 (s, 2F, -aryl-CF$_2$), -121.05 – -123.09 (m, 14F, CF$_2$), -126.09 (s, 2F, CF$_2$).

4e, mixture of 2-, 3-, 4-perfluoroalkyl isomers (45%, 16%, 39%)

$^{13}$C NMR (75 MHz, CDCl$_3$) $\delta$ = 163.81, 161.74, 91.70, 56.32, 55.34.

HRMS (ESI): [M+H]+ calcd for C$_{19}$H$_{12}$F$_{21}$O$_3$, 687.04456; found, 687.04468.

4f, mixture of 2-, 4-perfluoroalkyl isomers (66%, 34%)

$^{19}$F NMR (282 MHz, CDCl$_3$) $\delta$ = -81.48 (3F, CF$_3$), -103.65 (-aryl-CF$_2$, 2-perfluoroalkyl isomer), -104.14 (-aryl-F, 2-perfluoroalkyl isomer), -104.86 (-aryl-CF$_2$, 4-perfluoroalkyl isomer), -109.09 (-aryl-F, 4-perfluoroalkyl isomer), -121.48 – -123.29 (14F, CF$_2$), -126.74 (2F, CF$_2$).
4g,  

$^{19}$F NMR (282 MHz, CDCl$_3$) $\delta = -81.50$ (3F, -CF$_3$), -110.00 (2F, -aryl-CF$_2$), -121.51 – -123.89 (14F, -CF$_2$), -126.75 (2F, -CF$_2$).

4h,  mixture of 3-, 4-perfluoroalkyl isomers (27%, 73%).  

$^{19}$F NMR (282 MHz, CDCl$_3$) $\delta = -81.43$ (3F, -CF$_3$), -104.52 (-aryl-CF$_2$, 3-perfluoroalkyl isomer), -110.65 (-aryl-CF$_2$, 4-perfluoroalkyl isomer), -120.87 – -123.81 (14F, -CF$_2$), -126.63 (2F, -CF$_2$).

4i,  

$^{19}$F NMR (282 MHz, CDCl$_3$) $\delta = -81.48$ (3F, -CF$_3$), -108.05 (2F, -aryl-CF$_2$), -121.63 – -123.84 (14F, -CF$_2$), -126.71 (2F, -CF$_2$).

4j,  mixture of 2-, 4-perfluoroalkyl isomers (27%, 73%).  

$^1$H NMR (300 MHz, CDCl$_3$) $\delta = 7.49 – 7.26$ (2H, -aryl-H), 7.18 – 6.56 (2H, -aryl-H), 3.36 – 2.84 (4H, -CH$_2$), 1.14 – 0.90 (6H, -CH$_3$).

$^{19}$F NMR (282 MHz, CDCl$_3$) $\delta = -80.82$ (3F, -CF$_3$), -103.61 (-aryl-CF$_2$, 2-perfluoroalkyl isomer), -109.20 (-aryl-CF$_2$, 4-perfluoroalkyl isomer), -119.66 – -122.74 (14F, -CF$_2$), -126.15 (2F, -CF$_2$).

$^{13}$C NMR (75 MHz, CDCl$_3$) $\delta = 132.33$, 128.16, 125.81, 124.47, 49.10, 12.16 (d, $J = 8.7$ Hz, -N-C$_2$).

HRMS (ESI): [M+H]$^+$ calcd for C$_{20}$H$_{14}$F$_{21}$N, 668.08637; found, 668.08643.

4k,  mixture of 3-, 6-perfluoroalkyl isomers (34%, 66%), a grey yellow powder.
**1H NMR (300 MHz, CDCl₃)** δ = 7.07 – 6.97 (1H, -aryl-H), 6.44 – 6.43 (1H, -aryl-H), 4.17 (-NH₂, 3-perfluoroalkyl isomer), 3.75 (-NH₂, 6-perfluoroalkyl isomer), 2.31 – 2.25 (3H, -CH₃), 2.07 (3H, -CH₃).

**19F NMR (282 MHz, CDCl₃)** δ = -80.83 (3F, -CF₃), -101.99 (-aryl-CF₂, 3-perfluoroalkyl isomer), -104.77 (-aryl-CF₂, 6-perfluoroalkyl isomer), -120.92 – -122.75 (14F, -CF₂), -126.16 (2F, -CF₂).

**13C NMR (75 MHz, CDCl₃)** δ = 147.42, 137.03, 133.32, 130.64, 121.89, 121.66, 119.10, 117.73, 17.87, 16.70.

**HRMS (EI)**: [M]+ calcd for C₁₈H₁₀F₂₁N, 639.04724; found, 639.04692.

![Structure](image_url)

**4l**, mixture of 3-, 6-perfluoroalkyl isomers (10%, 90%), a grey yellow powder.

**1H NMR (300 MHz, CDCl₃)** δ = 7.06 – 6.83 (2H, -aryl-H), 3.77 (2H, -NH₂), 2.13 (-CH₃, 4-perfluoroalkyl isomer), 2.09 (-CH₃, 3-perfluoroalkyl isomer).

**19F NMR (282 MHz, CDCl₃)** δ = -80.77 (3F, -CF₃), -104.04 (-aryl-CF₂, 3-perfluoroalkyl isomer), -109.13 (-aryl-CF₂, 4-perfluoroalkyl isomer), -120.45 – -122.71 (14F, -CF₂), -126.08 (2F, -CF₂).

**13C NMR (75 MHz, CDCl₃)** δ = 126.70, 121.05, 29.72, 17.60.

**HRMS (EI)**: [M]+ calcd for C₁₈H₁₀F₂₁N, 639.04724; found, 639.04679.

![Structure](image_url)

**4m**, mixture of 3-, 6-perfluoroalkyl isomers (10%, 90%), a grey yellow powder.

**1H NMR (300 MHz, CDCl₃)** δ = 7.02 – 6.93 (m, 2H, -aryl-H), 6.65 – 6.58 (m, 1H, -aryl-H).

**19F NMR (282 MHz, CDCl₃)** δ = -80.75 (t, J = 9.9 Hz, 3F, CF₃), -109.01 (t, J = 14.2 Hz, 2F, -aryl-CF₂), -121.18 – -122.99 (m, 14F, -CF₂), -126.10 (s, 2F, -CF₂), -126.44 (td, J = 8.3, 4.7 Hz, 1F, -aryl-CF).

**13C NMR (101 MHz, CDCl₃)** δ = 156.16, 153.80, 142.20, 120.61, 120.38, 119.09, 115.13, 114.87, 111.59.

**HRMS (EI)**: [M]+ calcd for C₁₆H₅F₂₂N, 629.00652; found, 629.00601.

**HRMS (ESI)**: [M+H]+ calcd for C₁₆H₅F₂₂N, 630.01435; found, 630.02534.
1H NMR (300 MHz, CDCl₃) δ = 6.86 (dd, J = 8.8, 3.0 Hz, 1H, -aryl-H), 6.76 (d, J = 2.9 Hz, 1H, -aryl-H), 6.62 (d, J = 8.8 Hz, 1H, -aryl-H), 3.69 (5H, -NH₂ and -CH₃).

19F NMR (282 MHz, CDCl₃) δ = -80.76 (t, J = 10.0 Hz, 3F, -CF₃), -108.62 (t, 2F, -aryl-CF₂), -122.21 (m, 14F, -CF₂), -126.11 (s, 2F, -CF₂).

4o, mixture of 2-, 3-, 4-perfluoroalkyl isomers (44%, 9%, 47%).

19F NMR (282 MHz, CDCl₃) δ = -81.47 (3F, -CF₃), -112.02 (-aryl-CF₂, 2-perfluoroalkyl isomer), -113.53 (-aryl-CF₂, 3-perfluoroalkyl isomer), -114.29 (-aryl-CF₂, 4-perfluoroalkyl isomer) -121.75 - 123.90 (14F, -CF₂), -126.75 (2F, -CF₂).

13C NMR (75 MHz, CDCl₃) δ = 140.83, 101.52, 53.87, 53.79.


4q,

19F NMR (282 MHz, CDCl₃) δ = -81.40 (3F, -CF₃), -104.75 (2F, -aryl-CF₂), -121.45 (2F, -CF₂), -122.05 - 122.30 (10F, -CF₂), -123.25 (2F, -CF₂), -126.68 (2F, -CF₂).

4r,

1H NMR (300 MHz, CDCl₃) δ = 6.60 (s, 1H, -aryl-H), 2.40 (t, J = 2.4 Hz, 3H, -CH₃), 2.33 (s, 3H, -CH₃).
$^{19}$F NMR (282 MHz, CDCl$_3$) δ = -80.80 (t, $J = 10.0$ Hz, 3F, -CF$_3$), -105.82 (2F, -aryl-CF$_2$), -121.93 (12F, -CF$_2$), -122.73 (s, 2F, -CF$_2$), -126.14 (s, 2F, -CF$_2$).

$^4$s, mixture of 2-, 4-, 5-perfluoroalkyl isomers (37%, 28%, 35%).

$^{19}$F NMR (282 MHz, CDCl$_3$) δ = -81.51 (3F), -106.37 (-aryl-CF$_2$, 2-perfluoroalkyl isomer), -108.26 (-aryl-CF$_2$, 5-perfluoroalkyl isomer), -109.60 (-aryl-CF$_2$, 4-perfluoroalkyl isomer), -121.71 – -123.89 (14F, -CF$_2$), -126.75 (2F, -CF$_2$).

$^4$t, mixture of 1-, 2-perfluoroalkyl isomers (79%, 21%).

$^{19}$F NMR (282 MHz, CDCl$_3$) δ = -81.44 (3F, -CF$_3$), -104.91 (-aryl-CF$_2$, 1-perfluoroalkyl isomer), -110.52 (-aryl-CF$_2$, 2-perfluoroalkyl isomer), -120.72 – -123.27 (14F, -CF$_2$), -126.70 (2F, -CF$_2$).

$^4$u,

$^{19}$F NMR (282 MHz, CDCl$_3$) δ = -81.46 (t, $J = 9.7$ Hz, 3F, -CF$_3$), -111.21 (t, 2F, -aryl-CF$_2$), -121.83 (s, 2F, -CF$_2$), -122.43 (s, 6F, -CF$_2$), -123.28 (s, 2F, -CF$_2$), -126.72 (s, 2F, -CF$_2$).

$^4$v,

$^{19}$F NMR (282 MHz, CDCl$_3$) δ = -81.76 (tt, $J = 9.9$, 3.0 Hz, 3F, -CF$_3$), -111.48 (t, 2F, -aryl-CF$_2$), -123.39 (q, $J = 9.8$ Hz, 2F, -CF$_2$), -126.24 (m, 2F, -CF$_2$).

$^4$w,

$^{19}$F NMR (282 MHz, CDCl$_3$) δ = -59.77 (s, 3F, -CF$_3$)
12. Spectra of the perfluoroalkylated arenes
S2: \[
\begin{array}{c}
\text{O} \\
\text{C}_3\text{F}_{21} \\
\text{O}
\end{array}
\]
13. References