Sunlight Decatungstate Photoinduced Trifluoromethylations of (Hetero)aromatics and Electron-poor Olefins

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Electronic Supplementary Information (22 pages)

CONTENT

1 UV-Vis Spectra

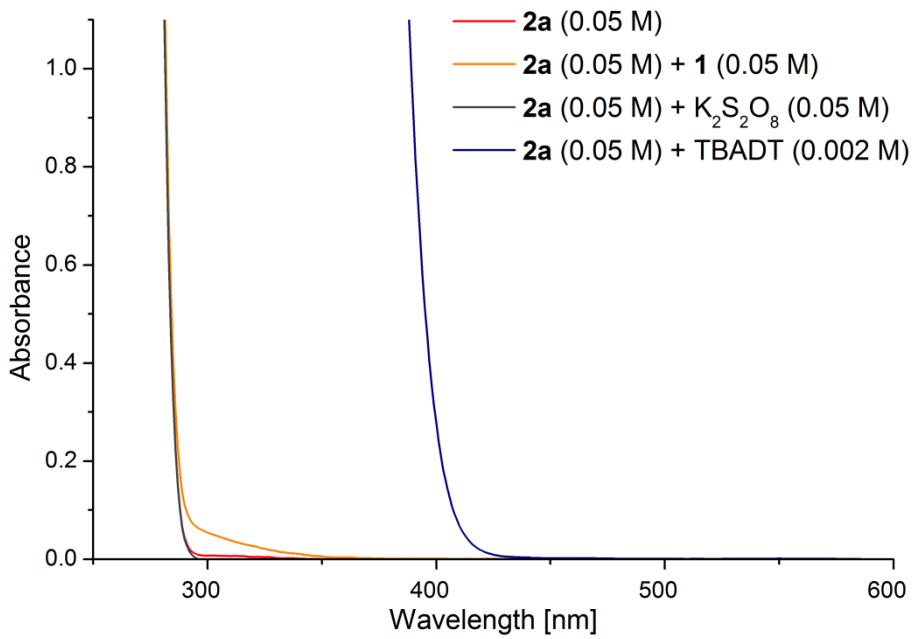


Figure S1. UV-Vis spectra of selected solutions under working conditions.

2 Kinetic Profile

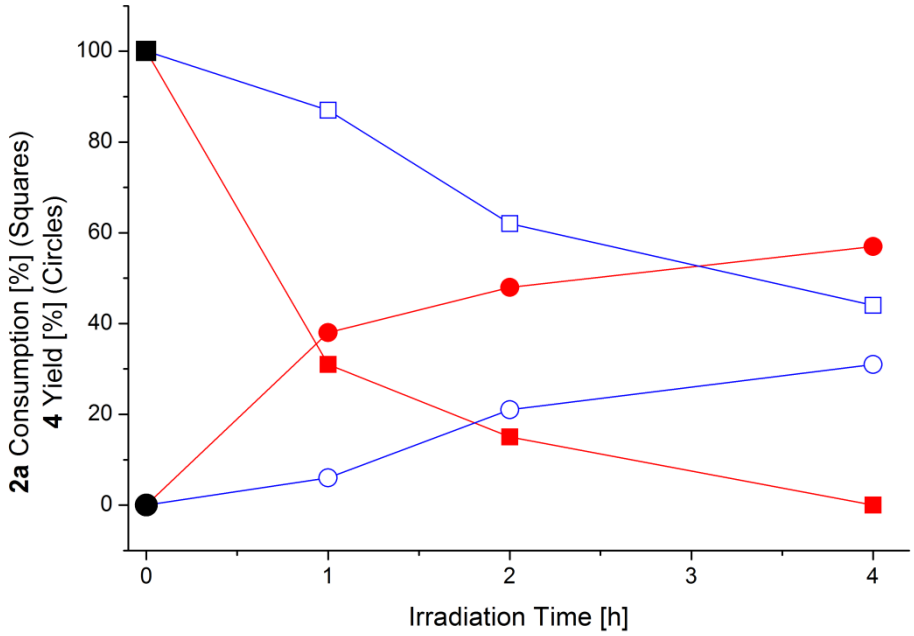


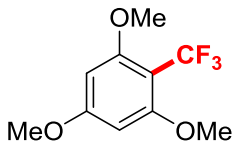
Figure S2. Time profiles of the reactions reported in entries 3 (red solid symbols) and 10 (blue open symbols) in Table 1; **2a** consumption and **4** yield have been reported with squares and circles, respectively.

2 Experimental Section

General: Compounds **1**, **2** and **3**, as well as all the additives employed, were commercially available and used as received, with the only exception of **3d**, that was prepared according to a procedure previously reported.[S1] The photocatalyst TBADT has been prepared according to a published procedure.[S2] Acetonitrile and water (HPLC purity grade) employed for photochemical reactions were used as received. NMR spectra were recorded on a 300 (for ^{1}H) or 75 (for ^{13}C) MHz spectrometer; the attributions were made on the basis of ^{1}H and ^{13}C NMR. Data for ^{1}H NMR are reported as follows: chemical shift referred to TMS (δ ppm), multiplicity (s = singlet, bs = broad singlet, d = doublet, t = triplet, q = quadruplet, quint = quintuplet, sext = sextuplet, hept = heptuplet, m = multiplet), coupling constant (Hz) and integration. Data for ^{13}C NMR are reported in terms of chemical shift. Reactions were monitored by gas chromatographic (GC) analyses (HP-5 capillary column). Chromatographic purification of products was accomplished using flash chromatography on 60 Å, 230-400 mesh silica gel and adopting petroleum ether (40-60 °C) and ethyl acetate as the eluants. Thin-layer chromatography (TLC) was performed on silica gel 60 F-254 plates. Visualization of the developed plates was performed by fluorescence quenching or by $KMnO_4$ staining. UV-Vis spectra were recorded with a double beam spectrophotometer equipped with Deuterium lamp (190-350 nm) and Halogen lamp (330-900 nm) and a Photomultiplier R928. Irradiations were performed in a SolarBox 1500e (Co.Fo.Me.Gra, Milan, Italy) equipped with a 1500 W Xe lamp (500 W m^{-2} light intensity).

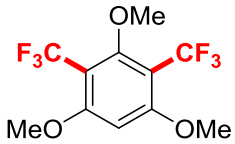
General Procedure for the TBADT Photoinduced Trifluoromethylation of (Hetero)Aromatics. An acetonitrile/water 5:1 solution (15 mL) of sodium triflinate (**1**; 0.75-4.5 mmol, 0.05-0.3 M, 1-6 equiv.) and the chosen (hetero)aromatic (**2**; 0.75 mmol, 0.05 M, 1 equiv.), in the presence of potassium persulfate (0.75-1.5 mmol, 0.05-0.1 M, 1-2 equiv.) and TBADT ($2\cdot10^{-3}$ M, 4 mol%) was poured in a Pyrex vessel[S2] and then purged for 3 min with nitrogen, capped with a septum, and irradiated under stirring for the indicated time in the SolarBox. The solvent was removed under reduced pressure from the photolyzed solution and the product isolated by purification of the residue by column chromatography.

1,3,5-Trimethoxy-2-(trifluoromethyl)benzene (4)



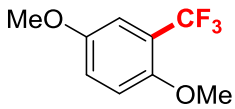
From 117 mg (0.75 mmol, 0.05 M) of sodium triflinate (**1**) and 126 mg (0.75 mmol, 0.05 M) of 1,3,5-trimethoxybenzene (**2a**). Purification of the residue by column chromatography (petroleum ether : ethyl acetate 8:2 as the eluant) afforded 96 mg of 1,3,5-trimethoxy-2-(trifluoromethyl)benzene (**4**, 54% yield) as a solid. m.p. 62-63 °C (Lit.[S3] 59-62 °C). Spectroscopic data of compound **4** were in accordance with the literature.[S4]

1,3,5-Trimethoxy-2,4-bis(trifluoromethyl)benzene (5)



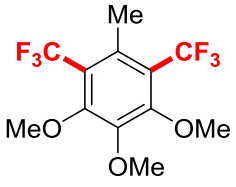
From 702 mg (4.5 mmol, 0.3 M) of sodium triflinate (**1**) and 126 mg (0.75 mmol, 0.05 M) of 1,3,5-trimethoxybenzene (**2a**). Purification of the residue by column chromatography (petroleum ether : ethyl acetate 9:1 as the eluant) afforded 180 mg of 1,3,5-trimethoxy-2,4-bis(trifluoromethyl)benzene (**5**, 79% yield) as a solid. m.p. 95-97 °C (Lit.[S4] 55-60 °C). Spectroscopic data of compound **5** were in accordance with the literature.[S4]

1,4-Dimethoxy-2-(trifluoromethyl)benzene (6)



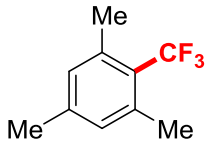
From 702 mg (4.5 mmol, 0.3 M) of sodium triflinate (**1**) and 104 mg (0.75 mmol, 0.05 M) of 1,4-dimethoxybenzene (**2b**). Purification of the residue by column chromatography (petroleum ether : ethyl acetate 9:1 as the eluant) afforded 70 mg of 1,4-dimethoxy-2-(trifluoromethyl)benzene (**6**, 45% yield) as a liquid. Spectroscopic data of compound **6** were in accordance with the literature.[S4]

1,2,3-Trimethoxy-5-methyl-4,6-bis(trifluoromethyl)benzene (7)



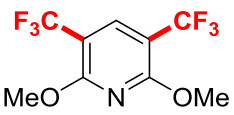
From 702 mg (4.5 mmol, 0.3 M) of sodium triflinate (**1**) and 137 mg (0.75 mmol, 0.05 M) of 1,2,3-trimethoxy-5-methylbenzene (**2c**). Purification of the residue by column chromatography (petroleum ether : ethyl acetate 99:1 as the eluant) afforded 98 mg of 1,2,3-trimethoxy-5-methyl-4,6-bis(trifluoromethyl)benzene (**4c**, 41% yield) as an oil. ^{1}H NMR ($CDCl_3$, 300 MHz) δ: 3.97 (s, 6H), 3.89 (s, 3H), 2.47 (hept, J = 3.0 Hz, 3H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ: 156.0, 145.8, 134.1 (hept, $J_{C\text{-}F}$ = 1.5 Hz), 123.9 (q, $J_{C\text{-}F}$ = 274.0 Hz), 120.2 (q, $J_{C\text{-}F}$ = 28.1 Hz), 61.8, 60.7, 17.1 (hept, $J_{C\text{-}F}$ = 4.5 Hz). Anal. Calcd. for $C_{12}H_{12}F_6O_3$: C, 45.29; H, 3.80. Found: C, 45.3; H, 3.7.

1,3,5-Trimethyl-2-(trifluoromethyl)benzene (8)



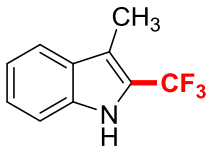
From 702 mg (4.5 mmol, 0.3 M) of sodium triflinate (**1**) and 104 μL (0.75 mmol, 0.05 M) of mesitylene (**2d**). Purification of the residue by column chromatography (petroleum ether as the eluant) afforded 58 mg of 1,3,5-trimethyl-2-(trifluoromethyl)benzene (**8**, 41% yield) as a liquid. Spectroscopic data of compound **8** were in accordance with the literature.[S5]

2,6-Dimethoxy-3,5-bis(trifluoromethyl)pyridine (9)



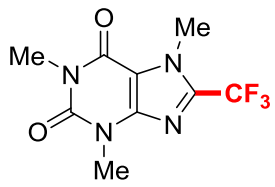
From 702 mg (4.5 mmol, 0.3 M) of sodium triflinate (**1**) and 99 μL (0.75 mmol, 0.05 M) of 2,6-dimethoxypyridine (**2e**). Purification of the residue by column chromatography (petroleum ether : ethyl acetate 99:1 as the eluant) afforded 107 mg of 2,6-dimethoxy-3,5-bis(trifluoromethyl)pyridine (**9**, 52% yield) as a solid. m.p. 52-53 °C. ^{1}H NMR ($CDCl_3$, 300 MHz) δ: 8.01 (s, 1H), 4.10 (s, 6H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ: 162.0, 137.1 (hept, $J_{C\text{-}F}$ = 4.5 Hz), 122.7 (q, $J_{C\text{-}F}$ = 268.8 Hz), 104.1 (q, $J_{C\text{-}F}$ = 34.7 Hz), 54.6. Anal. Calcd. for $C_9H_7F_6NO_2$: C, 39.29; H, 2.56; N, 5.09. Found: C, 39.3; H, 2.5; N, 5.1.

3-Methyl-2-(trifluoromethyl)-indole (10)



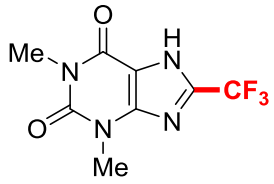
From 702 mg (4.5 mmol, 0.3 M) of sodium triflinate (**1**) and 98 mg (0.75 mmol, 0.05 M) of 3-methylindole (**2f**). Purification of the residue by column chromatography (petroleum ether : ethyl acetate 9:1 as the eluant) afforded 76 mg of 3-methyl-2-(trifluoromethyl)-indole (**10**, 51% yield) as a solid. m.p. 66-68 °C (Lit. 65.9-68.7 °C).[S6] Spectroscopic data of compound **10** were in accordance with the literature.[S4]

Caffeine-CF_3 (11)



From 702 mg (4.5 mmol, 0.3 M) of sodium triflinate (**1**) and 146 mg (0.75 mmol, 0.05 M) of caffeine (**2g**). Purification of the residue by column chromatography (petroleum ether : ethyl acetate 9:1 as the eluant) afforded 157 mg of caffeine-CF_3 (**11**, 80% yield) as a solid. m.p. 125-127 °C (Lit. 131-133 °C).[S7] Spectroscopic data of compound **11** were in accordance with the literature.[S4]

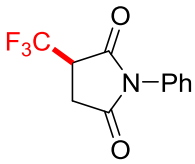
Theophylline-CF_3 (12)



From 702 mg (4.5 mmol, 0.3 M) of sodium triflinate (**1**) and 135 mg (0.75 mmol, 0.05 M) of theophylline (**2h**). Purification of the residue by column chromatography (petroleum ether : ethyl acetate 8:2 as the eluant) afforded 121 mg of theophylline-CF_3 (**12**, 65% yield) as a solid. m.p. > 250 °C (Lit. 266-268 °C).[S8] Spectroscopic data of compound **12** were in accordance with the literature.[S4]

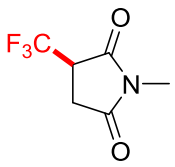
General Procedure for the TBADT Photocatalyzed Trifluoromethylation of Electron-Poor Olefins. An acetonitrile/water 5:1 solution (15 mL) of sodium triflinate (**1**; 4.5 mmol, 0.3 M, 3 equiv.) and the chosen electron-poor olefin (**3**; 1.5 mmol, 0.1 M, 1 equiv.), in the presence of TBADT ($4 \cdot 10^{-3}$ M, 4 mol%) was poured in a Pyrex vessel[S2] and then purged for 3 min with nitrogen, capped with a septum, and irradiated under stirring for the indicated time in the SolarBox. The solvent was removed under reduced pressure from the photolyzed solution and the product isolated by purification of the residue by column chromatography.

***N*-Phenyl 2-(trifluoromethyl)succinimide (13)**



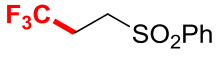
From 702 mg (4.5 mmol, 0.3 M) of sodium triflinate (**1**) and 260 mg (1.5 mmol, 0.1 M) of *N*-phenyl maleimide (**3a**). Purification of the residue by column chromatography (petroleum ether : ethyl acetate 9:1 as the eluant) afforded 146 mg of *N*-phenyl 2-(trifluoromethyl)succinimide (**13**, 40% yield) as a solid. m.p. 116-117 °C (Lit.[S9] 105-107 °C). Spectroscopic data of compound **13** were in accordance with the literature.[S10]

***N*-Methyl 2-(trifluoromethyl)succinimide (14)**



From 702 mg (4.5 mmol, 0.3 M) of sodium triflinate (**1**) and 167 mg (1.5 mmol, 0.1 M) of *N*-methyl maleimide (**3b**). Purification of the residue by column chromatography (petroleum ether : ethyl acetate 8:2 as the eluant) afforded 117 mg of *N*-methyl 2-(trifluoromethyl)succinimide (**14**, 43% yield) as an oil. Spectroscopic data of compound **14** were in accordance with the literature.[S9]

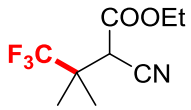
((3,3,3-Trifluoropropyl)sulfonyl)benzene (15)



From 702 mg (4.5 mmol, 0.3 M) of sodium triflinate (**1**) and 252 mg (1.5 mmol, 0.1 M) of phenylvinylsulfone (**3c**). Purification of the residue by column

chromatography (petroleum ether : ethyl acetate 95:5 as the eluant) afforded 154 mg of ((3,3,3-trifluoropropyl)sulfonyl)benzene (**15**, 43% yield) as a solid. m.p. 97-99 °C (Lit.[S11] 101.4-101.5 °C). Spectroscopic data of compound **15** were in accordance with the literature.[S11]

Ethyl 2-cyano-4,4,4-trifluoro-3,3-dimethylbutanoate (16)



From 702 mg (4.5 mmol, 0.3 M) of sodium triflinate (**1**) and 230 mg 230 mg (1.5 mmol, 0.1 M) of ethyl isopropylidene cyanoacetate (**3d**). Purification of the residue by column chromatography (petroleum ether : ethyl acetate 9:1 as the eluant) afforded 77 mg of ethyl 2-cyano-4,4,4-trifluoro-3,3-dimethylbutanoate (**16**, 23% overall yield; 52% yield considering 44% consumption of **3d**) as an oil. ^{1}H NMR ($CDCl_3$, 300 MHz) δ: 4.31 (q, J = 8 Hz, 2H), 3.70 (s, 1H), 1.48 (s, 3H), 1.39 (s, 3H), 1.35 (t, J = 8 Hz, 3H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ: 163.4, 126.7 (q, $J_{C\text{-}F}$ = 281.3 Hz), 113.9, 63.2, 43.5 (q, $J_{C\text{-}F}$ = 25 Hz), 43.0, 19.9, 18.8, 13.7. Anal. Calcd. for $C_{12}H_9F_3NO_2$: C, 48.43; H, 5.42; N, 6.28. Found: C, 48.4; H, 5.4; N, 6.3.

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S9 C. Brule, J.-P. Bouillon and C. Portella, Nucleophilic chain substitution on perfluoroketene dithioacetals by ethyl 2-trimethysilyl acetate. Application to the synthesis of 2-trifluoromethyl succinic acid derivatives, *Tetrahedron*, 2004, **60**, 9849-9855.

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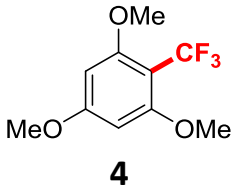
S11 R. Beniazza, M. Douarre, D. Lastécouères and J.-M. Vincent, Metal-free and light-promoted radical iodotrifluoromethylation of alkenes with Togni reagent as the source of CF_3 and iodine, *Chem. Commun.*, 2017, **53**, 3547-3550.

Copy of ^{1}H and ^{13}C NMR



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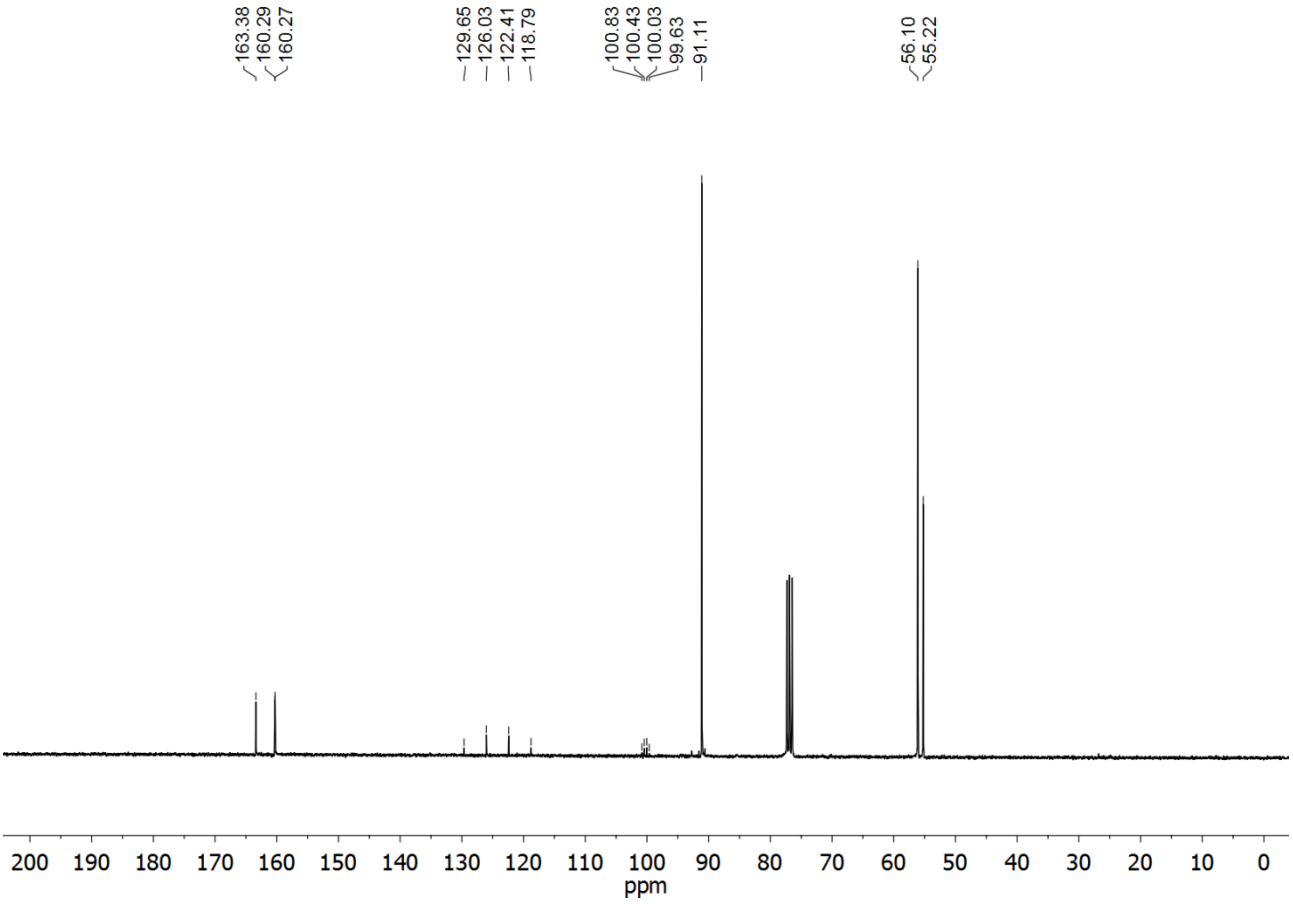

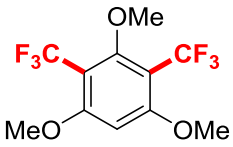
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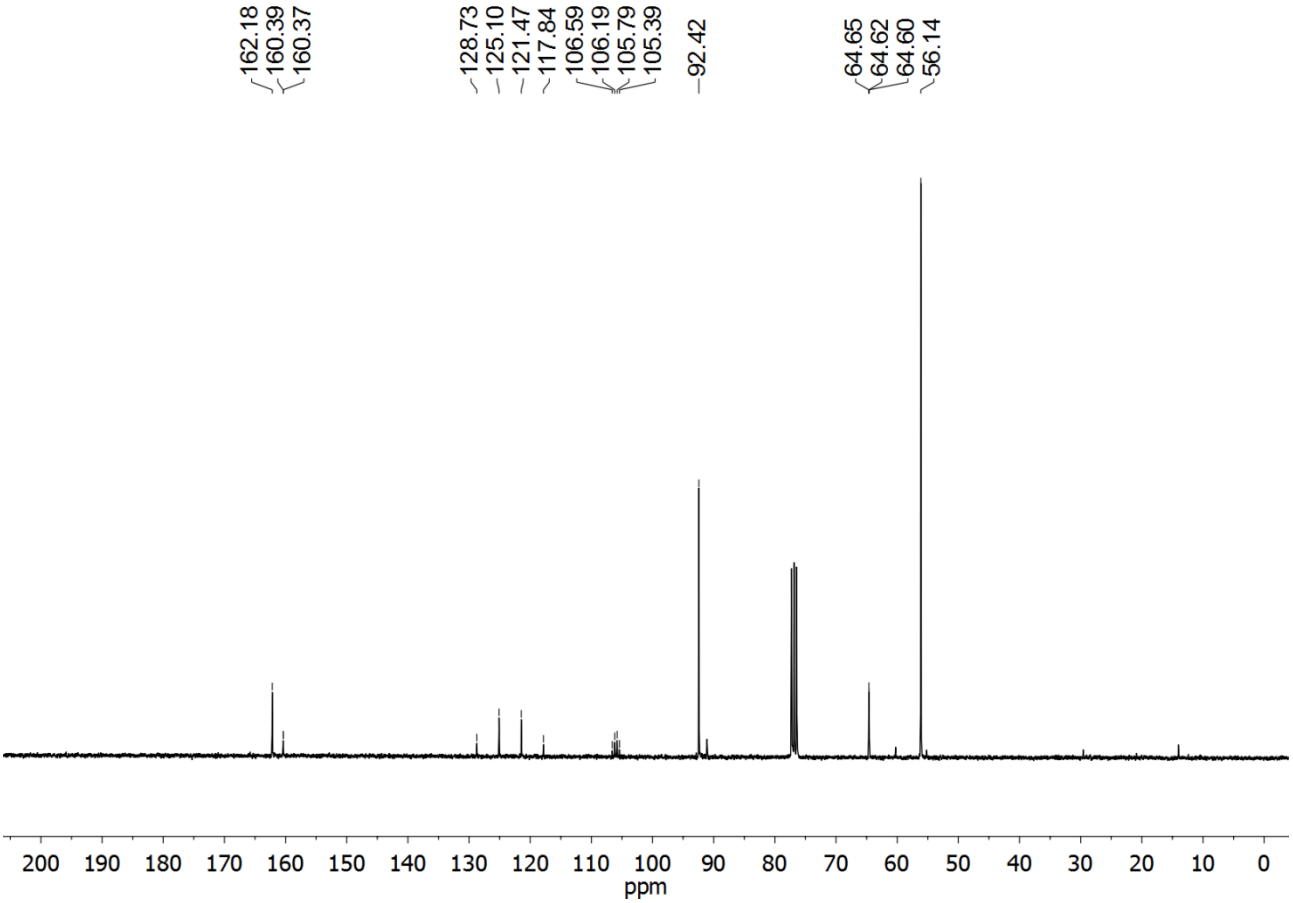
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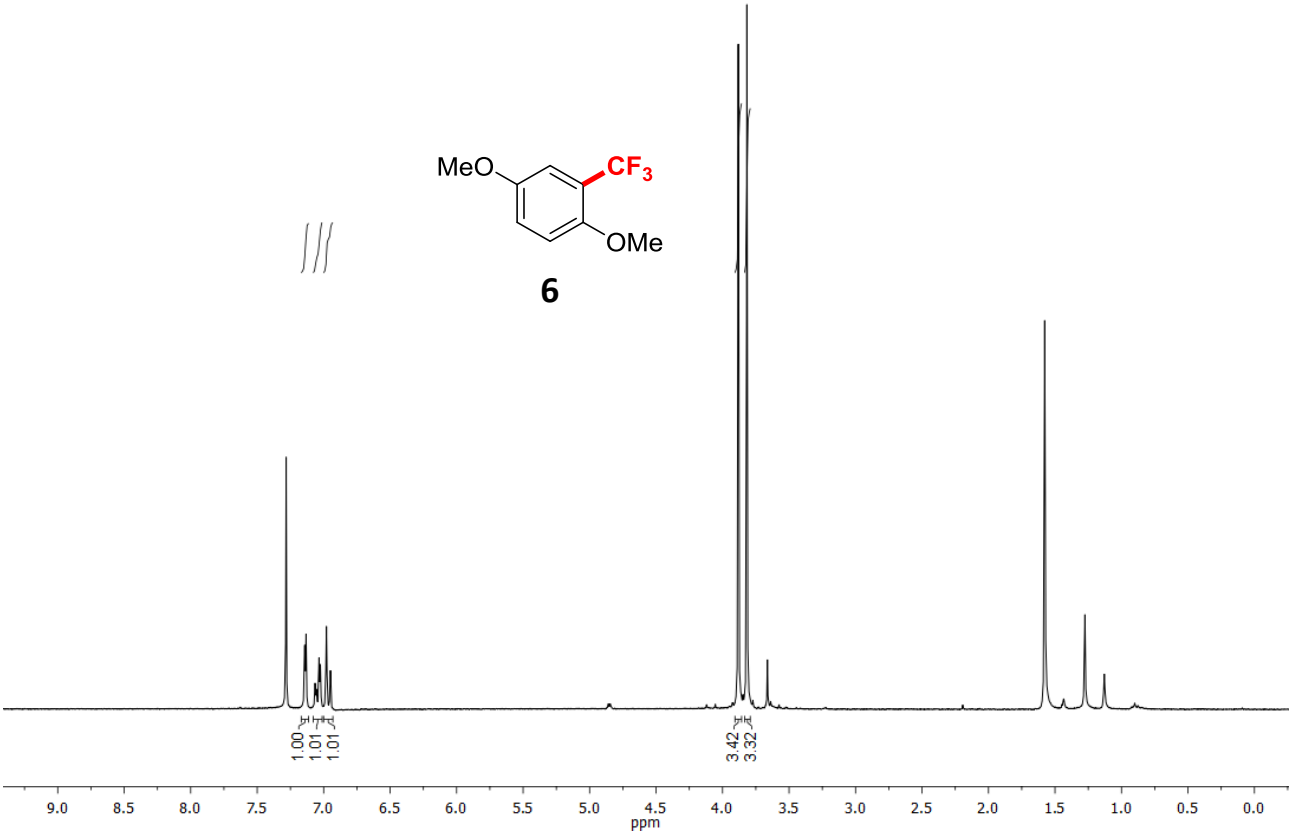
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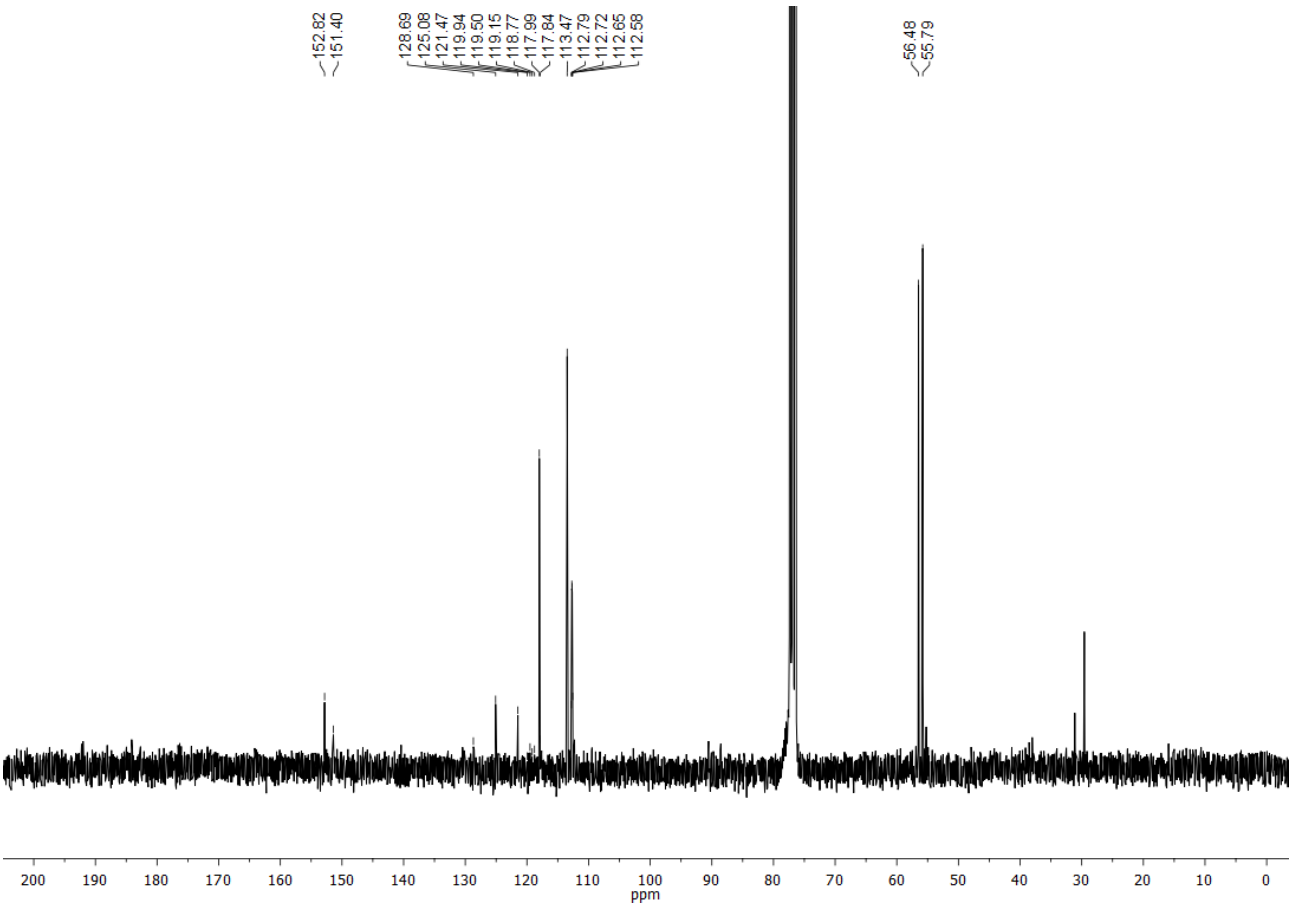
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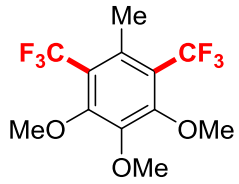
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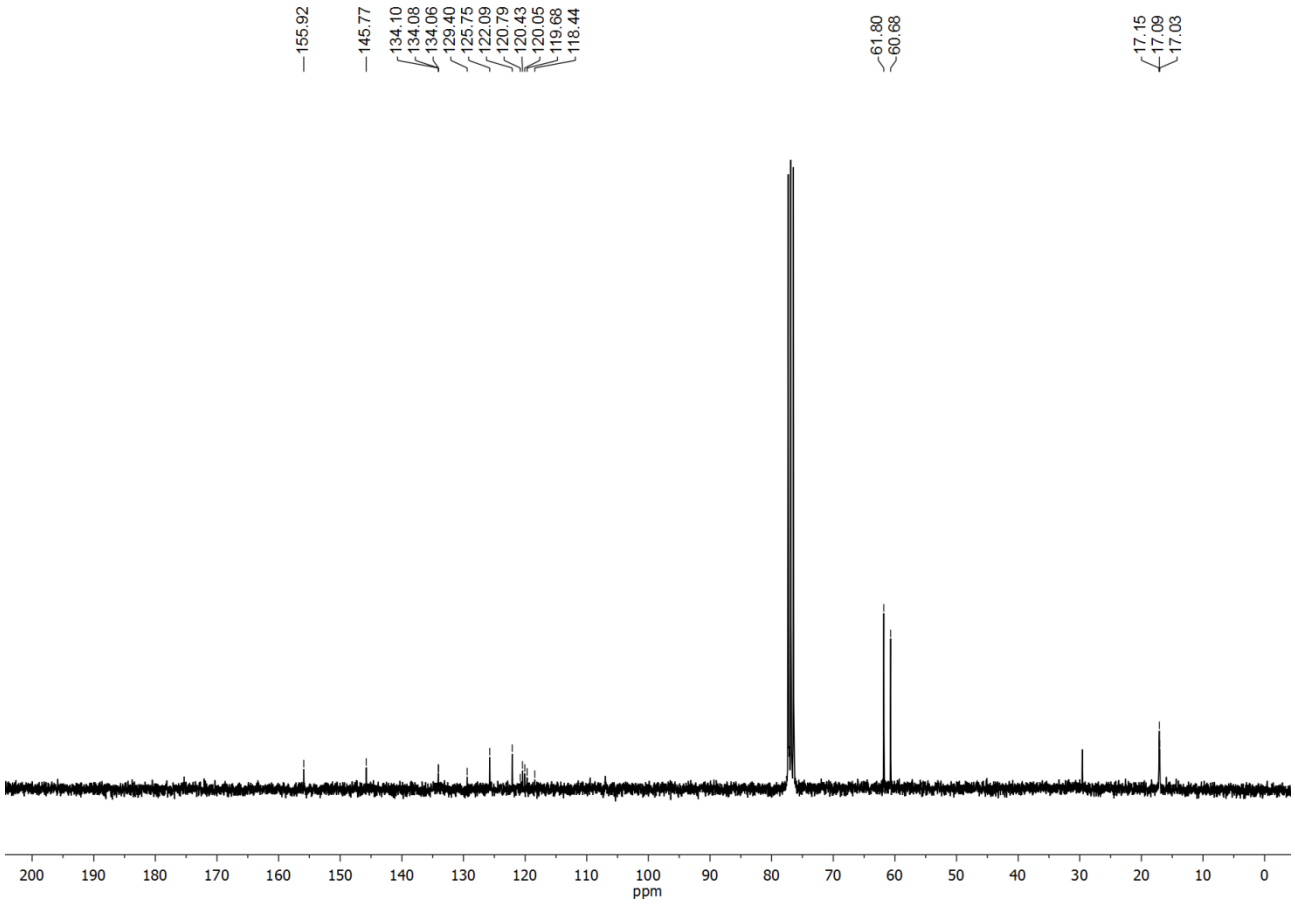
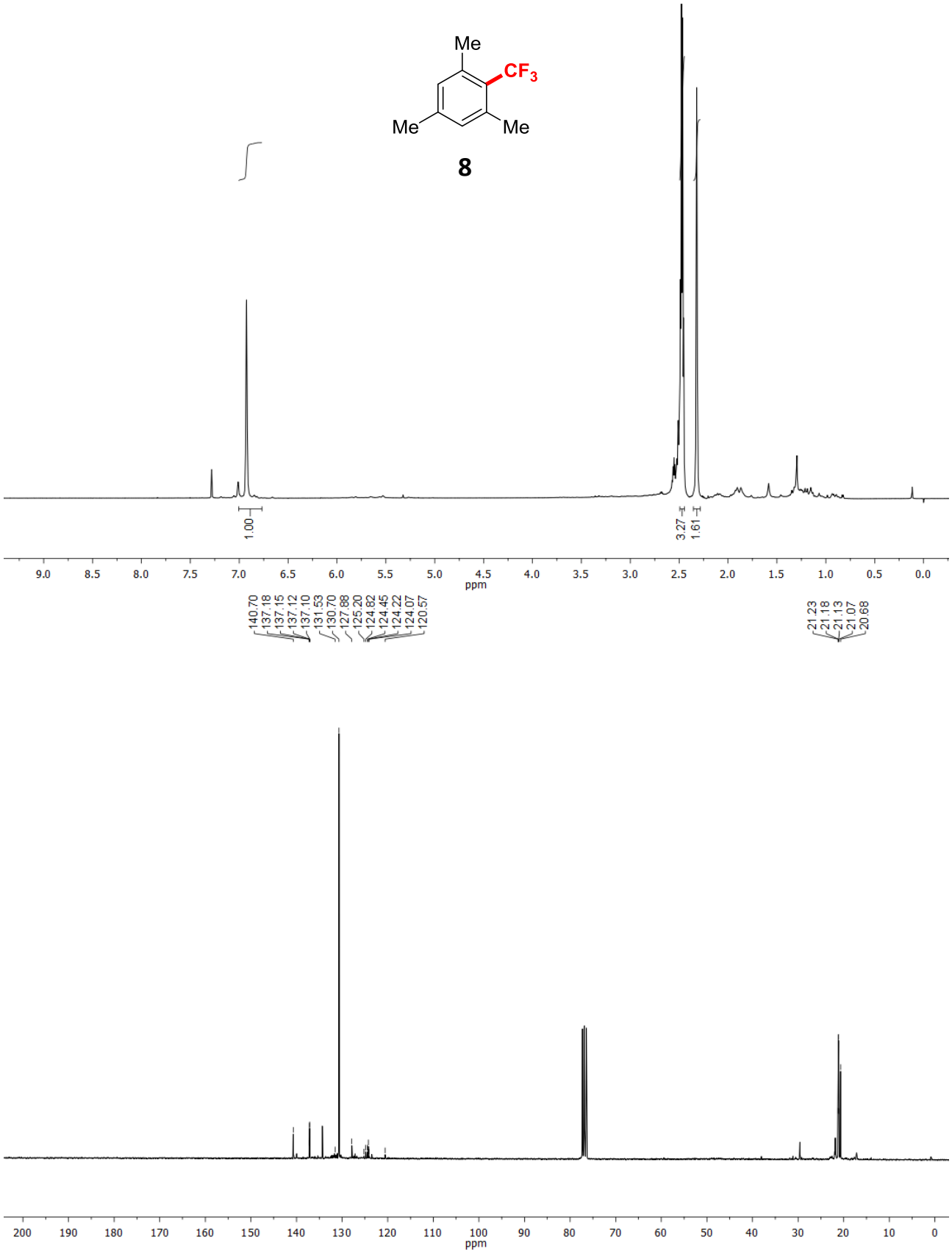
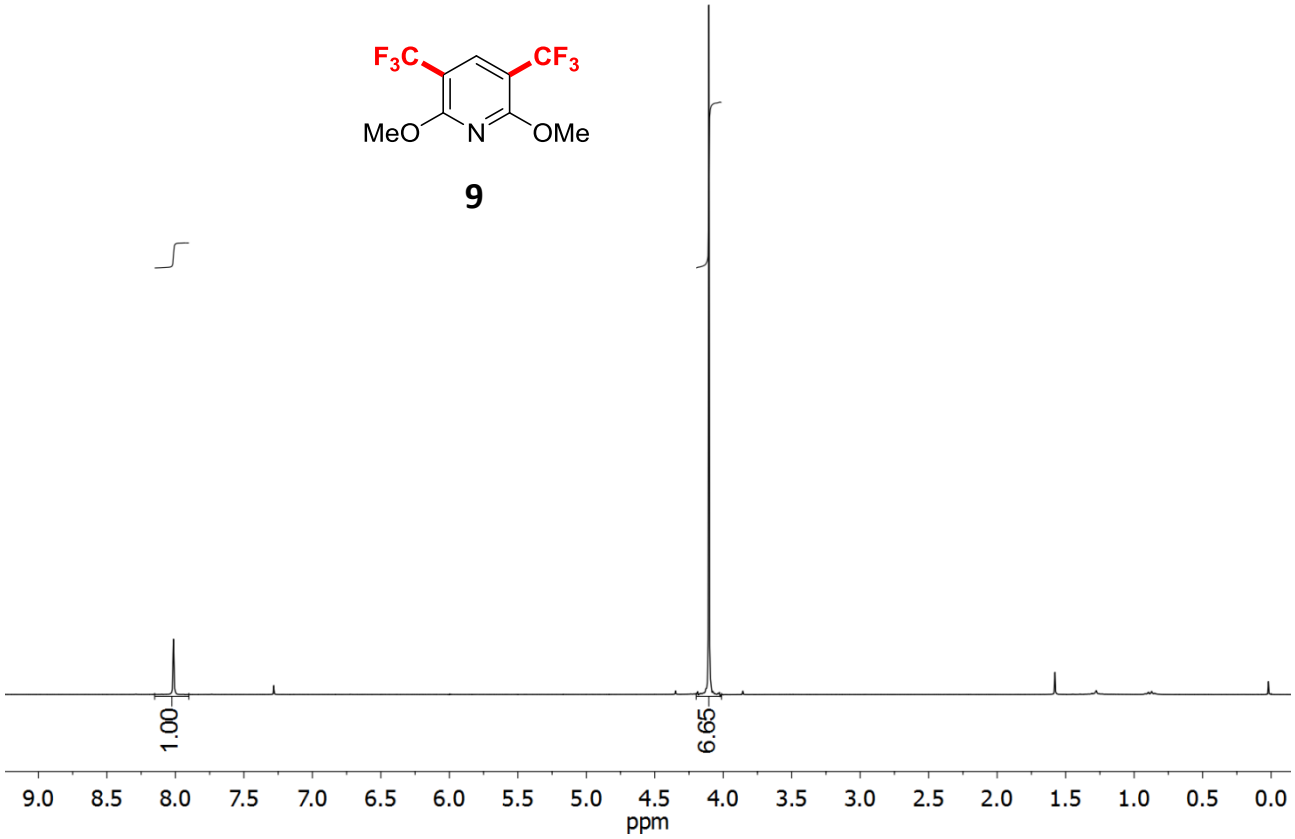
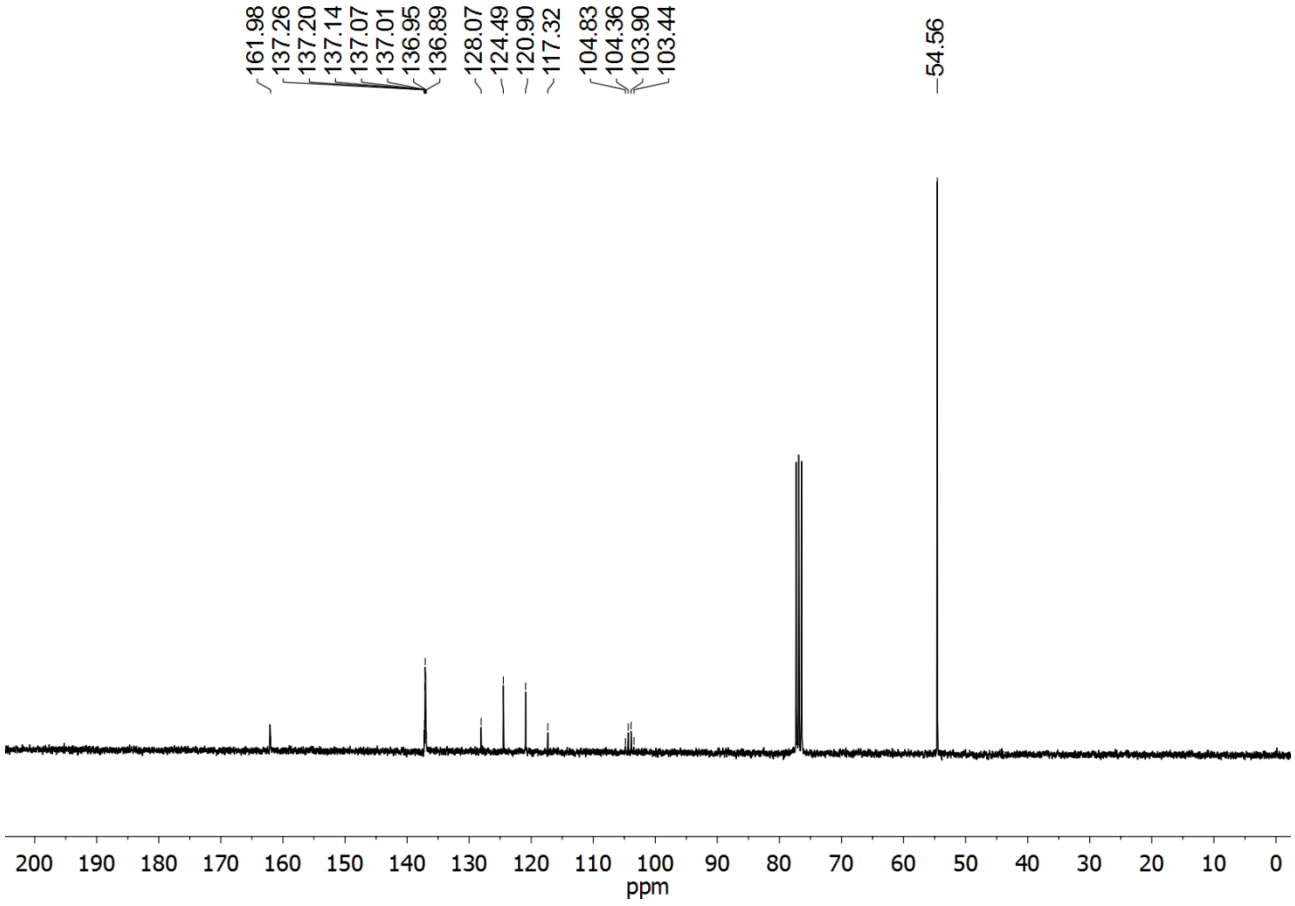
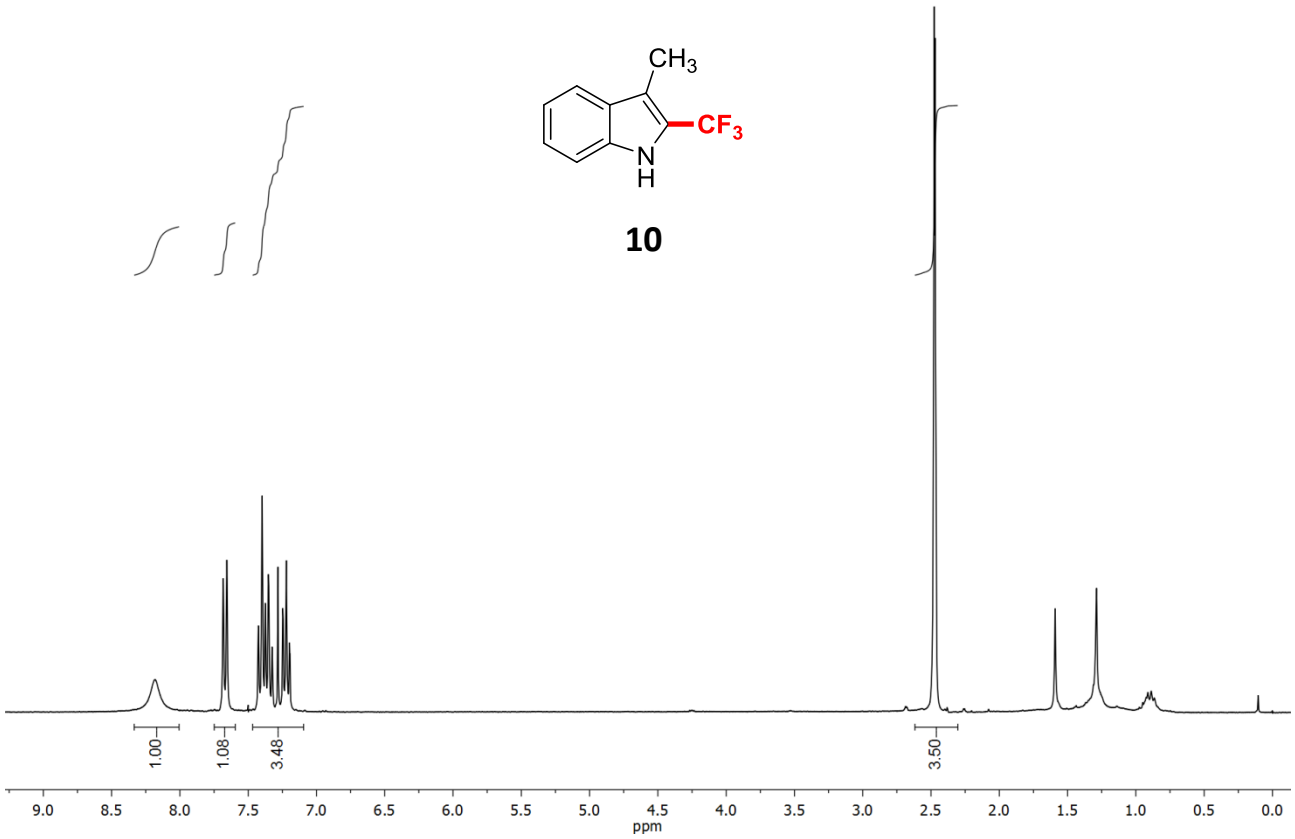
ppm


155.92
145.77
134.10
134.08
134.06
129.40
125.75
122.09
120.79
120.43
120.05
119.68
118.44
61.80
60.68
17.15
17.09
17.03
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
ppm

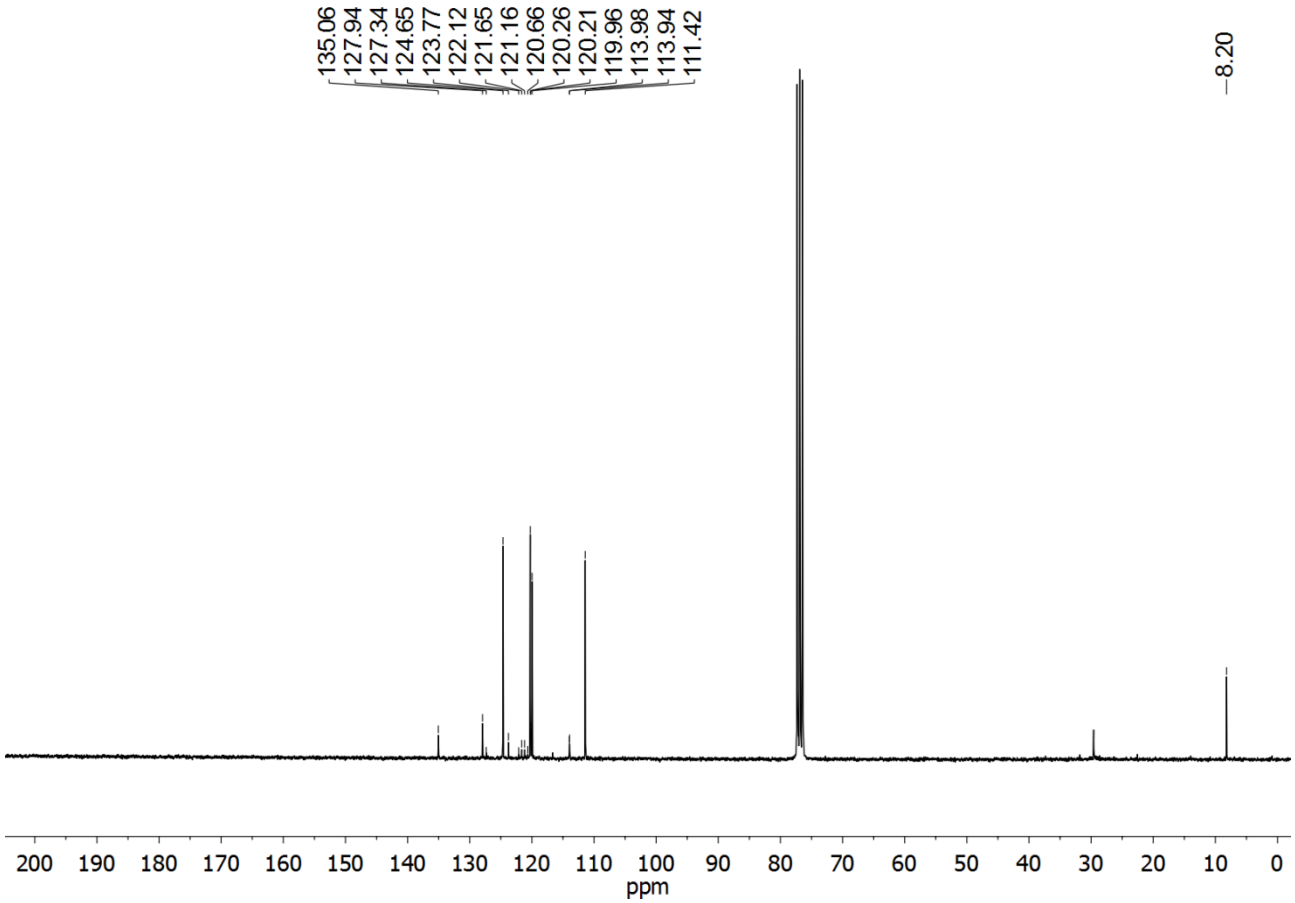

Me
CF3
Me
Me
8
1.00
3.27
1.61
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm
140.70
137.18
137.15
137.12
137.10
131.53
130.70
127.88
125.20
124.82
124.45
124.22
124.07
120.57
21.23
21.18
21.13
21.07
20.68
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

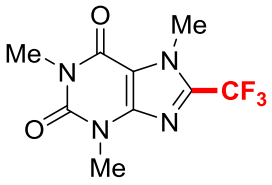

F3C
CF3
MeO
N
OMe
9
1.00
6.65
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
ppm


161.98
137.26
137.20
137.14
137.07
137.01
136.95
136.89
128.07
124.49
120.90
117.32
104.83
104.36
103.90
103.44
54.56
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
ppm


CH3
CF3
N
H
1.00
1.08
3.48
3.50
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
ppm

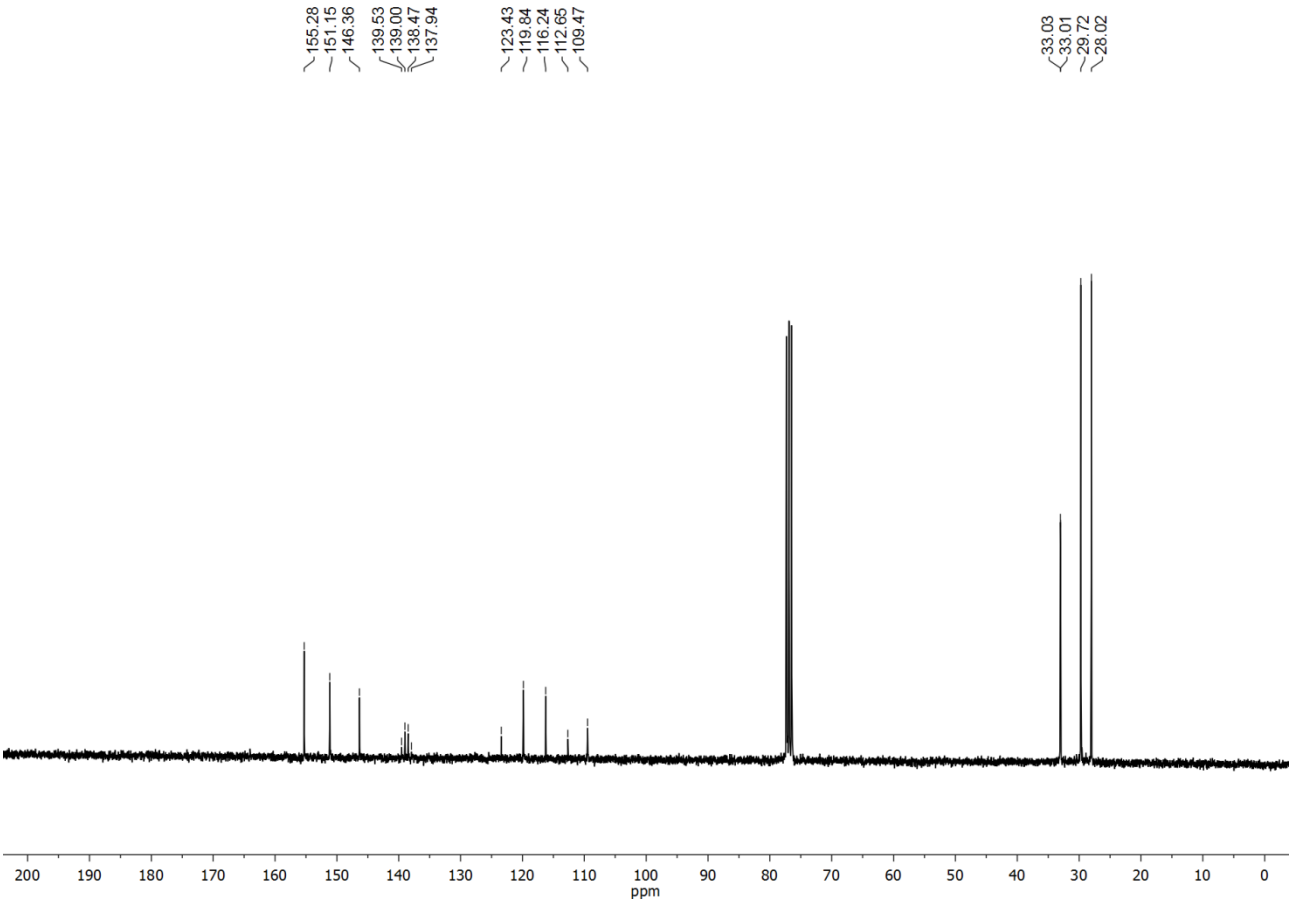
10

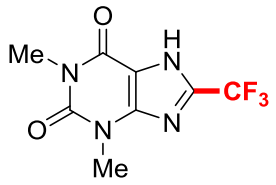

135.06
127.94
127.34
124.65
123.77
122.12
121.65
121.16
120.66
120.26
120.21
119.96
113.98
113.94
111.42
8.20
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
ppm


O
Me
Me
N
N
CF3
O
N
N
Me

11

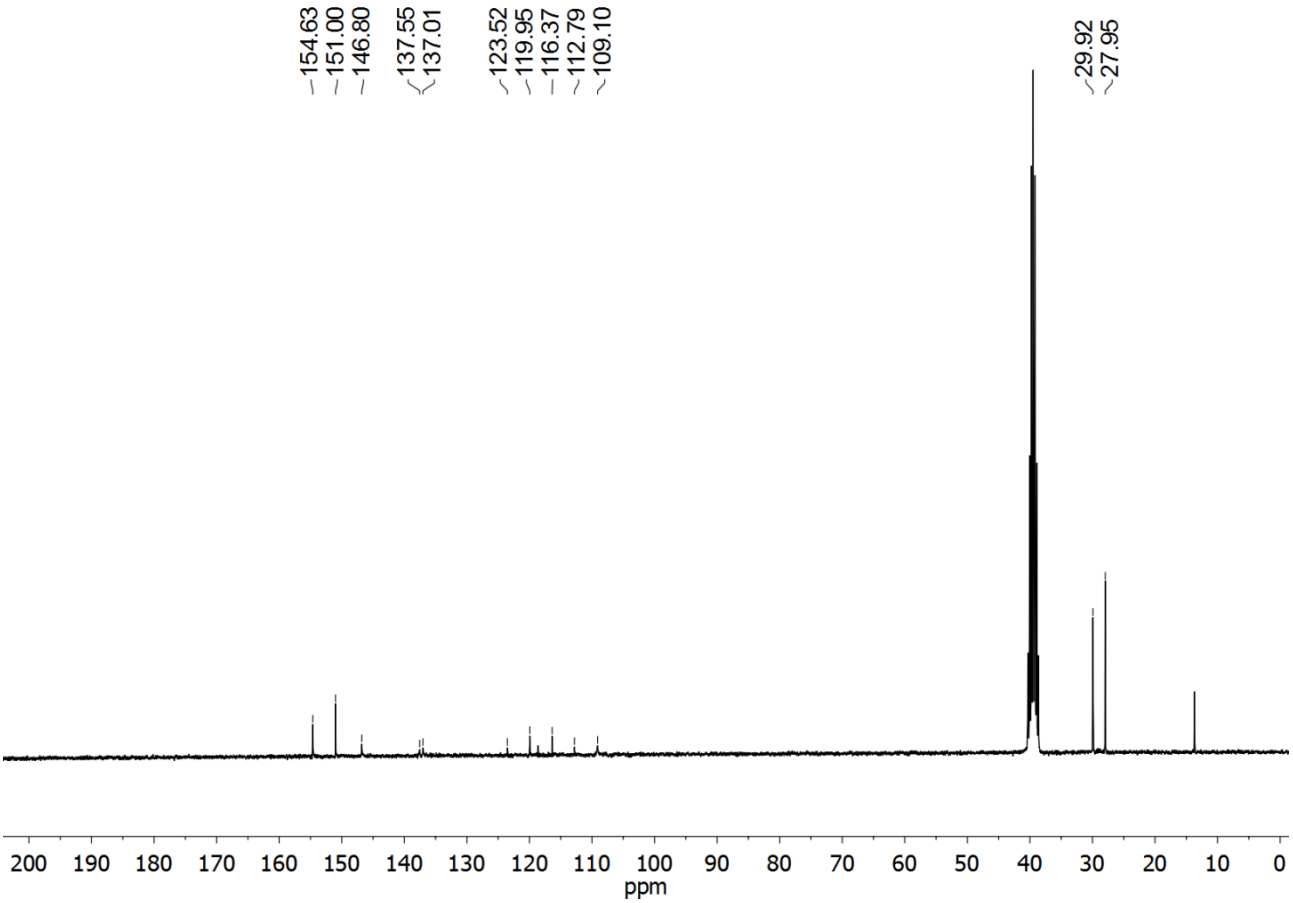
1.00
1.03
1.06
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
ppm

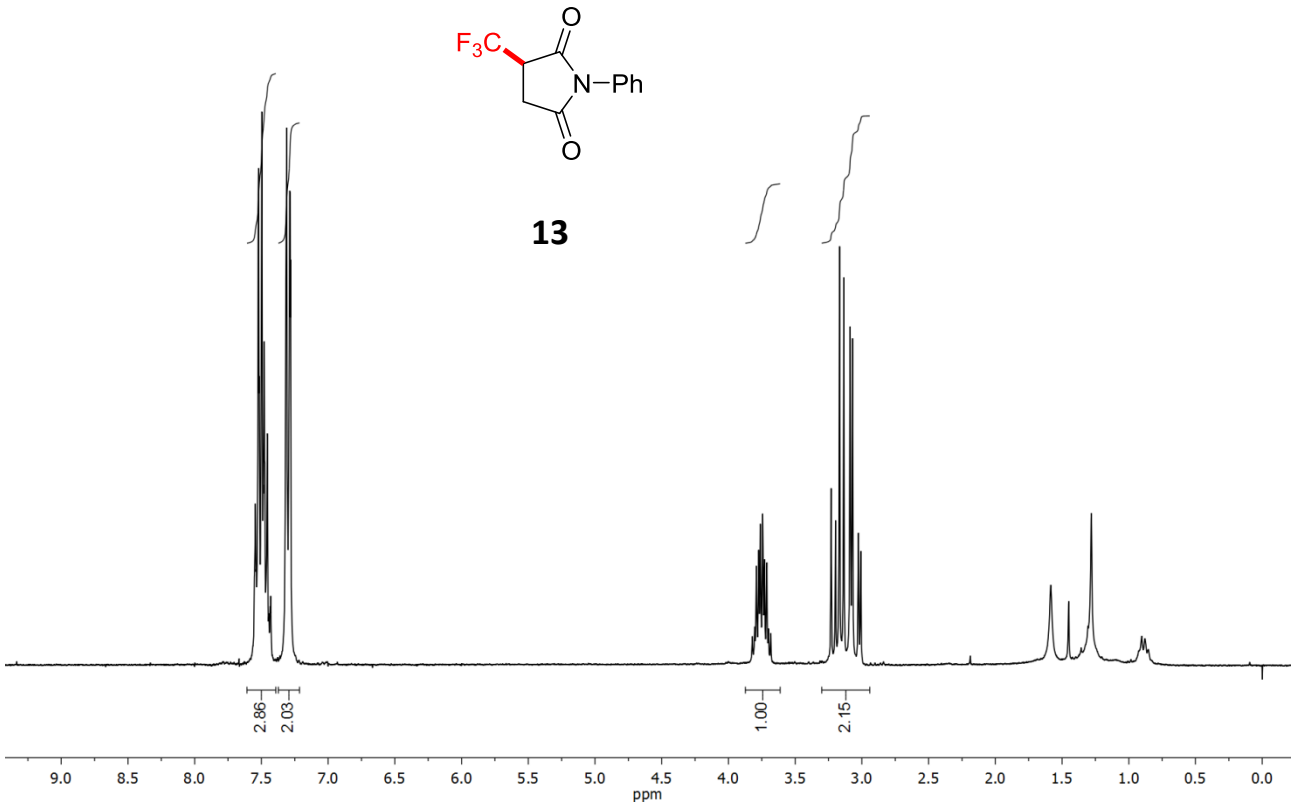

155.28
151.15
146.36
139.53
139.00
138.47
137.94
123.43
119.84
116.24
112.65
109.47
33.03
33.01
29.72
28.02
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
ppm

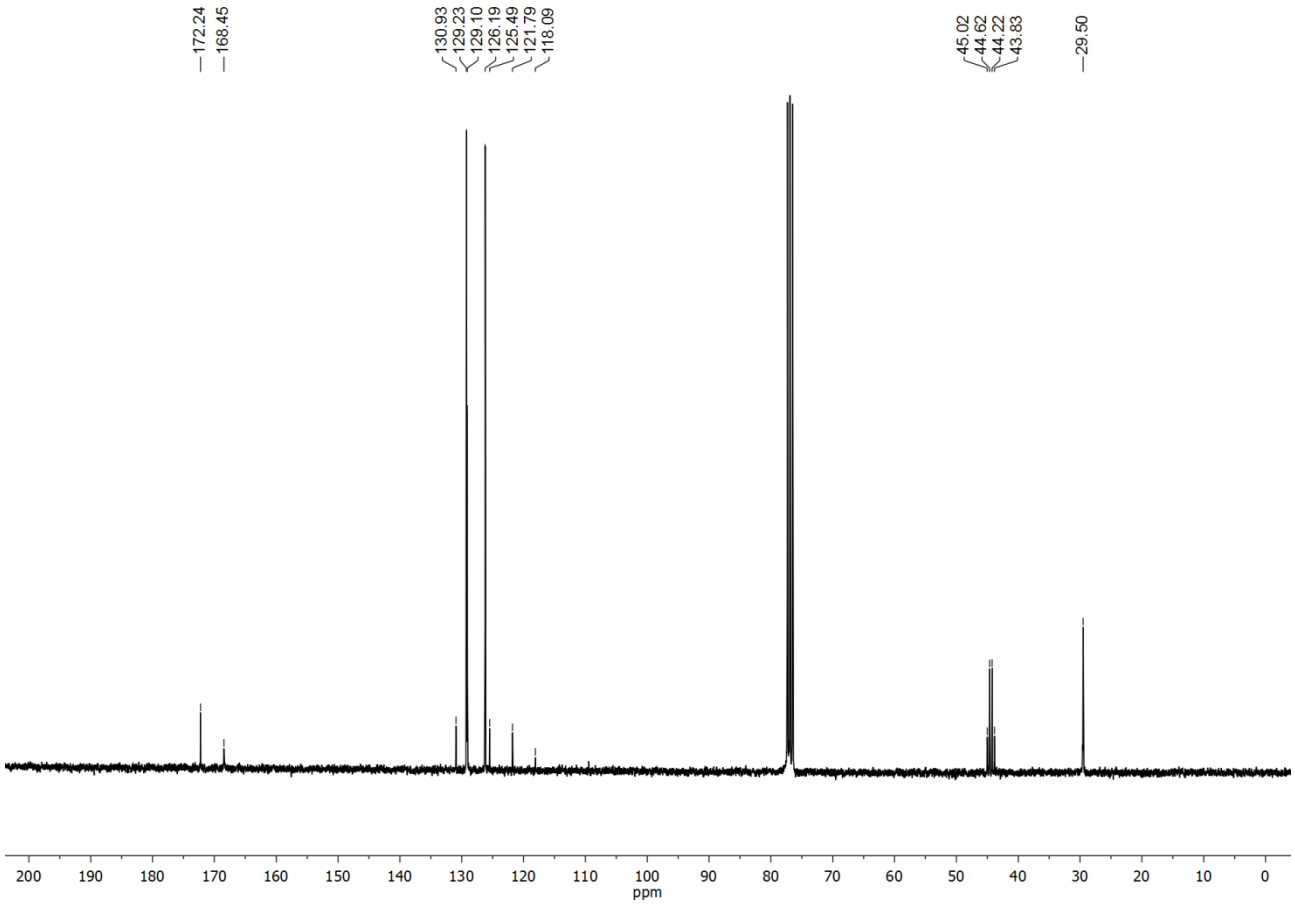

O
H
Me
N
N
CF3
O
N
N
Me

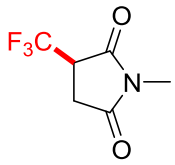
12

4.93
5.11
1.00
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
ppm


154.63
151.00
146.80
137.55
137.01
123.52
119.95
116.37
112.79
109.10
29.92
27.95
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
ppm

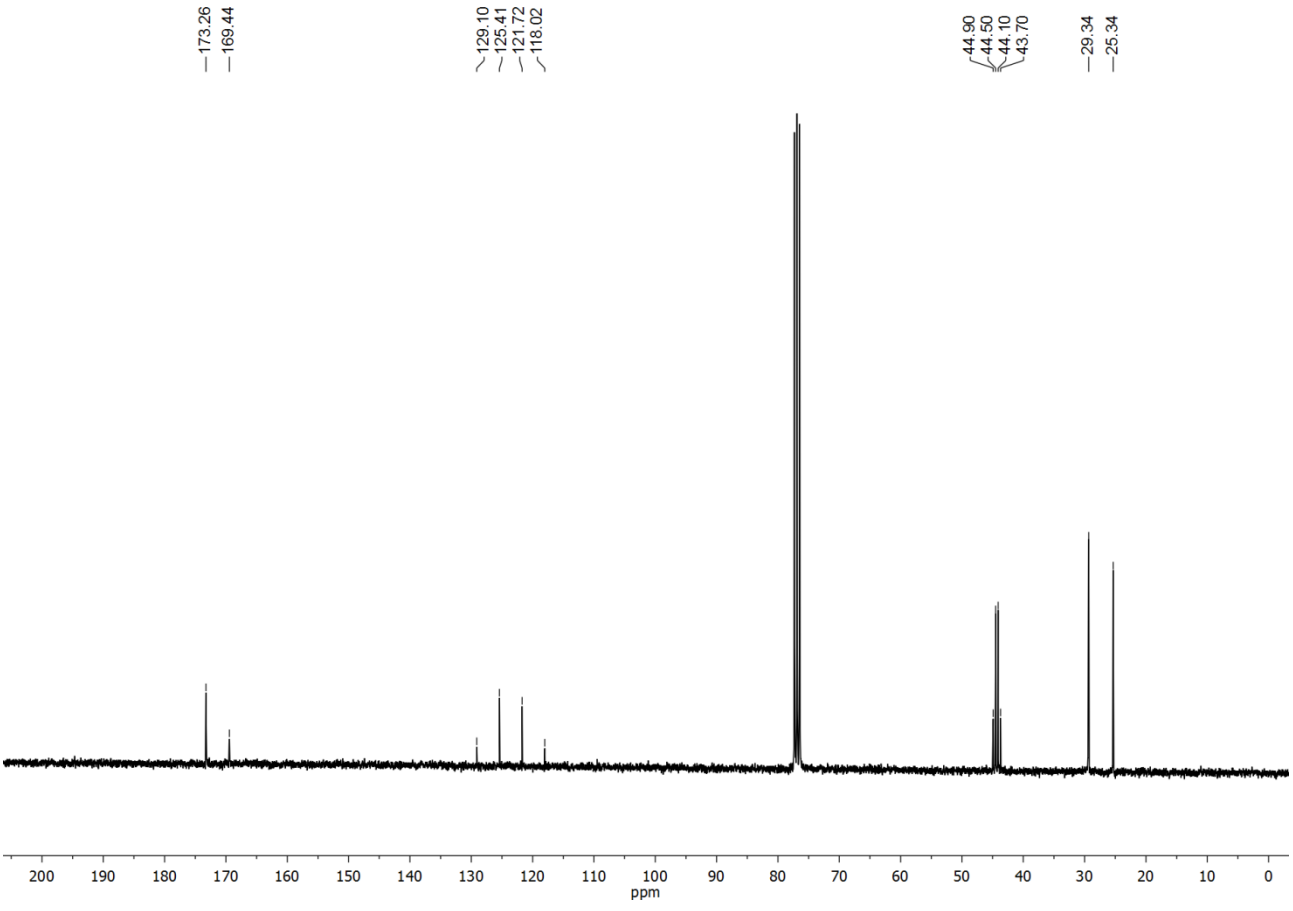

F3C
O
N–Ph
O
13
2.86
2.03
1.00
2.15
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
ppm

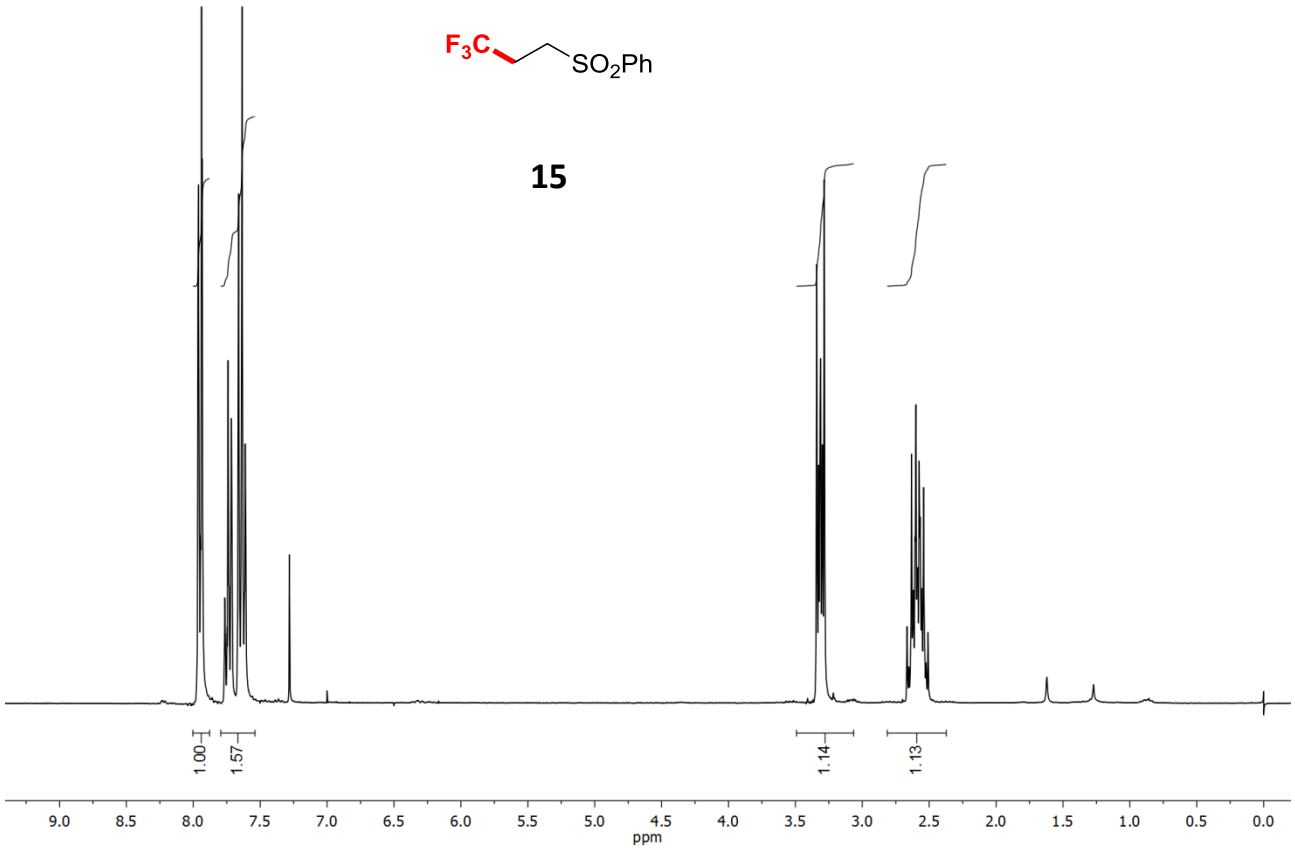

172.24
168.45
130.93
129.23
129.10
126.19
125.49
121.79
118.09
45.02
44.62
44.22
43.83
29.50
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
ppm

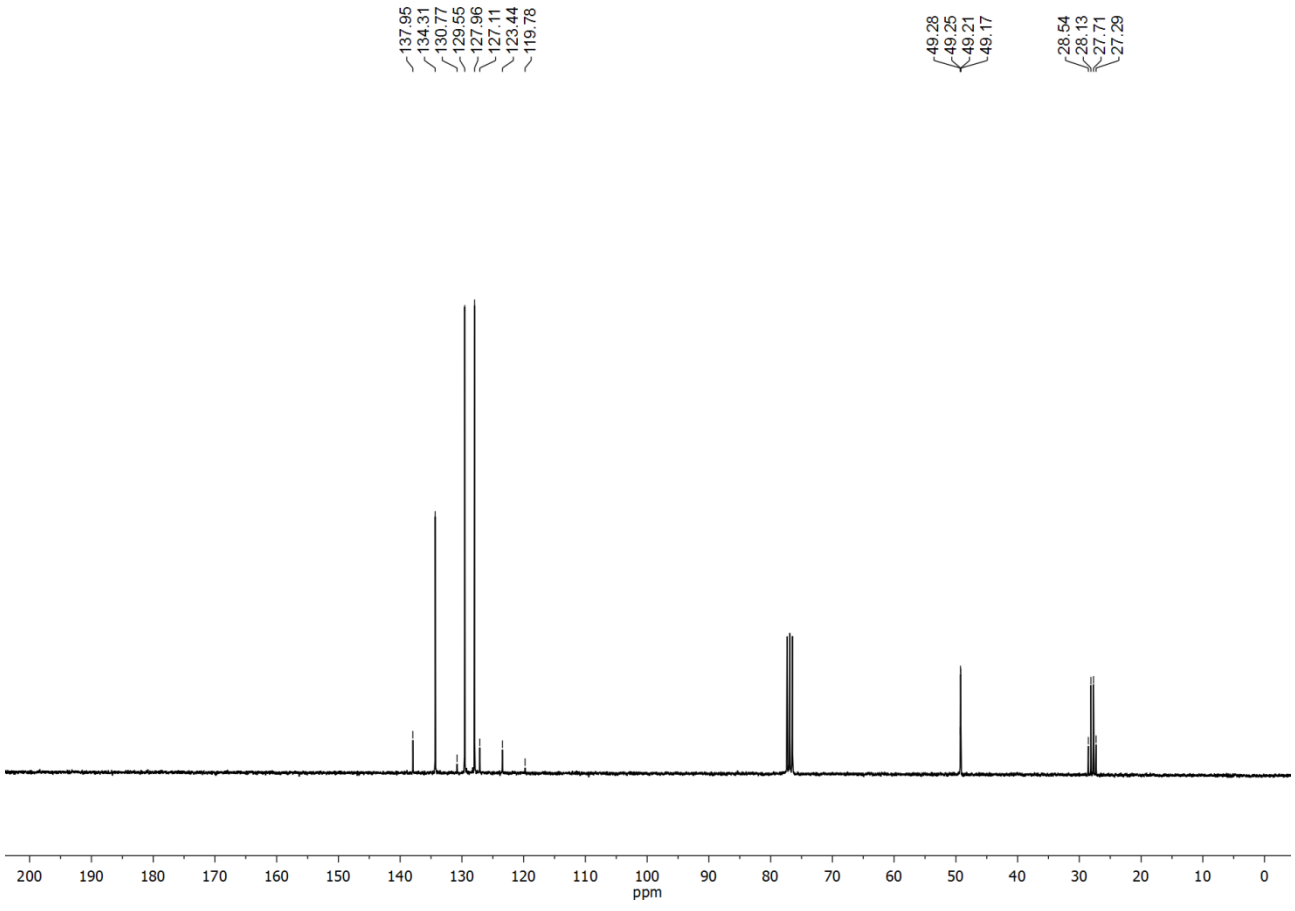

F3C
O
N
O

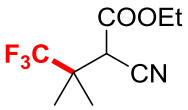
14

1.00
5.04
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm

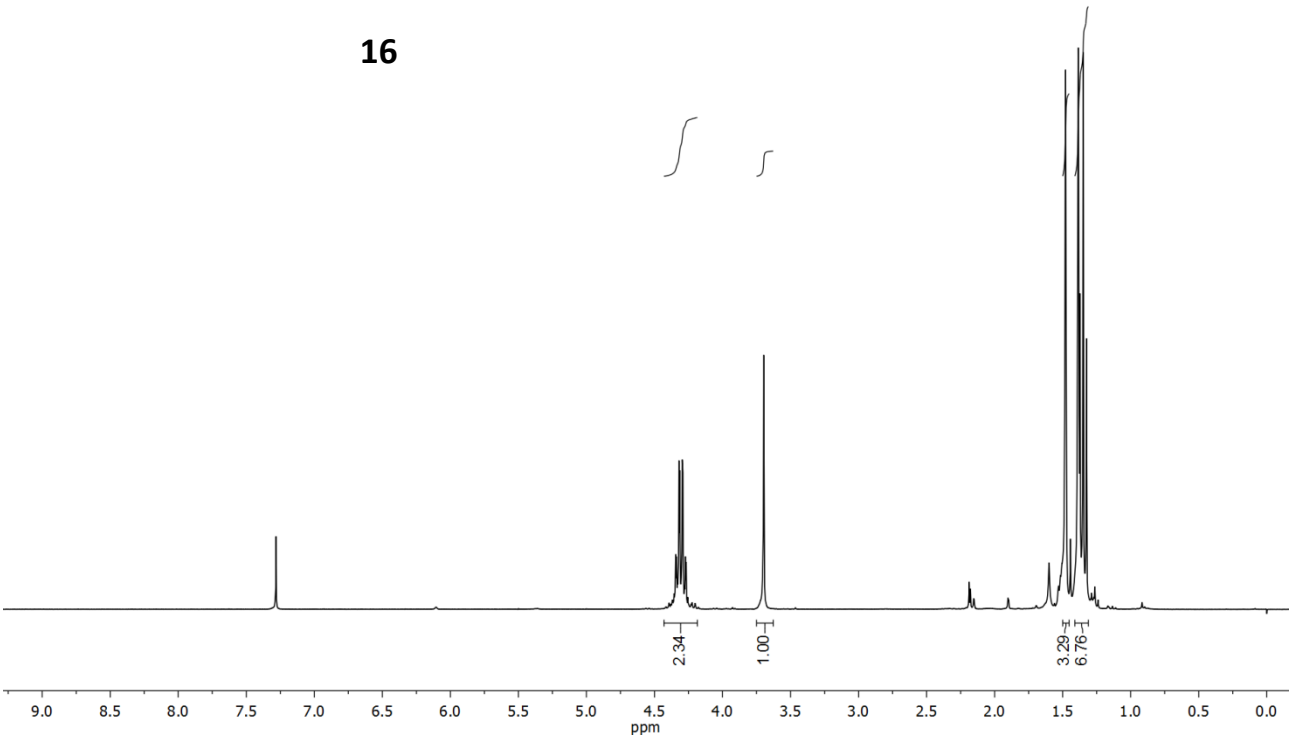

173.26
169.44
129.10
125.41
121.72
118.02
44.90
44.50
44.10
43.70
29.34
25.34
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

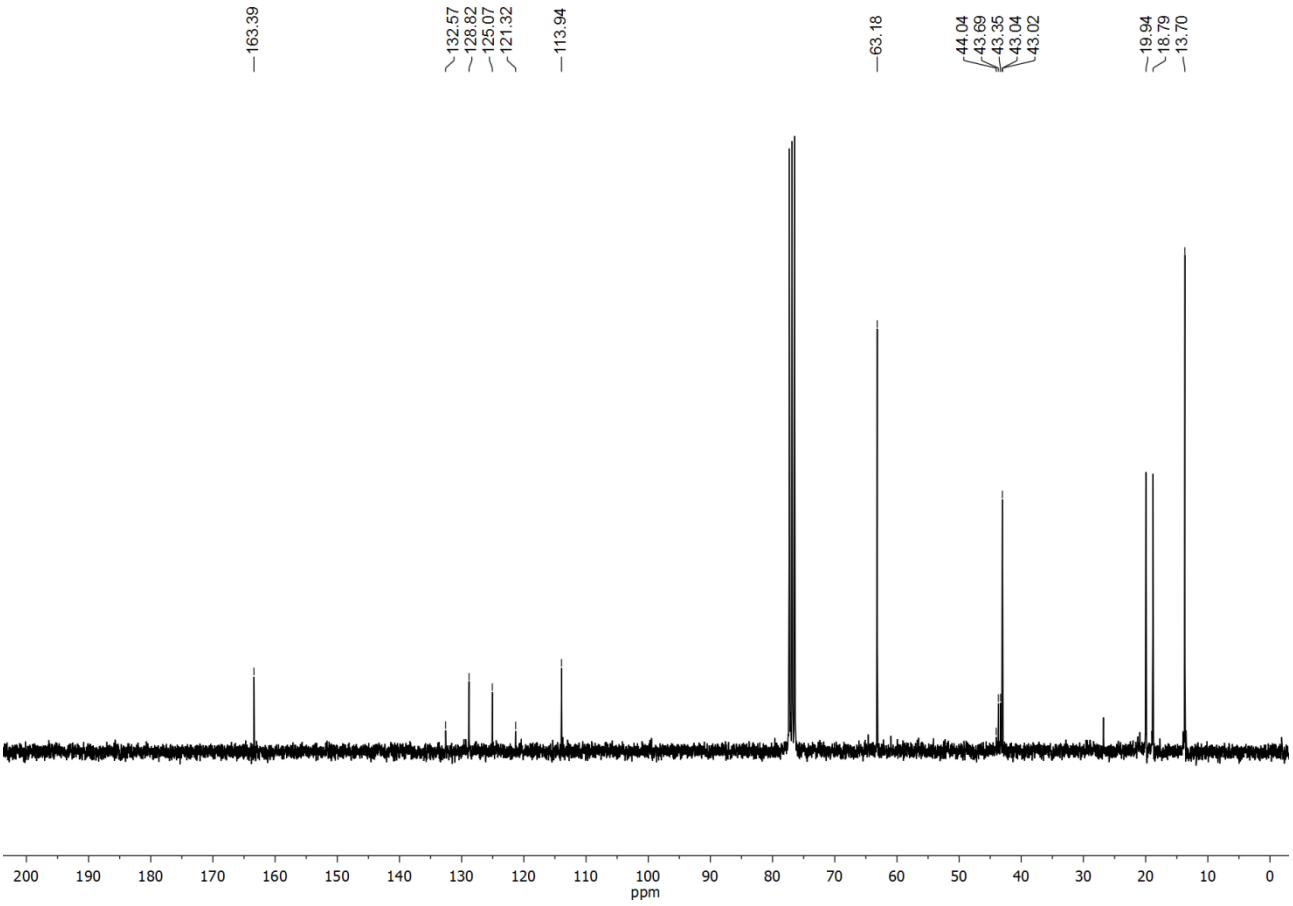

F3C
SO2Ph
15
1.00
1.57
1.14
1.13
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm


137.95
134.31
130.77
129.55
127.96
127.11
123.44
119.78
49.28
49.25
49.21
49.17
28.54
28.13
27.71
27.29
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


COOEt
F3C
CN

16


2.34
1.00
3.29
6.76
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm


163.39
132.57
128.82
125.07
121.32
113.94
63.18
44.04
43.69
43.35
43.04
43.02
19.94
18.79
13.70
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm