Pentafluorophenyl vinyl sulfonate enables efficient, metal free, radical-based alkene hydroacylation with aldehyde as limiting reagent

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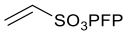
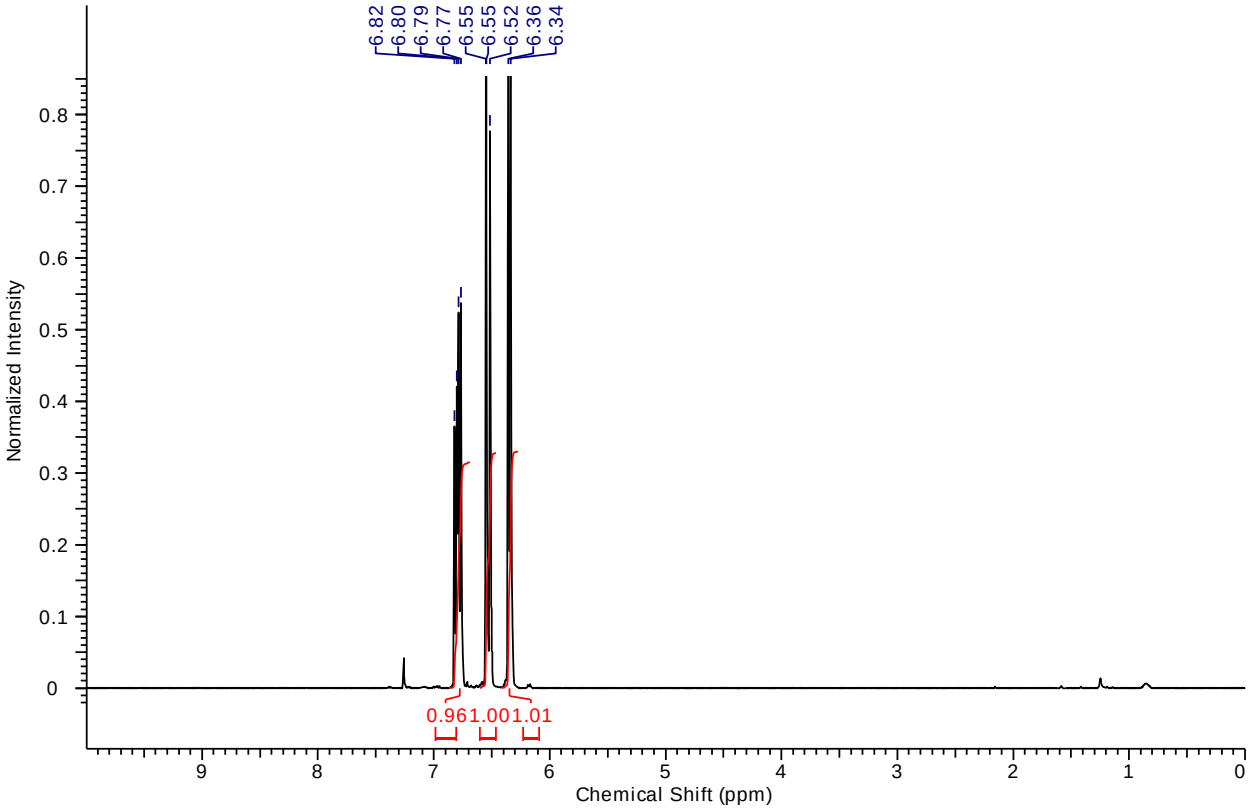
General Experimental

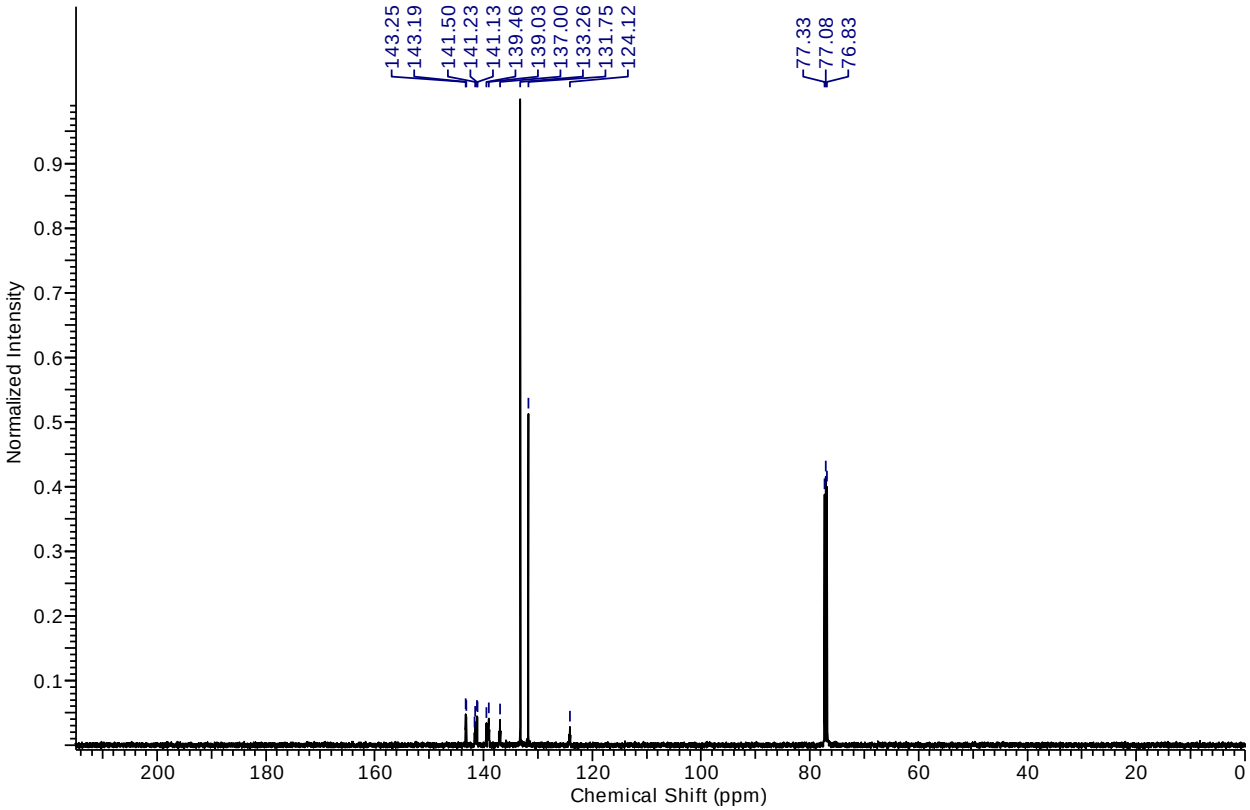
All reagents were purchased from Aldrich or AlfaAesar and were used as received without further purification. Where described below petrol refers to petroleum ether (b.p. 40–60 °C). All reactions were monitored by thin-layer chromatography (TLC) on pre-coated silica gel plates (254 μm). Flash column chromatography was carried out with Kiesegel 60M 0.04/0.063 mm (200–400 mesh) silica gel. ^{1}H NMR spectra were recorded at 300 MHz, 400 MHz, 500 MHz and 600 MHz and ^{13}C NMR at 75 MHz, 100 MHz, 125 MHz and 150 MHz on a Bruker AMX300, AMX400, AMX500 and AMX600 at 21 °C unless otherwise stated. The chemical shifts (δ) for ^{1}H and ^{13}C are quoted relative to residual signals of the solvent on the ppm scale. Coupling constants (*J* values) are reported in hertz (Hz). Due to the broadness of the ^{13}C NMR signals in the pentafluorophenyl moiety these peaks have not been assigned. Mass spectra were obtained on a VG70-SE mass spectrometer. Infrared spectra were obtained on a Perkin Elmer Spectrum 100 FTIR Spectrometer operating in ATR mode. Optical rotation was measured using a Perkin Elmer 343 polarimeter. Chiral High Performance Liquid Chromatography (HPLC) was performed on a Varian HPLC instrument equipped with a manual injector, binary pump, and a UV detector (214 nm) using CHIRALCEL® OD column (4.6 mm x 250 mm, 10 μm) from Chiral Technologies (West Chester, PA)

Pentafluorophenyl ethenesulfonate 2[1]

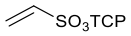


Pentafluorophenol (11.5 g, 62.5 mmol) and NEt_3 (19 mL, 138 mmol) in CH_2Cl_2 (20 mL) was added dropwise over 1 h to a solution at of 2-chloroethane sulfonyl chloride (10.1 g, 62.5 mmol) in CH_2Cl_2 (100 ml) at −78 °C. The mixture was allowed to warm slowly to 21 °C and diluted with CH_2Cl_2 (100 mL) and washed with H_2O (100 mL), 2 M HCl (2 × 100 mL) and sat. $NaHCO_3$ (2 × 100 mL), dried ($MgSO_4$) and the solvent removed *in vacuo*. Purification by column chromatography on silica gel (10% Et_2O/petrol) gave ethenesulfonic acid pentafluorophenyl ester **14** as a white solid (14.0 g, 51.0 mmol, 82%): ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.80 (dd, *J* = 10.0, 16.5 Hz, 1H), 6.53 (dd, *J* = 0.5, 16.5 Hz, 1H), 6.35 (dd, *J* = 0.5, 10.0 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 133.2 (CH_2), 131.8 (CH); IR (thin film) 2965, 1652, 1626, 1521 cm^{-1}; LRMS (EI) 274 (100, $[M]^+$).

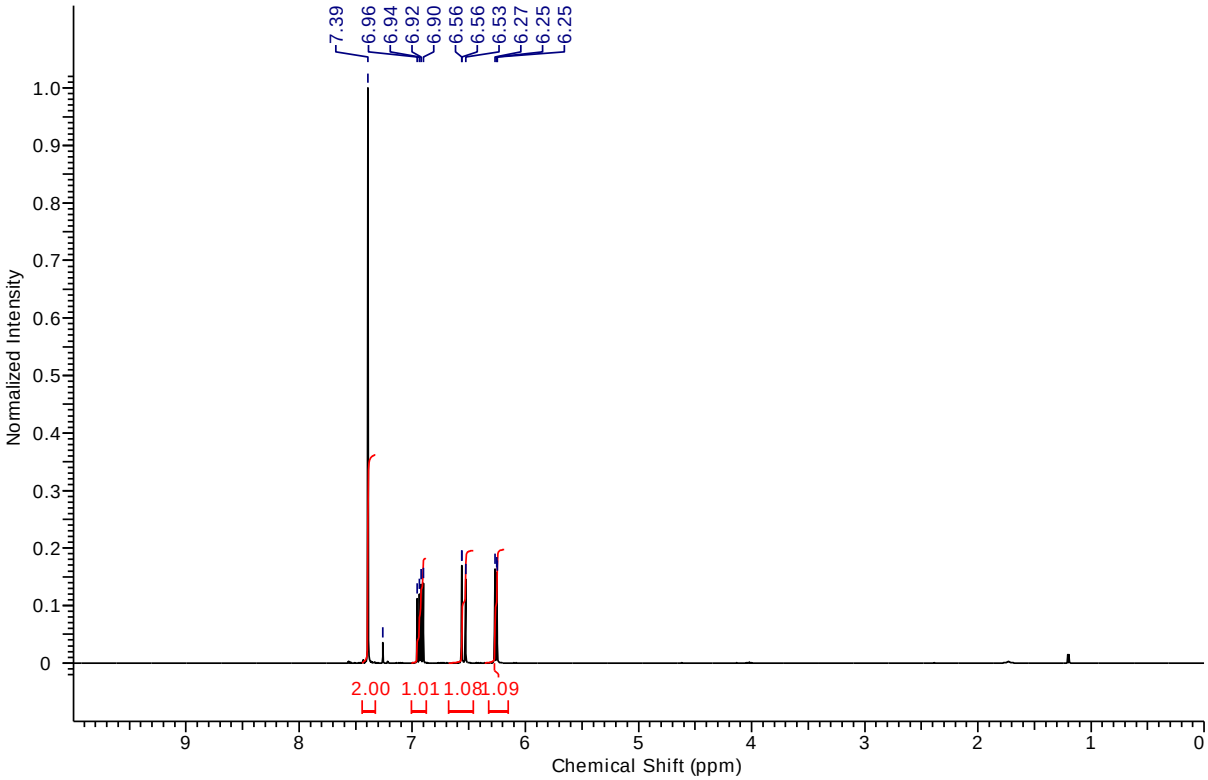

6.82
6.80
6.79
6.77
6.55
6.55
6.52
6.36
6.34
Normalized Intensity
0.961.001.01
Chemical Shift (ppm)

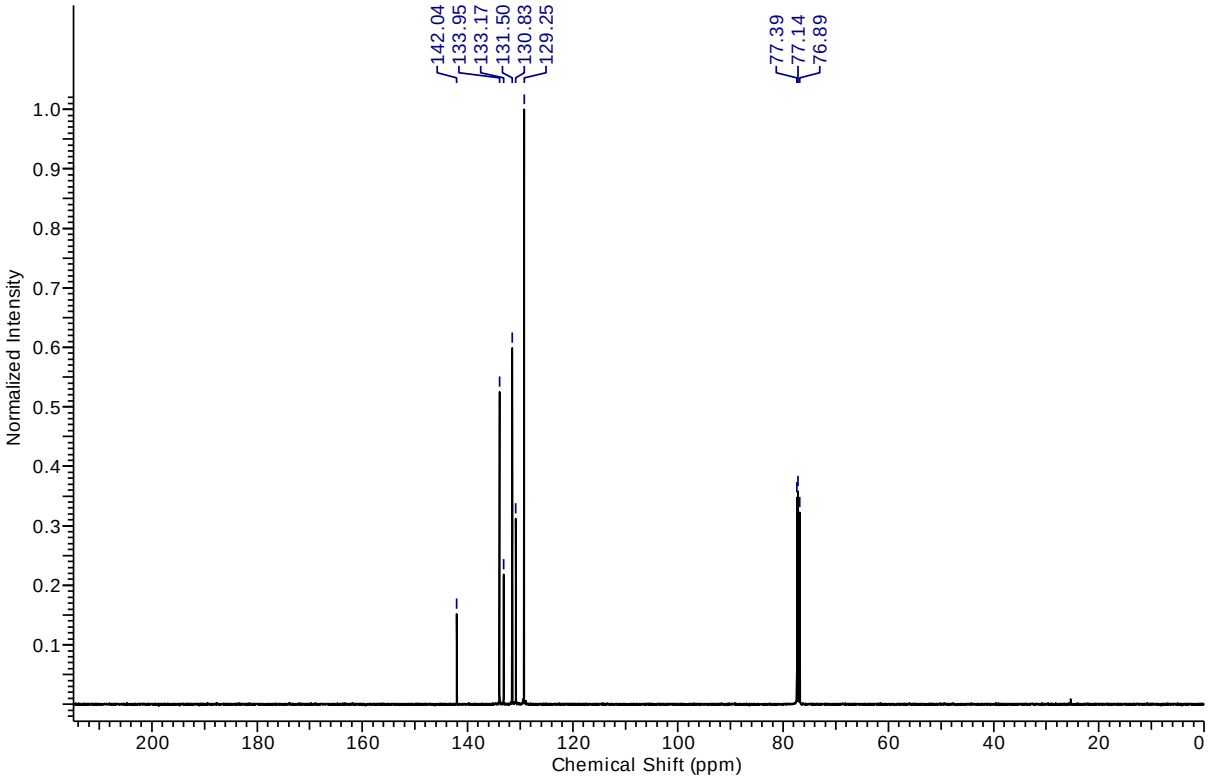

143.25
143.19
141.50
141.23
141.13
139.46
139.03
137.00
133.26
131.75
124.12
77.33
77.08
76.83
Normalized Intensity
Chemical Shift (ppm)

2,4,6-Trichlorophenyl ethenesulfonate[1]

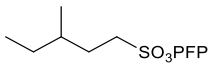


To a stirred solution of 2-chloroethane sulfonyl chloride (5.8 mL, 55 mmol) in CH_2Cl_2 (100 mL) at −10 °C was added dropwise, over 90 min, 2,4,6-trichlorophenol (9.9 g, 50 mmol) and NEt_3 (15.6 mL, 110 mmol) in CH_2Cl_2 (50 mL). The mixture was allowed to warm slowly to 21 °C and filtered through a plug of 10% K_2CO_3/silica with CH_2Cl_2 (250 mL). The solvent was removed *in vacuo* and purification by recrystallization (CH_2Cl_2/petrol) gave 2,4,6-trichlorophenyl ethenesulfonate as a white solid (11.6 g, 40.0 mmol, 80% yield): m.p. 53–55 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.39 (s, 2H), 6.92 (dd, 1H, *J* = 10.0, 16.5), 6.55 (dd, 1H, *J* = 1.0, 16.5), 6.26 (dd, 1H, *J* = 1.0, 10.0); ^{13}C NMR (126 MHz, $CDCl_3$) δ 142.0 (C), 134.0 (CH), 133.2 (C), 131.5 (CH_2), 130.8 (C), 129.3 (CH); IR (thin film) 3084, 1563 cm^{-1}; LRMS (CI) 287 (100, $[M+H]^+$).

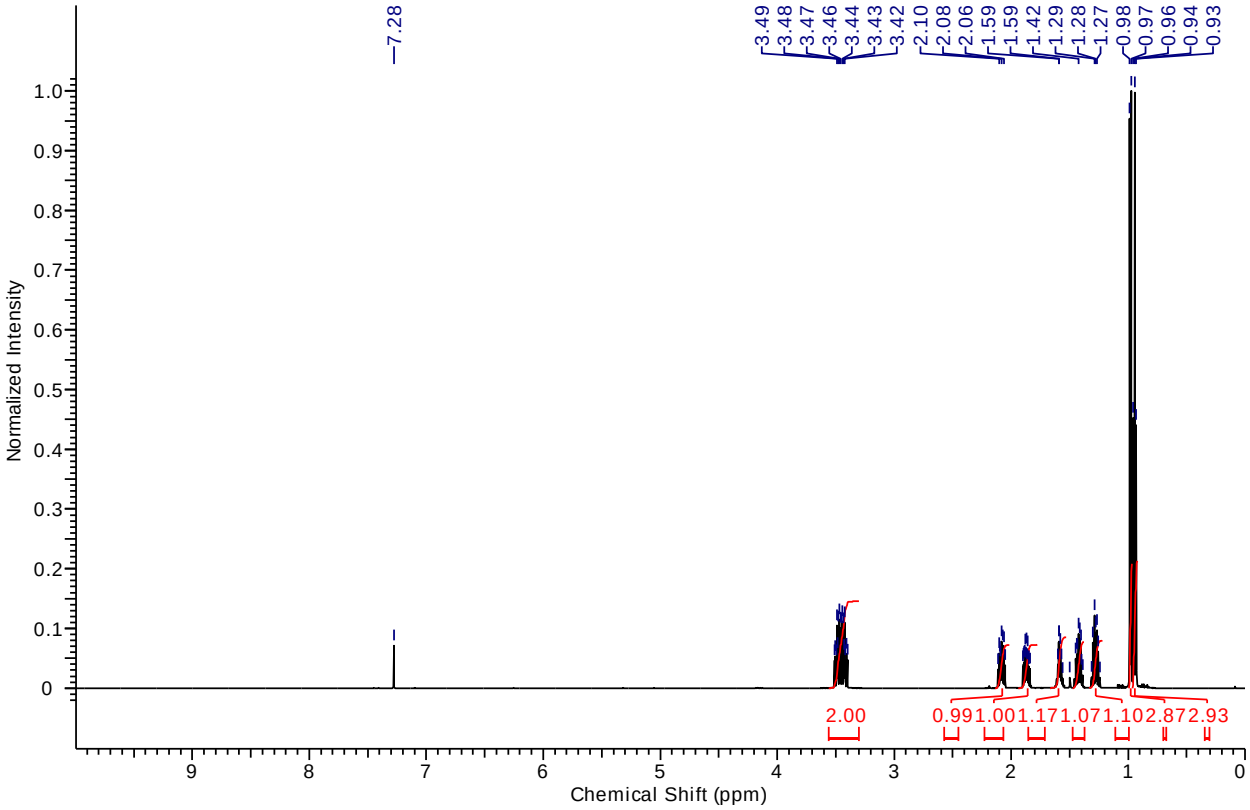


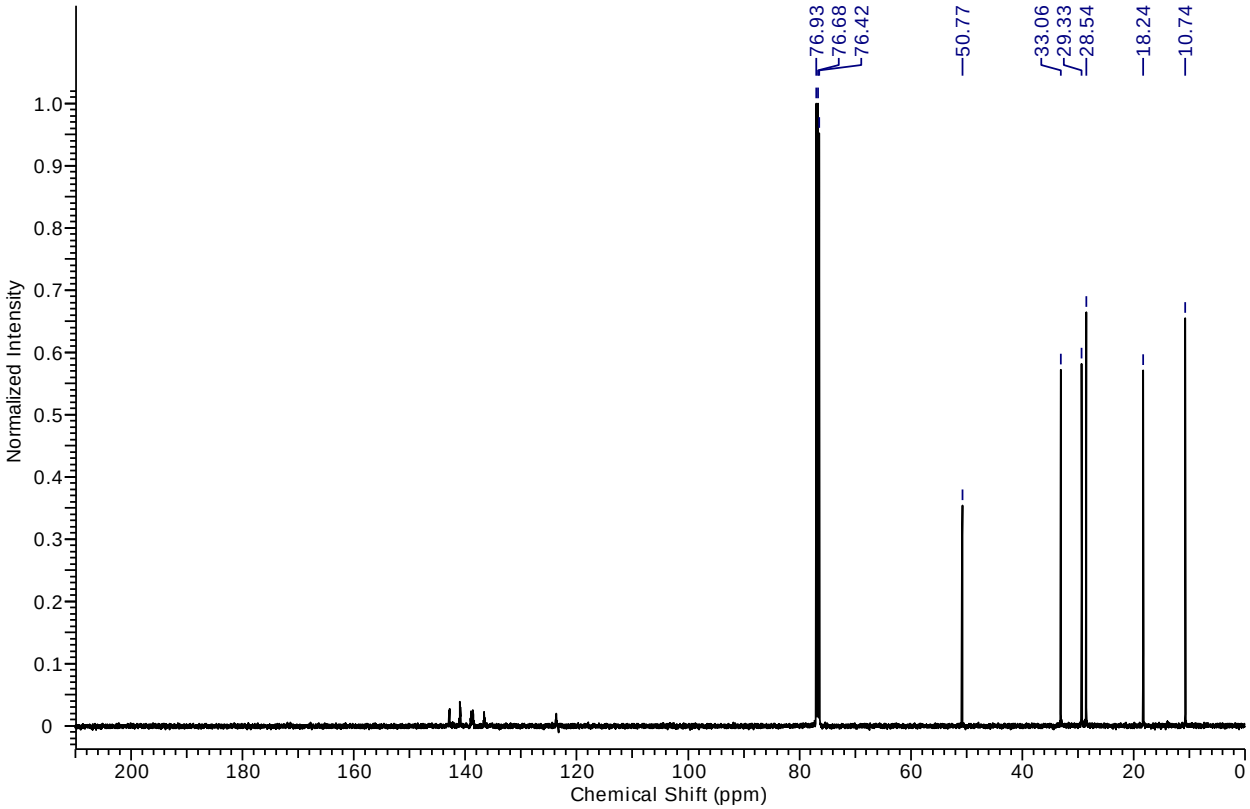


Pentafluorophenyl 3-methylpentane-1-sulfonate 6

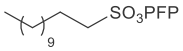


^{1}H NMR (600 MHz, $CDCl_3$) δ 3.51-3.40 (m, 2H), 2.11-2.05 (m, 1H), 1.87 (dddd, *J* = 19.0, 13.5, 7.5, 5.0 Hz, 1H), 1.61-1.55 (m, 1H), 1.46-1.38 (m, 1H), 1.31-1.24 (m, 1H), 0.98 (d, *J* = 7.5 Hz, 3H), 0.94 (t, *J* = 7.0 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 50.8 (CH_2), 33.1 (CH), 29.3 (CH_2), 28.5 (CH_2), 18.2 (CH_3), 10.7 (CH_3); IR (thin film) 2966, 2880, 1515, 1384, 1178 cm^{-1}; LRMS (CI) 333 (100,$[M+H]^+$); HRMS (CI) calcd for $C_{12}H_{14}F_5O_3S$ $[M+H]^+$ 333.0584, observed 333.0574.

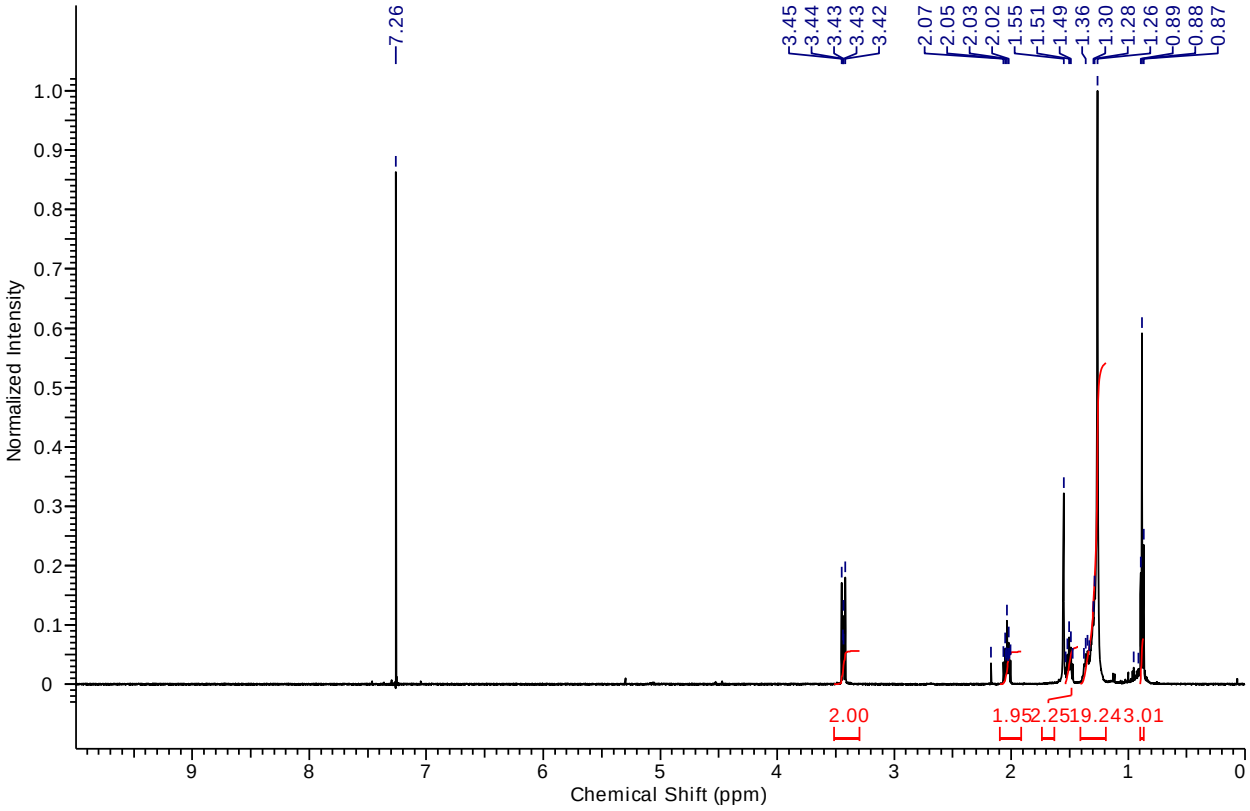

7.28
3.49
3.48
3.47
3.46
3.44
3.43
3.42
2.10
2.08
2.06
1.59
1.59
1.42
1.29
1.28
1.27
0.98
0.97
0.96
0.94
0.93
2.00
0.99
1.00
1.17
1.07
1.10
2.87
2.93
Normalized Intensity
Chemical Shift (ppm)

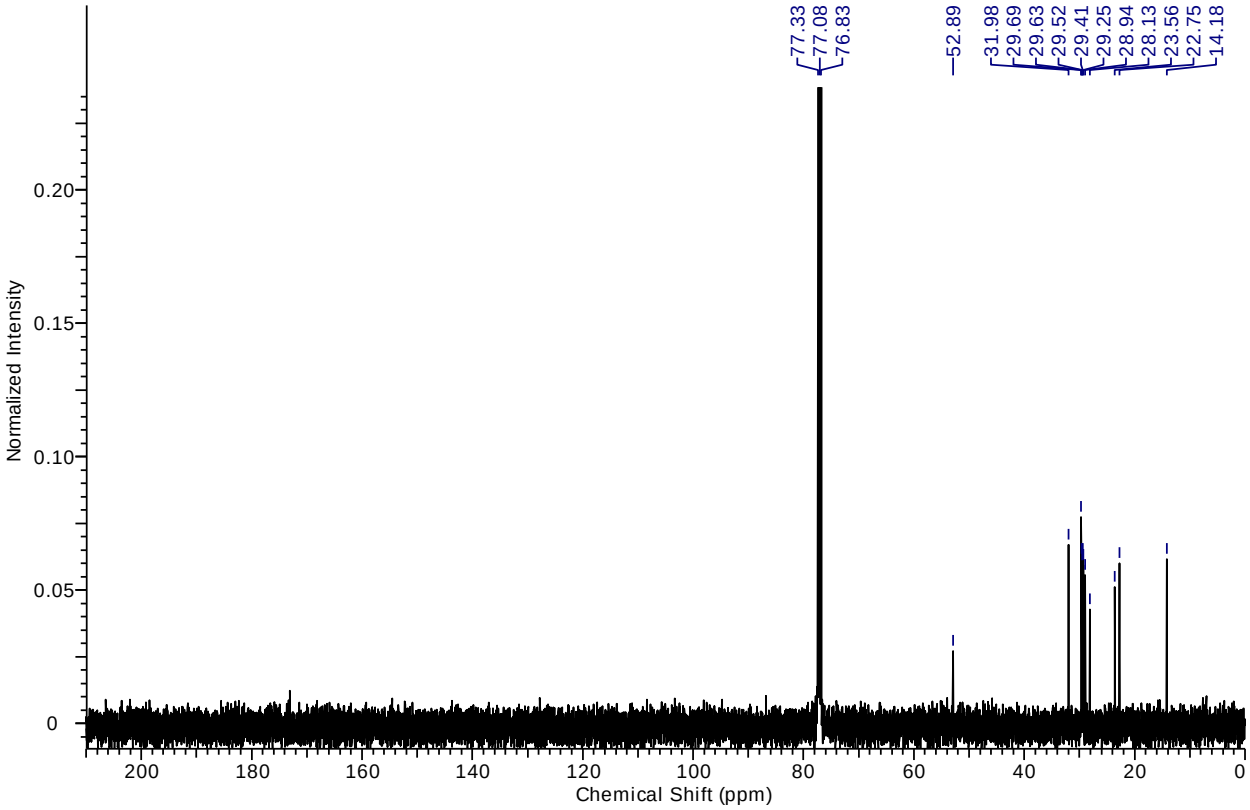

76.93
76.68
76.42
50.77
33.06
29.33
28.54
18.24
10.74
Normalized Intensity
Chemical Shift (ppm)

Pentafluorophenyl undecane-1-sulfonate 7

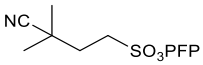


^{1}H NMR (500 MHz, $CDCl_3$) δ 3.46-3.41 (m, 2H), 2.06-2.00 (m, 2H), 1.55-1.47 (m, 2H), 1.40-1.23 (m, 18H), 0.88 (t, *J* = 7.0 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 52.9 (CH_2), 32.0 (CH_2), 29.7 (CH_2), 29.7 (CH_2), 29.6 (CH_2), 29.5 (CH_2), 29.4 (CH_2), 29.3 (CH_2), 28.9 (CH_2), 28.1 (CH_2), 23.6 (CH_2), 22.8 (CH_2), 14.2 (CH_3); IR (thin film) 2922, 2852, 1519, 1384, 1185 cm^{-1}; LRMS (CI) 431 (100, $[M+H]^+$); HRMS (CI) calcd for $C_{19}H_{28}F_5O_3S$ $[M+H]^+$ 431.1679, observed 431.1685.

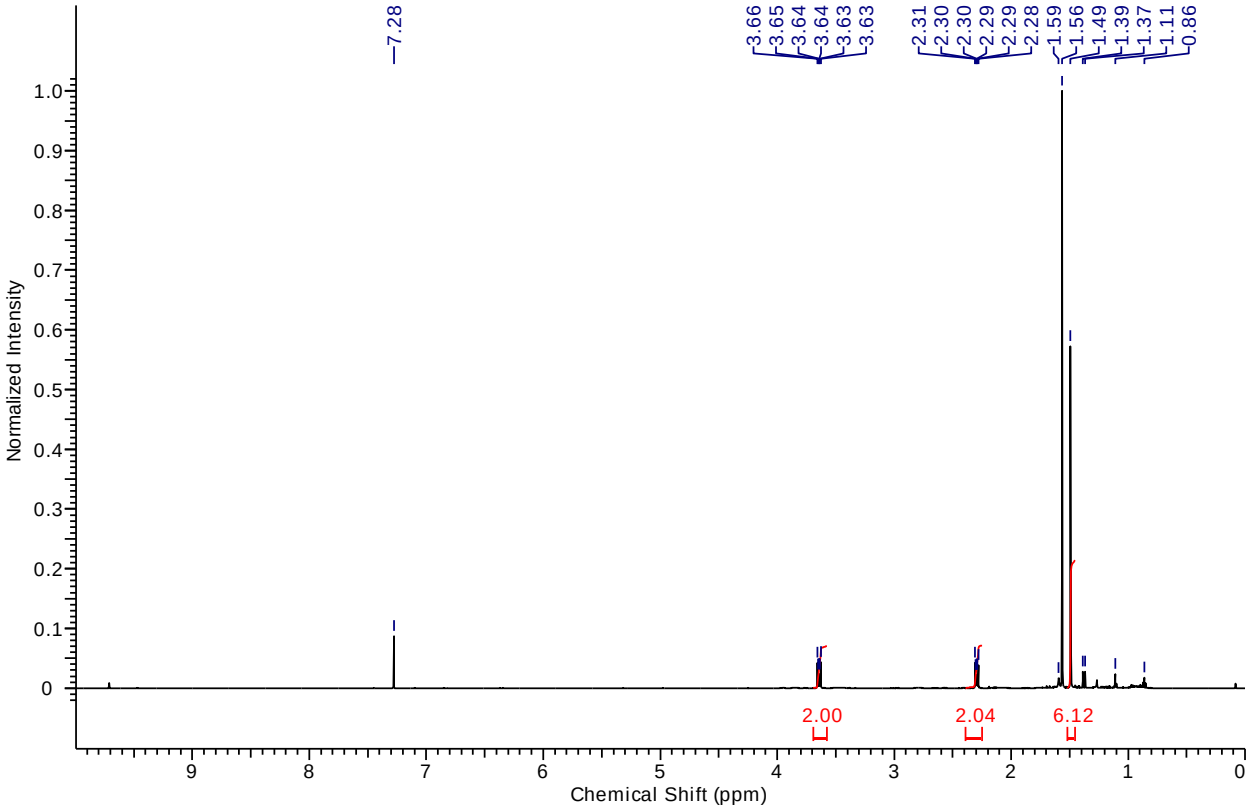


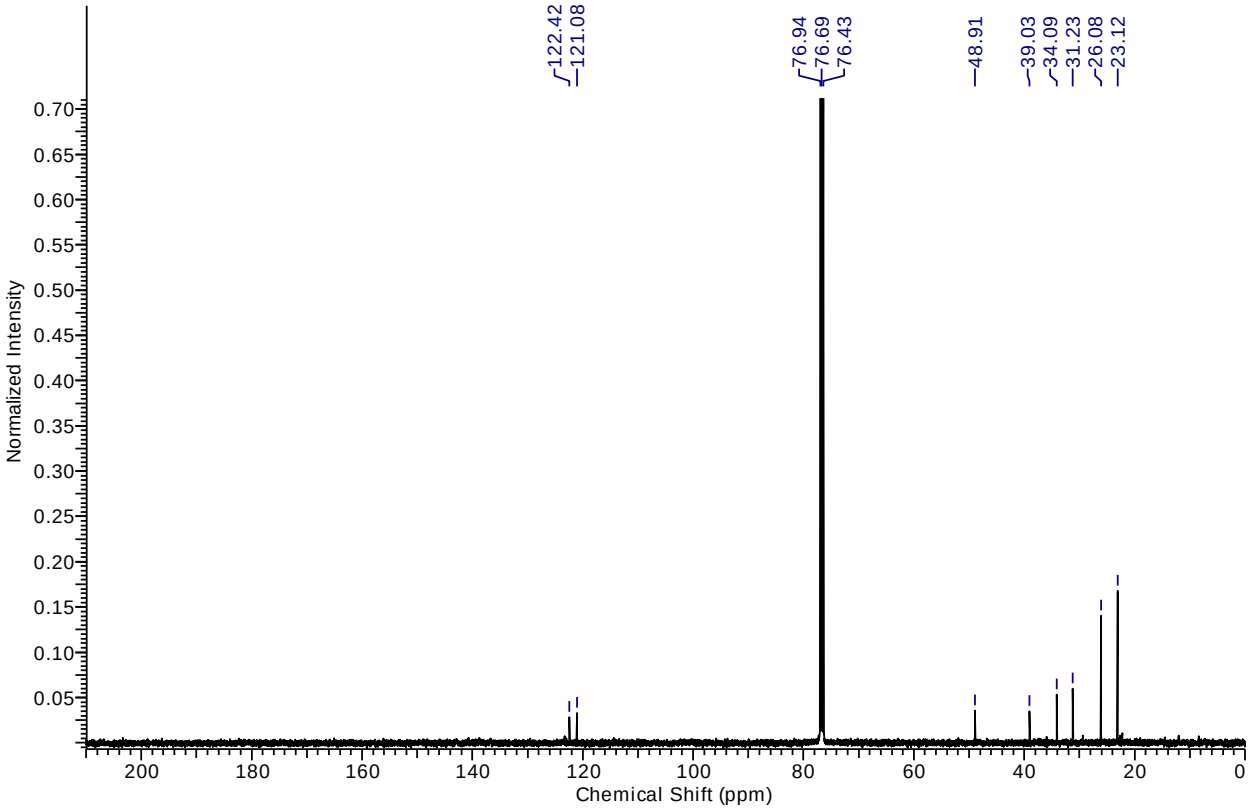


Pentafluorophenyl 3-cyano-3-methylbutane-1-sulfonate 8



^{1}H NMR (600 MHz, $CDCl_3$) δ 3.66-3.63 (m, 2H), 2.31-2.28 (m, 2H), 1.49 (s, 6H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 121.1 (C), 48.9 (CH_2), 39.0 (C), 34.5 (CH_2), 23.1 (CH3); IR (thin film) 2983, 2234, 1515, 1390, 1184 cm^{-1}; LRMS (CI) 344 (100, $[M+H]^+$); HRMS (CI) calcd for $C_{12}H_{11}F_5NO_3S$ $[M+H]^+$ 344.0380, observed 344.0386. Compound was inseparable from 2,2,3,3-tetramethylsuccinonitrile.


7.28
3.66
3.65
3.64
3.64
3.63
3.63
2.31
2.30
2.30
2.29
2.29
2.28
1.59
1.56
1.49
1.39
1.37
1.11
0.86
Normalized Intensity
2.00
2.04
6.12
Chemical Shift (ppm)


122.42
121.08
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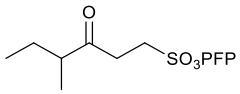
76.69
76.43
48.91
39.03
34.09
31.23
26.08
23.12
Normalized Intensity
Chemical Shift (ppm)

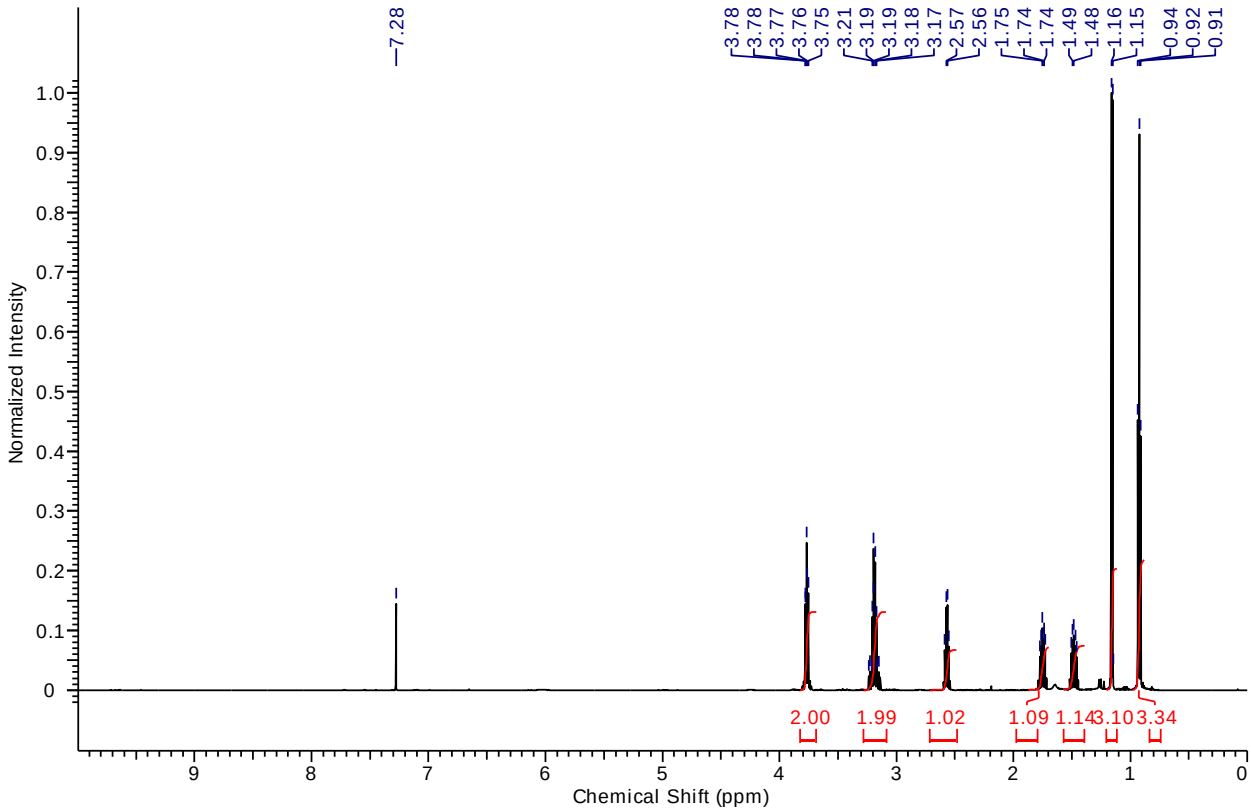
Typical procedure for the hydroacylation of an alkene

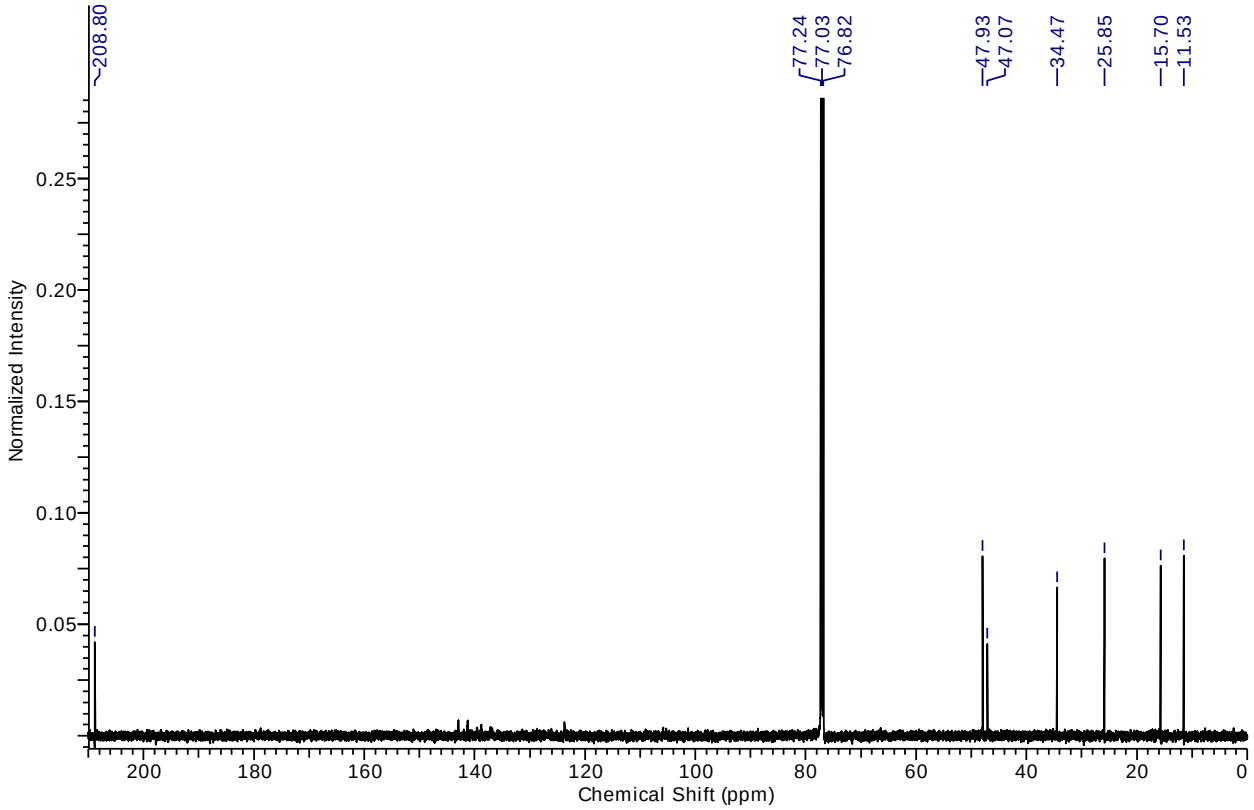
A solution of alkene (1.5 mmol) in benzene (1 mL) was freeze-thaw degassed three times and then stirred under an atmosphere of argon. To this, was added aldehyde (1 mmol) and AIBN (32 mg, 0.20 mmol) and the reaction mixture stirred at 40 °C for 72 h. The solvent was removed *in vacuo* and the crude residue purified as described below to afford the desired ketone sulfonate ester.

Pentafluorophenyl 4-methyl-3-oxohexane-1-sulfonate 3a

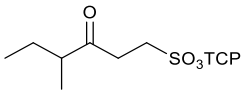


Purification by flash column chromatography (30-70% CH_2Cl_2/petrol) gave pentafluorophenyl 4-methyl-3-oxohexane-1-sulfonate **3a** as an off-white crystalline solid (230 mg, 0.64 mmol, 64%): ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.77-3.73 (m, 2H), 3.21-3.15 (m, 2H), 2.56 (sextet, *J* = 7.0 Hz, 1H), 1.76-1.73 (m, 1H), 1.50-1.48 (m, 1H), 1.15 (d, *J* = 7.0 Hz, 3H), 0.92 (t, *J* = 7.0 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 208.8 (C), 47.9 (CH_2), 47.0 (CH), 34.5 (CH_2), 25.9 (CH_2), 15.7 (CH_3), 11.5 (CH_3); IR (neat) 2962, 1710 cm^{-1}; LRMS (CI) 361 (100, $[M+H]^+$); HRMS (CI) calcd for $C_{13}H_{14}F_5O_4S$ $[M+H]^+$ 361.0455; observed 361.0459.

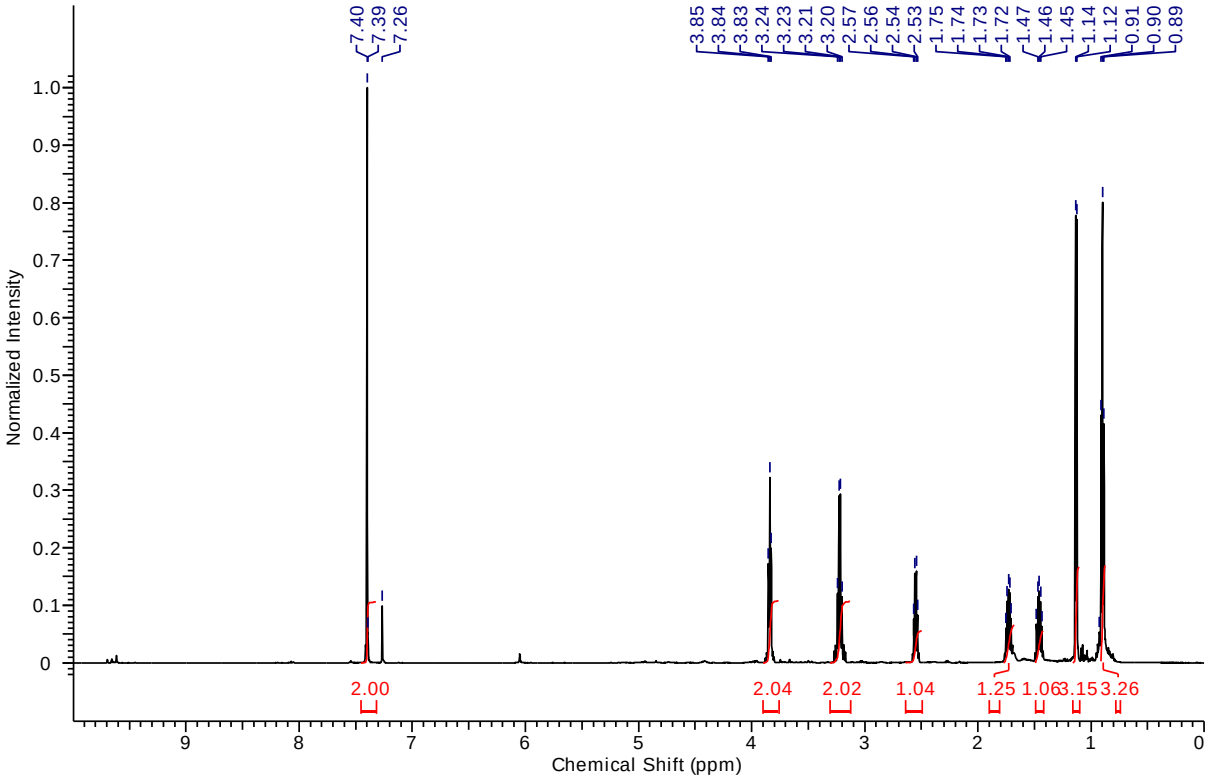




2,4,6-Trichlorophenyl 4-methyl-3-oxohexane-1-sulfonate



Purification by flash column chromatography (10-90% CH_2Cl_2/petrol) gave 2,4,6-trichlorophenyl 4-methyl-3-oxohexane-1-sulfonate as an off-white crystalline solid (78 mg, 0.21 mmol, 21%): ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.39 (s, 2H), 3.86-3.82 (m, 2H), 3.24-3.19 (m, 2H), 2.55 (sextet, *J* = 7.0 Hz, 1H), 1.76-1.73 (m, 1H), 1.49-1.45 (m, 1H), 1.13 (d, *J* = 7.0 Hz, 3H), 0.90 (t, *J* = 7.0 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 209.4 (C), 142.0 (C), 133.2 (C), 130.7 (C), 129.3 (CH), 48.8 (CH_2), 48.0 (CH), 34.9 (CH_2), 26.0 (CH_2), 15.9 (CH_3), 11.7 (CH_3); IR (neat) 3081, 2940, 1720, 1561 cm^{-1}; LRMS (CI) 373 (100, $[M+H]^+$); HRMS (CI) calcd for $C_{13}H_{16}Cl_3O_4S$ [M+H]+ 372.9835; observed 372.9829.


7.40
7.39
7.26
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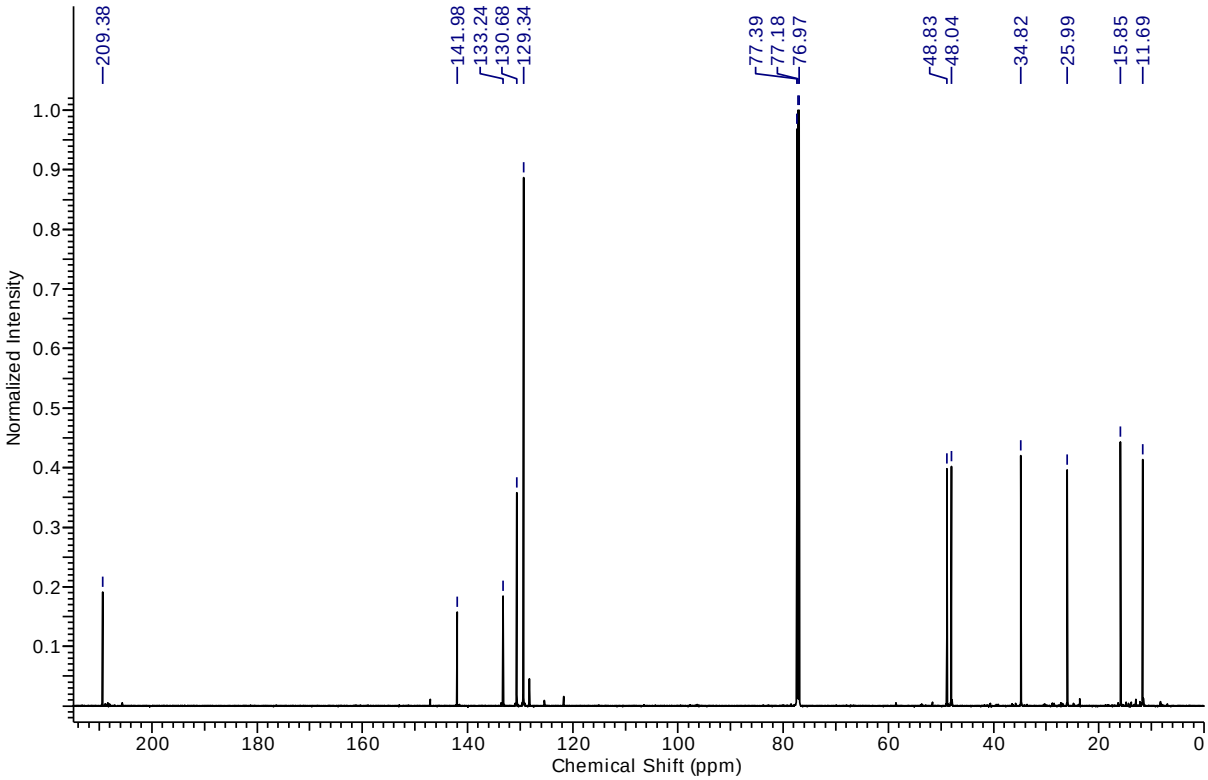
3.84
3.83
3.24
3.23
3.21
3.20
2.57
2.56
2.54
2.53
1.75
1.74
1.73
1.72
1.47
1.46
1.45
1.14
1.12
0.91
0.90
0.89
2.00
2.04
2.02
1.04
1.25
1.06
3.15
3.26
Normalized Intensity
Chemical Shift (ppm)


209.38
141.98
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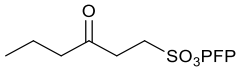
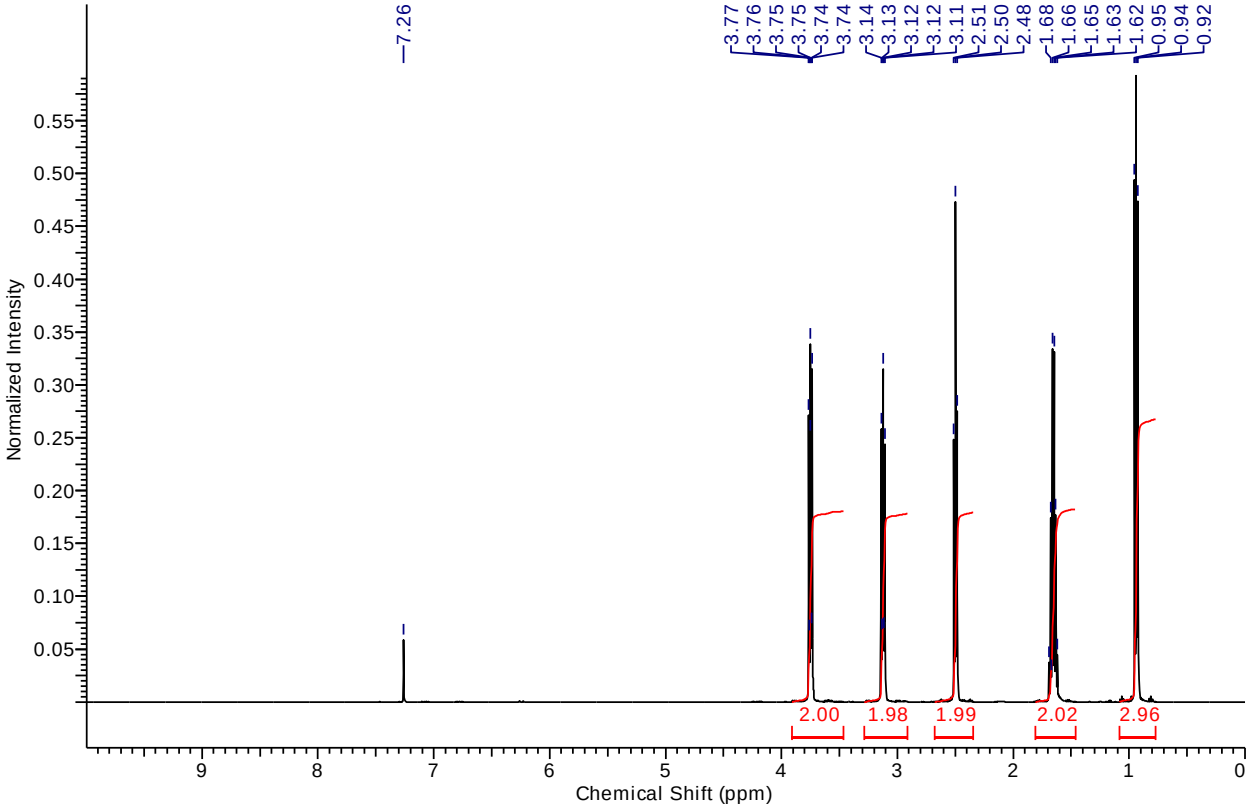
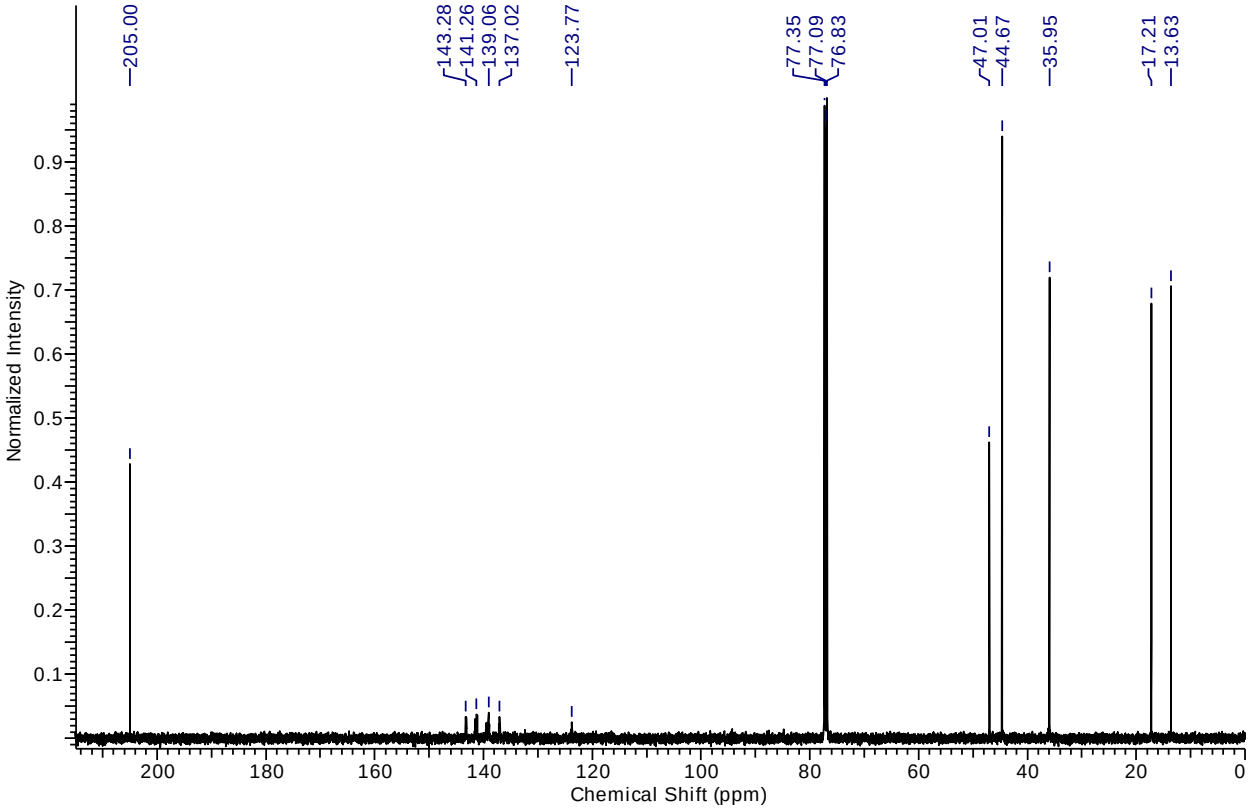
130.68
129.34
77.39
77.18
76.97
48.83
48.04
34.82
25.99
15.85
11.69
Normalized Intensity
Chemical Shift (ppm)

Pentafluorophenyl 3-oxohexane-1-sulfonate 3b[1]

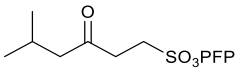


Purification by flash column chromatography (20-70% CH_2Cl_2/petrol) gave pentafluorophenyl 3-oxohexane-1-sulfonate **3b** as an off-white crystalline solid (246 mg, 0.71 mmol, 71%): ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.77-3.73 (m, 2H), 3.15-3.10 (m, 2H), 2.50 (t, *J* = 7.3 Hz, 2H), 1.71-1.59 (sextet, *J* = 7.3 Hz, 2H), 0.94 (t, *J* = 7.4 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 205.0 (C), 47.0 (CH_2), 44.7 (CH_2), 36.0 (CH_2), 17.2 (CH_2), 13.6 (CH_3); IR (neat) 2964, 1716 cm^{-1}; LRMS (CI) 364 (100, $[M+NH_4]^+$); HRMS (ES) calcd for $C_{12}H_{15}F_5NO_4S$ $[M+NH_4]^+$ 364.0636; observed 364.0636.

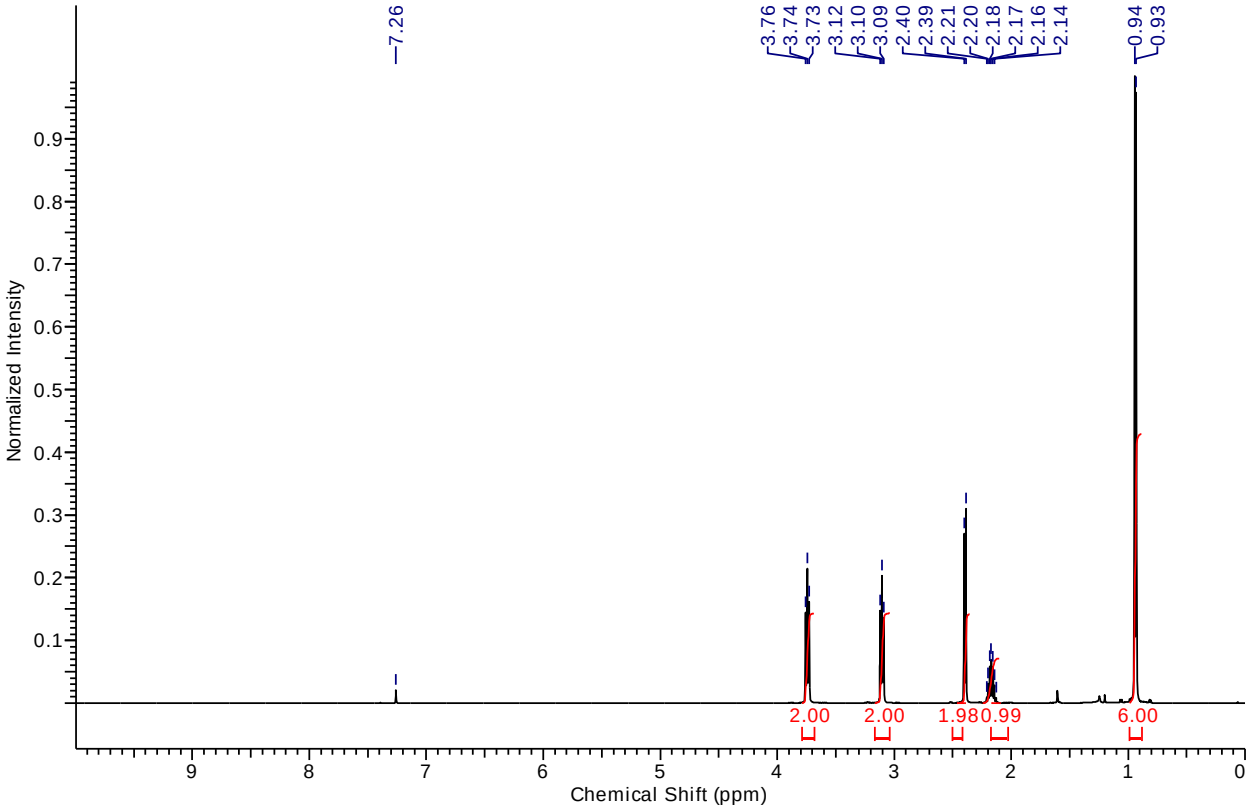




Pentafluorophenyl 5-methyl-3-oxohexane-1-sulfonate 3c[1]



Purification by flash column chromatography (20-70% CH_2Cl_2/petrol) gave pentafluorophenyl 5-methyl-3-oxohexane-1-sulfonate **3c** as an off-white crystalline solid (245 mg, 0.68 mmol, 68%): ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.78-3.73 (m, 2H), 3.14-3.09 (m, 2H), 2.40 (d, *J* = 6.9, 2H), 2.18 (septet, *J* = 6.7, 1H), 0.95 (d, *J* = 6.6, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 204.7 (C), 51.7 (CH_2), 47.0 (CH_2), 36.5 (CH_2), 24.7 (CH), 22.5 (CH_3); IR (neat) 2964, 1720 cm^{-1}; LRMS (CI) 378 (100, $[M+NH_4]^+$); HRMS (ES) calcd for $C_{13}H_{13}F_5NO_4S$ $[M+NH_4]^+$. 378.0793; observed 378.0796.


7.26
3.76
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3.73
3.12
3.10
3.09
2.40
2.39
2.21
2.20
2.18
2.17
2.16
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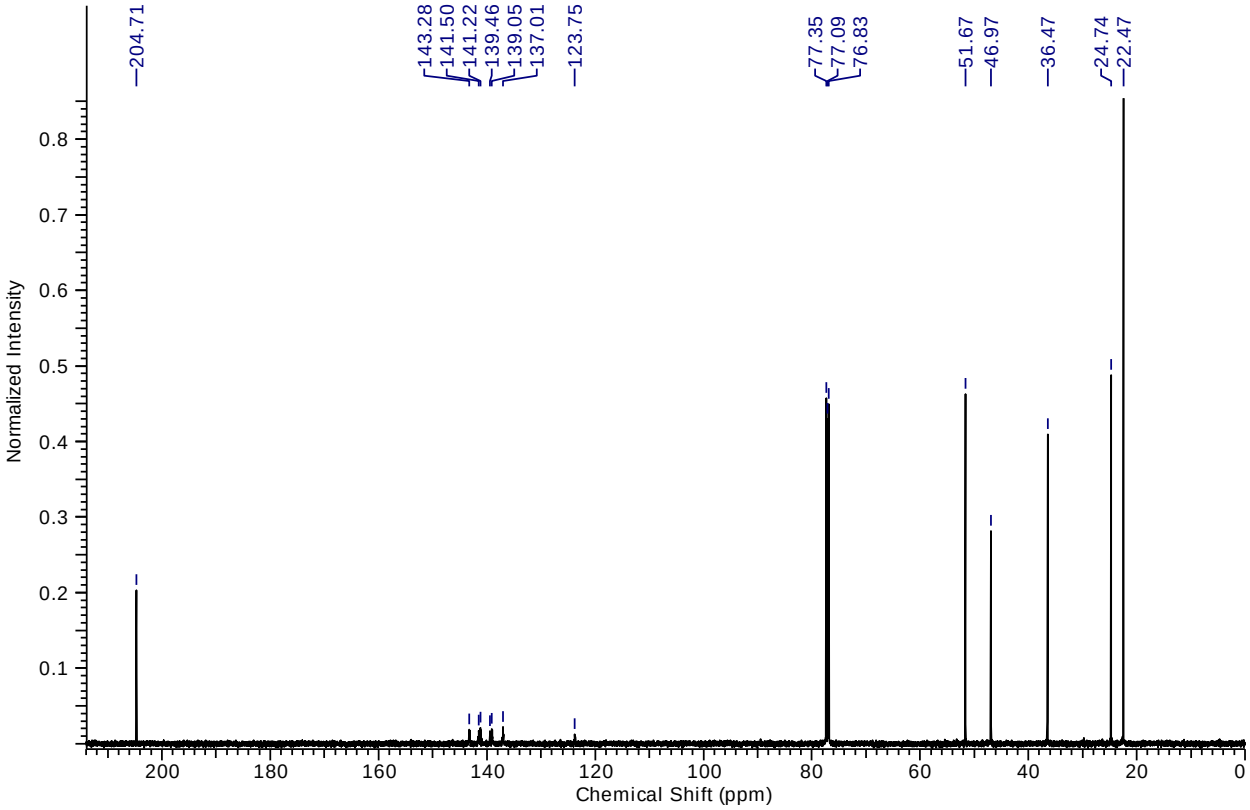
0.94
0.93
2.00
2.00
1.98
0.99
6.00
Normalized Intensity
Chemical Shift (ppm)


204.71
143.28
141.50
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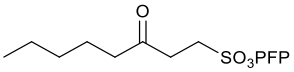
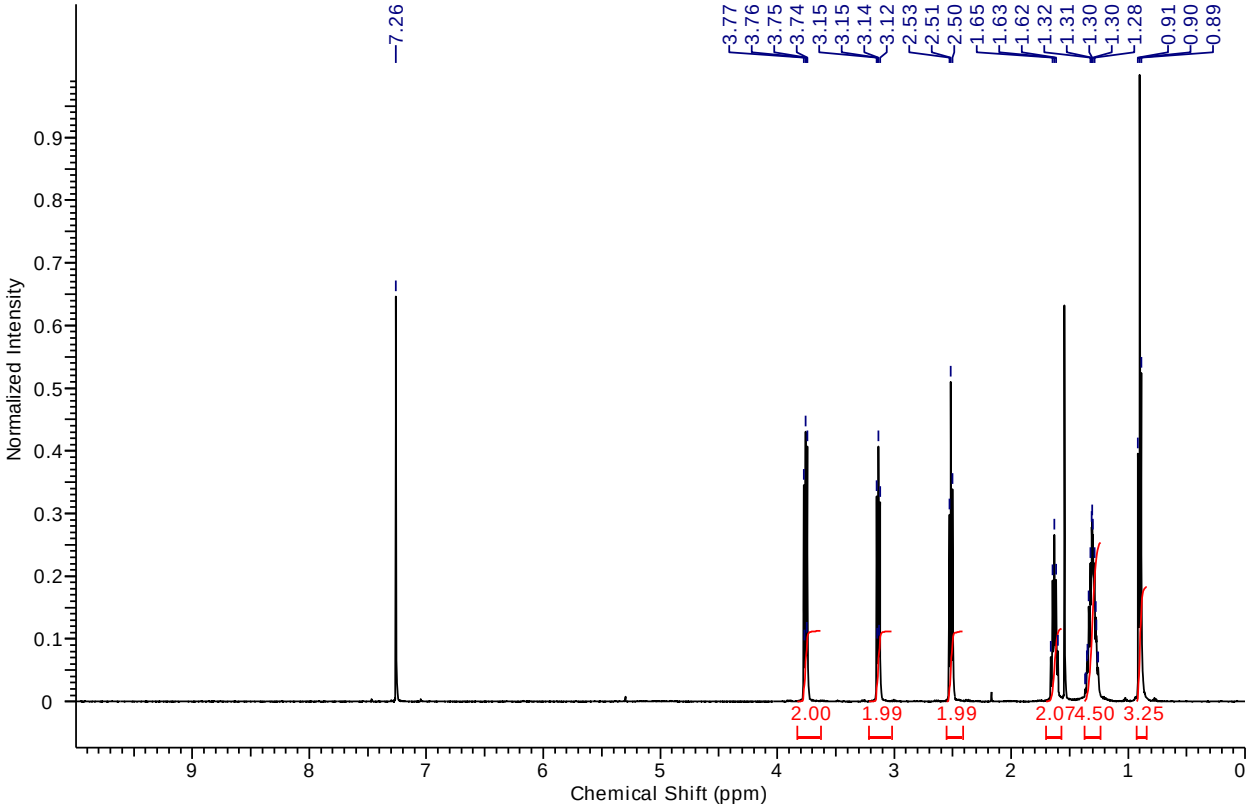
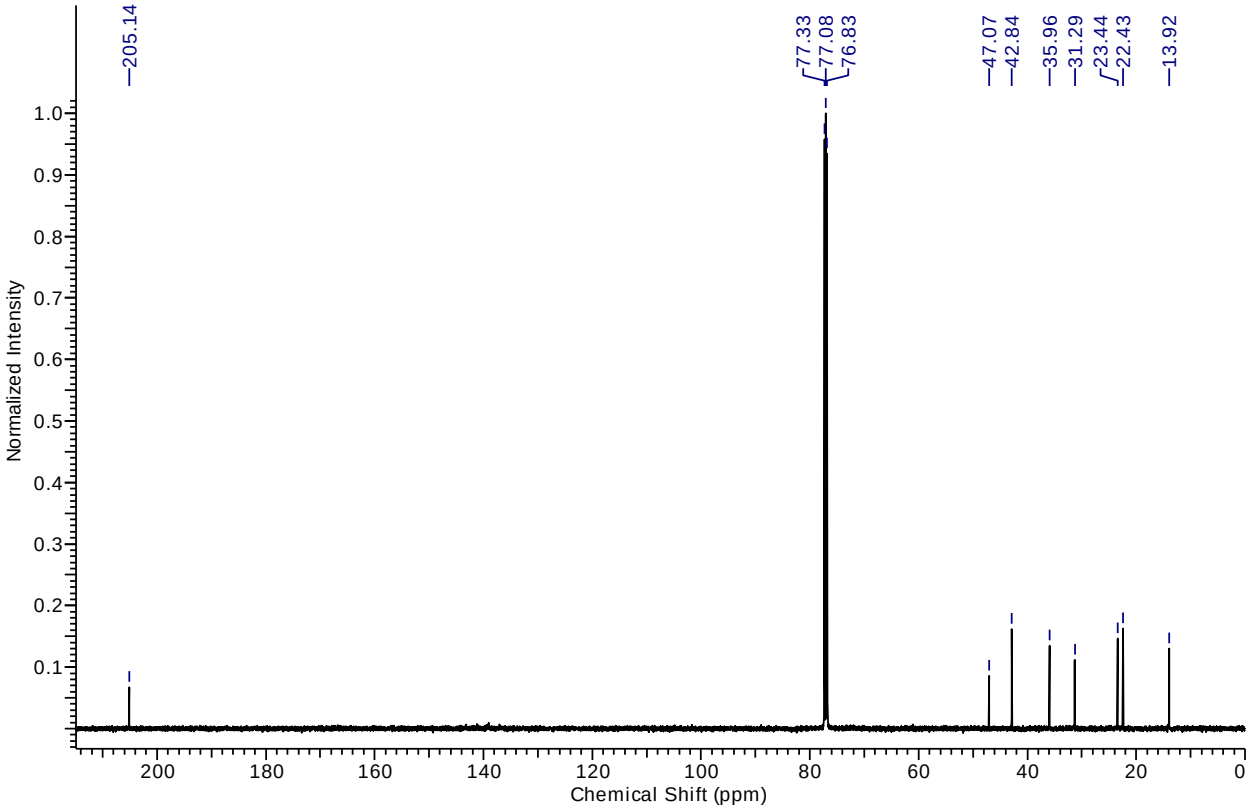
139.46
139.05
137.01
123.75
77.35
77.09
76.83
51.67
46.97
36.47
24.74
22.47
Normalized Intensity
Chemical Shift (ppm)

Pentafluorophenyl 3-oxooctane-1-sulfonate 3d

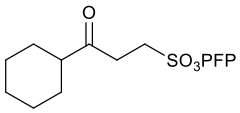


Purification by flash column chromatography (20-70% CH_2Cl_2/petrol) gave pentafluorophenyl 3-oxooctane-1-sulfonate **3d** as white crystals (269 mg, 0.72 mmol, 72%): ^{1}H NMR (500 MHz, $CDCl_3$) δ 3.78-3.74 (m, 2H), 3.15-3.11 (m, 2H), 2.51 (t, *J* = 7.5 Hz, 2H), 2.16 (sextet, *J* = 7.5 Hz, 2H), 1.65-1.62 (m, 2H), 1.33-1.27 (m, 4H), 0.90 (t, *J* = 7.5 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 205.1 (C), 47.1 (CH_2), 42.8 (CH_2), 36.0 (CH_2), 31.3 (CH_2), 23.4 (CH_2), 22.4 (CH_2), 13.9 (CH_3); IR (solid) 2937, 2871, 1721 cm^{-1}; LRMS (CI) 375 (100, $[M+H]^+$); HRMS (CI) calcd for $C_{14}H_{16}F_5O_4S$ $[M+H]^+$ 375.0690; observed 375.0685.

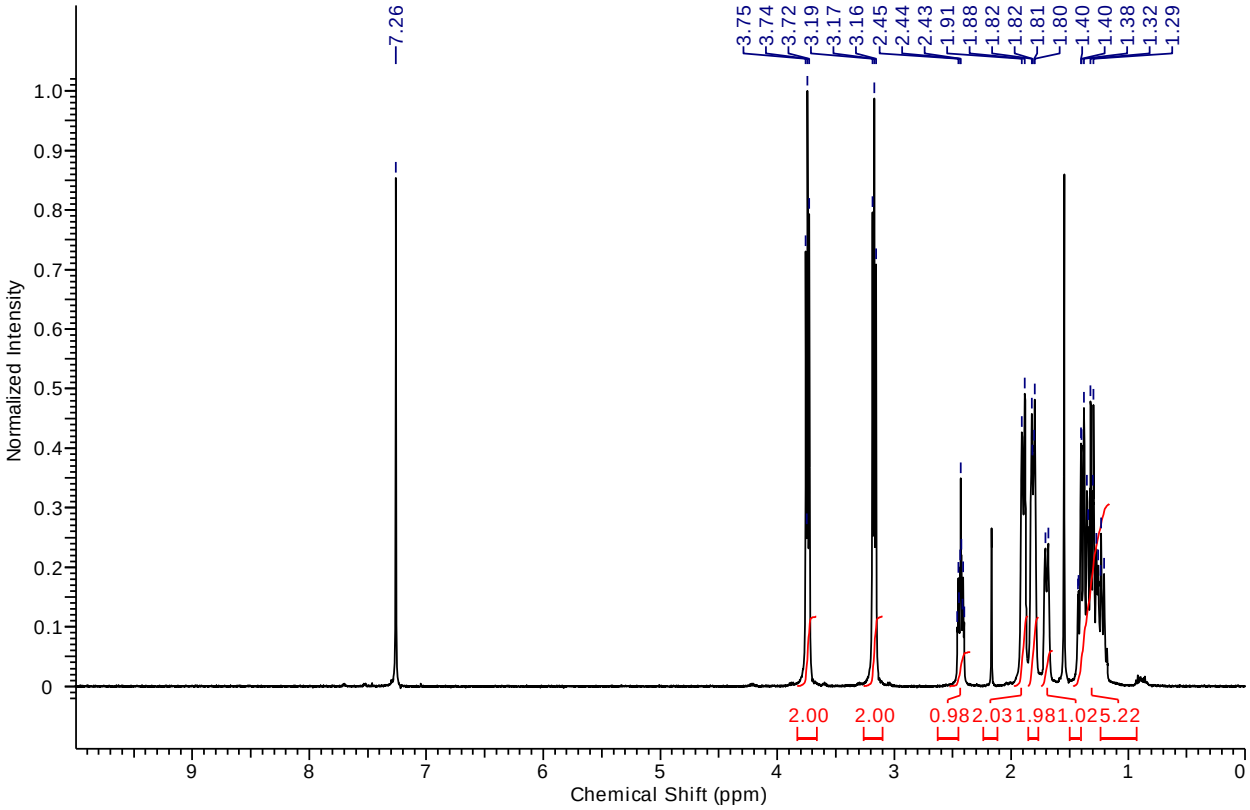


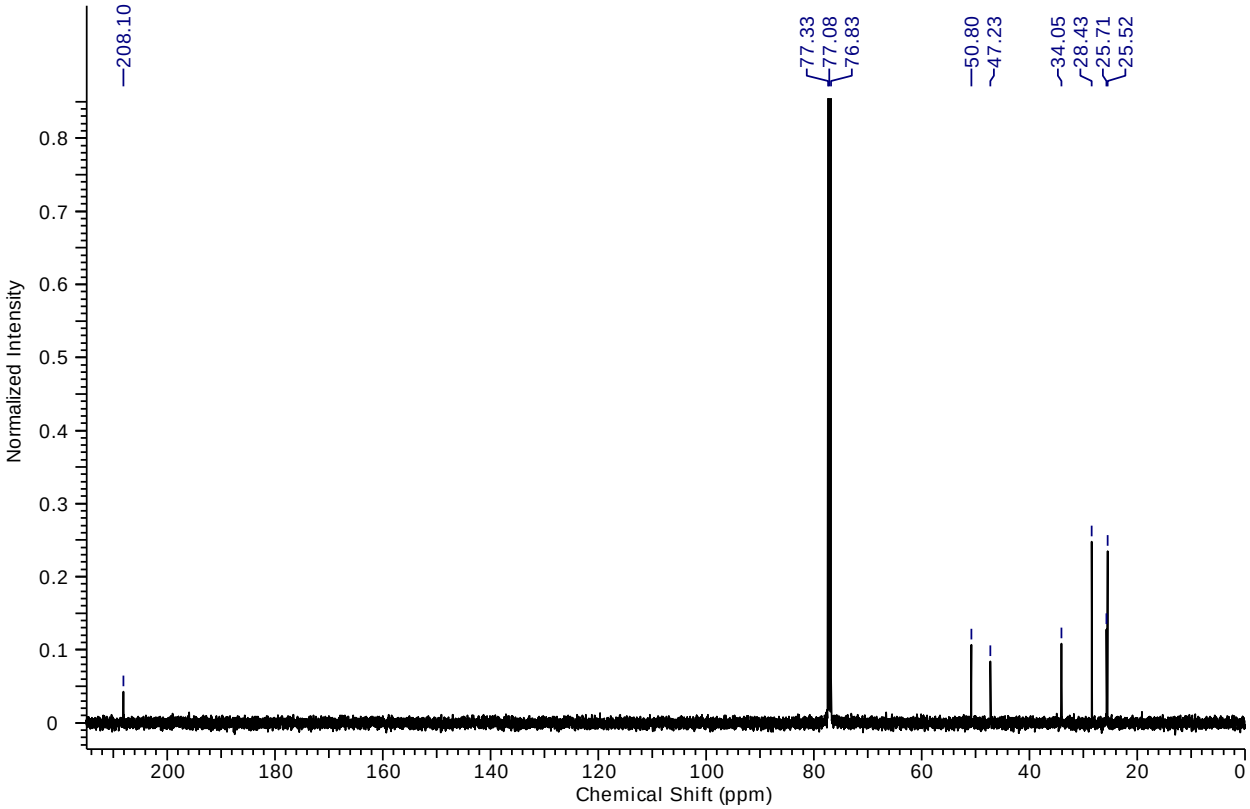


Pentafluorophenyl 3-cyclohexyl-3-oxopropane-1-sulfonate 3e[1]

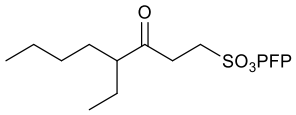


Purification by flash column chromatography (20-70% CH_2Cl_2/petrol) gave pentafluorophenyl 3-cyclohexyl-3-oxopropane-1-sulfonate **3e** as an off-white solid (235 mg, 0.61 mmol, 61%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.76-3.72 (m, 2H), 3.20-3.16 (m, 2H), 2.45 (tt, *J* = 3.5, 11.0, 1H), 1.97-1.64 (m, 5H), 1.48-1.15 (m, 5H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 208.1 (C), 50.8 (CH), 47.2(CH_2), 34.1 (CH_2), 28.4 (CH_2), 25.7 (CH_2), 25.5 (CH_2); IR (neat) 2934, 2855, 1706 cm^{-1}; LRMS (CI) 404 (100%, $[M+NH_4]^+$); HRMS (ES) calcd for $C_{15}H_{15}F_5NO_4S$ $[M+NH_4]^+$. 404.0949; observed 404.0949.

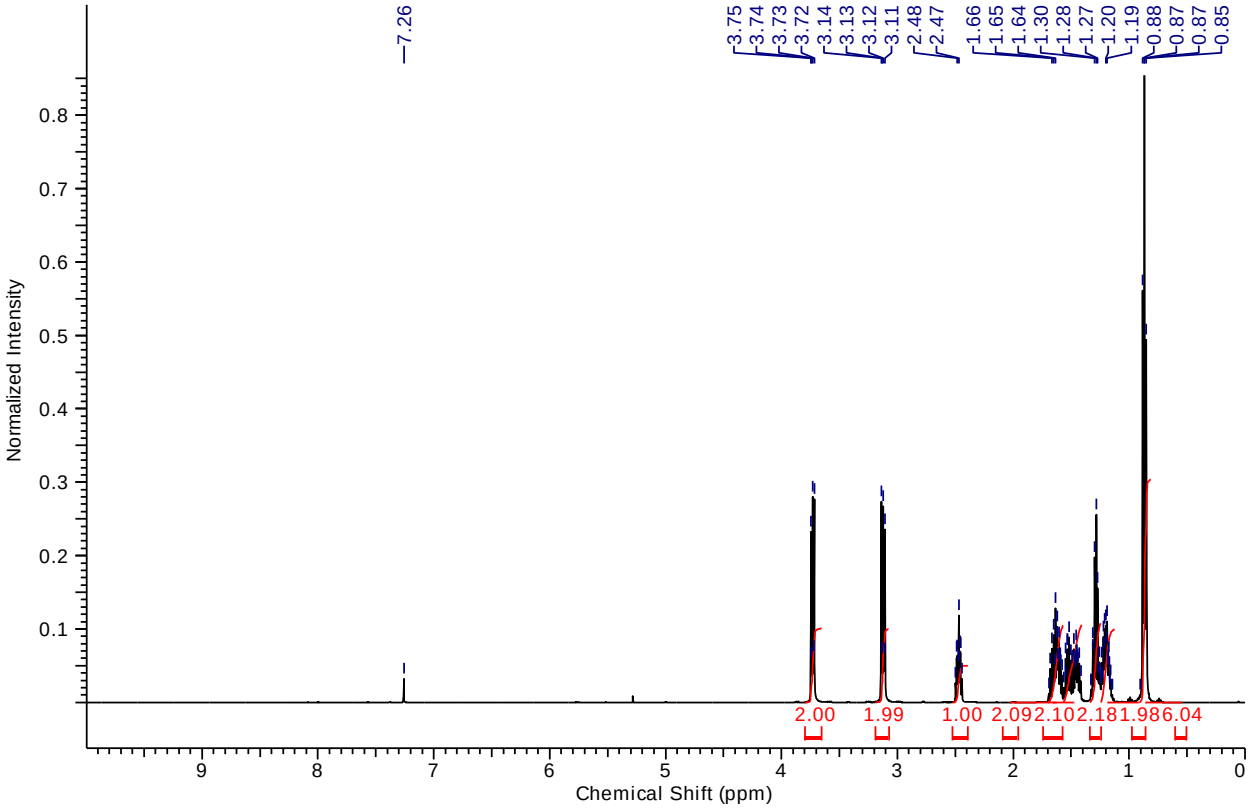

7.26
3.75
3.74
3.72
3.19
3.17
3.16
2.45
2.44
2.43
1.91
1.88
1.82
1.82
1.81
1.80
1.40
1.40
1.38
1.32
1.29
2.00
2.00
0.98
2.03
1.98
1.02
5.22
Normalized Intensity
Chemical Shift (ppm)

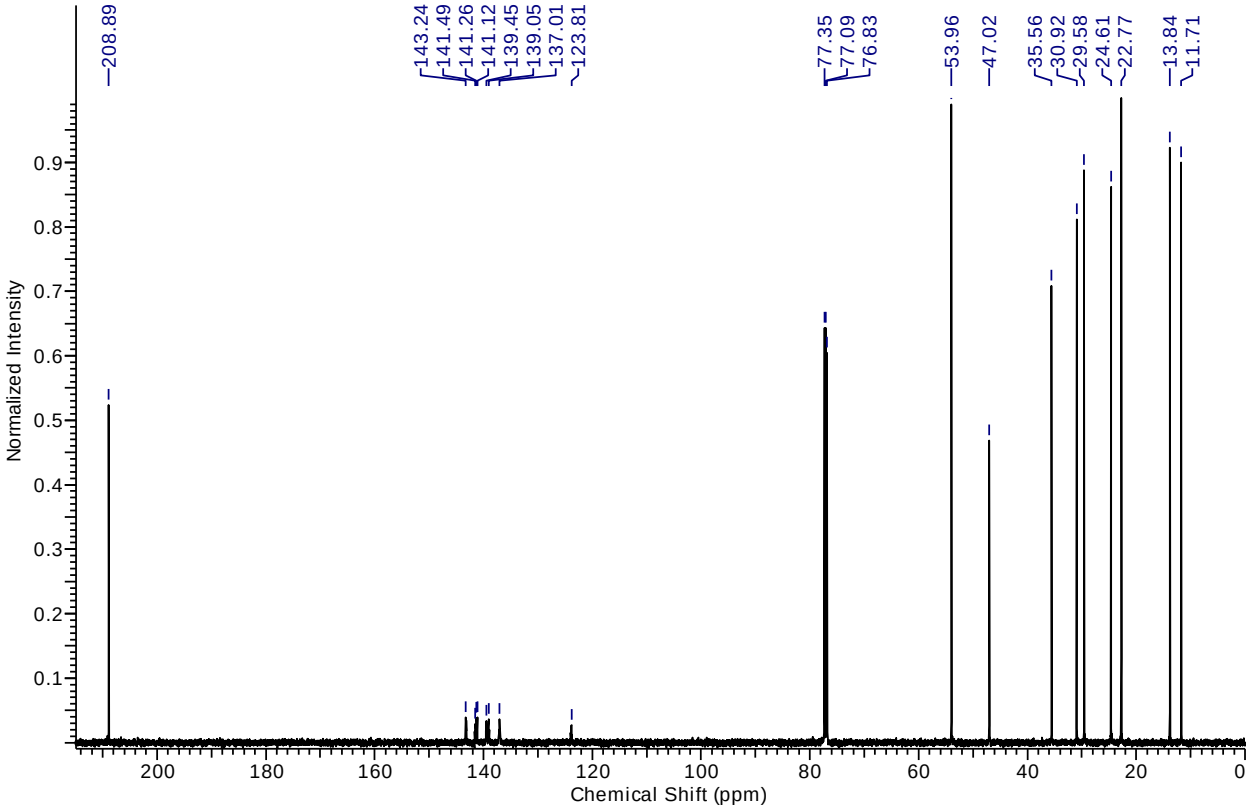

208.10
77.33
77.08
76.83
50.80
47.23
34.05
28.43
25.71
25.52
Normalized Intensity
Chemical Shift (ppm)

Pentafluorophenyl 4-ethyl-3-oxooctane-1-sulfonate 3f[1]

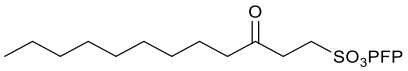


Purification by flash column chromatography (20-70% CH_2Cl_2/petrol) gave pentafluorophenyl 4-ethyl-3-oxooctane-1-sulfonate **3f** as a colourless oil (241 mg, 0.60 mmol, 60%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.76-3.71 (m, 2H), 3.15-3.10 (m, 2H), 2.47 (tt, *J* = 5.5, 8.0 Hz, 1H), 1.68-1.63 (m, 2H), 1.58-1.47 (m, 2H), 1.34-1.27 (m, 2H), 1.27-1.20 (m, 2H), 0.88 (t, *J* = 7.5 Hz, 3H), 0.85 (t, *J* = 7.5 Jz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 208.9 (C), 54.0 (CH), 47.1 (CH_2), 35.6 (CH_2), 30.9 (CH_2), 29.6 (CH_2), 24.6 (CH_2), 22.8 (CH_2), 13.8 (CH_3), 11.7 (CH_3); IR (neat) 2934, 2962, 2875, 1714 cm^{-1}; LRMS (CI) 420 (14, $[M+NH_4]^+$), 172 (100); HRMS (ES) calcd for $C_{16}H_{23}F_5NO_4S$ $[M+NH_4]^+$ 420.1262; observed 420.1265.

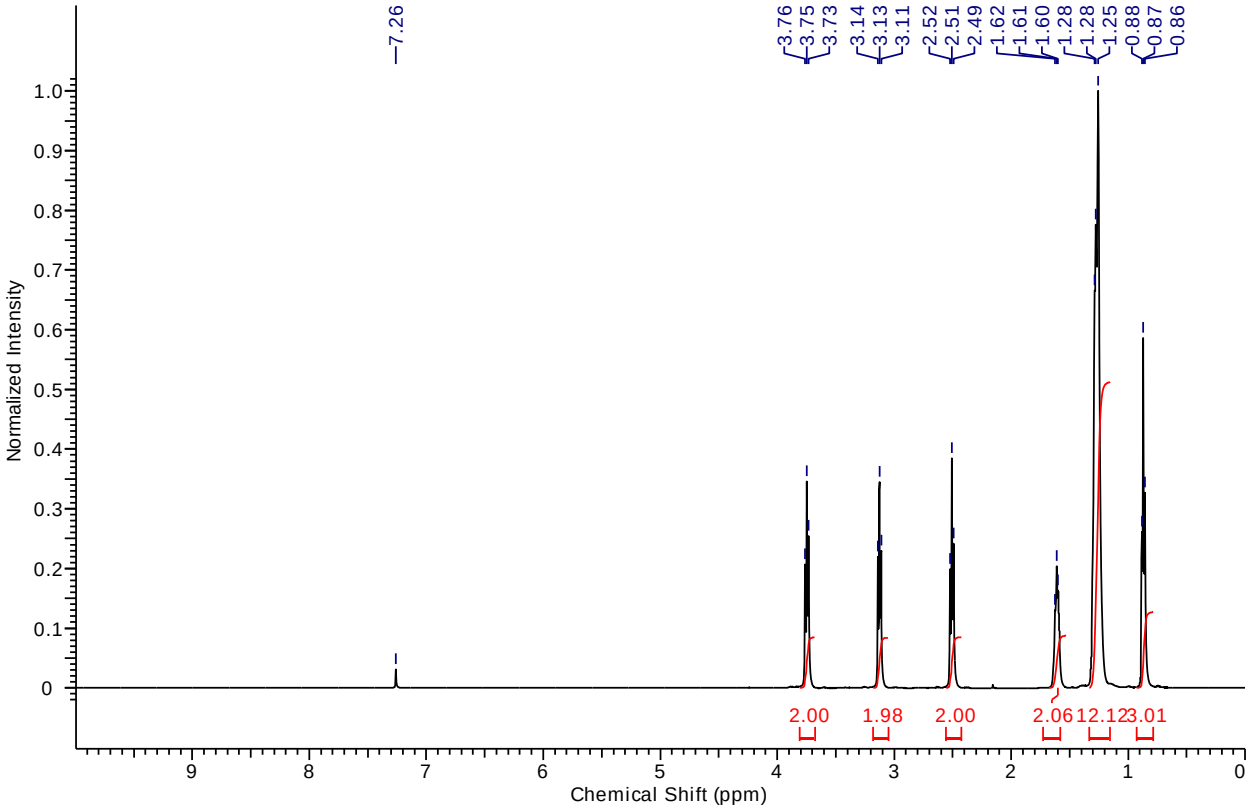


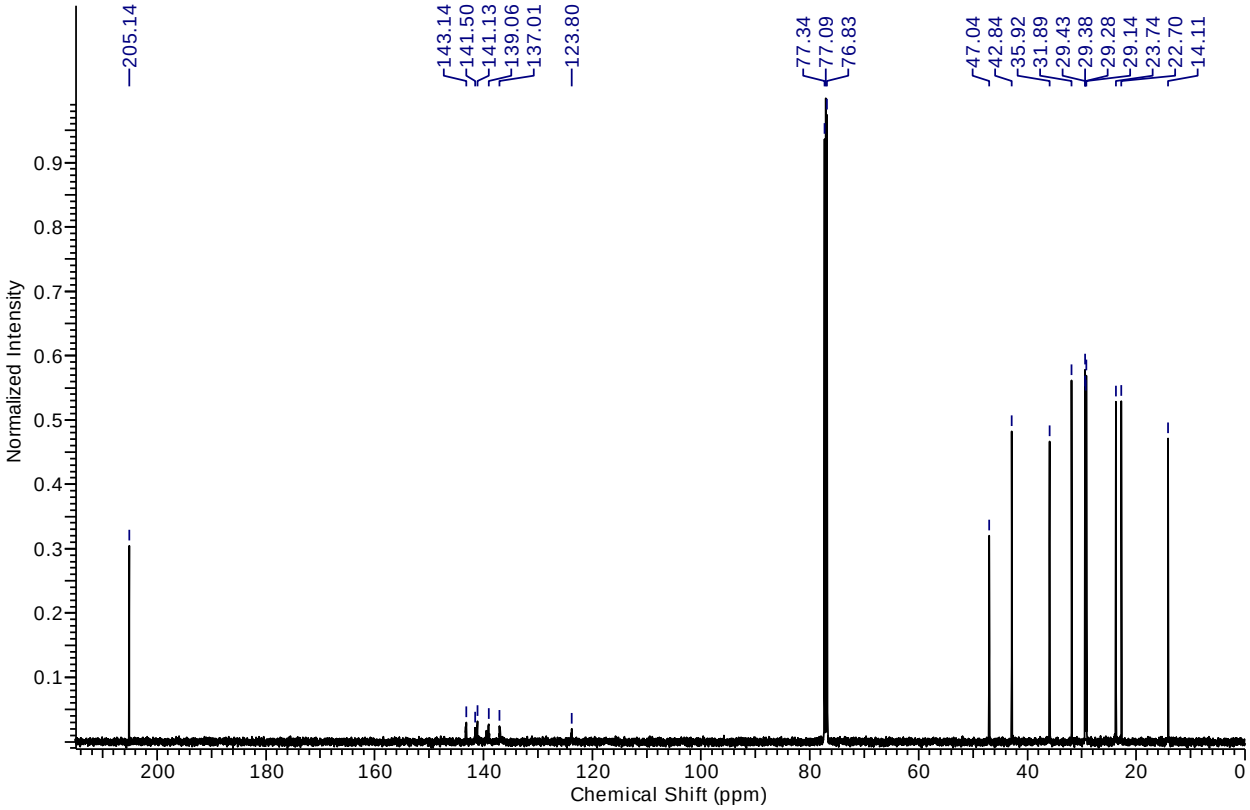


Pentafluorophenyl 3-oxododecane-1-sulfonate 3g[1]

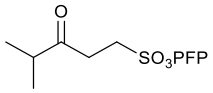


Purification by flash column chromatography (20-70% CH_2Cl_2/petrol) gave pentafluorophenyl 3-oxododecane-1-sulfonate **3g** as white crystals (301 mg, 0.70 mmol, 70%): ^{1}H NMR (500 MHz, $CDCl_3$) δ 3.75 (t, *J* = 7.5 Hz, 2H), 3.13 (t, *J* = 7.5 Hz, 2H), 2.51 (t, *J* = 7.5 Hz, 2H), 1.61 (t, *J* = 7.0 Hz, 2H), 1.29-1.21 (m, 12H), 0.87 (t, *J* = 6.5 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 205.1 (C), 47.0 (CH_2), 42.8 (CH_2), 35.9 (CH_2), 31.9 (CH_2), 29.6 (CH_2), 29.4 (CH_2), 29.3 (CH_2), 29.1 (CH_2), 23.7 (CH_2), 22.7 (CH_2), 14.1 (CH_3); IR (solid) 2954, 2918, 2849, 1710 cm^{-1}; LRMS (CI) 431 (100, $[M+H]^+$); HRMS (CI) calcd for $C_{18}H_{24}F_5O_4S$ $[M+H]^+$ 431.1310; observed 431.1307.

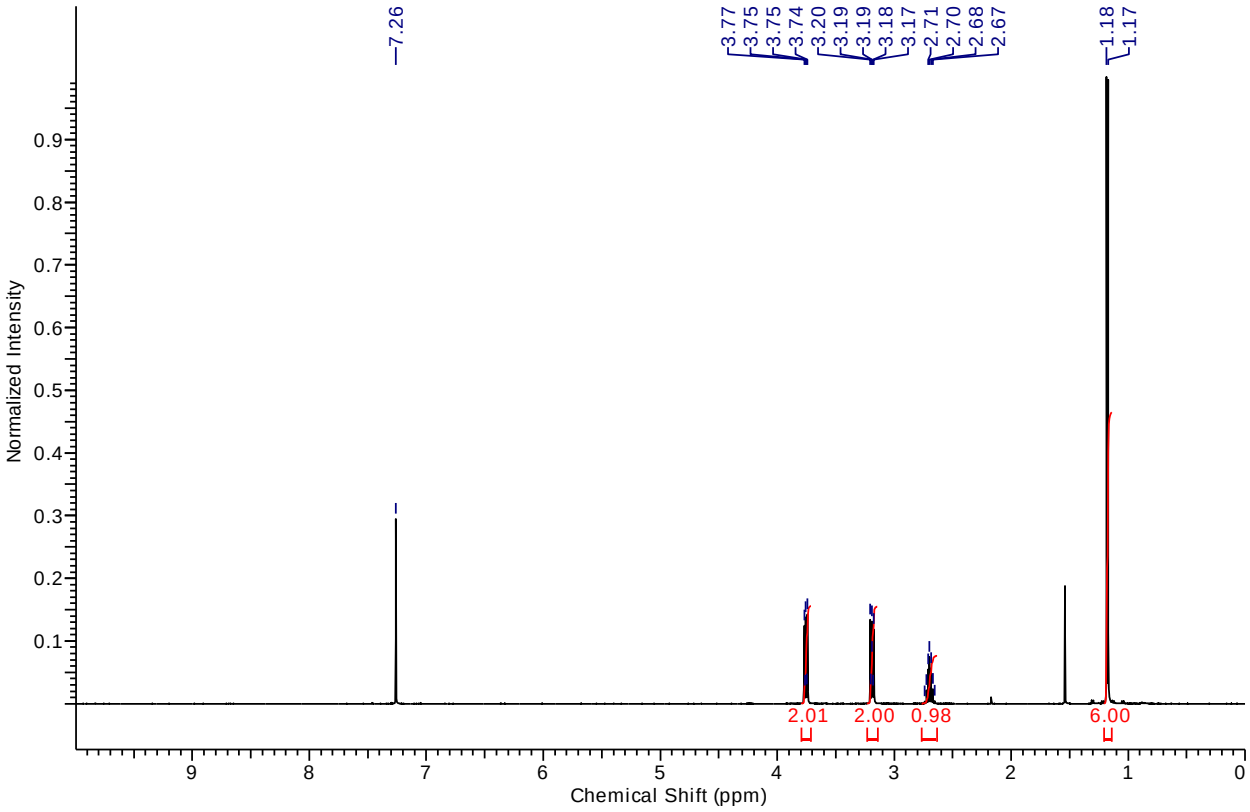

7.26
3.76
3.75
3.73
3.14
3.13
3.11
2.52
2.51
2.49
1.62
1.61
1.60
1.28
1.28
1.25
0.88
0.87
0.86
2.00
1.98
2.00
2.06
12.12
3.01
Normalized Intensity
Chemical Shift (ppm)

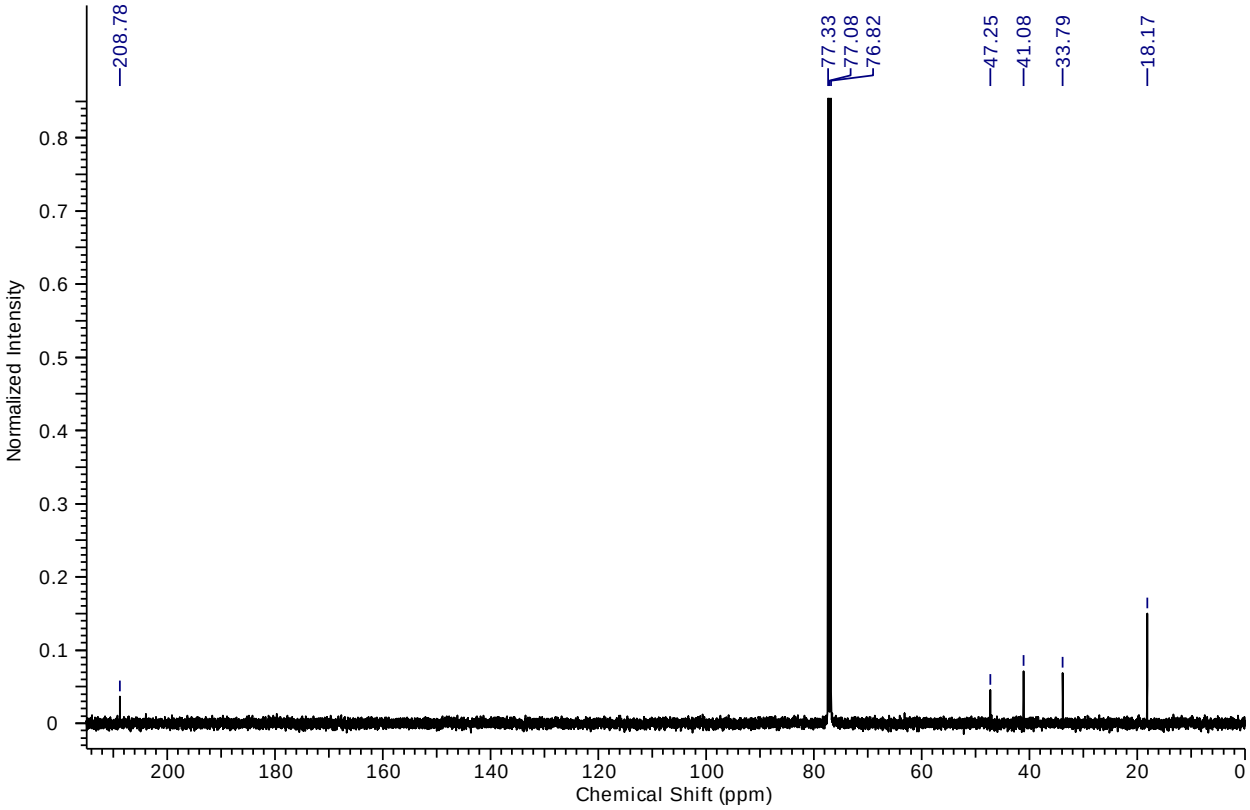

205.14
143.14
141.50
141.13
139.06
137.01
123.80
77.34
77.09
76.83
47.04
42.84
35.92
31.89
29.43
29.38
29.28
29.14
23.74
22.70
14.11
Normalized Intensity
Chemical Shift (ppm)

Pentafluorophenyl 4-methyl-3-oxopentane-1-sulfonate 3h[1]

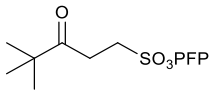


Purification by flash column chromatography (20-70% CH_2Cl_2/petrol) gave pentafluorophenyl 4-methyl-3-oxopentane-1-sulfonate **3h** as a colourless oil (215 mg, 0.62 mmol, 62%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.78-3.74 (m, 2H), 3.21-3.18 (m, 2H), 2.71 (septet, *J* = 7.0 Hz, 1H), 1.18 (d, *J* = 7.0 Hz, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 208.8 (C), 47.3 (CH_2), 41.1 (CH), 33.8 (CH_2), 18.2 (CH_3); IR (neat) 2976, 1716 cm^{-1}; LRMS (CI) 364 (100, $[M+NH_4]^+$); HRMS (ES) calcd for $C_{12}H_{15}F_5NO_4S$ $[M+NH_4]^+$. 364.0636; observed 364.0635.

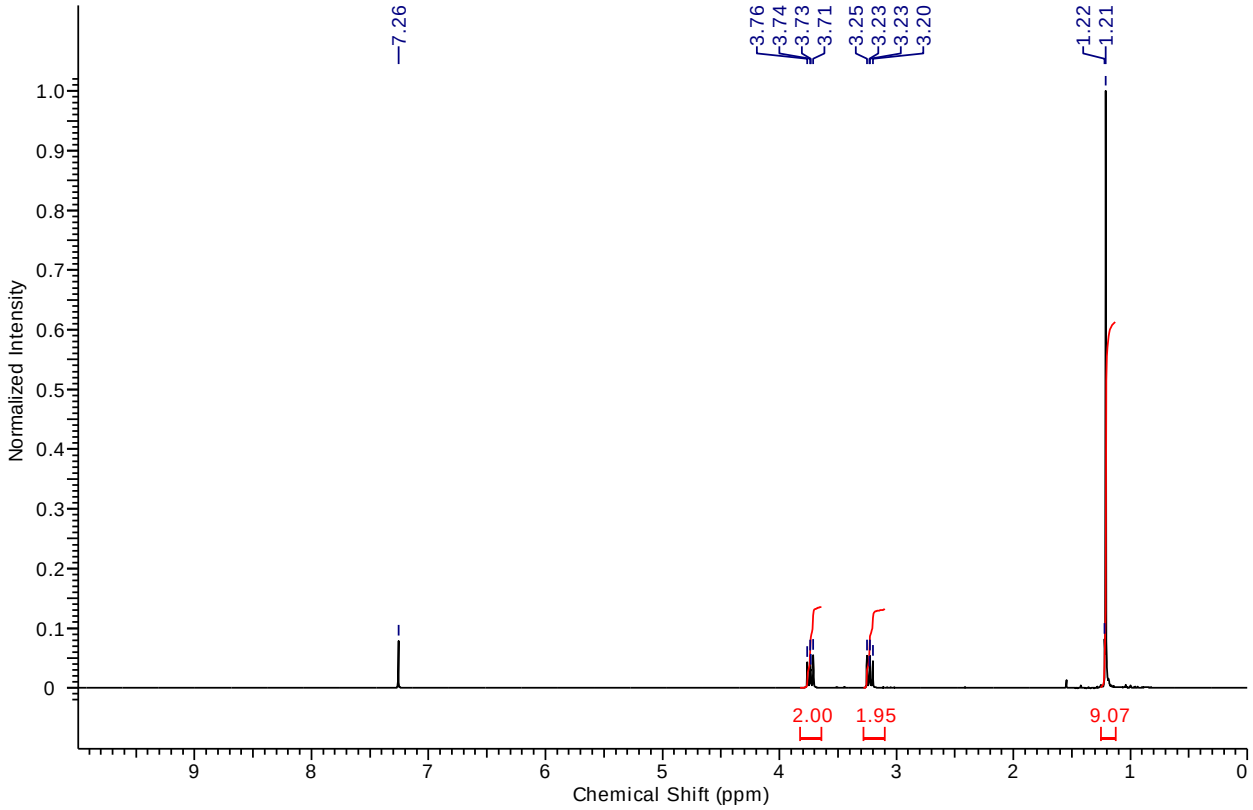


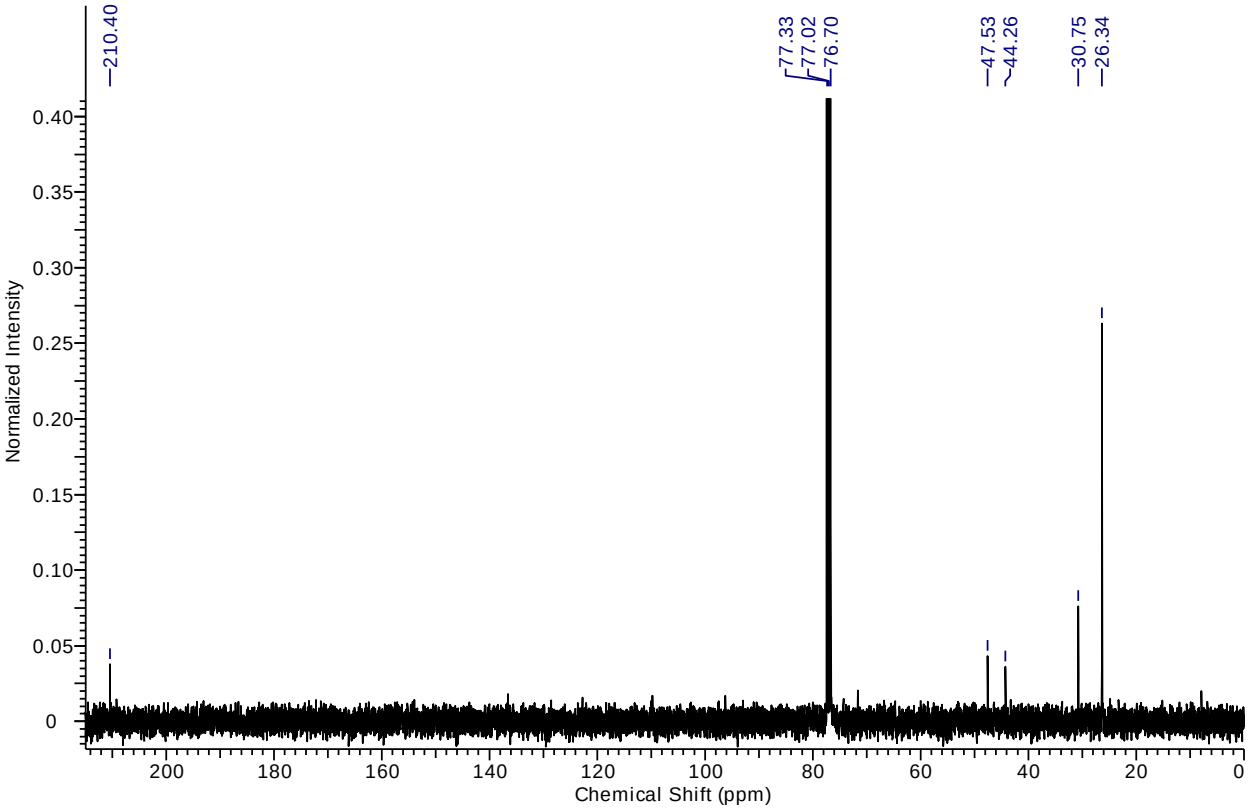


Pentafluorophenyl 4,4-dimethyl-3-oxopentane-1-sulfonate 3i[1]

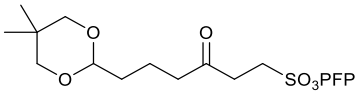


Purification by flash column chromatography (20-70% CH_2Cl_2/petrol) gave pentafluorophenyl 4,4-dimethyl-3-oxopentane-1-sulfonate **3i** as an off-white solid (184 mg, 0.51 mmol, 51%): ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.76-3.71 (m, 2H), 3.25-3.20 (m, 2H), 1.21 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 210.4 (C), 47.5 (CH_2), 44.3 (C), 30.8 (CH_2), 26.3 (CH_3); IR (neat) 2971, 1710 cm^{-1}; LRMS (CI) 378 (100, $[M+NH_4]^+$); HRMS (ES) calcd for $C_{13}H_{17}F_5NO_4S$ $[M+NH_4]^+$ 378.0793; observed 378.0797.

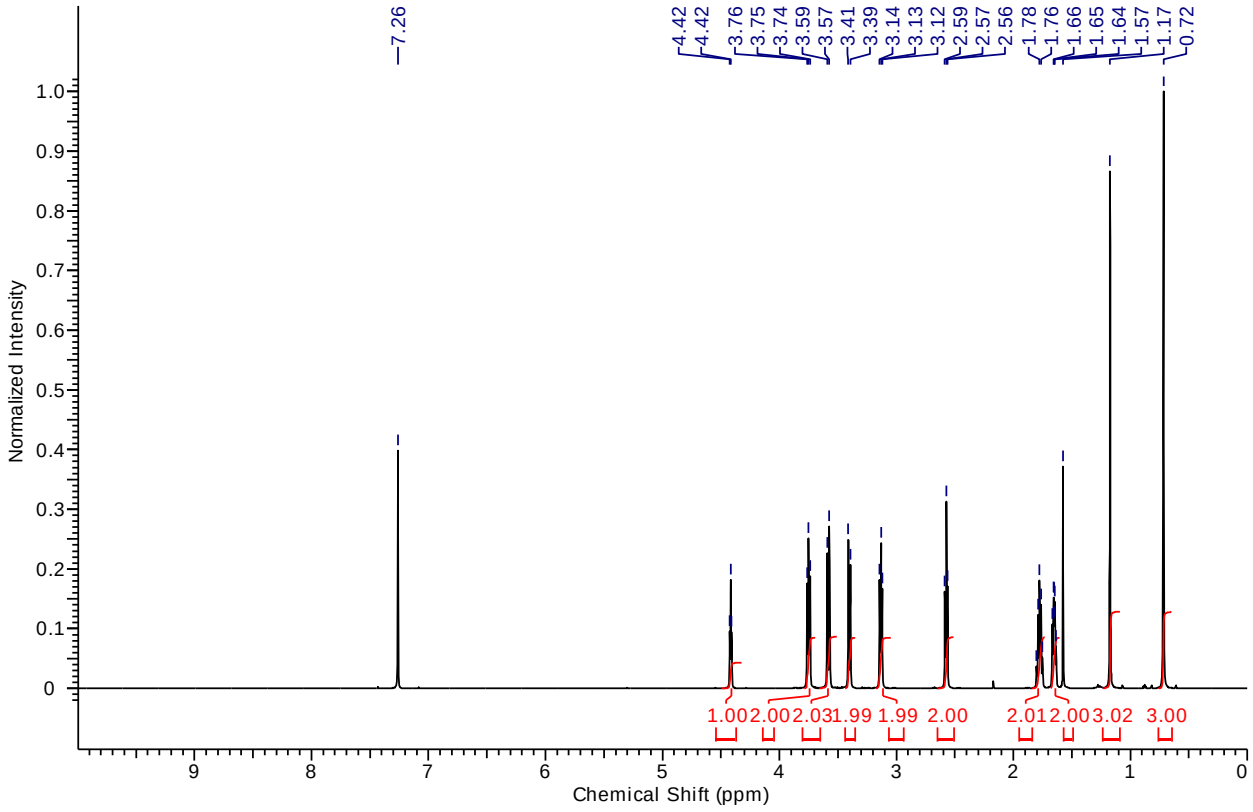

7.26
3.76
3.74
3.73
3.71
3.25
3.23
3.23
3.20
1.22
1.21
2.00
1.95
9.07
Normalized Intensity
Chemical Shift (ppm)

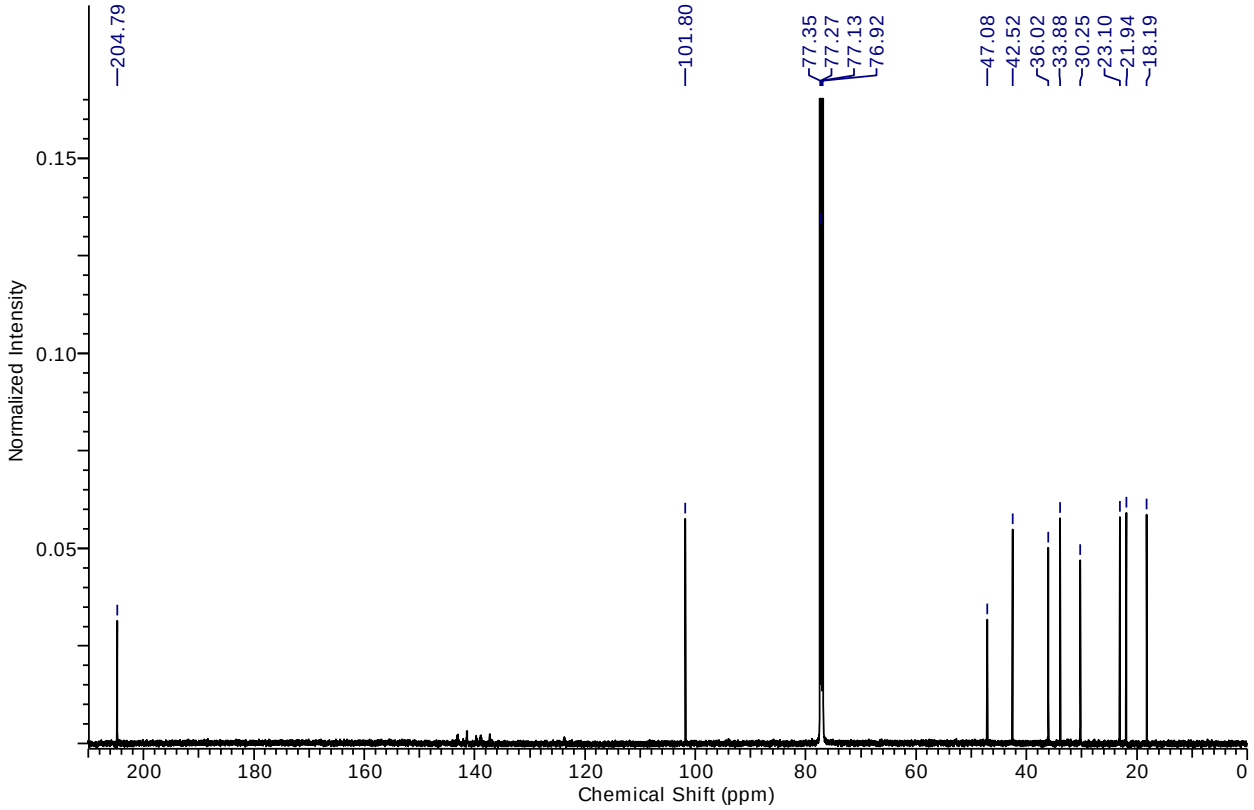

210.40
77.33
77.02
76.70
47.53
44.26
30.75
26.34
Normalized Intensity
Chemical Shift (ppm)

Pentafluorophenyl 6-(5,5-dimethyl-1,3-dioxan-2-yl)-3-oxohexane-1-sulfonate 3j[2]

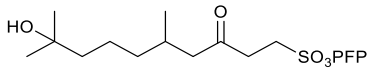


Purification by flash column chromatography (20-95% CH_2Cl_2/petrol) gave pentafluorophenyl 6-(5,5-dimethyl-1,3-dioxan-2-yl)-3-oxohexane-1-sulfonate **3j** as an oil (281 mg, 0.61 mmol, 61%): ^{1}H NMR (600 MHz, $CDCl_3$) δ 4.42 (t, *J* = 4.5 Hz, 1H), 3.77-3.75 (m, 2H), 3.58 (d, *J* = 11.0 Hz, 2H), 3.40 (d, *J* = 11.0 Hz, 2H), 3.14-3.11 (m, 2H), 2.57 (t, *J* = 7.0 Hz, 2H), 1.80-1.75 (m, 2H), 1.67-1.63 (m, 2H), 1.17 (s, 3H), 0.72 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 204.8 (C), 101.8 (CH), 47.1 (CH_2), 42.5 (CH_2), 36.0 (CH_2), 33.9 (CH_2), 30.3 (C), 23.1 (CH_3), 22.0 (CH_3), 18.2 (CH_2); IR (neat) 2953, 2857, 1718, 1520 cm^{-1}; LRMS (CI) 461 (100, $[M+H]^+$); HRMS (CI) calcd for $C_{18}H_{22}F_5O_6S$ $[M+H]^+$ 461.1052; observed 461.1058.

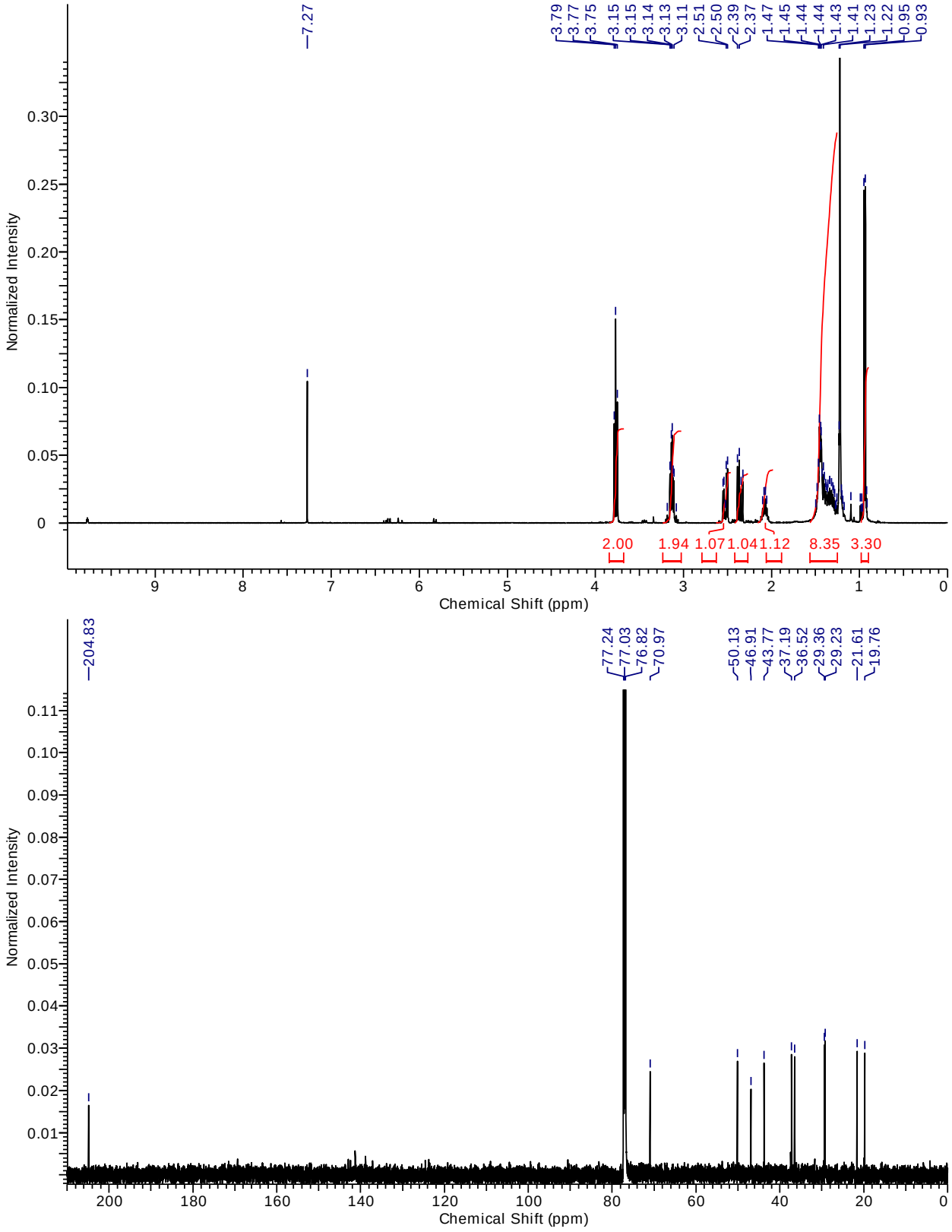




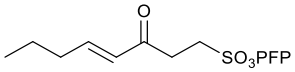
Pentafluorophenyl 9-hydroxy-5,9-dimethyl-3-oxodecane-1-sulfonate 3k[2]



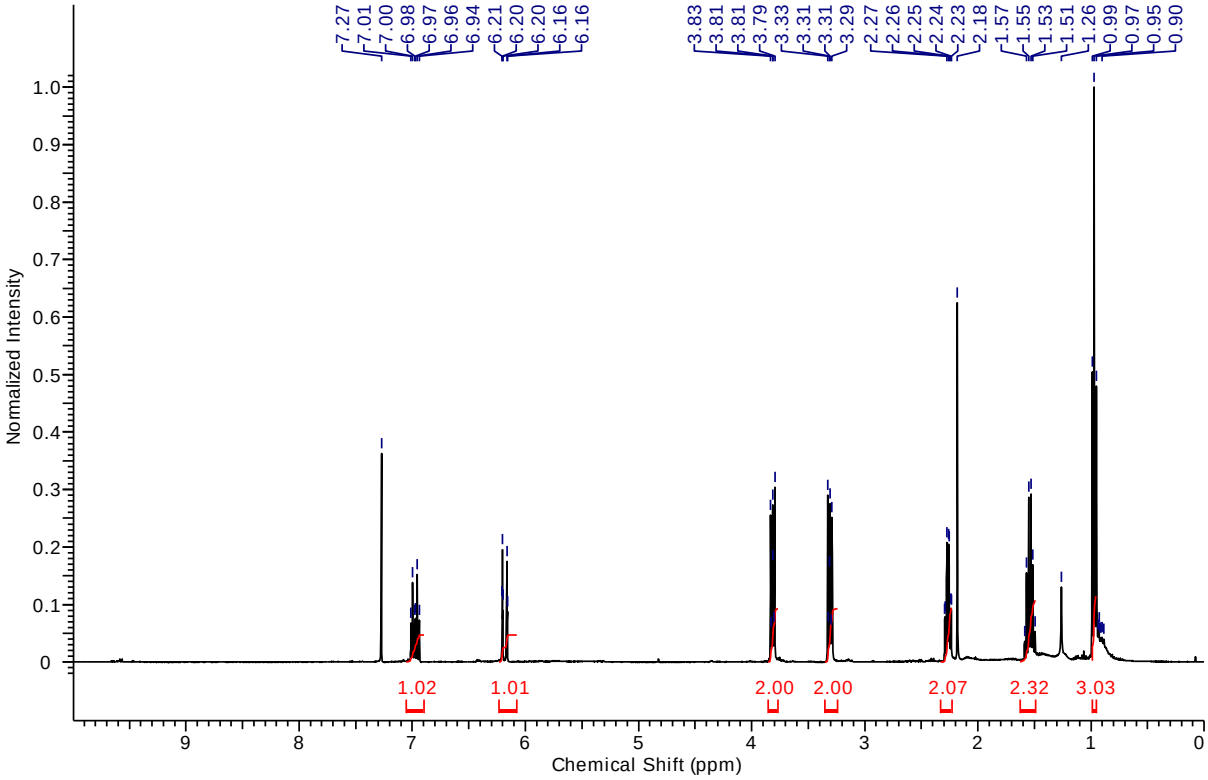
Purification by flash column chromatography (20% EtOAc/petrol) gave pentafluorophenyl 9-hydroxy-5,9-dimethyl-3-oxodecane-1-sulfonate **3k** as an oil (285 mg, 0.64 mmol, 64%): ^{1}H NMR (600 MHz, $CDCl_3$) δ 3.79-3.75 (m, 2H), 3.15-3.11 (m, 2H), 2.53 (dd, *J* = 16.0, 6.0 Hz, 1H), 2.35 (dd, *J* = 16.0, 8.0 Hz, 1H), 2.11-2.04 (m, 1H), 1.50-1.19 (m, 13H), 0.93 (d, *J* = 7.0 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 204.8 (C), 71.0 (C), 50.1 (CH_2), 46.9 (CH_2), 43.8 (CH_2), 37.2 (CH_2), 36.5 (CH_2), 29.4 (CH_3), 29.3 (CH_3), 29.2 (CH), 21.6 (CH_2), 19.8 (CH_3); IR (neat) 3417, 2968, 1718, 1518, 1383 cm^{-1}; LRMS (FAB) 469 (100, $[M+Na]^+$); HRMS (FAB) calcd for $C_{18}H_{23}F_5O_5SNa$ $[M+Na]^+$ 469.1084; observed 469.1090.

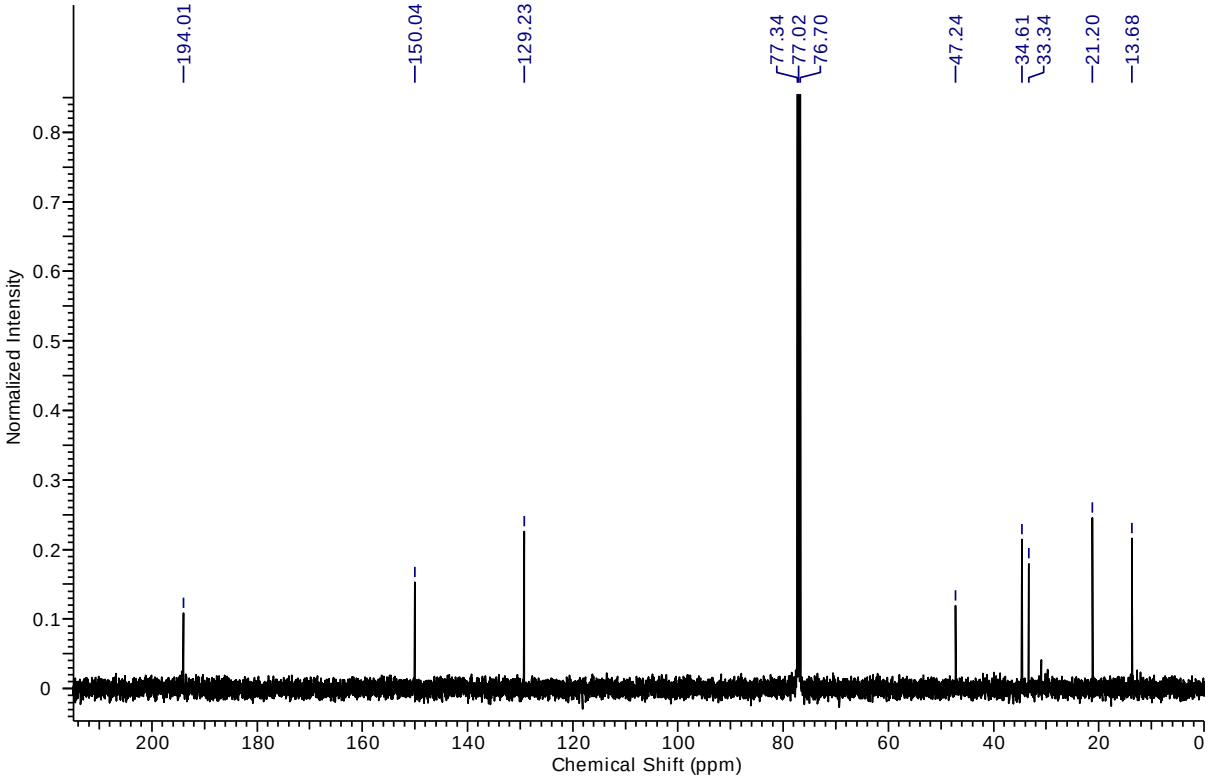

7.27
3.79
3.77
3.75
3.15
3.15
3.14
3.13
3.11
2.51
2.50
2.39
2.37
1.47
1.45
1.44
1.44
1.43
1.41
1.23
1.22
0.95
0.93
2.00
1.94
1.07
1.04
1.12
8.35
3.30
Normalized Intensity
Chemical Shift (ppm)
204.83
77.24
77.03
76.82
70.97
50.13
46.91
43.77
37.19
36.52
29.36
29.23
21.61
19.76
Normalized Intensity
Chemical Shift (ppm)

Pentafluorophenyl (*E*)-3-oxooct-4-ene-1-sulfonate 3m

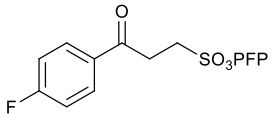


Purification by flash column chromatography (20-95% CH_2Cl_2/petrol) gave pentafluorophenyl (*E*)-3-oxooct-4-ene-1-sulfonate **3m** as an oil (201 mg, 0.54 mmol, 54%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 6.98 (dt, *J* = 15.5, 7.0 Hz, 1H), 6.18 (d, *J* = 15.5 Hz, 1H), 3.84-3.78 (m, 2H), 3.33-3.28 (m, 2H), 2.28-2.23 (m, 2H), 1.55 (sextet, *J* = 7.4 Hz, 2H), 0.97 (t, *J* = 7.5 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 194.0 (C), 150.0 (CH), 129.2 (CH), 47.2 (CH_2), 34.6 (CH_2), 33.3 (CH_2), 21.2 (CH_2), 13.7 (CH_3); IR (thin film) 3064, 2964, 1723, 1634 cm^{-1}; LRMS (CI) 373 (100, $[M+H]^+$); HRMS (CI) calcd for $C_{14}H_{14}F_5O_4S$ $[M+H]^+$ 373.0455; observed 373.0459.



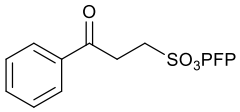


Pentafluorophenyl 3-(4-fluorophenyl)-3-oxopropane-1-sulfonate 3n[2]

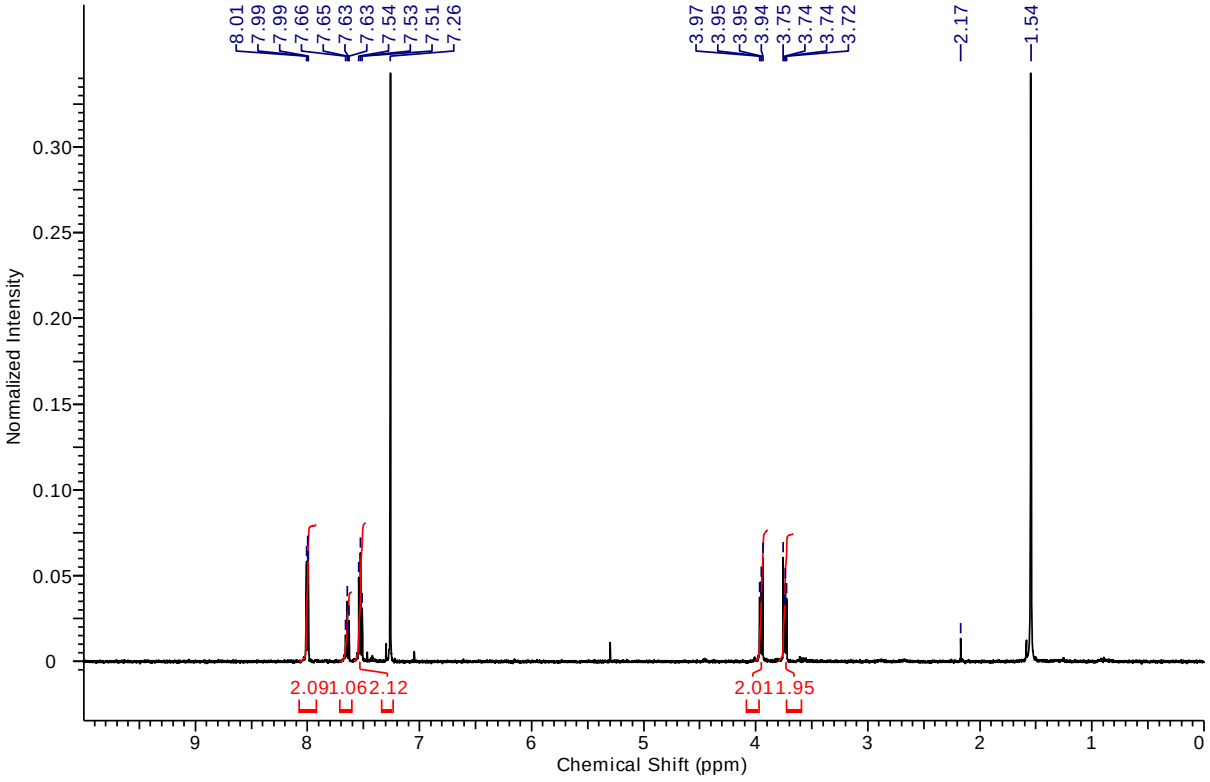


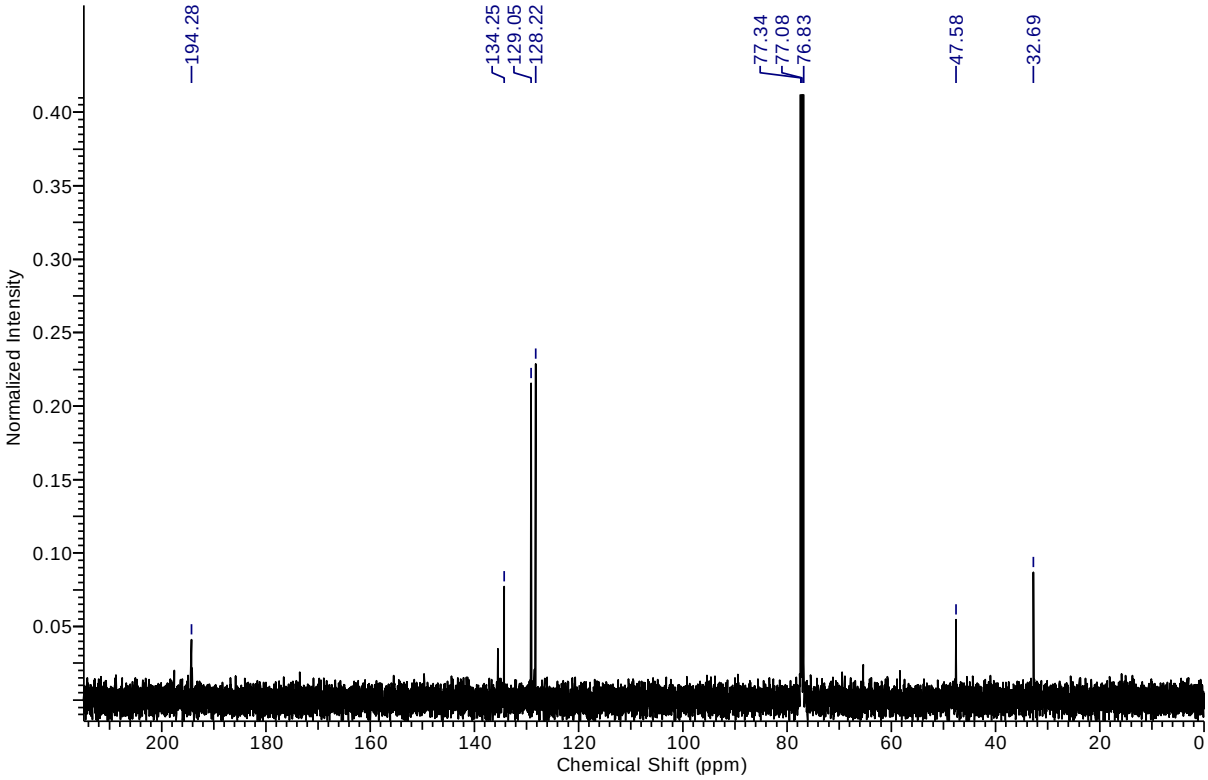
Purification by flash column chromatography (20-95% CH_2Cl_2/petrol) gave pentafluorophenyl 3-(4-fluorophenyl)-3-oxopropane-1-sulfonate **3n** as a white solid (255 mg, 0.64 mmol, 64%). m.p. 102-105 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.06-8.03 (m, 2H), 7.23-7.19 (m, 2H), 3.97-3.94 (m, 2H), 3.75-7.71 (m, 2H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 192.7 (C), 166.3 (d, $J_{C\text{-}F}$ = 255.0 Hz, C), 131.8 (C), 130.9 (d, $J_{C\text{-}F}$ = 13.5 Hz, CH), 116.2 (d, $J_{C\text{-}F}$ = 22.5 Hz, CH), 47.4 (CH_2), 32.6 (CH_2); IR (solid) 3069, 2960, 1684, 1381 cm^{-1}; LRMS (CI) 399 (100, $[M+H]^+$); HRMS (CI) calcd for $C_{15}H_9F_6O_4S$ $[M+H]^+$ 399.0126; observed 399.0120.

Pentafluorophenyl 3-phenyl-3-oxopropane-1-sulfonate 3o

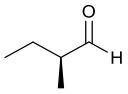


Purification by flash column chromatography (20-95% CH_2Cl_2/petrol) gave pentafluorophenyl 3-phenyl-3-oxopropane-1-sulfonate **3o** as an oil (232 mg, 0.61 mmol, 61%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.02-7.98 (m, 2H), 7.67-7.62 (m, 1H), 7.54-7.50 (m, 2H), 3.97-3.94 (m, 2H), 3.75-7.71 (m, 2H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 194.3 (C), 166.3 (d, J_{C-F} = 255.0 Hz, C), 135.6 (C), 134.3 (C), 129.1 (CH), 128.2 (CH), 47.6 (CH_2), 32.7 (CH_2); IR (solid) 3064, 2958, 1694 cm^{-1}; LRMS (CI) 381 (100, $[M+H]^+$); HRMS (CI) calcd for $C_{15}H_{10}F_5O_4S$ $[M+H]^+$ 381.0142; observed 381.0147.

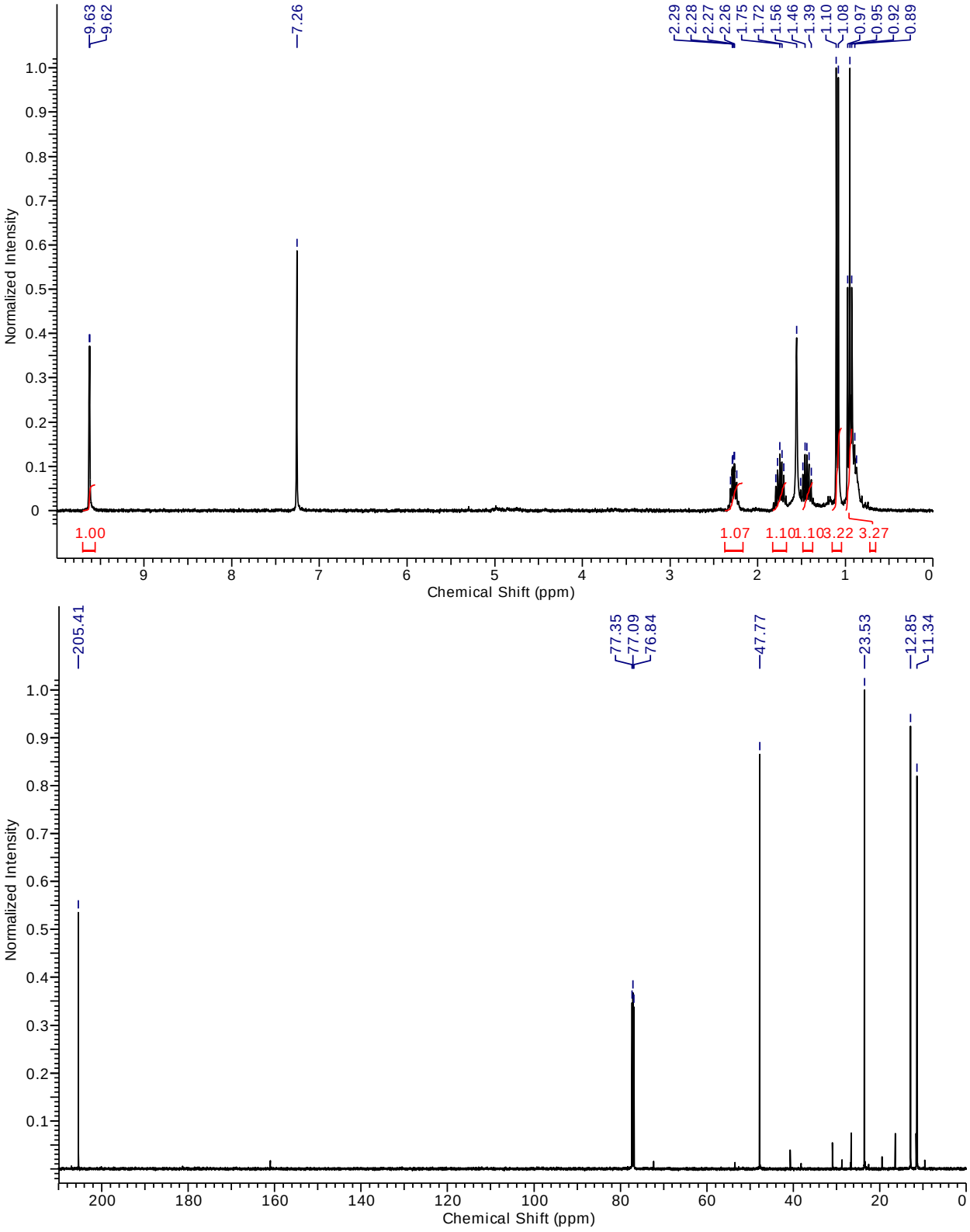




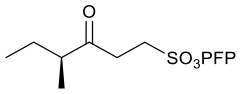
(*S*)-2-Methylbutanal 1p[3]



A two-necked flask was fitted with a pressure-equalising dropping funnel and a thermometer. The flask was charged with (*S*)-2-methylbutanol (13.5 mL, 11.0 g, 0.13 mol), 2,2,6,6-tetramethylpiperidin-1-oxyl (200 mg, 1.30 mmol), CH_2Cl_2 (40 mL), and a solution of KBr (1.48 g, 0.013 mol) in H_2O (6 mL). The reaction mixture was vigorously stirred and cooled to −10 °C, then was added aqueous NaOCl (2.4 M, 115 mL, 0.14 mol, pH 9.5) over 20 min, keeping the temperature of the reaction mixture between 10 and 15 °C. The mixture was stirred for a further 15 min, the orange organic phase was separated and the aqueous phase extracted with CH_2Cl_2 (15 mL). The combined organic extracts were washed with 10% aqueous HCl (50 mL) containing KI (0.40 g, 0.03 mol), 10% aqueous $Na_2S_2O_3$ (50 mL) and H_2O (30 mL). The organic phase was dried over $MgSO_4$ and then distilled at atmospheric pressure through a 20 cm Vigreux distillation column to give (*S*)-2-methylbutanal **1n** as a colourless oil (7.3 g, 75 mmol, 62%): b.p. 90-91 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.59 (d, *J* = 2.0 Hz, 1H), 2.24 (sextet of doublets, *J* = 7.0 and 2.0 Hz, 1H), 1.75-1.67 (m, 1H), 1.45-1.36 (m, 1H), 1.05 (d, *J* = 7.0 Hz, 3H), 0.91 (t, *J* = 7.5 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 205.4 (C), 47.8 (CH), 23.5 (CH_2), 12.9 (CH_3), 11.3 (CH_3); IR (thin film) 2970, 2938, 2878, 1705 cm^{-1}; LRMS (CI) 87 (30, $[M+H]^+$), 74 (100); HRMS (CI) calcd for $C_5H_{11}O$ $[M+H]^+$ 87.0804, observed 87.0809; $[\alpha]_D$ = +35.0 (c 2.44, Acetone, 21.0 °C), Lit. $[\alpha]_D$ = +35.5 (c 2.50, Acetone, 20.0 °C).[3]


9.63
9.62
7.26
2.29
2.28
2.27
2.26
1.75
1.72
1.56
1.46
1.39
1.10
1.08
0.97
0.95
0.92
0.89
Normalized Intensity
Chemical Shift (ppm)
1.00
1.07
1.10
1.10
3.22
3.27
205.41
77.35
77.09
76.84
47.77
23.53
12.85
11.34
Normalized Intensity
Chemical Shift (ppm)

Pentafluorophenyl (4*S*)-4-methyl-3-oxohexane-1-sulfonate 3p[2]



Purification by flash column chromatography (20-70% CH_2Cl_2/petrol) gave pentafluorophenyl (4*S*)-4-methyl-3-oxohexane-1-sulfonate **3p** as a colourless oil (223 mg, 0.62 mmol, 62%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.79-3.73 (m, 2H), 3.24-3.14 (m, 2H), 2.57 (sextet, *J* = 7.5 Hz, 1H), 1.75 (doublet of quintets, *J* = 14.0 and 7.5 Hz, 1H), 1.48 (doublet of quintets, *J* = 14.0 and 7.5 Hz, 1H), 1.16 (d, *J* = 7.5 Hz, 3H), 0.92 (t, *J* = 7.5 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 208.8 (C), 47.9 (CH), 47.1 (CH_2), 34.5 (CH_2), 25.9 (CH_2), 15.7 (CH_3), 11.5 (CH_3); IR (solid) 2970, 2940, 1716, 1516, 1384, 1184 cm^{-1}; LRMS (CI) 361 (100, $[M+H]^+$); HRMS (CI) calcd for $C_{13}H_{14}F_5O_4S$ $[M+H]^+$ 361.0533, observed 361.0526; $[\alpha]_D$ = +9.70 (c 18.0, $CHCl_3$, 22.5 ºC), Lit. $[\alpha]_D$ = +9.76 (*c* 18.9, $CHCl_3$, 23.5 °C).[2] HPLC conditions: CHIRALCEL-OD column, hexane:*i*-PrOH 97:3, 1.2 mL/min, t_R (minor) = 12.7 min, t_R (major) = 16.1 min, 97%ee.

NMRs are identical to that observed for pentafluorophenyl 4-methyl-3-oxohexane-1-sulfonate **3a**.

References

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2. V. Chudasama, A. R. Akhbar, K. A. Bahou, R. J. Fitzmaurice and S. Caddick, *Org. Biomol. Chem.*, 2013, **11**, 7301-7317.
3. P. L. Anelli, F. Montanari and S. Quici, *Org. Synth.*, 1990, **69**, 212-214.