Electronic Supplementary Material (ESI) for ChemComm.

Supporting Information

Rapid and scalable synthesis of fluoroketones via Cerium-mediated C–C bond cleavage

Yen-Chu Lu, Helen Jordan, Julian G. West*

Department of Chemistry, Rice University, 6500 Main St, Houston, TX, USA. Email: jgwest@rice.edu. Web: westchem.org

Table of Contents

General Information

All reagents were purchased from the commercially available sources and used without further purification. All reactions were carried out in a vial under an open atmosphere with magnetic stirring. All reactions were monitored by either ^{1}H NMR or thin layer chromatography (TLC) carried out on 0.25 mm pre-coated silia plates (F-254) purchased from Silicycle, Quebec, Canada, using shortwave UV light as visualizing agent and KMnO4 or phosphomolybdic acid (PMA) as developing agents. Flash column chromatography was performed using SiliaFlash-P60 silica gel (40 – 63 μm) purchased from Silicycle, Quebec, Canada. ^{1}H, ^{13}C and ^{19}F NMR spectra were recorded on a Bruker DRX-600 spectrometers operating at 600 MHz for proton nuclei, 151 MHz for carbon nuclei and 565 MHz for fluorine nuclei were calibrated using residual undeuterated solvent as an internal reference ($CDCl_3$: 7.26 ppm ^{1}H NMR and 77.20 ppm ^{13}C NMR). For reporting NMR peak multiplicities, the following abbreviations were used: s = singlet, d = doublet, t = triplet, q = quartet, p = pentet, hept = heptet, m = multiplet. High-resolution mass spectra (HRMS) were recorded on an Agilent UHPLC TOF mass spectrometer using electrospray ionization time-of-flight (ESI-TOF) or chemical ionization time-of-flight (CI-TOF) reflectron experiments.

Experimental Section

Substrate Synthesis

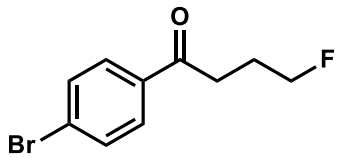
1-(4-bromophenyl)cyclobutanol (**1a**) was directly purchased from Fisher scientific company. Other tertiary cyclobutanol substrates **1b** − **1o** (except **1k**) were prepared by the addition of cyclobutanone to the corresponding Grignard reagent according to the literature procedure.[1] Cyclobutanol **1k** was prepared by the addition of cyclobutanol to the corresponding organolithium according to the literature procedure.[2] Cyclobutanol **1p** was prepared by Norrish-Yang cyclization reaction of valerophenone under irradiation according to the literature procedure.[3]

General procedure for the ring-opening fluorination

1-(4-bromophenyl)cyclobutanol (**1a**) (68.1 mg, 0.3 mmol, 1.0 equiv), Selectfluor (425.1 mg, 1.2 mmol, 4.0 equiv) and CH_3CN/H_2O (0.75/0.75 mL, 0.2 M) solvent were loaded to a vial (open flask). The mixture was stirred at 0 °C (ice bath) for 5 min followed by the addition of Cerium ammonium nitrate (180.9 mg, 0.33 mmol, 1.1 equiv), then warmed up to RT. Upon completion, the mixture was extracted with CH_2Cl_2 (3× 10 mL), dried over Na_2SO_4, filtered and concentrated in vacuo. The crude mixture was then purified by flash chromatography (Ethyl acetate/Hexanes = 1:16) to give γ-fluoroketone **2a** (42.6 mg, 58%).

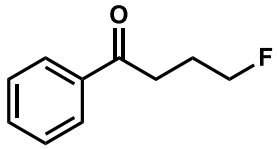
Characterization of γ-Fluorinated Ketones

1-(4-bromophenyl)-4-fluorobutan-1-one (2a)[4]



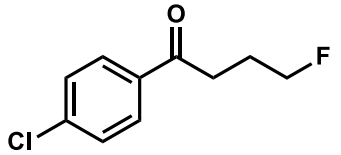
2a; colorless oil; **Yield**: 58%; $\mathbf{R_f}$ = 0.43 (EtOAc/Hexanes = 1:8); **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.85 – 7.79 (m, 2H), 7.62 – 7.56 (m, 2H), 4.54 (dt, *J* = 5.7, 47.3 Hz, 2H), 3.10 (t, *J* = 7.1 Hz, 2H), 2.19 – 2.07 (m, 2H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 198.2, 135.6, 132.1, 129.7, 128.5, 83.3 (d, J_{CF} = 163.5 Hz), 34.1 (d, J_{CF} = 4.0 Hz), 24.9 (d, J_{CF} = 19.8 Hz). **^{19}F NMR (565 Hz, $CDCl_3$):** δ -220.05 – -220.35 (m, 1F). **HRMS (CI-TOF):** calc'd for $C_{10}H_{11}BrFO$ $[M+H]^+$ 244.9977; Found 244.9983.

4-fluoro-1-phenylbutan-1-one (2b)[4]



2b; colorless oil; **Yield** = 63%; $\mathbf{R_f}$ = 0.43 (EtOAc/Hexanes = 1:8); **^{1}H NMR (600 MHz, $CDCl_3$):** δ 8.00 – 7.94 (m, 2H), 7.59 – 7.54 (m, 1H), 7.49 – 7.44 (m, 2H), 4.56 (dt, *J* = 5.8, 47.3 Hz, 2H), 3.15 (t, *J* = 7.1 Hz, 2H), 2.21 – 2.10 (m, 2H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 199.1, 136.8, 133.2, 128.6, 128.0, 83.3 (d, J_{CF} = 163.7 Hz), 34.0 (d, J_{CF} = 4.3 Hz), 24.9 (d, J_{CF} = 20.0 Hz). **^{19}F NMR (565 Hz, $CDCl_3$):** -219.89 – -220.17 (m, 1F). **HRMS (CI-TOF):** calc'd for $C_{10}H_{12}FO$ $[M+H]^+$ 167.0872; Found 167.0868.

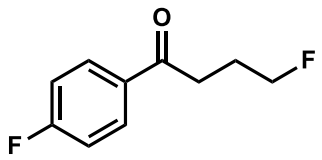
1-(4-chlorophenyl)-4-fluorobutan-1-one (2c)[4]



2c; colorless oil; **Yield**: 65%; $\mathbf{R_f}$ = 0.4 (EtOAc/Hexanes = 1:8); **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.92 – 7.88 (m, 2H), 7.45 – 7.41 (m, 2H), 4.54 (dt, *J* = 5.8, 47.2 Hz, 2H), 3.10 (t, *J* = 7.1 Hz, 2H), 2.18 – 2.08 (m, 2H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 198.0,

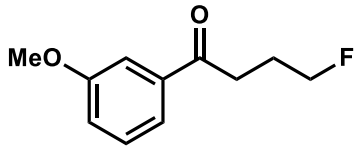
139.8, 135.2, 129.6, 129.1, 83.3 (d, J_{CF} = 163.4 Hz), 34.1 (d, J_{CF} = 3.6 Hz), 24.9 (d, J_{CF} = 19.8 Hz). **^{19}F NMR (565 Hz, $CDCl_3$):** -220.02 – -220.30 (m, 1F). **HRMS (CI-TOF):** calc'd for $C_{10}H_{11}ClFO$ $[M+H]^+$ 201.0482; Found 201.0488.

1-(4-fluorophenyl)-4-fluorobutan-1-one (2d)[4]



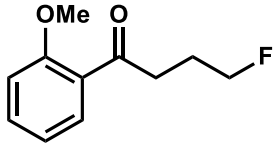
2d; colorless oil; **Yield**: 69%; **R_f** = 0.33 (EtOAc/Hexanes = 1:8); **^{1}H NMR (600 MHz, $CDCl_3$):** δ 8.03 – 7.97 (m, 2H), 7.16 – 7.10 (m, 2H), 4.55 (dt, *J* = 5.7, 47.3 Hz, 2H), 3.11 (t, *J* = 7.6 Hz, 2H), 2.19 – 2.09 (m, 2H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 197.7, 165.9 (d, J_{CF} = 253.1 Hz), 133.3 (d, J_{CF} = 2.9 Hz), 130.8 (d, J_{CF} = 9.3 Hz), 115.9 (d, J_{CF} = 21.8 Hz), 83.4 (d, J_{CF} = 163.2 Hz), 34.1 (d, J_{CF} = 3.9 Hz), 25.0 (d, J_{CF} = 19.9 Hz). **^{19}F NMR (565 Hz, $CDCl_3$):** -105.11 – -105.17 (m, 1F), -220.06 – -220.36 (m, 1F). **HRMS (CI-TOF):** calc'd for $C_{10}H_{11}F_2O$ $[M+H]^+$ 185.0778; Found 185.0782.

4-fluoro-1-(3-methoxyphenyl)butan-1-one (2e)[4]



2e; colorless oil; **Yield:** 65%; **R_f** = 0.3 (EtOAc/Hexanes = 1:8); **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.54 (d, *J* = 7.6 Hz, 1H), 7.49 (t, *J* = 2.3 Hz, 1H), 7.37 (t, *J* = 8.0 Hz, 1H), 7.11 (dd, *J* = 2.2, 8.2 Hz, 1H), 4.55 (dt, *J* = 5.8, 47.3 Hz, 2H), 3.85 (s, 3H), 3.12 (t, *J* = 7.1 Hz, 2H), 2.19 – 2.09 (m, 2H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 199.1, 160.0, 138.3, 129.8, 120.8, 119.8, 112.4, 83.5 (d, J_{CF} = 163.2 Hz), 55.6, 34.3 (d, J_{CF} = 4.1 Hz), 25.0 (d, J_{CF} = 19.9 Hz). **^{19}F NMR (565 Hz, $CDCl_3$):** -219.86 – -220.16 (m, 1F). **HRMS (CI-TOF):** calc'd for $C_{11}H_{14}FO_2$ $[M+H]^+$ 197.0978; Found 197.0976.

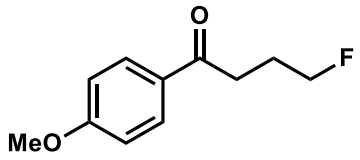
4-fluoro-1-(2-methoxyphenyl)butan-1-one (2f)[4]



2f; colorless oil; **Yield:** 65%; **R_f** = 0.33 (EtOAc/Hexanes = 1:8); **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.70 (dd, *J* = 1.7, 7.7 Hz, 1H), 7.48 – 7.43 (m, 1H), 7.00 (t, *J* = 7.4 Hz, 1H),

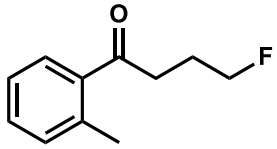
6.96 (d, J = 8.3 Hz, 1H), 4.52 (dt, J = 5.9, 47.3 Hz, 2H), 3.90 (s, 3H), 3.12 (t, J = 7.1 Hz, 2H), 2.15 – 2.05 (m, 2H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 201.6, 158.8, 133.7, 130.4, 128.2, 120.8, 111.7, 83.8 (d, J_{CF} = 163.4 Hz), 55.6, 39.4 (d, J_{CF} = 4.8 Hz), 25.3 (d, J_{CF} = 19.8 Hz). **^{19}F NMR (565 Hz, $CDCl_3$):** -219.13 – -219.42 (m, 1F). **HRMS (CI-TOF):** calc'd for $C_{11}H_{14}FO_2$ $[M+H]^+$ 197.0978; Found 197.0984.

4-fluoro-1-(4-methoxyphenyl)butan-1-one (2g)[4]



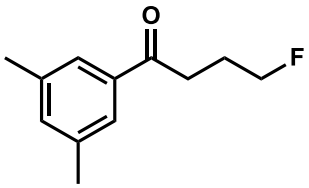
2g; colorless oil; **Yield**: 60%; **R_f** = 0.2 (EtOAc/Hexanes = 1:8); **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.97 – 7.93 (m, 2H), 6.96 – 6.88 (m, 2H), 4.54 (dt, J = 5.8, 47.3 Hz, 2H), 3.86 (s, 3H), 3.08 (t, J = 7.1 Hz, 2H), 2.19 – 2.08 (m, 2H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 197.8, 163.7, 130.4, 130.1, 113.9, 83.6 (d, J_{CF} = 163.5 Hz), 55.6, 33.7 (d, J_{CF} = 4.2 Hz), 25.2 (d, J_{CF} = 19.8 Hz). **^{19}F NMR (565 Hz, $CDCl_3$):** -219.75 – -220.08 (m, 1F). **HRMS (CI-TOF):** calc'd for $C_{11}H_{14}FO_2$ $[M+H]^+$ 197.0978; Found 197.0971.

4-fluoro-1-(*o*-tolyl)butan-1-one (2h)



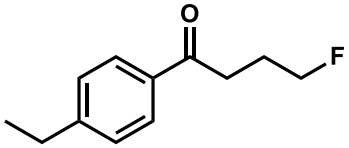
2h; colorless oil; **Yield**: 56%; **R_f**= 0.43 (EtOAc/Hexanes = 1:8); **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.68 – 7.65 (m, 1H), 7.38 (td, J = 1.3, 7.5 Hz, 1H), 7.29 – 7.23 (m, 2H), 4.55 (dt, J = 5.8, 47.2 Hz, 2H), 3.06 (t, J = 7.1 Hz, 2H), 2.50 (s, 3H), 2.18 – 2.08 (m, 2H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 203.3, 138.3, 137.9, 132.2, 131.6, 128.6, 125.9, 83.5 (d, J_{CF} = 163.7 Hz), 37.0 (d, J_{CF} = 3.7 Hz), 25.2 (d, J_{CF} = 19.9 Hz), 21.5. **^{19}F NMR (565 Hz, $CDCl_3$):** -219.82 – -220.10 (m, 1F). **HRMS (CI-TOF):** calc'd for $C_{11}H_{14}FO$ $[M+H]^+$ 181.1029; Found 181.1026.

1-(3,5-dimethylphenyl)-4-fluorobutan-1-one (2i)



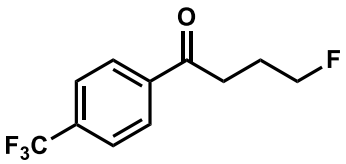
2i; colorless oil; **Yield**: 57%; $\mathbf{R_f}$ = 0.5 (EtOAc/Hexanes = 1:8); **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.57 (s, 2H), 7.20 (s, 1H), 4.55 (dt, *J* = 5.8, 47.3 Hz, 2H), 3.11 (t, *J* = 7.1 Hz, 2H), 2.37 (d, *J* = 0.5 Hz, 6H), 2.19 – 2.09 (m, 2H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 199.7, 138.4, 137.1, 135.0, 126.0, 83.6 (d, J_{CF} = 163.0 Hz), 34.2 (d, J_{CF} = 3.9 Hz), 25.1 (d, J_{CF} = 19.9 Hz), 21.4. **^{19}F NMR (565 Hz, $CDCl_3$):** -219.75 – -220.05 (m, 1F). **HRMS (CI-TOF):** calc'd for $C_{12}H_{16}FO$ $[M+H]^+$ 195.1180; Found 195.1174.

1-(4-ethylphenyl)-4-fluorobutan-1-one (2j)



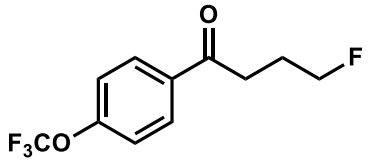
2j; colorless oil; **Yield**: 66%; $\mathbf{R_f}$ = 0.43 (EtOAc/Hexanes = 1:8); **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.92 – 7.88 (m, 2H), 7.29 (d, *J* = 8.3 Hz, 2H), 4.55 (dt, *J* = 5.8, 47.3 Hz, 2H), 3.12 (t, *J* = 7.1 Hz, 2H), 2.70 (q, *J* = 7.62 Hz, 2H), 2.20 – 2.09 (m, 2H), 1.26 (t, *J* = 7.6 Hz, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 198.9, 150.3, 134.7, 128.4, 128.3, 83.6 (d, J_{CF} = 163.3 Hz), 34.0 (d, J_{CF} = 4.3 Hz), 29.1, 25.0 (d, J_{CF} = 20.2 Hz), 15.4. **^{19}F NMR (565 Hz, $CDCl_3$):** -219.75 – -220.05 (m, 1F). **HRMS (CI-TOF):** calc'd for $C_{12}H_{16}FO$ $[M+H]^+$ 195.1185; Found 195.1183.

4-fluoro-1-(4-(trifluoromethyl)phenyl)butan-1-one (2k)[4]



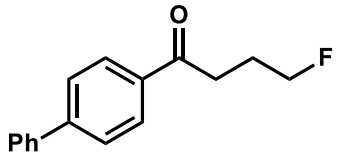
2k; colorless oil; **Yield**: 52%; $\mathbf{R_f}$ = 0.43 (EtOAc/Hexanes = 1:8); **^{1}H NMR (600 MHz, $CDCl_3$):** δ 8.07 (d, *J* = 8.1 Hz, 2H), 7.73 (d, *J* = 8.2 Hz, 2H), 4.56 (dt, *J* = 5.7, 47.2 Hz, 2H), 3.17 (t, *J* = 7.1 Hz, 2H), 2.22 – 2.11 (m, 2H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 198.3, 139.5, 134.6 (q, J_{CF} = 32.2 Hz), 128.5, 125.9 (q, J_{CF} = 3.5 Hz), 123.7 (q, J_{CF} = 271.3 Hz), 83.3 (d, J_{CF} = 163.7 Hz), 34.5 (d, J_{CF} = 3.7 Hz), 24.8 (d, J_{CF} = 19.8 Hz). **^{19}F NMR (565 Hz, $CDCl_3$):** -63.15 (s, 3F), -220.23 – -220.55 (m, 1F). **HRMS (CI-TOF):** calc'd for $C_{11}H_{11}F_4O$ $[M+H]^+$ 235.0746; Found 235.0750.

4-fluoro-1-(4-(trifluoromethoxy)phenyl)butan-1-one (2l)[4]



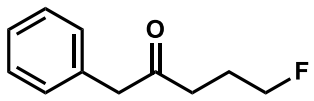
2l; colorless oil; **Yield**: 66%; $\mathbf{R_f}$= 0.33 (EtOAc/Hexanes = 1:8); **^{1}H NMR (600 MHz, $CDCl_3$):** δ 8.05 – 8.00 (m, 2H) 7.32 – 7.26 (m, 2H), 4.56 (dt, *J* = 5.7, 47.3 Hz, 2H), 3.13 (t, *J* = 7.1 Hz, 2H), 2.20 – 2.10 (m, 2H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 197.7, 152.8, 135.1, 130.2, 120.5 (q, J_{CF} = 257.2 Hz), 83.3 (d, J_{CF} = 163.6 Hz), 34.2 (d, J_{CF} = 4.2 Hz), 24.9 (d, J_{CF} = 19.8 Hz). **^{19}F NMR (565 Hz, $CDCl_3$):** -57.62 (s, 3F), -220.21 – -220.49 (m, 1F). **HRMS (CI-TOF):** calc'd for $C_{11}H_{11}F_4O_2$ $[M+H]^+$ 251.0695; Found 251.0703.

1-([1,1'-biphenyl]-4-yl)-4-fluorobutan-1-one (2m)[4]



2m; white solid; **Yield:** 62%; $\mathbf{R_f}$ = 0.37 (EtOAc/Hexanes = 1:8); **^{1}H NMR (600 MHz, $CDCl_3$):** δ 8.07 – 8.02 (m, 2H), 7.72 – 7.66 (m, 2H), 7.65 – 7.60 (m, 2H), 7.50 – 7.45 (m, 2H), 7.43 – 7.38 (m, 1H), 4.58 (dt, *J* = 5.8, 47.3 Hz, 2H), 3.18 (t, *J* = 7.1 Hz, 2H), 2.23 – 2.13 (m, 2H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 198.8, 146.0, 140.0, 135.6, 129.1, 128.7, 128.4, 127.4, 83.5 (d, J_{CF} = 163.2 Hz), 34.2 (d, J_{CF} = 4.3 Hz), 25.0 (d, J_{CF} = 19.9 Hz). **^{19}F NMR (565 Hz, $CDCl_3$):** -219.81 – -220.10 (m, 1F). **HRMS (CI-TOF):** calc'd for $C_{16}H_{16}FO$ $[M+H]^+$ 243.1185; Found 243.1189.

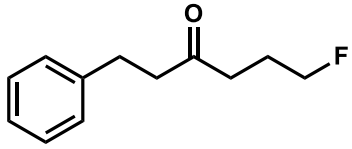
5-fluoro-1-phenylpentan-2-one (2n)[4]



2n; colorless oil; **Yield**: 41%; $\mathbf{R_f}$ = 0.3 (EtOAc/Hexanes = 1:8); **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.36 – 7.31 (m, 2H), 7.29 – 7.25 (m, 1H), 7.23 – 7.19 (m, 2H), 4.41 (dt, *J* = 5.8, 47.2 Hz, 2H), 3.71 (s, 2H), 2.61 (t, *J* = 7.1 Hz, 2H), 1.99 – 1.89 (m, 2H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 207.5, 134.2, 129.5, 129.0, 127.3, 83.3 (d, J_{CF} = 163.7 Hz), 50.4, 37.5 (d, J_{CF} = 4.3 Hz), 24.6 (d, J_{CF} = 20.1 Hz). **^{19}F NMR (565 Hz, $CDCl_3$):**

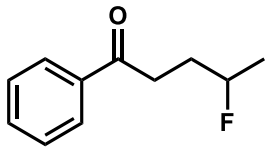
-220.03 – -220.32 (m, 1F). **HRMS (CI-TOF):** calc'd for $C_{11}H_{14}FO$ $[M+H]^+$ 181.1029; Found 181.1032.

6-fluoro-1-phenylhexan-3-one (2o)[5]



2o; colorless oil; **Yield**: 43%; $\mathbf{R_f}$ = 0.33 (EtOAc/Hexanes = 1:8); **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.31 – 7.26 (m, 2H), 7.22 – 7.16 (m, 3H), 4.44 (dt, *J* = 5.8, 47.3 Hz, 2H), 2.91 (t, *J* = 7.5 Hz, 2H), 2.76 (t, *J* = 7.9 Hz, 2H), 2.55 (t, *J* = 7.1 Hz, 2H), 2.01 – 1.91 (m, 2H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 209.1, 141.1, 128.7, 128.5, 126.3, 83.3 (d, J_{CF} = 163.4 Hz), 44.5, 38.4 (d, J_{CF} = 4.2 Hz), 29.9, 24.5 (d, J_{CF} = 19.7 Hz). **^{19}F NMR (565 Hz, $CDCl_3$):** -220.02 – -220.32 (m, 1F). **HRMS (CI-TOF):** calc'd for $C_{12}H_{16}FO$ $[M+H]^+$ 195.1185; Found 195.1183.

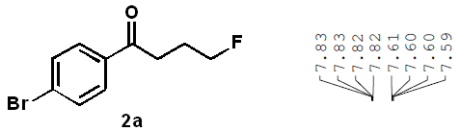
4-fluoro-1-phenylpentan-1-one (2p)[6]

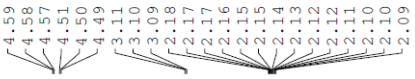


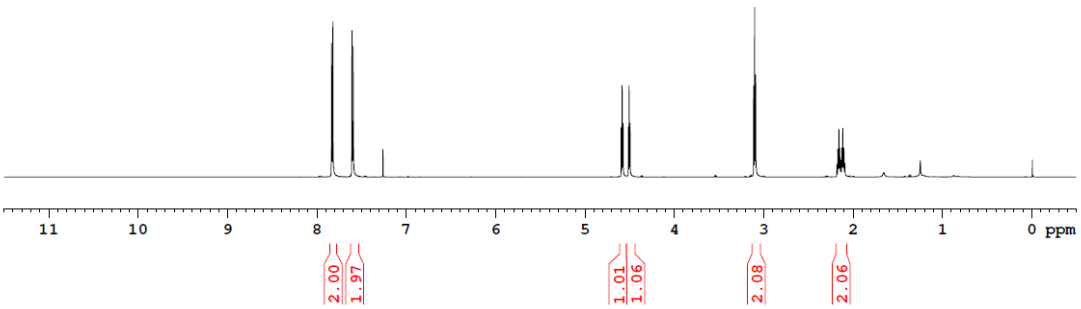
2p; yellow oil; **Yield:** 64%; $\mathbf{R_f}$ = 0.43 (EtOAc/Hexanes = 1:8); **^{1}H NMR (600 MHz, $CDCl_3$):** δ 7.98 (d, *J* = 7.3 Hz, 2H), 7.56 (t, *J* = 7.4 Hz, 1H), 7.46 (t, *J* = 7.8 Hz, 2H), 4.84 – 4.69 (m, 1H), 3.21 – 3.08 (m, 2H), 2.15 – 1.93 (m, 2H), 1.39 (dd, *J* = 6.1, 23.9 Hz, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 199.6, 136.9, 133.3, 128.8, 128.2, 90.5 (d, J_{CF} = 164.0 Hz), 34.1 (d, J_{CF} = 3.3 Hz), 31.2 (d, J_{CF} = 20.6 Hz), 21.3 (d, J_{CF} = 22.6 Hz). **^{19}F NMR (565 Hz, $CDCl_3$):** -175.00 – -175.33 (m, 1F). The spectra match the literature.

NMR Spectra of γ-Fluorinated Ketones

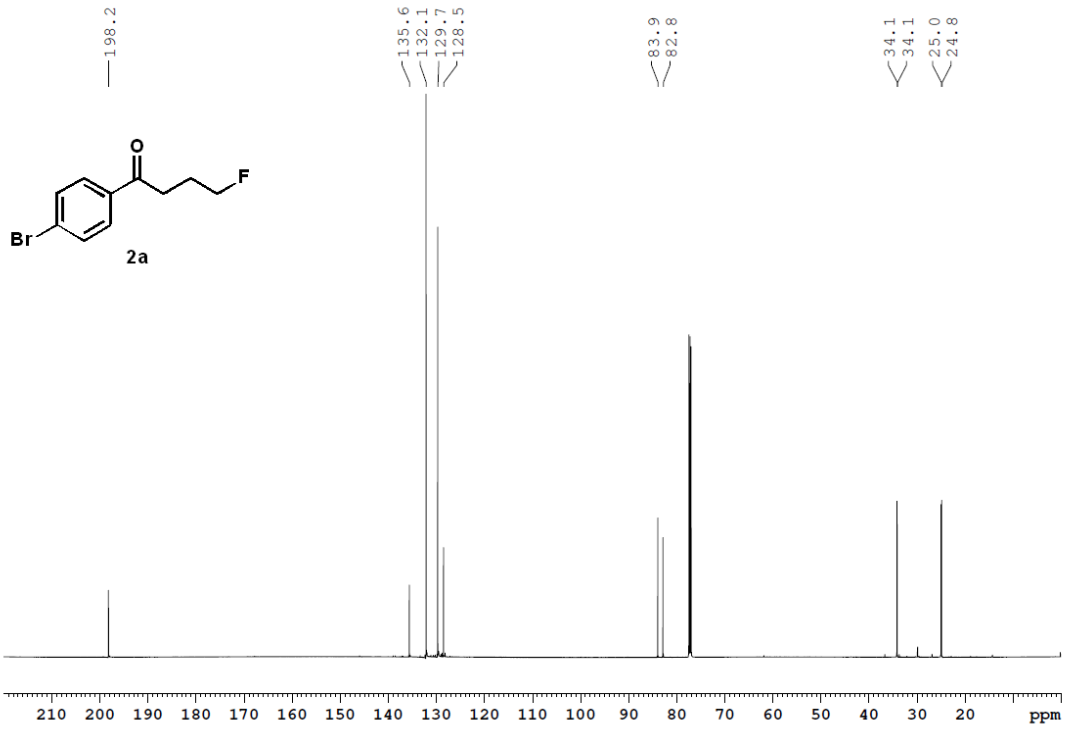
^{1}H NMR spectrum of **2a** (600 MHz, $CDCl_3$)



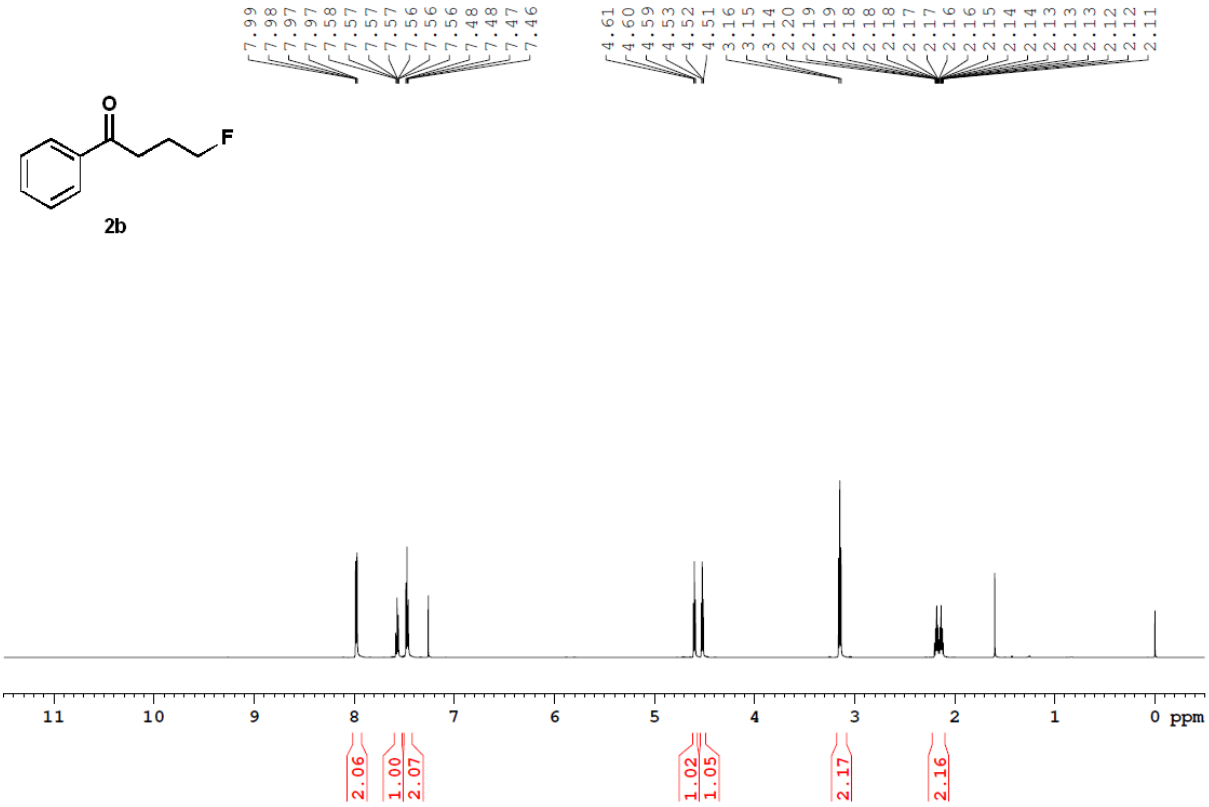




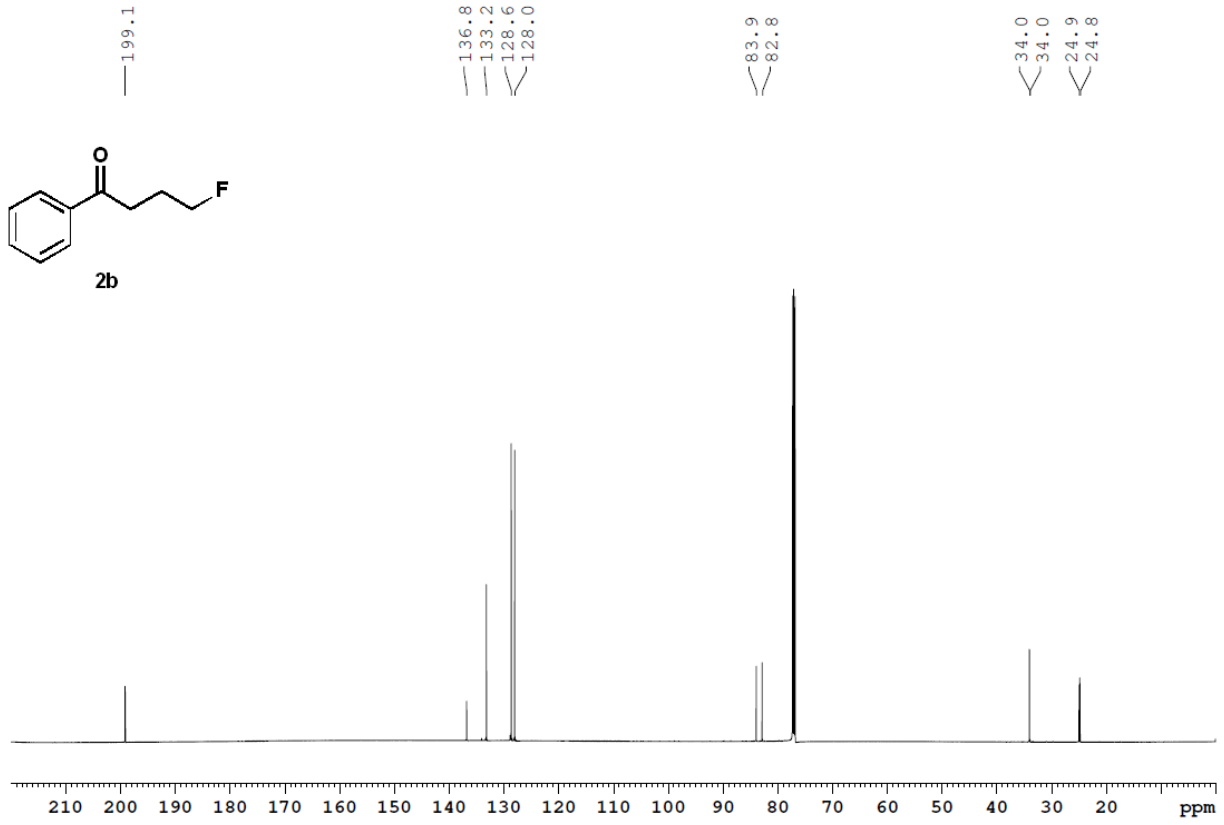
^{13}C NMR spectrum of **2a** (150 MHz, $CDCl_3$)



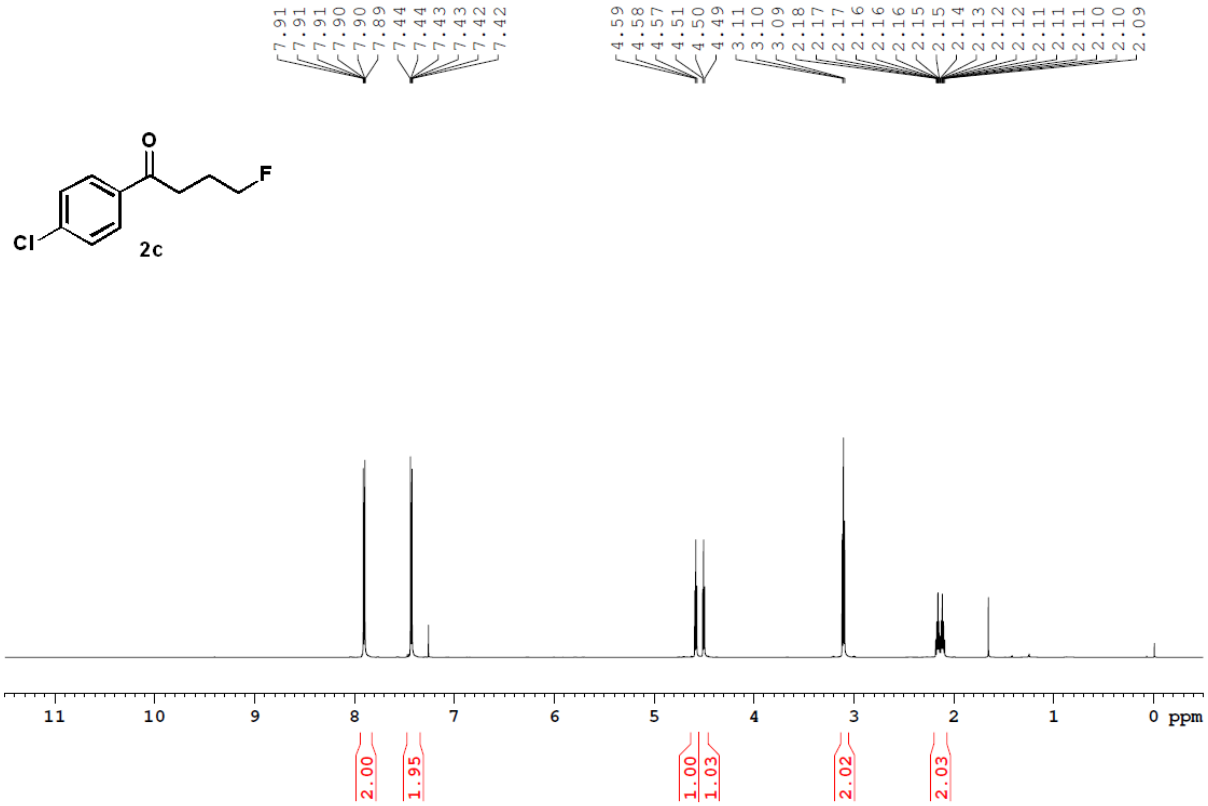
^{1}H NMR spectrum of **2b** (600 MHz, $CDCl_3$)



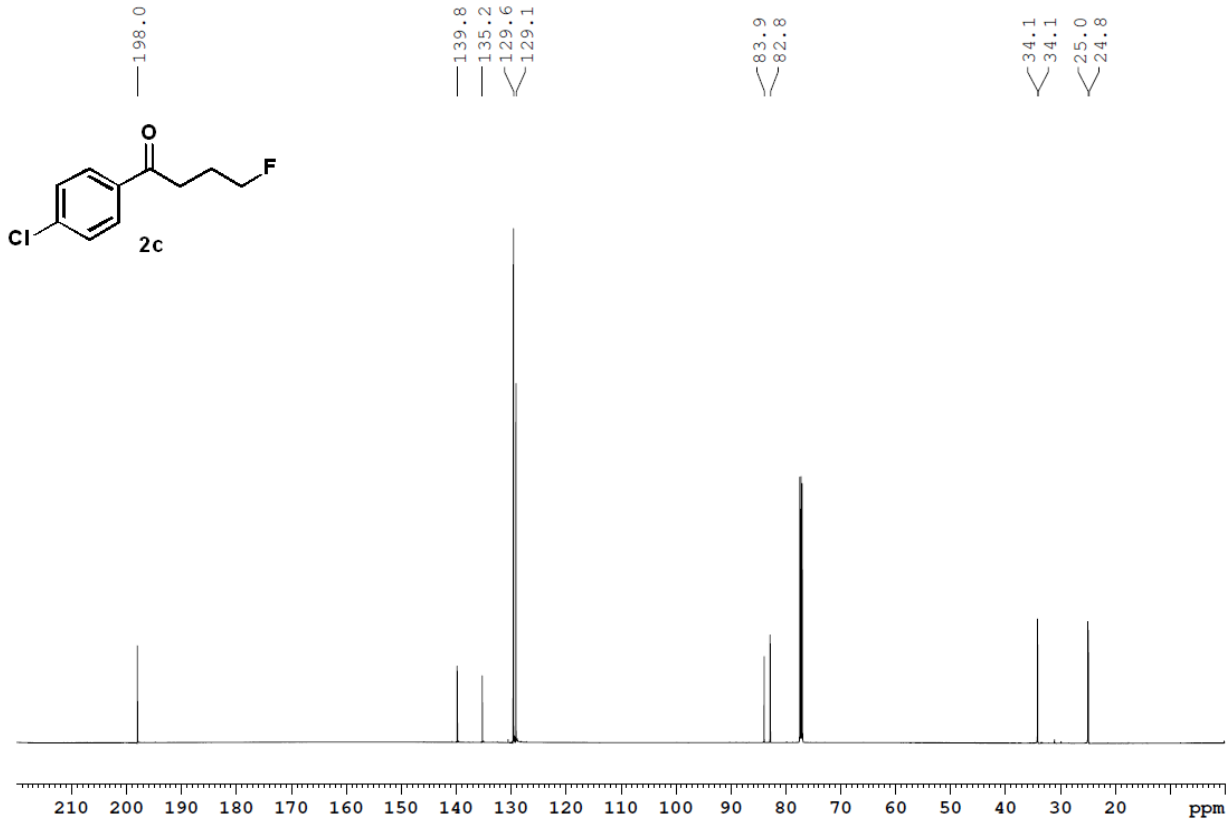
^{13}C NMR spectrum of **2b** (150 MHz, $CDCl_3$)



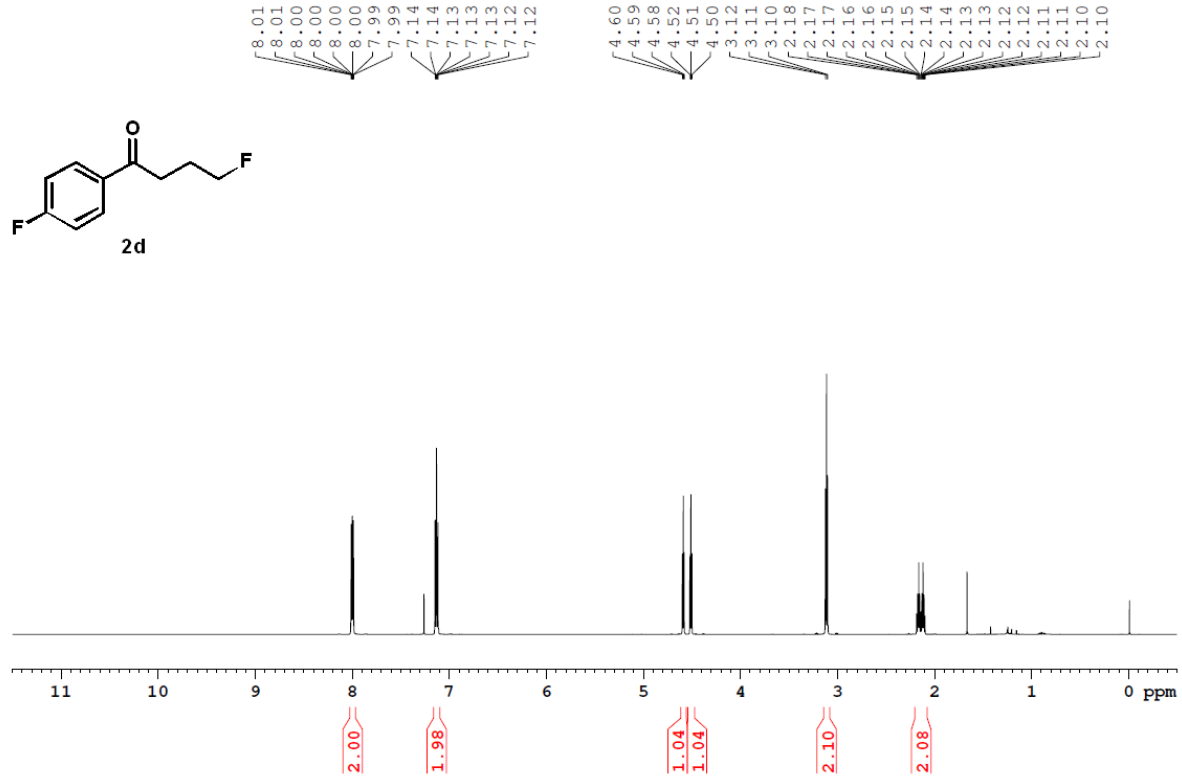
^{1}H NMR spectrum of **2c** (600 MHz, $CDCl_3$)



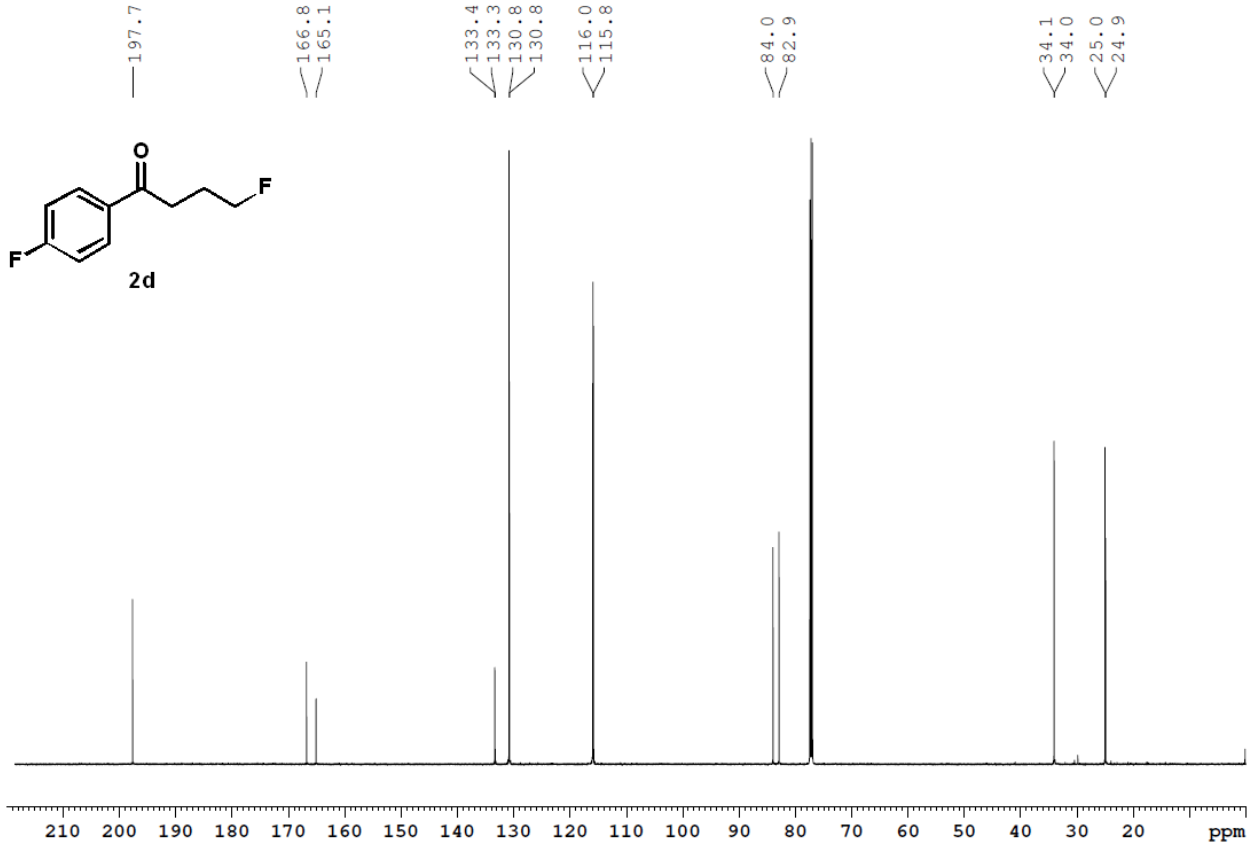
^{13}C NMR spectrum of **2c** (150 MHz, $CDCl_3$)



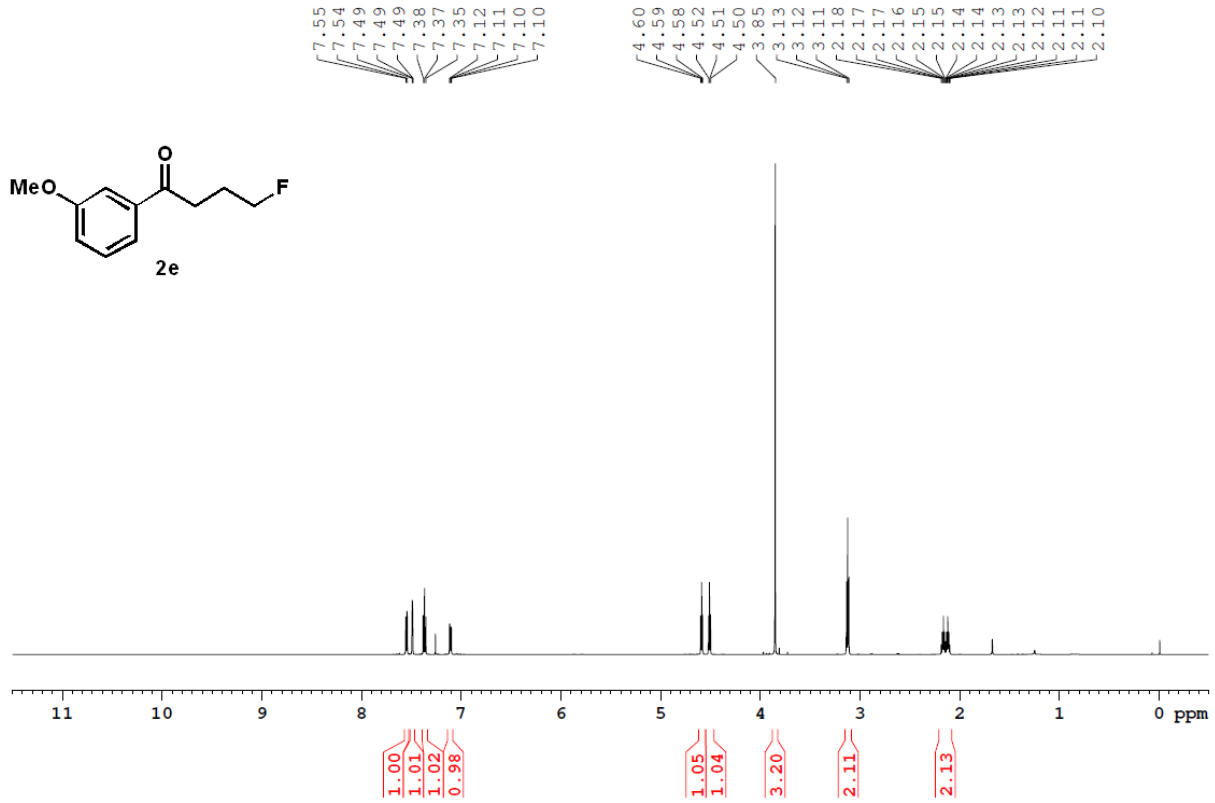
^{1}H NMR spectrum of **2d** (600 MHz, $CDCl_3$)



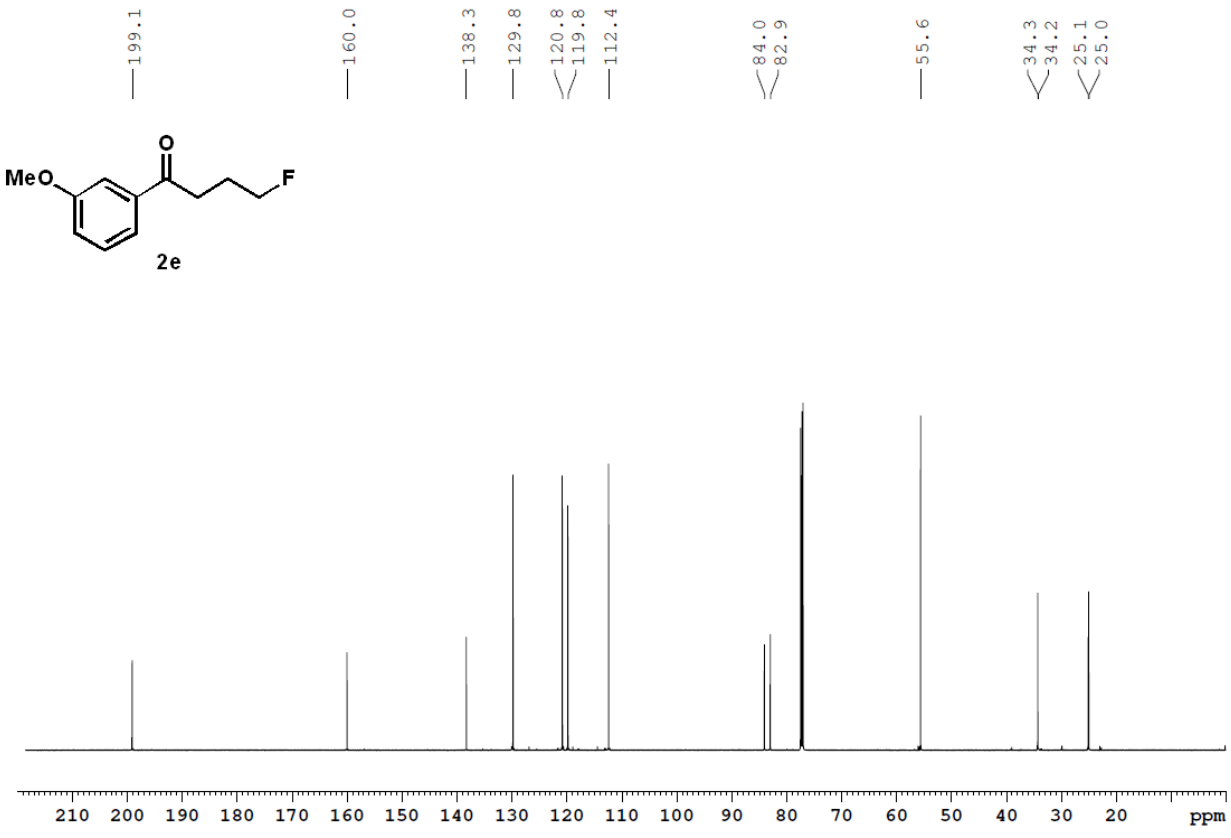
^{13}C NMR spectrum of **2d** (150 MHz, $CDCl_3$)



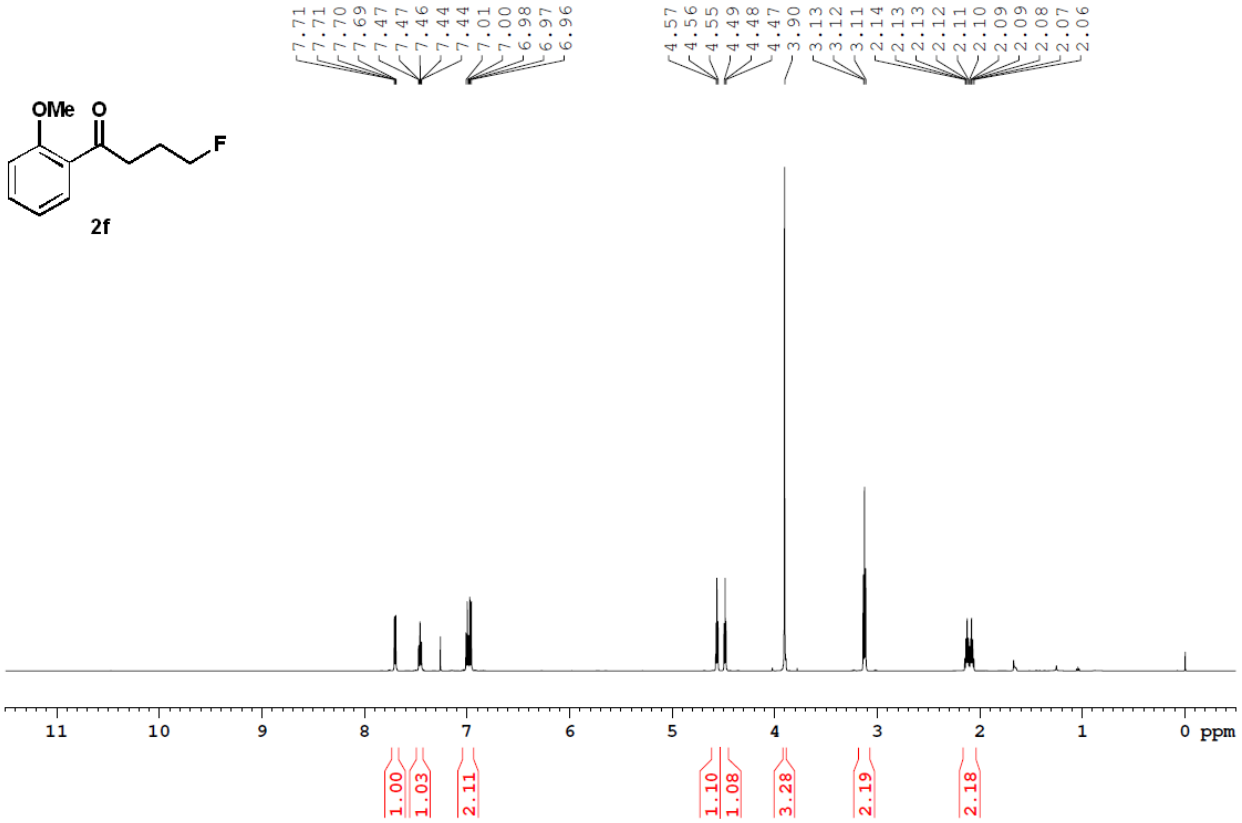
^{1}H NMR spectrum of **2e** (600 MHz, $CDCl_3$)



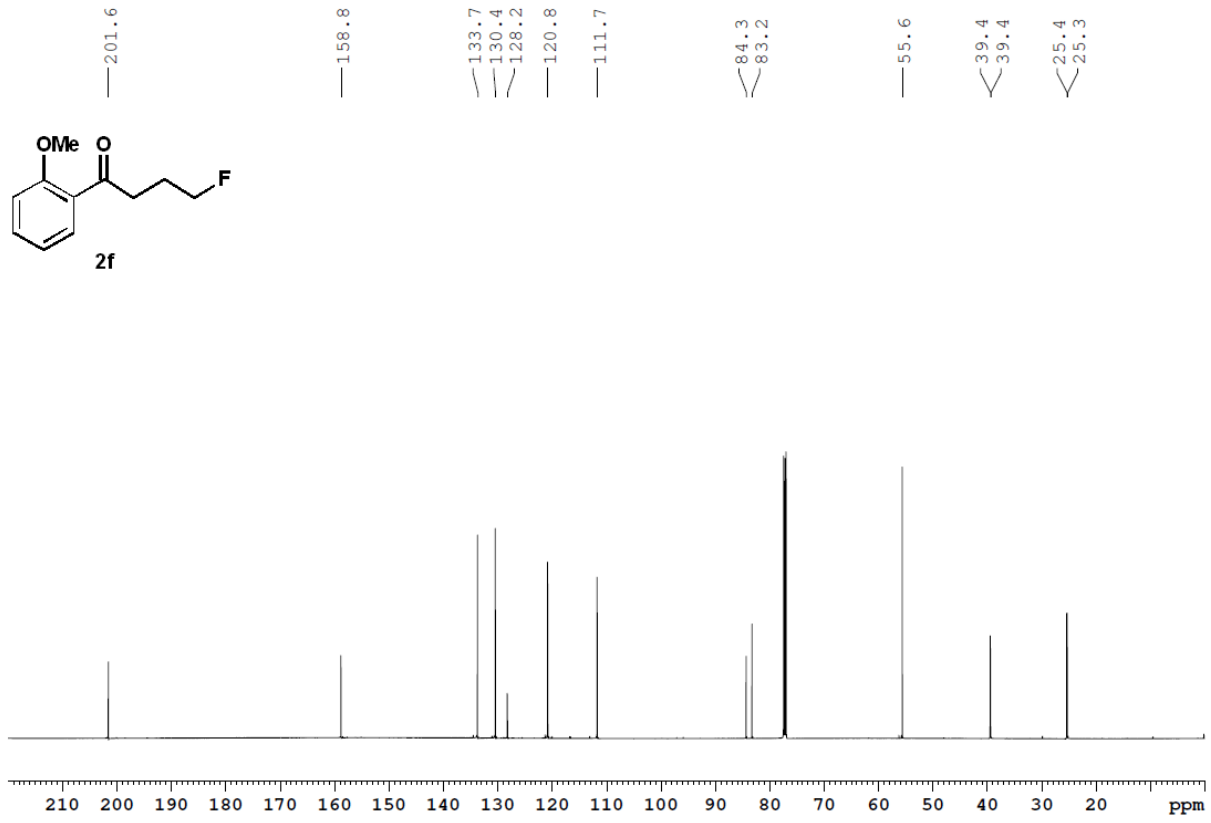
^{13}C NMR spectrum of **2e** (150 MHz, $CDCl_3$)



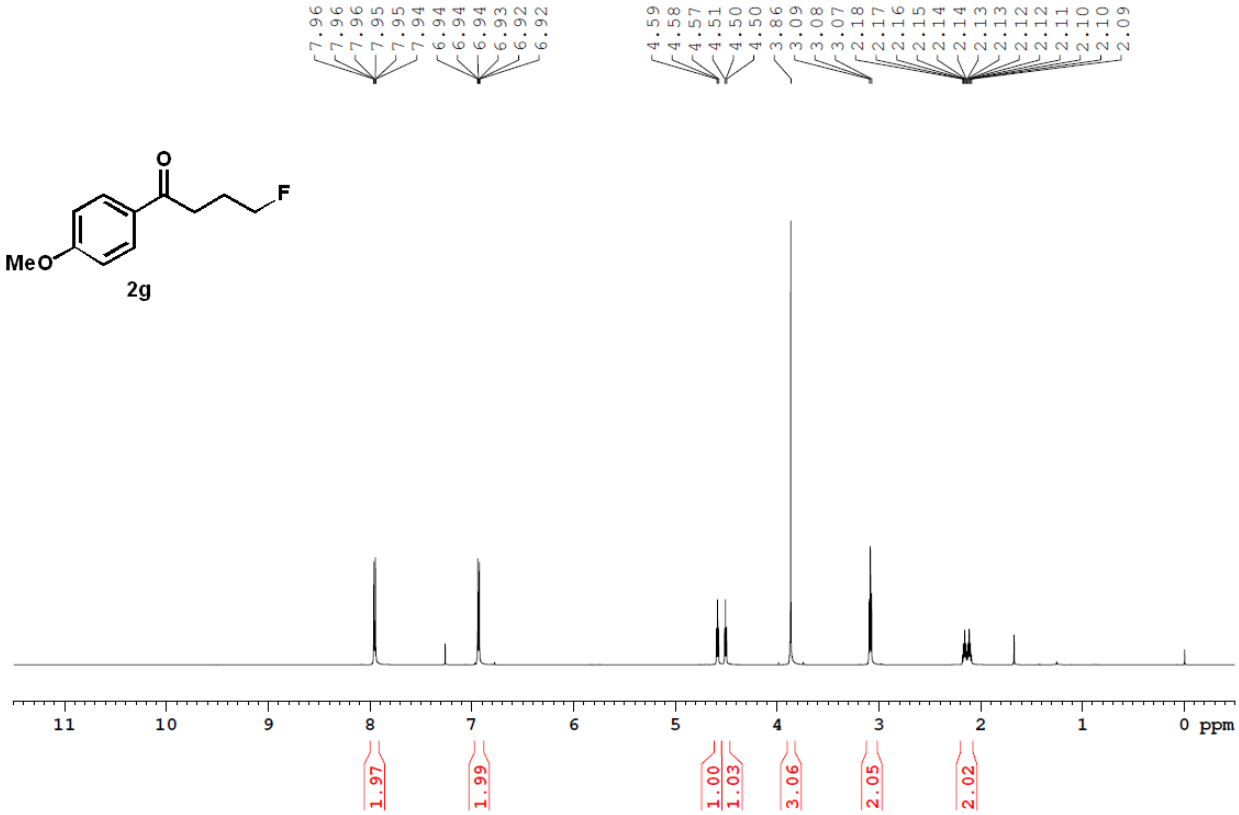
^{1}H NMR spectrum of **2f** (600 MHz, $CDCl_3$)



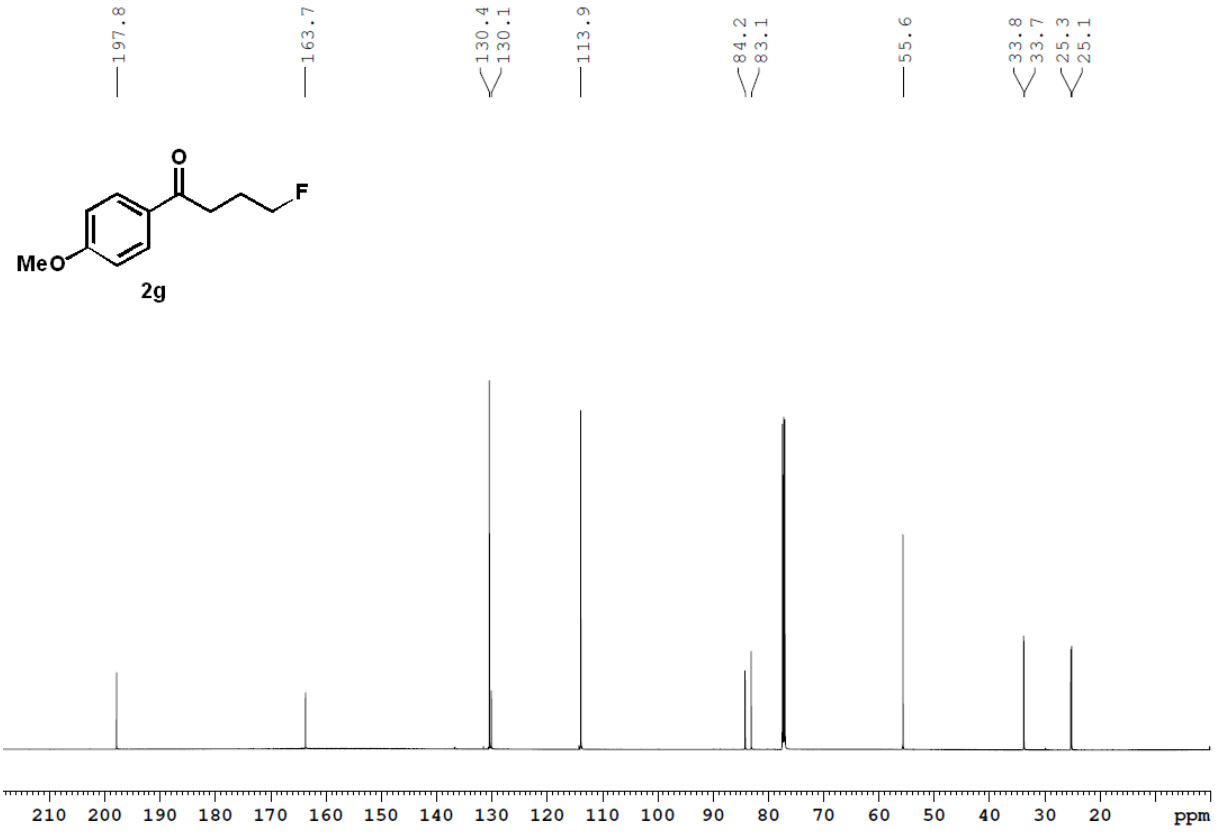
^{13}C NMR spectrum of **2f** (150 MHz, $CDCl_3$)



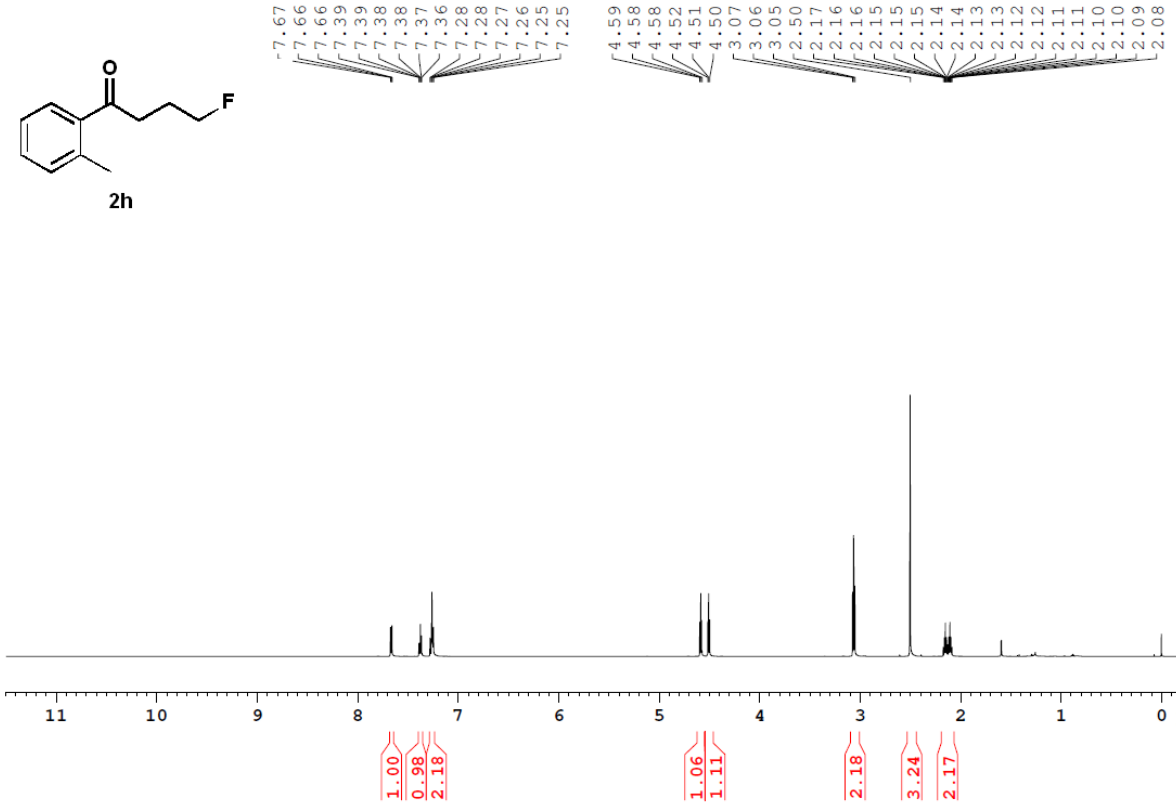
^{1}H NMR spectrum of **2g** (600 MHz, $CDCl_3$)



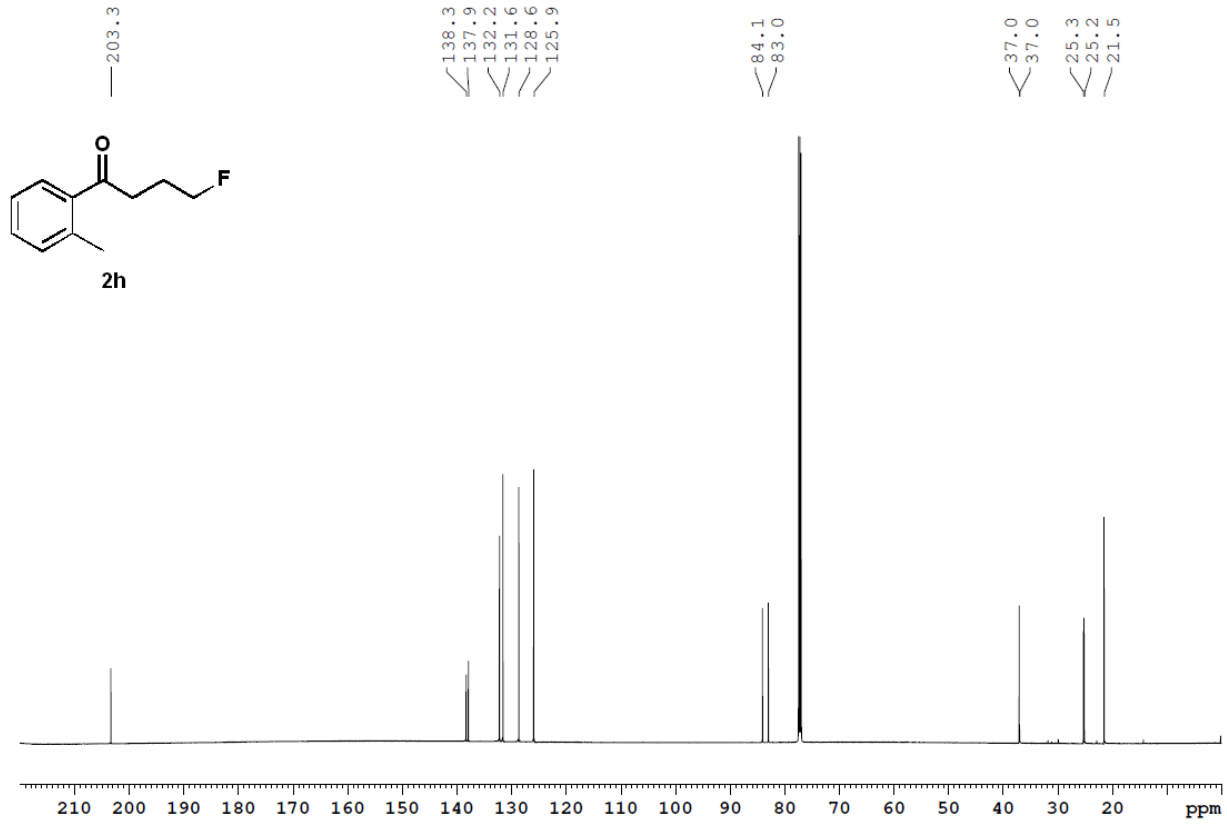
^{13}C NMR spectrum of **2g** (150 MHz, $CDCl_3$)



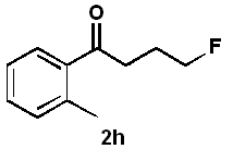
^{1}H NMR spectrum of **2h** (600 MHz, $CDCl_3$)



^{13}C NMR spectrum of **2h** (150 MHz, $CDCl_3$)

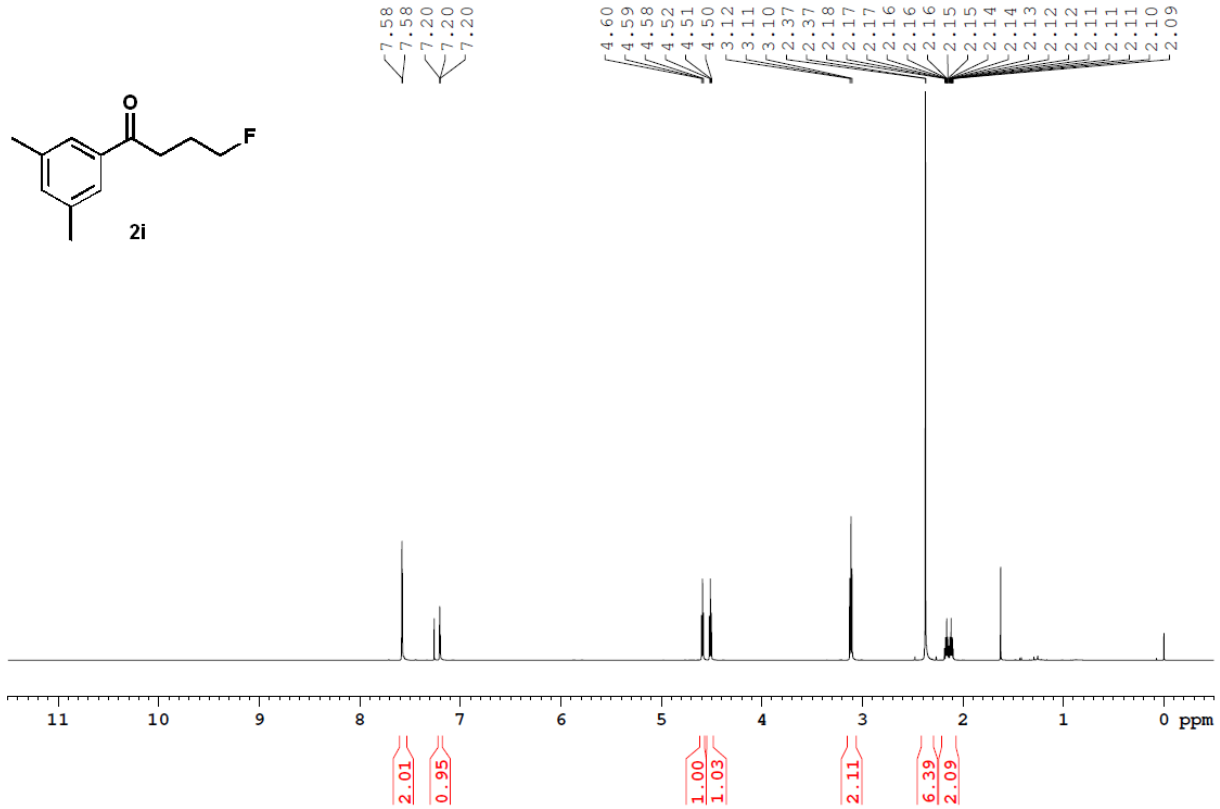


^{19}F NMR spectrum of **2h** (565 MHz, $CDCl_3$)

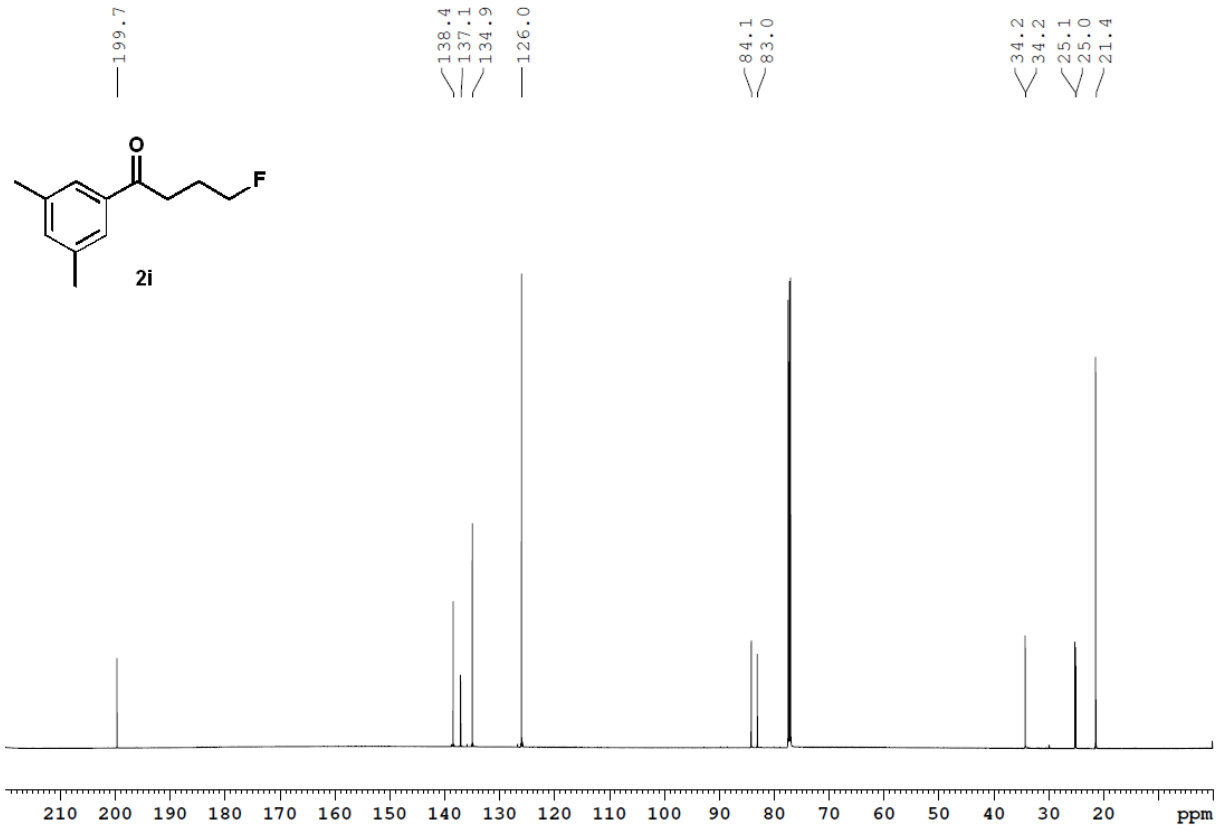


2h

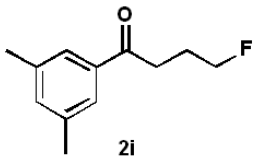
^{1}H NMR spectrum of **2i** (600 MHz, $CDCl_3$)



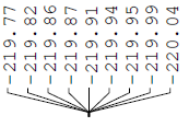
^{13}C NMR spectrum of **2i** (150 MHz, $CDCl_3$)

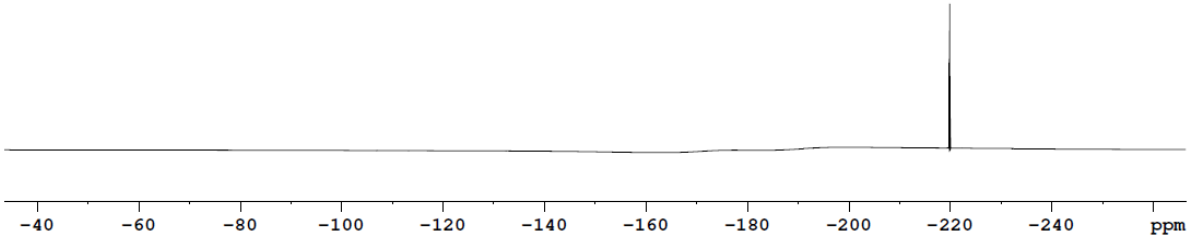


^{19}F NMR spectrum of **2i** (565 MHz, $CDCl_3$)

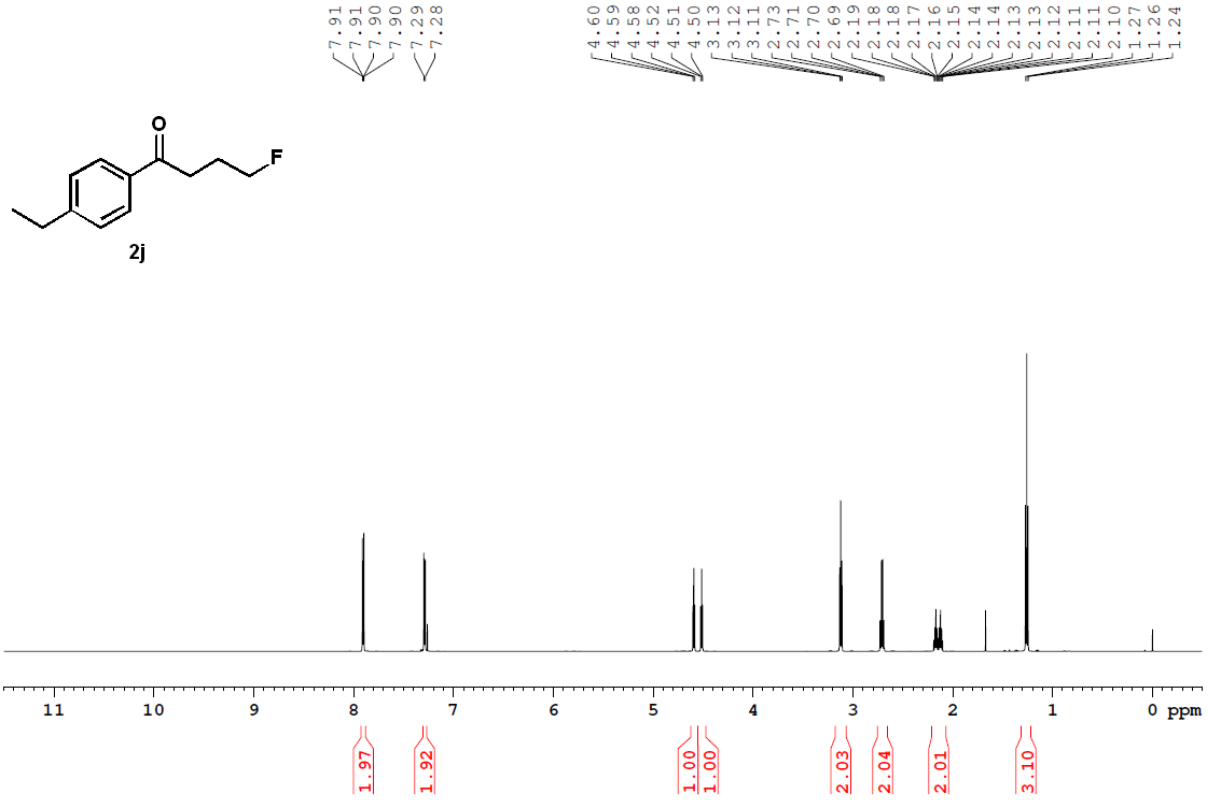


2i

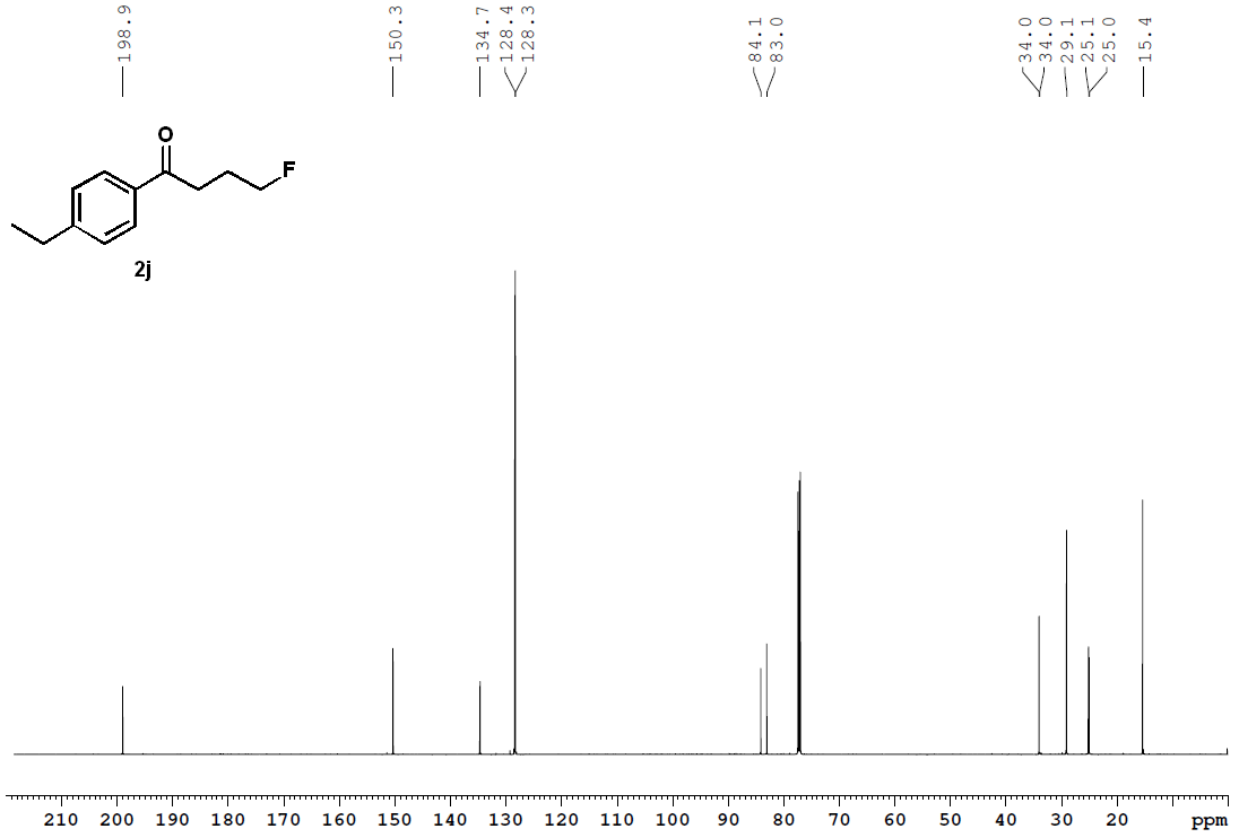




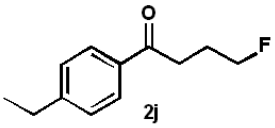
^{1}H NMR spectrum of **2j** (600 MHz, $CDCl_3$)



^{13}C NMR spectrum of **2j** (150 MHz, $CDCl_3$)

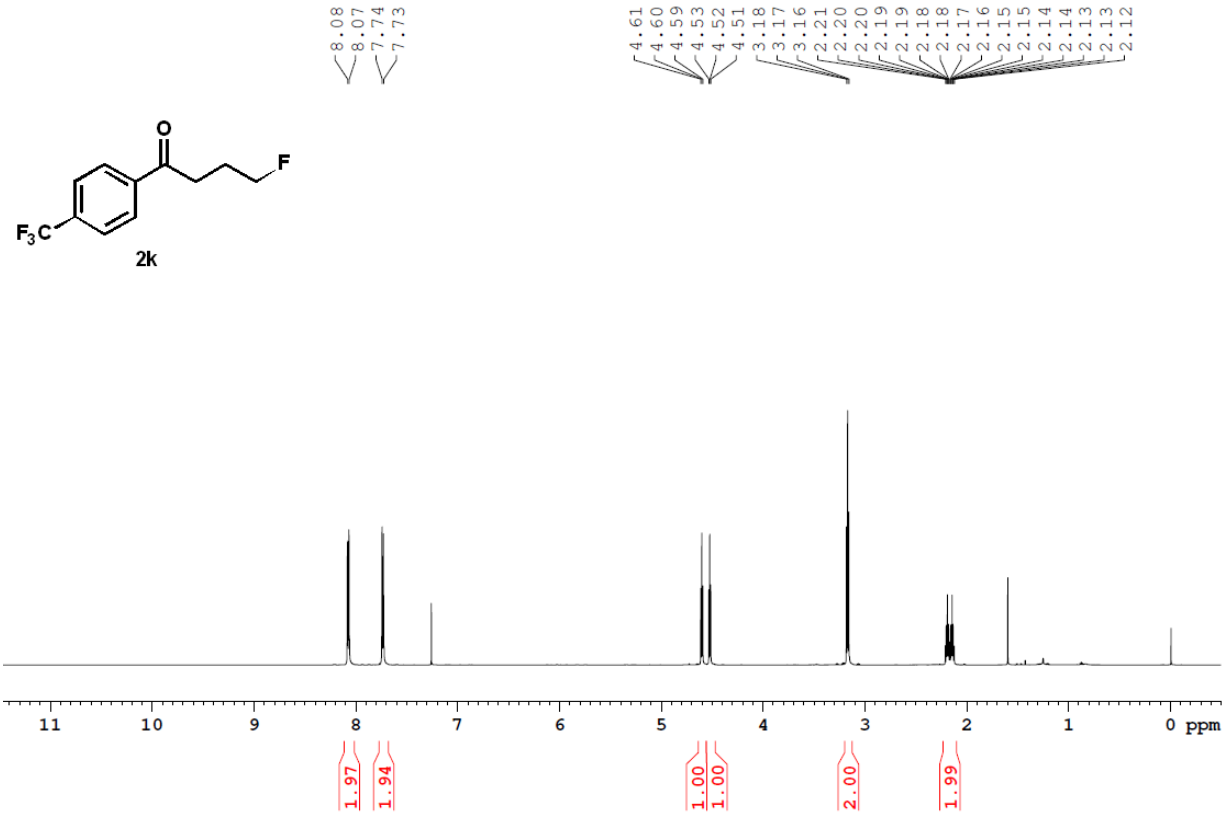


^{19}F NMR spectrum of **2j** (565 MHz, $CDCl_3$)

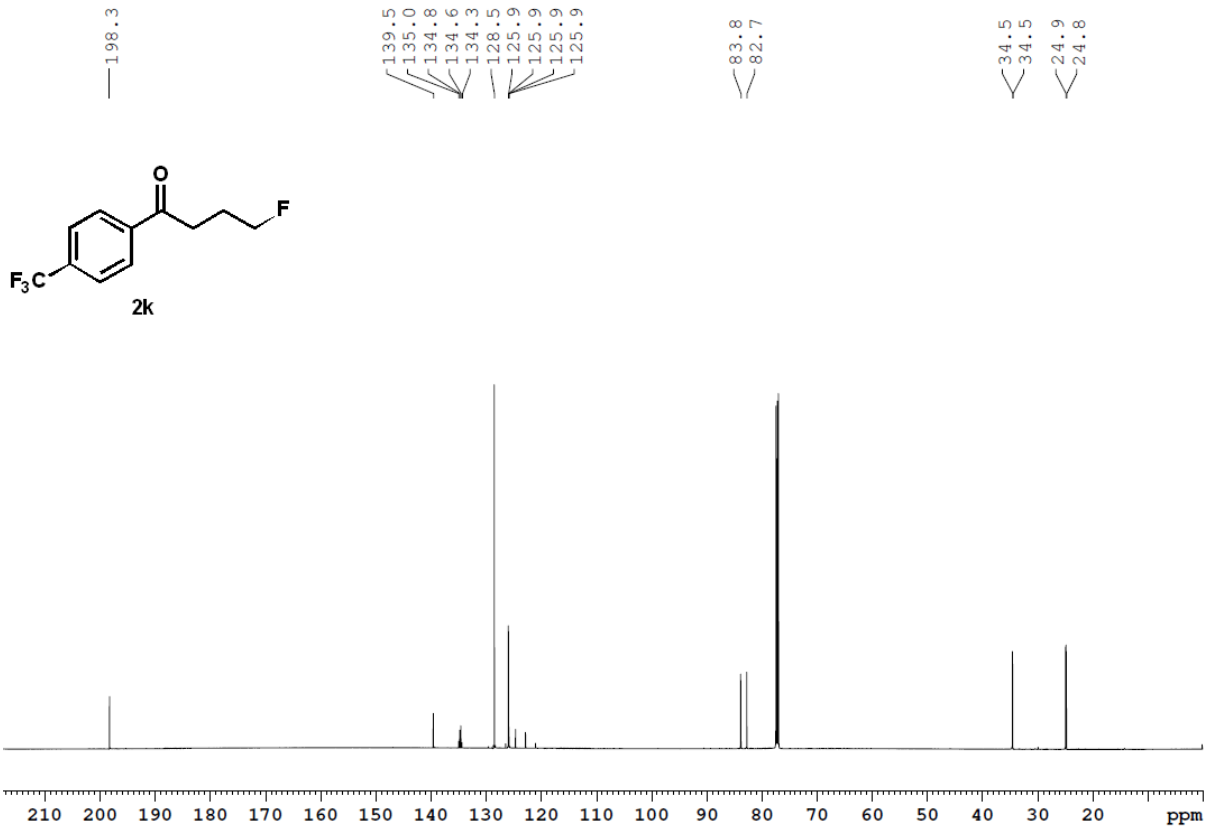


2j

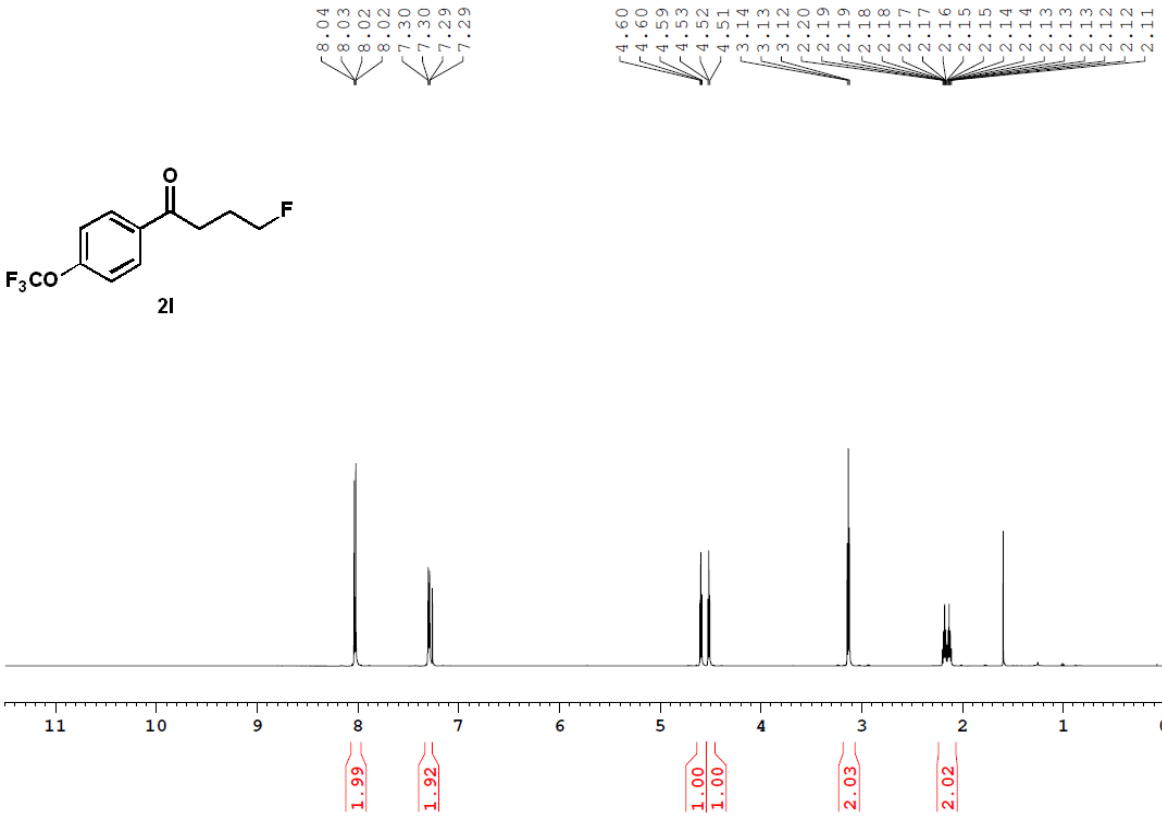
^{1}H NMR spectrum of **2k** (600 MHz, $CDCl_3$)



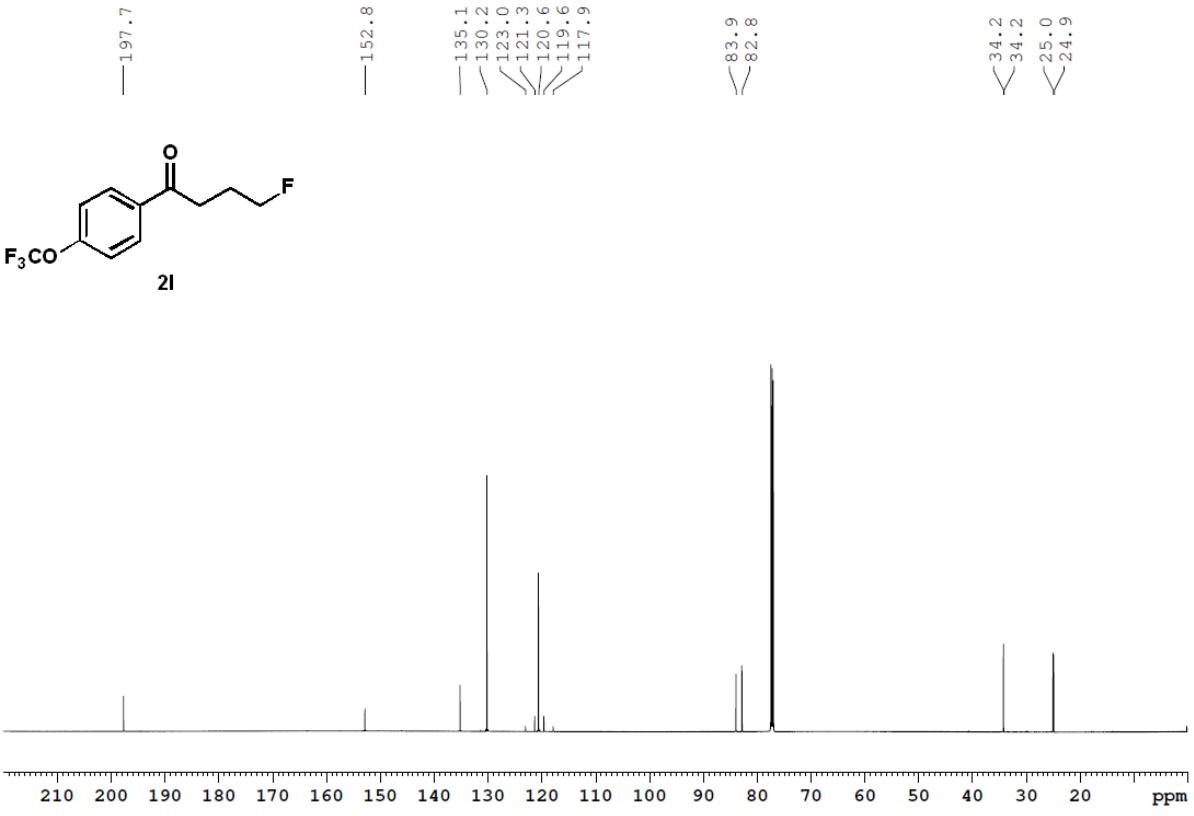
^{13}C NMR spectrum of **2k** (150 MHz, $CDCl_3$)



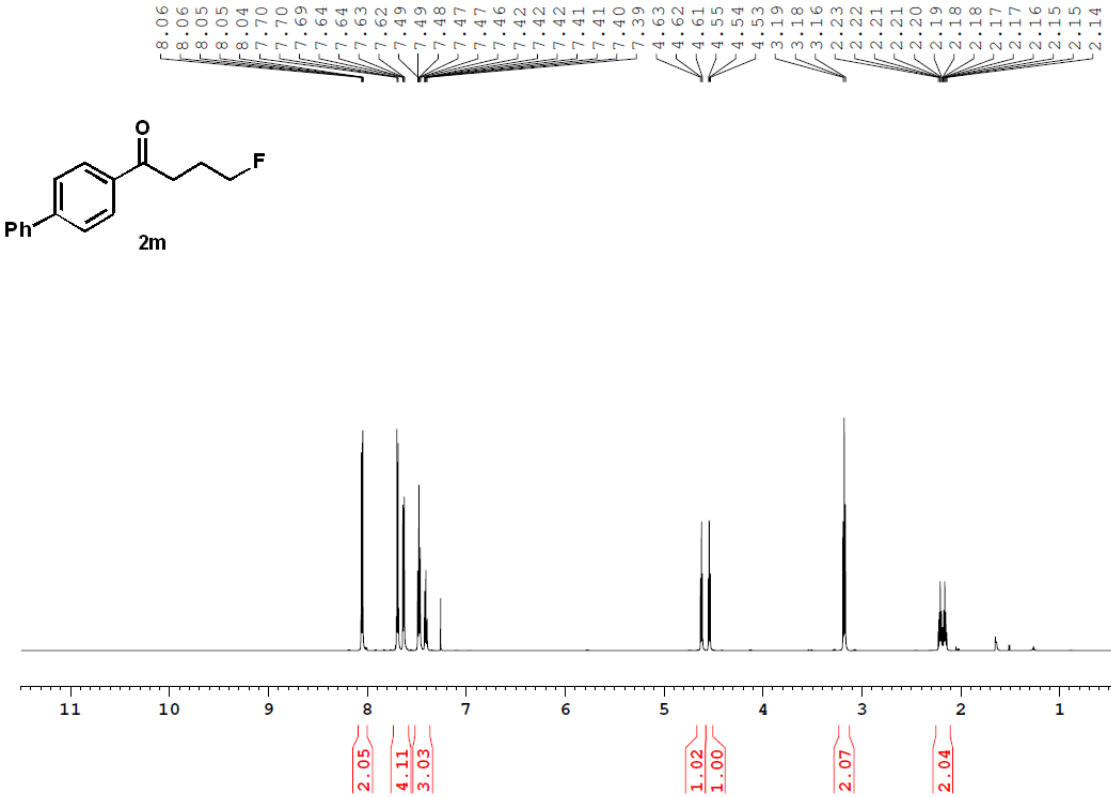
^{1}H NMR spectrum of **2l** (600 MHz, $CDCl_3$)



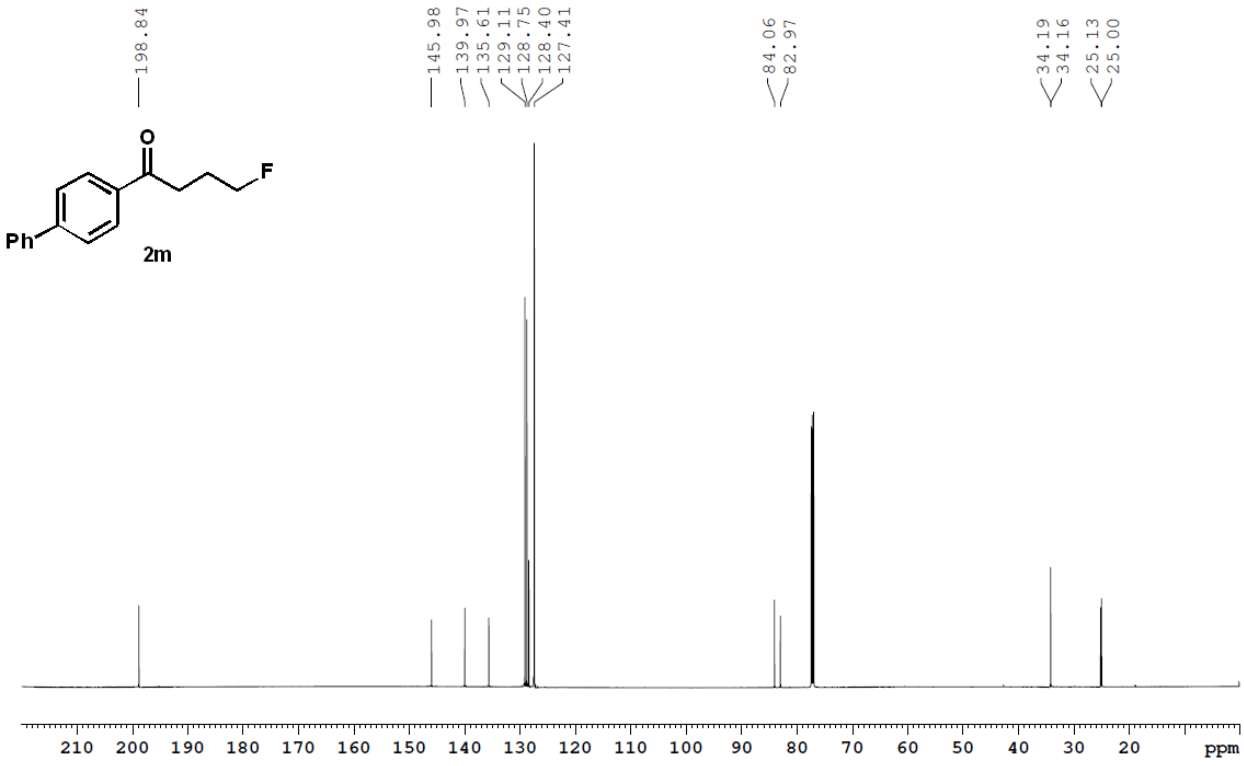
^{13}C NMR spectrum of **2l** (150 MHz, $CDCl_3$)



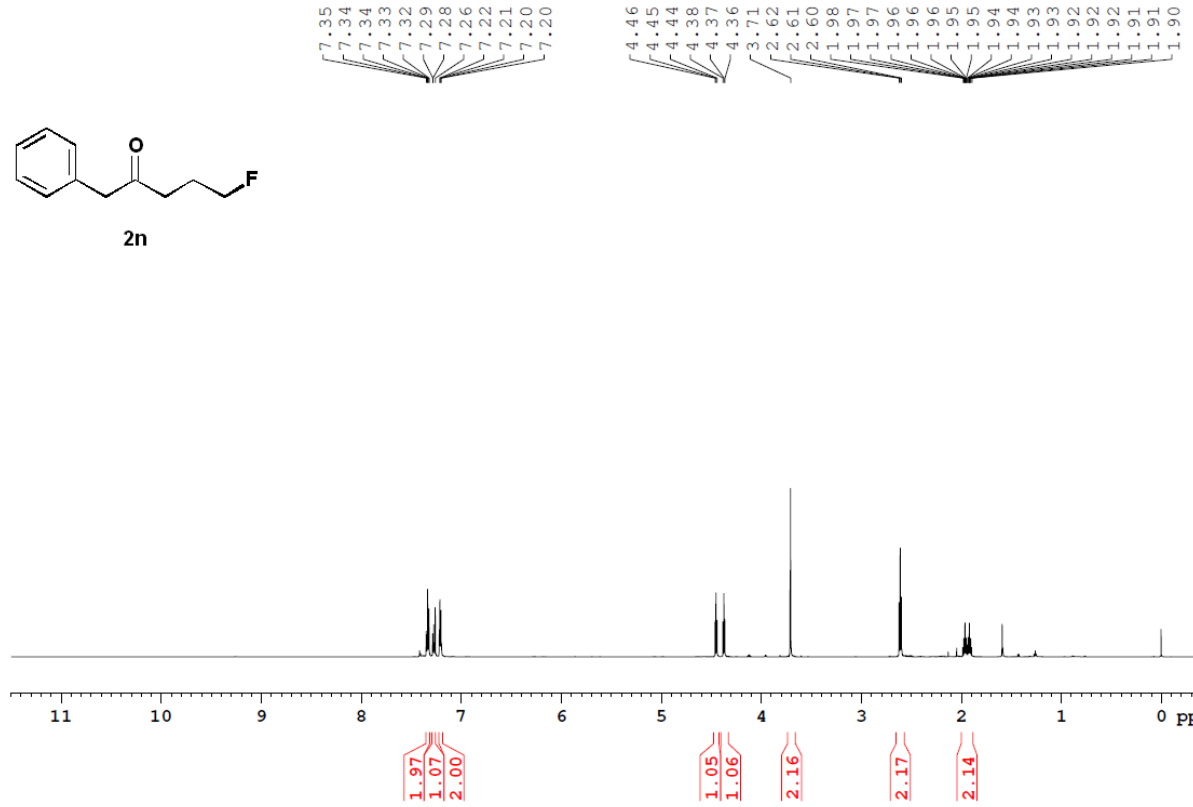
^{1}H NMR spectrum of **2m** (600 MHz, $CDCl_3$)



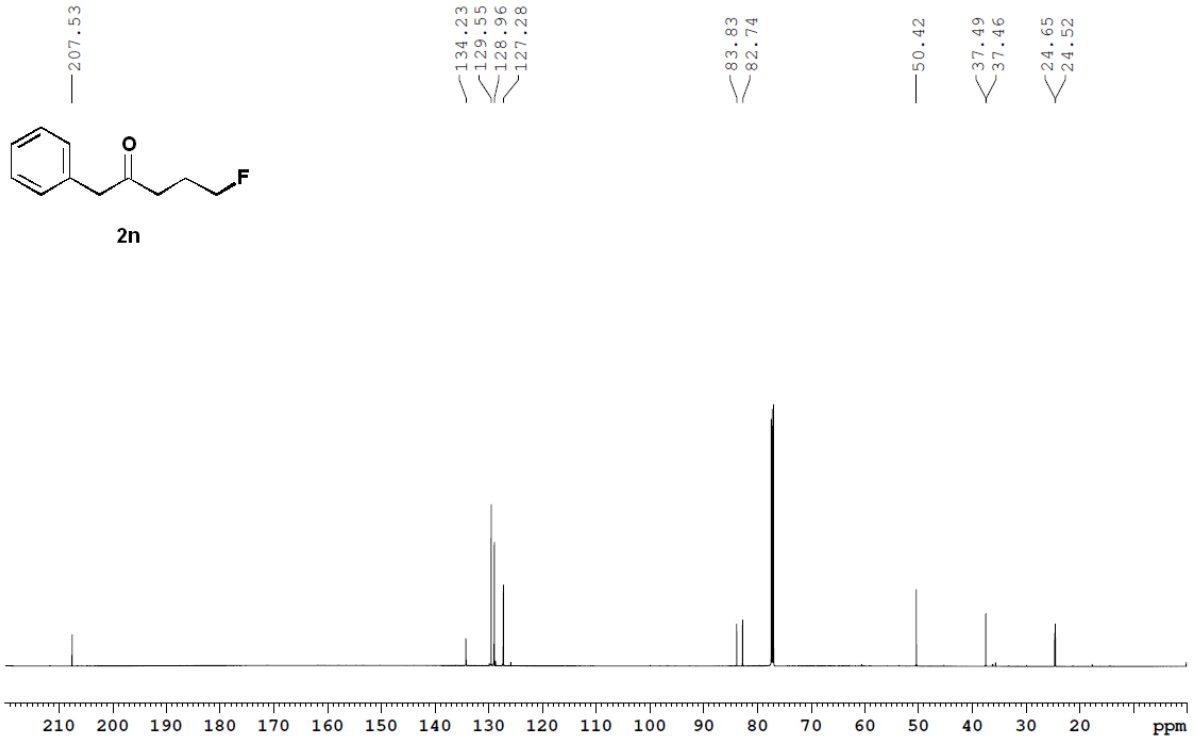
^{13}C NMR spectrum of **2m** (150 MHz, $CDCl_3$)



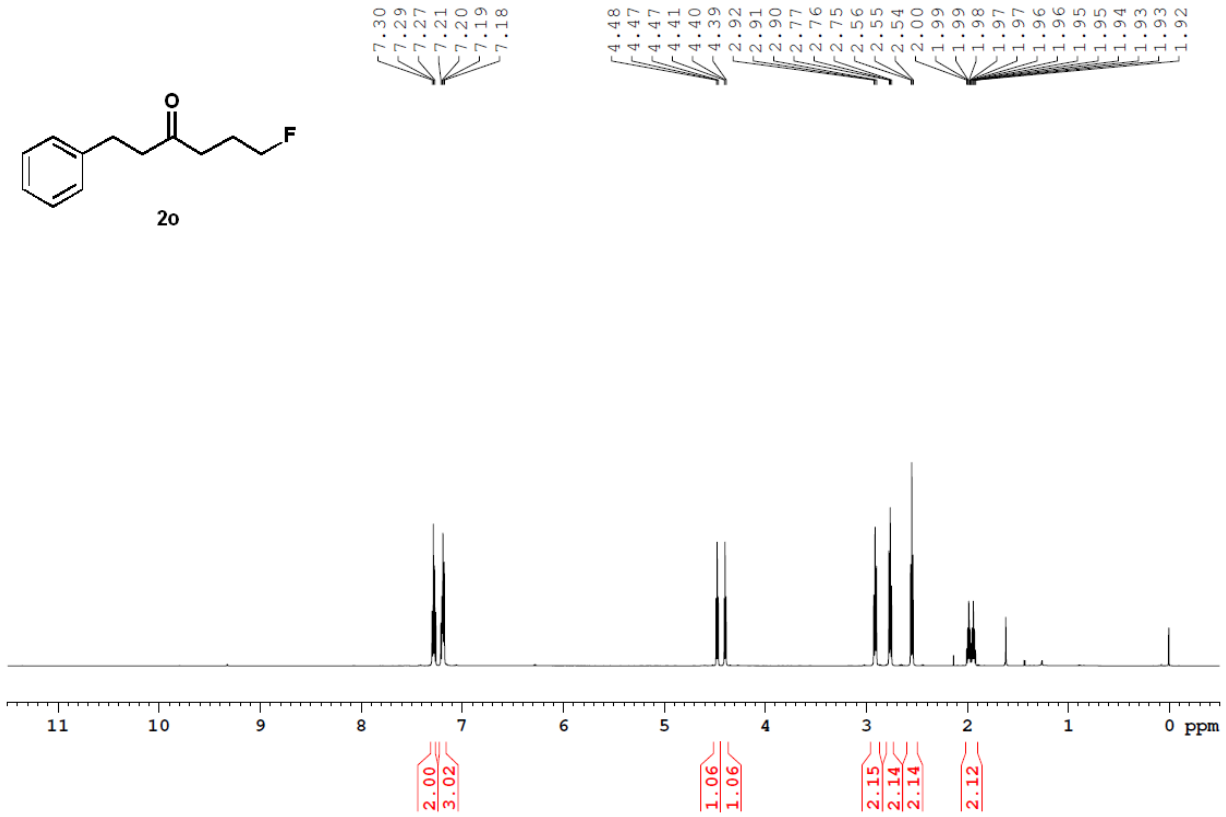
^{1}H NMR spectrum of **2n** (600 MHz, $CDCl_3$)



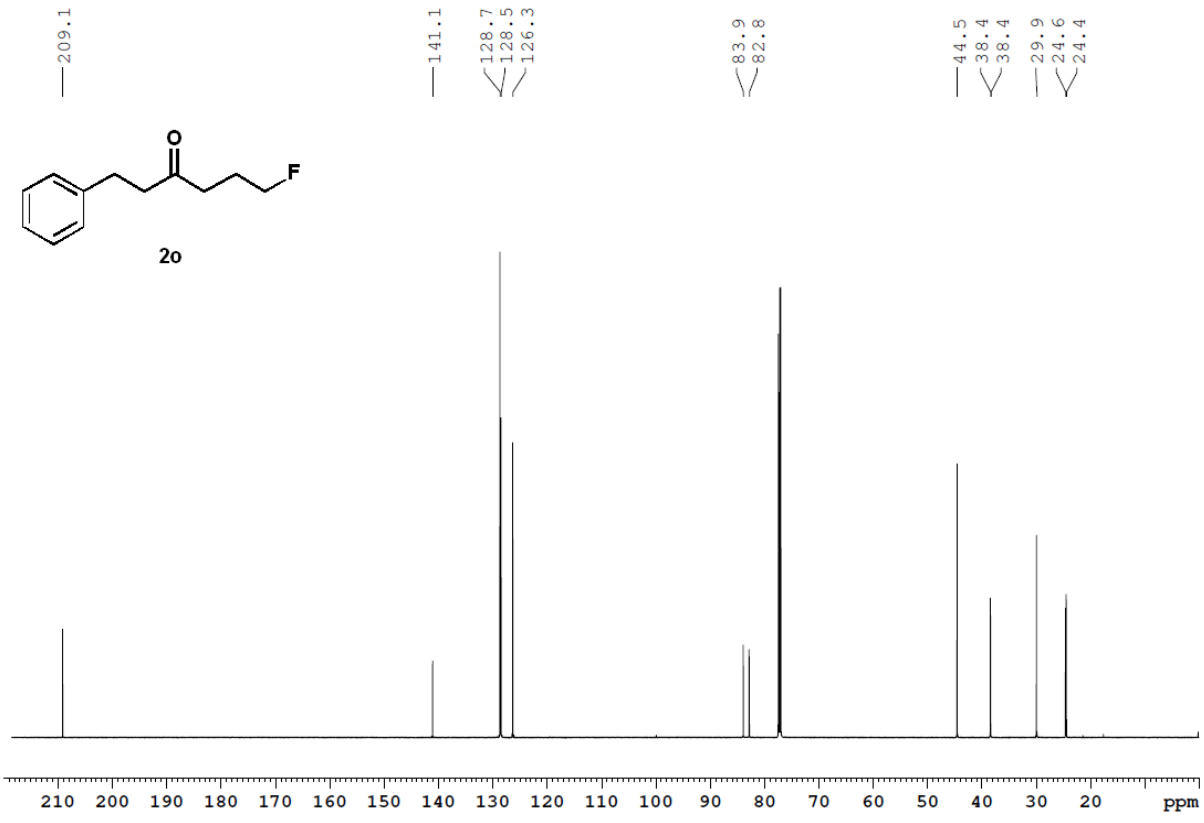
^{13}C NMR spectrum of **2n** (150 MHz, $CDCl_3$)



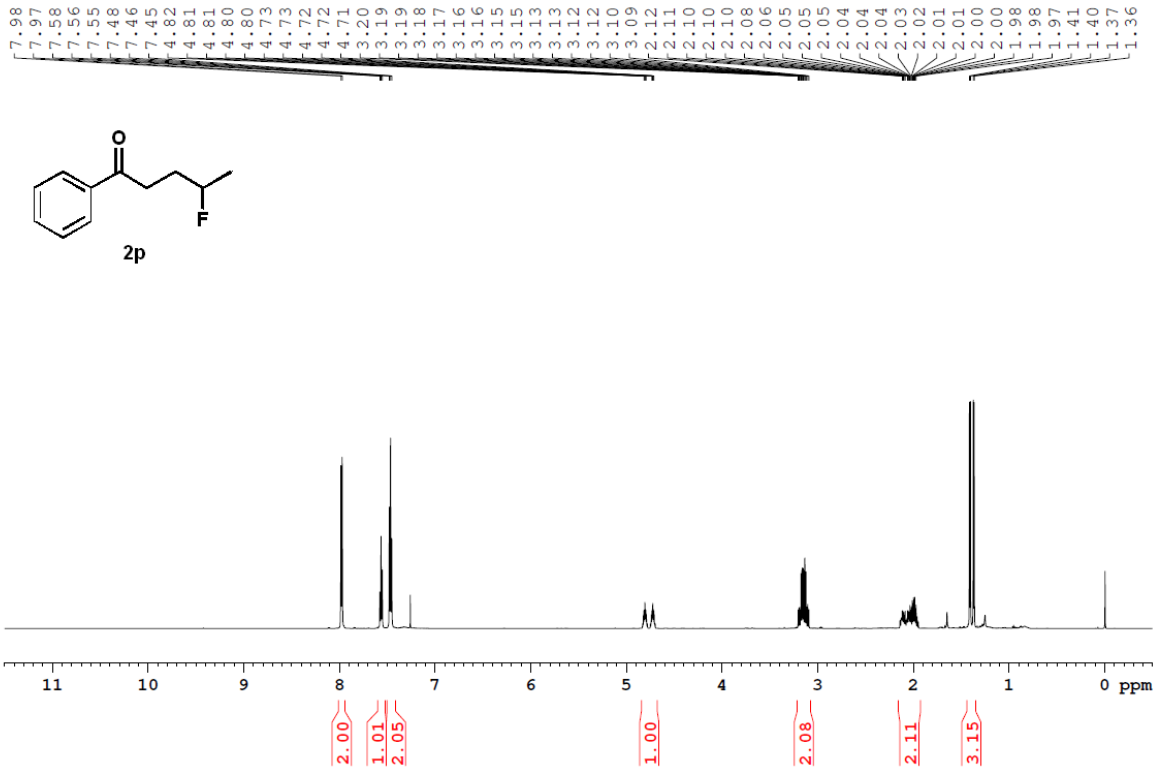
^{1}H NMR spectrum of **2o** (600 MHz, $CDCl_3$)



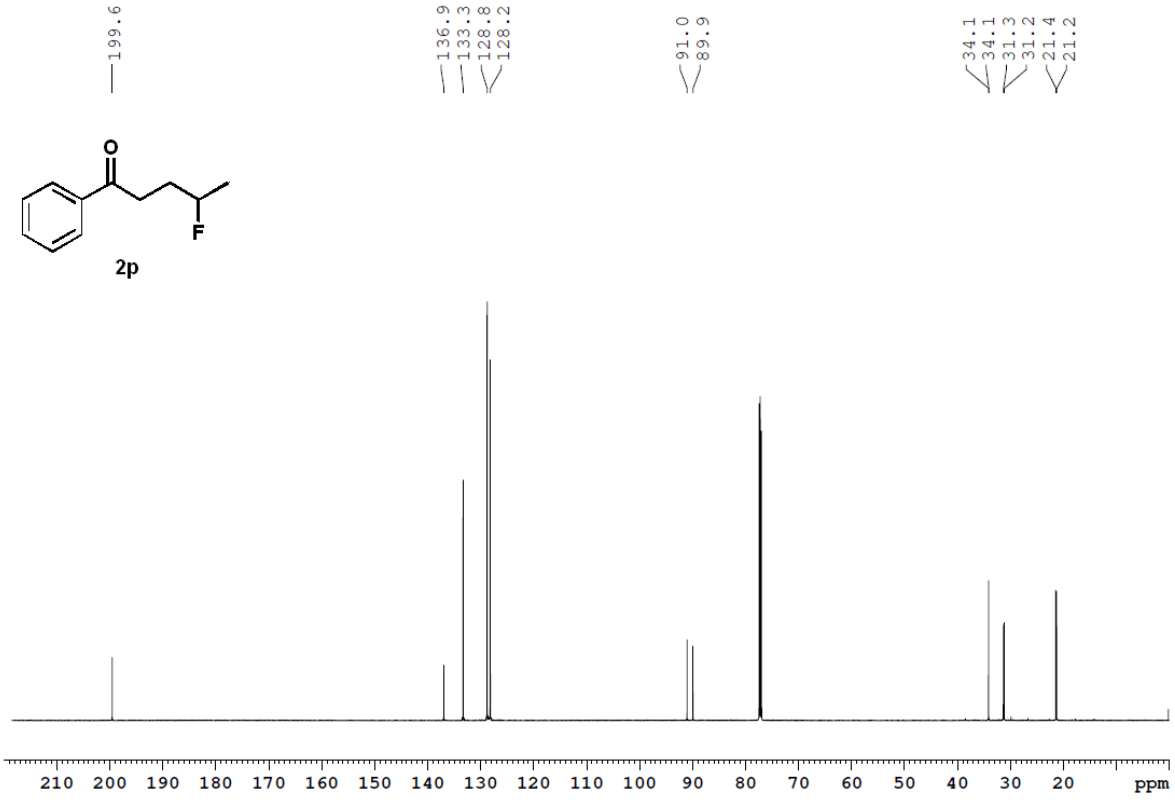
^{13}C NMR spectrum of **2o** (150 MHz, $CDCl_3$)



^{1}H NMR spectrum of **2p** (600 MHz, $CDCl_3$)



^{13}C NMR spectrum of **2p** (150 MHz, $CDCl_3$)



References

[1] B. D. W. Allen, M. D. Hareram, A. C. Seastram, T. McBride, T. Wirth, D. L. Browne, L. C. Morill, *Org. Lett.* 2019, **21**, 9241 − 9246.
[2] R. A. Croft, M. A. Dubois, A. J. Boddy, C. Denis, A. Lazaridou, A. S. Voisin-Chiret, R. Bureau, C. Choi, J. J. Mousseau, J. A. Bull, *Eur. J. Org. Chem.* 2019, 5385 – 5395.
[3] J. –B. Xia, C. Zhu, C. Chen, *Chem. Comm.* 2014, **50**, 11701 – 11704.
[4] H. Zhao, X. Fan, J. Yu, C. Zhu, *J. Am. Chem. Soc.* 2015, **137**, 3490 − 3493.
[5] N. Ishida, S. Okumura, Y. Nakanishi, M. Murakami, *Chem. Lett.* 2015, **44**, 821 – 823.
[6] F. Yin, Z. Wang, Z. Li, C. Li, *J. Am. Chem. Soc.* 2012, **134**, 10401 − 10404.