Supporting Information

Boron-trihalide-promoted Regioselective Ring-opening Reactions of *gem*-Difluorocyclopropyl Ketones

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Contents

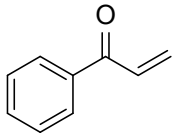
General Information

Reagents and solvents were purchased from commercial sources and used as received. Tetramethylsilane or residual proton signals were used as internal standards for ^{1}H NMR, ^{13}C NMR and ^{19}F NMR spectra. Data for ^{1}H NMR, ^{13}C NMR and ^{19}F NMR were recorded as follows: chemical shift (δ, ppm), multiplicity (s = singlet, d = doublet, t = triplet, m = multiplet or unresolved, brs = broad singlet, coupling constant(s) in Hz, integration).

General Procedure for the Synthesis of Aryl vinyl ketones:

Into the solution of paraformaldehyde (0.3 mol) and TAMA (*N*-methylanilinium trifluoroacetate, 50 mmol) in THF (50 mL) was added aryl methyl ketone (50 mmol) under N_2 atmosphere. The mixture was refluxed for 10 h. After being cooled to room temperature, the solvent was removed by concentration. The residue was dissolved with ethyl acetate. Hydrochloric acid solution was added to neutralize the mixture. The organic solution was separated and dried over Na_2SO_4. The solvent was removed by concentration, and the residue was subjected to silica-gel column chromatography with hexane/ethyl acetate to afford the aryl vinyl ketones product.

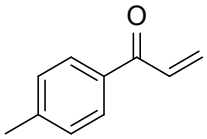
1-phenylprop-2-en-1-one[1]



5a

Colorless liquid (55%). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.95 (d, *J* = 7.7 Hz, 2 H), 7.58 (t, *J* = 7.4 Hz, 1 H), 7.48 (t, *J* = 7.7 Hz, 2 H), 7.16 (dd, *J* = 17.1, 10.7 Hz, 1 H), 6.44 (d, *J* = 17.1 Hz, 1 H), 5.94 (d, *J* = 10.6 Hz, 1 H) ppm.

1-(p-tolyl)prop-2-en-1-one[1]

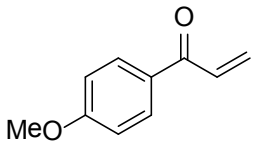


5b

Colorless liquid (42%). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.87 (d, *J* = 8.3 Hz, 2 H), 7.28 (d, *J* = 8.3 Hz, 2 H), 7.17 (dd, *J* = 17.1, 10.5 Hz,1 H), 6.43 (dd, *J* = 17.1, 1.7 Hz, 1 H), 5.90 (dd, *J* = 10.5, 1.7

Hz, 1 H), 2.42 (s, 3 H) ppm.

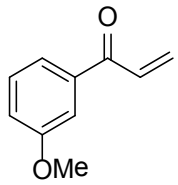
1-(4-methoxyphenyl)prop-2-en-1-one[1]



5c

Colorless liquid (40%). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.97 (d, J = 8.9 Hz, 2 H), 7.18 (dd, J = 17.1, 10.5 Hz, 1 H), 6.96 (d, J = 8.9 Hz, 2 H), 6.43 (dd, J = 17.1, 1.5 Hz, 1 H), 5.88 (dd, J = 10.5 Hz, J = 1.5 Hz, 1 H), 3.88 (s, 3 H) ppm.

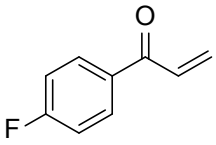
1-(3-methoxyphenyl)prop-2-en-1-one[1]



5d

Colorless liquid (71%). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.56-7.47 (m, 2 H), 7.39 (t, J = 7.8 Hz, 1 H), 7.19-7.10 (m, 2 H), 6.44 (d, J = 17.0 Hz, 1 H), 5.93 (d, J = 10.5 Hz, 1 H), 3.87 (s, 3 H) ppm.

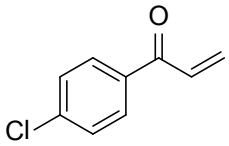
1-(4-fluorophenyl)prop-2-en-1-one[1]



5e

Colorless liquid (37%). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.99 (m, 2 H), 7.14 (m, 3 H), 6.44 (dd, J = 17.0 Hz, J = 1.5 Hz, 1 H), 5.94 (dd, J = 10.6, 1.5 Hz, 1 H) ppm; ^{19}F NMR (282 MHz, $CDCl_3$): δ = -105.55 - -105.64 (m, 1 F) ppm.

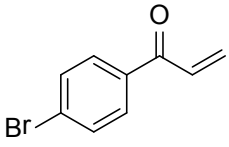
1-(4-chlorophenyl)prop-2-en-1-one[1]



5f

Colorless liquid (72%). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.90 (d, *J* = 8.4 Hz, 2 H), 7.46 (d, *J* = 8.4 Hz, 2 H), 7.12 (dd, *J* = 17.1, 10.5 Hz, 1 H), 6.45 (dd, *J* = 17.1, 1.1 Hz, 1 H), 5.96 (dd, *J* = 10.5 Hz, *J* = 1.1 Hz, 1 H) ppm.

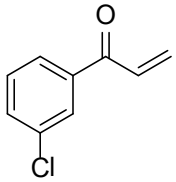
1-(4-bromophenyl)prop-2-en-1-one[1]



5g

Colorless liquid (59%). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.82 (d, *J* = 8.5 Hz, 2 H), 7.63 (d, *J* = 8.5 Hz, 2 H), 7.11 (dd, *J* = 17.2, 10.5 Hz, 1 H), 6.45 (d, *J* = 17.2 Hz, 1 H), 5.96 (d, *J* = 10.5 Hz, 1 H) ppm.

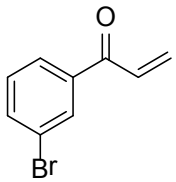
1-(3-chlorophenyl)prop-2-en-1-one[2]



5h

Colorless liquid (32%). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.92 (t, J = 1.4 Hz, 1 H), 7.82 (d, J = 7.9 Hz, 1 H), 7.55 (d, J = 7.9 Hz, 1 H), 7.43 (t, J = 7.9 Hz, 1 H), 7.11 (dd, *J* = 17.3, 10.6 Hz, 1 H), 6.46 (dd, *J* = 17.2, 1.7 Hz, 1 H), 5.98 (dd, *J* = 10.6, 1.7 Hz, 1 H) ppm.

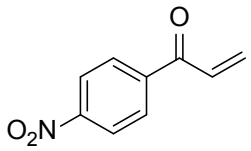
1-(3-bromophenyl)prop-2-en-1-one[1]



5i

Colorless liquid (51%). ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.07 (t, *J* = 1.8 Hz, 1 H), 7.86 (dt, *J* = 7.9, 1.2 Hz, 1 H), 7.73-7.69 (m, 1 H), 7.37 (t, *J* = 7.9 Hz, 1 H), 7.11 (dd, *J* = 17.3, 10.5Hz, 1 H), 6.46 (dd, *J* = 17.3, 1.5Hz, 1 H), 5.98 (dd, *J* = 10.5, 1.5 Hz, 1 H) ppm.

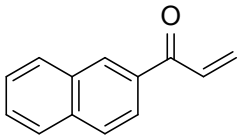
1-(4-nitrophenyl)prop-2-en-1-one[3]



5j

White solid (27%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.34 (d, *J* = 8.7 Hz, 2 H), 8.08 (d, *J* = 8.7 Hz, 2 H), 7.13 (dd, *J* = 17.2, 10.5 Hz, 1 H), 6.49 (d, *J* = 17.2 Hz, 1 H), 6.08 (d, *J* = 10.5 Hz, 1 H) ppm.

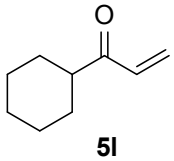
1-(naphthalen-2-yl)prop-2-en-1-one[4]



5k

White solid (45%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.47 (s, 1 H), 8.05 (dd, *J* = 8.6, 1.5 Hz, 1 H), 7.99-7.88 (m, 3 H), 7.65-7.54 (m, 2 H), 7.33 (dd, *J* = 17.2, 10.5 Hz, 1 H), 6.51 (dd, *J* = 17.2, 1.5 Hz, 1 H), 5.99 (dd, *J* = 10.5, 1.5Hz, 1 H) ppm.

1-cyclohexylprop-2-en-1-one[5]



5l

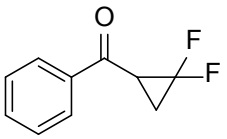
Colorless liquid (16%) ^{1}H NMR (400 MHz, $CDCl_3$) δ = 6.41 (dd, *J* = 17.5, 10.5 Hz, 1H), 6.24 (dd, *J*=17.5, 1.4 Hz, 1H), 5.76 – 5.71 (m, 1H), 2.60 (ddd, *J* = 11.3 Hz, *J* = 7.3 Hz, *J* = 3.2 Hz, 1H), 1.86 – 1.74 (m, 4H), 1.68 (d, *J* = 10.5 Hz, 1H), 1.42 – 1.17 (m, 5H) ppm.

General Procedure for the Synthesis of *gem*-Difluorocyclopropyl Ketones:

Into the mixture of aryl vinyl ketones (20 mmol) and anhydrous sodium fluoride (2 mmol) was added m-xylene (1 mL) under N_2. The mixture was heated to 110°C and stirred for 5 min. TFDA

($FSO_2CF_2CO_2SiMe_3$, 40 mmol) was added dropwise in 30 min. Then the mixture was stirred for further 30 min at 110°C. When the substrate was completely conversed detected by TLC, the mixture was cooled to room temperature. After removal of the solvent under reduced pressure, the residue was subjected to column chromatography to afford the pure product (Hexane : Et_2O = 20 : 1).

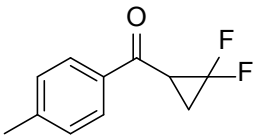
(2,2-difluorocyclopropyl)(phenyl)methanone[6]



1a

Colorless liquid (77%). ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.01 (d, *J* = 7.3 Hz, 2 H), 7.63 (t, *J* = 7.3 Hz, 1 H), 7.52 (t, *J* = 7.3 Hz, 2 H), 3.39 (m, 1 H), 2.43 (m, 1 H), 1.81 (m, 1 H) ppm; ^{19}F NMR (282 MHz, $CDCl_3$): δ: -124.16 (dtd, *J* = 149.0, 13.0, 6.0 Hz, 1 F), -140.04 (ddd, *J* = 149.0, 12.2, 4.8 Hz, 1 F) ppm;

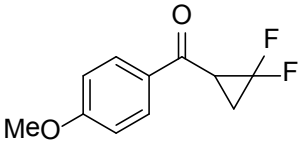
(2,2-difluorocyclopropyl)(p-tolyl)methanone[7]



1b

White solid (38%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.91 (d, *J* = 8.0 Hz, 2 H), 7.31 (d, *J* = 8.0 Hz, 2 H), 3.37 (m, 1 H), 2.41 (m, 1 H), 2.44 (s, 3 H), 1.78 (m, 1 H) ppm; ^{19}F NMR (282 MHz, $CDCl_3$): δ = -124.18 (dtd, *J* = 149.0, 12.4, 5.9 Hz 1 F), -140.13 (ddd, *J* = 149.0, 12.1, 4.7 Hz, 1 F) ppm

(2,2-difluorocyclopropyl)(4-methoxyphenyl)methanone[7]

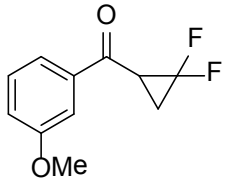


1c

Slightly yellow liquid (41%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.00 (d, *J* = 8.7 Hz, 2 H), 6.98 (d, *J* = 8.7 Hz, 2 H), 3.89 (s, 3 H), 3.34 (m, 1 H), 2.40 (m, 1 H), 1.77 (m, 1 H) ppm; ^{19}F NMR (282 MHz,

$CDCl_3$): δ = -124.39 (dtd, *J* = 149.0, 13.0, 5.8 Hz, 1 F), -140.35 (ddd, *J* = 149.0, 12.2, 4.6 Hz, 1 F) ppm

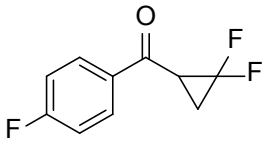
(2,2-difluorocyclopropyl)(3-methoxyphenyl)methanone[7]



1d

Colorless liquid (71%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.60 (d, *J* = 7.9 Hz, 1 H), 7.52 (s, 1 H), 7.43 (t, *J* = 7.9 Hz, 1 H), 7.17 (dd, *J* = 7.9, 2.6 Hz, 1 H), 3.87 (s, 3 H), 3.38 (m, 1 H), 2.43 (m, 1 H), 1.81 (m, 1 H) ppm; ^{19}F NMR (282 MHz, $CDCl_3$): δ = -124.73 (dm, *J* = 148.0 Hz, 1 F), -140.65 (dm, J = 148.0 Hz, 1 F) ppm

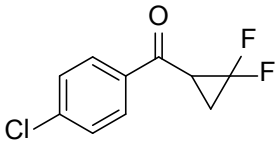
(2,2-difluorocyclopropyl)(4-fluorophenyl)methanone[7]



1e

Colorless liquid (28%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.08-8.02 (m, 2 H), 7.23-7.16 (m, 2 H), 3.35 (m, 1 H), 2.43 (m, 1 H), 1.82 (m, 1 H) ppm; ^{19}F NMR (282 MHz, $CDCl_3$): δ -103.89 (m, 1 F), -124.28 (dtd, *J* = 148.5, 12.7, 5.9 Hz, 1 F), -140.07 (ddm, *J* = 148.5, 12.0 Hz, 1 F) ppm

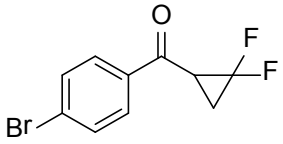
(4-chlorophenyl)(2,2-difluorocyclopropyl)methanone[6]



1f

Slightly yellow solid (22%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.95 (d, *J* = 8.4 Hz, 2 H), 7.49 (d, *J* = 8.4 Hz, 2 H), 3.34(m, 1 H), 2.43 (m, 1 H), 1.82 (m, 1 H) ppm; ^{19}F NMR (282 MHz, $CDCl_3$): δ -124.07 (dtd, *J* = 149.0, 12.3, 5.7 Hz, 1 F), -139.90 (ddd, J = 149.0, 12.2, 4.9 Hz, 1 F) ppm;

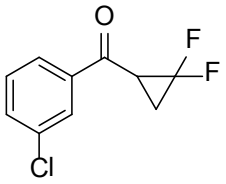
(4-bromophenyl)(2,2-difluorocyclopropyl)methanone



1g

White solid (m.p. 67-69°C, 32%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.87 (d, *J* = 8.8 Hz, 2 H), 7.66 (d, *J* = 8.8 Hz, 2 H), 3.35 (m, 1 H), 2.43 (m, 1 H), 1.84 (m, 1 H) ppm; ^{19}F NMR (282 MHz, $CDCl_3$): δ -124.56 (dtd, *J* = 148.3, 12.3, 5.9 Hz, 1 F), -140.36 (ddd, J = 148.3, 12.1, 4.7 Hz, 1 F) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz): δ 189.5, 135.7, 132.3, 129.9, 129.1, 111.5 (t, *J* = 287.6 Hz), 29.7 (dd, *J* = 11.7, 9.6 Hz), 15.8 (dd, *J* = 11.0, 8.8 Hz) ppm; EI-MS (m/z, %): 183 (100), 185 (92.6), 76 (54.0), 155 (50.2), 157 (49.6), 75 (47.3), 50 (44.1), 133 (39.2). IR (KBr): 3117, 3095, 3075, 3060, 1671, 1582, 1453, 1400, 1381, 1319, 1247, 1180, 1008, 846, 703, 658, 515, 479cm^{-1}. HRMS for $C_{10}H_7OF_2Br$: 259.9648; Found: 259.9649.

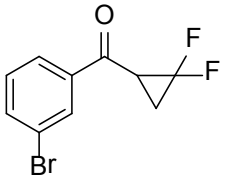
(3-chlorophenyl)(2,2-difluorocyclopropyl)methanone[7]



1h

White solid (70%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.97 (t, *J* = 1.8 Hz, 1 H), 7.89 (dt, *J* = 7.9, 1.8 Hz, 1 H), 7.60 (dt, *J* = 7.9, 1.8 Hz, 1H), 7.47 (t, *J* = 7.9 Hz, 1 H), 3.36 (m, 1 H), 2.45 (m, 1 H), 1.84 (m, 1 H) ppm; ^{19}F NMR (282 MHz, $CDCl_3$): δ = -124.52 (dm, *J* = 148. 4 Hz, 1 F), -140.36 (dm, *J* = 148.1 Hz, 1 F) ppm.

(3-bromophenyl)(2,2-difluorocyclopropyl)methanone

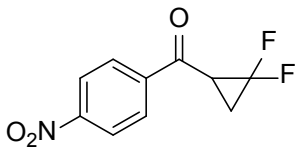


1i

White solid (m.p. 32-33°C, 62%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.12 (s, 1 H), 7.93 (d, *J* = 7.9 Hz, 1 H), 7.75 (d, *J* = 7.9 Hz, 1 H), 7.41 (t, *J* = 7.9 Hz, 1 H), 3.37 (m, 1 H), 2.44 (m, 1 H), 1.85 (m, 1 H) ppm; ^{19}F NMR (282 MHz, $CDCl_3$): δ = -124.48 (dtd, *J* = 148.5, 12.2, 6.0 Hz, 1 F), -140.28 (ddd, *J* = 148.5, 12.1, 4.8 Hz, 1 F) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 189.3, 138.7, 136.6,

131.4, 130.4, 127.0, 123.2, 111.5 (dd, J = 288.4, 286.9 Hz), 29.8 (dd, J = 11.7, 10.3 Hz), 15.9 (dd, J = 11.0, 8.8 Hz) ppm; EI-MS (m/z, %): 183 (100), 185 (99), 155 (48.6), 157 (47.7), 133 (28.6), 76 (28.0), 181 (26.6), 75 (22.9). IR (KBr): 3116, 3062, 3026, 1669, 1566, 1459, 1374, 1316, 1247, 1203, 1055, 1008, 929, 919, 908, 817, 773, 704, 679, 667, 478 cm^{-1}. HRMS for $C_{10}H_7OF_2Br$: 259.9648; Found: 259.9651.

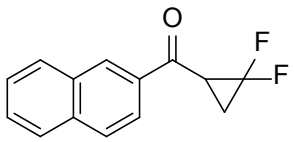
(2,2-difluorocyclopropyl)(4-nitrophenyl)methanone



1j

White solid (m.p. 62-64°C,44%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.38 (d, J = 8.5 Hz, 2 H), 8.18 (d, J = 8.5 Hz, 2 H), 3.44 (m, 1 H), 2.50 (m, 1 H), 1.94 (m, 1 H) ppm; ^{19}F NMR (282 MHz, $CDCl_3$): δ = -123.66 (dtd, J = 148.1, 12.2, 6.0 Hz, 1 F), -139.32 (ddd, J = 148.1, 12.0, 4.7 Hz, 1 F) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 189.3, 150.7, 141.3, 129.4, 124.1, 111.4 (t, J = 288.5 Hz), 30.2 (dd, J = 11.8, 10.3 Hz), 16.3 (dd, J = 11.4, 9.1Hz) ppm; EI-MS (m/z, %): 150 (100), 104 (58.4), 76 (54.2), 133 (41.3), 50 (37.8), 51 (26.3), 75 (25.6), 77 (25.5). IR (KBr): 3113, 3087, 3052, 1677, 1607, 1451, 1413, 1321, 1298, 1208, 1052, 963, 923, 856, 729, 703, 685, 479cm^{-1}. HRMS for $C_{10}H_7NO_3F_2$: 227.0394; Found: 227.0397.

(2,2-difluorocyclopropyl)(naphthalen-2-yl)methanone

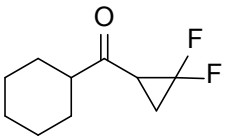


1k

White solid (m.p. 91-93 °C, 57%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.52 (s, 1 H), 8.07-7.98 (m, 2 H), 7.91 (t, J = 8.8 Hz, 2 H), 7.65-7.55 (m, 2 H), 3.56 (m, 1 H), 2.49 (m, 1 H), 1.86 (m, 1 H) ppm; ^{19}F NMR (282 MHz, $CDCl_3$): δ -124.51 (dtd, J = 148.1, 12.5, 5.9 Hz, 1 F), -140.43 (ddd, J = 148.1, 12.3, 5.1 Hz, 1 F) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 190.4, 135.9, 134.5, 132.5, 130.5, 129.7, 128.9, 128.8, 127.9, 127.1, 123.8, 111.7 (dd, J = 288.1, 286.6 Hz), 29.84 (dd, J = 11.8, 9.6 Hz), 15.76 (dd, J = 11.0, 9.0 Hz) ppm; EI-MS (m/z, %): 127 (100), 155 (75.2), 232 (46.3), 128

(24.8), 126 (24.1), 183 (21.0), 77 (18.6), 51 (14.4). IR (KBr): 3113, 3053, 3021, 1676, 1624, 1453, 1373, 1237,1061, 1043, 1008, 925, 768, 744, 690, 484, 478cm^{-1}. HRMS for $C_{14}H_{10}OF_2$: 232.0700; Found: 232.0702.

cyclohexyl(2,2-difluorocyclopropyl)methanone



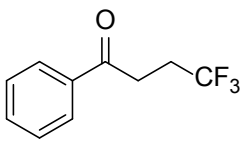
1l

Colorless liquid (21%) ^{1}H NMR (400 MHz, $CDCl_3$) δ = 2.79 (ddd, *J* = 14.0, 10.3, 8.0 Hz, 1H), 2.47 (tt, *J* = 11.1, 3.4 Hz, 1H), 2.18 (m, 1H), 2.02 – 1.95 (m, 1H), 1.87 (dd, *J* = 10.0, 4.4, 1H), 1.83 – 1.75 (m, 2H), 1.73 – 1.57 (m, 2H), 1.45 – 1.16 (m, 5H). ^{19}F NMR (282 MHz, $CDCl_3$): δ = -124.7 – -125.2(m, 1 F), -139.9 – -140.4 (m, 1 F) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) δ = 203.36, 111.38 (dd, *J* = 288.0, 285.3 Hz), 51.65, 31.02 (dd, *J* = 12.0, 9.0 Hz), 27.85, 27.52, 25.68, 25.50, 25.22, 15.54 (dd, *J*= 11.1, 9.0Hz). IR (KBr): 2933, 2857, 1709, 1451, 1374, 1317, 1241, 1044, 1022, 1005, 955, 911, 893, 669; GC-MS : 108.1; HRMS: 108.1014; Found:108.1013.

General procedure for the ring-opening of *gem*-difluorocyclopropayl ketones promoted by boron trifluoride:

Into the solution of *gem*-difluorocyclopropyl ketone (0.2 mmol) in $CHCl_3$ (1 mL) was added $BF_3 \bullet Et_2O$ (0.4 mmol). The mixture was stirred at 60 ^{o}C until the reaction was complete determined by ^{19}F NMR. After being cooled to room temperature, saturated $NaHCO_3$ solution was added to quench the reaction. After extraction with CH_2Cl_2 (10 mL x 3), the organic solution was dried over Na_2SO_4. The solvent was removed by concentration, and the residue was subjected to column chromatography to afford the β-trifluoromethyl ketones.

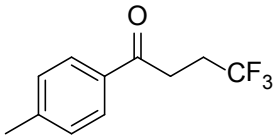
4,4,4-trifluoro-1-phenylbutan-1-one[8]



2a

White solid (95%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.98 (d, *J* = 7.3 Hz, 2 H), 7.61 (t, J = 7.3 Hz, 1 H), 7.49 (t, *J* =7.3 Hz, 2 H), 3.27 (t, *J* = 7.7 Hz, 2 H), 2.68-2.52 (m, 2 H) ppm; ^{19}F NMR (282 MHz, $CDCl_3$): δ = -66.39 (t, *J* = 10.3 Hz, 3 F) ppm.

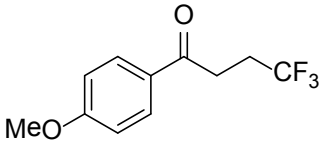
4,4,4-Trifluoro-1-(*p*-tolyl)butan-1-one.



2b

White solid (m.p. 83-84°C, 85%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.87 (d, *J* = 8.1 Hz, 2 H), 7.28 (d, *J* = 8.1 Hz, 2 H), 3.23 (t, *J* = 7.5 Hz, 2 H), 2.66-2.50 (m, 2 H), 2.42 (s, 3 H) ppm.; ^{19}F NMR (282 MHz, $CDCl_3$): δ -66.21 (t, *J* = 10.3 Hz, 3 F) ppm.; ^{13}C NMR ($CDCl_3$, 100 MHz): δ 195.9, 144.5, 133.8, 129.5, 128.1, 127.2 (q, *J* = 275.9 Hz), 31.05 (t, *J* = 2.9 Hz), 28.42 (q, *J* = 29.3 Hz), 21.63 ppm.; EI-MS (m/z, %): 119 (100), 91 (37.2), 65 (11.6), 120 (9.03), 89 (7.71), 77 (6.04), 216 (5.99), 90 (5.20).; IR(KBr): 3115, 2994, 1680, 1609, 1439, 1337, 1309, 1259, 1227, 1147, 1098, 983, 976, 824, 781, 641, 570, 459cm^{-1}.; HRMS for $C_{11}H_{11}OF_3$: 216.0762; Found: 216.0760.

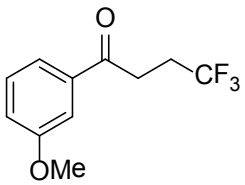
4,4,4-Trifluoro-1-(4-methoxyphenyl)butan-1-one[9]



2c

White solid (m.p. 65-67°C, 76%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.95 (d, *J* = 8.8 Hz, 2 H), 6.95 (d, *J* = 8.8 Hz, 2 H), 3.88 (s, 3 H), 3.21 (t, *J* = 7.6 Hz, 2 H), 2.66-2.50 (m, 2 H) ppm; ^{19}F NMR (282 MHz, $CDCl_3$): δ = -66.80 (t, *J* = 11.9 Hz, 3 F); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 194.8, 163.9, 130.3, 129.3, 127.3 (q, *J* = 275.9 Hz), 113.9, 55.5, 30.78 (d, *J* = 2.9 Hz), 28.47 (q, *J* = 30 Hz) ppm.

4,4,4-Trifluoro-1-(3-methoxyphenyl)butan-1-one.

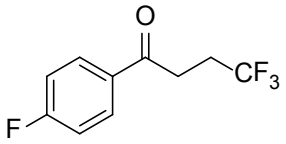


2d

Colorless liquid (84%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.54 (d, *J* = 7.8 Hz, 1 H), 7.48 (s, 1 H), 7.39 (t, *J* = 7.8 Hz, 1 H), 7.14 (d, *J* = 7.8 Hz, 1 H), 3.86 (s, 3 H), 3.24 (t, *J* = 7.5 Hz, 2 H), 2.66-2.50 (m, 2 H) ppm; ^{19}F NMR (282 MHz, $CDCl_3$): δ -66.14 (t, *J* = 10.3 Hz, 3 F) ppm; ^{13}C

NMR ($CDCl_3$, 100 MHz): δ 196.2, 160.0, 137.5, 129.8, 127.2 (q, J = 275.9 Hz), 120.6, 120.0, 112.4, 55.45, 31.31 (q, J = 2.2 Hz), 28.40 (q, J = 30.1 Hz) ppm; EI-MS (m/z, %): 135 (100), 232 (36.33), 107 (28.69), 77 (17.48), 92 (11.55), 136 (9.33), 64 (4.73), 233 (4.61); IR (KBr): 3078, 3008, 2963, 2840, 1682, 1600, 1585, 1487, 1447, 1388, 1365, 1259, 1146, 1099, 1070, 977, 874, 778, 686, 619, 556cm^{-1}; HRMS for C11H11O2F3: 232.0711; Found: 232.0712.

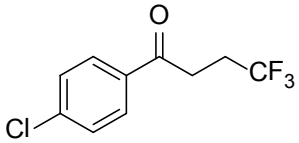
4,4,4-Trifluoro-1-(4-fluorophenyl)butan-1-one.



2e

Slightly yellow liquid (95%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.02 (dd, J = 8.8 Hz, J = 5.2 Hz, 2 H), 7.17 (t, J = 8.8 Hz, 2 H), 3.25 (t, J = 7.3 Hz, 2H), 2.68-2.52 (m, 2 H) ppm.; ^{19}F NMR (282 MHz, $CDCl_3$): δ -66.85 (t, J = 9.9 Hz, 3 F), -104.57 (m, 1 F) ppm.; ^{13}C NMR ($CDCl_3$, 100 MHz): δ 194.7, 166.1 (d, J = 255.3 Hz), 132.6 (d, J = 3 Hz), 130.7 (d, J = 9.5 Hz), 127.1 (q, J = 275.9 Hz), 115.9 (d, J = 22Hz), 31.14 (d, J = 2.2 Hz), 28.35 (q, J = 30.1 Hz) ppm.; EI-MS (m/z, %): 123 (100), 95 (37.0), 75 (11.7), 124 (9.68), 220 (4.75), 69 (4.07), 201 (3.85), 96 (3.18).; IR (KBr): 3077, 2964, 2924, 1693, 1600, 1511, 1447, 1413, 1333, 1262, 1226, 1154, 1101, 980, 843, 642, 590, 569, 492, 418cm^{-1}; HRMS for $C_{10}H_8OF_4$: 220.0511; Found: 220.0510.

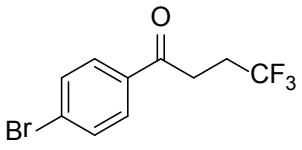
1-(4-Chlorophenyl)-4,4,4-trifluorobutan-1-one.



2f

White solid (m.p. 68-70^{o}C, 75%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.92 (d, J = 8.5 Hz, 2 H), 7.47 (d, J = 8.5 Hz, 2 H), 3.23 (t, J = 7.5 Hz, 2 H), 2.64-2.55 (m, 2 H) ppm; ^{19}F NMR (282 MHz, $CDCl_3$): δ -66.19 (t, J = 10.3 Hz, 3 F) ppm; ^{13}C NMR ($CDCl_3$, 100MHz): δ 195.1, 140.2, 134.5, 129.4, 129.1, 127.1 (q, J = 275.8 Hz), 31.22 (d, J = 2.2 Hz), 28.31 (q, J = 30.0 Hz) ppm; EI (m/z, %): 139 (100), 141 (35.1), 111 (31.7), 75 (14.7), 113 (10.5), 140 (9.39), 236 (6.36), 76 (4.40); IR(KBr): 1686, 1651, 1593, 1489, 1441, 1403, 1335, 1260, 1144, 1096, 979, 840, 827, 782, 629, 526cm^{-1}; HRMS for $C_{10}H_8OF_3Cl$: 236.0216; Found: 236.0218.

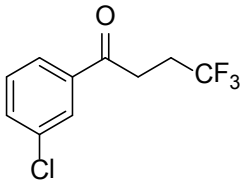
1-(4-Bromophenyl)-4,4,4-trifluorobutan-1-one.



2g

White solid (m.p. 82-84°C, 93%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.83 (d, *J* = 8.7 Hz, 2 H), 7.63 (d, *J* = 8.7 Hz, 2 H), 3.22 (t, *J* = 7.5 Hz, 2H), 2.67-2.51 (m, 2 H) ppm; ^{19}F NMR (282 MHz, $CDCl_3$): δ -66.21 (t, *J* = 10.3 Hz, 3 F) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz): δ 195.3, 134.9, 132.1, 129.5, 128.9, 127.1 (q, *J* = 275.8 Hz), 31.20 (d, *J* = 2.9 Hz), 28.29 (q, *J* = 29.3 Hz) ppm; EI-MS (m/z, %): 183 (100), 185 (82.34), 157 (32.36), 155 (31.20), 76 (26.45), 75 (21.29), 50 (17.32), 193 (16.11).; IR (KBr): 2966.3, 2922.8, 1686.4, 1588.6, 1560.8, 1388.4, 1259.3, 1010.9, 780.7, 626.4cm^{-1}. HRMS for $C_{10}H_8OF_3Br$: 279.9711; Found: 279.9715.

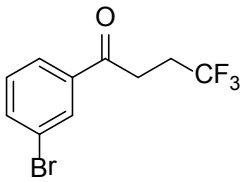
1-(3-Chlorophenyl)-4,4,4-trifluorobutan-1-one.



2h

Slightly yellow liquid (70%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.94 (t, *J* = 1.8 Hz, 1 H), 7.85 (dt, *J* = 7.9 Hz, *J* = 1.8Hz, 1 H), 7.58 (dm, *J* = 7.9 Hz, 1 H), 7.44 (t, *J* = 7.9 Hz, 1 H), 3.25 (t, *J* = 7.6 Hz, 2 H), 2.68-2.52 (m, 2 H) ppm.; ^{19}F NMR (282 MHz, $CDCl_3$): δ = -66.82 (t, *J* = 9.9 Hz, 3 F) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz): δ 195.1, 137.6, 135.2, 133.6, 130.1, 128.2, 127.0 (q, *J* = 275.8 Hz), 126.1, 31.38 (q, *J* = 2.9 Hz), 28.26 (q, *J* = 30.1 Hz) ppm; EI-MS (m/z, %): 139 (100), 141 (35.4), 111 (35.0), 75 (13.8), 113 (11.7), 236 (9.94), 140 (9.37), 76 (4.71).; IR (KBr): 3071, 2963, 2923, 1697, 1573, 1473, 1451, 1422, 1389, 1322, 1272, 1224, 1145, 1001, 999, 978, 977, 903, 805, 776, 720, 681, 660, 620, 570cm^{-1}. HRMS for $C_{10}H_8OF_3Cl$: 236.0216; Found: 236.0215.

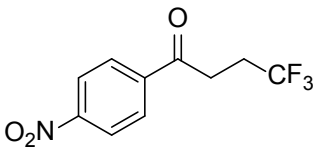
1-(3-Bromophenyl)-4,4,4-trifluorobutan-1-one.[10]



2i

Slightly yellow liquid (89%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.09 (s, 1 H), 7.89 (d, *J* = 7.9 Hz, 1 H), 7.73 (d, *J* = 7.9 Hz, 1 H), 7.38 (t, *J* = 7.9 Hz, 1 H), 3.24 (t, *J* = 7.3 Hz, 2 H), 2.67-2.51 (m, 2 H) ppm; ^{19}F NMR (282 MHz, $CDCl_3$): δ -66.28 (t, *J* = 10.4 Hz, 3 F) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 195.0, 137.8, 136.5, 131.2, 130.4, 127.0 (q, *J* = 275.9 Hz), 126.5, 31.36 (q, *J* = 2.9 Hz), 28.27 (q, *J* = 29.3 Hz) ppm; EI-MS (m/z, %): 183 (100), 185 (93.62), 76 (41.18), 155 (38.88), 157 (37.76), 75 (33.12), 50 (28.50), 77 (19.49).; IR (KBr): 3067.6, 2962.0, 2922.0, 1696.5, 1568.2, 1388.5, 1331.1, 1100.2, 976.4, 774.1, 679.9cm^{-1}. HRMS for $C_{10}H_8OF_3Br$: 279.9711; Found: 279.9716.

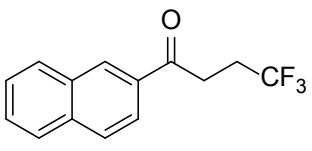
4,4,4-Trifluoro-1-(4-nitrophenyl)butan-1-one.



2j

White solid (m.p. 69-71°C, 77%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.36 (d, *J* = 8.5 Hz, 2 H), 8.16 (d, *J* = 8.5 Hz, 2 H), 3.34 (t, *J* = 7.3 Hz, 2 H), 2.72-2.56 (m, 2 H) ppm.; ^{19}F NMR (282 MHz, $CDCl_3$): δ -66.82 (t, *J* = 11.9 Hz, 3 F).; ^{13}C NMR ($CDCl_3$, 100 MHz): δ 194.8, 150.7, 140.4, 129.1, 126.9 (q, *J* = 275.8 Hz), 124.0, 31.88 (d, *J* = 2.9 Hz), 28.20 (q, *J* = 30.1 Hz) ppm.; EI-MS (m/z, %): 150 (100), 104 (23.8), 76 (14.2), 92 (10.8), 77 (8.60), 151 (8.34), 50 (7.03), 75 (6.17).; IR (KBr): 3114, 2931, 1691, 1604, 1513, 1444, 1337, 1264, 1225, 1151, 1095, 978, 966, 781, 744, 688, 628, 571, 507cm^{-1}; HRMS for $C_{10}H_8NO_3F_3$: 247.0456; Found: 247.0452.

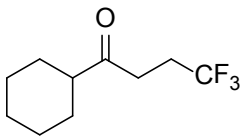
4,4,4-Trifluoro-1-(naphthalen-2-yl)butan-1-one.



2k

White solid (m.p. 92-94°C, 83%) ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.45 (s, 1 H), 8.02-7.95 (m, 2 H), 7.91-7.86 (m, 2 H), 7.64-7.54 (m, 2 H), 3.38 (t, *J* = 7.9 Hz, 2 H), 2.72-2.56 (m, 2 H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$): δ -66.66 (t, *J* = 10.0 Hz, 3 F) ppm.; ^{13}C NMR ($CDCl_3$, 100 MHz): δ 196.2, 135.8, 133.5, 132.5, 129.8, 129.6, 128.8, 128.7, 127.9, 127.3 (q, *J* = 275.1 Hz), 127.0, 123.6, 31.28 (d, *J* = 2.9 Hz), 28.50 (q, *J* = 29.4 Hz)ppm; EI-MS (m/z, %): 155 (100), 127 (72.5), 252 (26.6), 126 (16.8), 156 (13.1), 77 (11.1), 128 (8.71), 101 (4.94).; IR(KBr): 2964, 1683, 1626, 1436, 1420, 1358, 1323, 1262, 1225, 1138, 979, 918, 869, 748, 643, 563, 485, 461cm^{-1}; HRMS for $C_{14}H_{11}OF_3$: 252.0762; Found: 252.0768.

1-Cyclohexyl-4,4,4-trifluorobutan-1-one



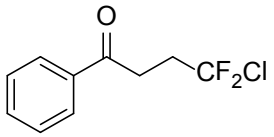
2l

Slightly yellow liquid (74%) ^{1}H NMR (400 MHz, $CDCl_3$) δ = 2.71 – 2.66 (m, 2H), 2.44 – 2.30 (m, 3H), 1.88 – 1.73 (m, 4H), 1.70 – 1.62 (m, 1H), 1.40 – 1.15 (m, 5H). ^{19}F NMR (376 MHz, $CDCl_3$) δ = -66.72(t, *J* = 10.9 Hz, 3F). ^{13}C NMR (101MHz, $CDCl_3$) δ = 210.09, 126.97 (q, *J* = 275.7 Hz), 50.68, 32.69 (dd, *J* = 5.0, 2.4 Hz), 28.32, 27.82 (dd, *J* = 59.4, 29.7 Hz), 25.63, 25.44. IR (KBr): 2934, 2858, 1714, 1450, 1374, 1326, 1257, 1221, 1141, 997, 969, 624; GC-MS: 208.1. HRMS: 208.1076; Found: 208.1075.

General Procedure for the ring-opening of *gem*-difluorocyclopropayl ketones promoted by boron trichloride:

Into the solution of *gem*-difluorocyclopropyl ketone (0.2 mmol) in $CHCl_3$ (1.0 mL) was added BCl_3 (0.4 mL, 1 M in CH_2Cl_2) slowly at room temperature. The mixture was stirred at the same temperature until the reaction was complete determined by ^{19}F NMR. Saturated $NaHCO_3$ solution was added to quench the reaction. After extraction with CH_2Cl_2 (10 mL x 3), the organic solution was dried over Na_2SO_4. The solvent was removed by concentration, and the residue was subjected to column chromatography to afford the β-chlorodifluoromethyl ketones.

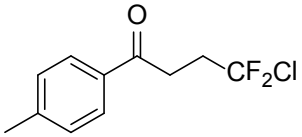
4-Chloro-4,4-difluoro-1-phenylbutan-1-one[11]



3a

Colorless liquid (63%) ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.00 – 7.96 (m, 2H), 7.63 – 7.58 (m, 1H), 7.51 – 7.46 (m, 2H), 3.34 – 3.29 (m, 2H), 2.86 – 2.75 (m, 2H). ^{19}F NMR (376 MHz, $CDCl_3$) δ = -51.05 (t, *J* = 12.9 Hz, 2F).

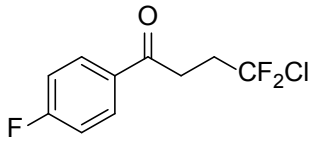
4-Chloro-4,4-difluoro-1-(p-tolyl)butan-1-one[11]



3b

Colorless liquid (83%) ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.87 (d, *J* = 8.2 Hz, 2H), 7.28 (d, *J* = 8.2 Hz, 2H), 3.31 – 3.25 (m, 2H), 2.82-2.76 (m, 2H), 2.42 (s, 3H). ^{19}F NMR (376 MHz, $CDCl_3$) δ = -51.00 (t, *J* = 12.9 Hz, 2F).

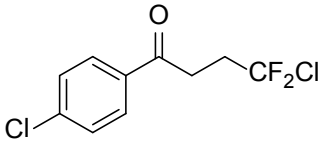
4-Chloro-4,4-difluoro-1-(4-fluorophenyl)butan-1-one.



3c

Yellow liquid (82%) ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.01 (dd, *J* = 8.2, 5.6 Hz, 2H), 7.16 (t, *J* = 8.2, 2H), 3.32 – 3.24 (m, 2H), 2.86-2.72 (m, 2H). ^{19}F NMR (376 MHz, $CDCl_3$) δ = -51.12 (t, *J* = 12.8 Hz, 2F), -104.20 – -104.30 (m, 1F). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 194.69, 165.97(d, *J* = 255.7 Hz), 132.53 (d, *J* = 3.1Hz), 130.67 (d, *J* = 9.4 Hz), 129.55 (t, *J* = 291.1 Hz), 115.89 (d, *J* = 22.0 Hz), 36.24 (t, *J* = 25.2 Hz). 32.44 (t, *J* = 2.7 Hz). IR (KBr): 2962, 1692, 1601, 1508, 1436, 1412, 1317, 1231, 1208, 1184, 1158, 1102, 1047, 997, 931, 842, 815, 669, 604, 562, 522, 490; GC-MS: 236.0. HRMS: 236.0214; Found: 236.0216.

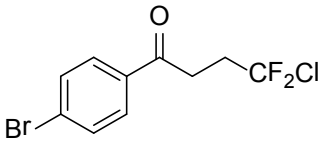
4-Chloro-1-(4-chlorophenyl)-4,4-difluorobutan-1-one.



3d

Yellow solid (m.p. 52-54 ^{o}C, 77%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.90 (d, *J* = 8.2 Hz, 2H), 7.31 (d, *J* = 8.2 Hz, 2H), 3.34 – 3.27 (m, 2H), 2.86-2.78 (m, 2H). ^{19}F NMR (376 MHz, $CDCl_3$) δ = -51.00 (t, *J* = 12.9 Hz, 2F). ^{13}CNMR (101MHz, $CDCl_3$) δ = 195.09, 140.08, 134.37, 129.51 (t, *J* = 291.2 Hz), 129.40, 129.07, 36.19 (t, *J* = 25.2 Hz), 32.52 (t, *J* = 2.8 Hz). IR (KBr): 2959, 2925, 1692, 1591, 1572, 1489, 1435, 1401, 1315, 1299, 1209, 1185, 1094, 1047, 1014, 994, 932, 838, 785, 757, 662, 560, 530, 463; GC-MS: 252.0; HRMS: 251.9919; Found:251.9920.

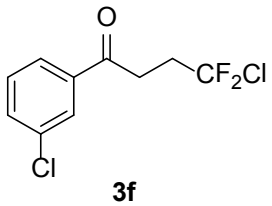
1-(4-Bromophenyl)-4-chloro-4,4-difluorobutan-1-one.



3e

Yellow solid (m.p. 46-48 ^{o}C, 80%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.84 (d, *J* = 8.0 Hz, 2H), 7.63 (d, *J* = 8.0 Hz, 2H), 3.31 – 3.23 (m, 2H), 2.86 – 2.72 (m, 2H). ^{19}F NMR (376 MHz, $CDCl_3$) δ = -51.12 (t, *J* = 12.8 Hz, 2F). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 195.25, 134.77, 132.37 (t, *J* = 281.1 Hz), 132.07, 129.49, 128.84, 36.15 (t, *J* = 25.2 Hz), 32.47 (t, *J* = 2.8 Hz); IR (KBr): 3088, 3062, 2959, 2924, 2855, 2361, 1690, 1586, 1568, 1485, 1398, 1314, 1207, 1070, 1010, 986, 931, 803, 782, 748, 659, 568, 522, 456; GC-MS: 298.0; HRMS: 295.9414; Found:295.9415.

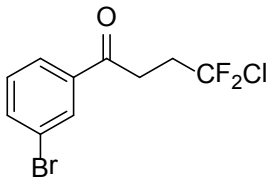
4-Chloro-1-(3-chlorophenyl)-4,4-difluorobutan-1-one.



3f

Yellow liquid (82%) ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.93 – 7.90 (m, 1H), 7.83 (d, *J* = 7.8, 1H), 7.57 – 7.52 (m, 1H), 7.44 – 7.38 (m, 1H), 3.29 – 3.23 (m, 2H), 2.84 – 2.71 (m, 2H). ^{19}F NMR (376 MHz, $CDCl_3$) δ = -51.15 (t, *J* = 12.8 Hz, 2F). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 195.01, 137.52, 135.09, 133.47, 130.06, 129.42 (t, *J* = 291.3 Hz), 128.07, 126.04, 36.10 (t, *J* = 25.3 Hz), 32.63 (t, *J* = 2.8 Hz); IR (KBr): 3069, 2960, 2926, 2855, 1696, 1573, 1473, 1421, 1313, 1207, 1185, 1106, 1047, 938, 904, 778, 728, 698, 681, 670, 570, 558; GC-MS:252.0; HRMS: 251.9918; Found: 251.9920.

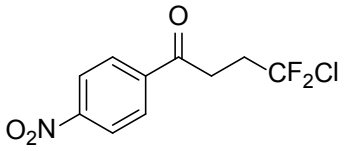
1-(3-Bromophenyl)-4-chloro-4,4-difluorobutan-1-one.



3g

Yellow liquid (83%) ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.09 (s, 1H), 7.89 (d, *J* = 7.9 Hz, 1H), 7.72 (dd, *J* = 7.9, 0.9 Hz, 1H), 7.37 (t, *J* = 7.9 Hz, 1H), 3.32 – 3.24 (m, 2H), 2.83-2.74 (m, 2H). ^{19}F NMR (376 MHz, $CDCl_3$) δ = -51.14 (t, *J* = 12.8 Hz, 2F); ^{13}CNMR(101MHz,$CDCl_3$) δ = 194.95, 137.74, 136.43, 131.05, 130.34, 129.45 (t, *J* = 291.3 Hz), 126.55, 123.12, 36.14 (t, *J* = 25.3 Hz), 32.64 (t, *J* = 2.7 Hz). IR (KBr): 3067, 2959, 2925, 1694, 1567, 1420, 1314, 1207, 1184, 1104, 1047, 997, 937, 775, 711, 680, 664, 587, 558; GC-MS: 298.0; HRMS: 295.9412; Found: 295.9415.

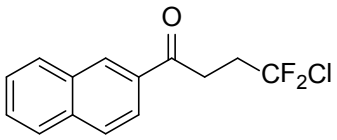
4-Chloro-4,4-difluoro-1-(4-nitrophenyl)butan-1-one.



3h

Slightly yellow solid (m.p. 45-47 °C, 60%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.36 – 8.32 (m, 2H), 8.17 – 8.13 (m, 2H), 3.39 – 3.34 (m, 2H), 2.89 – 2.77 (m, 2H). ^{19}F NMR (376 MHz, $CDCl_3$) δ = -51.26 (t, *J* = 12.7 Hz, 2F). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 194.84, 150.57, 140.35, 129.27 (t, *J* = 291.2 Hz), 129.10, 124.00, 36.04 (t, *J* = 25.4 Hz), 33.16 (t, *J* = 2.8 Hz); IR (KBr): 3112, 3081, 2922, 2861, 1697,1604, 1528, 1435, 1410, 1347, 1317, 1207, 1186, 1103, 1047, 996, 934, 857, 743, 687, 668, 660, 574, 559, 543, 511, 432; GC-MS: 263.0; HRMS: 263.0159; Found:263.0161.

4-Chloro-4,4-difluoro-1-(naphthalen-2-yl)butan-1-one.

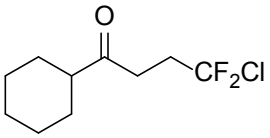


3i

Yellow solid (m.p. 72-74 °C, 80%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.49 (s, 1H), 8.03 (dd, *J* = 8.8, 1.4 Hz, 1H), 7.98 (d, *J* = 8.0 Hz, 1H), 7.90 (t, *J* = 8.8, 2H), 7.62-7.58 (m, 2H), 3.48 – 3.41 (m, 2H), 2.93 – 2.80 (m, 2H). ^{19}F NMR (376 MHz, $CDCl_3$) δ = -50.94 (t, *J* = 12.9 Hz, 2 F). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 196.19, 135.70, 133.37, 132.38, 129.78, 129.67 (t, *J* = 291.1 Hz), 129.55, 128.71, 128.61, 127.76, 126.93, 123.50, 36.39 (t, *J* = 25.1 Hz), 32.55 (t, *J* = 2.6 Hz); IR (KBr):

3061, 2960, 2926, 1687, 1628, 1469, 1452, 1435, 1353, 1311, 1206, 1183, 1102, 1046, 1021, 995, 934, 896, 862, 802, 747, 668, 558, 476; GC-MS: 268.1; HRMS: 268.0470; Found: 268.0466.

4-Chloro-1-cyclohexyl-4,4-difluorobutan-1-one.



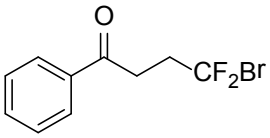
3j

Slightly yellow liquid (49%) ^{1}H NMR (400 MHz, $CDCl_3$) δ = 2.79-2.68 (m, 2H), 2.64 – 2.52 (m, 2H), 2.42-2.32 (m, 1H), 1.89 – 1.73 (m, 4H), 1.71 – 1.63 (m, 1H), 1.42 – 1.12 (m, 5H). ^{19}F NMR (376 MHz, $CDCl_3$) δ = -51.19 (m, 2F). ^{13}CNMR (101MHz, $CDCl_3$) δ = 210.14, 129.53 (t, *J* = 291.2 Hz), 50.74, 35.81 (t, *J* = 25.0 Hz), 34.07 (t, *J* = 2.5 Hz), 28.35, 25.64, 25.46. IR (KBr): 2933, 2857, 1713, 1451, 1316, 1294, 1207, 1189, 1102, 1027, 998, 936, 887, 659; GC-MS: 224.1; HRMS: 224.0776; Found: 224.0779.

General Procedure for the ring-opening of *gem*-difluorocyclopropayl ketones promoted by boron tribromide:

Into the solution of *gem*-difluorocyclopropyl ketone (0.2 mmol) in $CHCl_3$ (1.0 mL) was added BBr_3 (1 mL, 0.4 M in CH_2Cl_2) slowly at -78 ^{o}C. The mixture was stirred at the same temperature until the reaction was complete determined by ^{19}F NMR. After being warmed to room temperature, saturated $NaHCO_3$ solution was added to quench the reaction. After extraction with CH_2Cl_2 (10 mL x 3), the organic solution was dried over Na_2SO_4. The solvent was removed by concentration, and the residue was subjected to silica-gel column chromatography to afford the β-bromodifluoromethyl ketones.

4-Bromo-4,4-difluoro-1-phenylbutan-1-one.

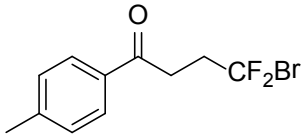


4a

Yellow liquid (57%) ^{1}H NMR (400 MHz, $CDCl_3$) :δ = 8.00 – 7.96 (m, 2H), 7.63 – 7.57 (m, 1H), 7.52-7.45 (m, 2H), 3.34-3.28 (m, 2H), 2.92-2.80 (m, 2H). ^{19}F NMR (376MHz, $CDCl_3$): δ = -44.03 (t, *J* = 13.6 Hz, 2F). ^{13}C NMR (101MHz,$CDCl_3$): δ = 196.15, 136.07, 133.59, 128.75, 128.01, 122.43 (t, *J* = 304.7 Hz), 38.69 (t, *J* = 22.6 Hz), 33.14 (t, *J* = 2.8 Hz). IR (KBr): 3063, 2956, 2935,

1690, 1598, 1450, 1433, 1321, 1306, 1205, 1177, 1102, 1041, 975, 917, 747, 730, 689, 627, 554; GC-MS:262.0; HRMS: 261.9808; Found: 261.9805.

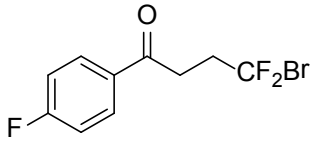
4-Bromo-4,4-difluoro-1-(p-tolyl)butan-1-one.



4b

Yellow solid (m.p. 47-49 ^{o}C, 81%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.83 (d, *J* = 8.2 Hz, 2H), 7.24 (d, *J* = 8.2 Hz, 2H), 3.27 – 3.21 (m, 2H), 2.84-2.78 (m, 2H), 2.38 (s, 3H). ^{19}F NMR (376 MHz, $CDCl_3$) δ = -43.98 (t, *J* = 13.6 Hz, 2F). ^{13}C NMR (101MHz, $CDCl_3$) δ = 195.79, 144.49, 133.63, 129.41, 128.12, 122.50 (t, *J* = 304.8 Hz), 38.75 (t, *J* = 22.6 Hz), 32.99 (t, *J* = 2.8 Hz), 21.66. IR (KBr): 3034, 2958, 2926, 1686, 1607, 1433, 1410, 1319, 1304, 1200, 1040, 980, 921, 820, 788, 636, 550, 461; GC-MS: 276.0; HRMS: 275.9963; Found: 275.9961.

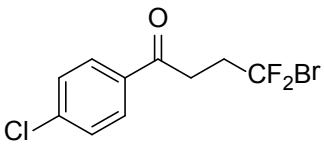
4-Bromo-4,4-difluoro-1-(4-fluorophenyl)butan-1-one.



4c

Yellow liquid (48%) ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.00 – 7.91 (m, 2H), 7.10 (t, *J* = 8.5, 2H), 3.27 – 3.19 (m, 2H), 2.86 – 2.72 (m, 2H). ^{19}F NMR (282 MHz, $CDCl_3$) δ = -44.60 (t, *J* = 13.4 Hz, 2F), -104.68 (m, 1F). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 194.53, 165.97 (d, *J* = 255.8 Hz), 132.53, 130.68 (d, *J* = 9.4 Hz), 122.31 (t, *J* = 305.0 Hz), 115.89 (d, *J* = 22.0 Hz), 38.62 (t, *J* = 22.7 Hz), 33.05 (t, *J* = 2.6 Hz). IR (KBr): 2935, 1690, 1600, 1508, 1433, 1412, 1316, 1238, 1211, 1178, 1158, 1103, 1041, 991, 921, 843, 633, 601, 550, 437; GC-MS: 280.0. HRMS: 279.9716; Found: 279.9711.

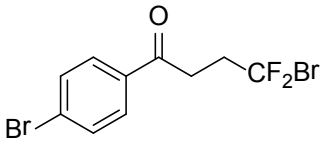
4-Bromo-1-(4-chlorophenyl)-4,4-difluorobutan-1-one.



4d

Yellow solid (m.p. 58-60 ^{o}C, 71%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.87 (d, *J* = 8.3 Hz, 2H), 7.41 (d, *J* = 8.3 Hz, 2H), 3.27 – 3.20 (m, 2H), 2.87 – 2.74 (m, 2H). ^{19}F NMR (376 MHz, $CDCl_3$) δ = -44.16 (t, *J* = 13.5 Hz, 2F). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 194.92, 140.09, 134.37, 129.41, 129.08, 122.25 (t, *J* = 304.6 Hz), 38.59 (t, *J* = 22.7 Hz), 33.13 (t, *J* = 2.8 Hz). IR (KBr): 2935, 1693, 1591, 1488, 1433, 1401, 1314, 1298, 1209, 1176, 1094, 989, 920, 834, 803, 750, 629, 528, 463; GC-MS: 298.0; HRMS: 295.9412; Found: 295.9415.

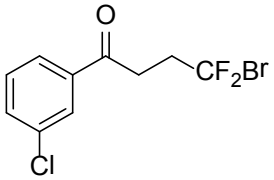
4-Bromo-1-(4-bromophenyl)-4,4-difluorobutan-1-one.



4e

Yellow solid (m.p. 57-59 ^{o}C, 74%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.85 – 7.81 (m, 2H), 7.64 – 7.59 (m, 2H), 3.30 – 3.24 (m, 2H), 2.91 – 2.78 (m, 2H). ^{19}F NMR (376 MHz, $CDCl_3$) δ = -44.14 (t, *J* = 13.5 Hz, 2F). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 195.11, 134.77, 132.07, 129.50, 128.84, 122.24 (t, *J* = 304.7 Hz), 38.57 (t, *J* = 22.7 Hz), 33.11 (t, *J* = 2.8 Hz). IR (KBr): 2960, 2919, 1693, 1586, 1568, 1484, 1433, 1399, 1315, 1299, 1206, 1176, 1101, 1070, 1041, 1011, 987, 920, 836, 801, 782, 741, 628, 557, 520, 455; GC-MS: 341.9; HRMS: 339.8909; Found: 339.8910.

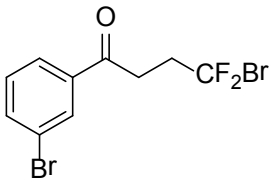
4-Bromo-1-(3-chlorophenyl)-4,4-difluorobutan-1-one.



4f

Yellow liquid (58%) ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.95-7.92 (m, 1H), 7.89-7.82 (m, 1H), 7.59-7.53 (m, 1H), 7.46-7.42 (m, 1H), 3.33-3.26 (m, 2H), 2.92 – 2.79 (m, 2H). ^{19}F NMR (376 MHz, $CDCl_3$) δ = -44.20 (t, *J* = 13.5 Hz, 2F). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 194.88, 137.55, 135.13, 133.52, 130.09, 128.10, 126.09, 122.16 (t, *J* = 301.5 Hz), 38.53 (t, *J* = 22.7 Hz), 33.27 (t, *J* = 2.9 Hz). IR (KBr): 3069, 2920, 1694, 1573, 1422, 1313, 1206, 1178, 1104, 1041, 998, 973, 920, 777, 721, 680, 628, 555, 525, 471; GC-MS: 298.0; HRMS: 295.9412; Found: 295.9415.

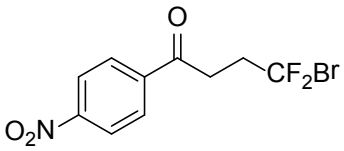
4-Bromo-1-(3-bromophenyl)-4,4-difluorobutan-1-one.



4g

Yellow liquid (61%) ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.11 – 8.08 (m, 1H), 7.92-7.88 (m, 1H), 7.74 – 7.70 (m, 1H), 7.41-7.35(m, 1H), 3.31 – 3.26 (m, 2H), 2.92 – 2.80 (m, 2H). ^{19}F NMR (376 MHz, $CDCl_3$) δ = -44.20 (t, *J* = 13.5Hz, 2F). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 194.81, 137.73, 136.45, 131.06, 130.35, 126.54, 123.13, 122.17 (t, *J* = 304.7 Hz), 38.53 (t, *J* = 22.7 Hz), 33.26 (t, *J* = 2.8 Hz). IR (KBr): 3066, 2933, 1694, 1567, 1471, 1420, 1313, 1205, 1177, 1104, 1069, 1041, 996, 918, 775, 704, 679, 654, 627, 555; GC-MS: 341.9. HRMS: 339.8912; Found: 339.8910.

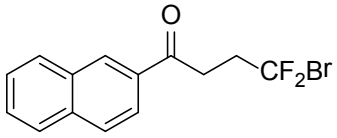
4-Bromo-4,4-difluoro-1-(4-nitrophenyl)butan-1-one.



4h

Yellow solid (m.p. 65-67 °C, 54%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.36 – 8.32 (m, 2H), 8.17 – 8.12 (m, 2H), 3.42-3.36 (m, 2H), 2.96 – 2.83 (m, 2H). ^{19}F NMR (376 MHz, $CDCl_3$) δ = -44.38 (t, *J* = 13.5 Hz, 2F). ^{13}C NMR (101MHz, $CDCl_3$) δ = 194.68, 150.58, 140.36, 129.10, 124.00, 121.94 (t, *J* = 303.9 Hz), 38.42 (t, *J* = 22.9 Hz), 33.75 (t, *J* = 2.8 Hz). IR (KBr): 3112, 3081, 2922, 2859, 1698, 1604, 1531, 1433, 1409, 1348, 1317, 1207, 1102, 1042, 990, 922, 857, 743, 687, 630, 559, 549, 509; GC-MS: 307.0; HRMS: 306.9651; Found: 306.9656.

4-Bromo-4,4-difluoro-1-(naphthalen-2-yl)butan-1-one.

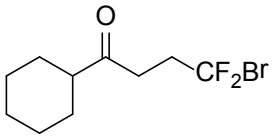


4i

Yellow solid (m.p. 76-78 °C, 57%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.48 (s, 1H), 8.03 (dd, *J* = 8.7, 1.6 Hz, 1H), 7.98 (d, *J* = 8.2 Hz, 1H), 7.90 (t, *J* = 8.2 Hz, 2H), 7.65 – 7.55 (m, 2H), 3.47 – 3.41 (m, 2H), 2.99 – 2.87 (m, 2H). ^{19}F NMR (376 MHz, $CDCl_3$) δ = -43.93 (t, *J* = 13.6 Hz, 2F). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 196.06, 135.74, 133.38, 132.40, 129.83, 129.59, 128.76, 128.65, 127.81, 126.97, 123.53, 122.50 (t, *J* = 304.7 Hz), 38.82 (t, *J* = 22.6 Hz), 33.19 (t, *J* = 2.7Hz). IR

(KBr): 3061, 2958, 2934, 1689, 1628, 1596, 1470, 1434, 1377, 1352, 1310, 1174, 1101, 1041, 989, 944, 914, 862, 823, 747, 708, 638, 625, 595, 550, 476; GC-MS: 312.0; HRMS: 311.9963; Found: 311.9961.

4-Bromo-1-cyclohexyl-4,4-difluorobutan-1-one.



4j

Faint yellow liquid (65%) ^{1}H NMR (400 MHz, $CDCl_3$) δ = 2.78 – 2.71 (m, 2H), 2.71 – 2.58 (m, 2H), 2.36 (ddd, *J* = 11.2, 7.3, 3.3 Hz, 1H), 1.90 – 1.72 (m, 4H), 1.72 – 1.61 (m, 1H), 1.40 – 1.12 (m, 5H). ^{19}F NMR (376 MHz, $CDCl_3$) δ = -44.14 (t, *J* = 13.4 Hz, 2F). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 210.00, 122.35 (t, *J* = 304.7 Hz), 50.74, 38.21 (t, *J* = 22.5 Hz), 34.70 (t, *J* = 2.6 Hz), 28.35, 25.64, 25.47. IR (KBr): 2933, 2856, 1713, 1450, 1315, 1204, 1102, 1022, 996, 923, 887, 669, 628, 550; GC-MS: 268.1. HRMS: 268.0276; Found: 268.0274.

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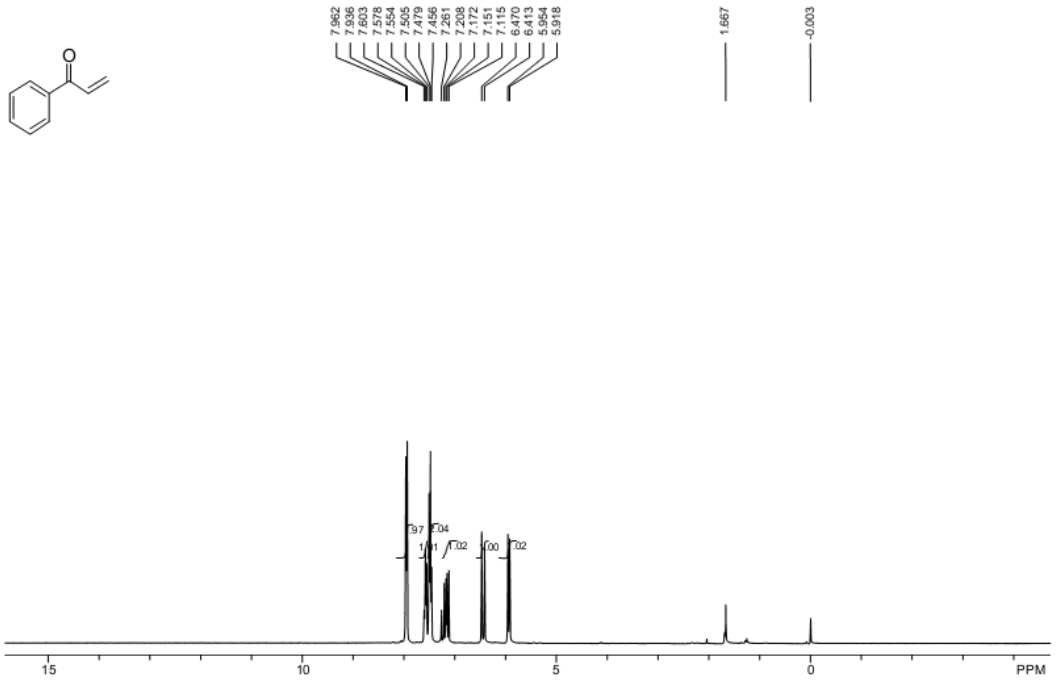
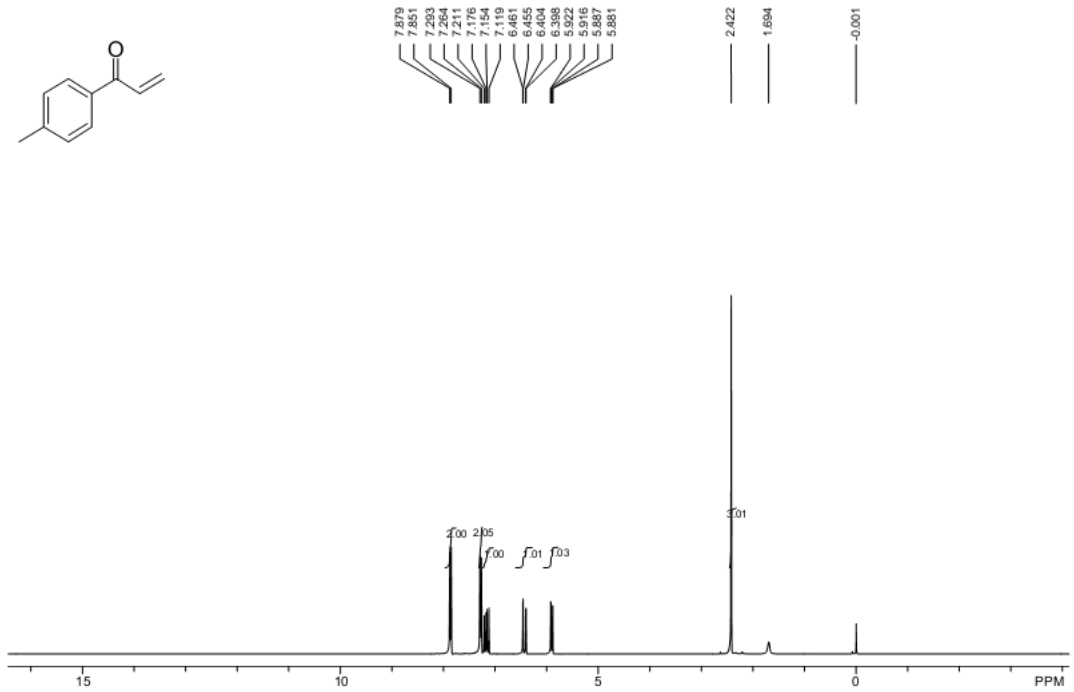
^{1}H NMR, ^{19}F NMR and ^{13}C NMR Spectra

^{1}H NMR spectrum of compound of **5a**

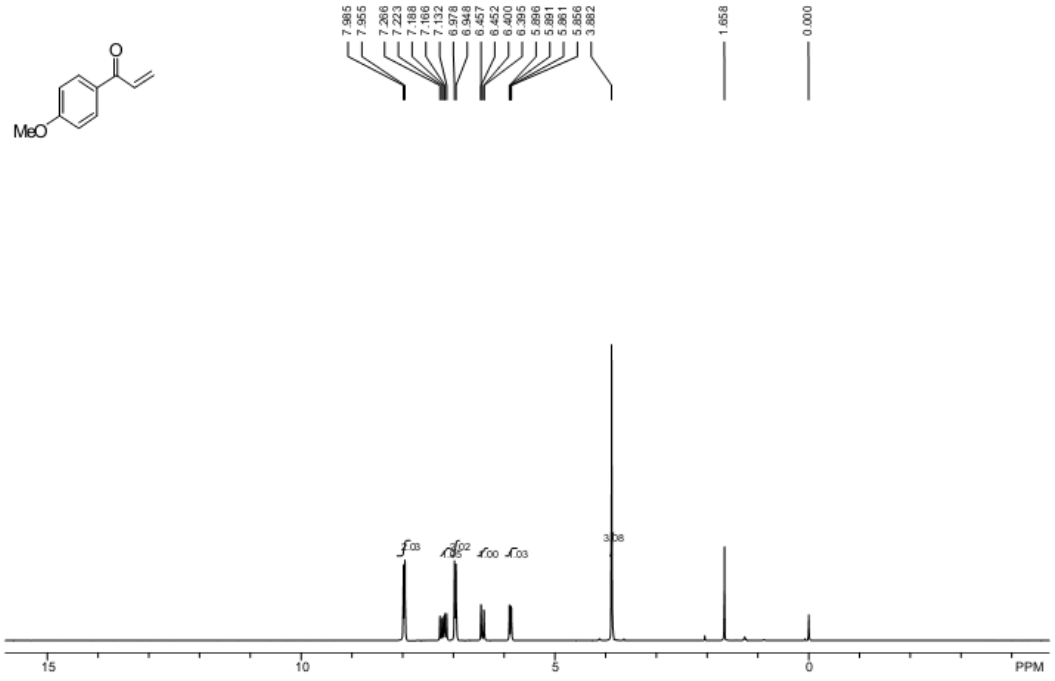


^{1}H NMR spectrum of compound of **5b**

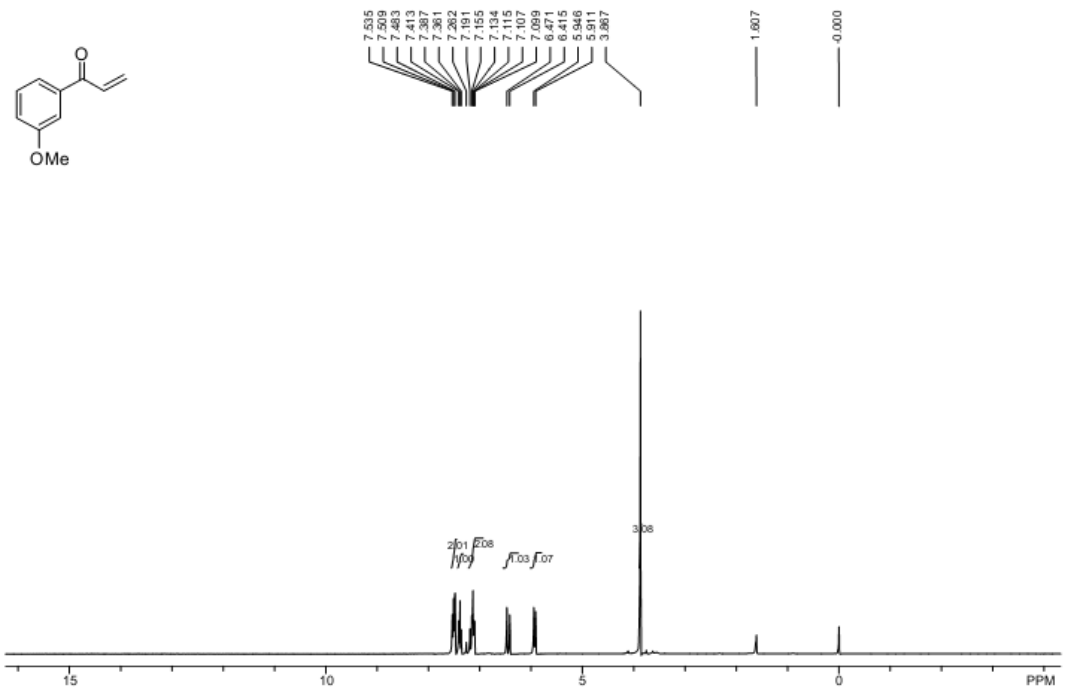


^{1}H NMR spectrum of compound of

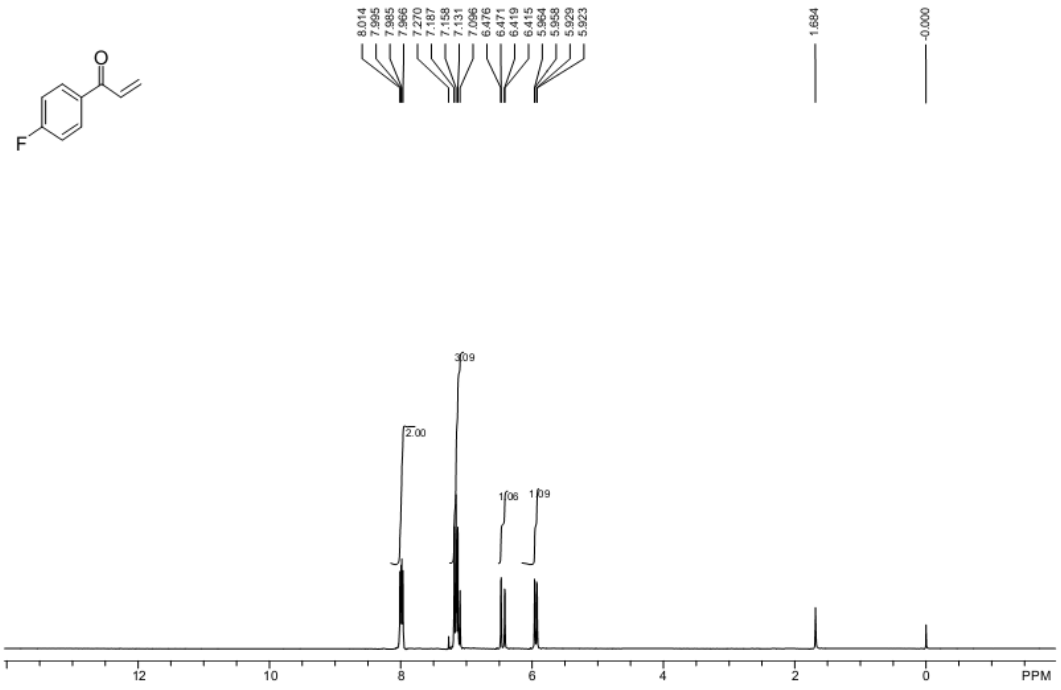
5c



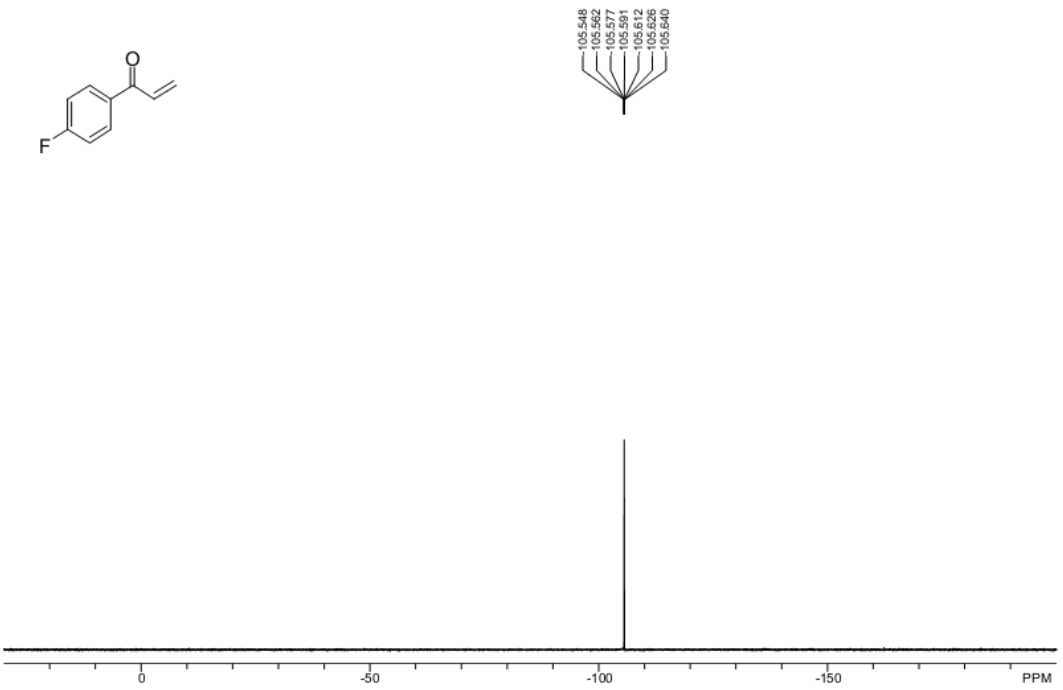
^{1}H NMR spectrum of compound of **5d**



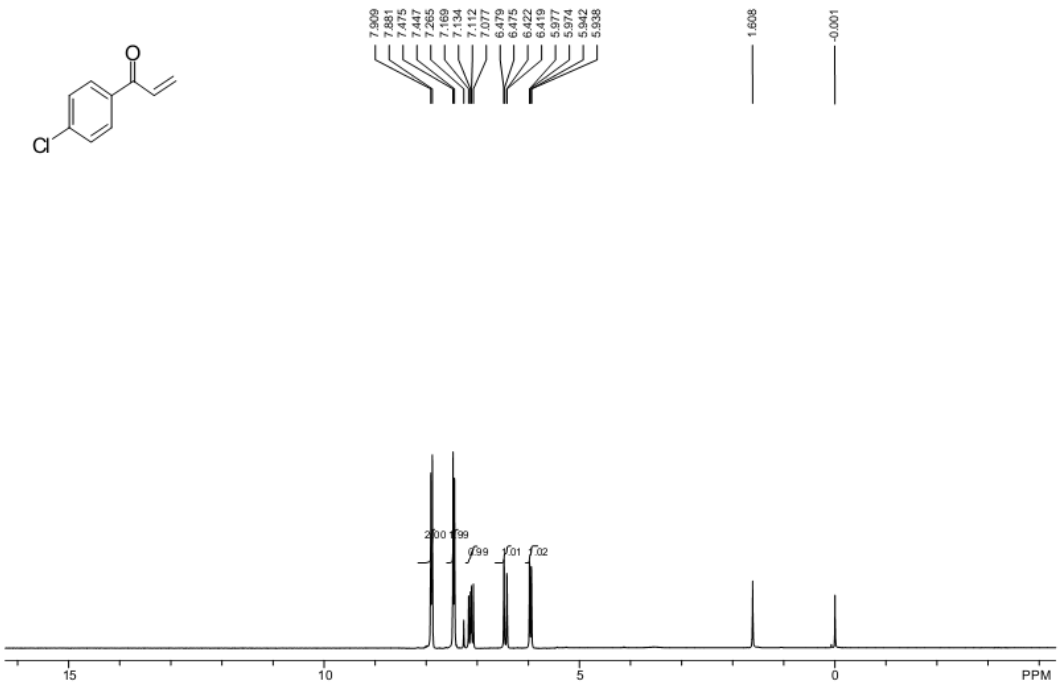
^{1}H NMR spectrum of compound of **5e**



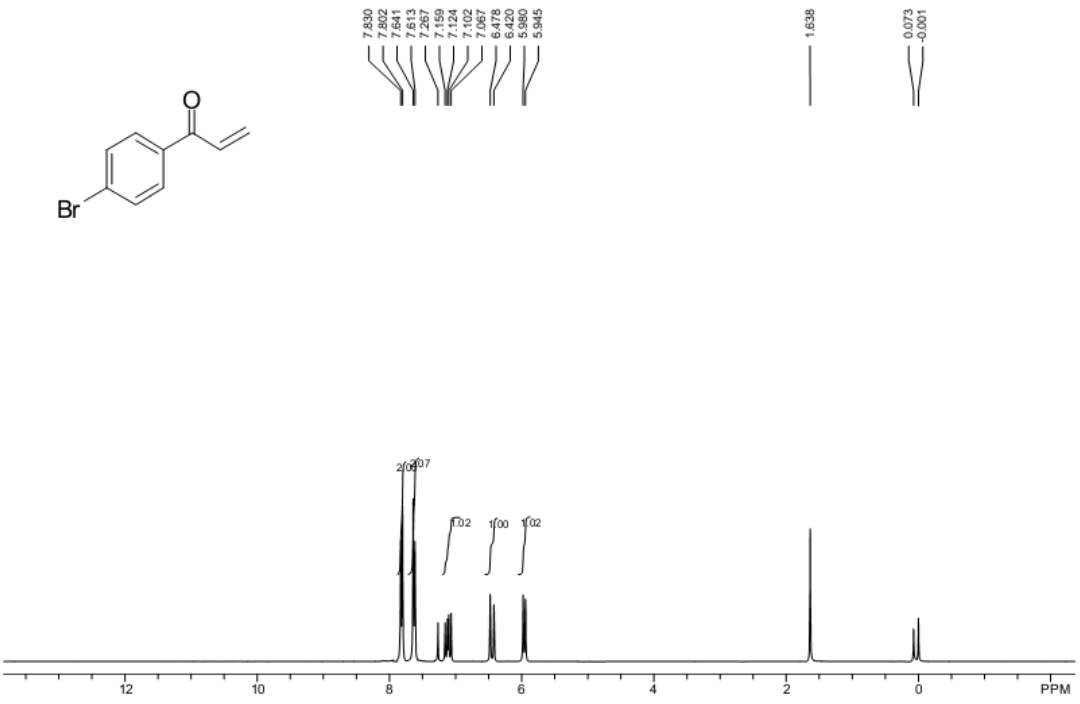
^{19}F NMR spectrum of compound of **5e**



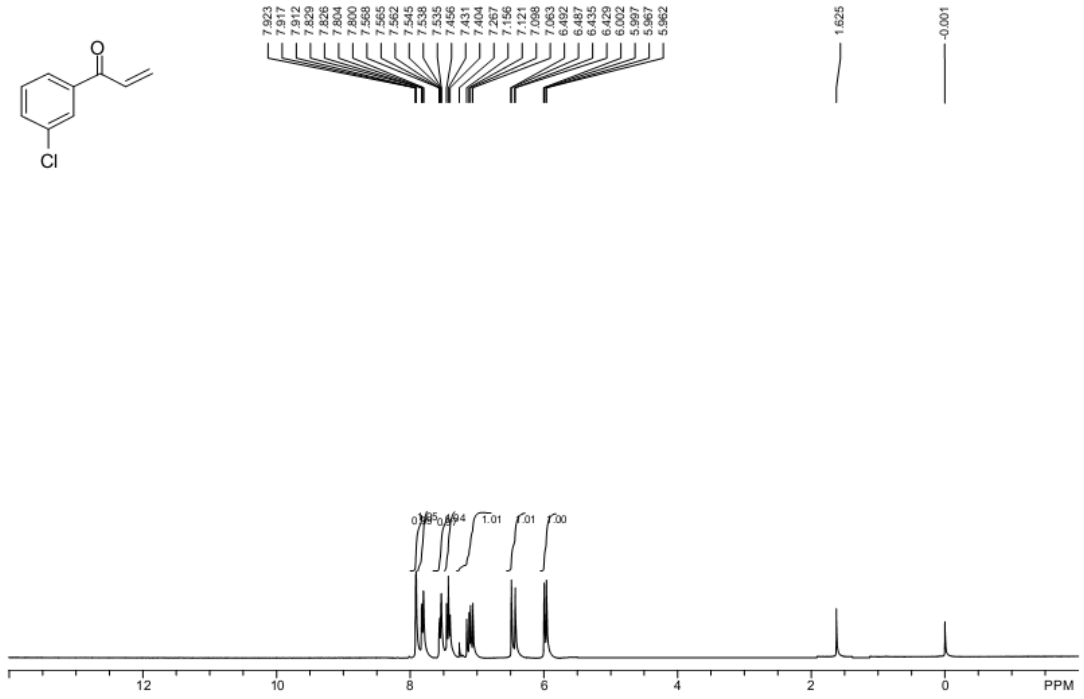
^{1}H NMR spectrum of compound of **5f**



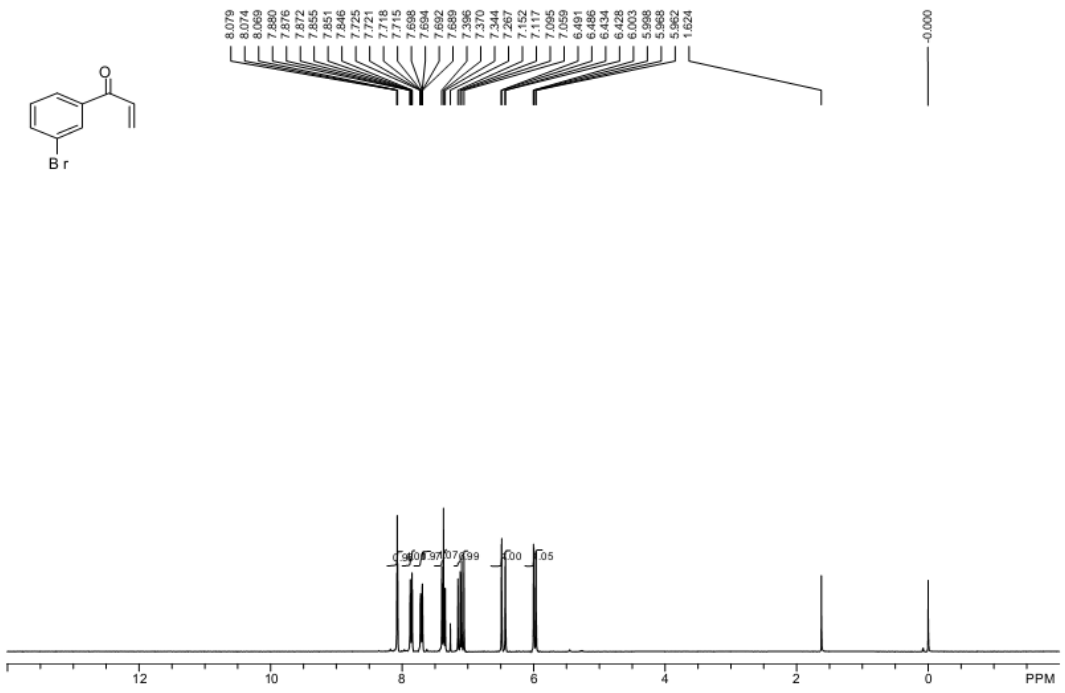
^{1}H NMR spectrum of compound of **5g**



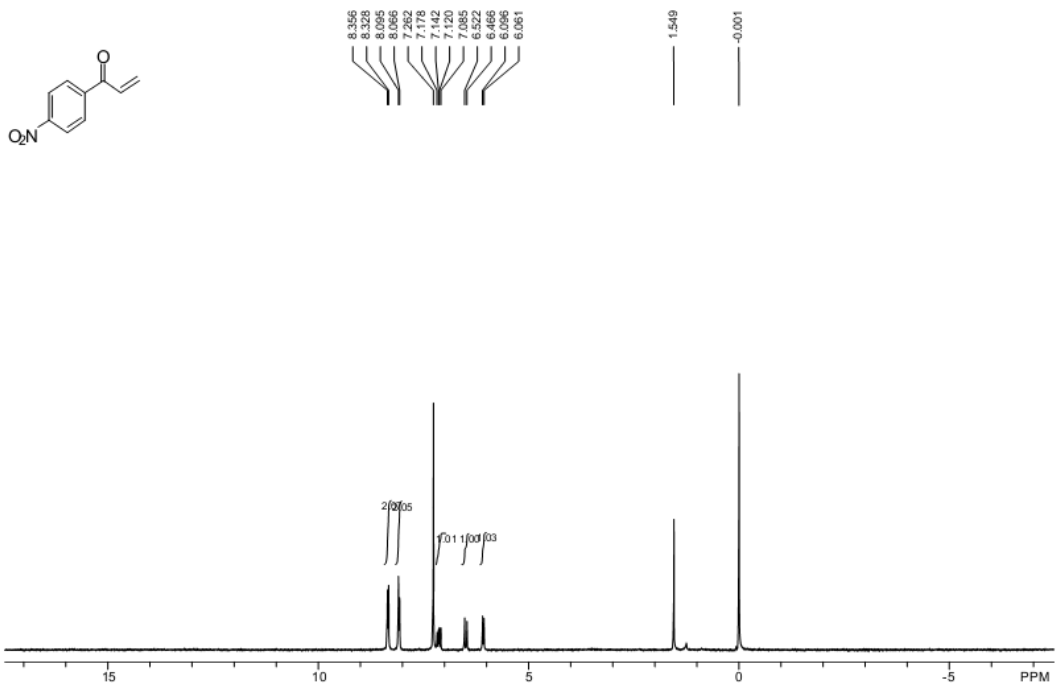
^{1}H NMR spectrum of compound of **5h**



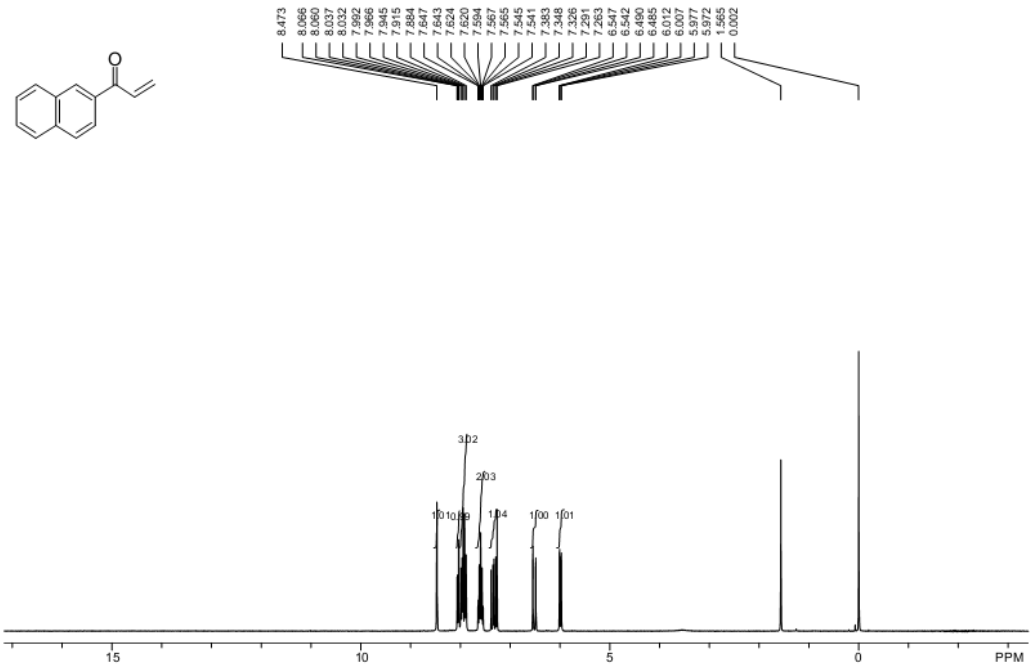
^{1}H NMR spectrum of compound of **5i**



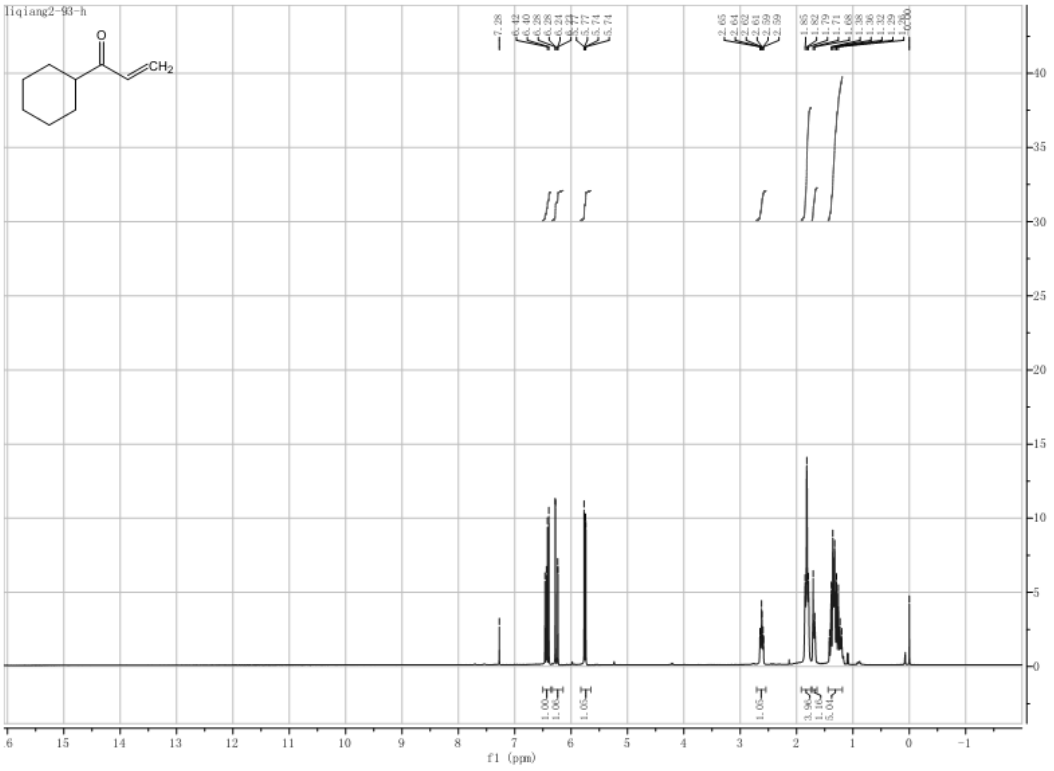
^{1}H NMR spectrum of compound of **5j**



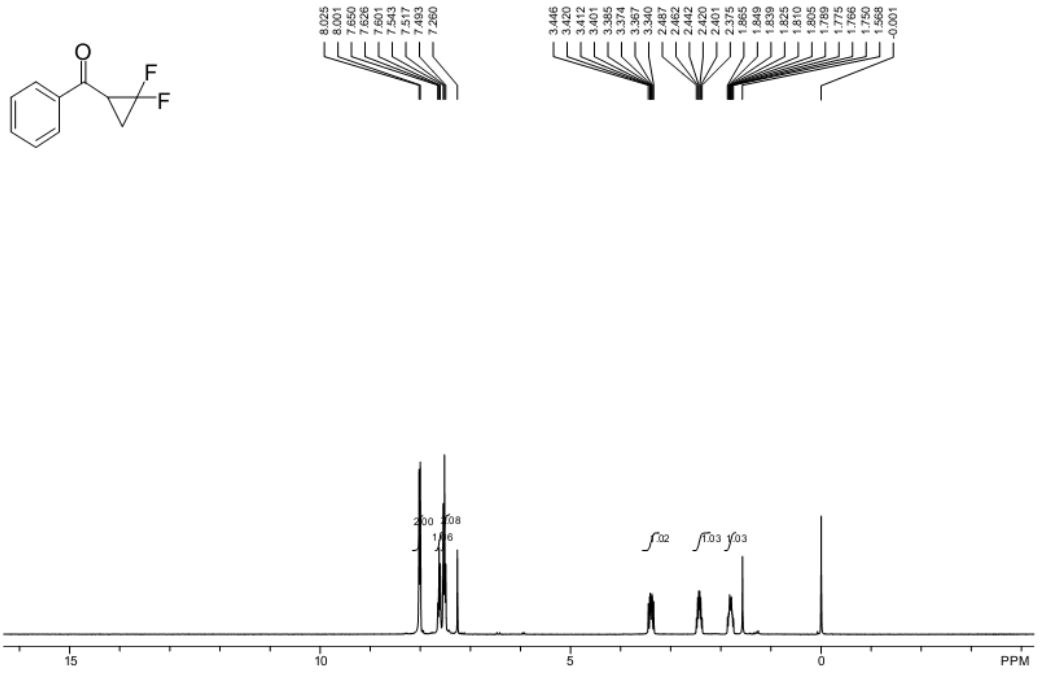
^{1}H NMR spectrum of compound of **5k**



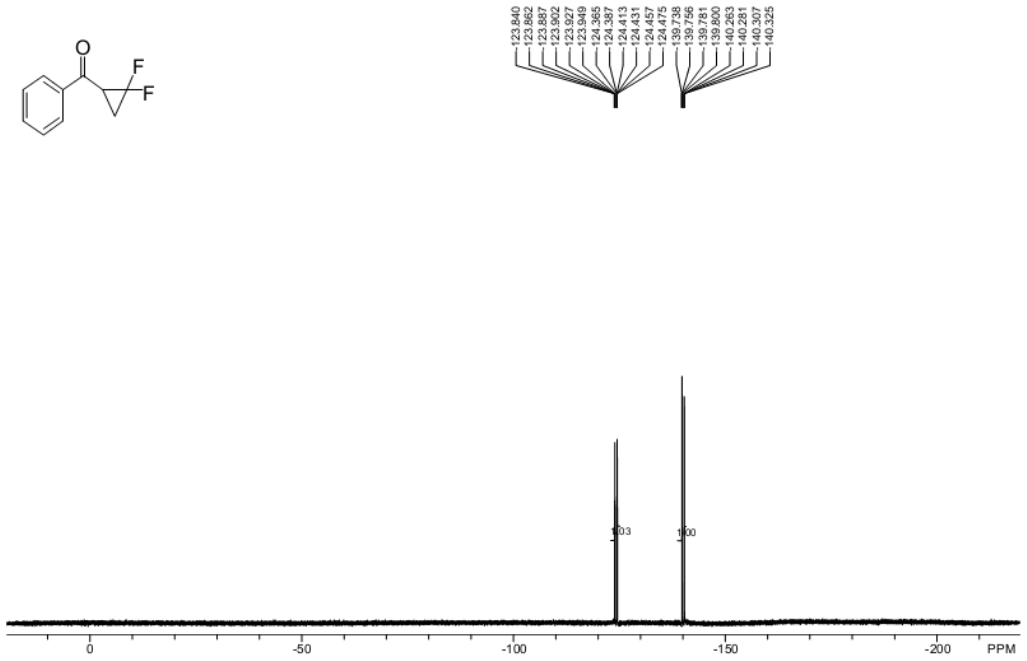
^{1}H NMR spectrum of compound of **5l**



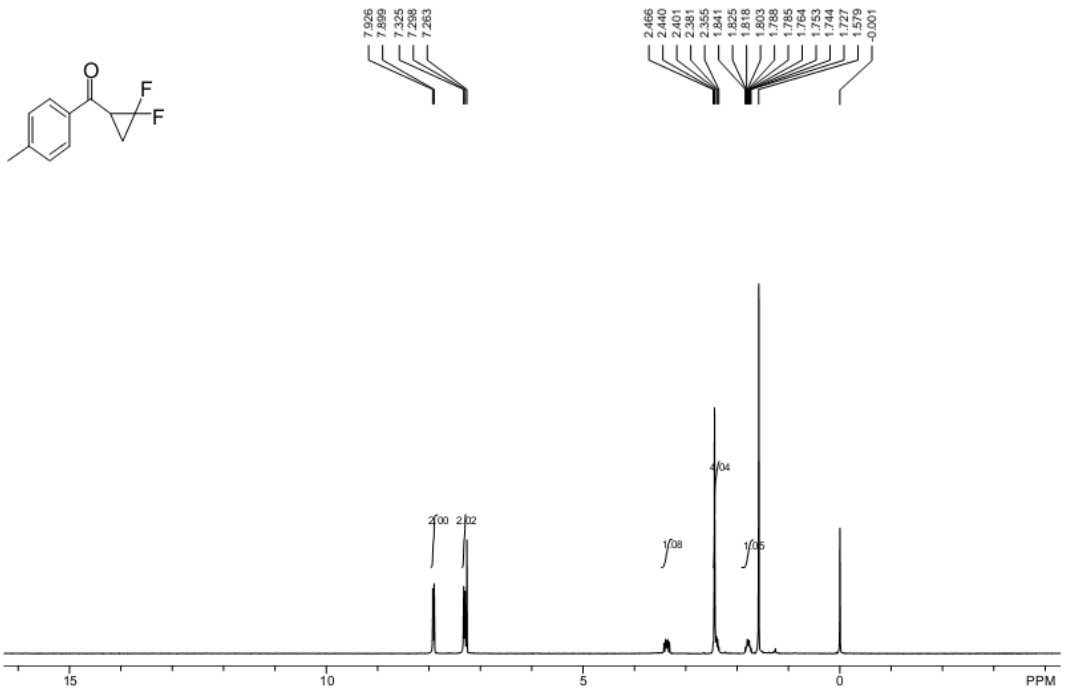
^{1}H NMR spectrum of compound of **1a**



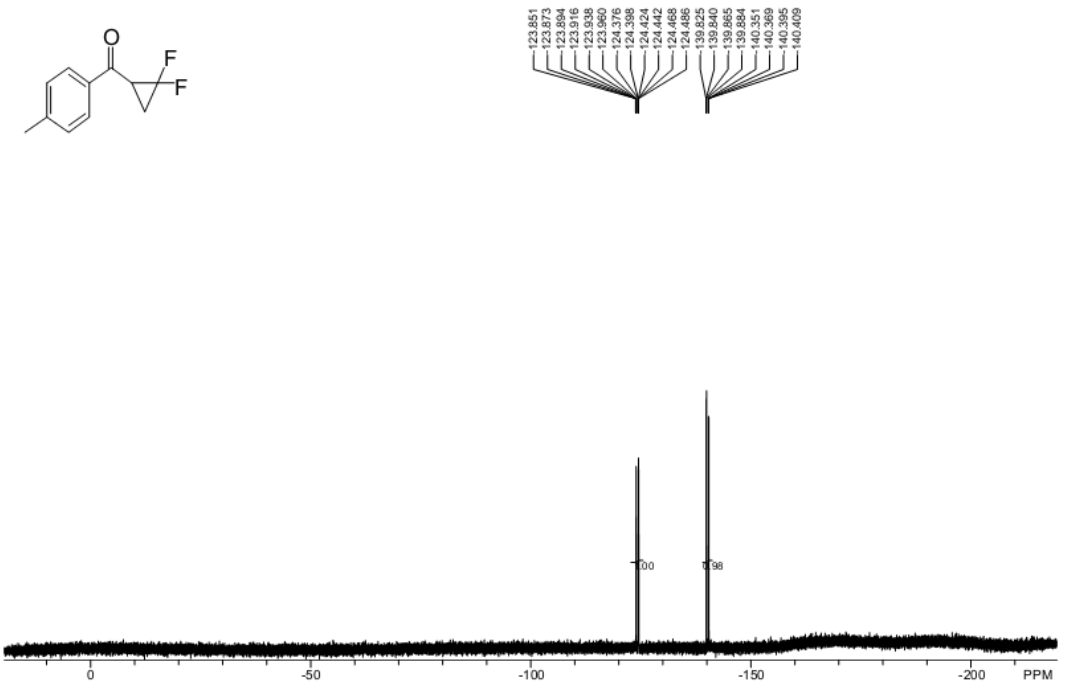
^{19}F NMR spectrum of compound of **1a**



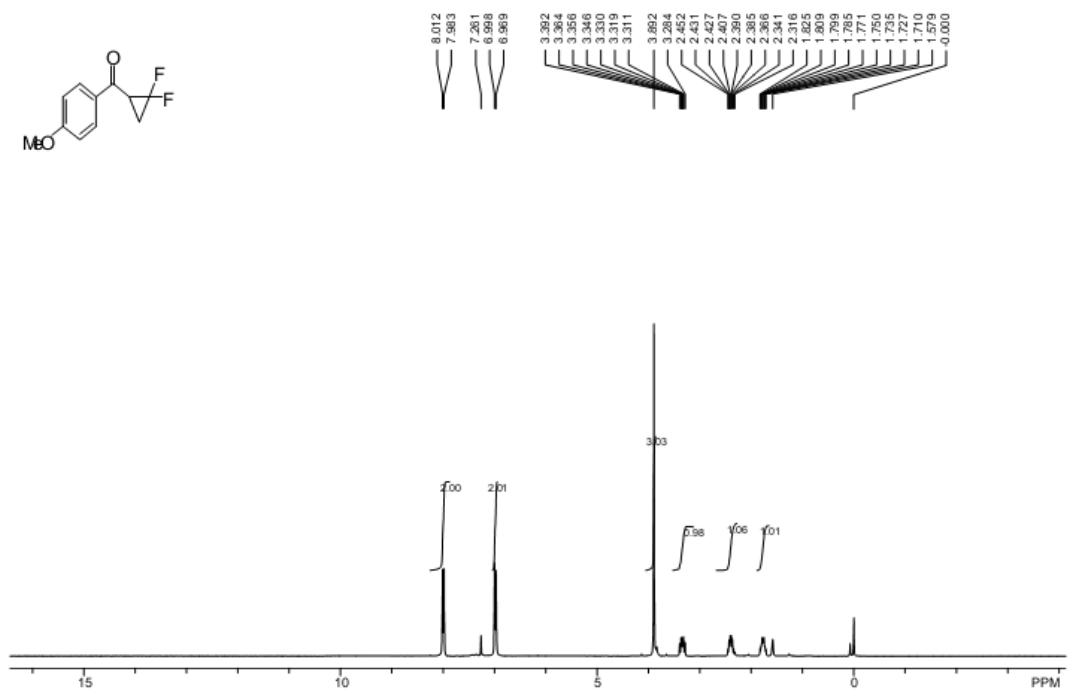
^{1}H NMR spectrum of compound of **1b**



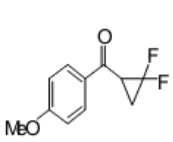
^{19}F NMR spectrum of compound **1b**

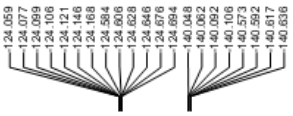


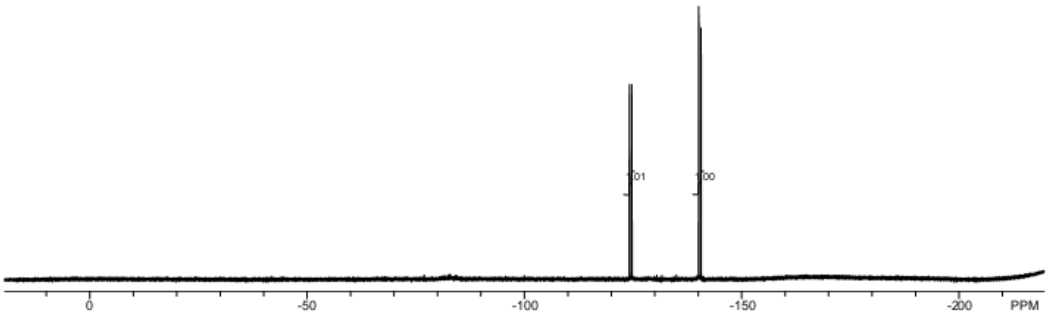
^{1}H NMR spectrum of compound of **1c**



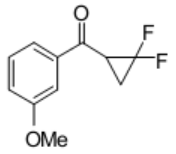
^{19}F NMR spectrum of compound of **1c**

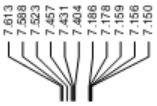


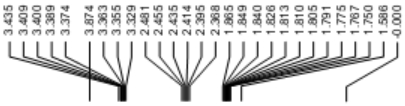


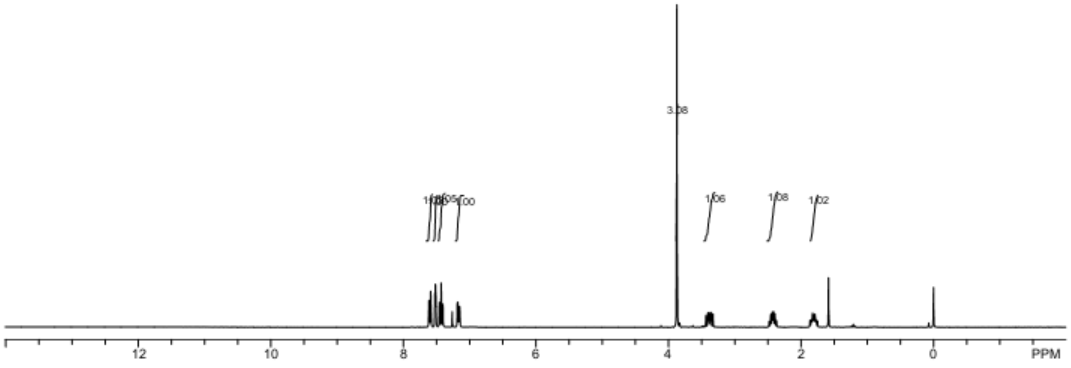


^{1}H NMR spectrum of compound of **1d**

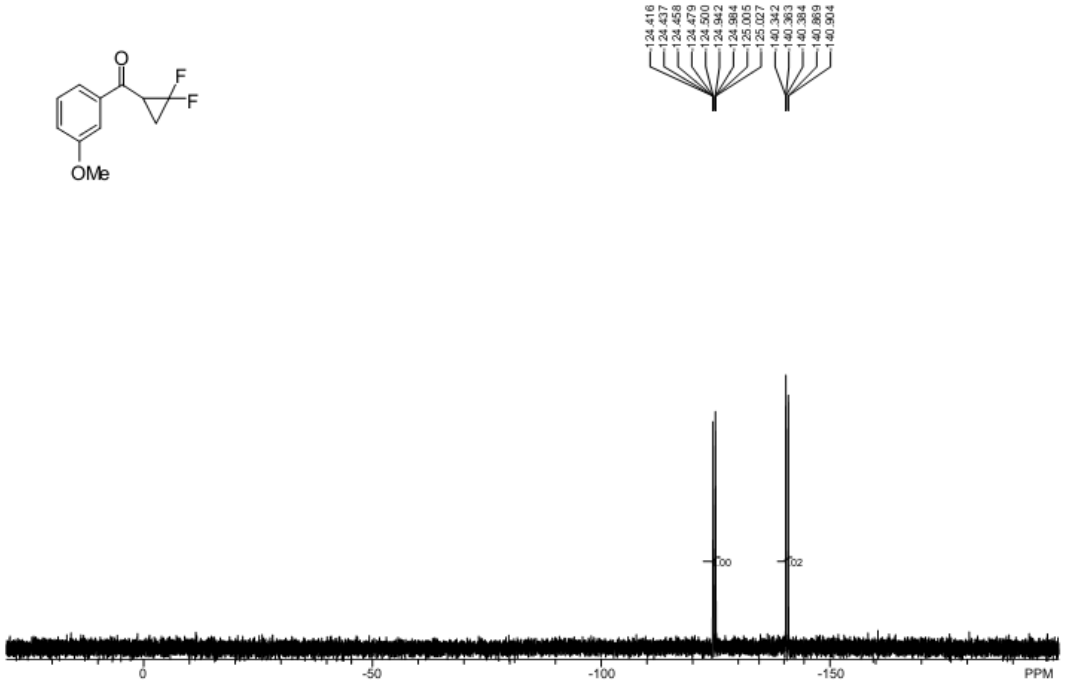




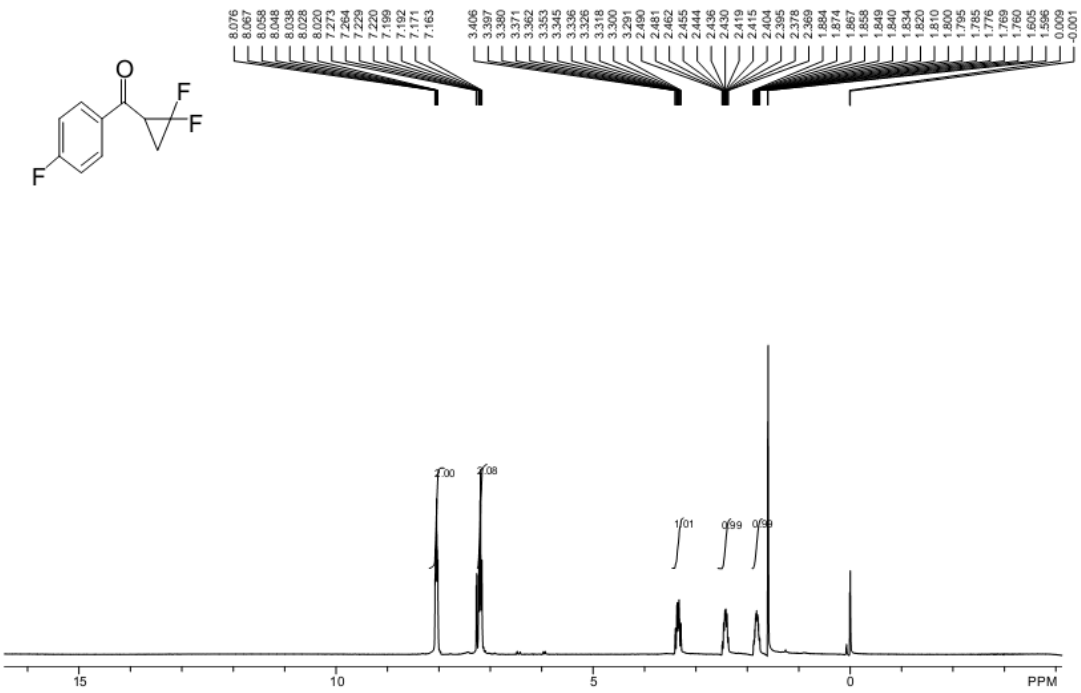




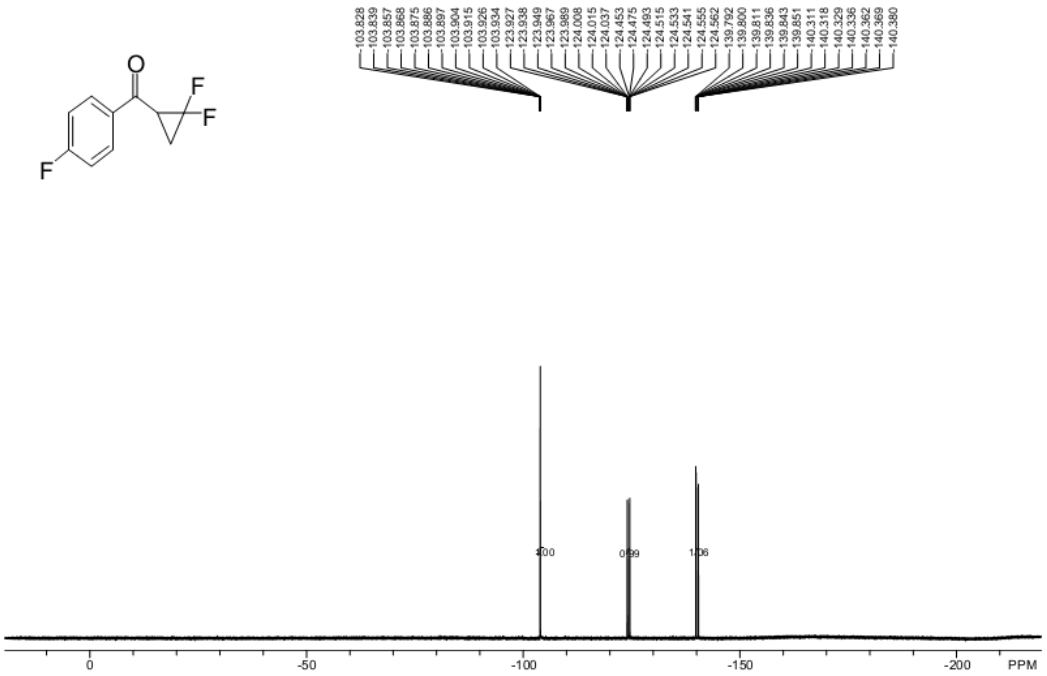
^{19}F NMR spectrum of compound of **1d**



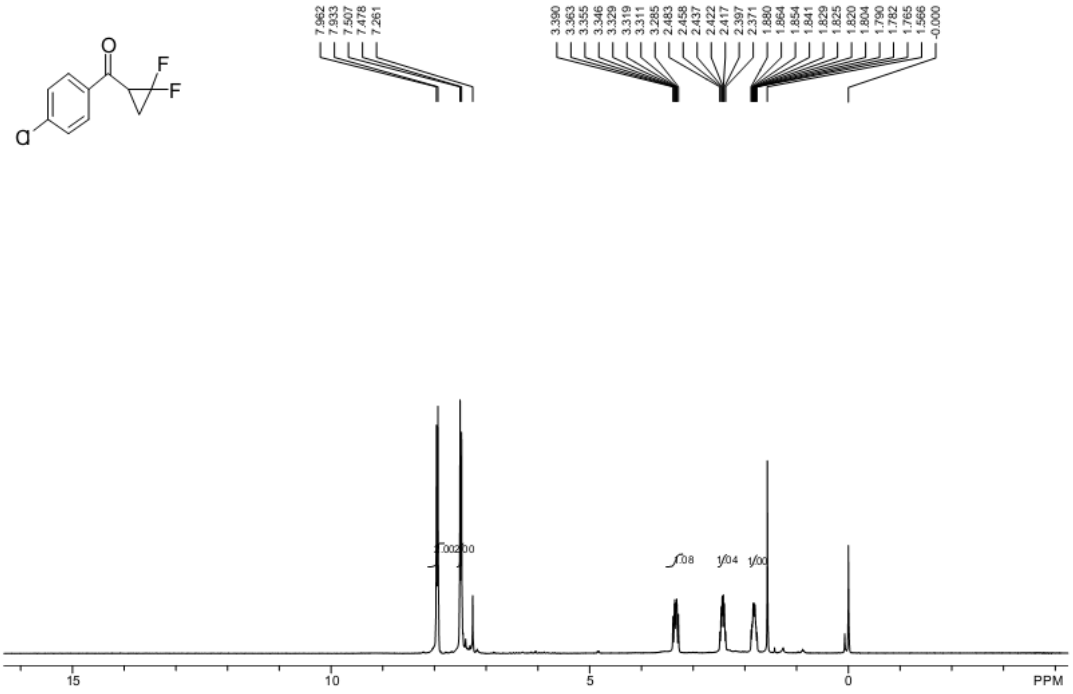
^{1}H NMR spectrum of compound of **1e**



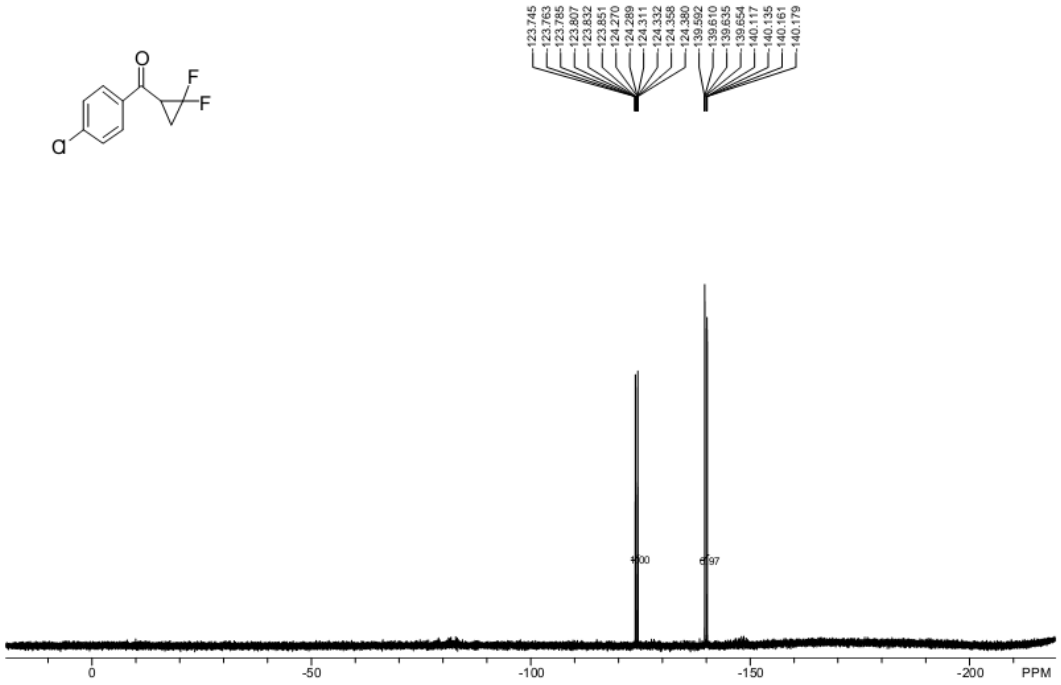
^{19}F NMR spectrum of compound of **1e**



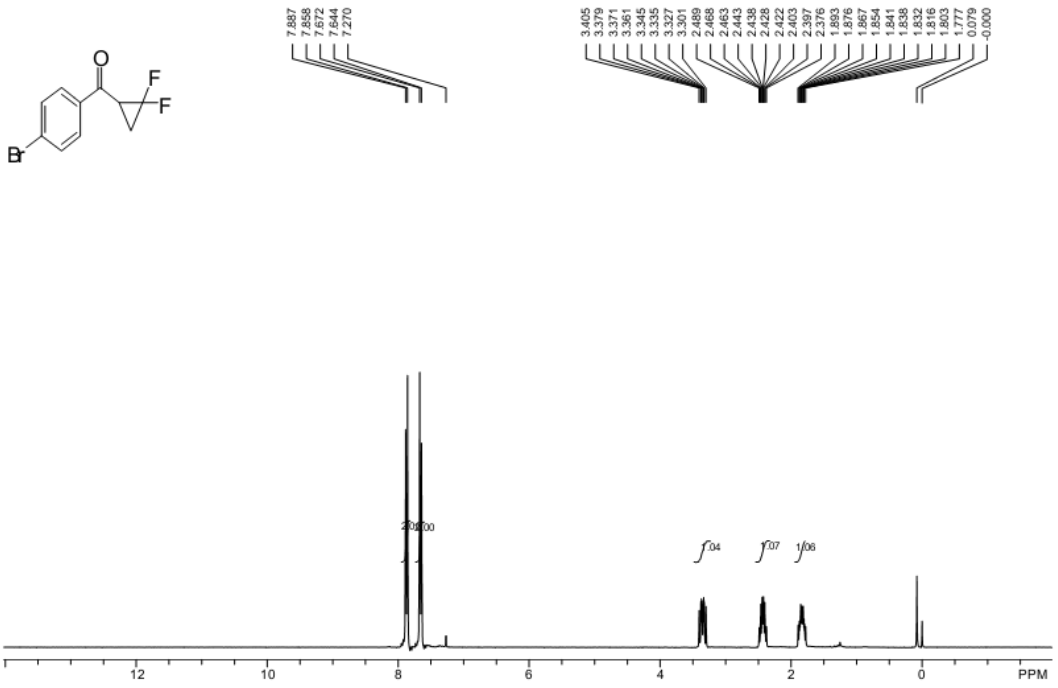
^{1}H NMR spectrum of compound **1f**



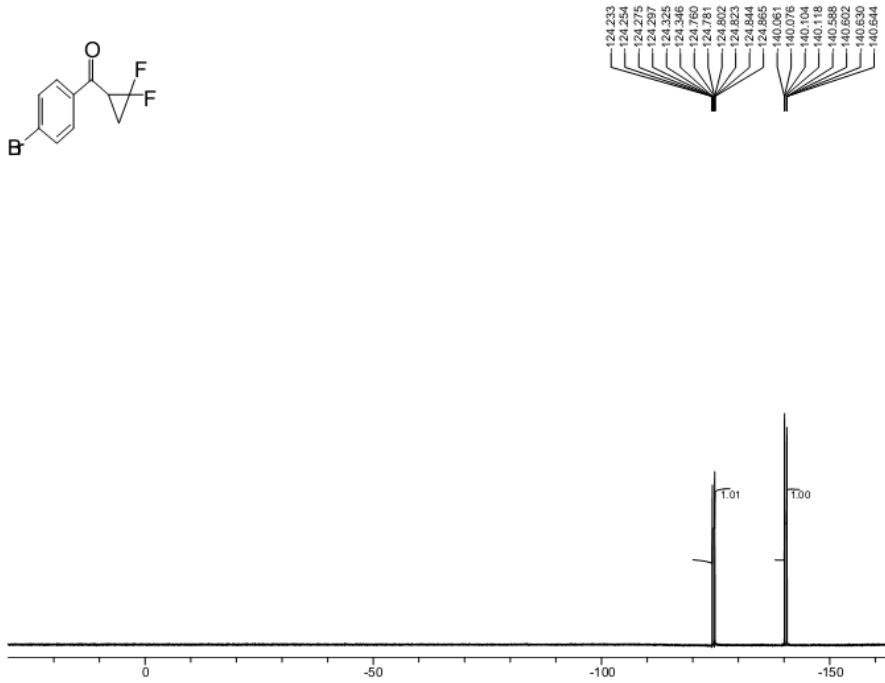
^{19}F NMR spectrum of compound of **1f**



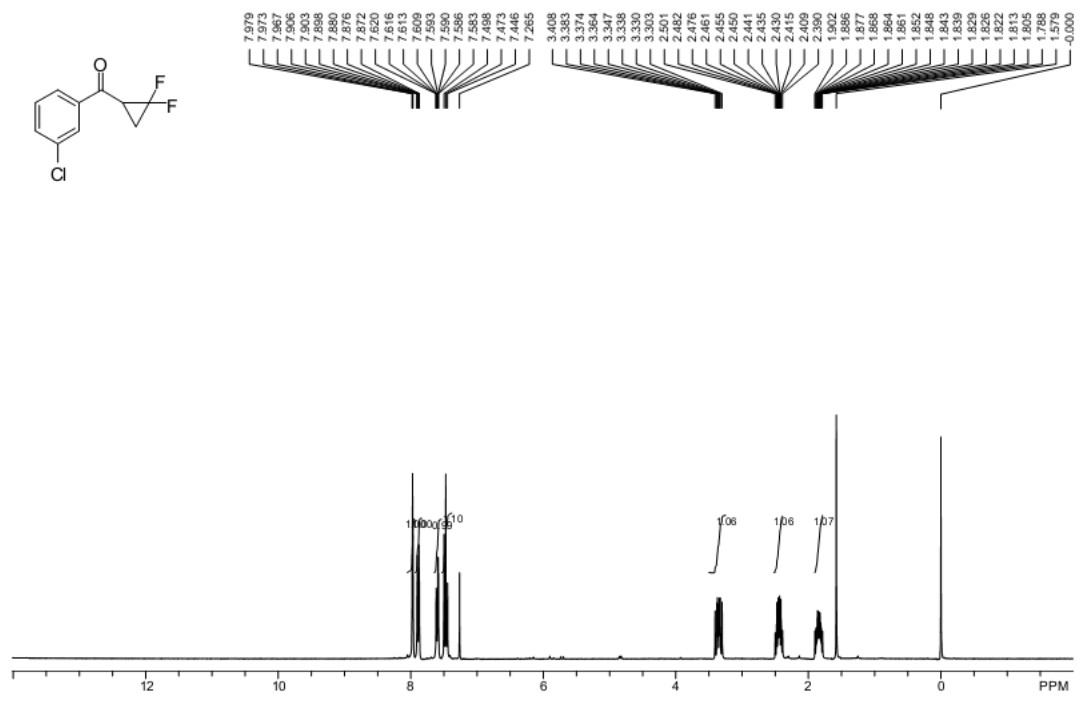
^{1}H NMR spectrum of compound of **1g**



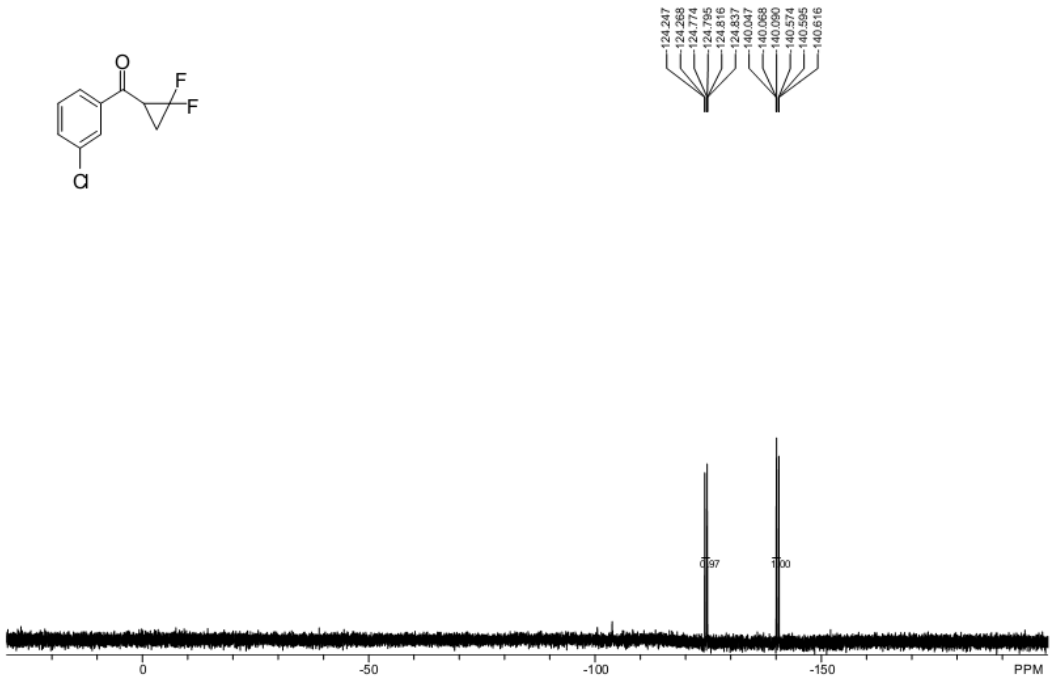
^{19}F NMR spectrum of compound of **1g**



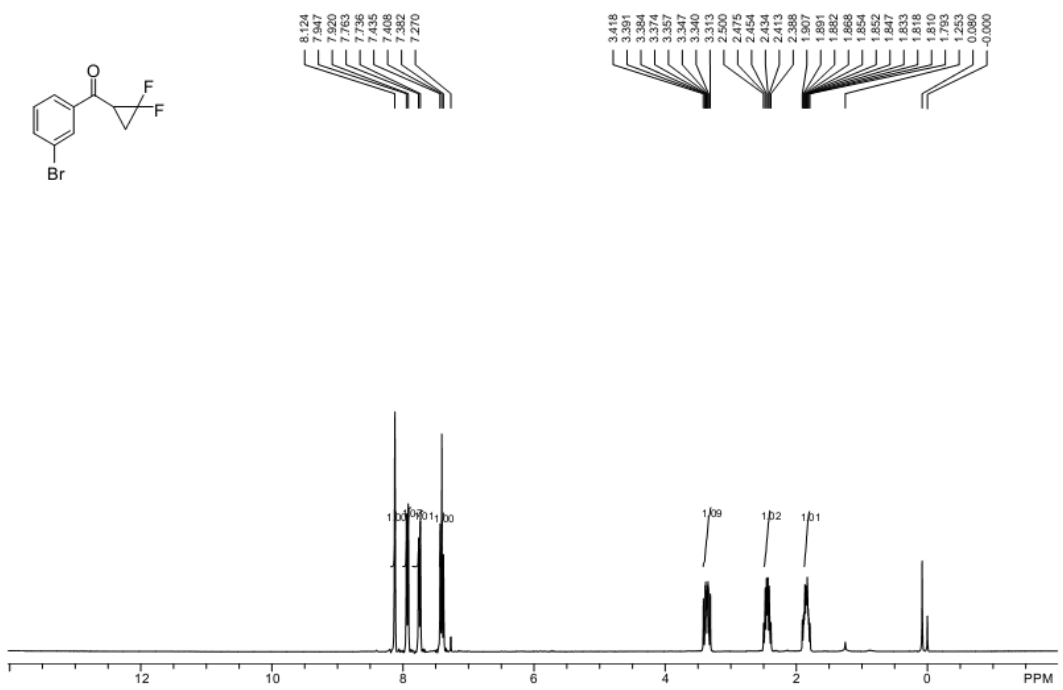
^{1}H NMR spectrum of compound of **1h**



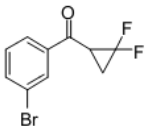
^{19}F NMR spectrum of compound of **1h**

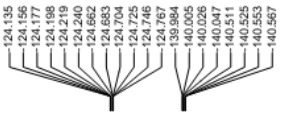


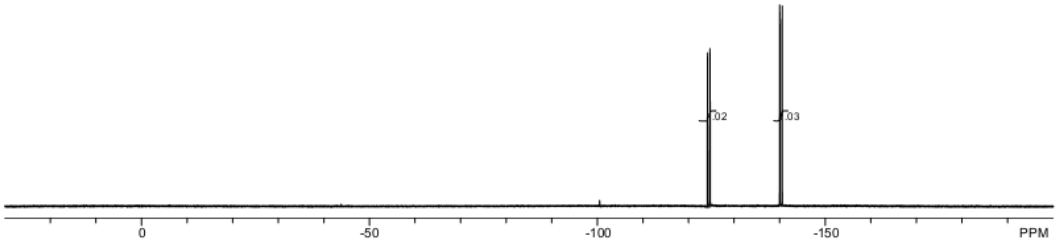
^{1}H NMR spectrum of compound of **1i**



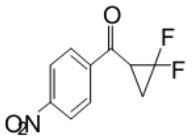
^{19}F NMR spectrum of compound of **1i**

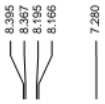


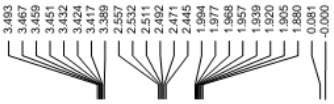


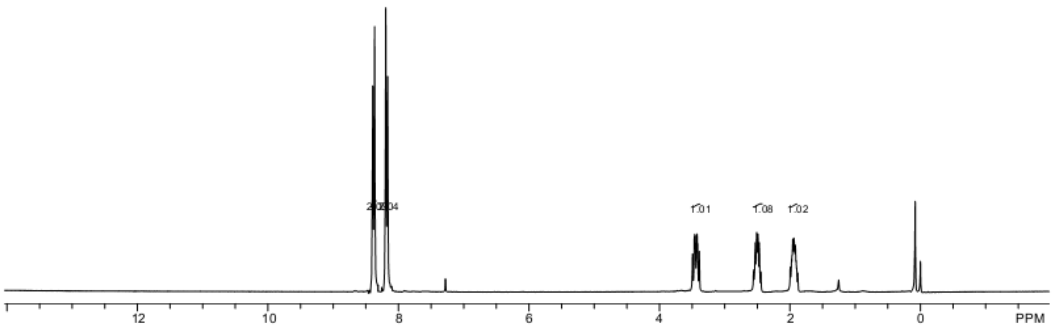


^{1}H NMR spectrum of compound **1j**

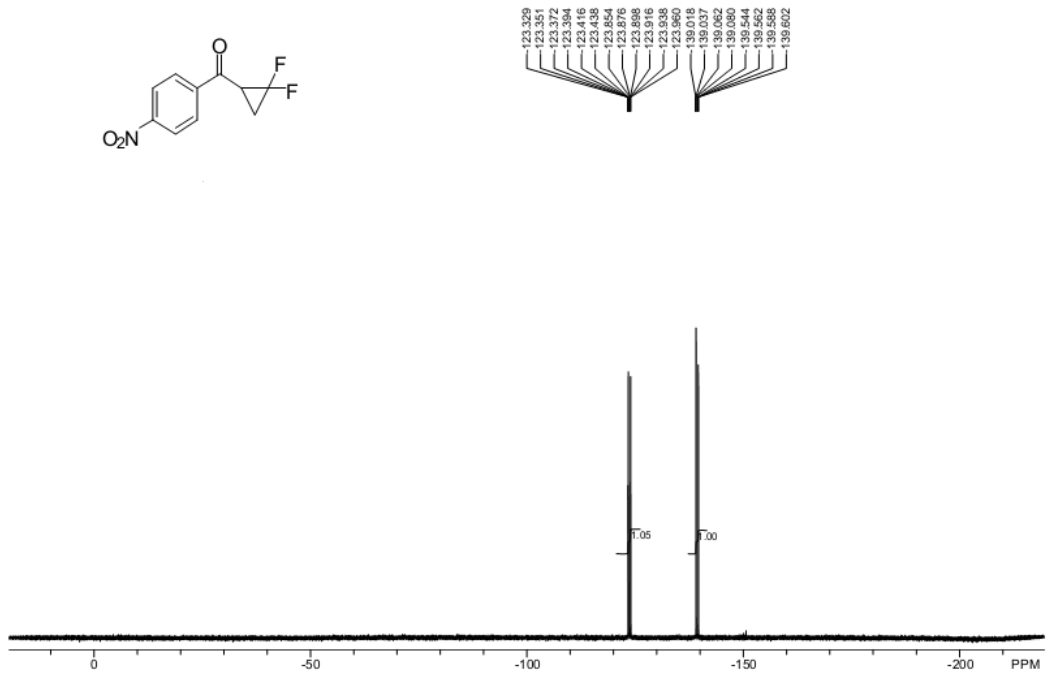




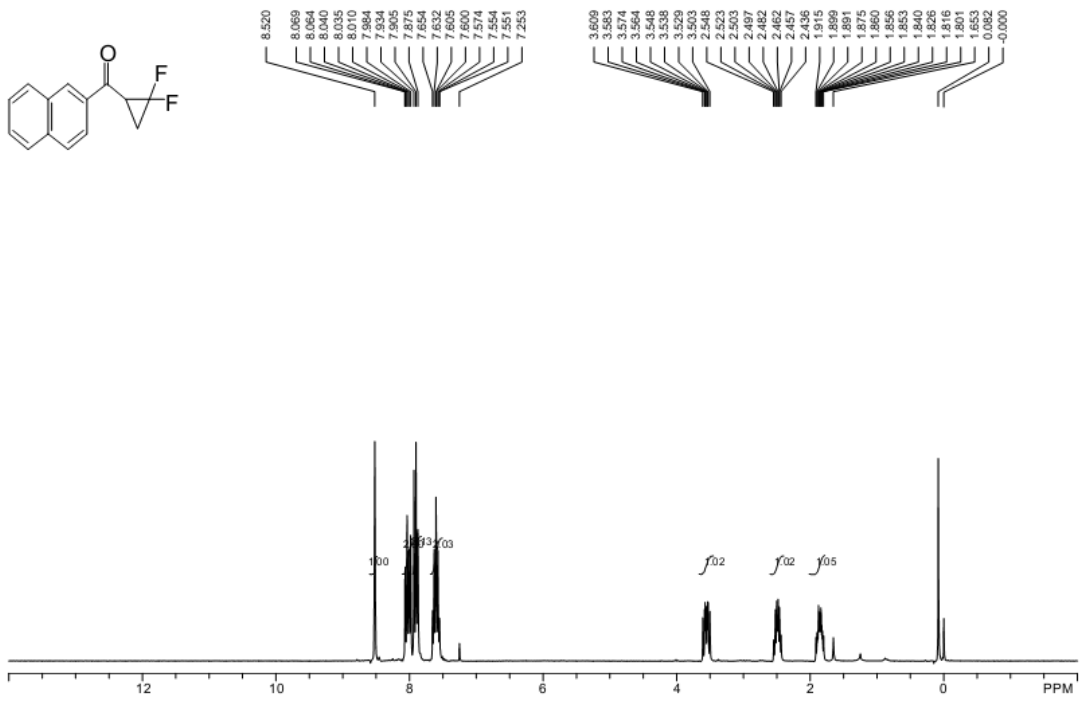




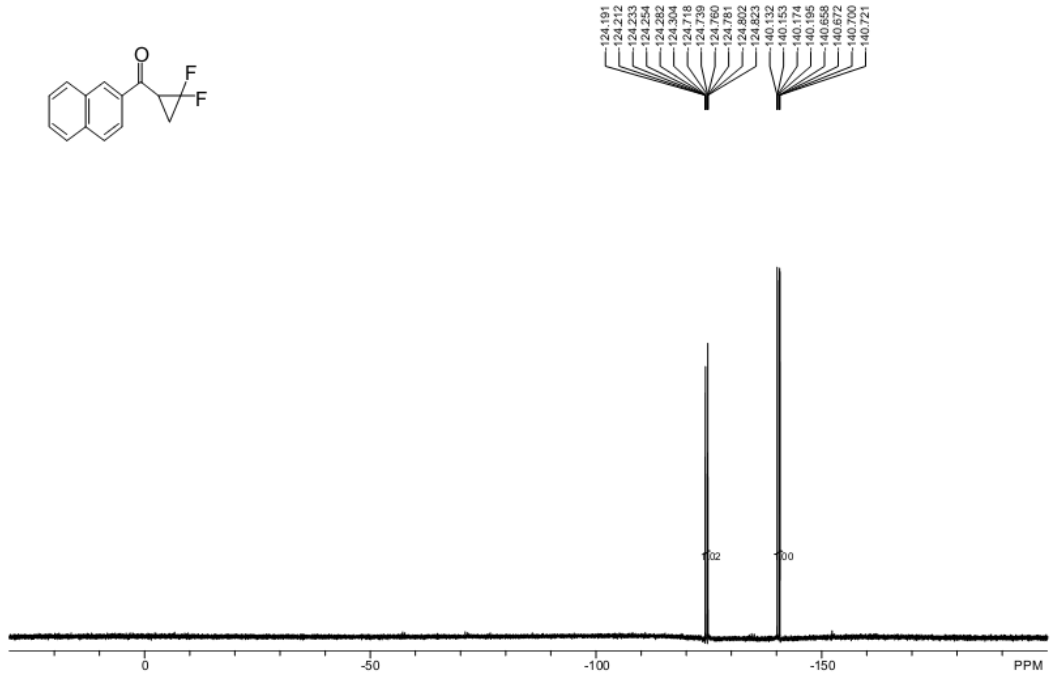
^{19}F NMR spectrum of compound of **1j**



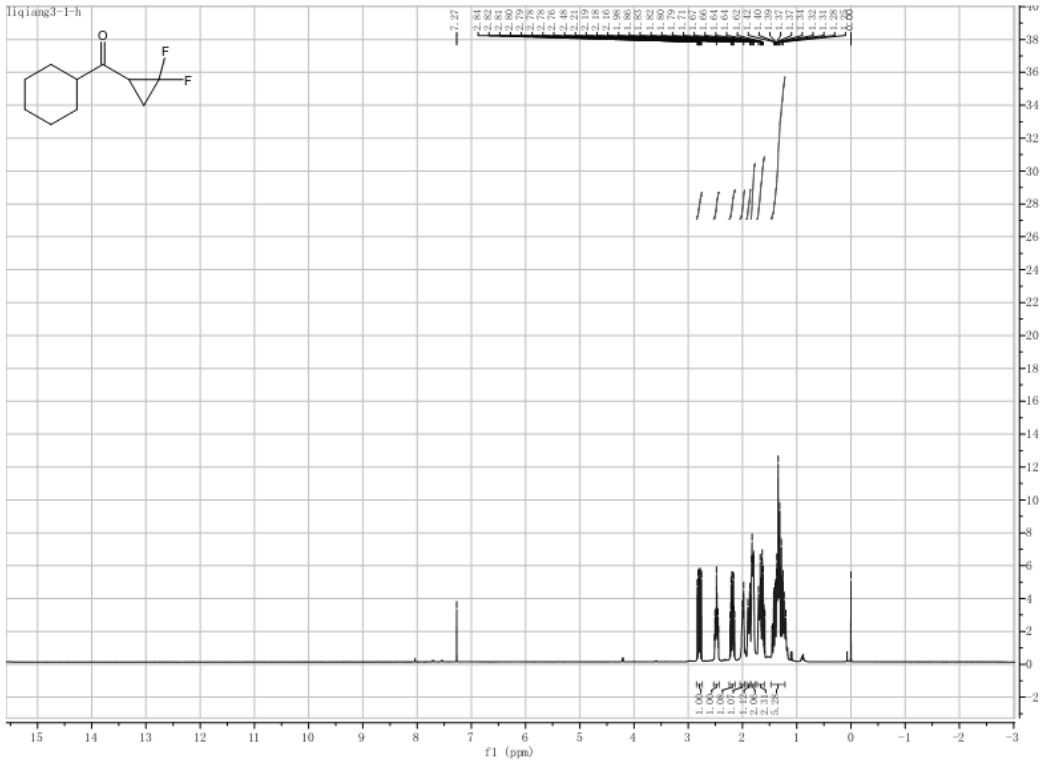
^{1}H NMR spectrum of compound of **1k**



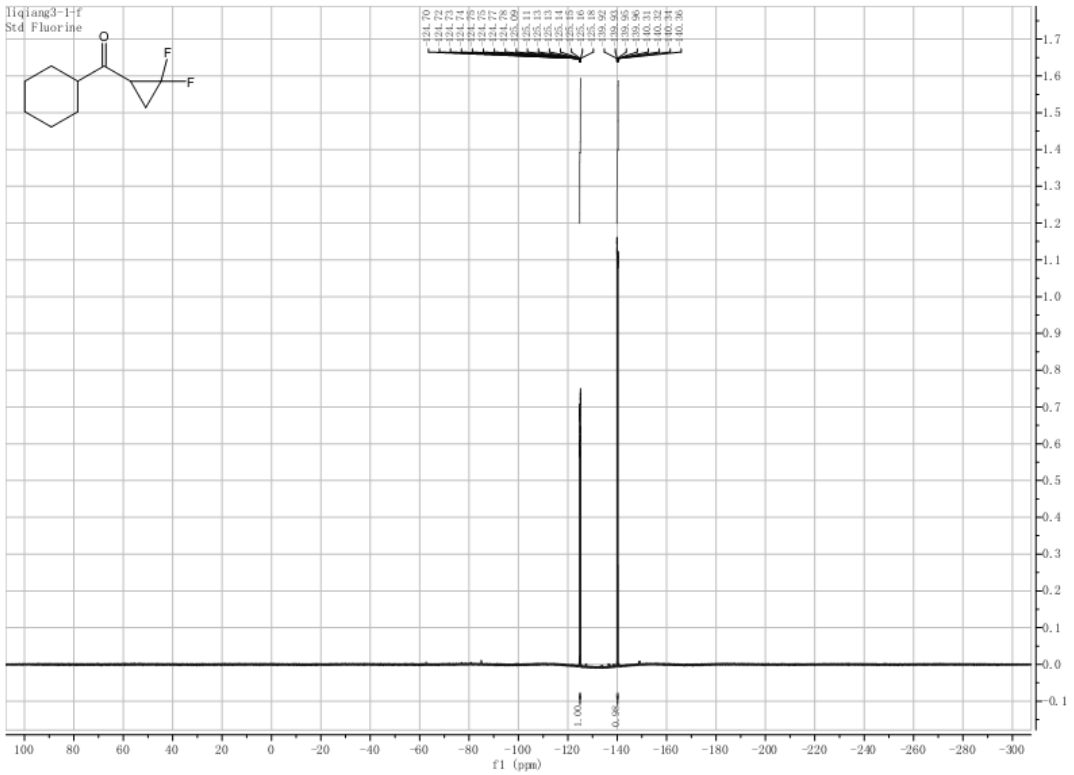
^{19}F NMR spectrum of compound of **1k**



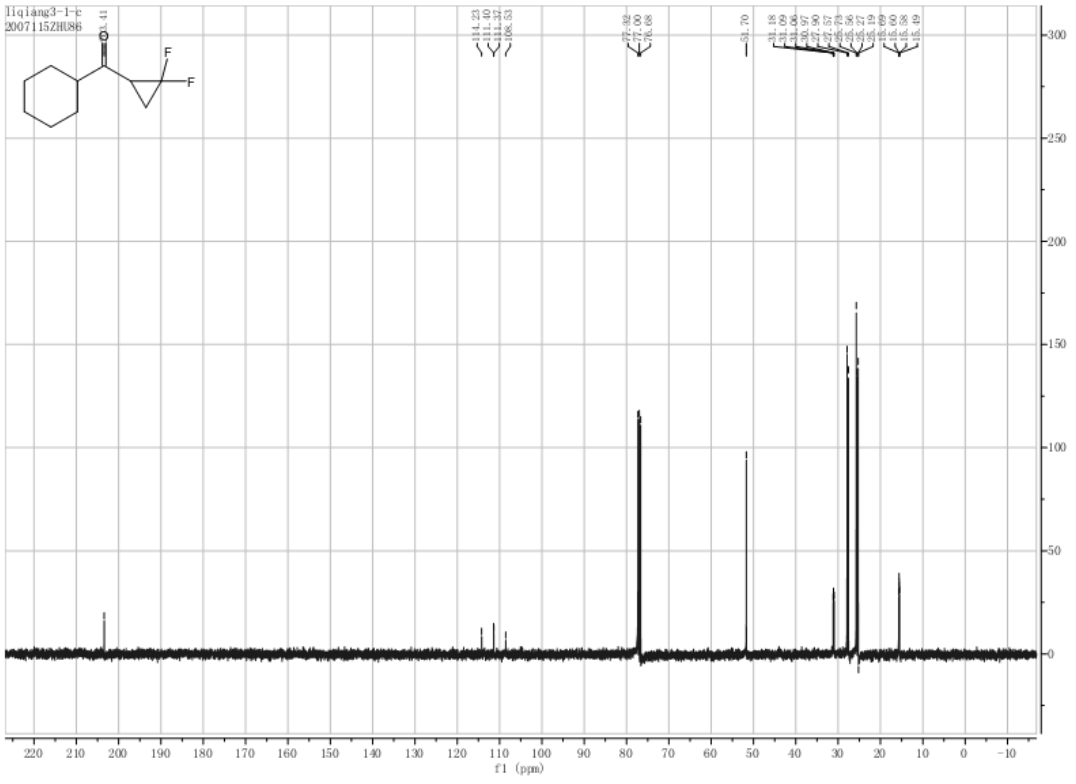
^{1}H NMR spectrum of compound of **1l**



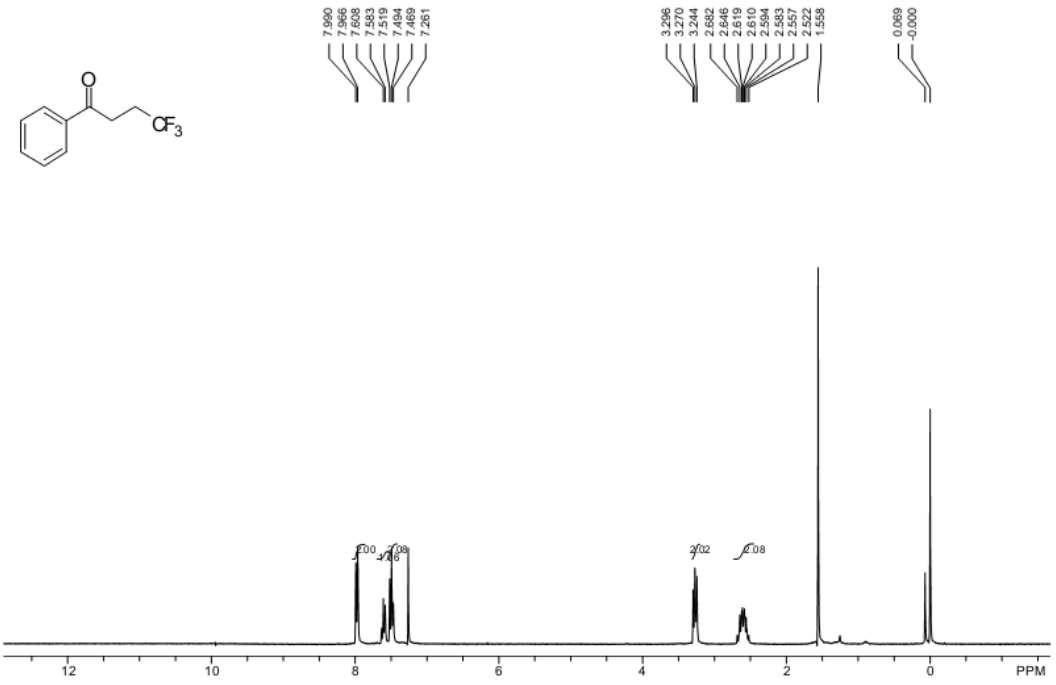
^{19}F NMR spectrum of compound of **1l**



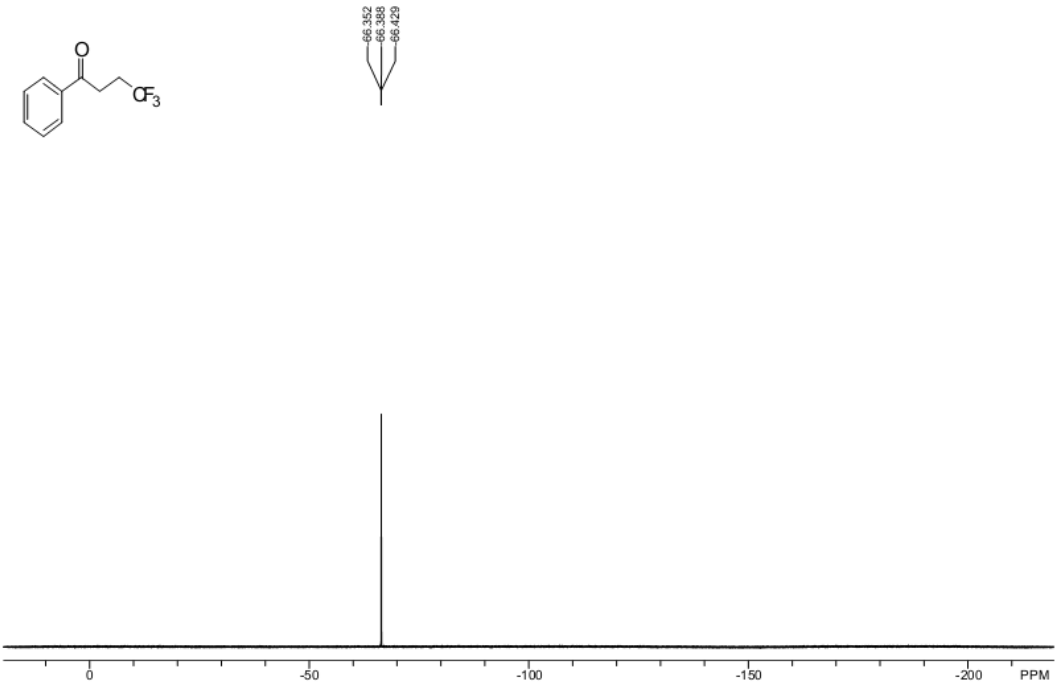
^{13}C NMR spectrum of compound of **1l**



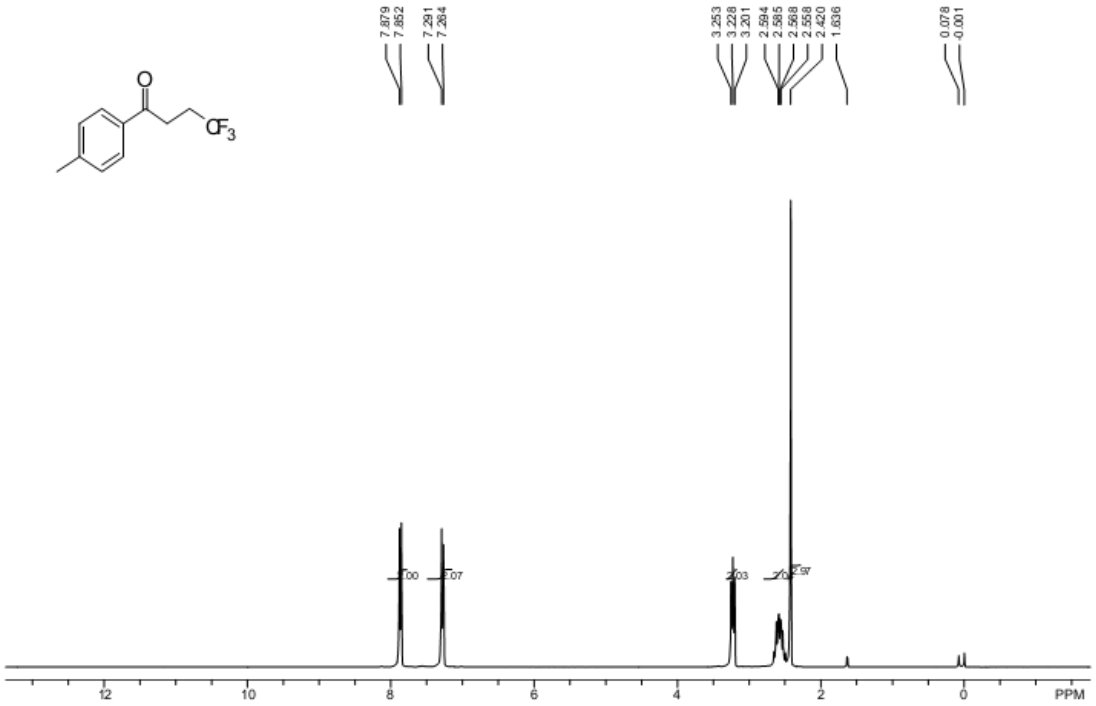
^{1}H NMR spectrum of compound of **2a**



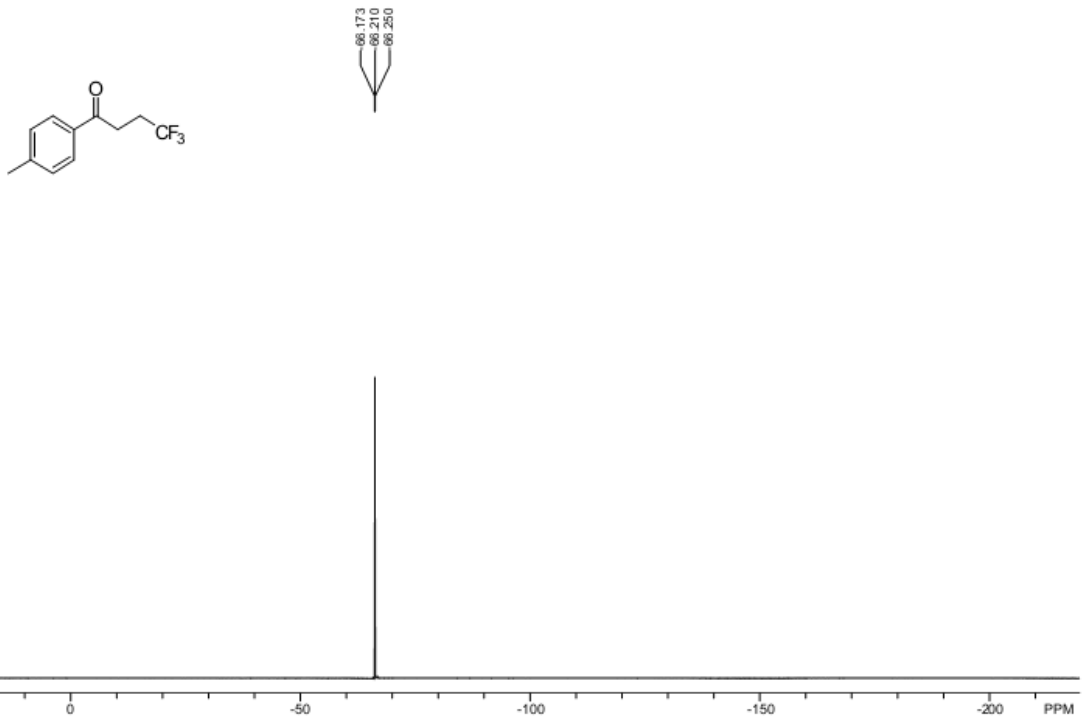
^{19}F NMR spectrum of compound of **2a**



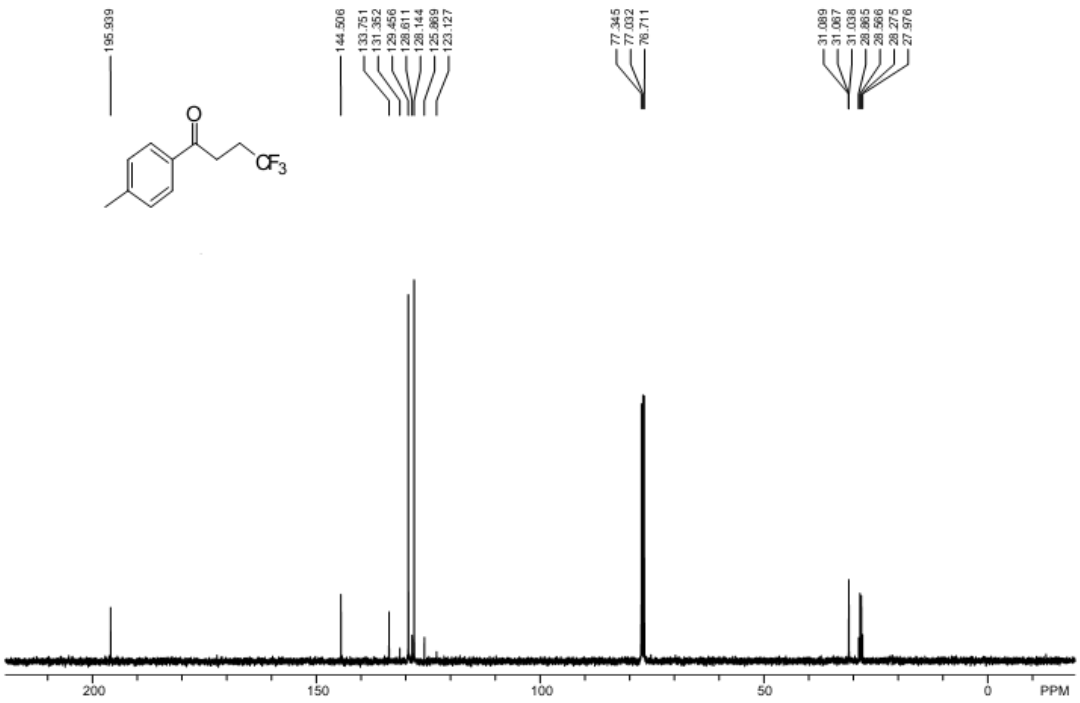
^{1}H NMR spectrum of compound of **2b**



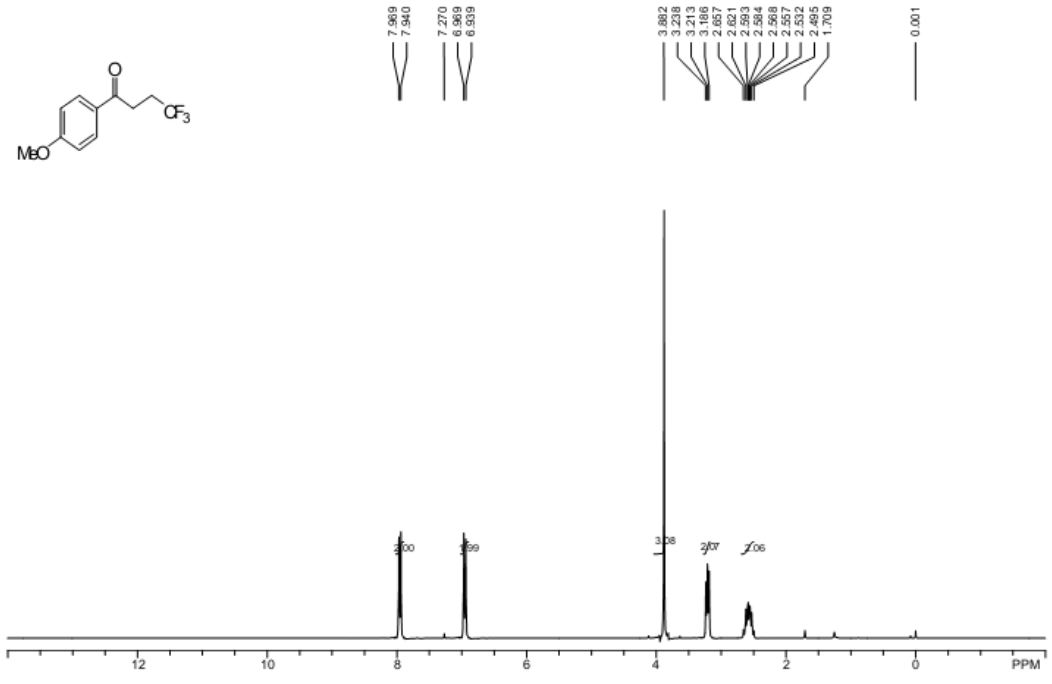
^{19}F NMR spectrum of compound of **2b**



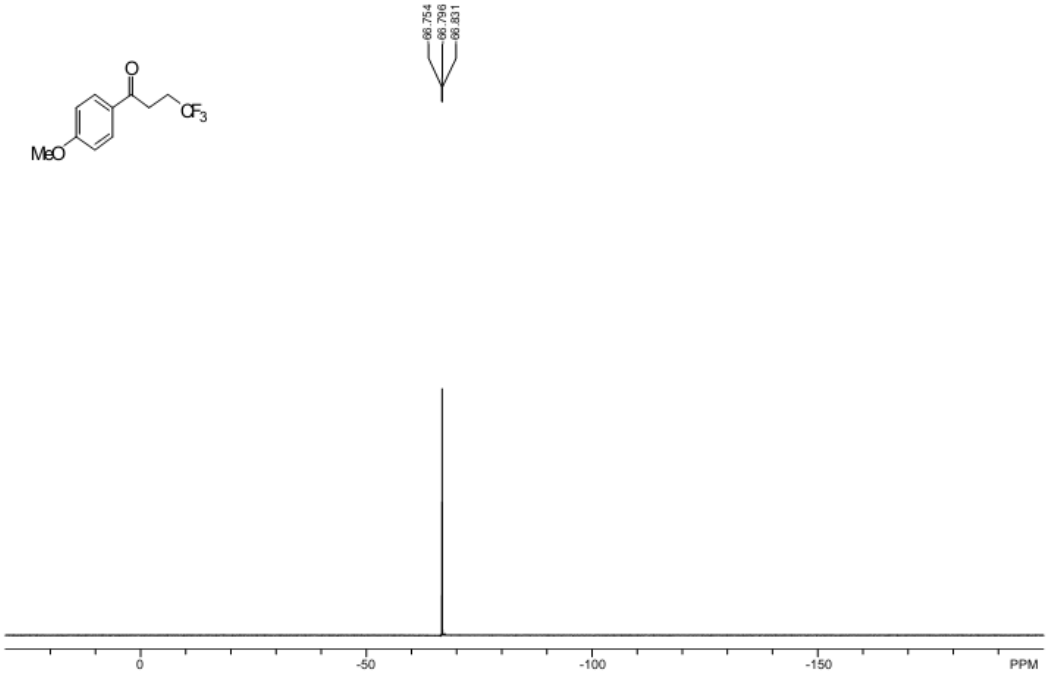
^{13}C NMR spectrum of compound of **2b**



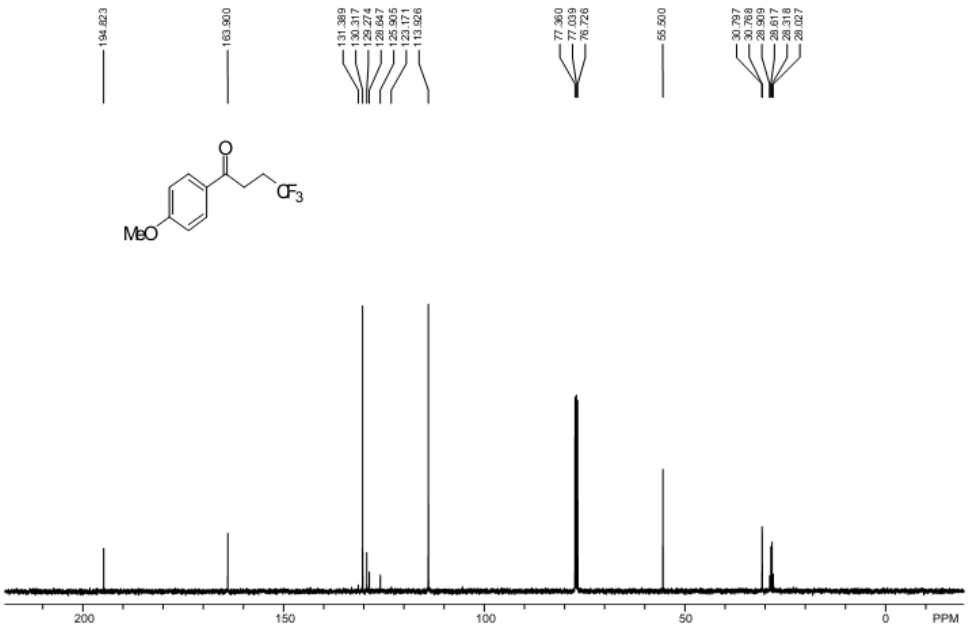
^{1}H NMR spectrum of compound of **2c**



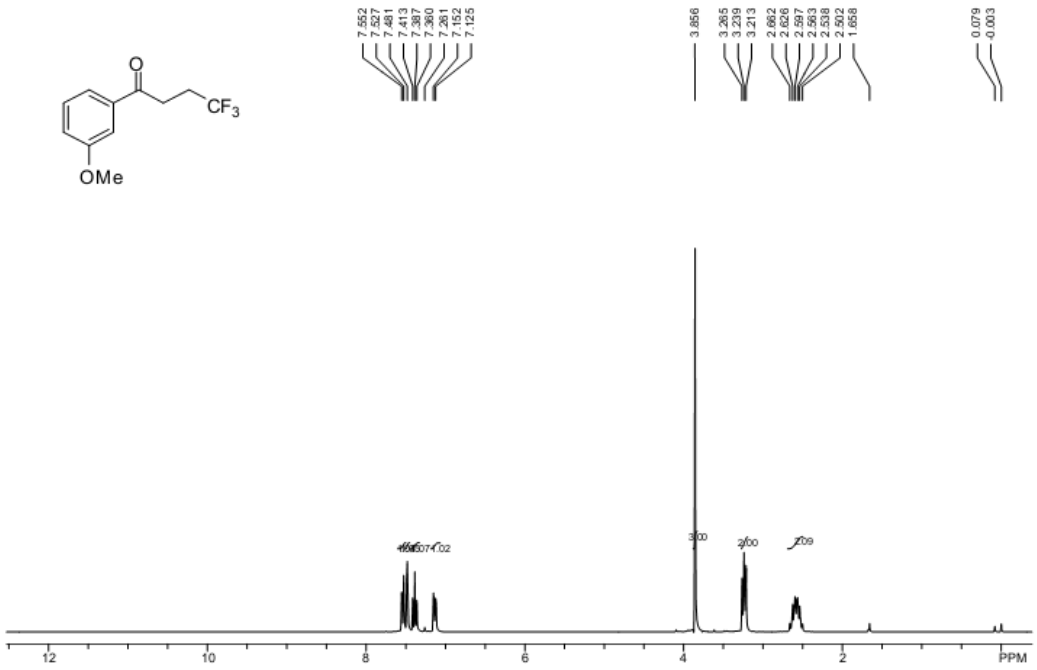
^{19}F NMR spectrum of compound of **2c**



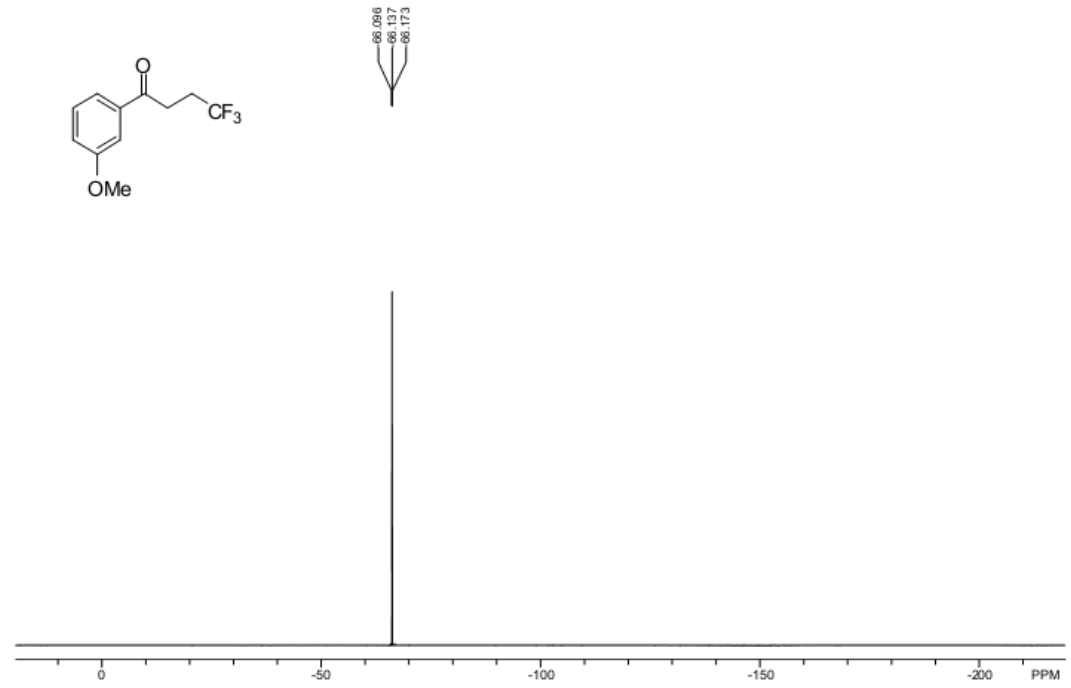
^{13}C NMR spectrum of compound of **2c**



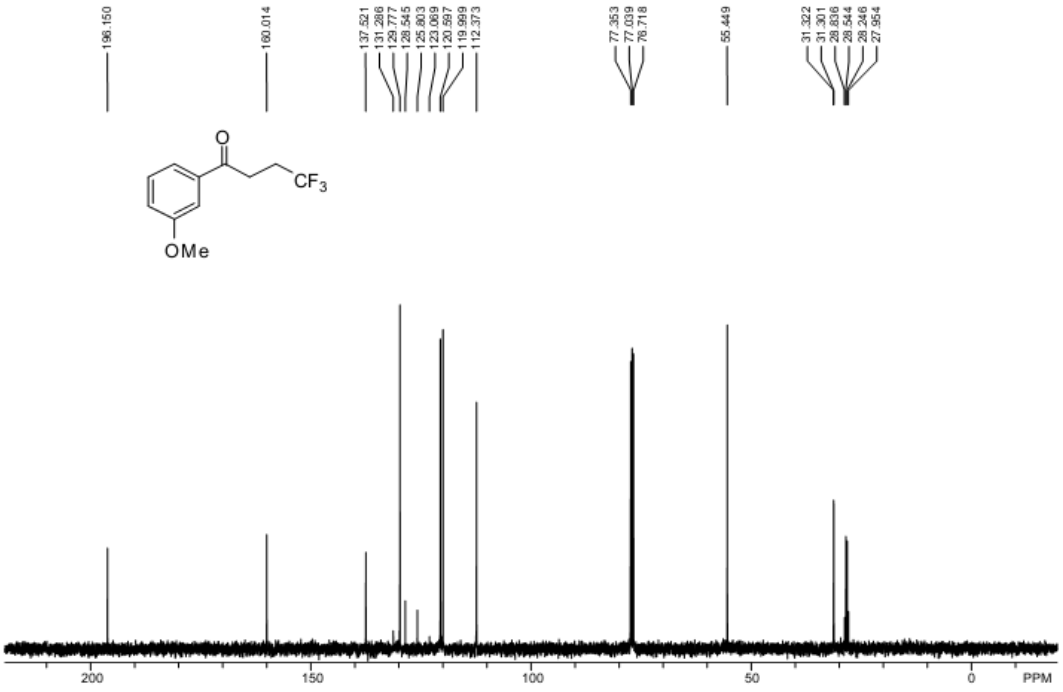
^{1}H NMR spectrum of compound of **2d**



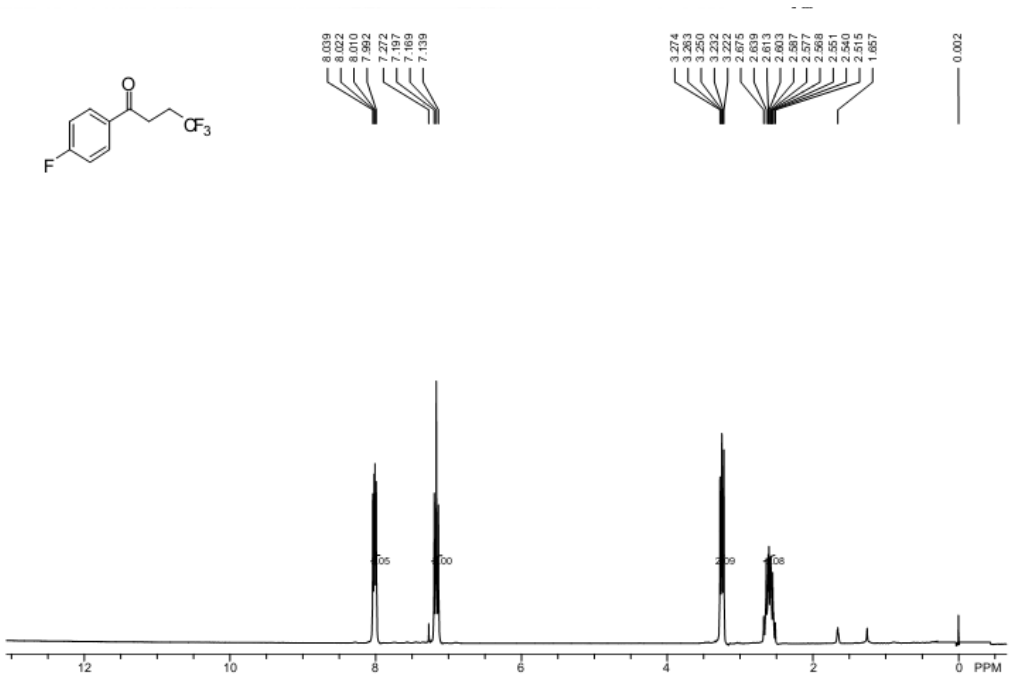
^{19}F NMR spectrum of compound of **2d**



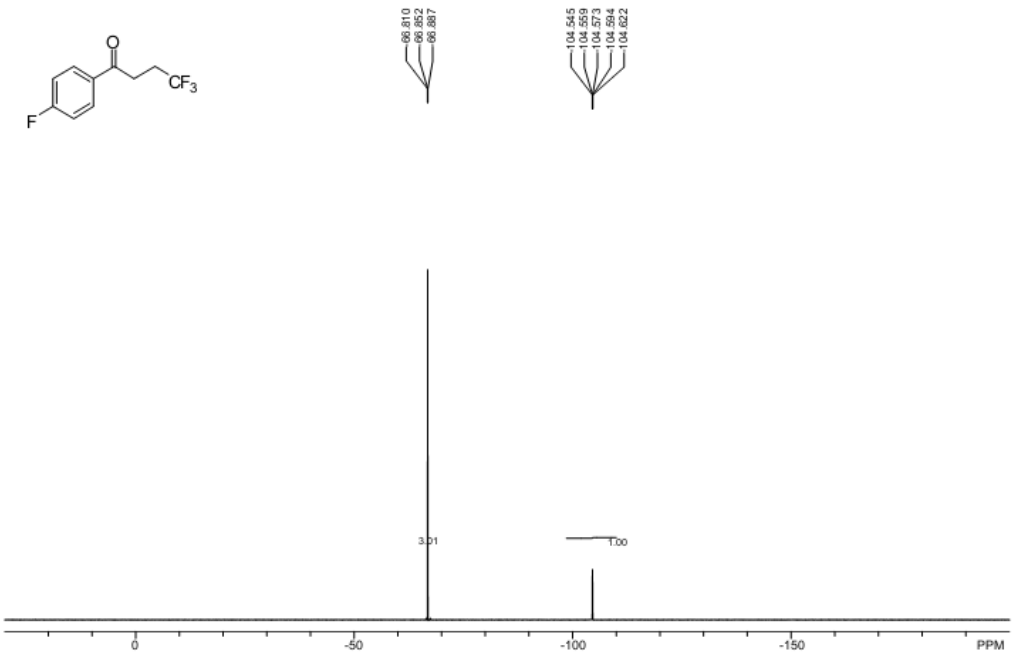
^{13}C NMR spectrum of compound of **2d**



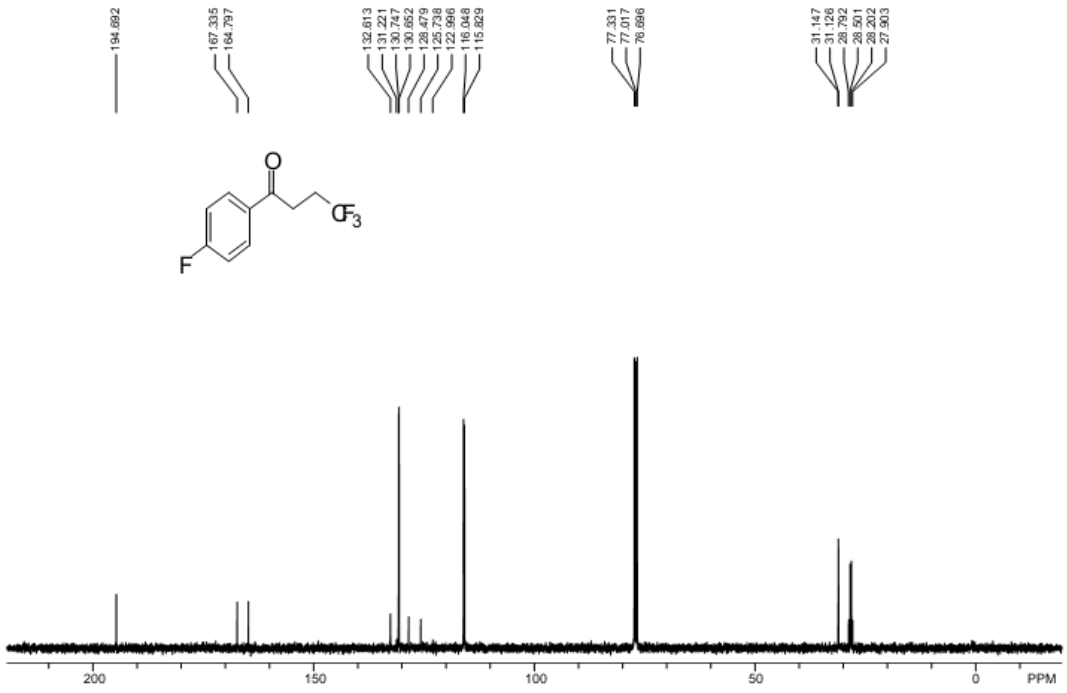
^{1}H NMR spectrum of compound of **2e**



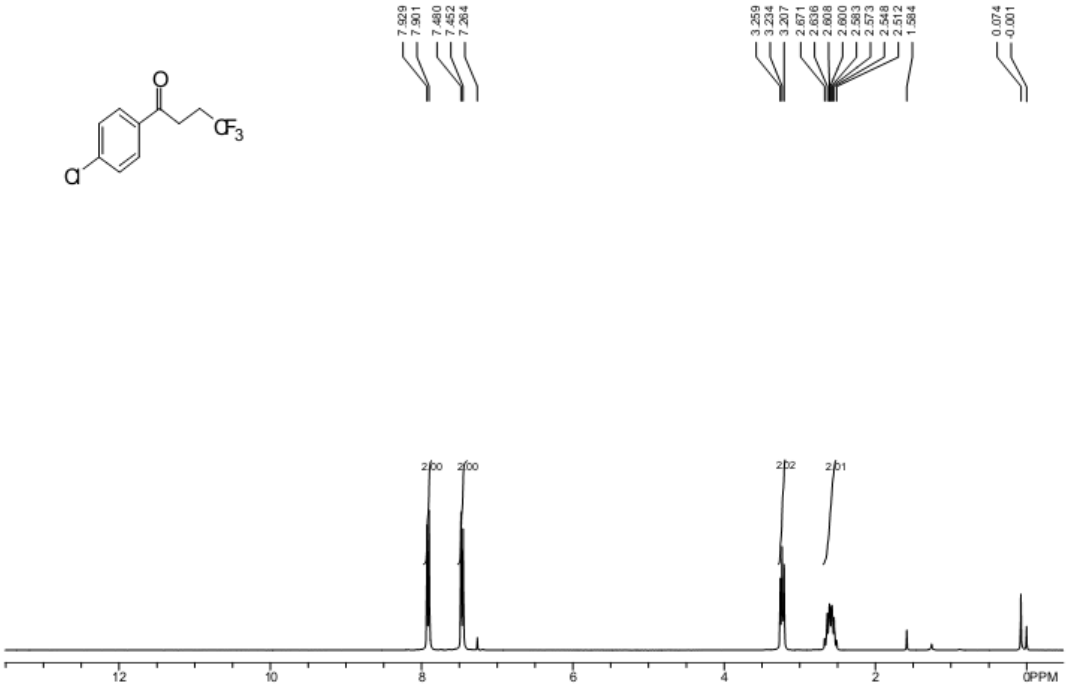
^{19}F NMR spectrum of compound of **2e**



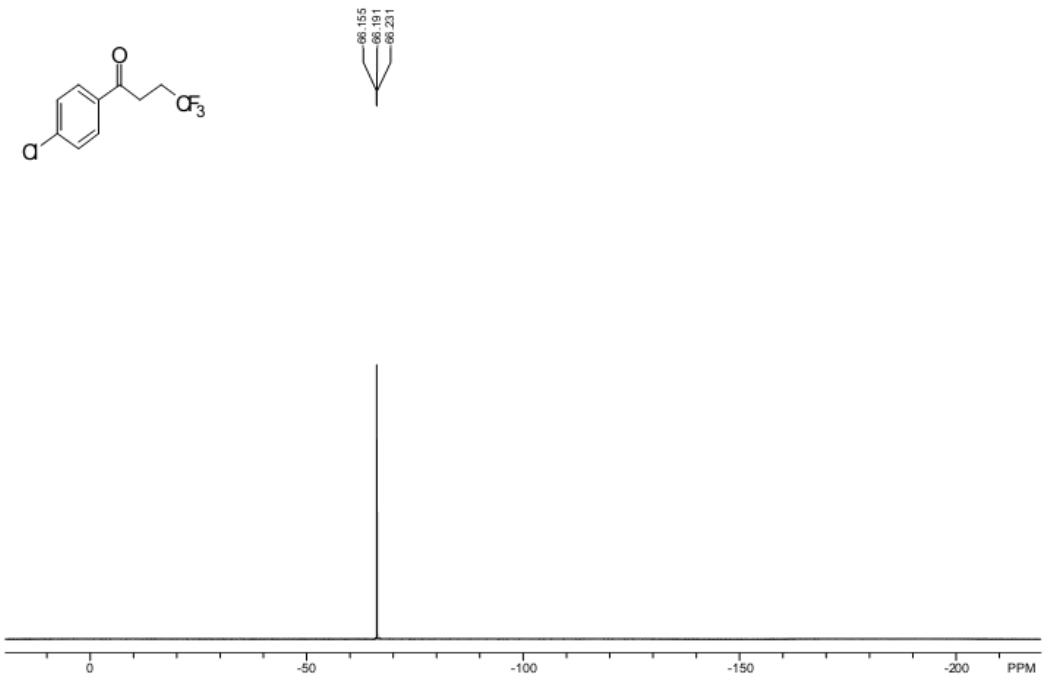
^{13}C NMR spectrum of compound of **2e**



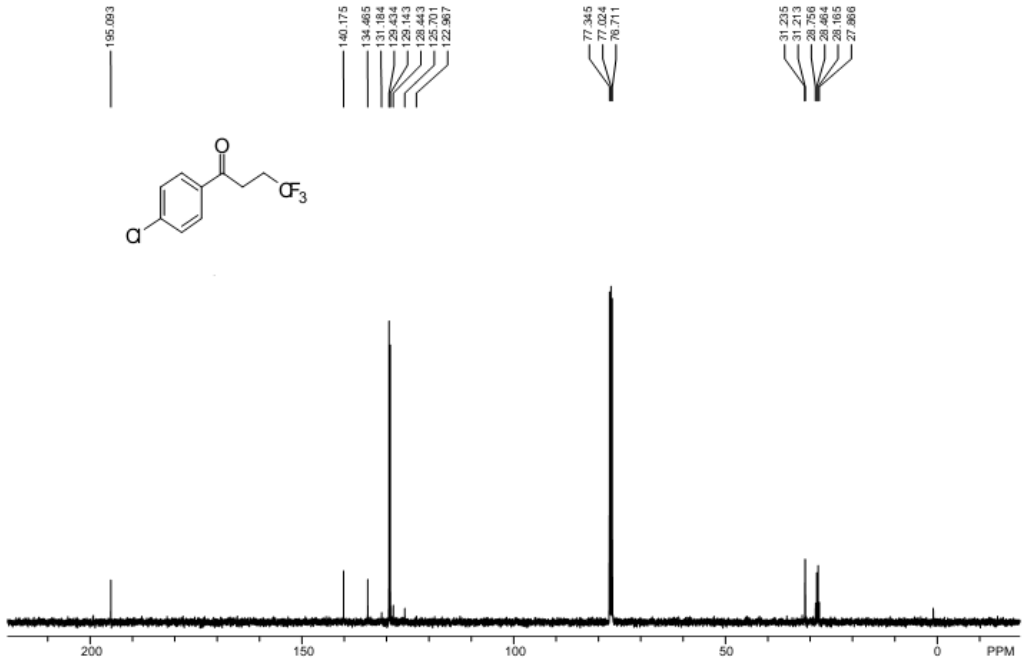
^{1}H NMR spectrum of compound of **2f**



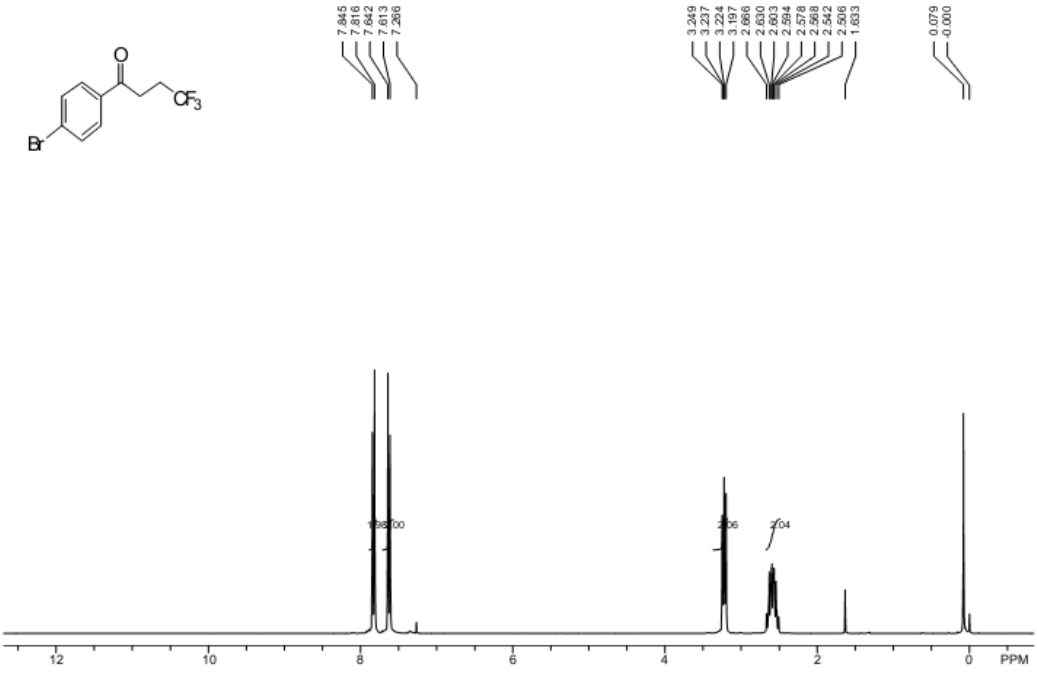
^{19}F NMR spectrum of compound of **2f**



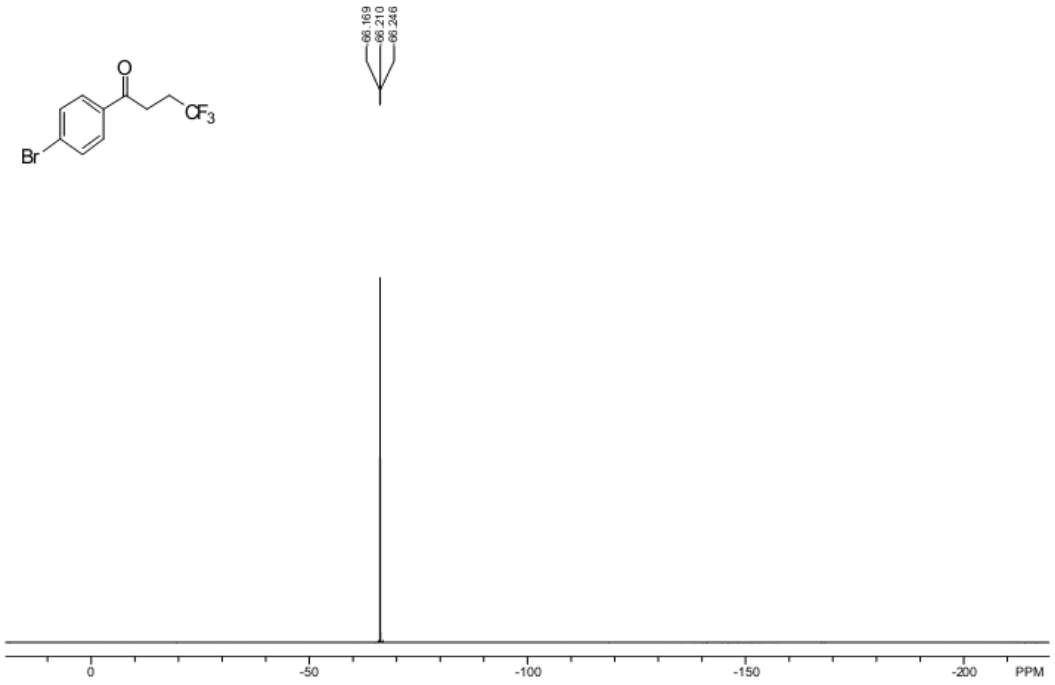
^{13}C NMR spectrum of compound of **2f**



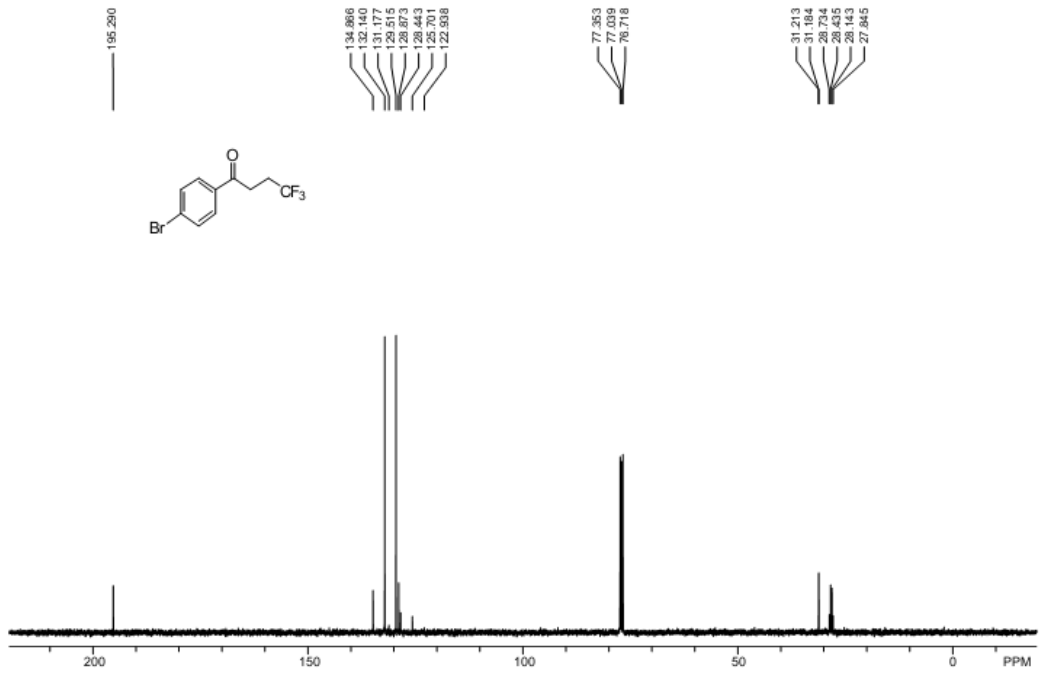
^{1}H NMR spectrum of compound of **2g**



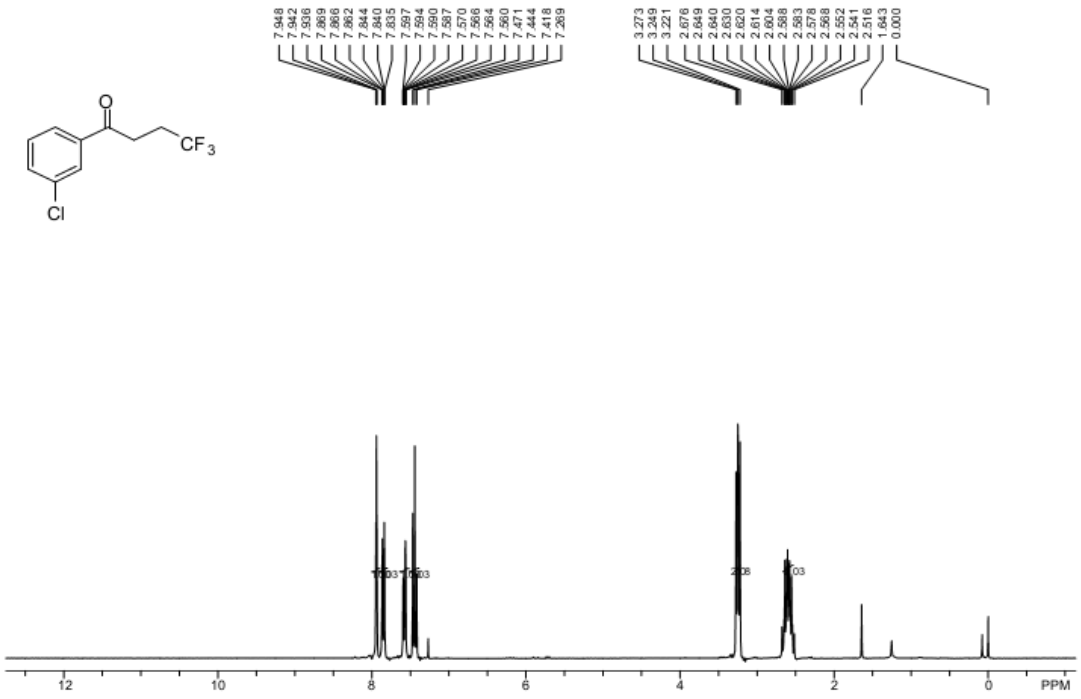
^{19}F NMR spectrum of compound of **2g**



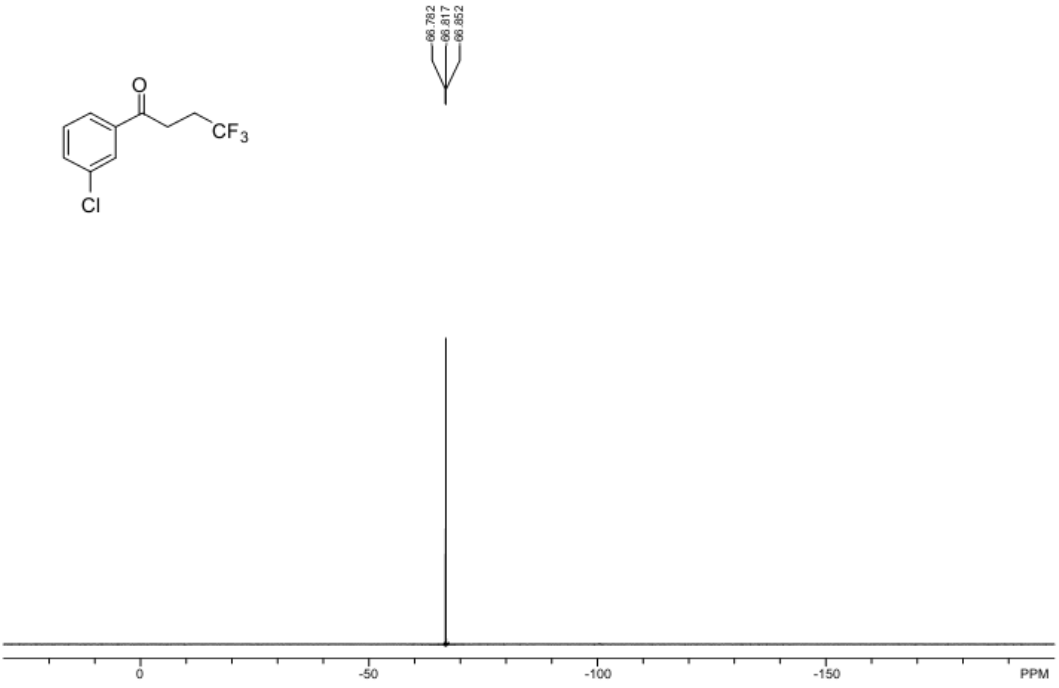
^{13}C NMR spectrum of compound of **2g**



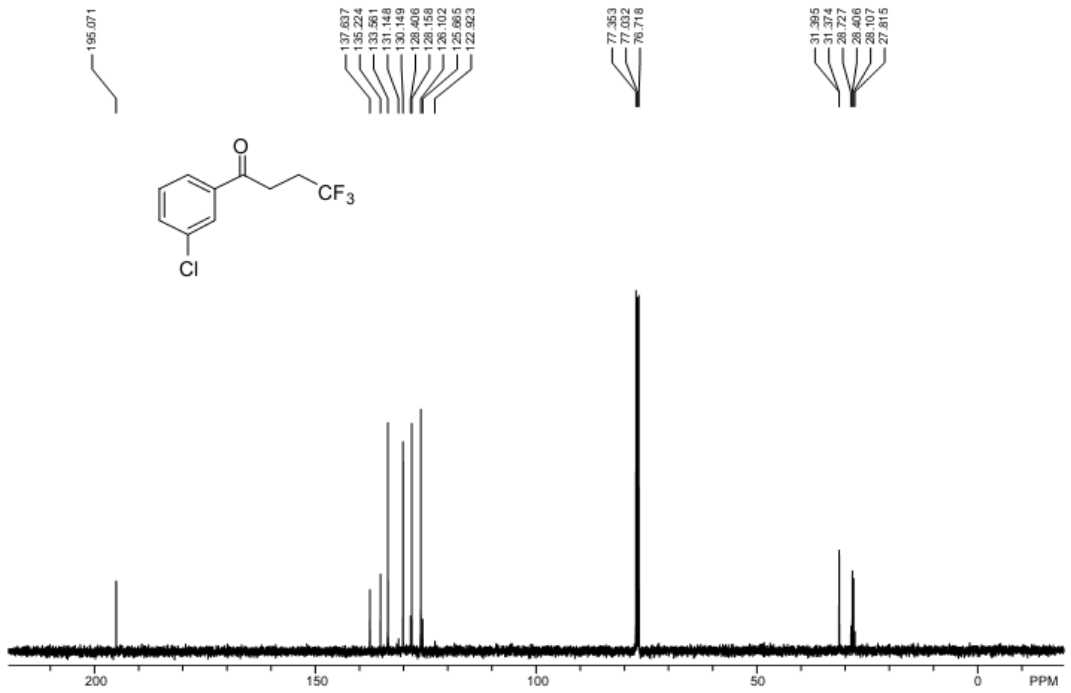
^{1}H NMR spectrum of compound of **2h**



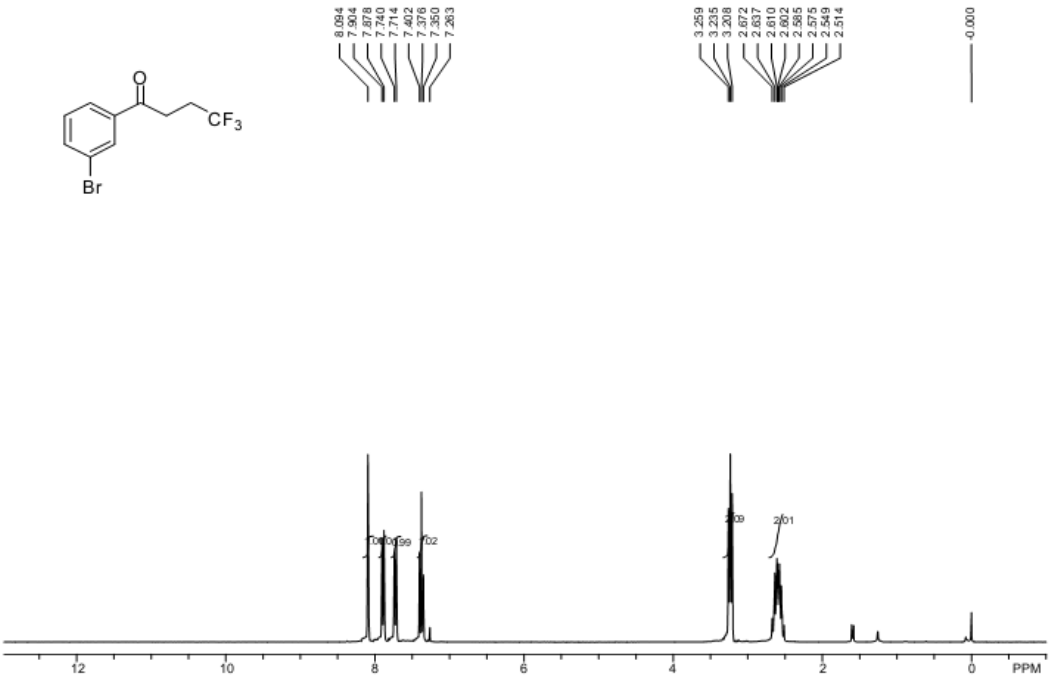
^{19}F NMR spectrum of compound of **2h**



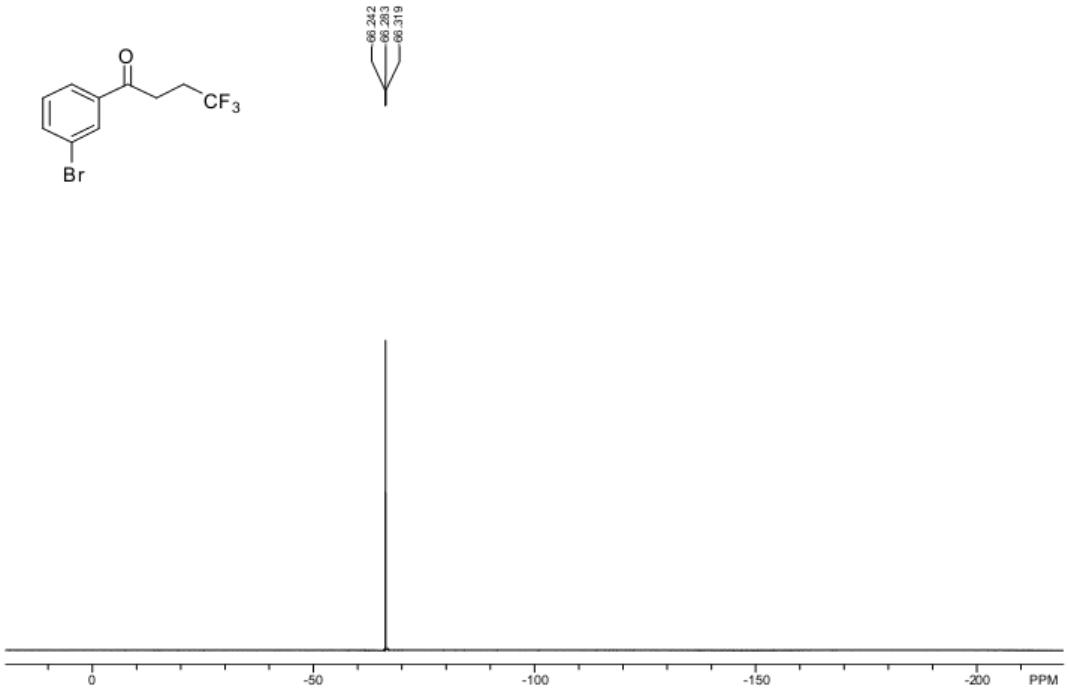
^{13}C NMR spectrum of compound of **2h**



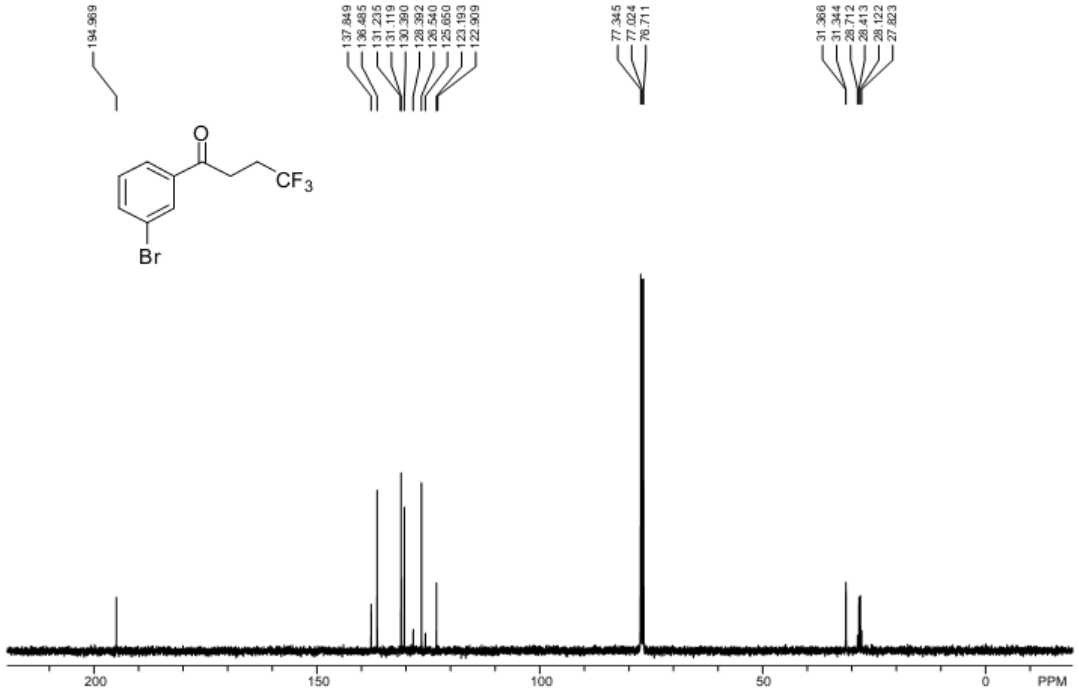
^{1}H NMR spectrum of compound of **2i**



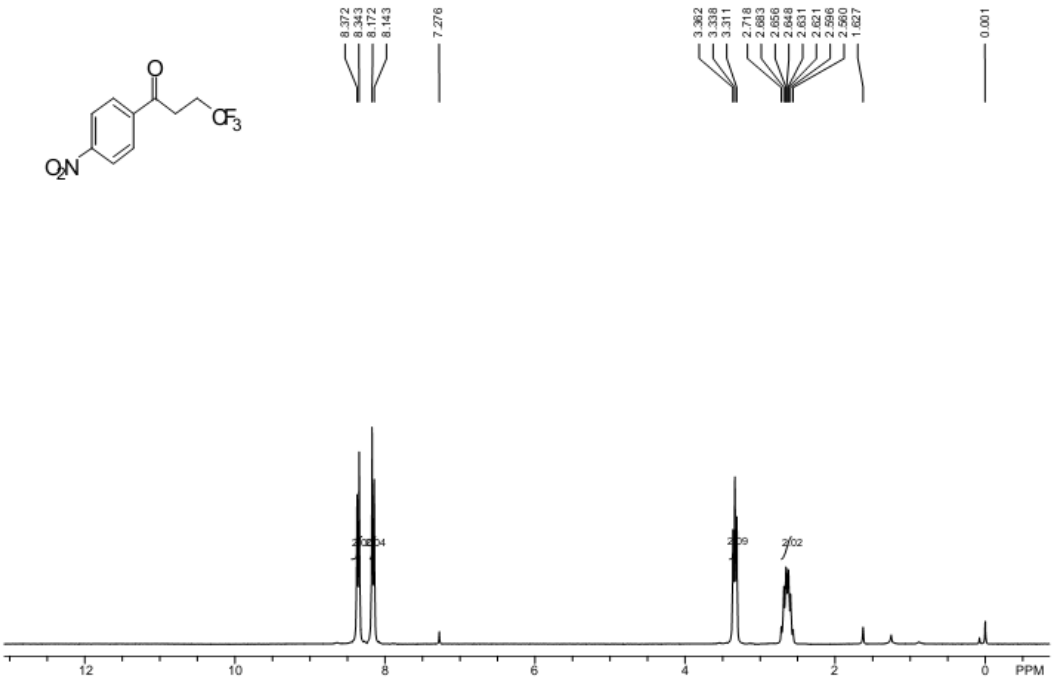
^{19}F NMR spectrum of compound of **2i**



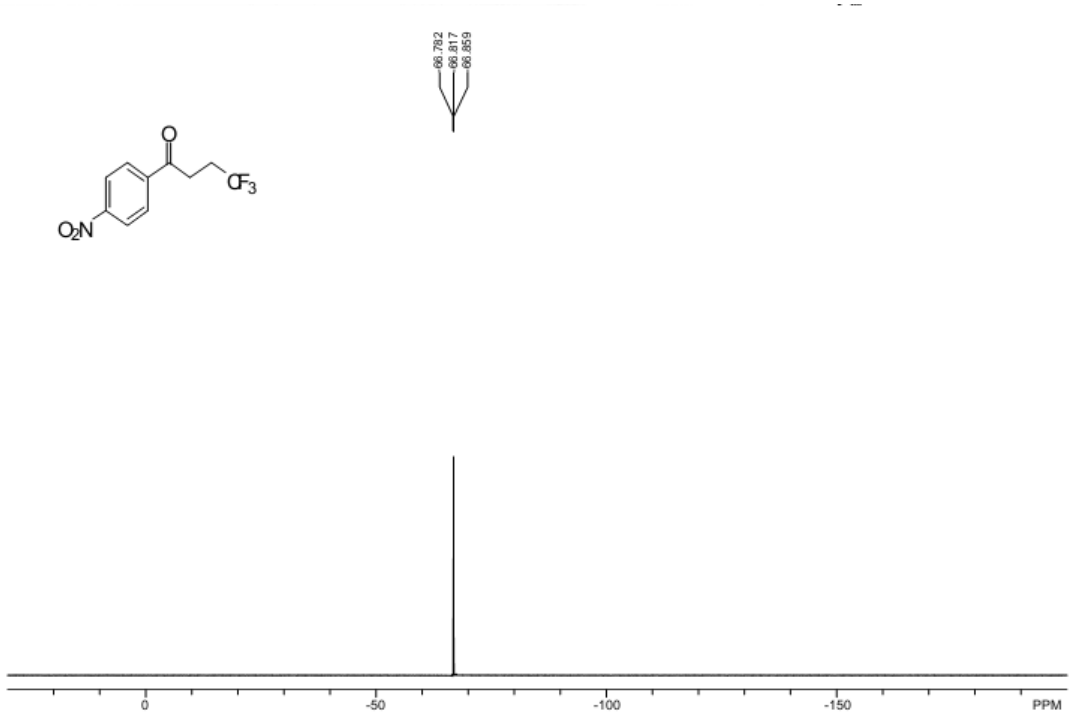
^{13}C NMR spectrum of compound of **2i**



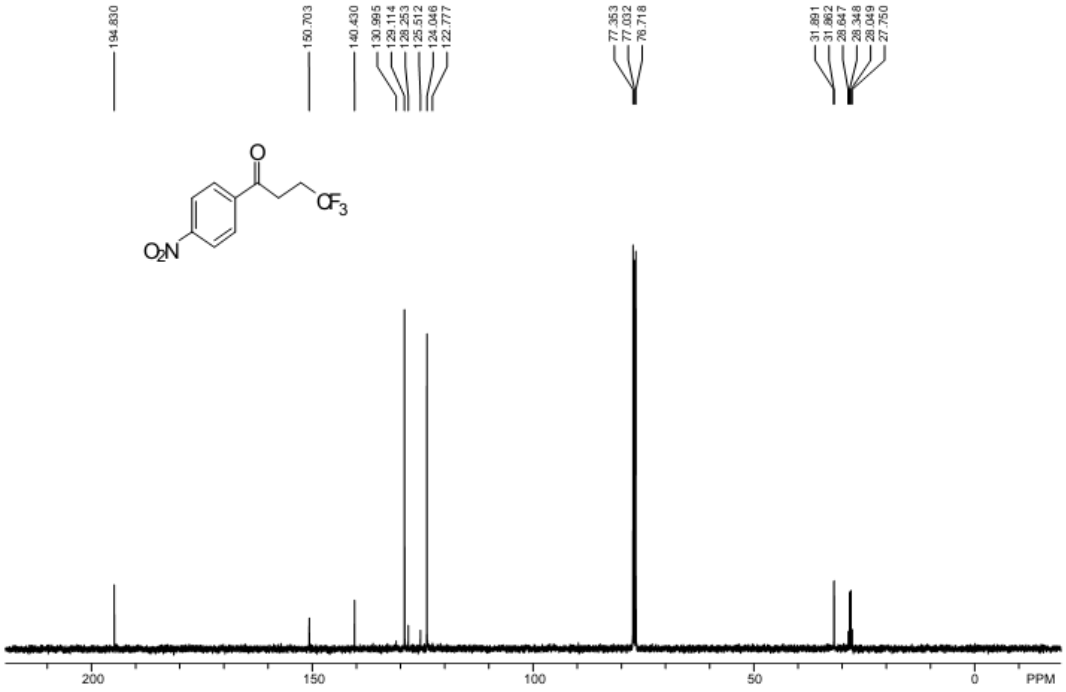
^{1}H NMR spectrum of compound of **2j**



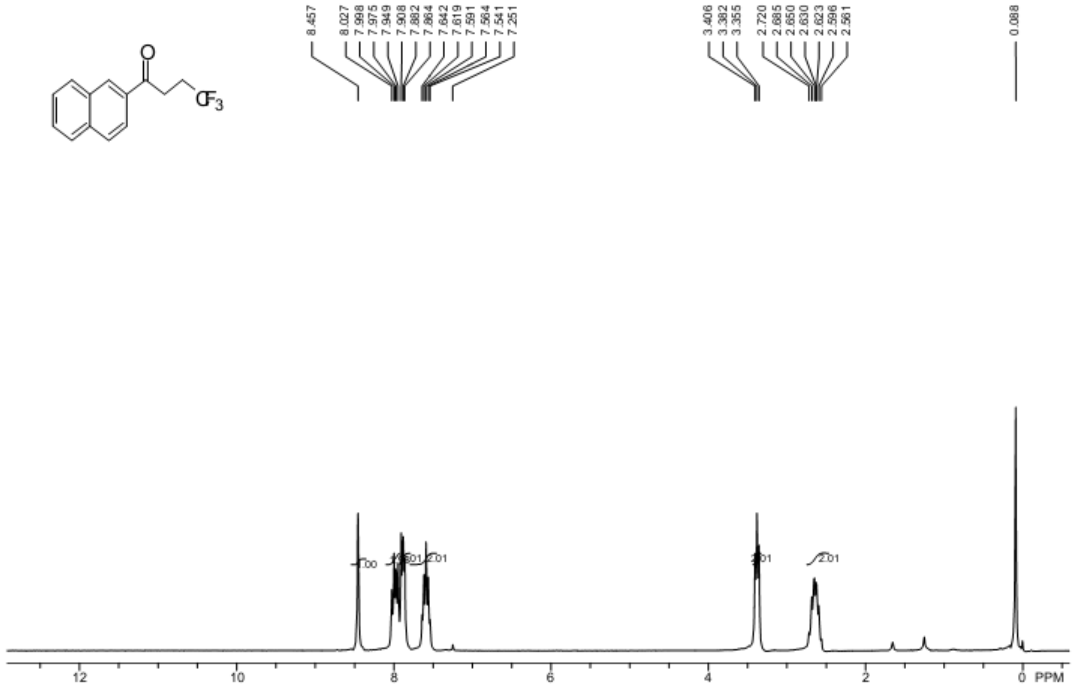
^{19}F NMR spectrum of compound of **2j**



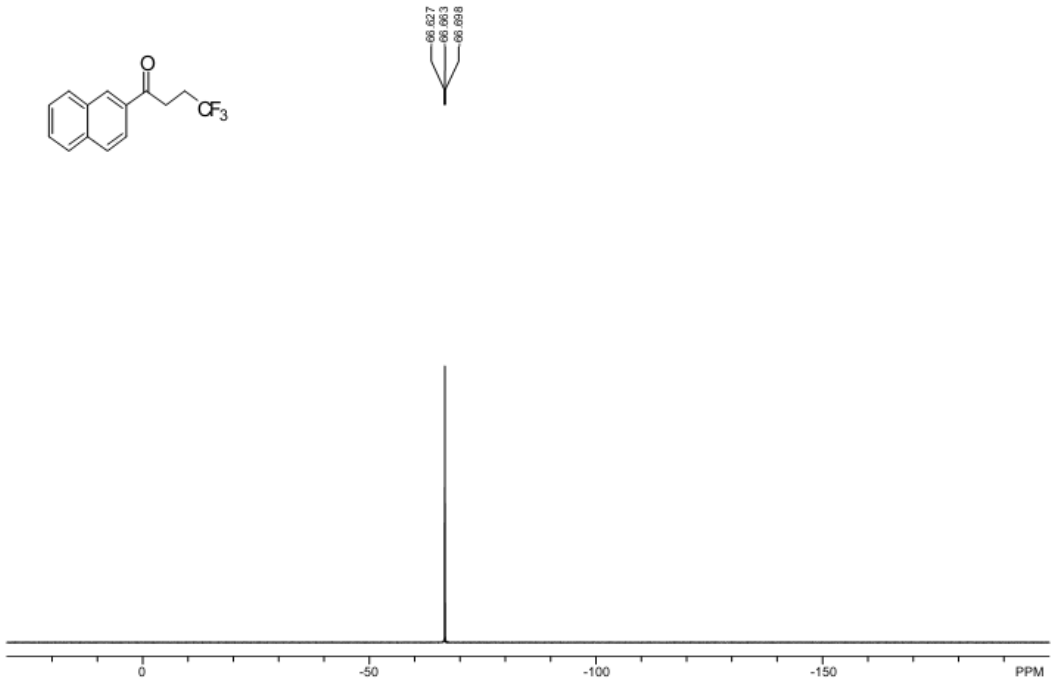
^{13}C NMR spectrum of compound of **2j**



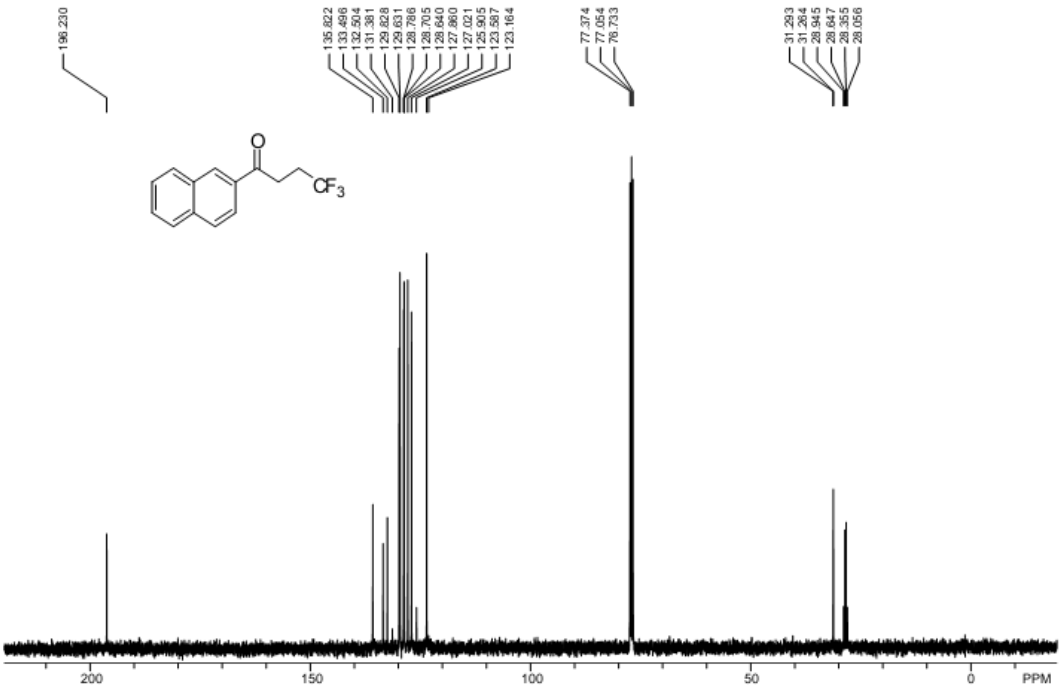
^{1}H NMR spectrum of compound of **2k**



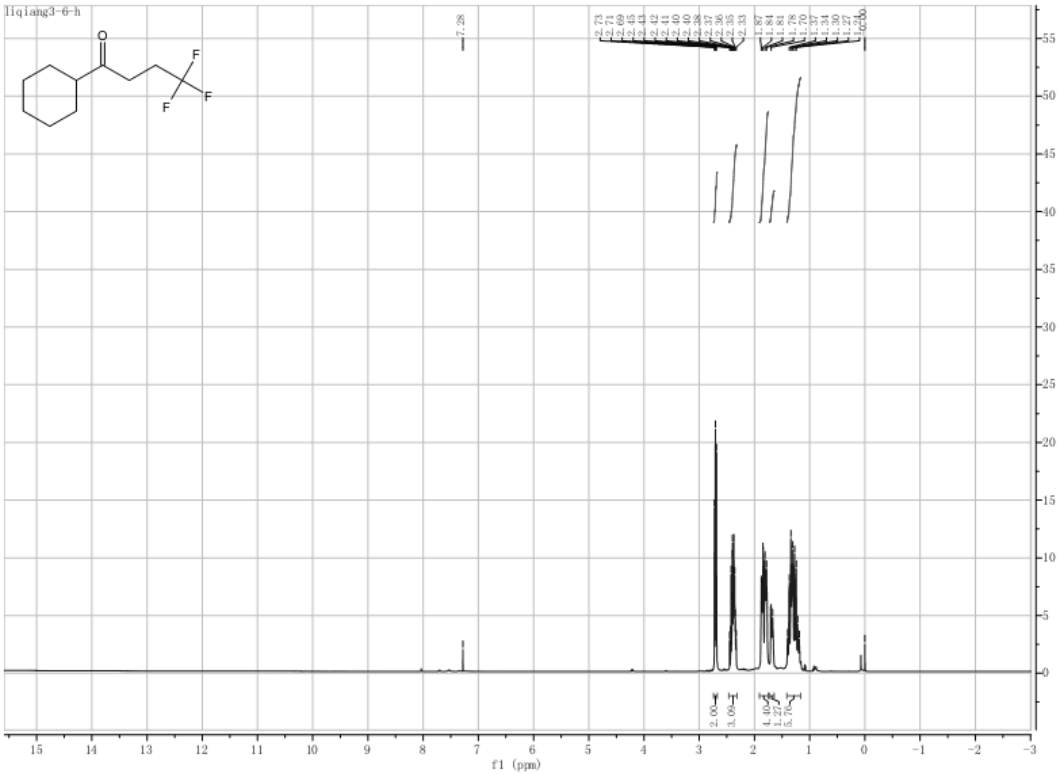
^{19}F NMR spectrum of compound of **2k**



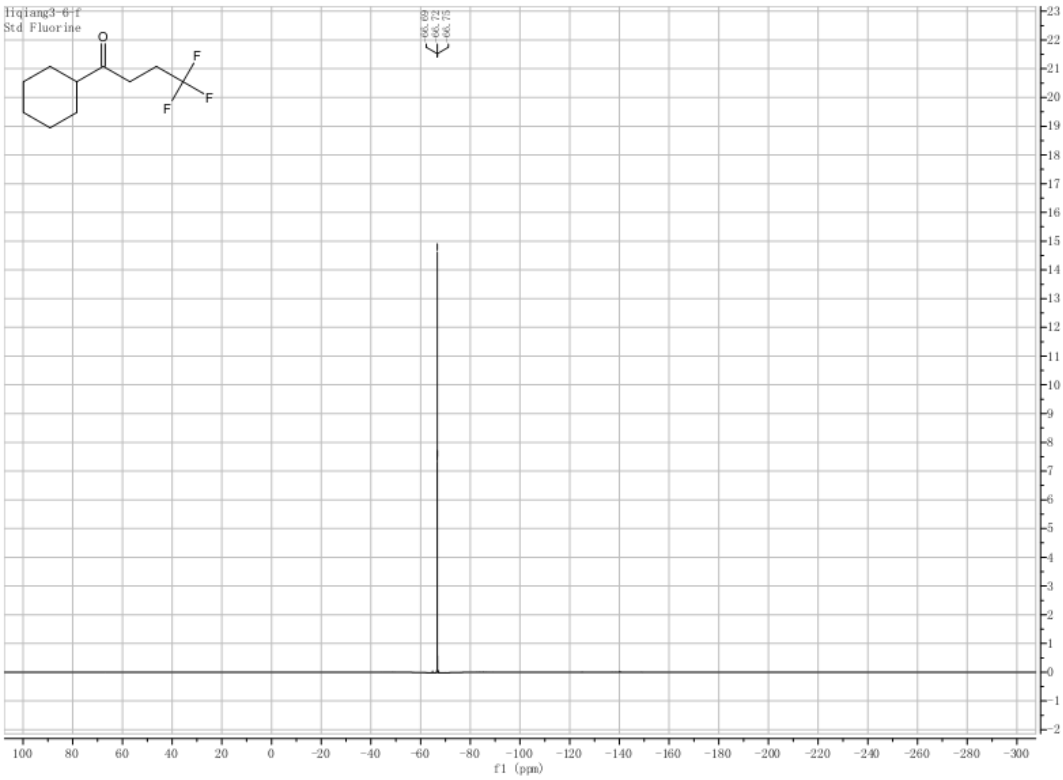
^{13}C NMR spectrum of compound of **2k**



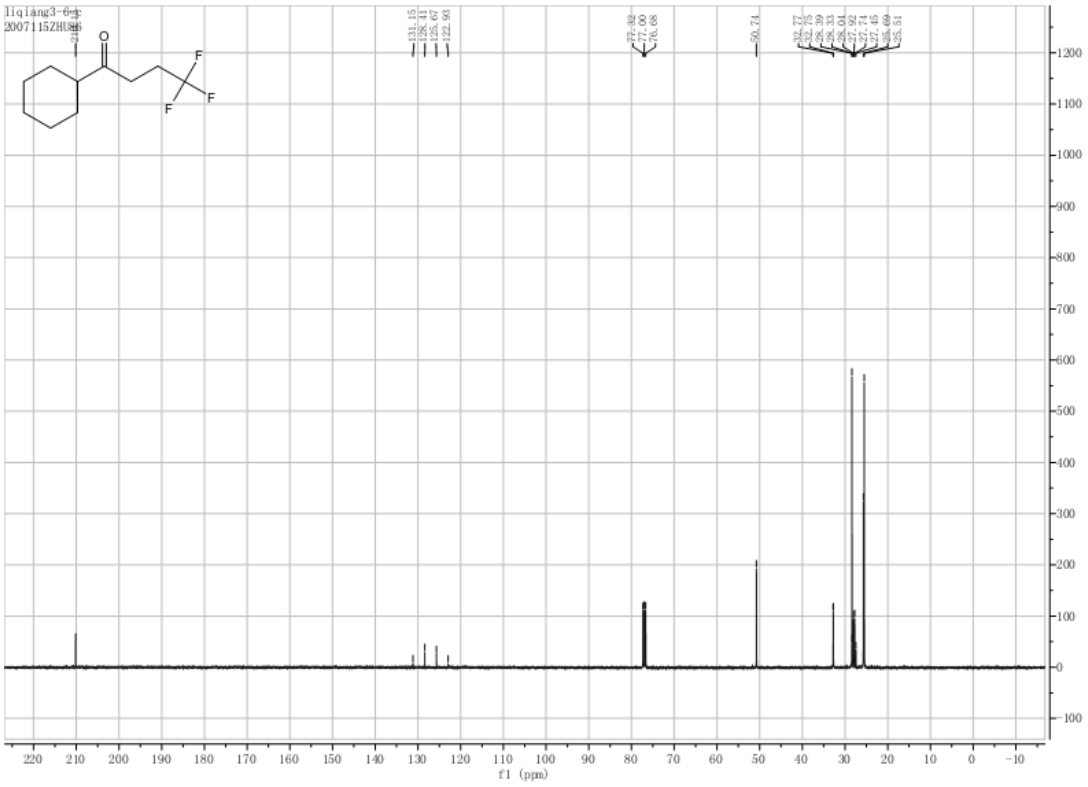
^{1}H NMR spectrum of compound of **2l**



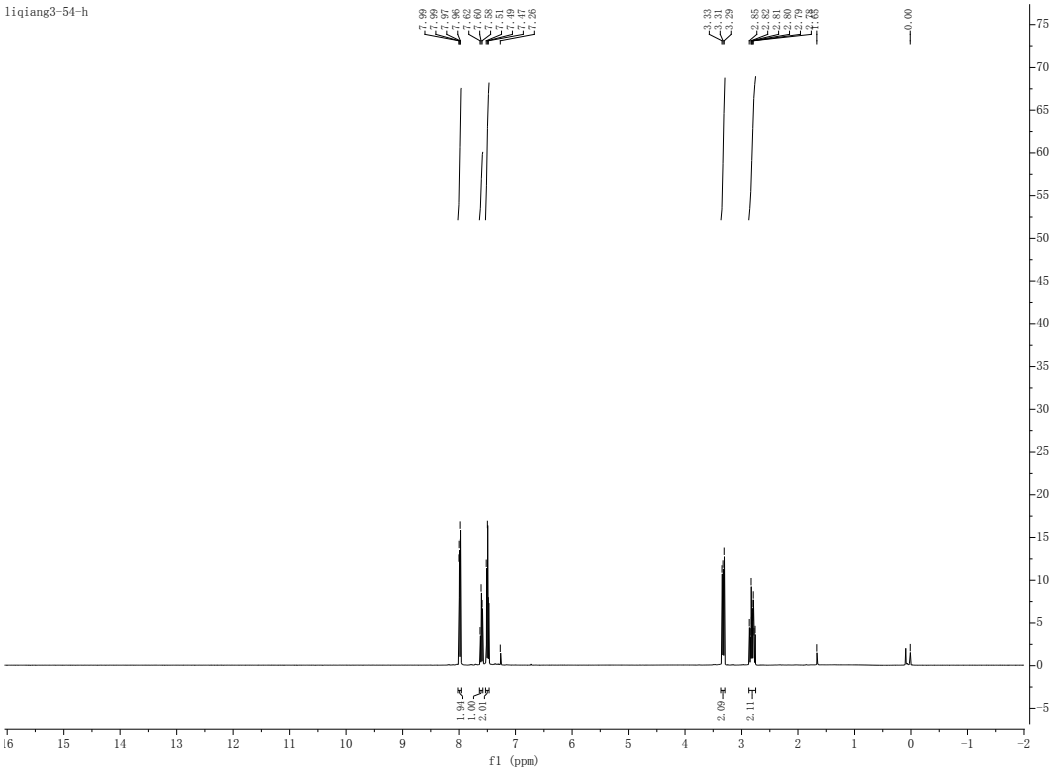
^{19}F NMR spectrum of compound of **2l**



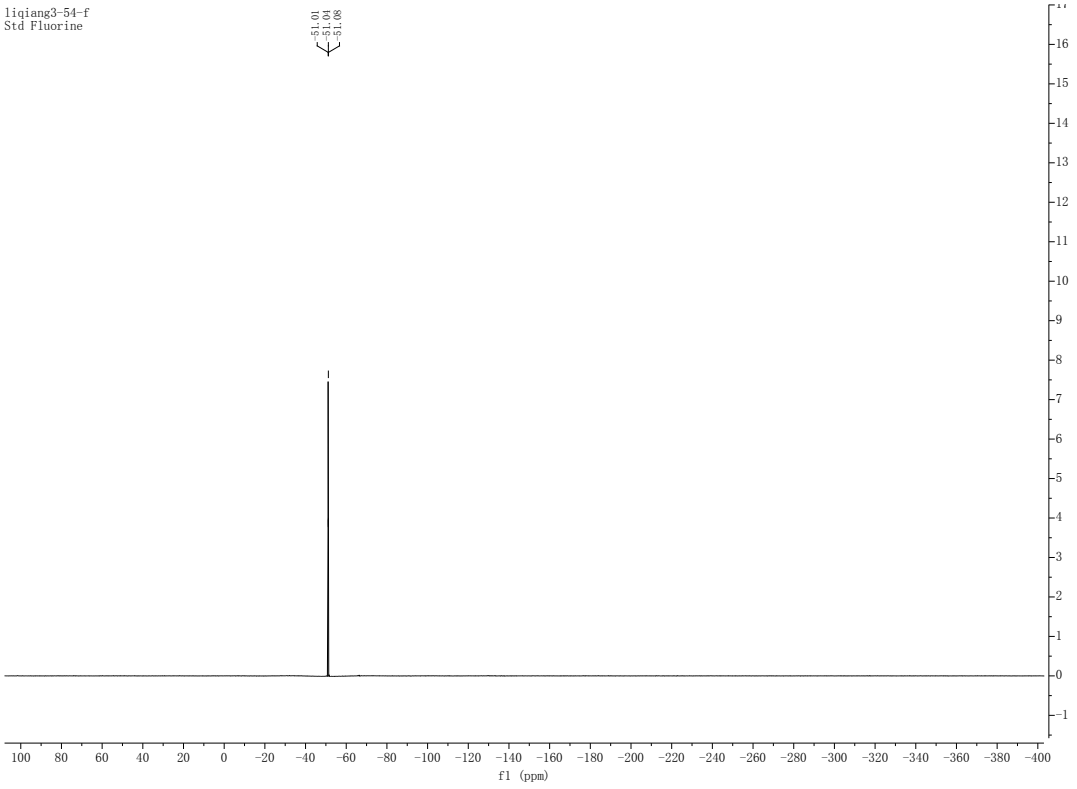
^{13}C NMR spectrum of compound of **2l**



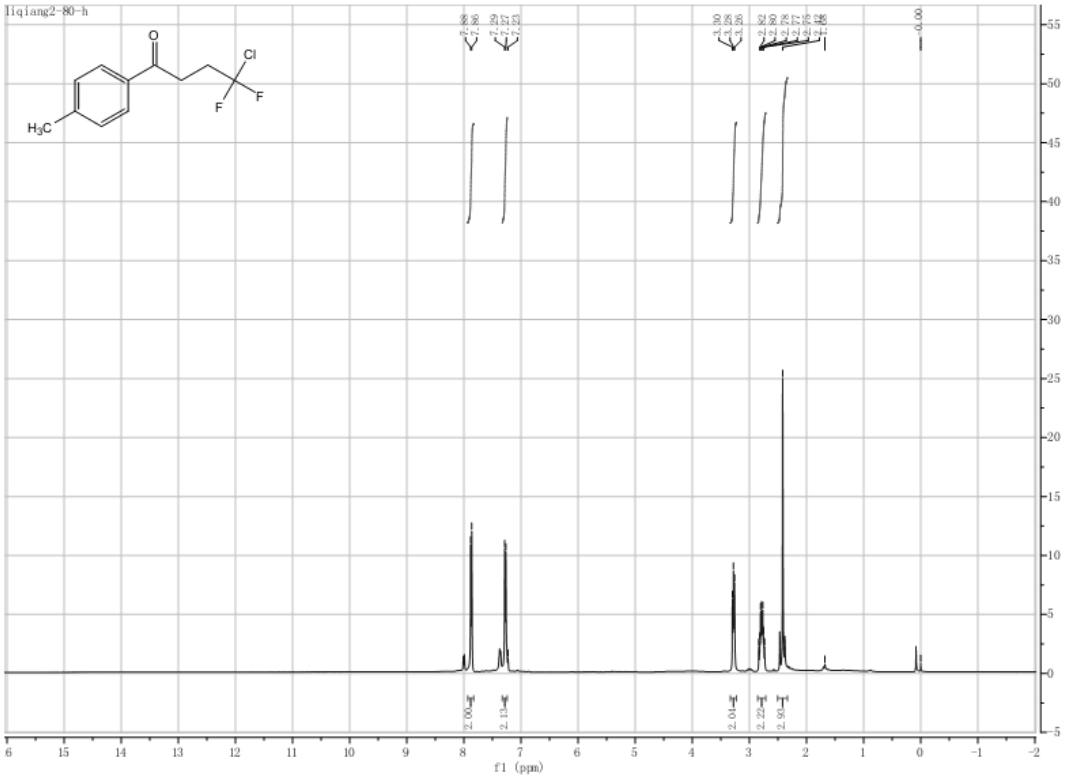
^{1}H NMR spectrum of compound of **3a**



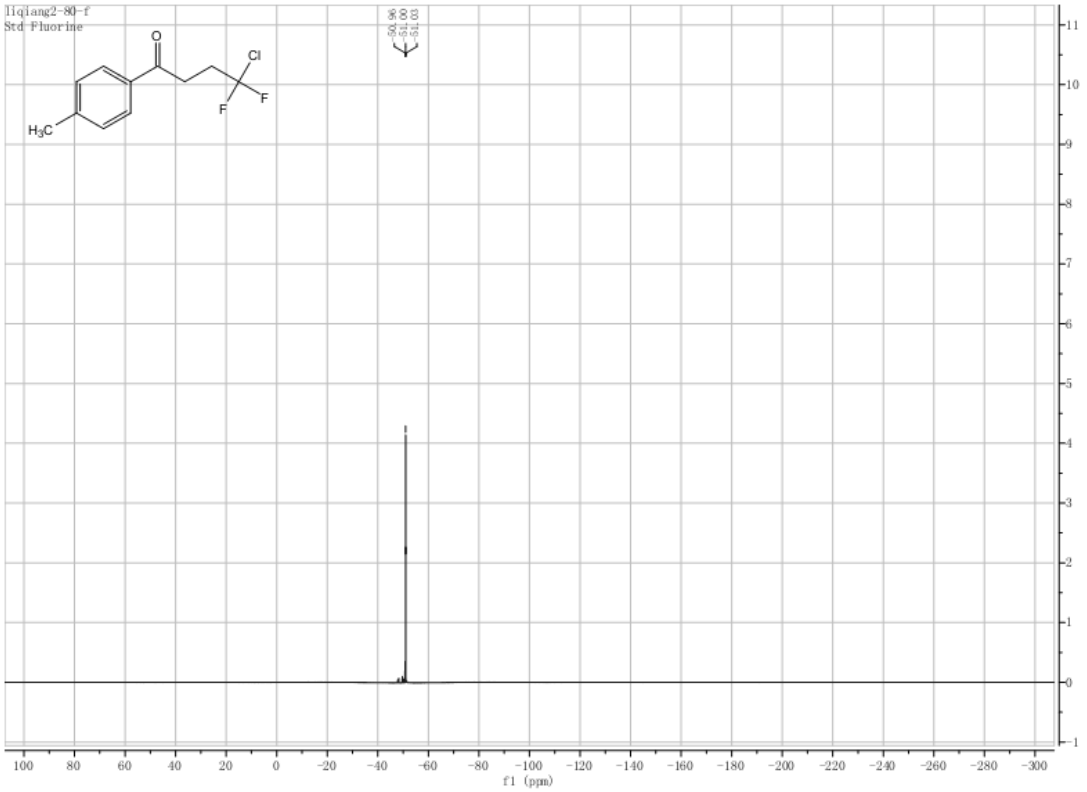
^{19}F NMR spectrum of compound of **3a**



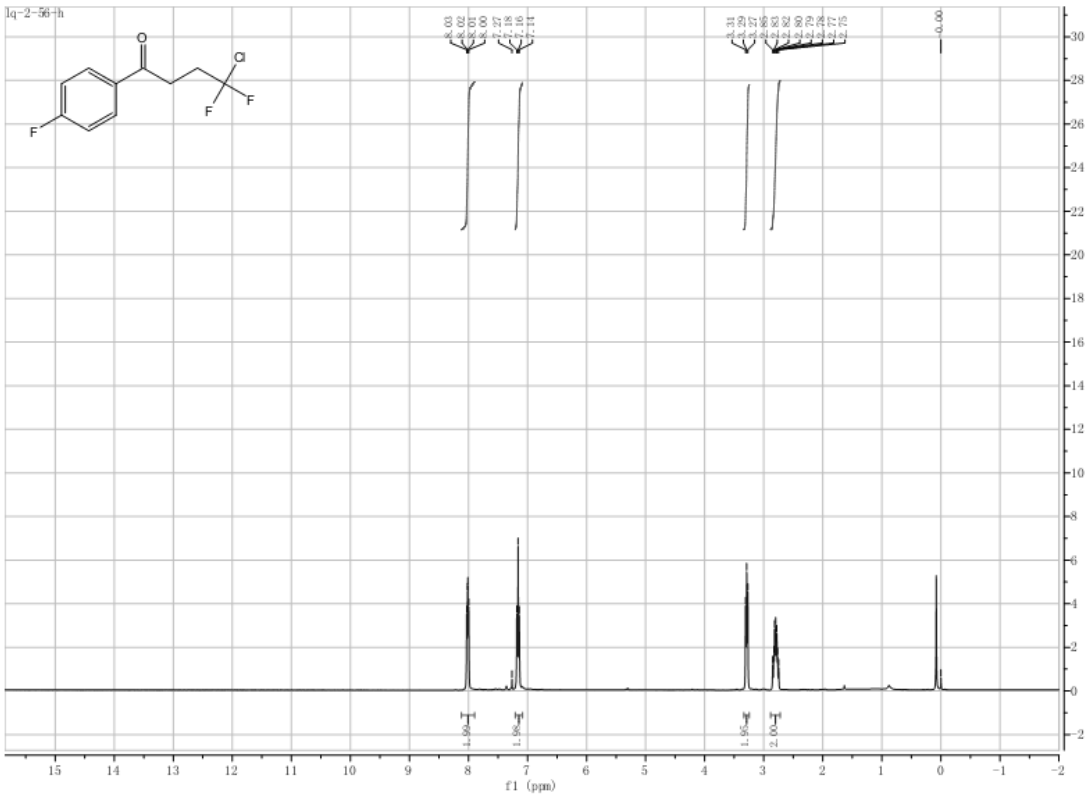
^{1}H NMR spectrum of compound of **3b**



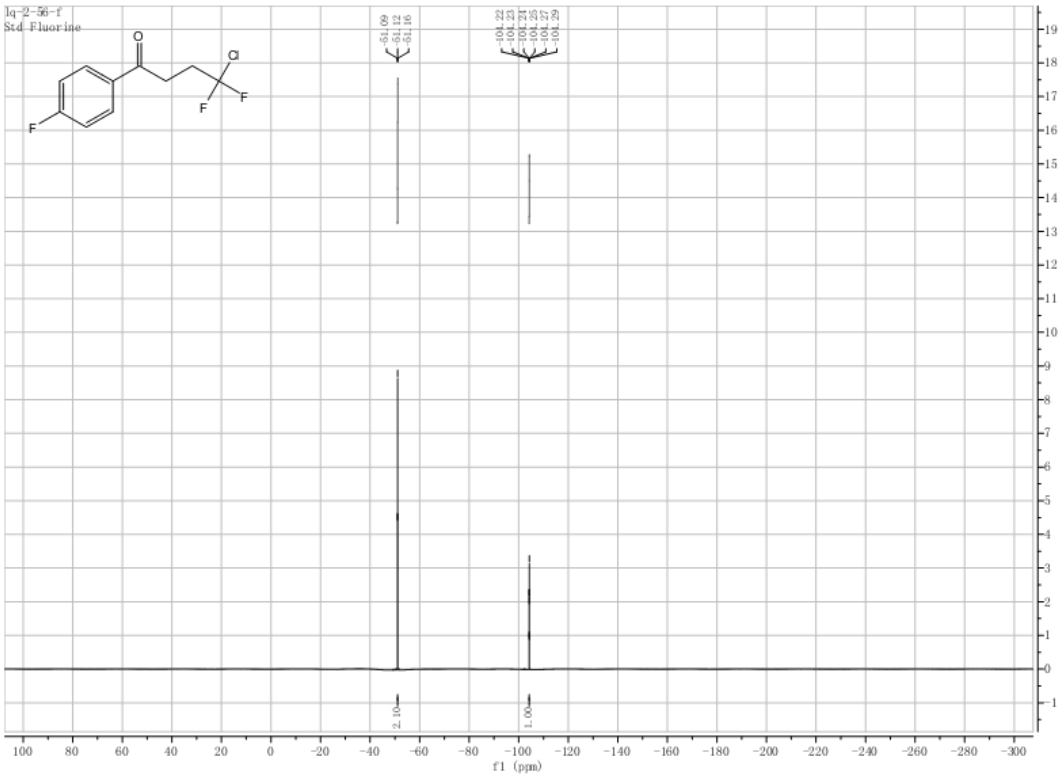
^{19}F NMR spectrum of compound of **3b**



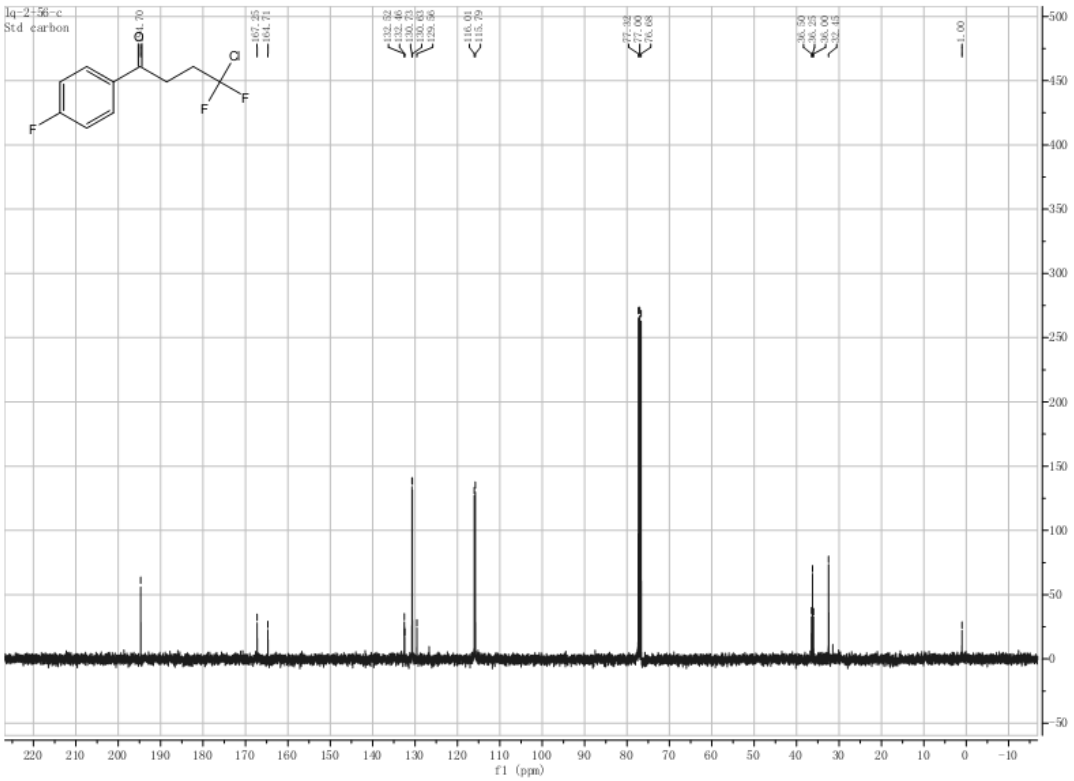
^{1}H NMR spectrum of compound of **3c**



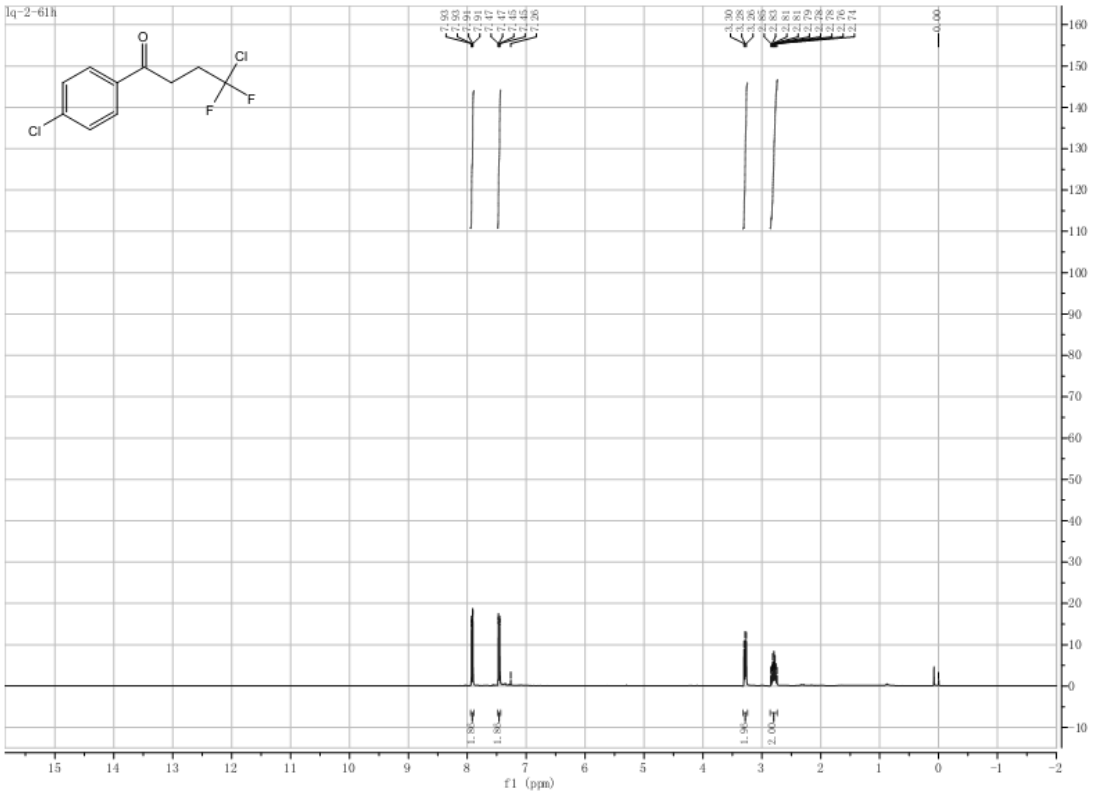
^{19}F NMR spectrum of compound of **3c**



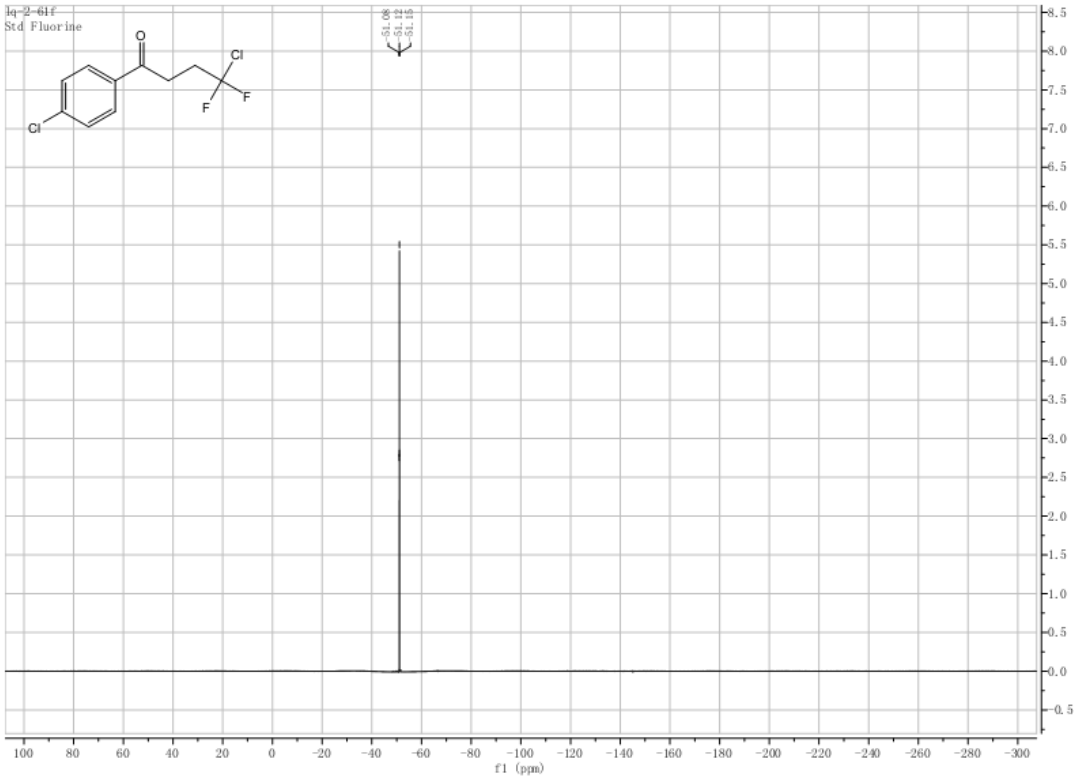
^{13}C NMR spectrum of compound of **3c**



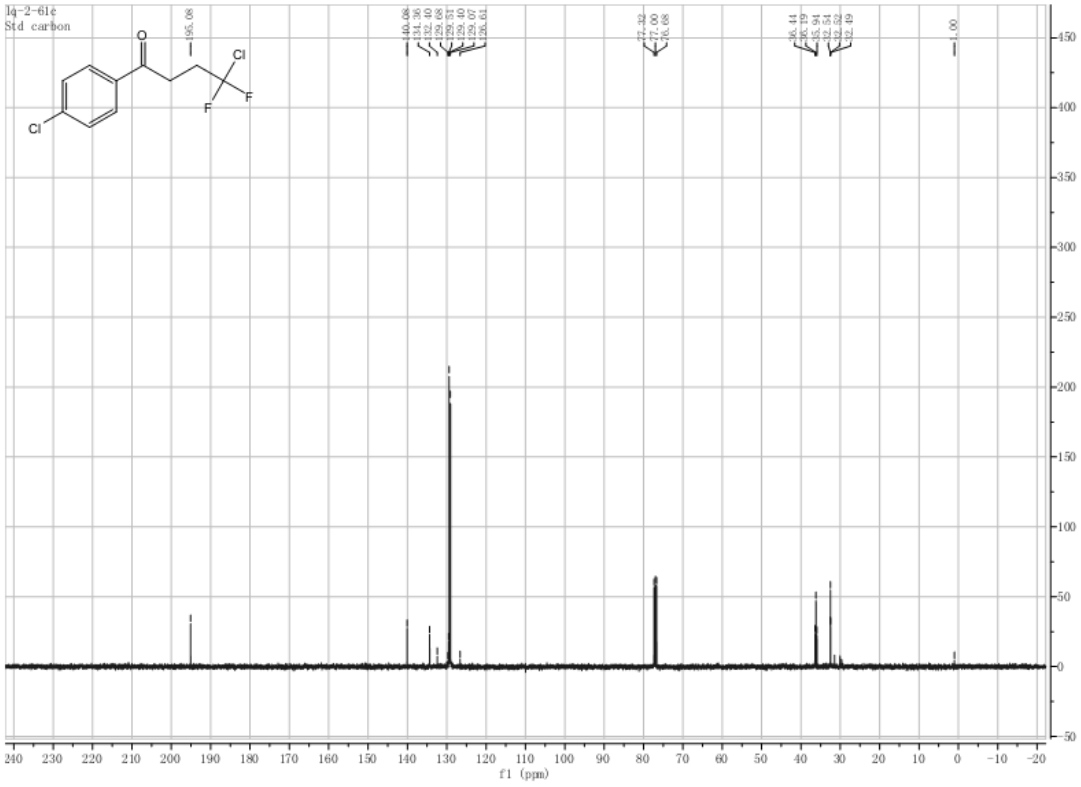
^{1}H NMR spectrum of compound of **3d**



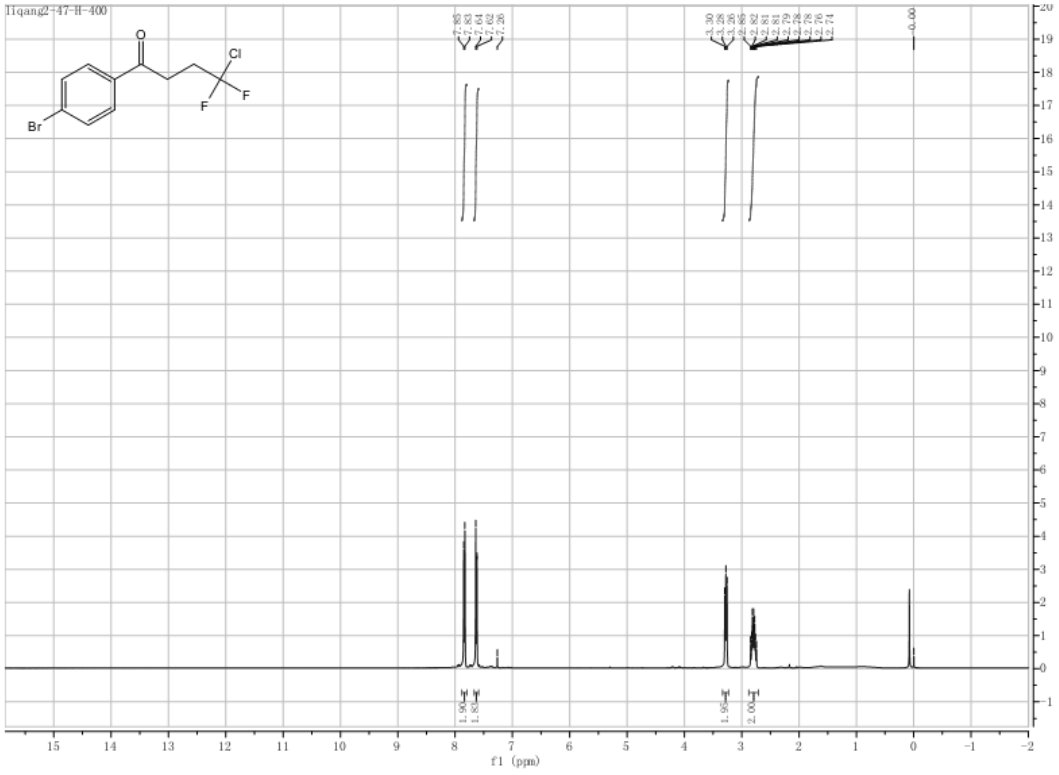
^{19}F NMR spectrum of compound of **3d**



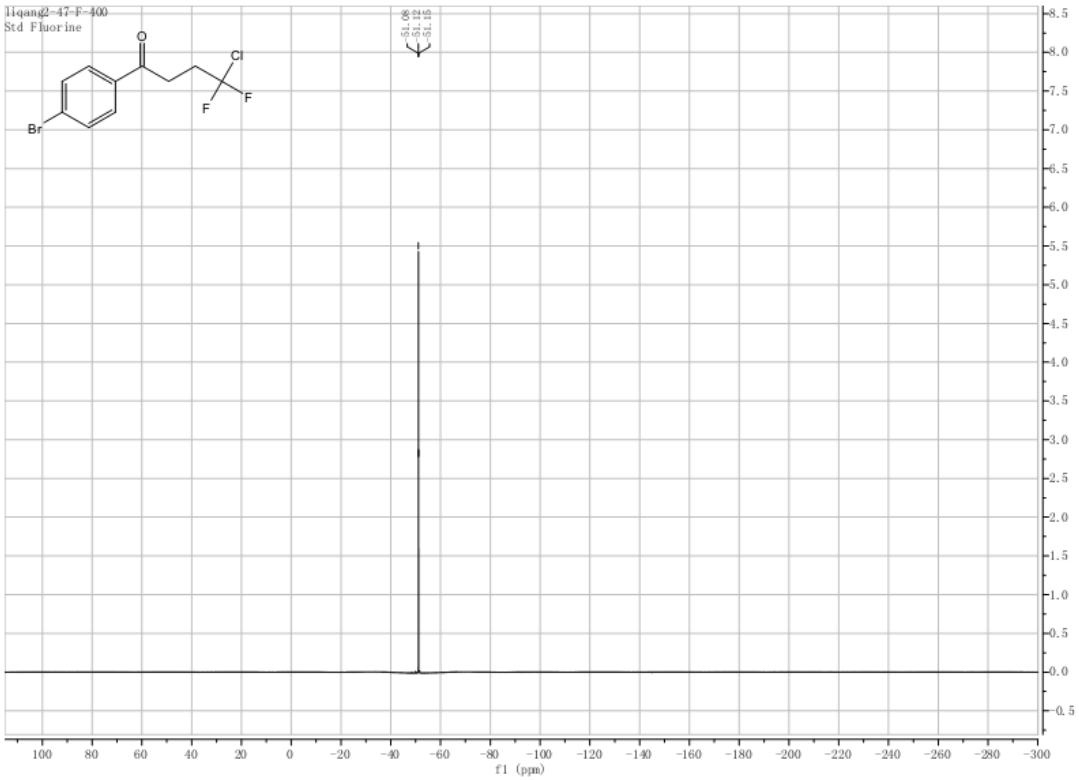
^{13}C NMR spectrum of compound of **3d**



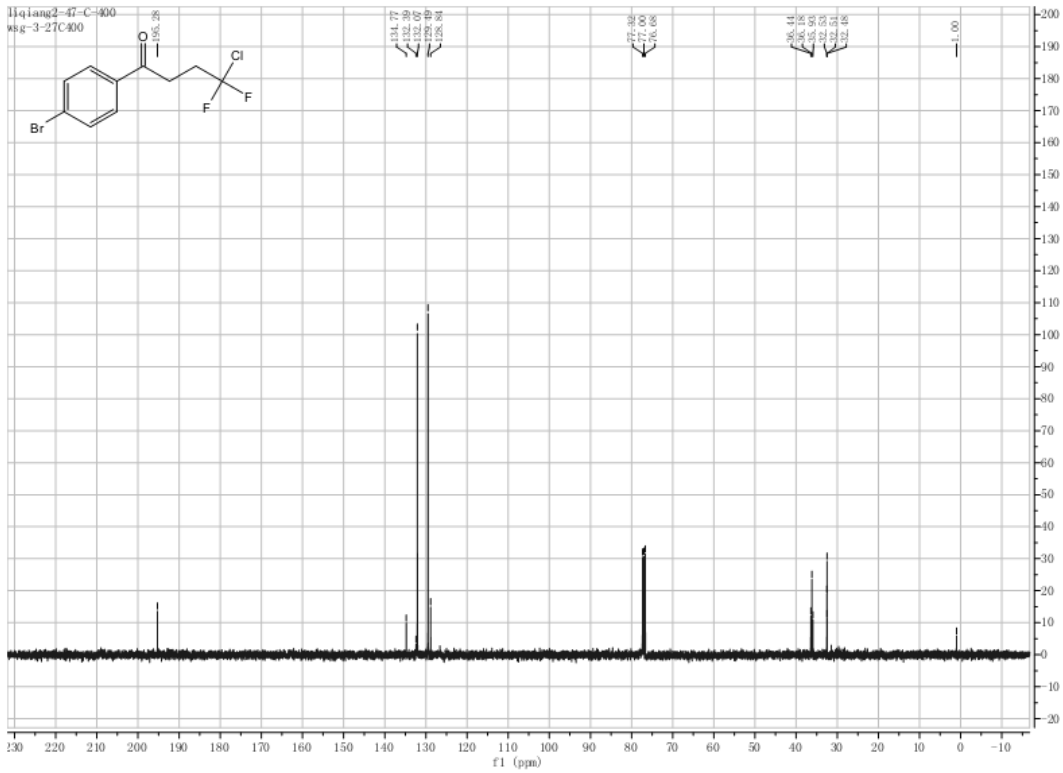
^{1}H NMR spectrum of compound of **3e**



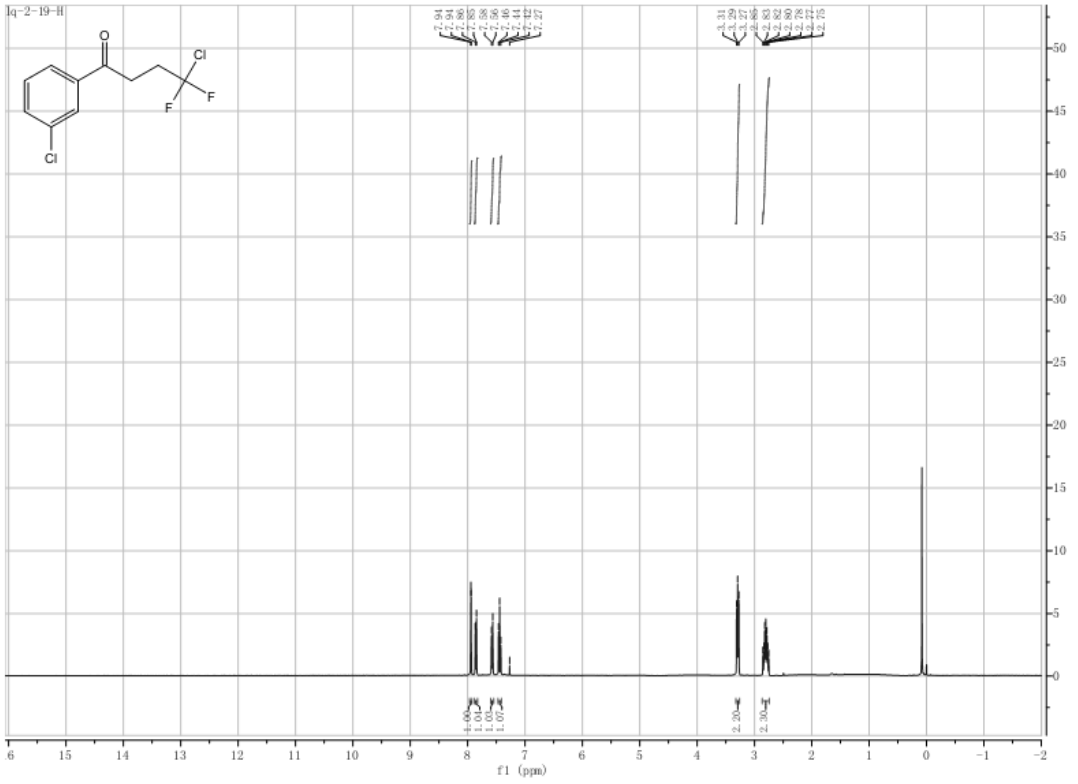
^{19}F NMR spectrum of compound of **3e**



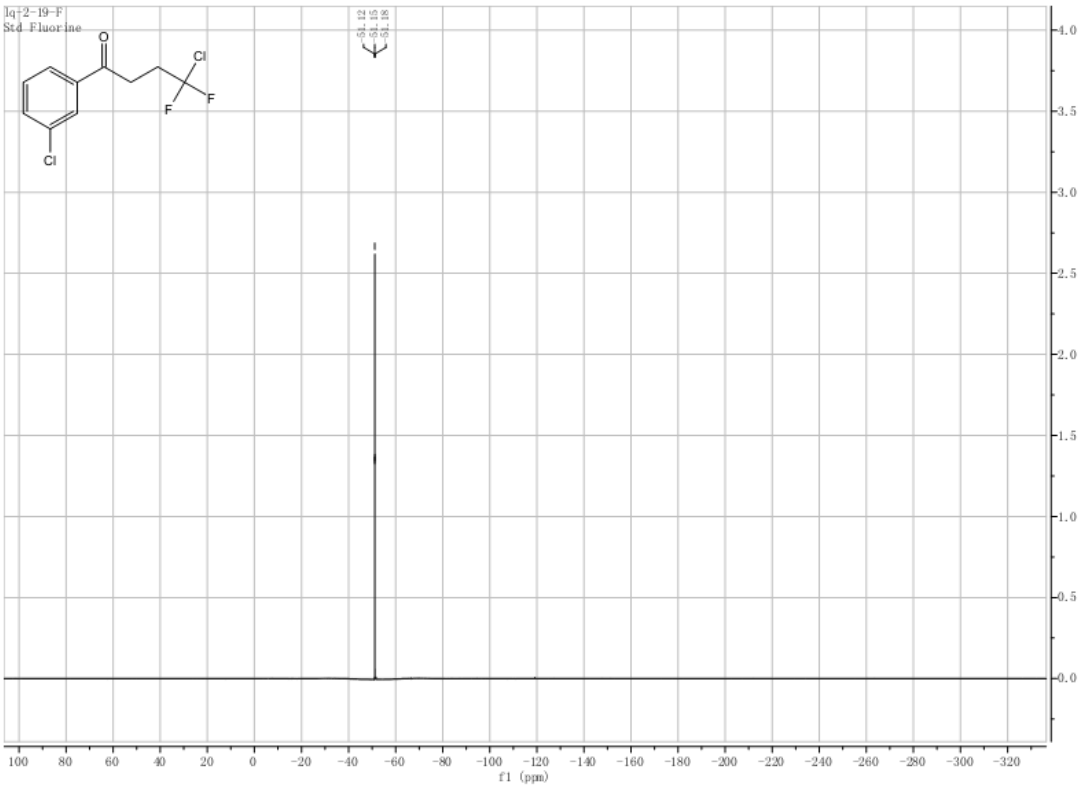
^{13}C NMR spectrum of compound of **3e**



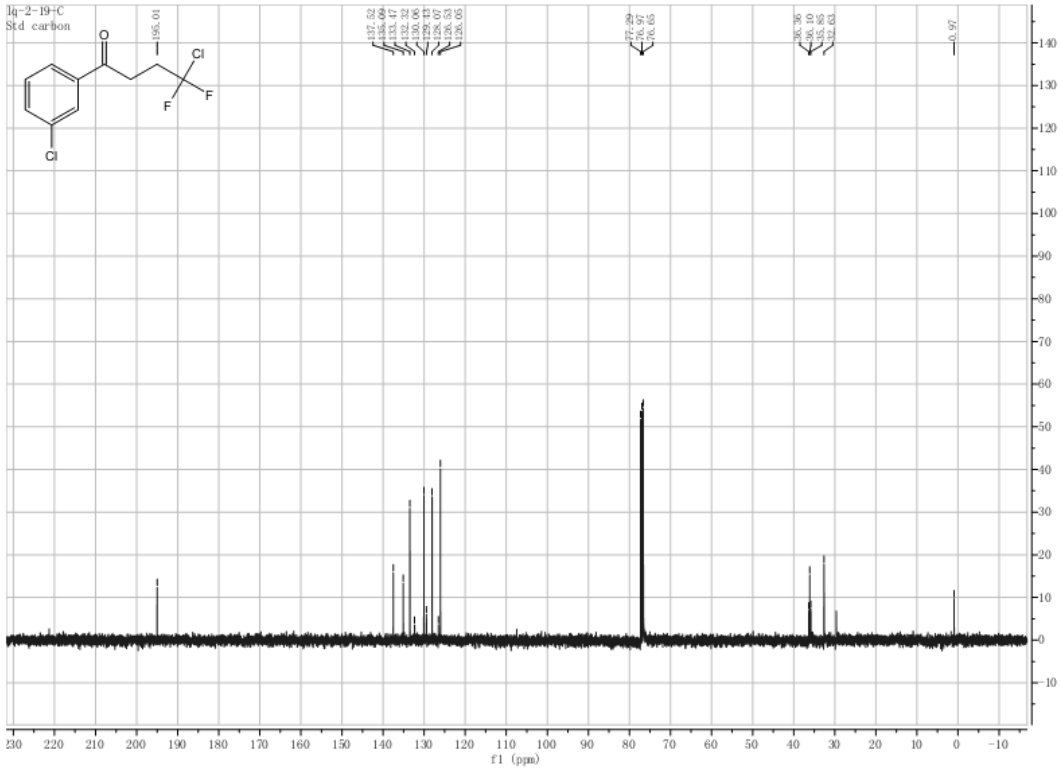
^{1}H NMR spectrum of compound of **3f**



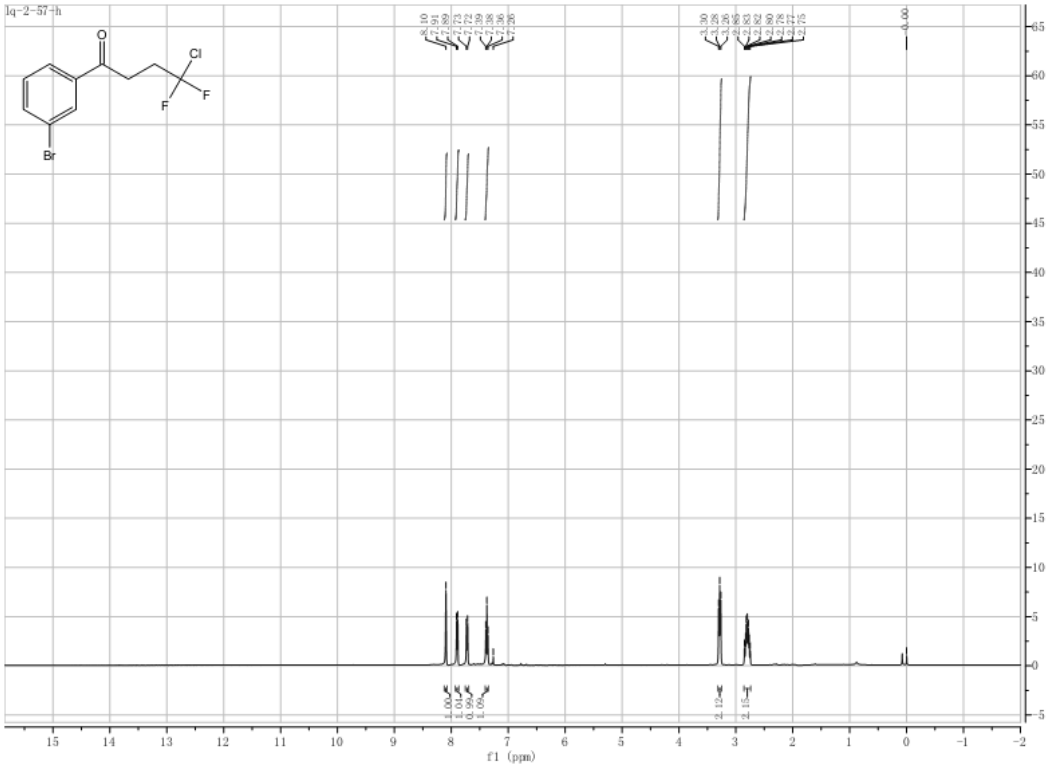
^{19}F NMR spectrum of compound of **3f**



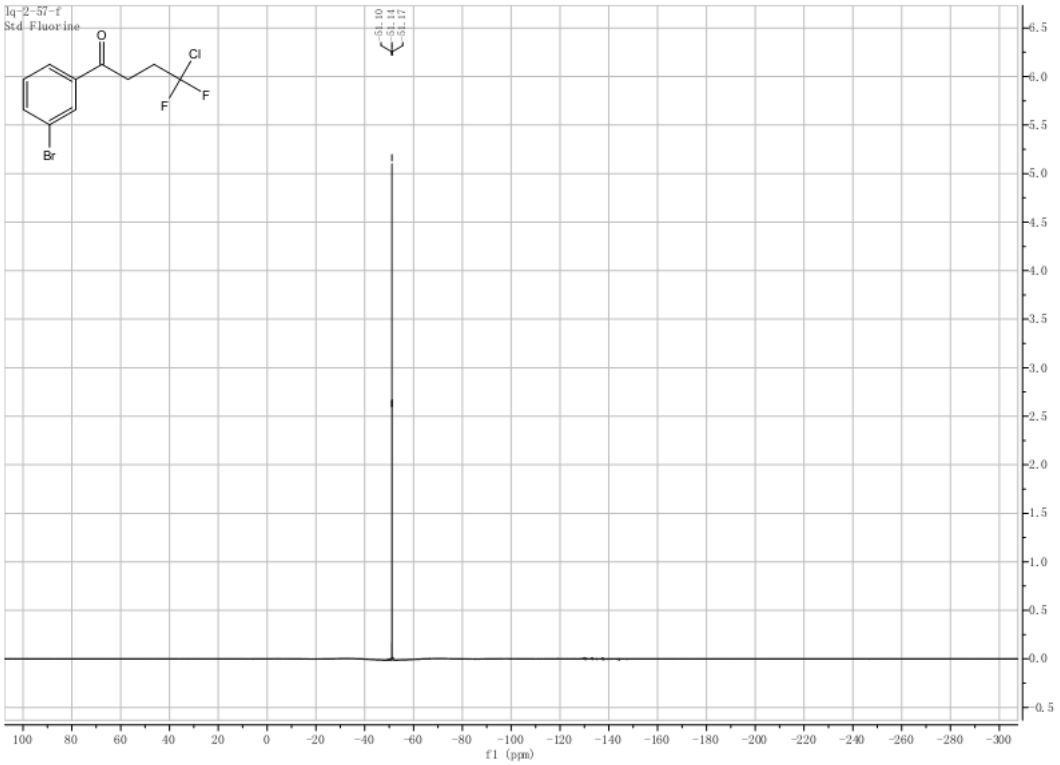
^{13}C NMR spectrum of compound of **3f**



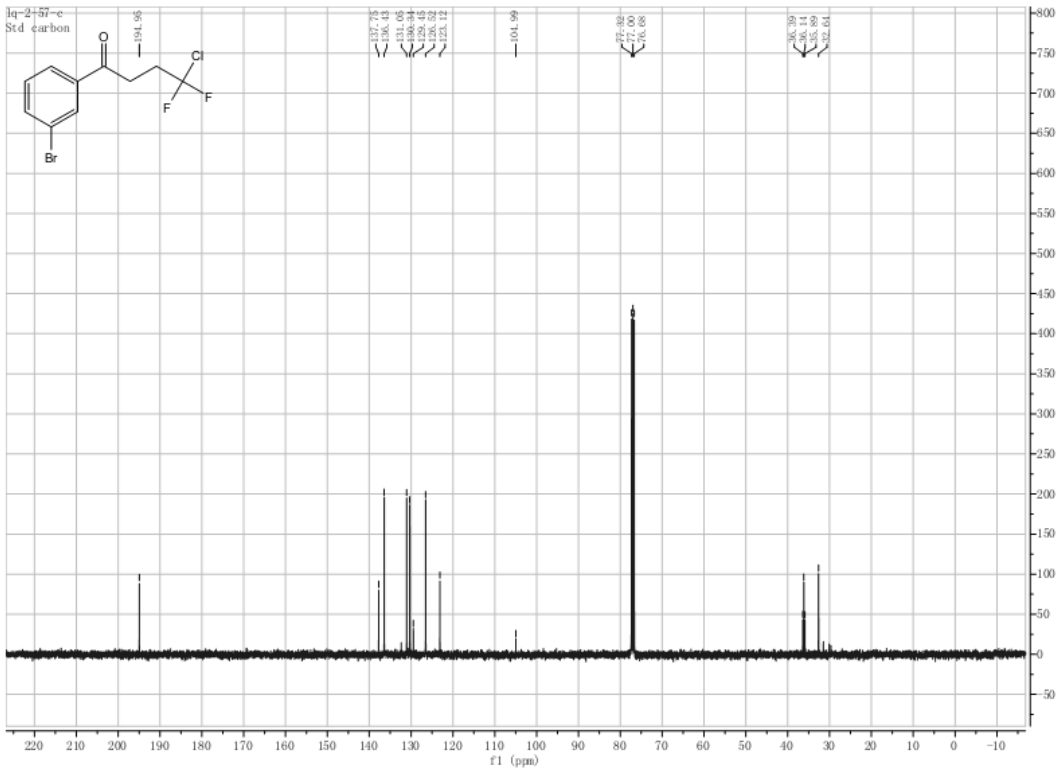
^{1}H NMR spectrum of compound of **3g**



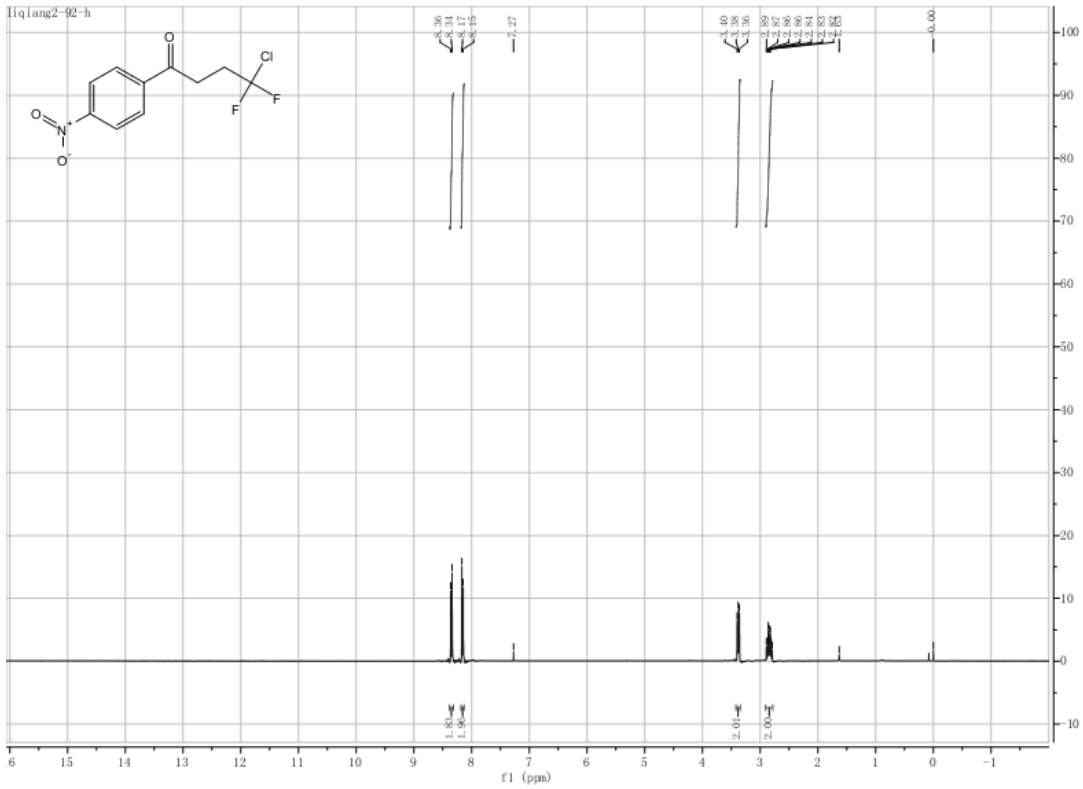
^{19}F NMR spectrum of compound of **3g**



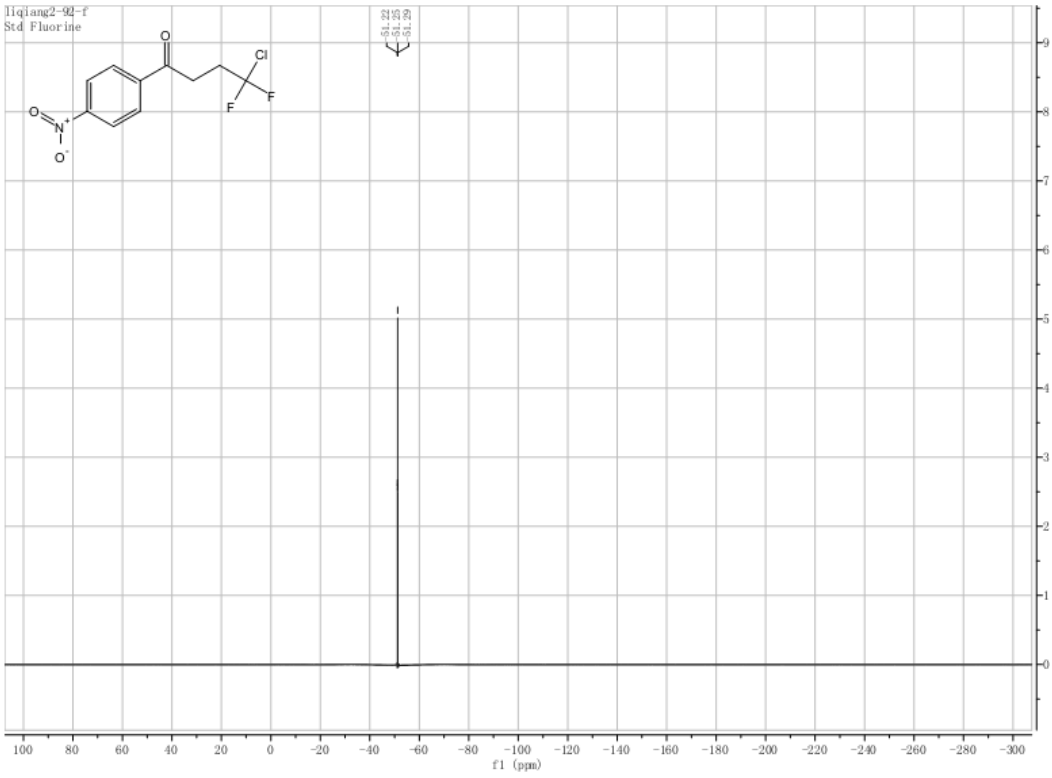
^{13}C NMR spectrum of compound of **3g**



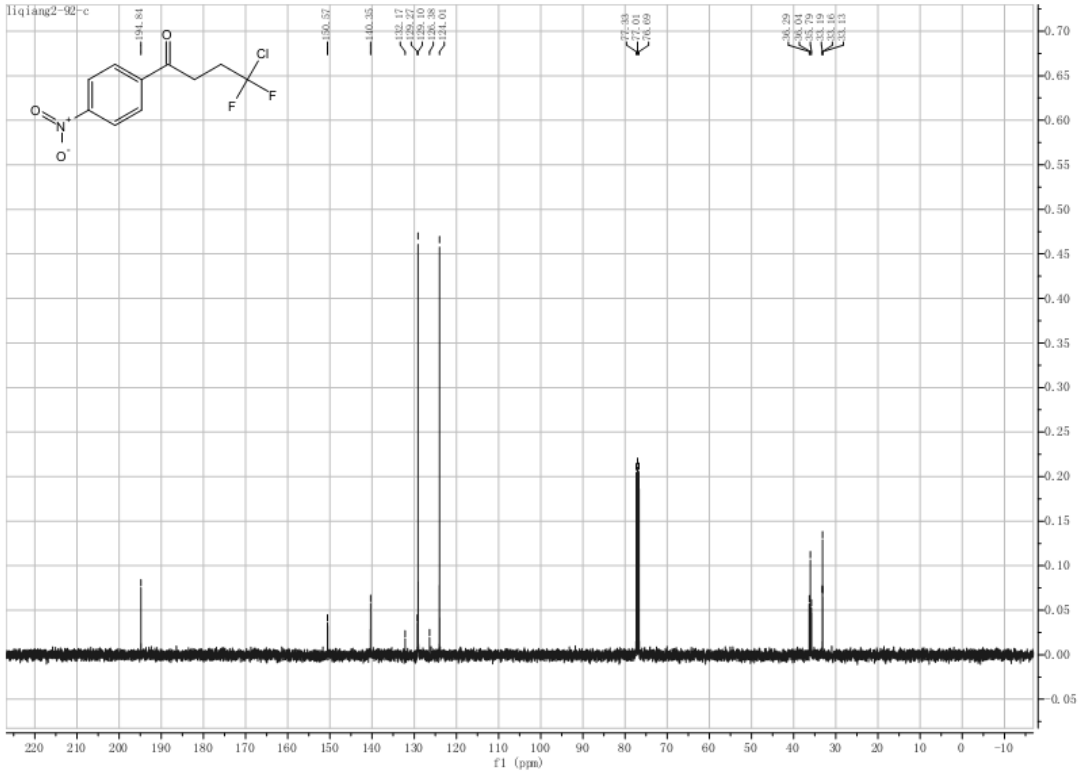
^{1}H NMR spectrum of compound of **3h**



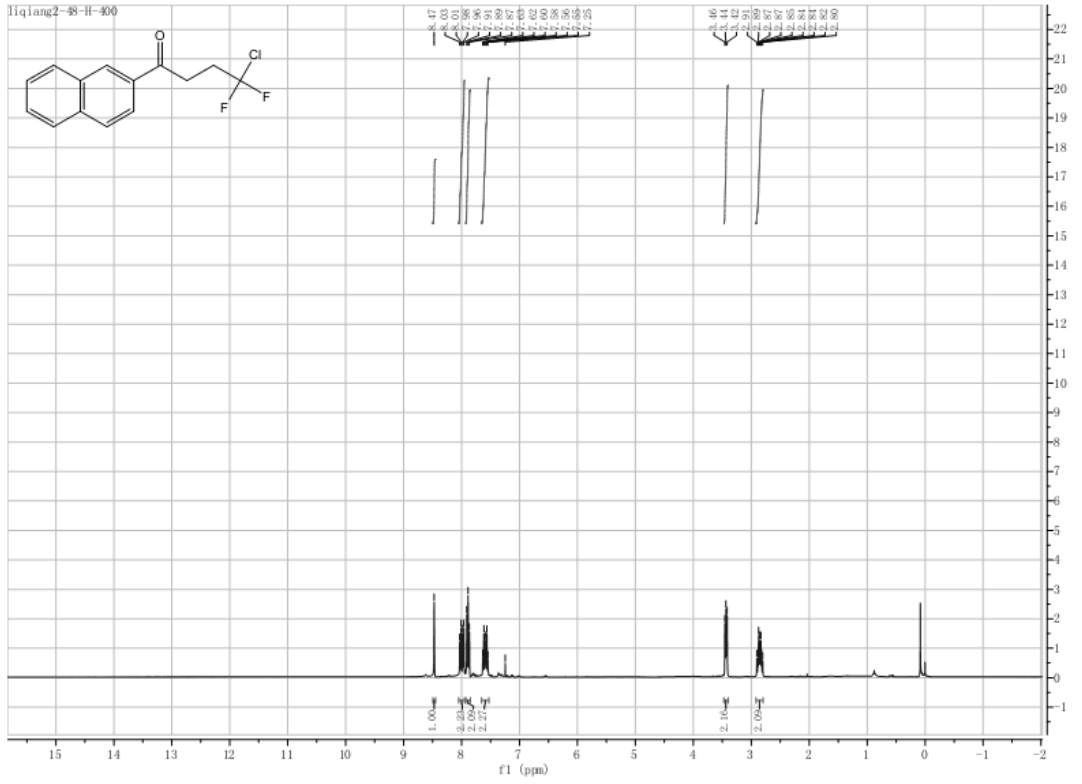
^{19}F NMR spectrum of compound of **3h**



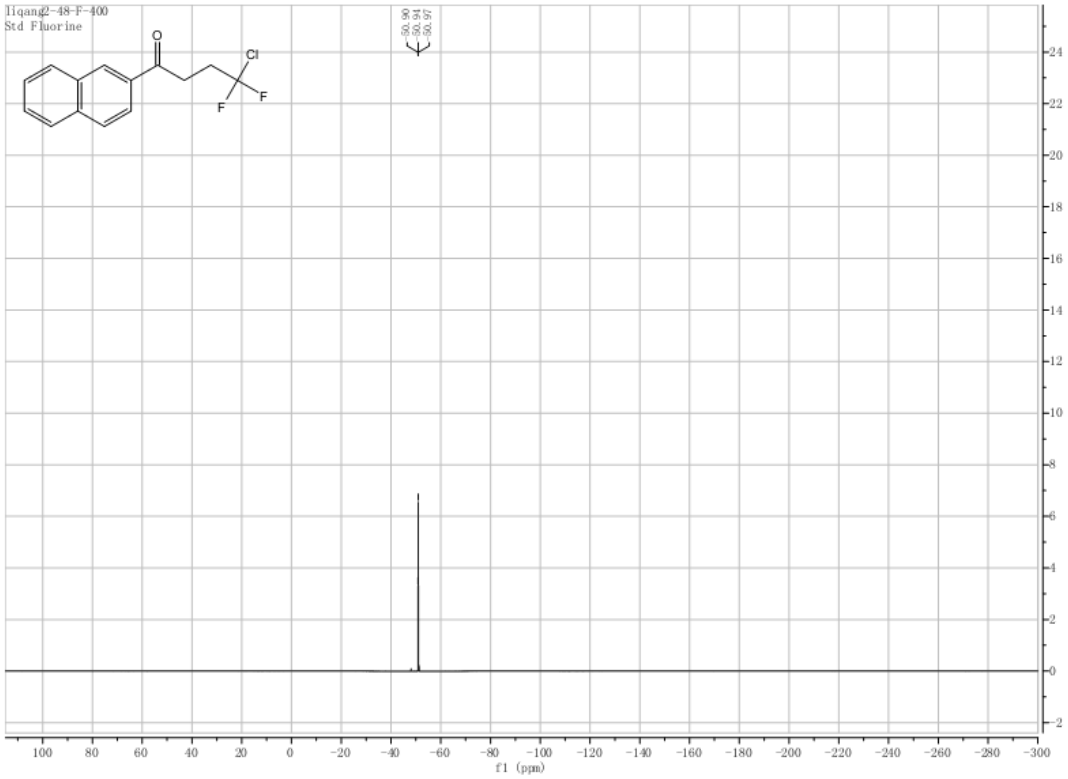
^{13}C NMR spectrum of compound of **3h**



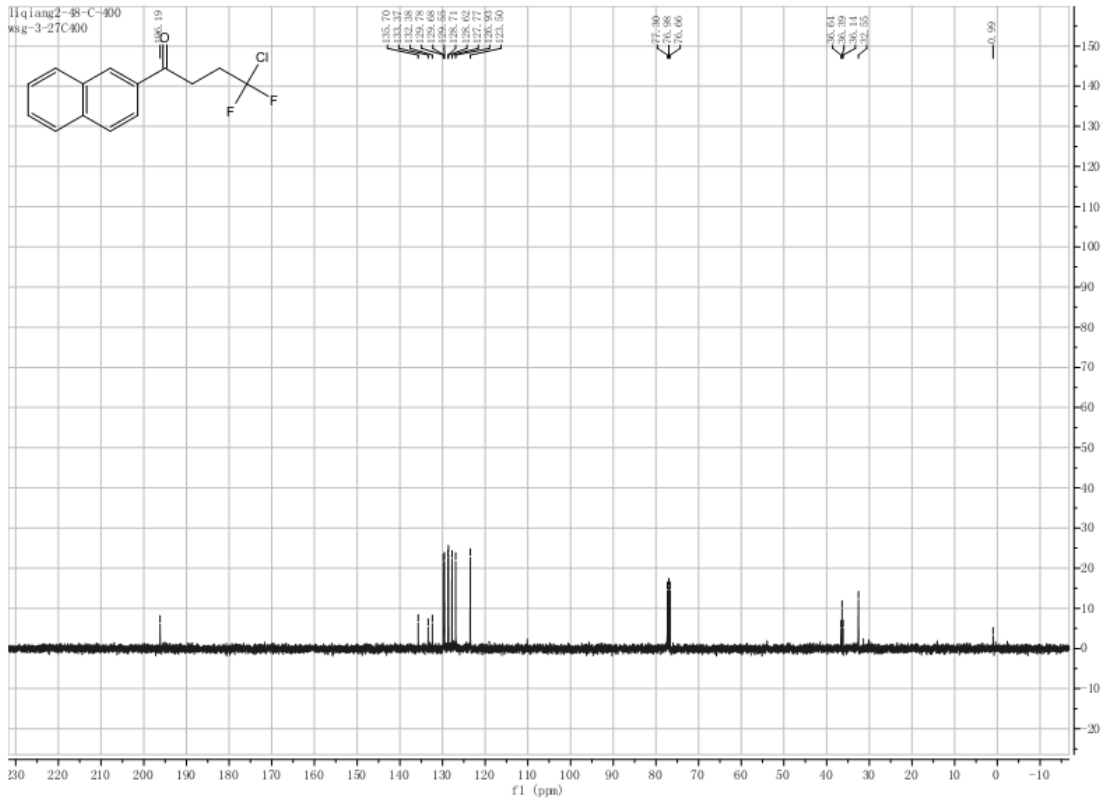
^{1}H NMR spectrum of compound of **3i**



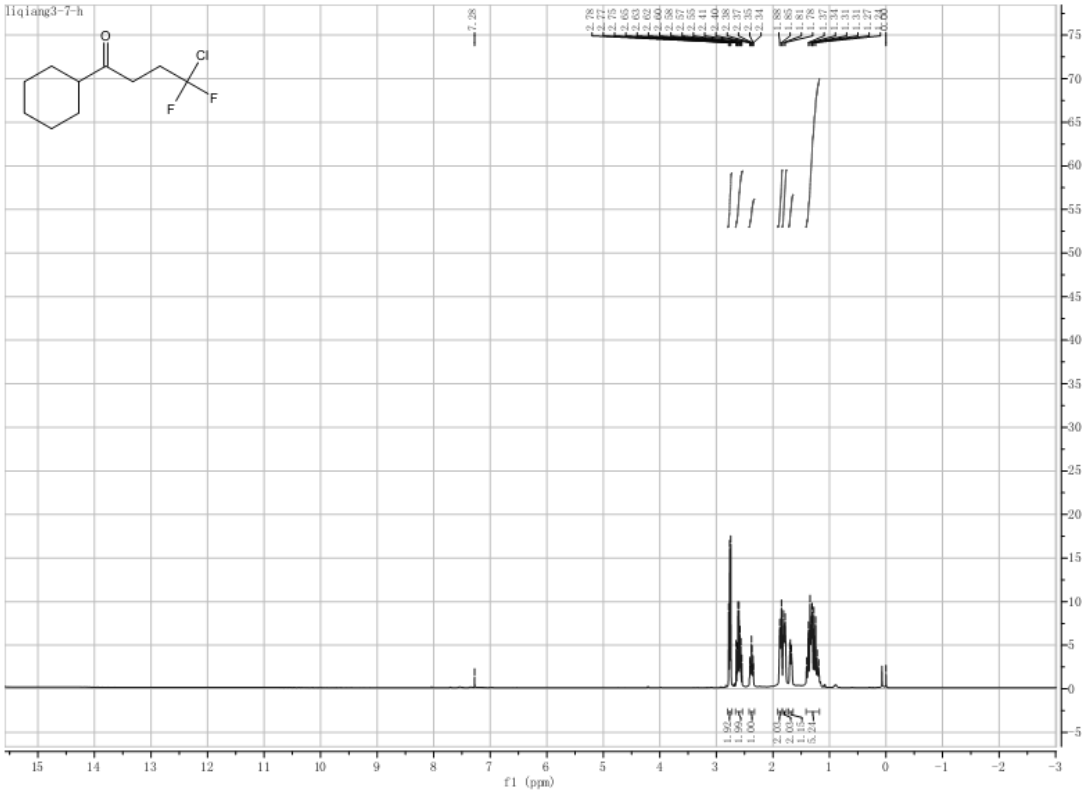
^{19}F NMR spectrum of compound of **3i**



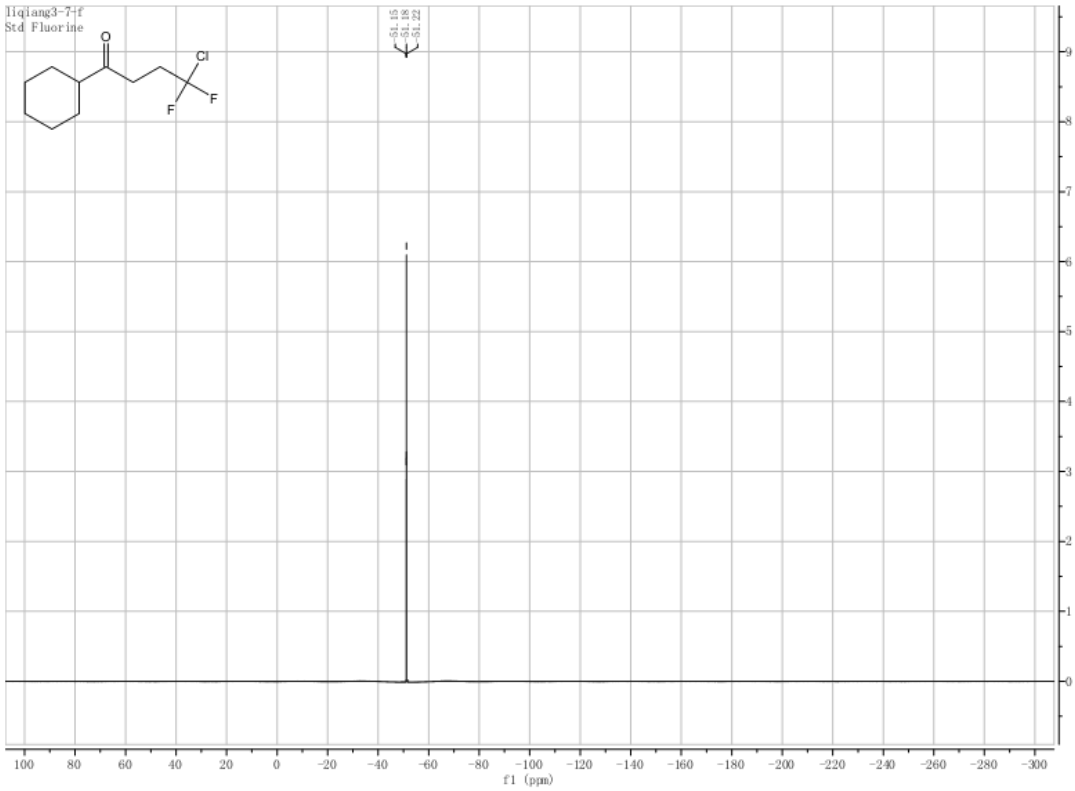
^{13}C NMR spectrum of compound of **3i**



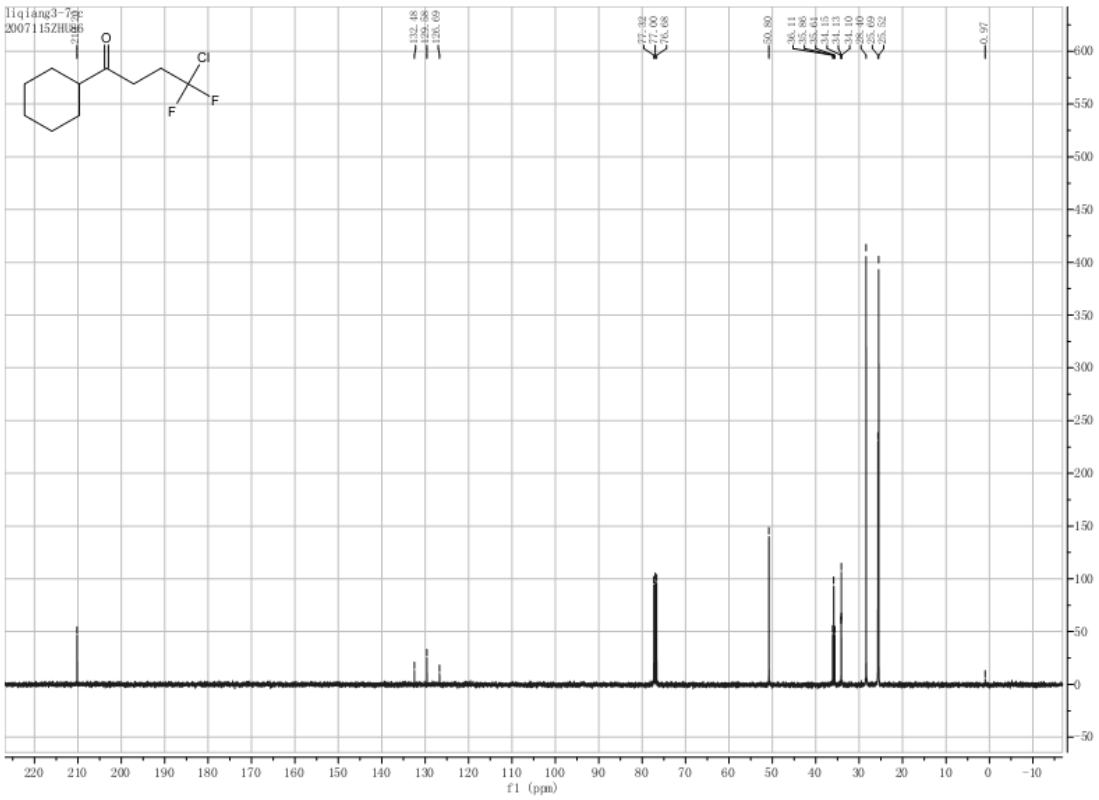
^{1}H NMR spectrum of compound of **3j**



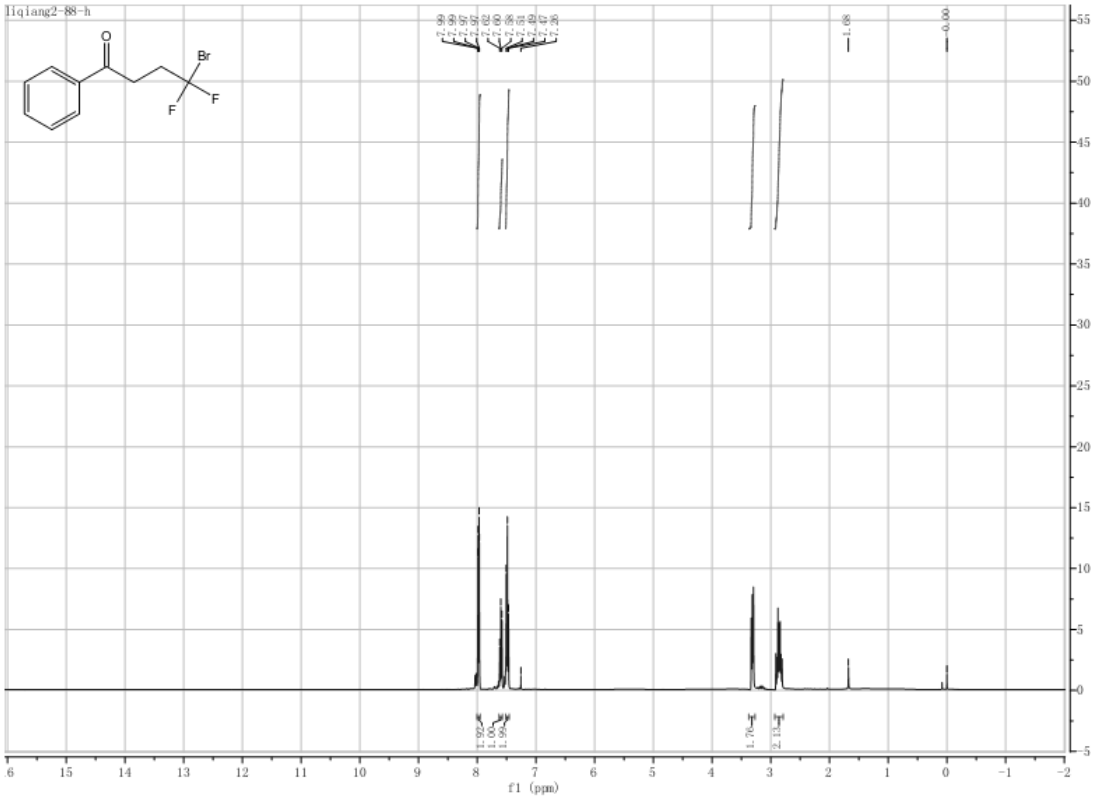
^{19}F NMR spectrum of compound of **3j**



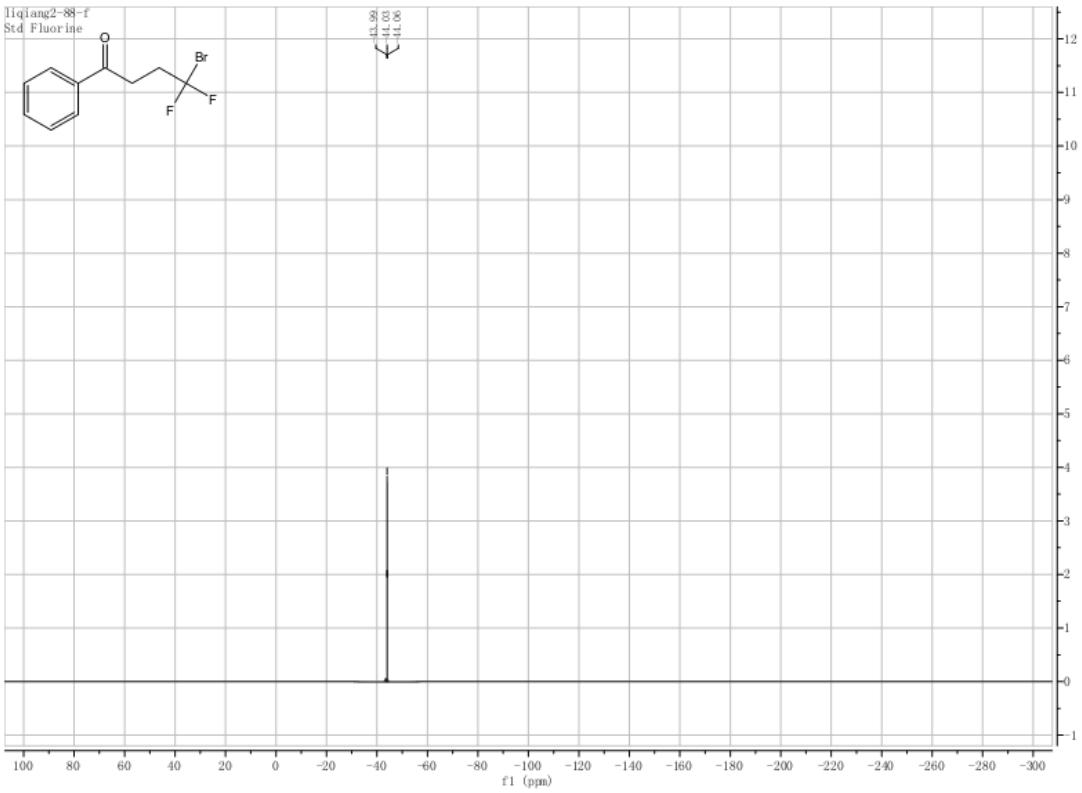
^{13}C NMR spectrum of compound of **3j**



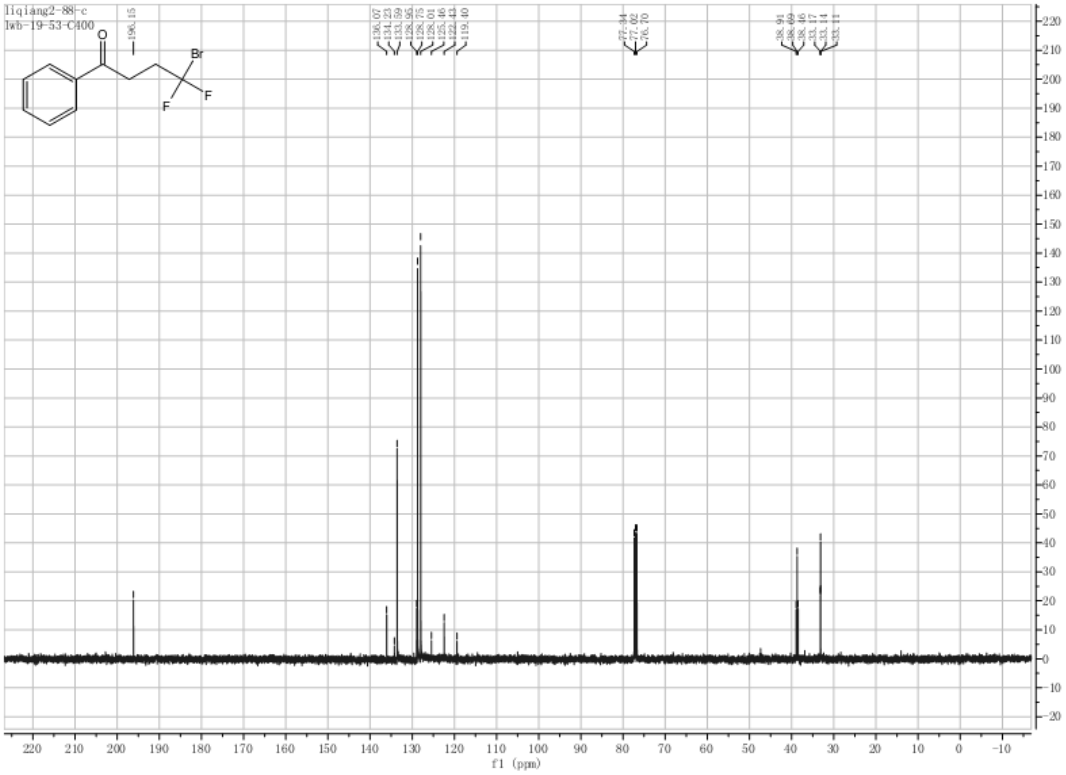
^{1}H NMR spectrum of compound of **4a**



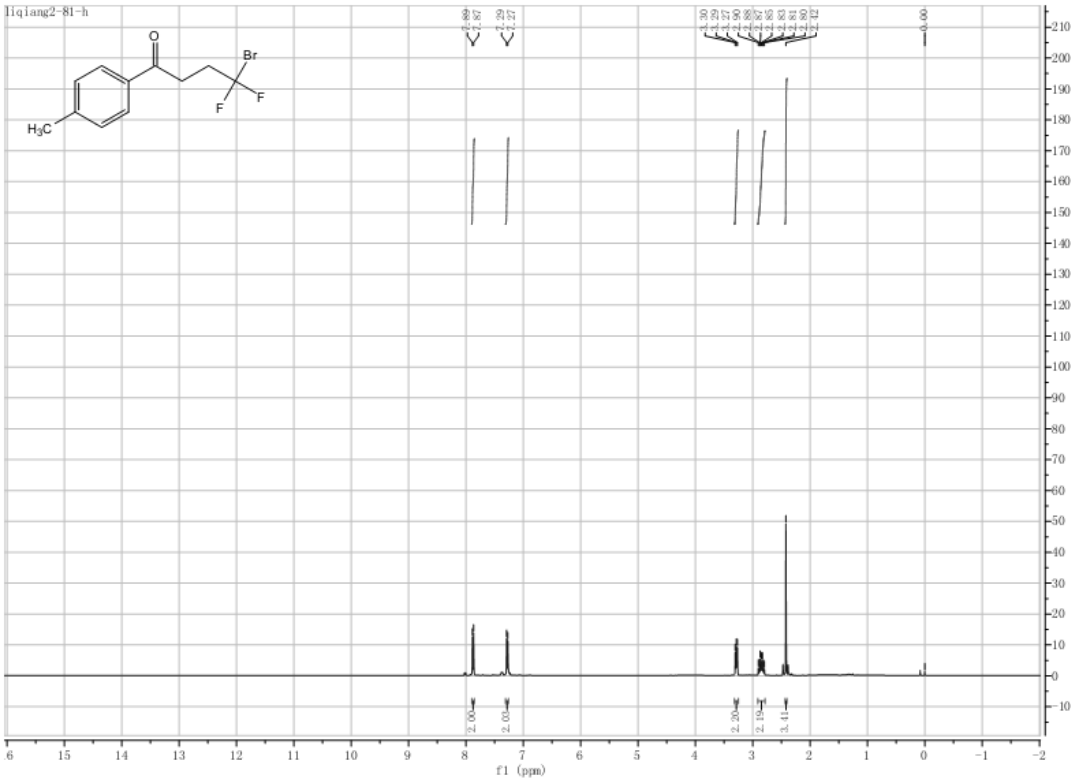
^{19}F NMR spectrum of compound of **4a**



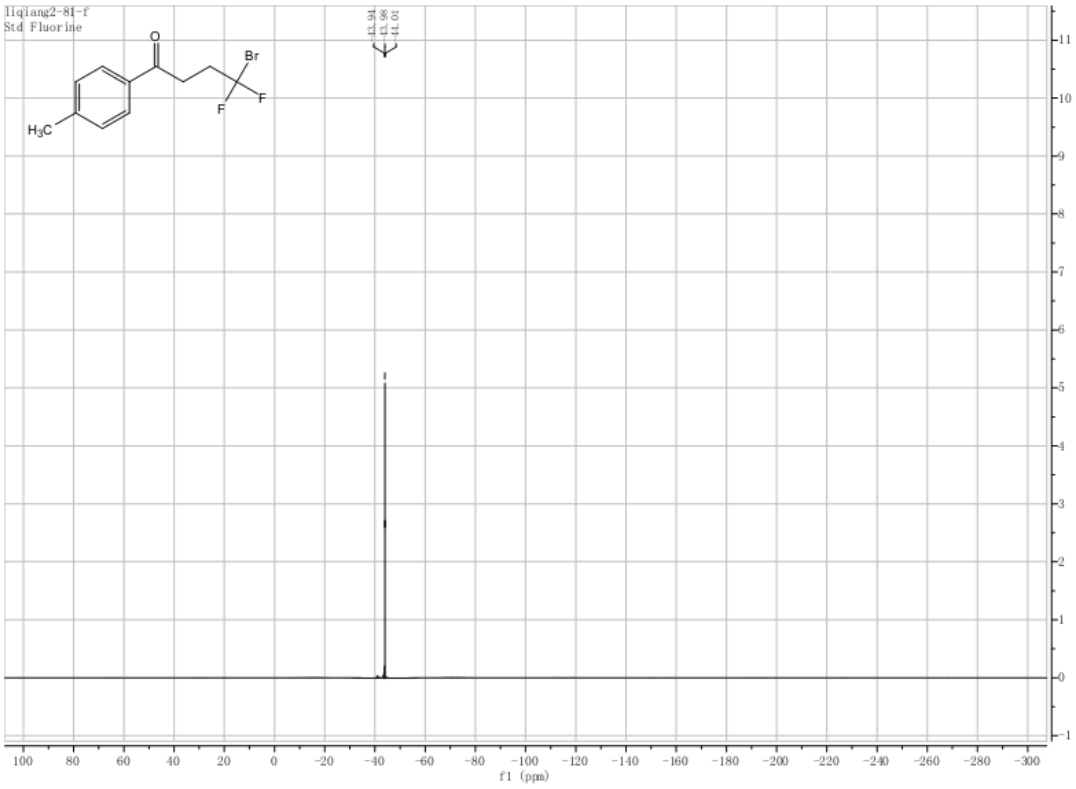
^{13}C NMR spectrum of compound of **4a**



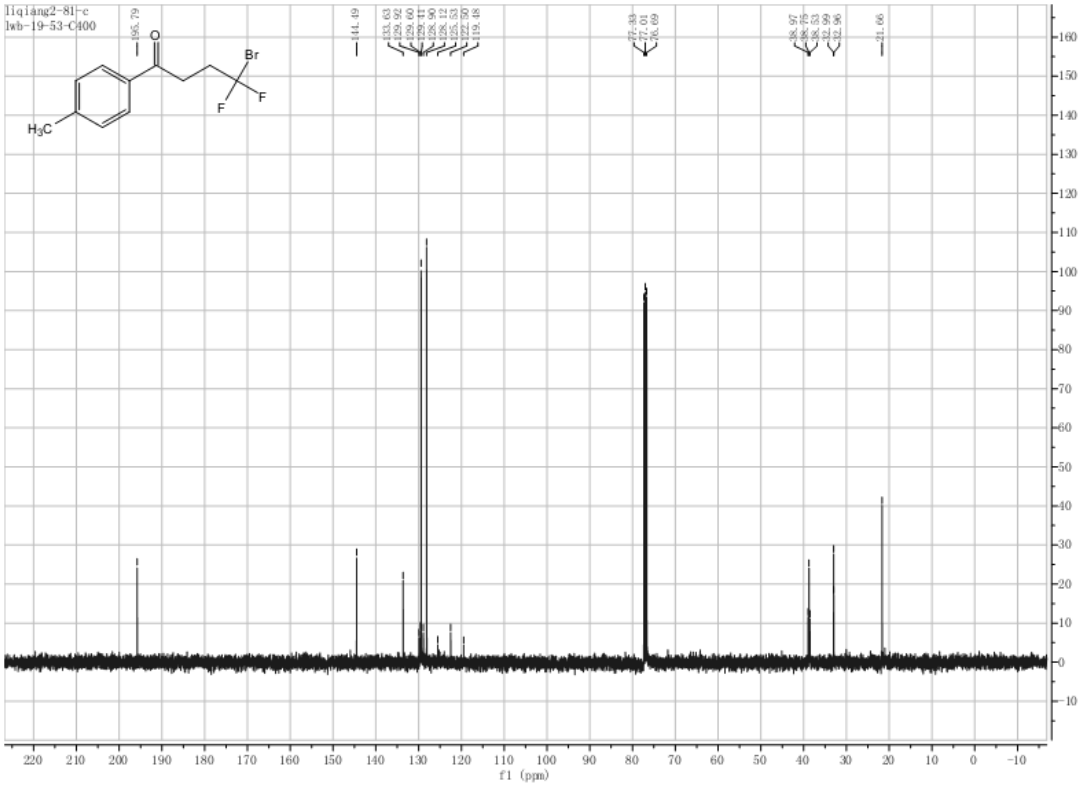
^{1}H NMR spectrum of compound of **4b**



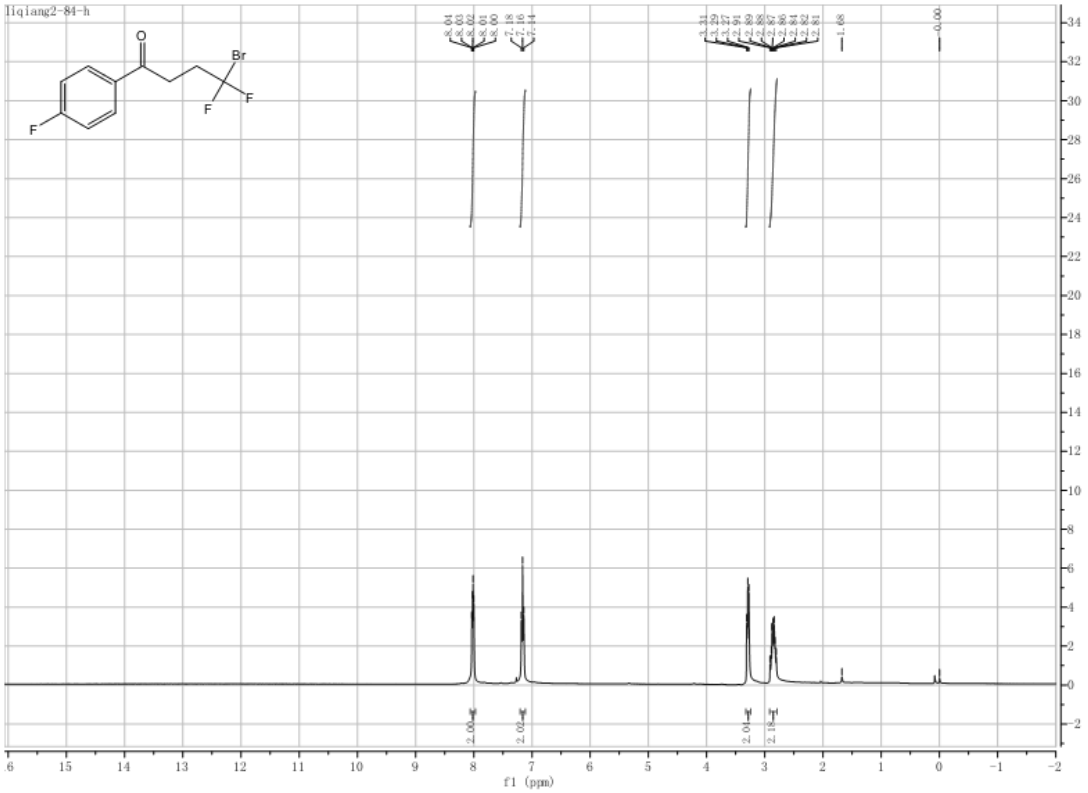
^{19}F NMR spectrum of compound of **4b**



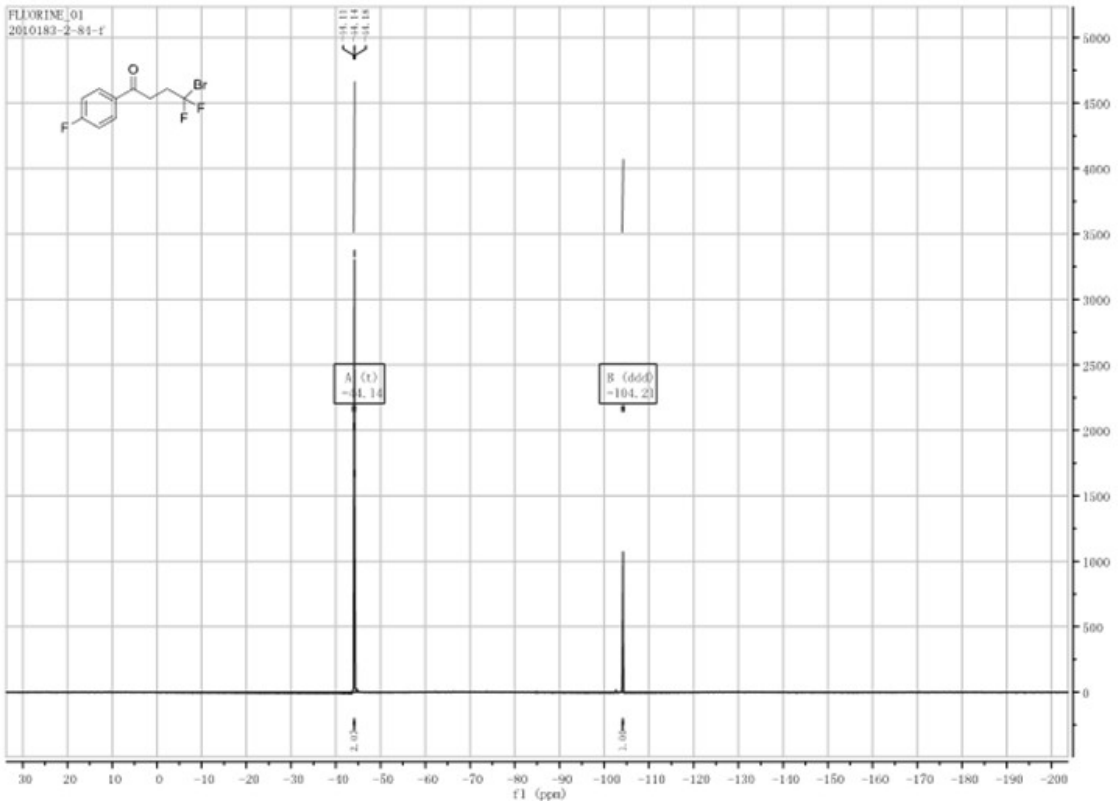
^{13}C NMR spectrum of compound of **4b**



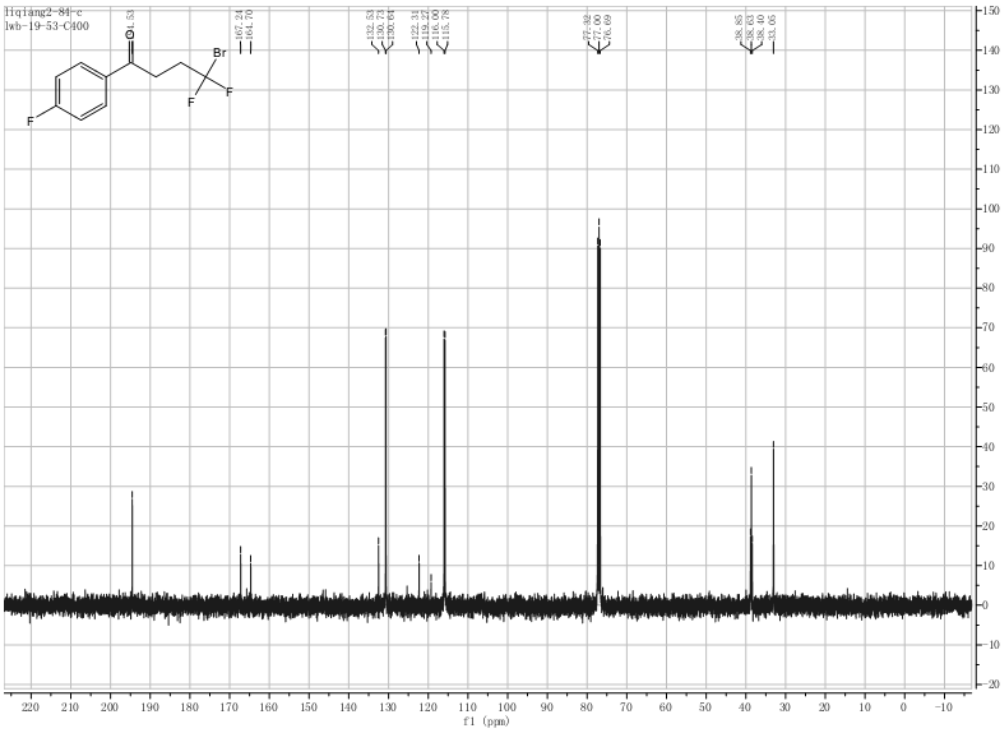
^{1}H NMR spectrum of compound of **4c**



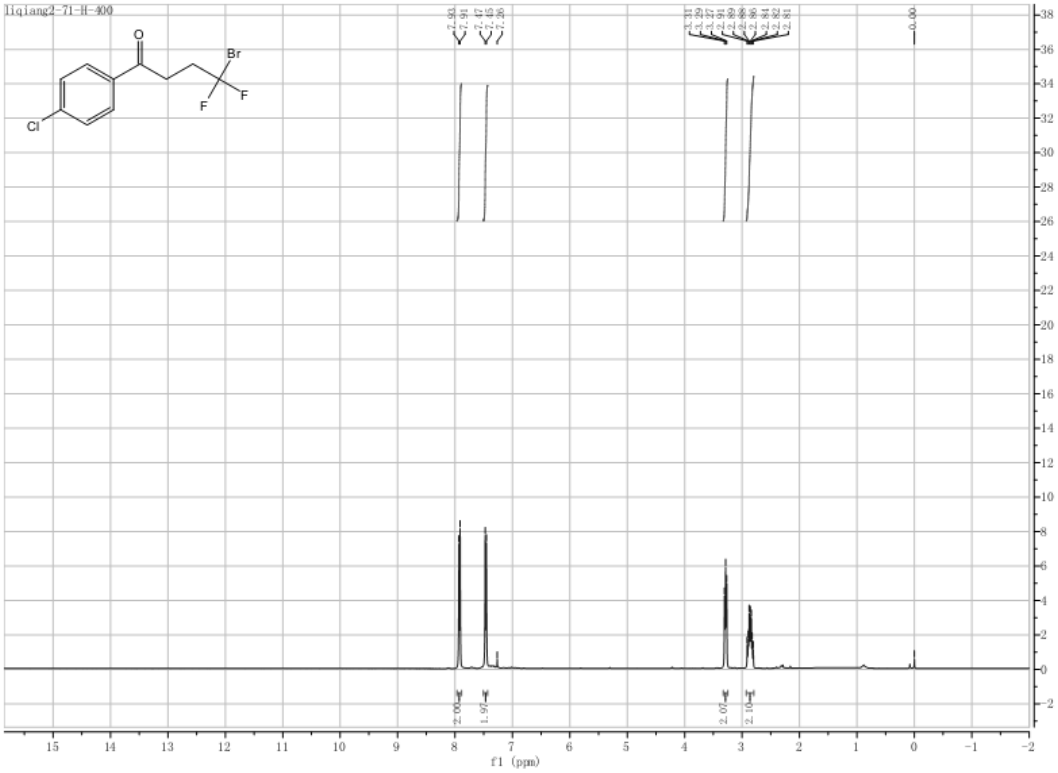
^{19}F NMR spectrum of compound of **4c**



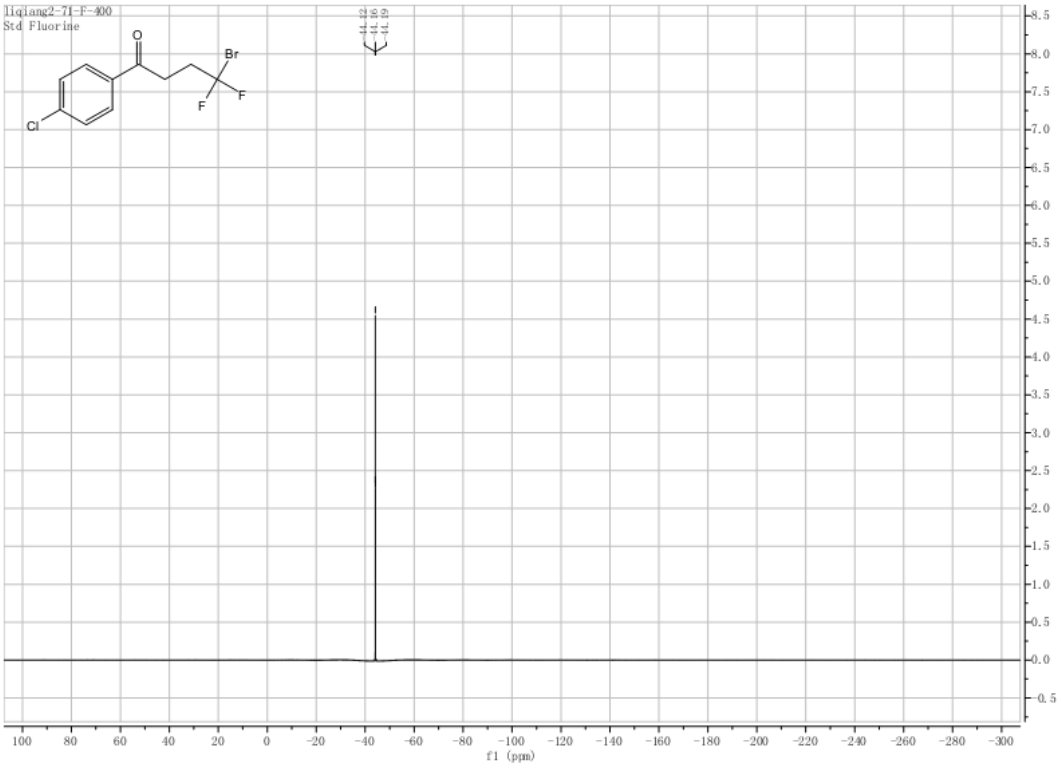
^{13}C NMR spectrum of compound of **4c**



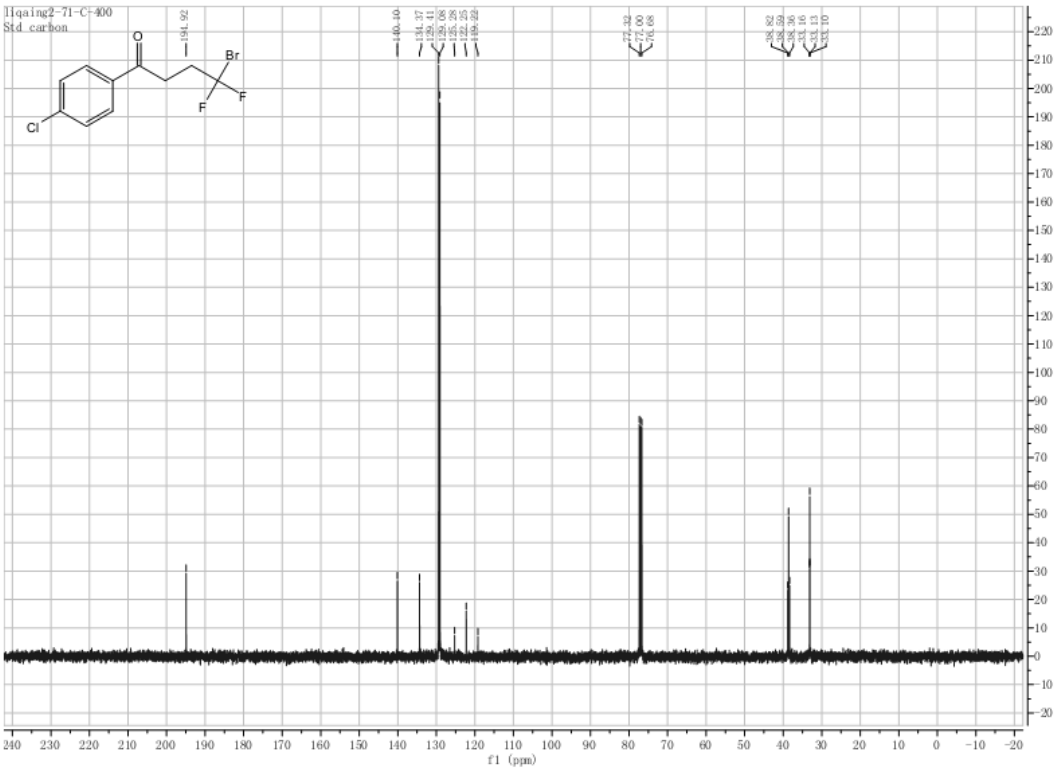
^{1}H NMR spectrum of compound of **4d**



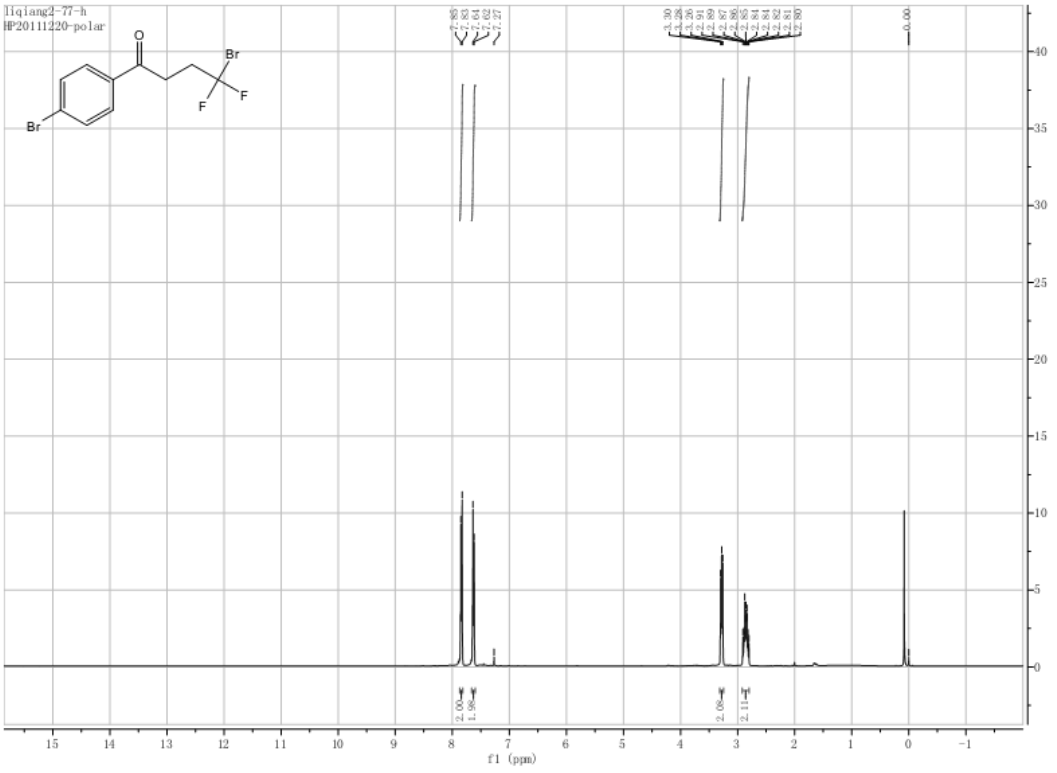
^{19}F NMR spectrum of compound of **4d**



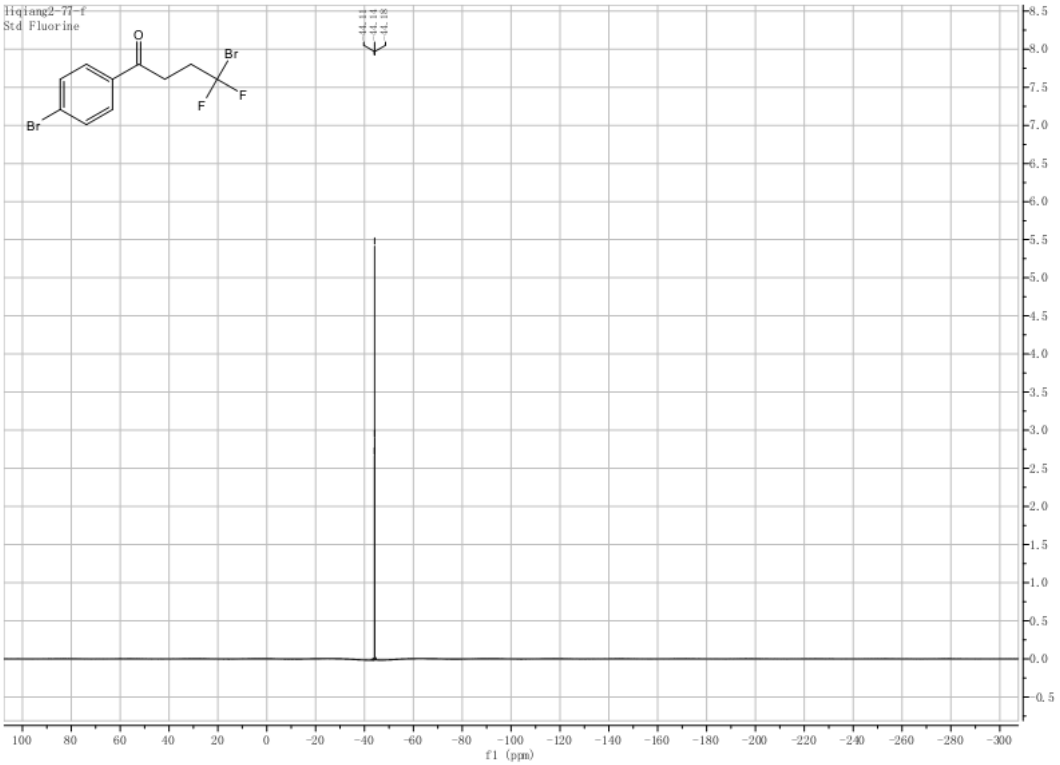
^{13}C NMR spectrum of compound of **4d**



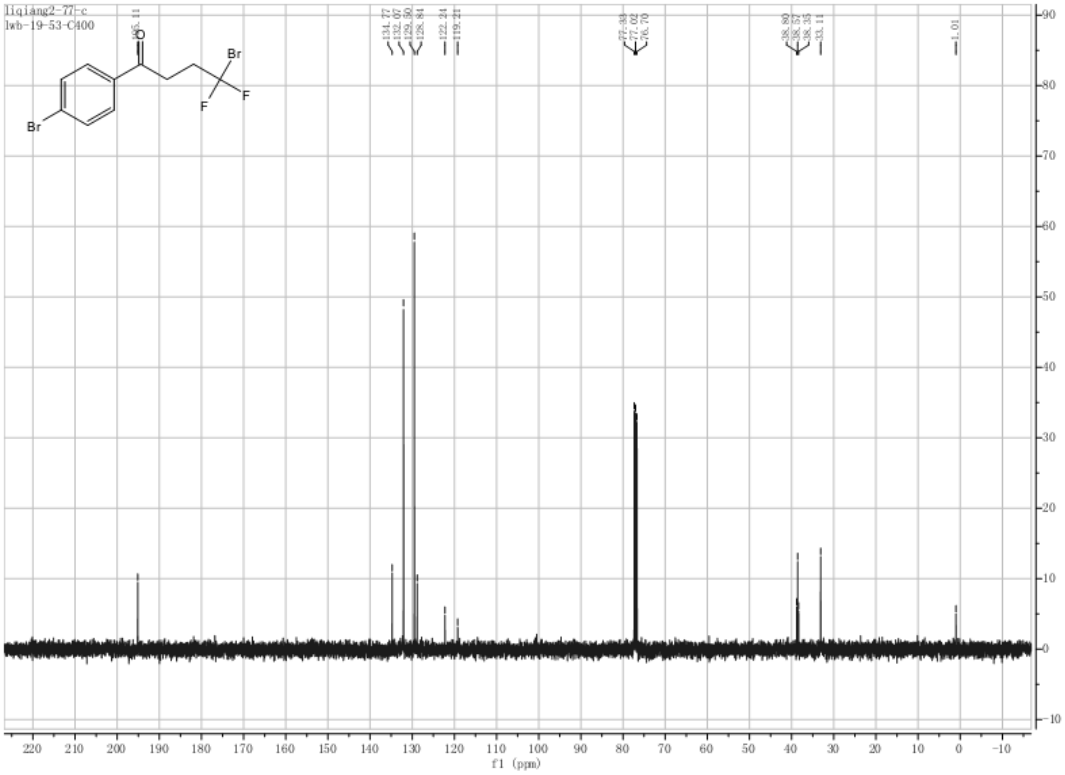
^{1}H NMR spectrum of compound of **4e**



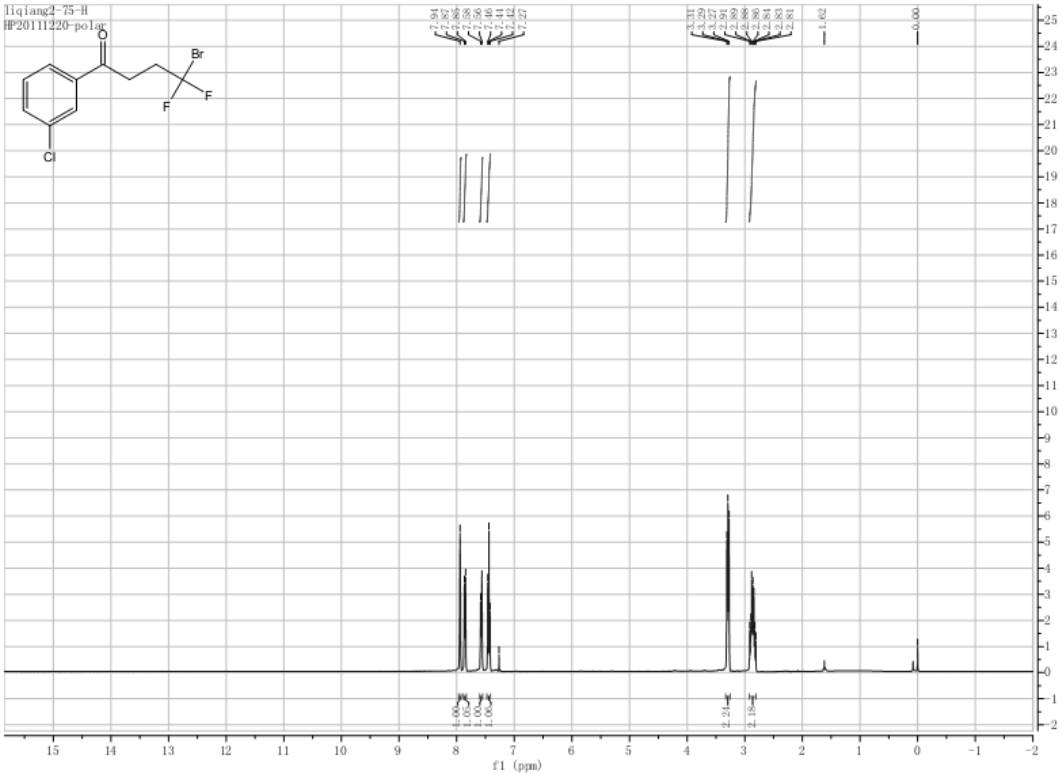
^{19}F NMR spectrum of compound of **4e**



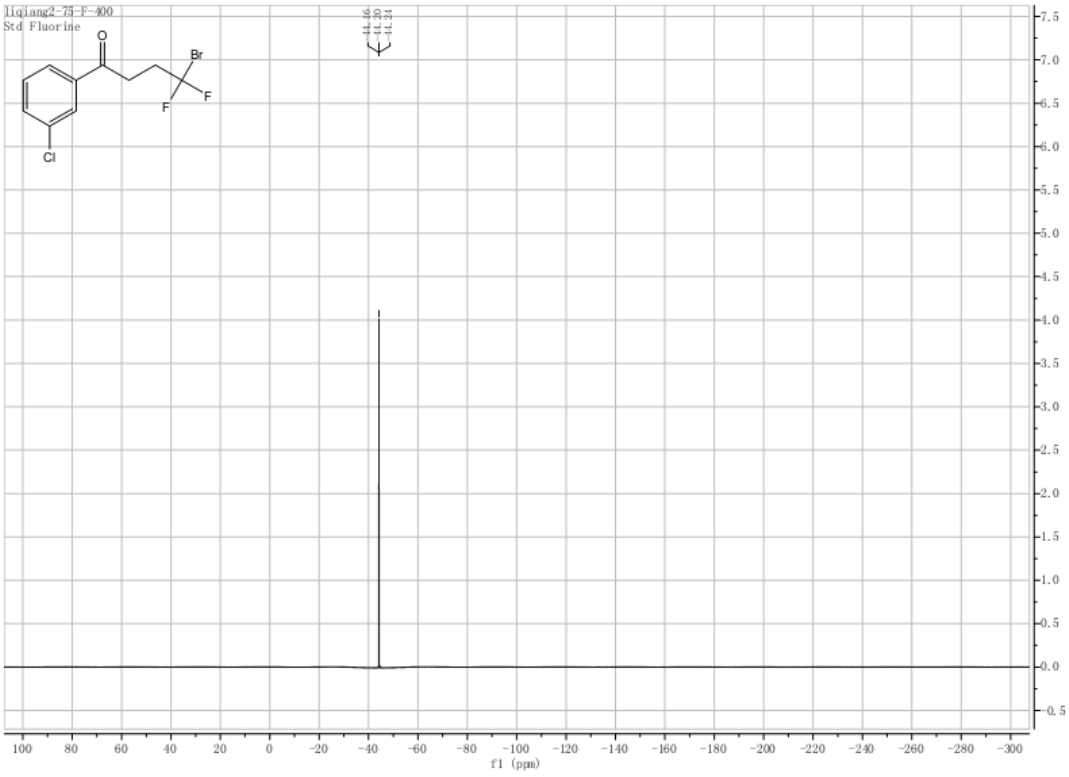
^{13}C NMR spectrum of compound of **4e**



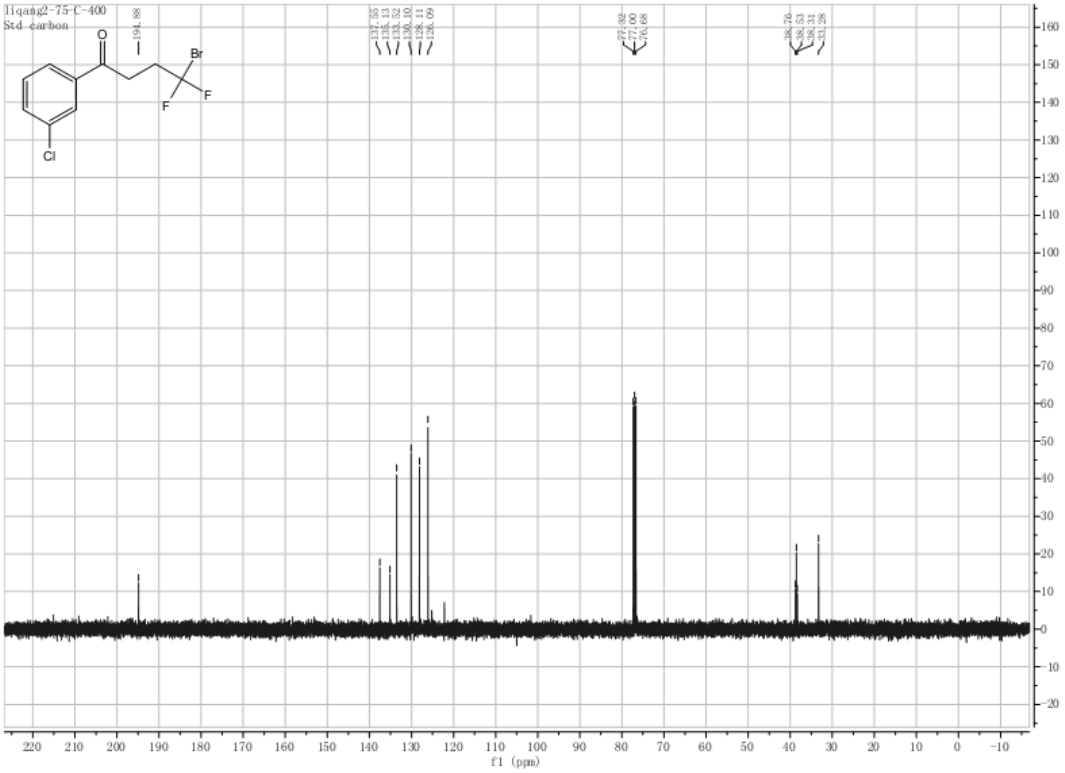
^{1}H NMR spectrum of compound of **4f**



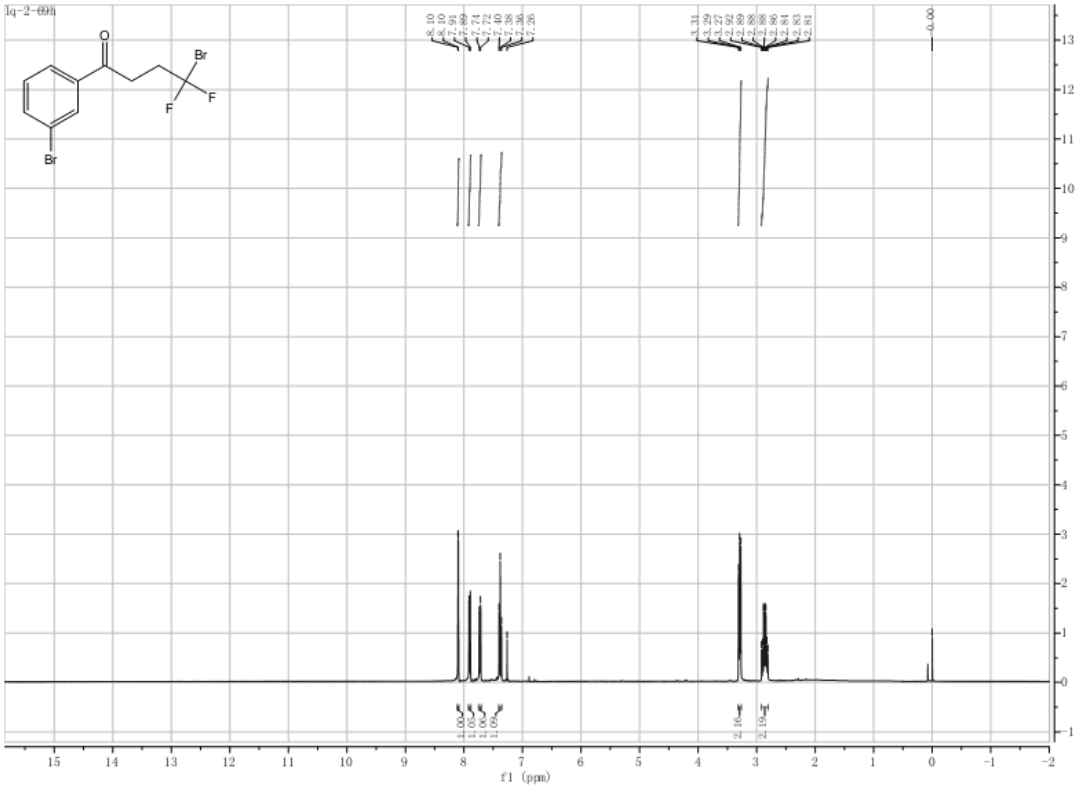
^{19}F NMR spectrum of compound of **4f**



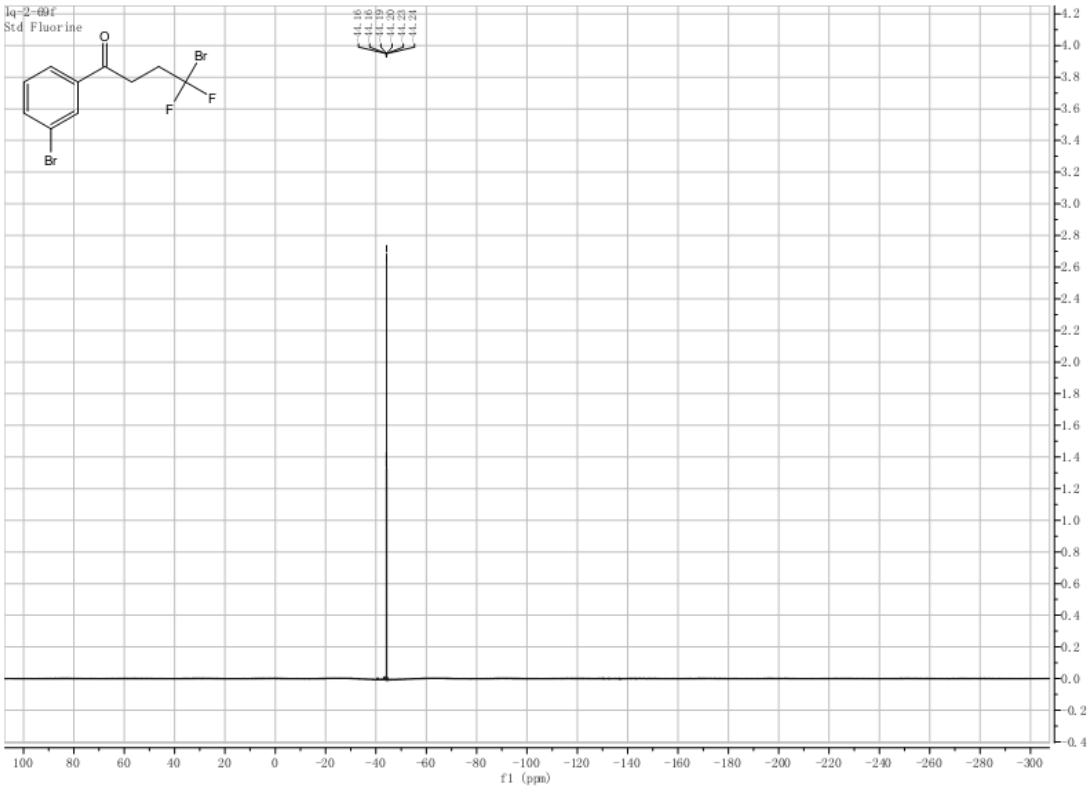
^{13}C NMR spectrum of compound of **4f**



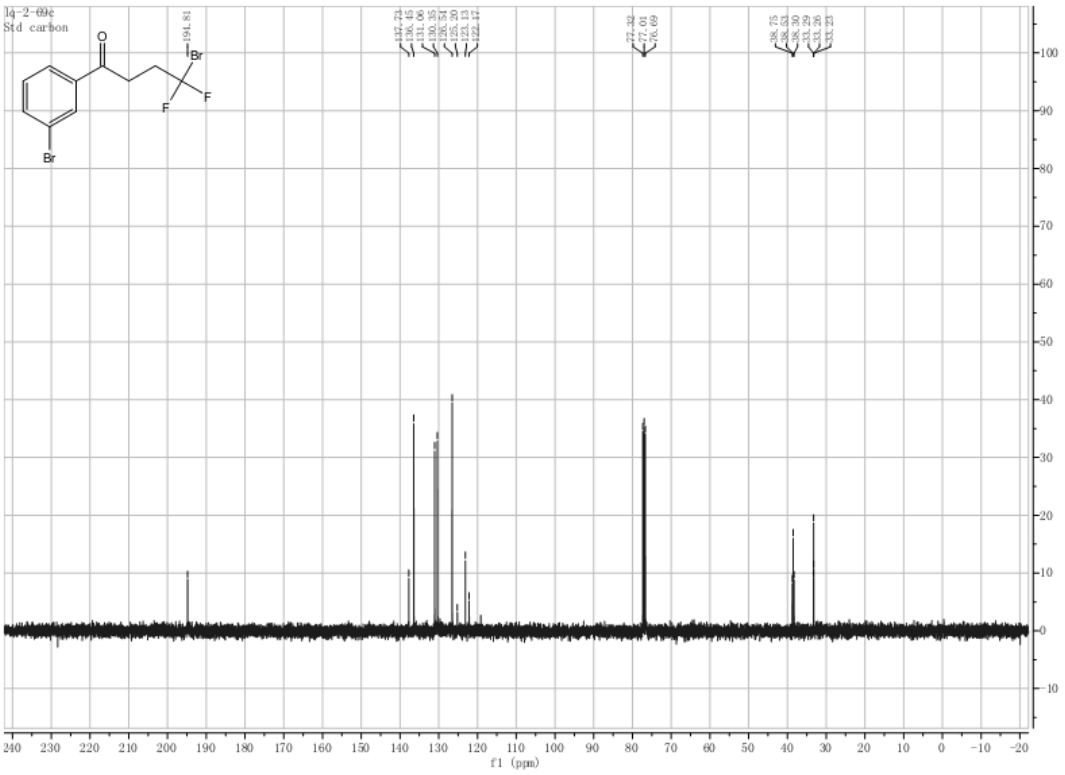
^{1}H NMR spectrum of compound of **4g**



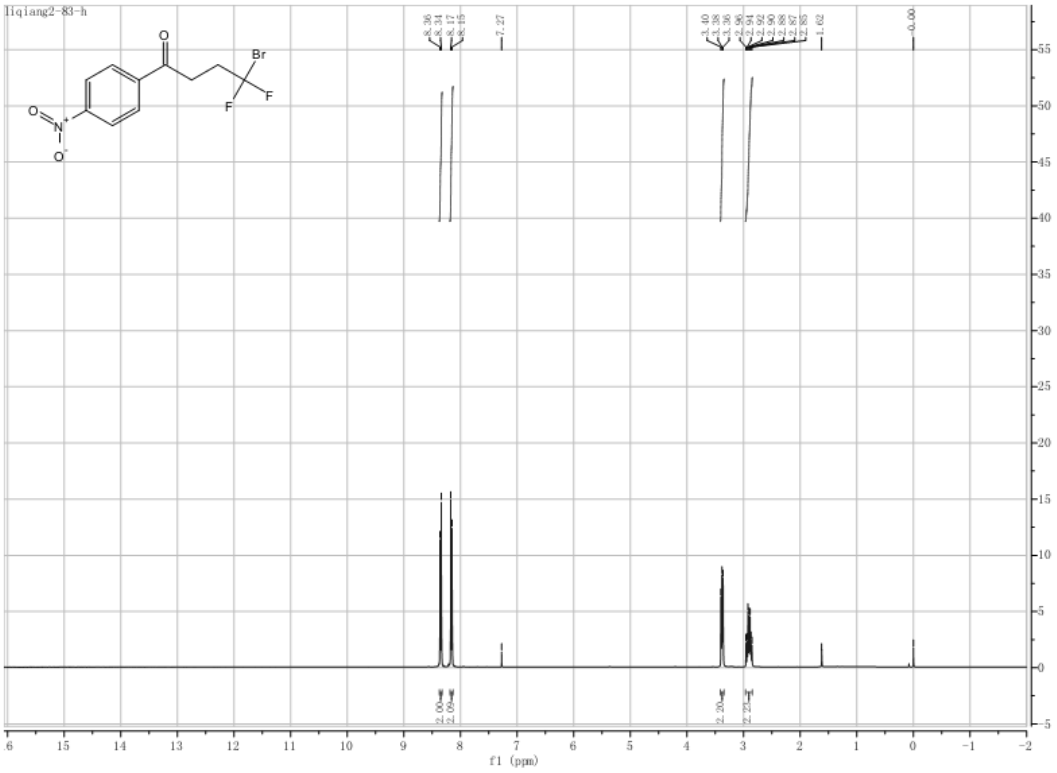
^{19}F NMR spectrum of compound of **4g**



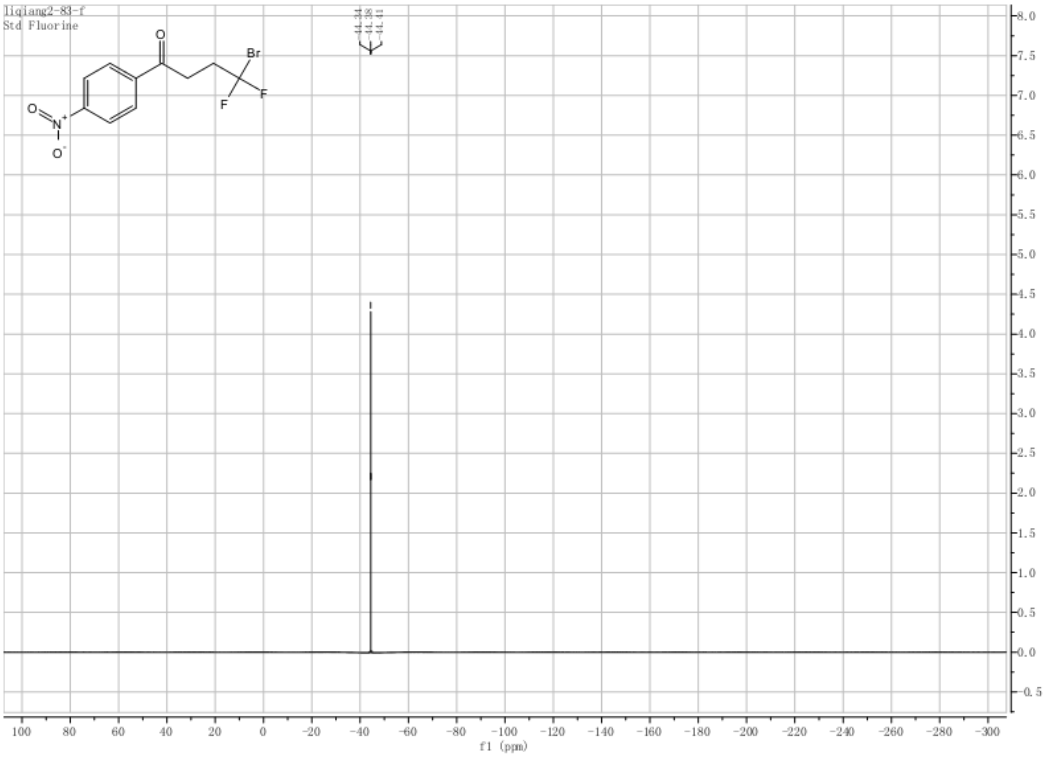
^{13}C NMR spectrum of compound of **4g**



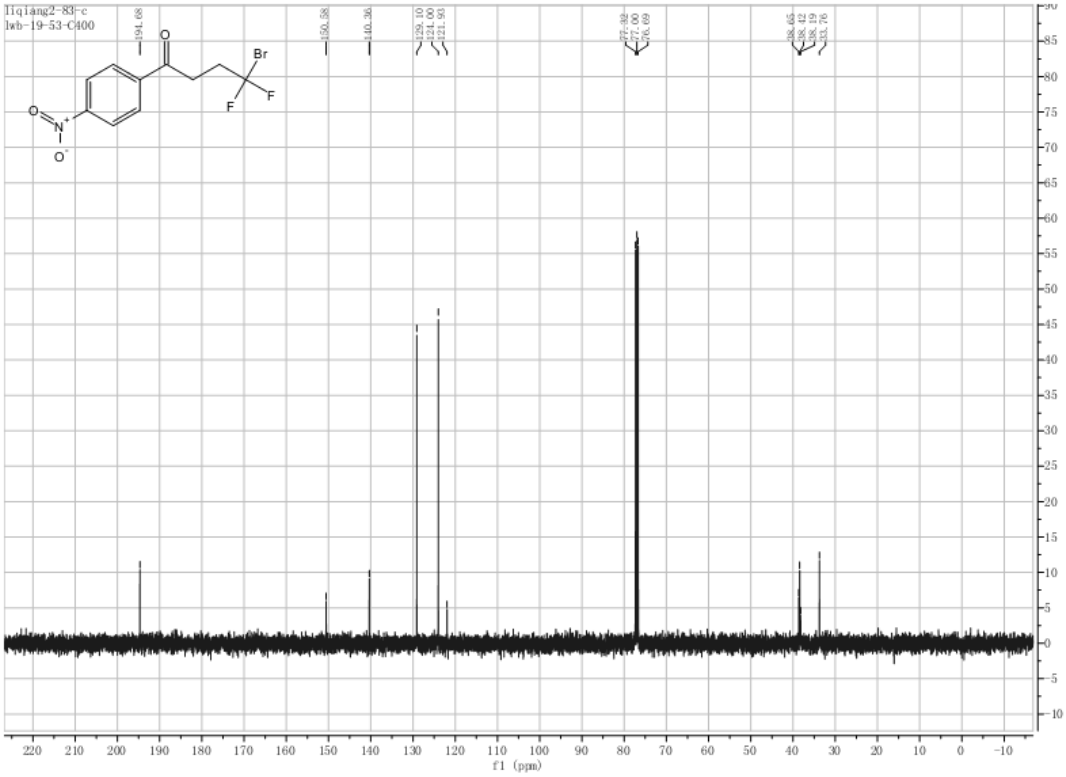
^{1}H NMR spectrum of compound of **4h**



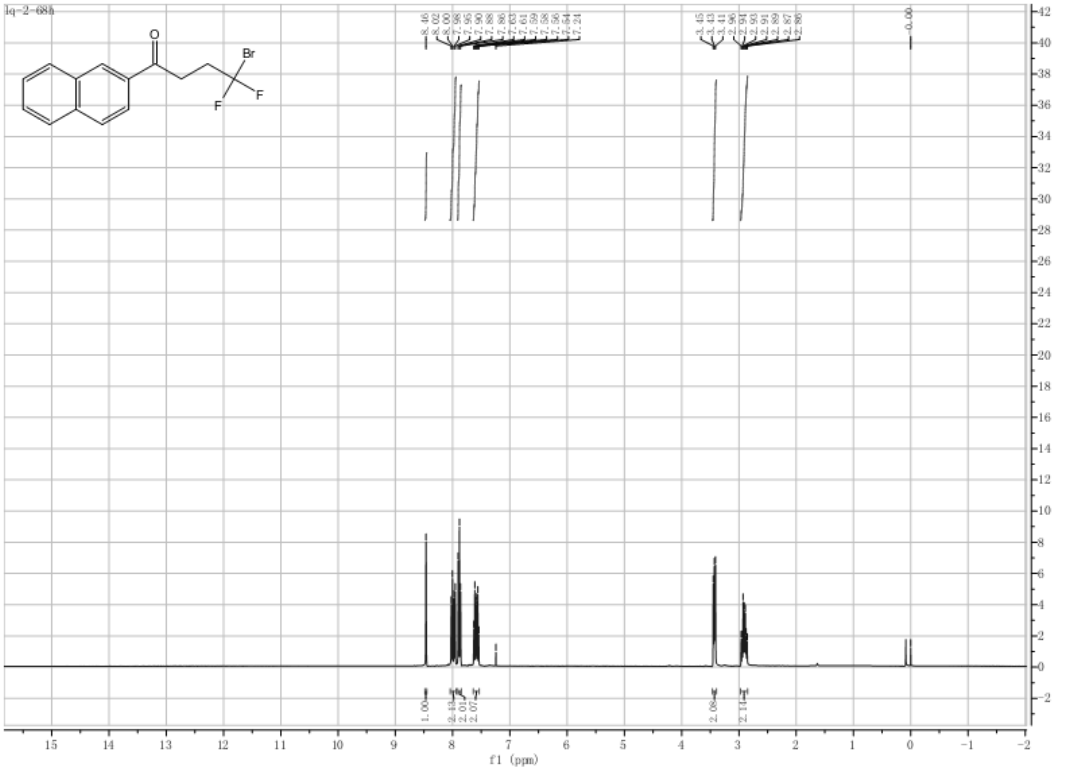
^{19}F NMR spectrum of compound of **4h**



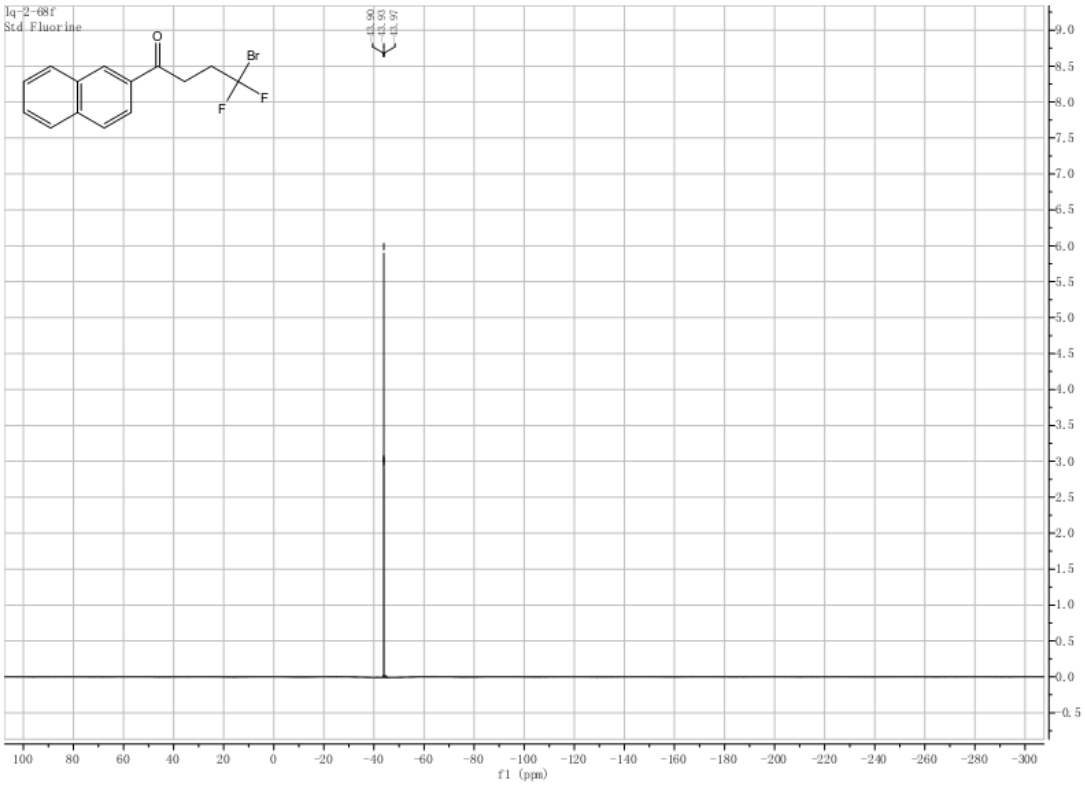
^{13}C NMR spectrum of compound of **4h**



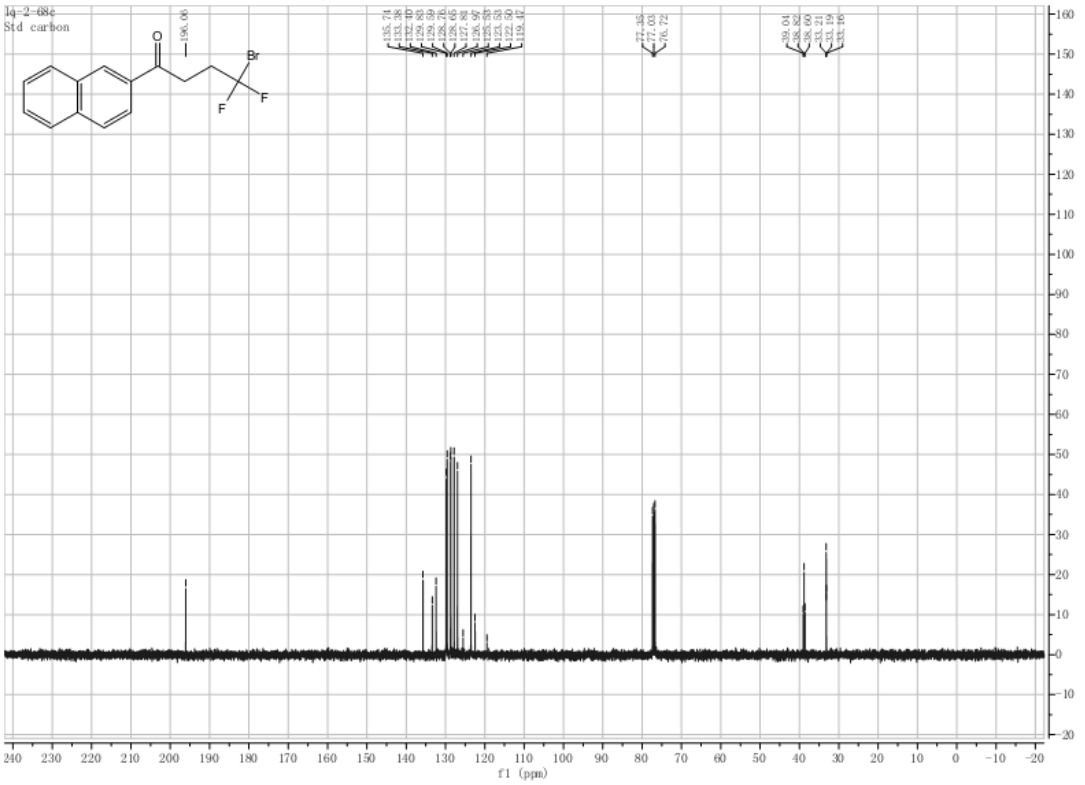
^{1}H NMR spectrum of compound of **4i**



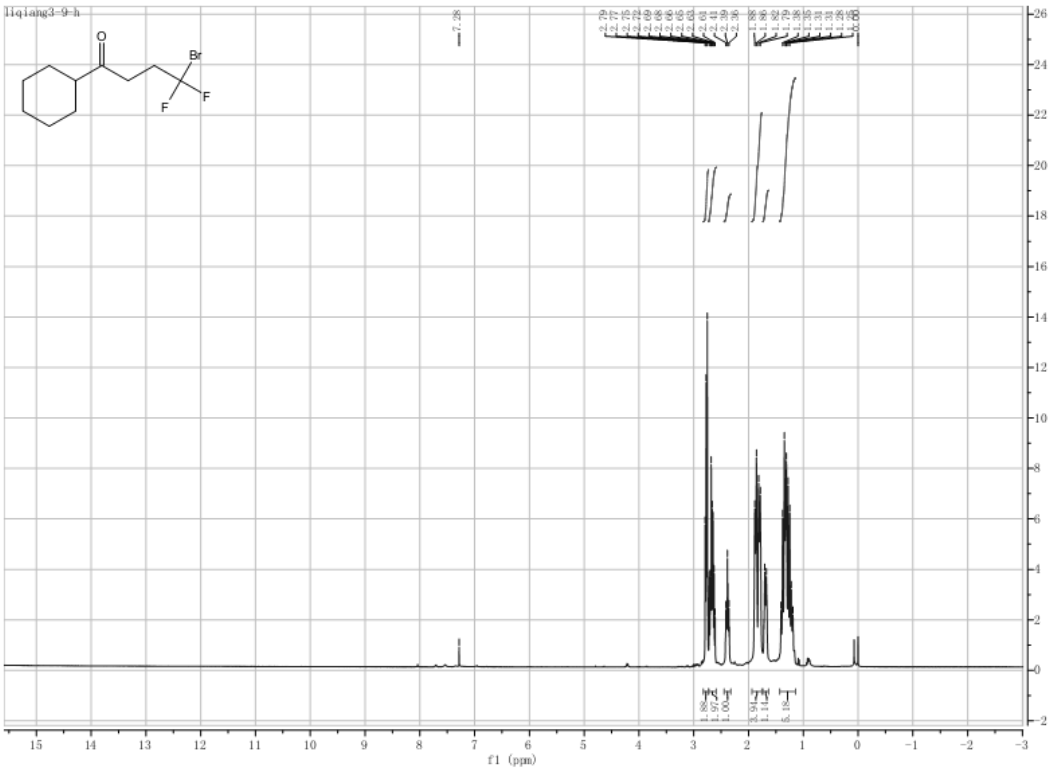
^{19}F NMR spectrum of compound of **4i**



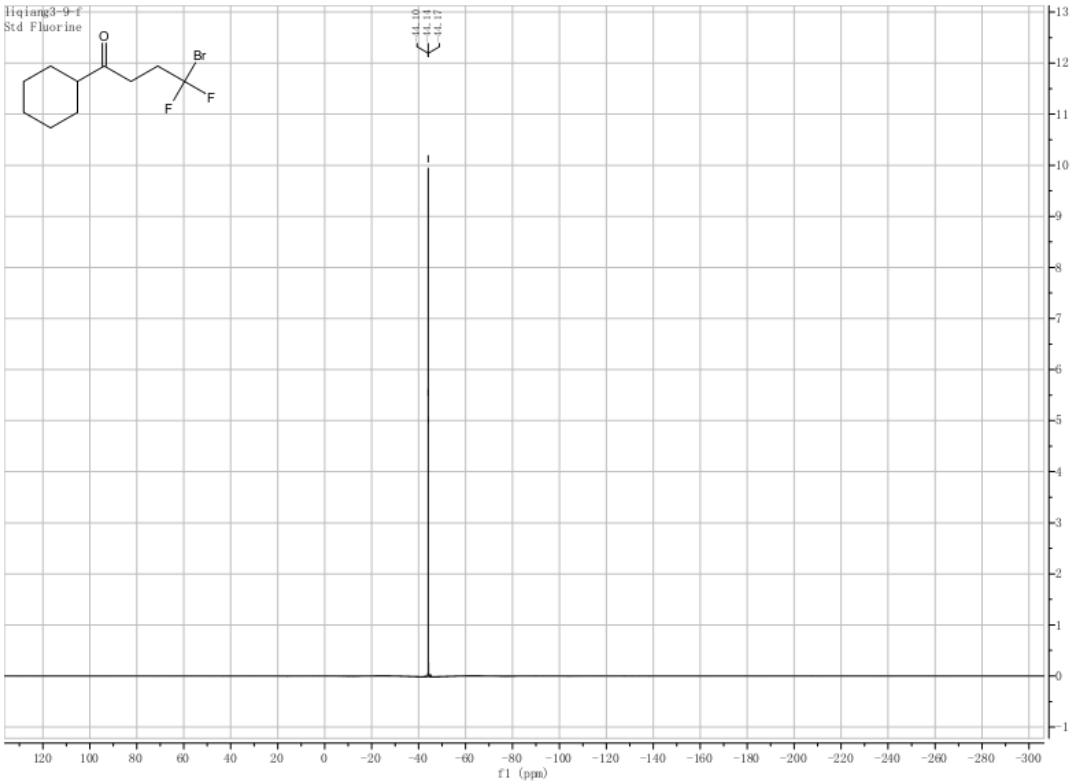
^{13}C NMR spectrum of compound of **4i**



^{1}H NMR spectrum of compound of **4j**



^{19}F NMR spectrum of compound of **4j**



^{13}C NMR spectrum of compound of **4j**