Supplementary Information

Catalytic Asymmetric Intramolecular Propargylation of Cyclopropanols to Access the Cuparane Core

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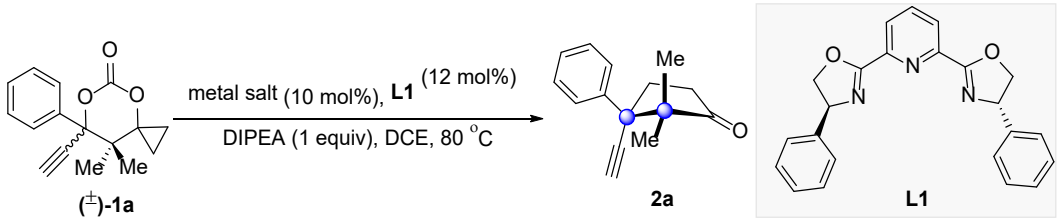
1. General Information

All commercially available reagents were used without further purification unless otherwise noted. All reactions were carried out under a nitrogen atmosphere in oven-dried glassware with magnetic stirring unless otherwise stated. All solvents employed in the reactions were distilled from appropriate drying agents prior to use. ^{1}H NMR and ^{13}C NMR spectra were obtained on an Agilent 400MR spectrometer or Agilent 600MR DD2 spectrometer at ambient temperature. ^{19}F NMR was obtained on an Agilent 600MR spectrometer at ambient temperature. ^{1}H NMR spectra were reported in ppm with either tetramethylsilane or the residual solvent resonance as the internal standard [δ 7.26 ($CHCl_3$); TMS: 0.00 ppm]. ^{13}C NMR spectra were reported in ppm with residual solvent as the internal standard [δ = 77.16 ppm ($CDCl_3$)]. Data were reported as follows: chemical shift (δ, ppm), multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, dd = doublet of doublets, dt = doublet of triplets, td = triplet of doublets), coupling constant (J) in hertz (Hz), and integration. IR spectra were recorded on a Bruker 100 FT-IR spectrometer and are reported in terms of frequency of absorption (cm^{-1}). ESI-HRMS was performed on Bruker Solari X 7.0 T spectrometer. APCI-HRMS was performed on Thermo UHPLC-Q Exactive Plus spectrometer. X-ray crystallography analysis of single crystals was performed on an Agilent SuperNova-CCD X-Ray diffractometer and XtaLAB Synergy. Chiral high-performance liquid chromatography (HPLC) analysis was performed using an Agilent 1260 with commercial ChiralPak 4.6 × 250 mm columns. Melting points were recorded on a SGW X-4A apparatus. Optical rotations were measured with a Rudolph polarimeter.

2. Optimization of Reaction Conditions

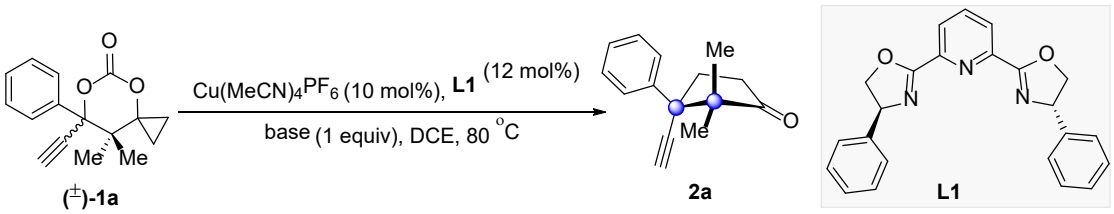
2.1 Table S1. Screening of the metal salts[a]



entry	metal salt	yield (%)[b]	*ee* (%)[c]
1	$Cu(OTf)_2$	40	36
2	$Cu(OAc)_2$	55	2
3	$CuCl_2$	20	30
4	$CuBr_2$	42	38
5	CuBr	35	36
6	CuI	55	36
7	CuCl	15	34
8	CuOTf	22	10
9	$Cu(MeCN)_4BF_4$	67	64
10	$Cu(MeCN)_4PF_6$	75	66

[a]Conditions unless otherwise stated: (±)-**1a** (0.1 mmol), metal salts (10 mol%), **L1** (12 mol%), DIPEA (1 equiv), DCE (4 mL), 80 °C, 48 h. [b]Isolated yield of **2a**. [c]Determined by chiral HPLC analysis.

2.2 Table S2. Screening of the bases[a]

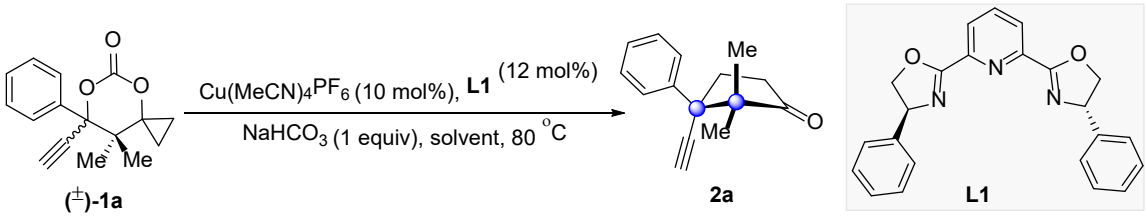


entry	base	yield (%)[b]	*ee* (%)[c]
1	DIPEA	75	66
2	Et_3N	30	48
3	DBU	/	/
4	Na_2CO_3	48	60
5	K_2CO_3	19	8
6	Cs_2CO_3	trace	trace
7	Cy_2NMe	76	66
8	$NaHCO_3$	86	68
9	pyridine	19	34
10	DMAP	8	0
11	PhONa	29	30

12	4-methylmorpholine	29	66
13	1,8-bis(dimethylamino)naphtalene	86	38

[a]Conditions unless otherwise stated: (±)-**1a** (0.1 mmol), $Cu(MeCN)_4PF_6$ (10 mol%), **L1** (12 mol%), base (1 equiv), DCE (4 mL), 80 °C, 48 h. [b]Isolated yield of **2a**. [c]Determined by chiral HPLC analysis.

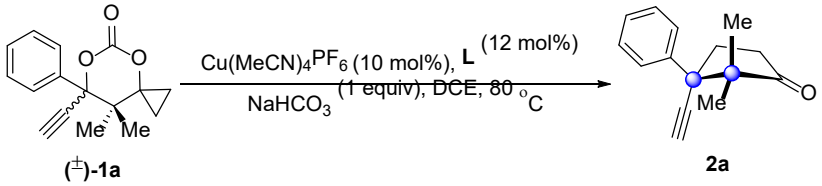
2.3 Table S3. Screening of the solvents[a]



entry	solvent	yield (%)[b]	*ee* (%)[c]
1	THF	29	32
2	1, 4-dioxane	38	44
3	MeOH	38	44
4	$CHCl_3$	60	58
5	MeCN	21	46
6	toluene	33	46
7	EtOAc	33	52
8	DCE	86	68
9	DMF	/	/
10	TFE	45	-52
11	HFIP	22	-40
12	$PhCF_3$	56	66

[a]Conditions unless otherwise stated: (±)-**1a** (0.1 mmol), $Cu(MeCN)_4PF_6$ (10 mol%), **L1** (12 mol%), $NaHCO_3$ (1 equiv), solvent (4 mL), 80 °C, 48 h. [b]Isolated yield of **2a**. [c]Determined by chiral HPLC analysis.

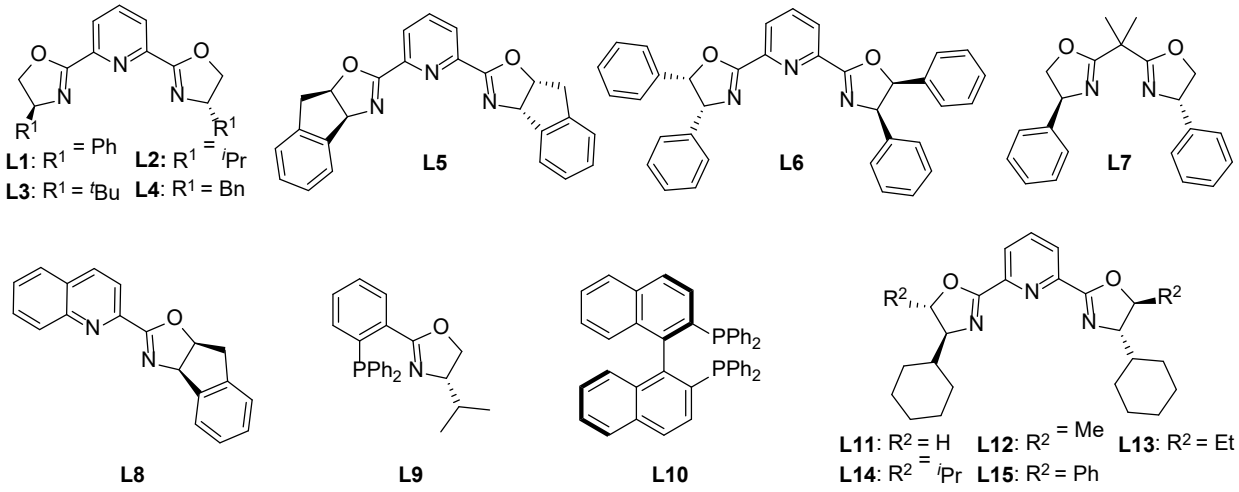
2.4 Table S4. Screening of the ligands[a]



entry	ligand	yield (%)[b]	*ee* (%)[c]
1	**L1**	86	68
2	**L2**	86	64
3	**L3**	19	40
4	**L4**	67	15
5	**L5**	57	−22
6	**L6**	48	6

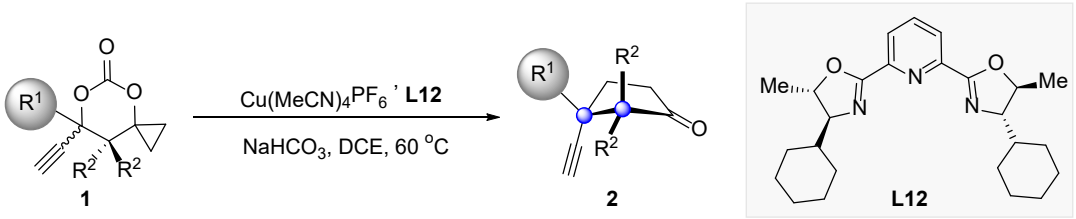
7	**L7–L10**	0	/
8	**L11**	85	90
9	**L12**	90	94
10[d]	**L12**	95	95
11[d]	**L13**	85	95
12[d]	**L14**	85	86
13[d]	**L15**	20	70

[a]Conditions unless otherwise stated: (±)-**1a** (0.1 mmol), $Cu(MeCN)_4PF_6$ (10 mol%), **L** (12 mol%), $NaHCO_3$ (1 equiv), DCE (4 mL), 80 °C, 48 h. [b]Isolated yield of **2a**. [c]Determined by chiral HPLC analysis. [d]Reaction was conducted at 60 ºC.



3. Preparation and Characterization Data of 2

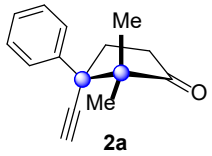
3.1 General procedure for the preparation of 2



A mixture of $Cu(MeCN)_4PF_6$ (3.7 mg, 0.01 mmol, 10 mol%) and **L12** (4.9 mg, 0.012 mmol, 12 mol%) in anhydrous DCE (4 mL) in an oven-dried glass tube was stirred at room temperature for 30 min under a nitrogen atmosphere (balloon). Substrate **1** (0.1 mmol) and $NaHCO_3$ (8.4 mg, 0.1 mmol, 1 equiv) was then added. The resulting mixture was stirred at 60 °C for 24–48 h until **1** was fully consumed as monitored by the TLC analysis. The crude product was concentrated in vacuo, purified by flash column chromatography on silica gel (petroleum ether/EtOAc) to afford compound **2**. The *ee* values were determined by chiral HPLC analysis of the isolated products.

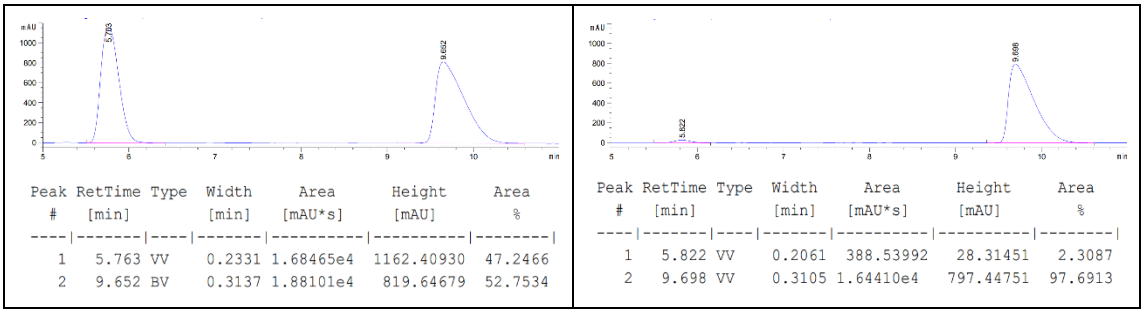
3.2 Characterization data of 2

(*S*)-3-ethynyl-2,2-dimethyl-3-phenylcyclopentan-1-one (2a)



2a

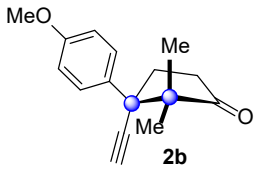
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.4) afforded **2a** (20 mg, 95%) as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.52 (d, J = 7.5 Hz, 2H), 7.38 (t, J = 7.6 Hz, 2H), 7.31 (t, J = 7.3 Hz, 1H), 2.80–2.71 (m, 2H), 2.61–2.54 (m, 1H), 2.41–2.32 (m, 2H), 1.27 (s, 3H), 0.61 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 219.8, 138.8, 128.3, 127.5, 127.5, 87.4, 73.5, 54.3, 51.8, 34.6, 29.6, 20.4, 19.9 ppm. **IR** (KBr): ν_{max} = 3251, 2976, 2931, 1738, 1464, 1382, 1267, 696 cm^{-1}. **HRMS** (APCI) (m/z): Calcd for $C_{15}H_{16}O$, $[M+H]^+$, 213.1274; found: 213.1267. **[α]$_D^{25}$**: −38.3 (*c* 0.1, $CHCl_3$). **m.p.**: 140.0–141.0 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 5.822 min (minor), t_R = 9.698 min (major) (95% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.763	VV	0.2331	1.68465e4	1162.40930	47.2466
2	9.652	BV	0.3137	1.88101e4	819.64679	52.7534

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.822	VV	0.2061	388.53992	28.31451	2.3087
2	9.698	VV	0.3105	1.64410e4	797.44751	97.6913

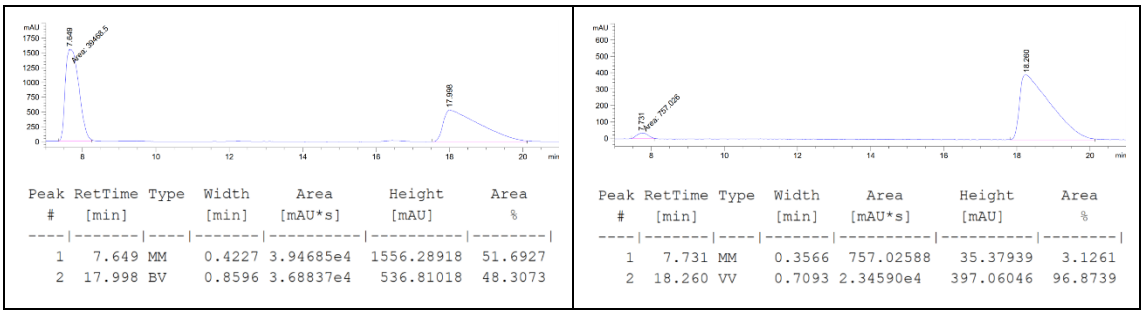
(*S*)-3-ethynyl-3-(4-methoxyphenyl)-2,2-dimethylcyclopentan-1-one (2b)



2b

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.48) afforded **2b** (21.8 mg, 90%) as a colorless oil. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.42 (d, J = 7.8 Hz, 2H), 6.91 (d, J = 7.8 Hz, 2H), 3.82 (s, 3H), 2.78–2.67 (m, 2H), 2.60–2.51 (m, 1H), 2.42–2.28 (m, 2H), 1.24 (s, 3H), 0.61 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 220.0, 159.0, 130.9, 128.7, 113.7, 87.7, 73.4, 55.4, 54.3, 51.2, 34.7, 29.9, 20.4, 19.8 ppm. **IR** (KBr): ν_{max} = 3288, 2969, 2930, 1741, 1513, 1252, 1035, 832 cm^{-1}. **HRMS** (APCI) (m/z): Calcd for $C_{16}H_{18}O_2$, $[M+Na]^+$, 265.1199; found: 265.1204. **[α]$_D^{25}$**: −96.4 (*c* 0.1, $CHCl_3$). **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 7.731 min (minor), t_R = 18.260 min (major) (94%

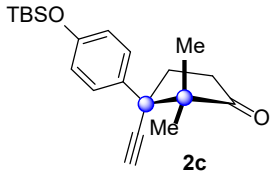
ee).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.649	MM	0.4227	3.94685e4	1556.28918	51.6927
2	17.998	BV	0.8596	3.68837e4	536.81018	48.3073

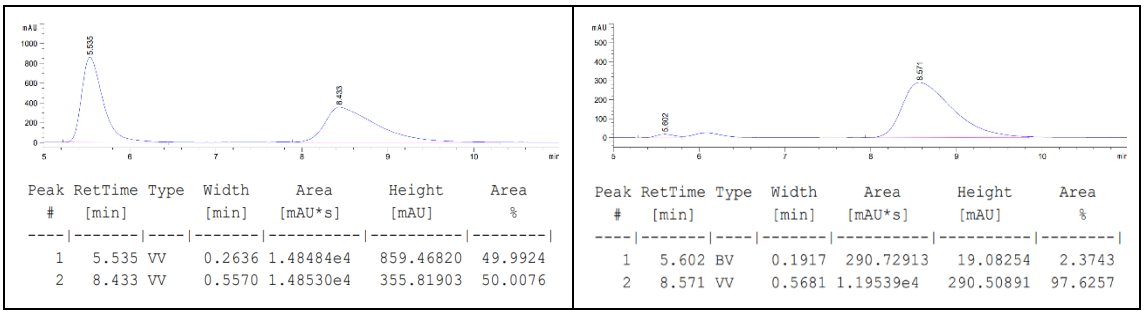
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.731	MM	0.3566	757.02588	35.37939	3.1261
2	18.260	VV	0.7093	2.34590e4	397.06046	96.8739

(*S*)-3-(4-((*tert*-butyldimethylsilyl)oxy)phenyl)-3-ethynyl-2,2-dimethylcyclopentan-1-one (2c)



2c

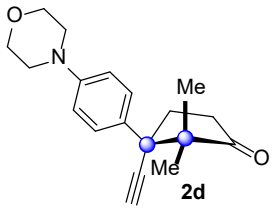
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.6) afforded **2c** (32.9 mg, 96%) as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.35 (d, J = 8.4 Hz, 2H), 6.83 (d, J = 8.4 Hz, 2H), 2.76–2.67 (m, 2H), 2.59–2.51 (m, 1H), 2.38–2.29 (m, 2H), 1.23 (s, 3H), 0.99 (s, 9H), 0.59 (s, 3H), 0.20 (s, 6H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 220.1, 155.1, 131.4, 128.6, 119.8, 87.7, 73.3, 54.3, 51.3, 34.7, 29.8, 25.8, 20.4, 19.8, 18.3, −4.3 ppm. **IR** (KBr): ν_{max} = 3304, 2957, 2859, 1743, 1510, 1260, 1084, 917, 840 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{21}H_{30}O_2Si$, $[M+Na]^+$, 365.1907; found: 365.1903. **[α]$_D^{25}$**: −79.4 (*c* 0.32, $CHCl_3$). **m.p.**: 94.2–96.6 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 1 : 99, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 5.602 min (minor), t_R = 8.571 min (major) (95% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.535	VV	0.2636	1.48484e4	859.46820	49.9924
2	8.433	VV	0.5570	1.48530e4	355.81903	50.0076

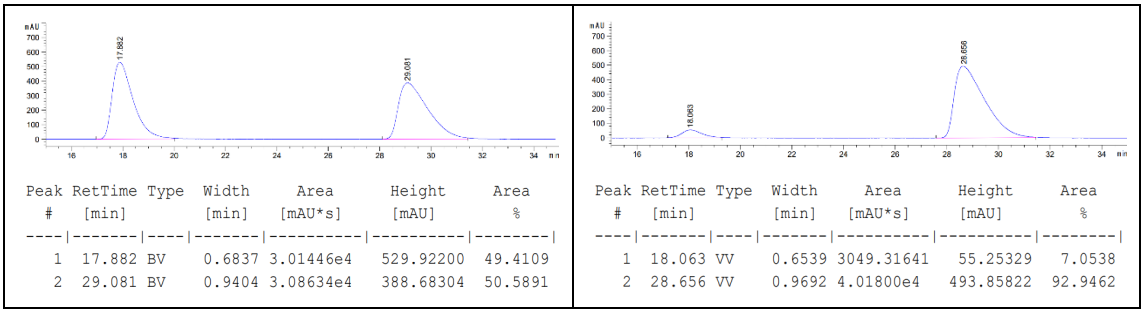
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.602	BV	0.1917	290.72913	19.08254	2.3743
2	8.571	VV	0.5681	1.19539e4	290.50891	97.6257

(*S*)-3-ethynyl-2,2-dimethyl-3-(4-morpholinophenyl)cyclopentan-1-one (2d)



2d

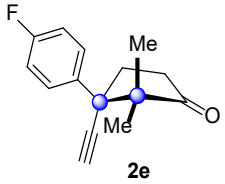
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.5) afforded **2d** (28 mg, 94%) as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.40 (d, J = 8.8 Hz, 2H), 6.91 (d, J = 8.8 Hz, 2H), 3.90–3.83 (m, 4H), 3.20–3.13 (m, 4H), 2.78–2.66 (m, 2H), 2.61–2.49 (m, 1H), 2.40–2.25 (m, 2H), 1.24 (s, 3H), 0.62 (s, 3H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 220.2, 150.5, 130.0, 128.4, 115.2, 87.7, 73.3, 67.0, 54.3, 51.2, 49.2, 34.7, 29.8, 20.4, 19.9 ppm. **IR** (KBr): ν_{max} = 3288, 2964, 2925, 1739, 1516, 1229, 1121, 929, 824 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{19}H_{23}NO_2$, $[M+H]^+$, 298.1802; found: 298.1791. **[α]$_D^{25}$**: −92.3 (*c* 0.26, $CHCl_3$). **m.p.**: 113.4–135.1 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 18.063 min (minor), t_R = 28.656 min (major) (86% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	17.882	BV	0.6837	3.01446e4	529.92200	49.4109
2	29.081	BV	0.9404	3.08634e4	388.68304	50.5891

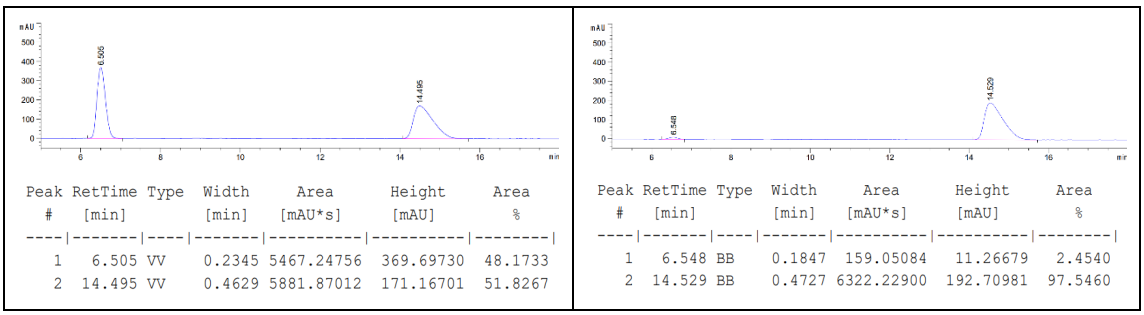
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	18.063	VV	0.6539	3049.31641	55.25329	7.0538
2	28.656	VV	0.9692	4.01800e4	493.85822	92.9462

(*S*)-3-ethynyl-3-(4-fluorophenyl)-2,2-dimethylcyclopentan-1-one (2e)



2e

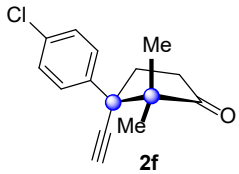
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.35) afforded **2e** (22.5 mg, 98%) as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.50–7.46 (m, 2H), 7.07 (t, J = 8.7 Hz, 2H), 2.78–2.67 (m, 2H), 2.63–2.52 (m, 1H), 2.42–2.30 (m, 2H), 1.25 (s, 3H), 0.60 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 219.5, 162.2 (d, J_{CF} = 246.7 Hz), 134.6 (d, J_{CF} = 3.1 Hz), 129.2 (d, J_{CF} = 8.0 Hz), 115.2 (d, J_{CF} = 21.3 Hz), 87.2, 73.8, 54.3, 51.4, 34.6, 29.9, 20.4, 19.8 ppm. **^{19}F NMR** (564 MHz, $CDCl_3$) δ −115.43 (s, 1F) ppm. **IR** (KBr): ν_{max} = 3267, 2966, 2921, 1728, 1510, 1267, 1087, 703 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{15}H_{15}FO$, $[M-H]^-$, 229.1034; found: 229.1034. **[α]$_D^{25}$**: −152.0 (*c* 0.41, $CHCl_3$). **m.p.**: 104.2–106.3 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 6.548 min (minor), t_R = 14.529 min (major) (95% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.505	VV	0.2345	5467.24756	369.69730	48.1733
2	14.495	VV	0.4629	5881.87012	171.16701	51.8267

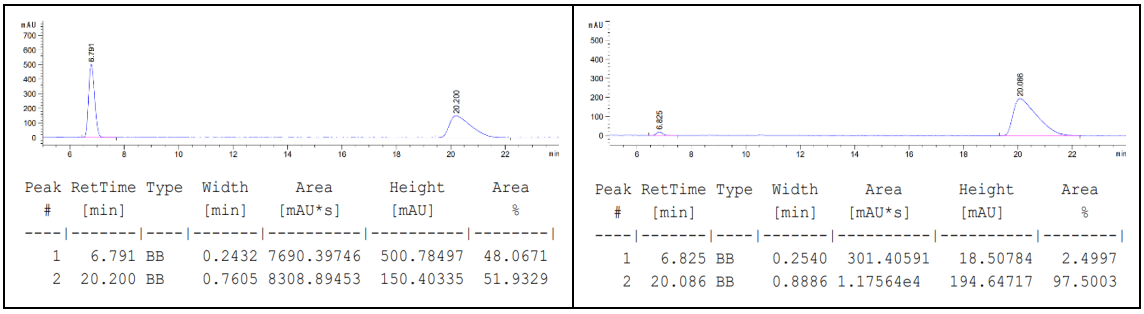
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.548	BB	0.1847	159.05084	11.26679	2.4540
2	14.529	BB	0.4727	6322.22900	192.70981	97.5460

(*S*)-3-(4-chlorophenyl)-3-ethynyl-2,2-dimethylcyclopentan-1-one (2f)



2f

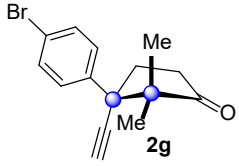
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.4) afforded **2f** (22.7 mg, 92%) as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.44 (d, J = 8.2 Hz, 2H), 7.35 (d, J = 8.3 Hz, 2H), 2.77–2.68 (m, 2H), 2.61–2.53 (m, 1H), 2.43–2.32 (m, 2H), 1.24 (s, 3H), 0.60 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 219.3, 137.5, 133.6, 129.0, 128.5, 86.9, 73.9, 54.2, 51.5, 34.6, 29.8, 20.4, 19.8 ppm. **IR** (KBr): ν_{max} = 3066, 2970. 2919, 1732, 1618, 1468, 1401, 1381, 1134, 1011, 842, 672, 522, 475 cm^{-1}. **HRMS** (APCI) (m/z): Calcd for $C_{15}H_{15}ClO$, $[M+H]^+$, 247.0884; found: 247.0876. **[α]$_D^{25}$**: −134 (*c* 0.06, $CHCl_3$). **m.p.**: 114.0–115.4 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 6.825 min (minor), t_R = 20.086 min (major) (95% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.791	BB	0.2432	7690.39746	500.78497	48.0671
2	20.200	BB	0.7605	8308.89453	150.40335	51.9329

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.825	BB	0.2540	301.40591	18.50784	2.4997
2	20.086	BB	0.8886	1.17564e4	194.64717	97.5003

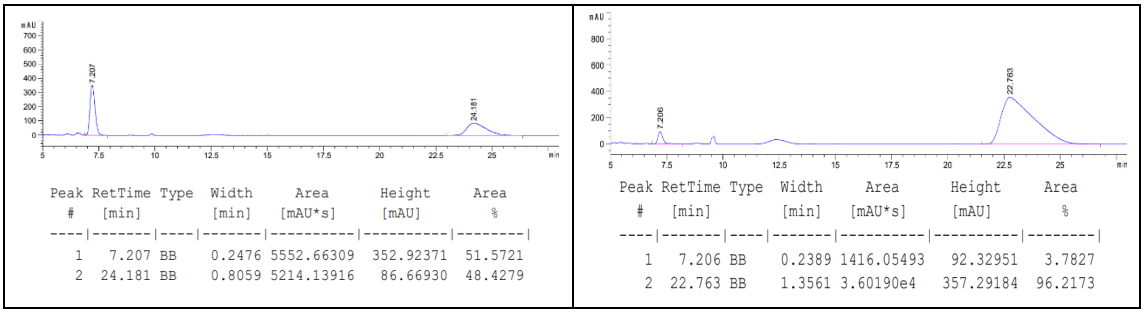
(*S*)-3-(4-bromophenyl)-3-ethynyl-2,2-dimethylcyclopentan-1-one (2g)



2g

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.25) afforded **2g** (25 mg, 86%) as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.50 (d, J = 8.4 Hz, 2H), 7.38 (d, J = 8.4 Hz, 2H), 2.79–2.66 (m, 2H), 2.64–2.51 (m, 1H), 2.43–2.29 (m, 2H), 1.24 (s, 3H), 0.60 (s, 3H) ppm. **^{13}C NMR** (100 MHz,

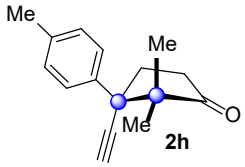
$CDCl_3$) δ 219.3, 137.9, 131.4, 129.3, 121.7, 86.8, 73.9, 54.2, 51.5, 34.6, 29.6, 20.4, 19.8 ppm. **IR** (KBr): ν_{max} = 3291, 2972, 2926, 1740, 1479, 1079, 826, 656 cm^{-1}. **HRMS** (APCI) (m/z): Calcd for $C_{15}H_{15}BrO$, $[M+H]^+$, 291.0379; found: 291.0371. **[α]**$_D^{25}$: −41.1 (*c* 0.12, $CHCl_3$). **m.p.**: 220.3–223.5 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 7.206 min (minor), t_R = 22.763 min (major) (92% *ee*).



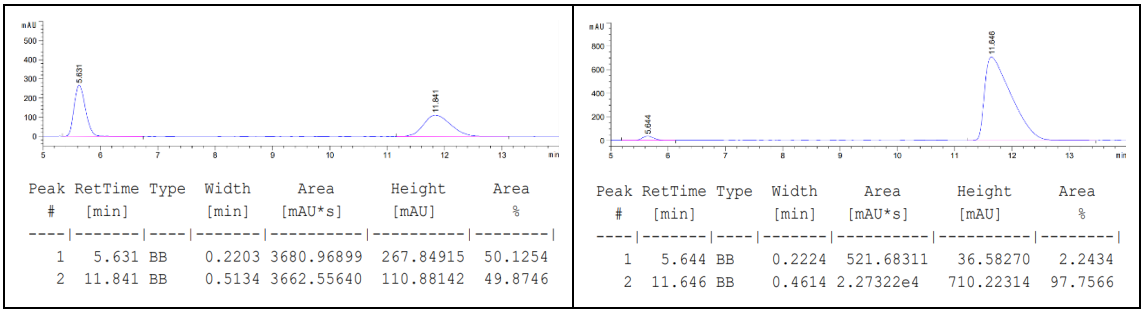
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.207	BB	0.2476	5552.66309	352.92371	51.5721
2	24.181	BB	0.8059	5214.13916	86.66930	48.4279

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.206	BB	0.2389	1416.05493	92.32951	3.7827
2	22.763	BB	1.3561	3.60190e4	357.29184	96.2173

(*S*)-3-ethynyl-2,2-dimethyl-3-(p-tolyl)cyclopentan-1-one (2h)



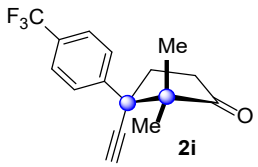
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.42) afforded **2h** (22 mg, 97%) as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.40 (d, *J* = 7.8 Hz, 2H), 7.18 (d, *J* = 7.8 Hz, 2H), 2.77–2.69 (m, 2H), 2.60–2.51 (m, 1H), 2.39–2.30 (m, 5H), 1.26 (s, 3H), 0.61 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 220.0, 137.2, 135.8, 129.0, 127.5, 87.6, 73.3, 54.2, 51.5, 34.7, 29.7, 21.1, 20.4, 19.9 ppm. **IR** (KBr): ν_{max} = 3304, 2974, 2932, 1741, 1402, 1085, 628 cm^{-1}. **HRMS** (APCI) (m/z): Calcd for $C_{16}H_{18}O$, $[M+H]^+$, 227.1430; found: 227.1421. **[α]**$_D^{25}$: −117.2 (*c* 0.42, $CHCl_3$). **m.p.**: 74.3–75.7 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 5.644 min (minor), t_R = 11.646 min (major) (96% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.631	BB	0.2203	3680.96899	267.84915	50.1254
2	11.841	BB	0.5134	3662.55640	110.88142	49.8746

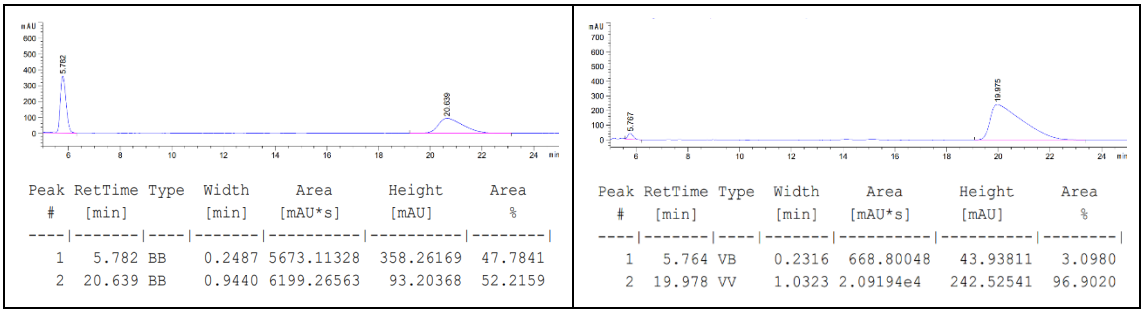
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.644	BB	0.2224	521.68311	36.58270	2.2434
2	11.646	BB	0.4614	2.27322e4	710.22314	97.7566

(*S*)-3-ethynyl-2,2-dimethyl-3-(4-(trifluoromethyl)phenyl)cyclopentan-1-one (2i)

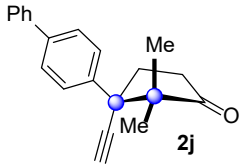


2i

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.23) afforded **2i** (21.6 mg, 77%) as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.64 (s, 4H), 2.85–2.70 (m, 2H), 2.67–2.52 (m, 1H), 2.49–2.28 (m, 2H), 1.27 (s, 3H), 0.61 (s, 3H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 219.0, 143.0, 128.0, 125.3 (q, J_{CF} = 8.8 Hz), 86.6, 74.2, 54.4, 51.9, 34.6, 29.7, 20.4, 19.8 ppm. **^{19}F NMR** (564 MHz, $CDCl_3$) δ −62.6 (s, 3F) ppm. **IR** (KBr): ν_{max} = 3302, 2971, 2925, 1744, 1328, 1169, 1125, 1076, 839 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{16}H_{15}F_3O$, $[M-H]^-$, 279.1002; found: 279.1007. **$[\alpha]_D^{25}$**: −100.3 (*c* 0.17, $CHCl_3$). **m.p.**: 172.2–174.5 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 5.764 min (minor), t_R = 19.978 min (major) (94% *ee*).

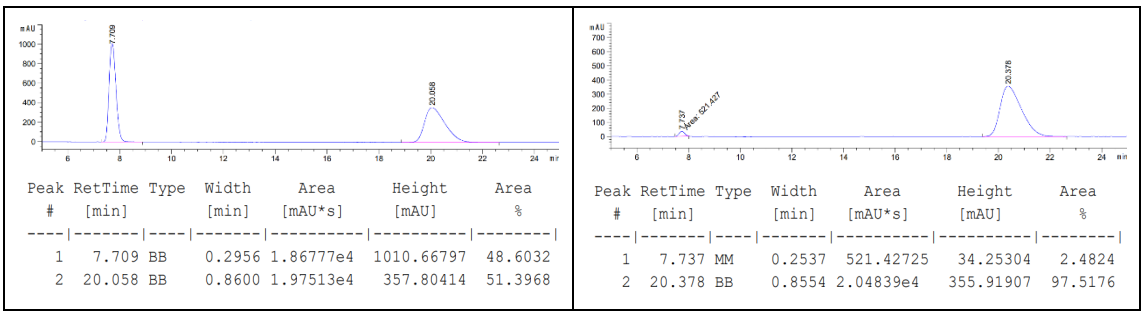


(*S*)-3-([1,1'-biphenyl]-4-yl)-3-ethynyl-2,2-dimethylcyclopentan-1-one (2j)



2j

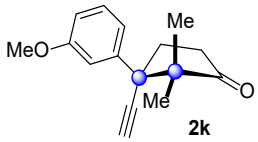
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.42) afforded **2j** (27.4 mg, 95%) as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.62–7.58 (m, 6H), 7.46 (t, *J* = 7.3 Hz, 2H), 7.37 (t, *J* = 7.3 Hz, 1H), 2.84–2.73 (m, 2H), 2.64–2.57 (m, 1H), 2.45–2.36 (m, 2H), 1.32 (s, 3H), 0.68 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 219.8, 140.6, 140.4, 137.9, 128.9, 128.0, 127.6, 127.2, 127.0, 87.4, 73.6, 54.4, 51.7, 34.7, 29.8, 20.5, 19.9 ppm. **IR** (KBr): ν_{max} = 3287, 2964, 2926, 1743, 1402, 1261, 1084, 780 cm^{-1}. **HRMS** (APCI) (m/z): Calcd for $C_{21}H_{20}O$, $[M+H]^+$, 289.1587; found: 289.1577. **$[\alpha]_D^{25}$**: −140.7 (*c* 0.69, $CHCl_3$). **m.p.**: 131.1–132.2 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 7.737 min (minor), t_R = 20.378 min (major) (95% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.709	BB	0.2956	1.86777e4	1010.66797	48.6032
2	20.058	BB	0.8600	1.97513e4	357.80414	51.3968

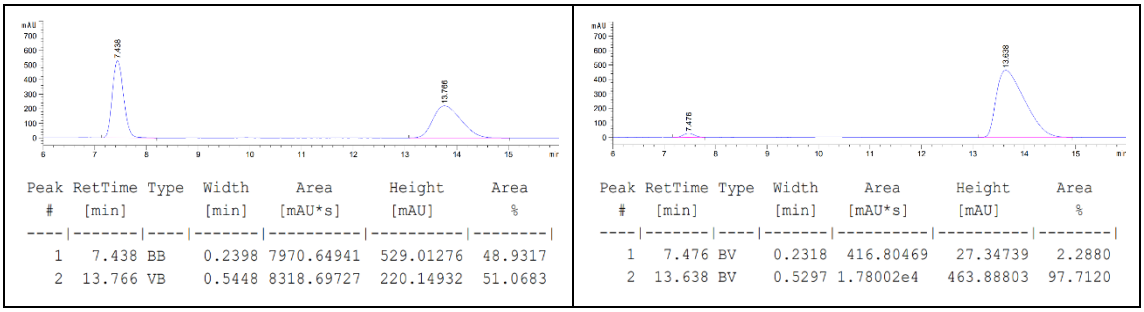
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.737	MM	0.2537	521.42725	34.25304	2.4824
2	20.378	BB	0.8554	2.04839e4	355.91907	97.5176

(*S*)-3-ethynyl-3-(3-methoxyphenyl)-2,2-dimethylcyclopentan-1-one (2k)



2k

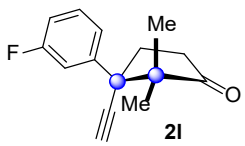
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.26) afforded **2k** (21.8 mg, 90%) as a colorless oil. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.29 (t, J = 8.0 Hz, 1H), 7.08 (d, J = 7.0 Hz, 2H), 6.85 (d, J = 7.7 Hz, 1H), 3.83 (s, 3H), 2.77–2.69 (m, 2H), 2.60–2.52 (m, 1H), 2.41–2.30 (m, 2H), 1.28 (s, 3H), 0.62 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 219.8, 159.6, 140.6, 129.2, 119.9, 114.4, 112.2, 87.4, 73.5, 55.4, 54.3, 51.8, 34.7, 29.8, 20.4, 20.0 ppm. **IR** (KBr): ν_{max} = 3284, 2966, 2923, 1738, 1281, 692 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{16}H_{18}O_2$, $[M+Na]^+$, 265.1199; found: 265.1204. **$[\alpha]_D^{25}$**: −166.7 (*c* 0.15, $CHCl_3$). **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 7.476 min (minor), t_R = 13.638 min (major) (95% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.438	BB	0.2398	7970.64941	529.01276	48.9317
2	13.766	VB	0.5448	8318.69727	220.14932	51.0683

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.476	BV	0.2318	416.80469	27.34739	2.2880
2	13.638	BV	0.5297	1.78002e4	463.88803	97.7120

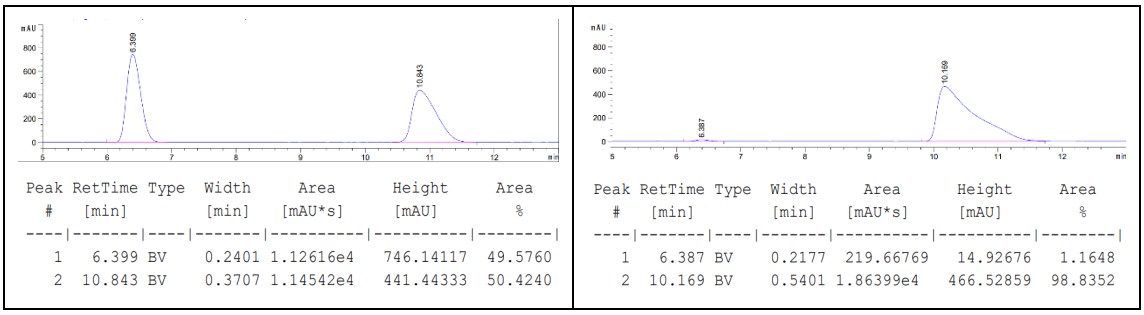
(*S*)-3-ethynyl-3-(3-fluorophenyl)-2,2-dimethylcyclopentan-1-one (2l)



2l

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.38) afforded **2l** (20.5 mg, 89%) as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.34 (td, J = 7.9, 6.0 Hz, 1H), 7.30–7.21 (m, 2H), 7.04–6.98 (m, 1H), 2.79–2.66 (m, 2H), 2.65–2.52 (m, 1H), 2.43–2.32 (m, 2H), 1.26 (s, 3H), 0.62 (s, 3H) ppm. **^{13}C**

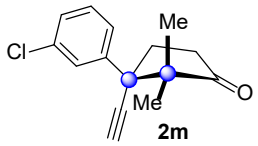
NMR (100 MHz, $CDCl_3$) δ 219.3, 162.8 (d, J = 245.6 Hz), 141.6 (d, J_{CF} = 7.0 Hz), 129.7 (d, J_{CF} = 8.3 Hz), 123.2 (d, J_{CF} = 2.6 Hz), 114.9 (d, J_{CF} = 22.8 Hz), 114.5 (d, J_{CF} = 21.0 Hz), 86.8, 74.0, 54.3, 51.7, 34.6, 29.8, 20.4, 19.9 ppm. **^{19}F NMR** (564 MHz, $CDCl_3$) δ −112.81 (s, 1F) ppm. **IR** (KBr): ν_{max} = 3290, 2969, 2921, 1740, 1625, 1263, 1081, 624 cm^{-1}. **HRMS** (APCI) (m/z): Calcd for $C_{15}H_{15}FO$, $[M+H]^+$, 231.1180; found: 231.1172. **[α]**$_D^{25}$: −116.7 (*c* 0.15, $CHCl_3$). **m.p.**: 53.2–54.9 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 6.387 min (minor), t_R = 10.169 min (major) (98% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.399	BV	0.2401	1.12616e4	746.14117	49.5760
2	10.843	BV	0.3707	1.14542e4	441.44333	50.4240

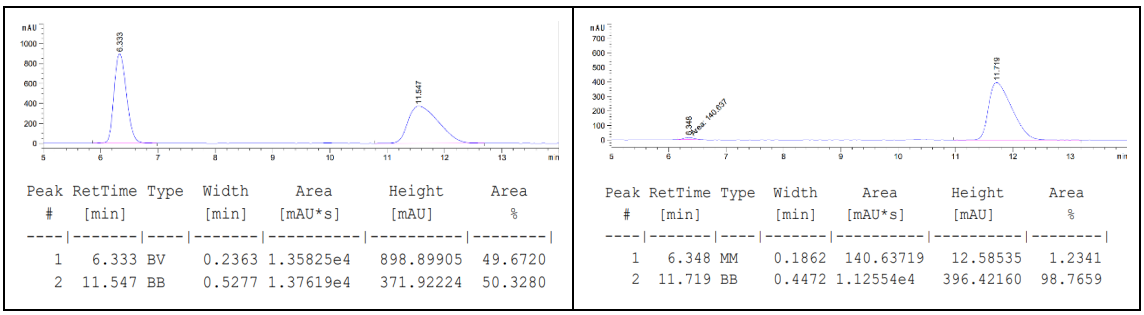
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.387	BV	0.2177	219.66769	14.92676	1.1648
2	10.169	BV	0.5401	1.86399e4	466.52859	98.8352

(*S*)-3-(3-chlorophenyl)-3-ethynyl-2,2-dimethylcyclopentan-1-one (2m)



2m

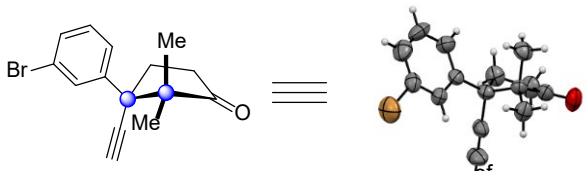
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.5) afforded **2m** (24.2 mg, 98%) as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.50 (s, 1H), 7.39 (d, J = 5.9 Hz, 1H), 7.30 (d, J = 7.6 Hz, 2H), 2.77–2.68 (m, 2H), 2.62–2.54 (m, 1H), 2.44–2.32 (m, 2H), 1.26 (s, 3H), 0.62 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 219.1, 141.1, 134.4, 129.5, 127.9, 127.8, 125.8, 86.7, 74.1, 54.3, 51.7, 34.5, 29.7, 20.4, 19.9 ppm. **IR** (KBr): ν_{max} = 3295, 2971, 2926, 1742, 1264, 1085, 619 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{15}H_{15}ClO$, $[M-H]^-$, 245.0739; found: 245.0735. **[α]**$_D^{25}$: −139.0 (*c* 0.62, $CHCl_3$). **m.p.**: 78.6–80.1 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 6.348 min (minor), t_R = 11.719 min (major) (98% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.333	BV	0.2363	1.35825e4	898.89905	49.6720
2	11.547	BB	0.5277	1.37619e4	371.92224	50.3280

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.348	MM	0.1862	140.63719	12.58535	1.2341
2	11.719	BB	0.4472	1.12554e4	396.42160	98.7659

(*S*)-3-(3-bromophenyl)-3-ethynyl-2,2-dimethylcyclopentan-1-one (2n)

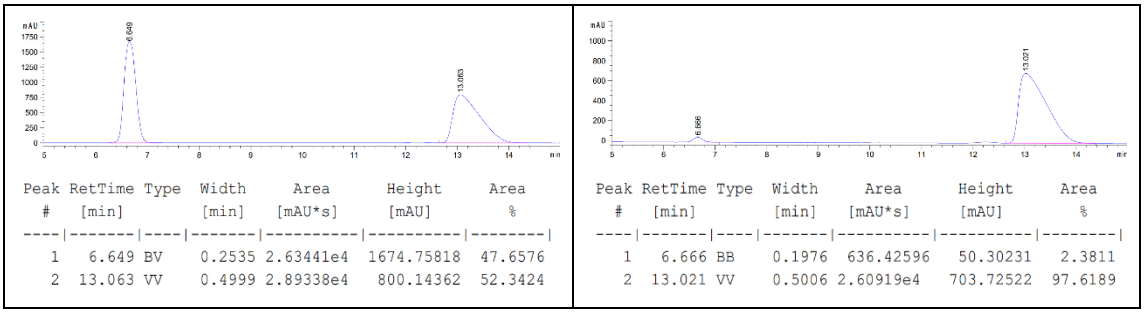


2n

X-ray of **2n**

(CCDC 2321372)

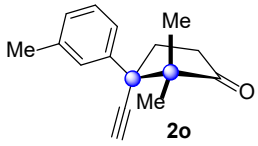
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.28) afforded **2n** (25 mg, 86%) as a white solid. The colorless crystal of **2n** for X-ray crystallographic analysis was obtained by slow diffusion of *n*-hexane to a solution of **2n** in EtOAc. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.65 (s, 1H), 7.44 (t, J = 7.8 Hz, 2H), 7.25 (t, J = 7.8 Hz, 1H), 2.77–2.67 (m, 2H), 2.63–2.53 (m, 1H), 2.42 (s, 1H), 2.39–2.33 (m, 1H), 1.26 (s, 3H), 0.62 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 219.1, 141.4, 130.8, 130.7, 129.8, 126.3, 122.7, 86.7, 74.1, 54.3, 51.7, 34.5, 29.7, 20.4, 19.9 ppm. **IR** (KBr): ν_{max} = 3292, 2974, 2929, 1742, 1469, 1082, 648 cm^{-1}. **HRMS** (APCI) (m/z): Calcd for $C_{15}H_{15}BrO$, $[M+H]^+$, 291.0379; found: 291.0374. **[α]**$_D^{25}$: −134.0 (*c* 0.2, $CHCl_3$). **m.p.**: 105.3–107.1 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 6.666 min (minor), t_R = 13.021 min (major) (95% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.649	BV	0.2535	2.63441e4	1674.75818	47.6576
2	13.063	VV	0.4999	2.89338e4	800.14362	52.3424

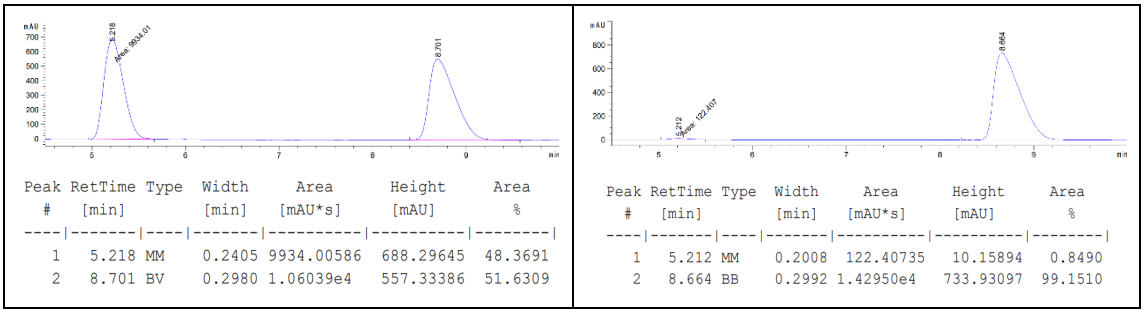
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.666	BB	0.1976	636.42596	50.30231	2.3811
2	13.021	VV	0.5006	2.60919e4	703.72522	97.6189

(*S*)-3-ethynyl-2,2-dimethyl-3-(*m*-tolyl)cyclopentan-1-one (2o)



2o

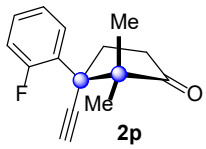
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.46) afforded **2o** (22 mg, 97%) as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.32 (s, 1H), 7.30 (d, J = 7.9 Hz, 1H), 7.26 (t, J = 7.5 Hz, 1H), 7.12 (d, J = 7.2 Hz, 1H), 2.79–2.70 (m, 2H), 2.61–2.53 (m, 1H), 2.44–2.29 (m, 5H), 1.27 (s, 3H), 0.61 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 220.0, 138.8, 137.9, 128.3, 128.3, 128.2, 124.6, 87.6, 73.4, 54.3, 51.8, 34.7, 29.7, 21.8, 20.4, 20.0 ppm. **IR** (KBr): ν_{max} = 3291, 2970, 2924, 1740, 1461, 1268, 1082, 643 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{16}H_{18}O$, $[M+Na]^+$, 249.1250; found: 249.1246. **[α]**$_D^{25}$: −142.1 (*c* 0.19, $CHCl_3$). **m.p.**: 43.1–44.7 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 5.212 min (minor), t_R = 8.664 min (major) (98% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.218	MM	0.2405	9934.00586	688.29645	48.3691
2	8.701	BV	0.2980	1.06039e4	557.33386	51.6309

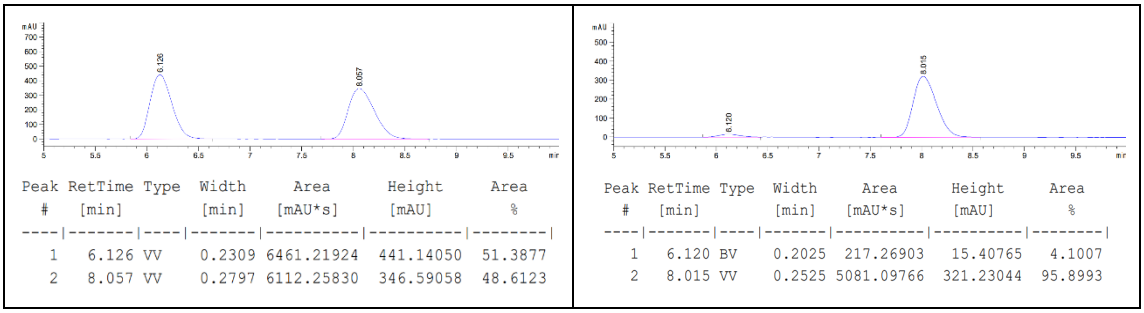
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.212	MM	0.2008	122.40735	10.15894	0.8490
2	8.664	BB	0.2992	1.42950e4	733.93097	99.1510

(*R*)-3-ethynyl-3-(2-fluorophenyl)-2,2-dimethylcyclopentan-1-one (2p)



2p

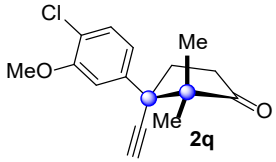
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.26) afforded **2p** (22.5 mg, 98%) as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.59 (td, J = 8.0, 1.8 Hz, 1H), 7.34–7.27 (m, 1H), 7.16 (td, J = 7.6, 1.5 Hz, 1H), 7.11–7.02 (m, 1H), 3.09–2.98 (m, 1H), 2.81–2.69 (m, 1H), 2.60–2.50 (m, 1H), 2.48–2.41 (m, 1H), 2.41 (s, 1H), 1.30 (d, J = 1.8 Hz, 3H), 0.73 (s, 3H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 219.7, 161.3 (d, J_{CF} = 249.0 Hz), 130.6 (d, J_{CF} = 4.3 Hz), 129.6 (d, J_{CF} = 8.9 Hz), 125.8 (d, J_{CF} = 11.0 Hz), 124.1 (d, J_{CF} = 3.2 Hz), 116.9 (d, J_{CF} = 24.7 Hz), 86.5, 73.4, 54.9, 50.8, 34.8, 30.40 (d, J_{CF} = 6.3 Hz), 20.8 (d, J_{CF} = 4.2 Hz), 20.4 ppm. **^{19}F NMR** (564 MHz, $CDCl_3$) δ −106.68 (s, 1F) ppm. **IR** (KBr): ν_{max} = 3249, 2967, 2924, 1739, 1273, 1081, 756 cm^{-1}. **HRMS** (APCI) (m/z): Calcd for $C_{15}H_{15}FO$, $[M+H]^+$, 231.1180; found: 231.1171. **[α]$_D^{25}$**: −146.3 (*c* 0.1, $CHCl_3$). **m.p.**: 92.8–94.1 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 6.120 min (minor), t_R = 8.015 min (major) (92% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.126	VV	0.2309	6461.21924	441.14050	51.3877
2	8.057	VV	0.2797	6112.25830	346.59058	48.6123

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.120	BV	0.2025	217.26903	15.40765	4.1007
2	8.015	VV	0.2525	5081.09766	321.23044	95.8993

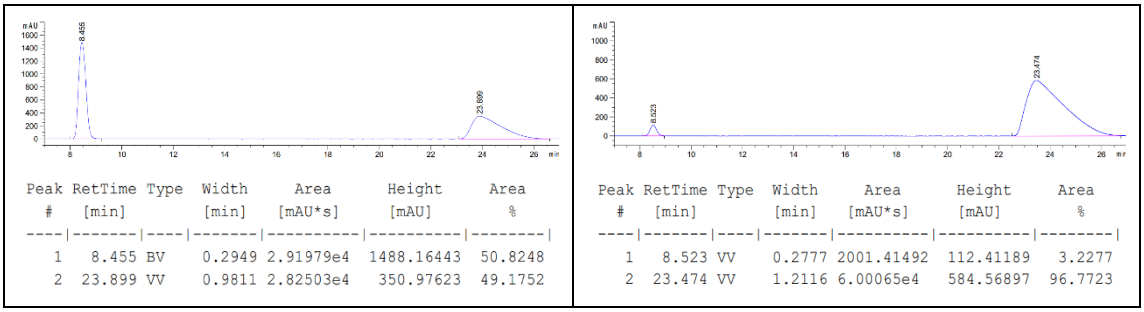
(*S*)-3-(4-chloro-3-methoxyphenyl)-3-ethynyl-2,2-dimethylcyclopentan-1-one (2q)



2q

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.23) afforded **2q**

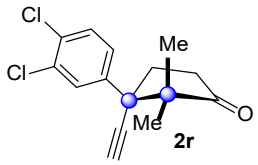
(22.1 mg, 80%) as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.35 (d, J = 8.3 Hz, 1H), 7.15–7.09 (m, 1H), 6.99 (dd, J = 8.3, 1.8 Hz, 1H), 3.93 (s, 3H), 2.79–2.64 (m, 2H), 2.62–2.51 (m, 1H), 2.45–2.31 (m, 2H), 1.27 (s, 3H), 0.63 (s, 3H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 219.2, 154.8, 139.1, 129.8, 121.9, 120.1, 112.1, 86.9, 74.0, 56.3, 54.3, 51.8, 34.6, 29.9, 20.4, 20.0 ppm. **IR** (KBr): ν_{max} = 3292, 2970, 2928, 1742, 1580, 1260, 1067, 701 cm^{-1}. **HRMS** (APCI) (m/z): Calcd for $C_{16}H_{17}ClO_2$, $[M+H]^+$, 277.0990; found: 277.0991. **[α]**$_D^{25}$: −110 (*c* 0.18, $CHCl_3$). **m.p.**: 150.3–152.0 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 8.523 min (minor), t_R = 23.474 min (major) (94% *ee*).



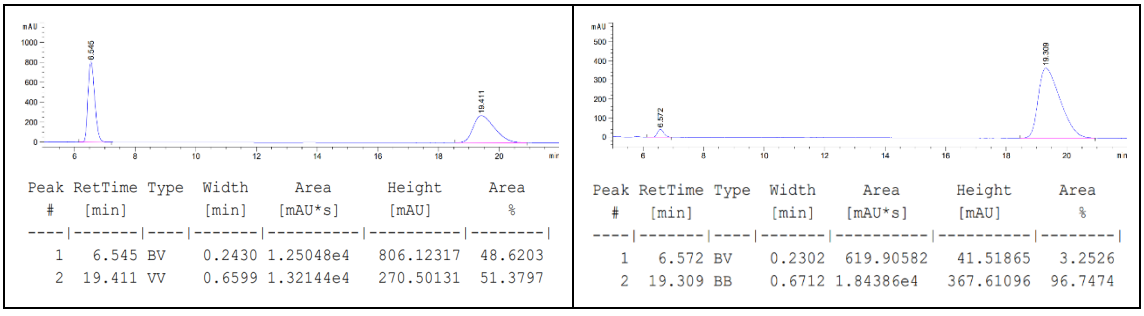
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.455	BV	0.2949	2.91979e4	1488.16443	50.8248
2	23.899	VV	0.9811	2.82503e4	350.97623	49.1752

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.523	VV	0.2777	2001.41492	112.41189	3.2277
2	23.474	VV	1.2116	6.00065e4	584.56897	96.7723

(*S*)-3-(3,4-dichlorophenyl)-3-ethynyl-2,2-dimethylcyclopentan-1-one (2r)



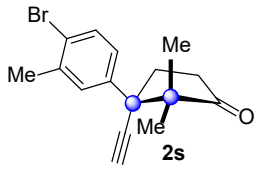
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.37) afforded **2r** (20 mg, 71%) as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.60 (d, J = 1.9 Hz, 1H), 7.45 (d, J = 8.5 Hz, 1H), 7.34 (dd, J = 8.4, 2.0 Hz, 1H), 2.79–2.52 (m, 3H), 2.43 (s, 1H), 2.41–2.31 (m, 1H), 1.25 (s, 3H), 0.63 (s, 3H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 218.7, 139.3, 132.6, 131.8, 130.2, 129.7, 127.0, 86.3, 74.4, 54.3, 51.4, 34.5, 29.8, 20.4, 19.8 ppm. **IR** (KBr): ν_{max} = 3297, 2970, 2925, 1740, 1468, 1082, 669 cm^{-1}. **HRMS** (APCI) (m/z): Calcd for $C_{15}H_{14}Cl_2O$, $[M+H]^+$, 281.0495; found: 281.0488. **[α]**$_D^{25}$: −77.1 (*c* 0.2, $CHCl_3$). **m.p.**: 118.0–120.3 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 6.572 min (minor), t_R = 19.309 min (major) (94% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.545	BV	0.2430	1.25048e4	806.12317	48.6203
2	19.411	VV	0.6599	1.32144e4	270.50131	51.3797

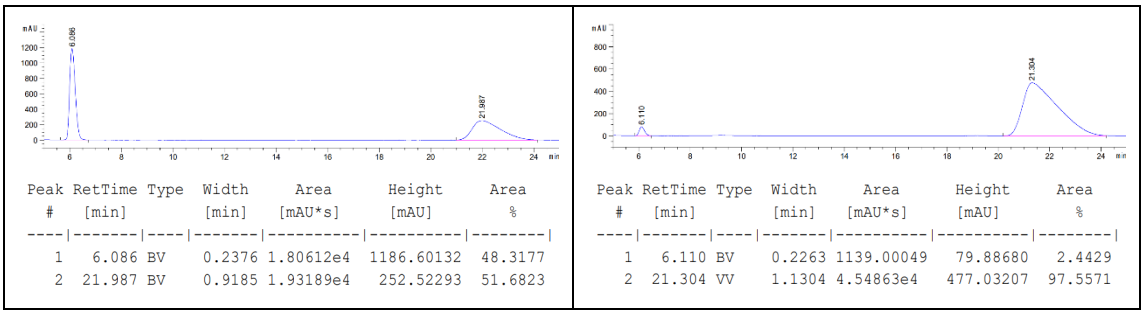
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.572	BV	0.2302	619.90582	41.51865	3.2526
2	19.309	BB	0.6712	1.84386e4	367.61096	96.7474

(*S*)-3-(4-bromo-3-methylphenyl)-3-ethynyl-2,2-dimethylcyclopentan-1-one (2s)

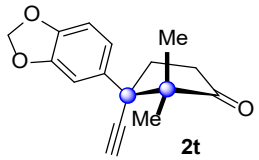


2s

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.42) afforded **2s** (25.0 mg, 82%) as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.52 (d, J = 8.4 Hz, 1H), 7.39–7.34 (m, 1H), 7.17 (dd, J = 8.3, 1.9 Hz, 1H), 2.76–2.67 (m, 2H), 2.60–2.53 (m, 1H), 2.43 (s, 3H), 2.39 (s, 1H), 2.38–2.31 (m, 1H), 1.25 (s, 3H), 0.61 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 219.4, 138.2, 137.8, 132.2, 130.1, 126.6, 124.1, 87.0, 73.8, 54.2, 51.5, 34.6, 29.8, 23.3, 20.4, 19.9 ppm. **IR** (KBr): ν_{max} = 3295, 2974, 2925, 1741, 1628, 1474, 1028, 820 cm^{-1}. **HRMS** (APCI) (m/z): Calcd for $C_{16}H_{17}BrO$, $[M+H]^+$, 305.0536; found: 305.0533. **[α]**$_D^{25}$: −103.9 (*c* 0.24, $CHCl_3$). **m.p.**: 150.1–151.0 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 6.110 min (minor), t_R = 21.304 min (major) (95% *ee*).

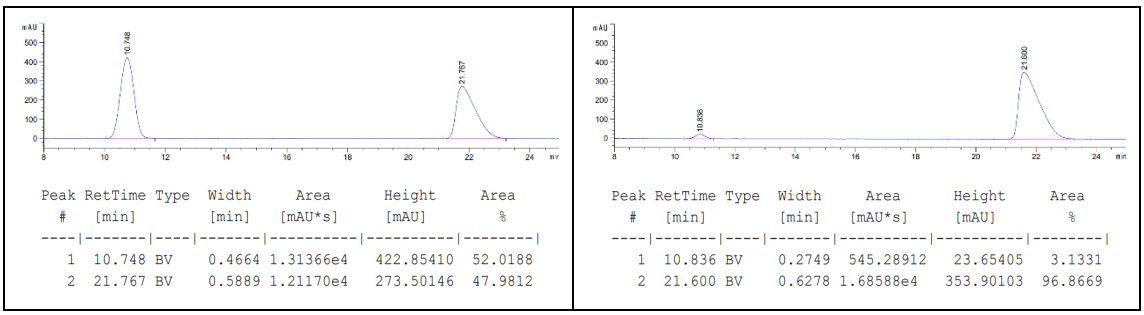


(*S*)-3-(benzo[*d*][1,3]dioxol-5-yl)-3-ethynyl-2,2-dimethylcyclopentan-1-one (2t)



2t

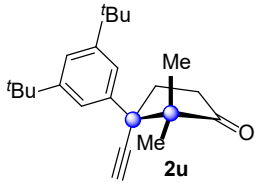
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.59) afforded **2t** (19.2 mg, 75%) as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.03 (s, 1H), 6.96 (d, J = 8.2 Hz, 1H), 6.81 (d, J = 8.2 Hz, 1H), 5.98 (s, 2H), 2.77–2.62 (m, 2H), 2.60–2.49 (m, 1H), 2.41–2.27 (m, 2H), 1.25 (s, 3H), 0.62 (s, 3H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 219.8, 147.8, 147.0, 132.8, 120.7, 108.5, 107.9, 101.3, 87.5, 73.5, 54.3, 51.6, 34.7, 30.0, 20.4, 19.9 ppm. **IR** (KBr): ν_{max} = 3290, 2972, 2923, 1740, 1497, 1247, 1087, 811 cm^{-1}. **HRMS** (APCI) (m/z): Calcd for $C_{16}H_{16}O_3$, $[M+H]^+$, 257.1172; found: 257.1163. **[α]**$_D^{25}$: −199.3 (*c* 0.11, $CHCl_3$). **m.p.**: 91.0–93.0 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 10.836 min (minor), t_R = 21.600 min (major) (94% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	10.748	BV	0.4664	1.31366e4	422.85410	52.0188
2	21.767	BV	0.5889	1.21170e4	273.50146	47.9812

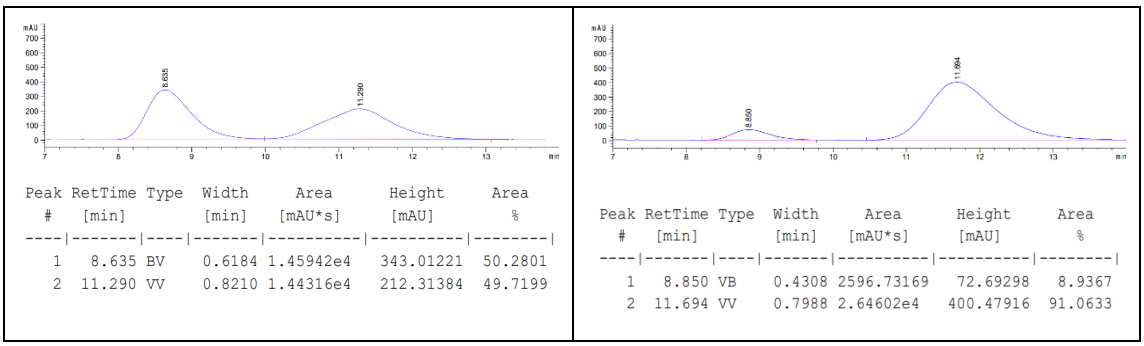
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	10.836	BV	0.2749	545.28912	23.65405	3.1331
2	21.600	BV	0.6278	1.68588e4	353.90103	96.8669

(*S*)-3-(3,5-di-*tert*-butylphenyl)-3-ethynyl-2,2-dimethylcyclopentan-1-one (2u)



2u

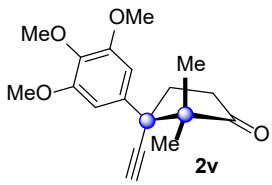
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.53) afforded **2u** (26 mg, 80%) as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.35 (s, 3H), 2.85–2.69 (m, 2H), 2.63–2.52 (m, 1H), 2.41–2.33 (m, 2H), 1.34 (s, 18H), 1.25 (s, 3H), 0.59 (s, 3H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 220.3, 150.4, 137.5, 121.9, 121.3, 87.8, 73.4, 54.3, 52.3, 35.1, 34.8, 31.6, 29.7, 20.4, 19.8 ppm. **IR** (KBr): ν_{max} = 3298, 2956, 2928, 1735, 1597, 1252, 737 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{23}H_{32}O$, $[M+Na]^+$, 347.2345; found: 347.2343. **[α]$_D^{25}$**: −51.2 (*c* 0.26, $CHCl_3$). **m.p.**: 135.3–137.6 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 8.850 min (minor), t_R = 11.694 min (major) (82% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.635	BV	0.6184	1.45942e4	343.01221	50.2801
2	11.290	VV	0.8210	1.44316e4	212.31384	49.7199

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.850	VB	0.4308	2596.73169	72.69298	8.9367
2	11.694	VV	0.7988	2.64602e4	400.47916	91.0633

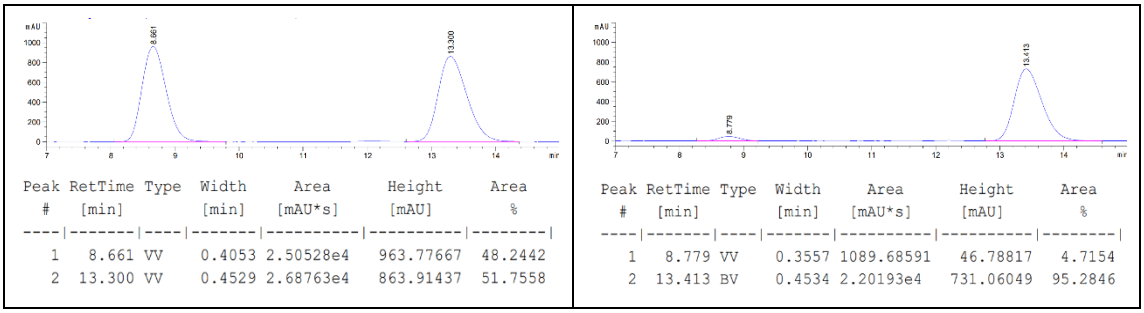
(*S*)-3-ethynyl-2,2-dimethyl-3-(3,4,5-trimethoxyphenyl)cyclopentan-1-one (2v)



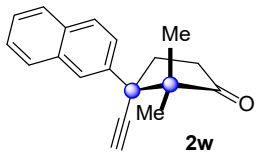
2v

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.37) afforded **2v** (23.4 mg, 74%) as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 6.72 (s, 2H), 3.88 (s, 6H), 3.85 (s, 3H), 2.79–2.63 (m, 2H), 2.61–2.51 (m, 1H), 2.43–2.32 (m, 2H), 1.29 (s, 3H), 0.64 (s, 3H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ

219.7, 152.9, 137.6, 134.5, 105.1, 87.3, 73.7, 61.0, 56.4, 54.4, 52.0, 34.7, 29.9, 20.4, 20.0 ppm. **IR** (KBr): ν_{max} = 3279, 2975, 2932, 1739, 1409, 1126, 637 cm^{-1}. **HRMS** (APCI) (m/z): Calcd for $C_{18}H_{22}O_4$, $[M+H]^+$, 303.1591; found: 303.1580. **[α]**$_D^{25}$: −97.2 (*c* 0.18, $CHCl_3$). **m.p.**: 129.1–130.1 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 15 : 85, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 8.779 min (minor), t_R = 13.413 min (major) (91% *ee*).

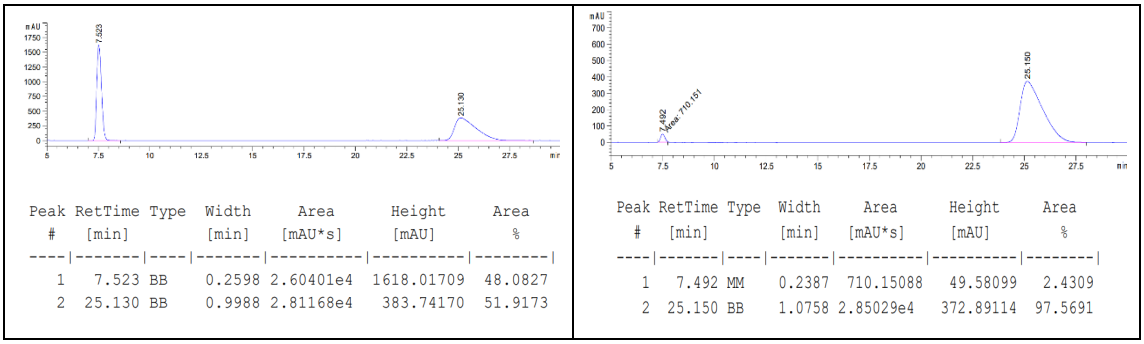


(*S*)-3-ethynyl-2,2-dimethyl-3-(naphthalen-2-yl)cyclopentan-1-one (2w)

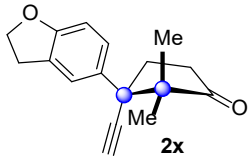


2w

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.38) afforded **2w** (24.1 mg, 92%) as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.93 (s, 1H), 7.86 (d, *J* = 8.5 Hz, 3H), 7.68 (dd, *J* = 8.6, 1.9 Hz, 1H), 7.53–7.48 (m, 2H), 2.94–2.89 (m, 1H), 2.84–2.77 (m, 1H), 2.64 (dd, *J* = 18.9, 8.4 Hz, 1H), 2.51–2.45 (m, 1H), 2.45 (s, 1H), 1.36 (s, 3H), 0.65 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 219.8, 136.5, 133.2, 132.7, 128.3, 127.9, 127.6, 126.4, 126.3, 126.2, 126.0, 87.4, 73.8, 54.5, 52.0, 34.7, 29.8, 20.5, 20.2 ppm. **IR** (KBr): ν_{max} = 3295, 2971, 2950, 1739, 1382, 1085, 820, 476 cm^{-1}. **HRMS** (APCI) (m/z): Calcd for $C_{19}H_{18}O$, $[M+H]^+$, 263.1430; found: 263.1420. **[α]**$_D^{25}$: −126.1 (*c* 0.72, $CHCl_3$). **m.p.**: 122.0–123.8 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 7.492 min (minor), t_R = 25.150 min (major) (95% *ee*).

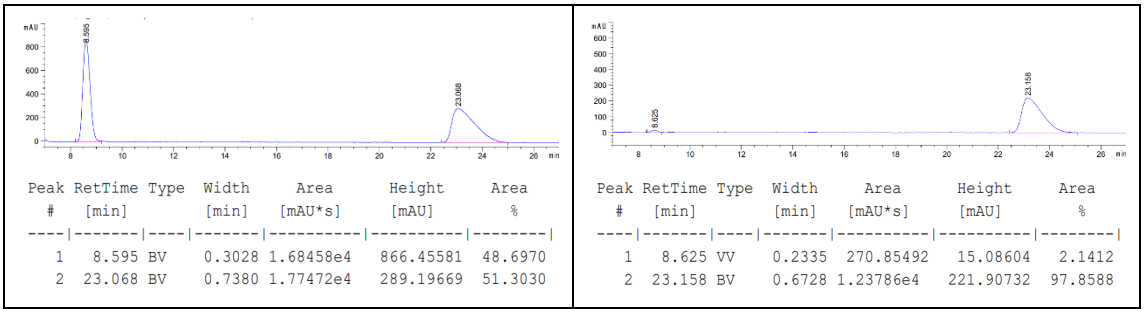


(*S*)-3-(2,3-dihydrobenzofuran-5-yl)-3-ethynyl-2,2-dimethylcyclopentan-1-one (2x)

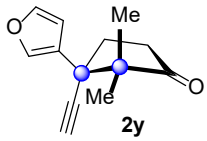


2x

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.38) afforded **2x** (18.3 mg, 72%) as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.35 (s, 1H), 7.23 (d, J = 8.3 Hz, 1H), 6.77 (d, J = 8.4 Hz, 1H), 4.59 (t, J = 8.7 Hz, 2H), 3.24 (t, J = 8.6 Hz, 2H), 2.77–2.66 (m, 2H), 2.62–2.50 (m, 1H), 2.41–2.25 (m, 2H), 1.25 (s, 3H), 0.62 (s, 3H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 220.2, 159.6, 130.8, 127.2, 127.2, 124.3, 108.8, 87.9, 73.3, 71.6, 54.3, 51.4, 34.7, 30.1, 30.0, 20.4, 19.9 ppm. **IR** (KBr): ν_{max} = 3284, 2971, 2925, 1740, 1494, 1235, 1084, 820 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{17}H_{18}O_2$, $[M+Na]^+$, 277.1199; found: 277.1194. **[α]**$_D^{25}$: −54 (*c* 0.15, $CHCl_3$). **m.p.**: 85.2–86.4 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 8.625 min (minor), t_R = 23.158 min (major) (96% *ee*).

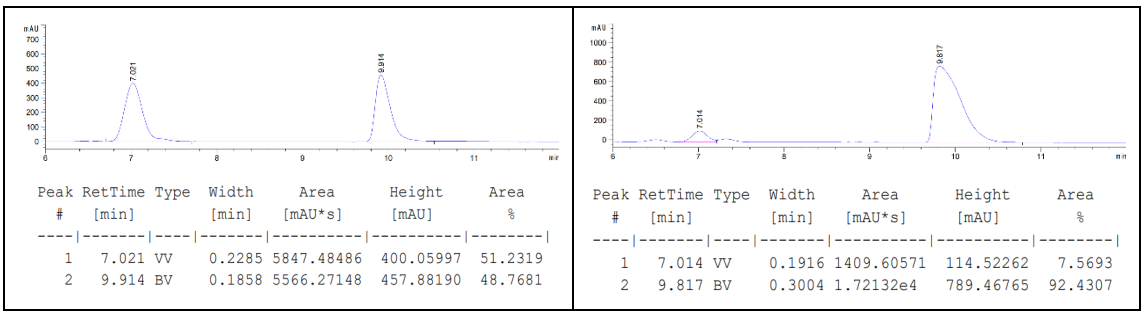


(*S*)-3-ethynyl-3-(furan-3-yl)-2,2-dimethylcyclopentan-1-one (2y)



2y

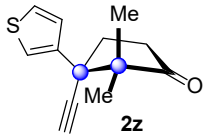
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.42) afforded **2y** (13.7 mg, 68%) as a colorless oil. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.42 (dt, J = 7.2, 1.5 Hz, 2H), 6.38 (s, 1H), 2.69–2.58 (m, 1H), 2.54–2.37 (m, 3H), 2.34 (s, 1H), 1.23 (s, 3H), 0.77 (s, 3H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 219.8, 143.4, 140.1, 125.3, 110.1, 86.1, 72.8, 53.6, 45.4, 34.3, 31.4, 20.3, 20.0 ppm. **IR** (KBr): ν_{max} = 3300, 2975, 2923, 1740, 1629, 1084, 671 cm^{-1}. **HRMS** (APCI) (m/z): Calcd for $C_{13}H_{14}O_2$, $[M+H]^+$, 203.1067; found: 2103.1061. **[α]**$_D^{25}$: −76.7 (*c* 0.09, $CHCl_3$). **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 7.014 min (minor), t_R = 9.817 min (major) (85% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.021	VV	0.2285	5847.48486	400.05997	51.2319
2	9.914	BV	0.1858	5566.27148	457.88190	48.7681

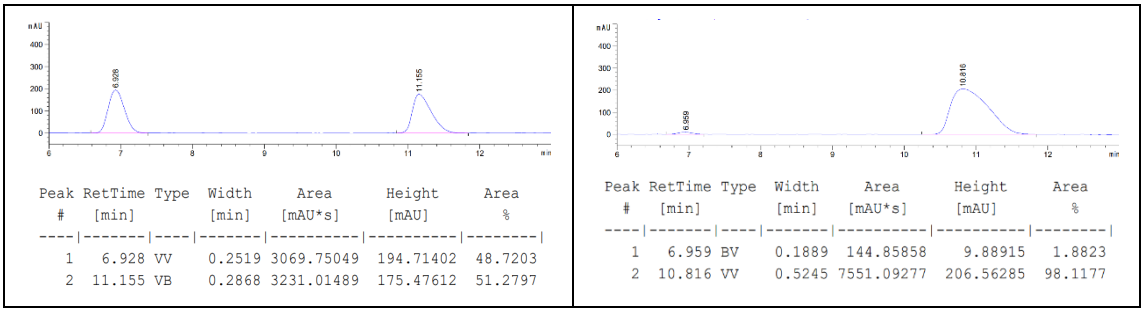
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.014	VV	0.1916	1409.60571	114.52262	7.5693
2	9.817	BV	0.3004	1.72132e4	789.46765	92.4307

(*R*)-3-ethynyl-2,2-dimethyl-3-(thiophen-3-yl)cyclopentan-1-one (2z)



2z

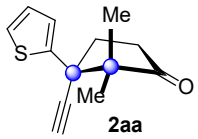
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.42) afforded **2z** (21.4 mg, 98%) as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.33 (dd, J = 5.0, 3.0 Hz, 1H), 7.23 (dd, J = 2.8, 1.2 Hz, 1H), 7.14 (dd, J = 5.0, 1.2 Hz, 1H), 2.72–2.50 (m, 3H), 2.50–2.42 (m, 1H), 2.39 (s, 1H), 1.27 (s, 3H), 0.68 (s, 3H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 219.8, 140.7, 127.3, 125.8, 121.9, 86.8, 73.3, 54.1, 49.1, 34.5, 31.3, 20.4, 20.0 ppm. **IR** (KBr): ν_{max} = 3292, 2971, 2925, 1740, 1264, 1082, 791 cm^{-1}. **HRMS** (APCI) (m/z): Calcd for $C_{13}H_{14}OS$, $[M+H]^+$, 219.0838; found: 219.0832. **$[\alpha]_D^{25}$**: −129.7 (*c* 0.18, $CHCl_3$). **m.p.**: 51.2–53.0 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 6.959 min (minor), t_R = 10.816 min (major) (96% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.928	VV	0.2519	3069.75049	194.71402	48.7203
2	11.155	VB	0.2868	3231.01489	175.47612	51.2797

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.959	BV	0.1889	144.85858	9.88915	1.8823
2	10.816	VV	0.5245	7551.09277	206.56285	98.1177

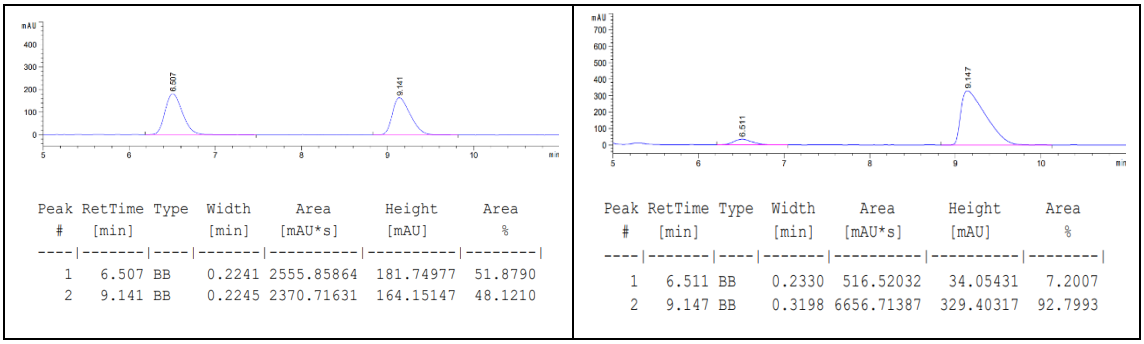
(*R*)-3-ethynyl-2,2-dimethyl-3-(thiophen-2-yl)cyclopentan-1-one (2aa)



2aa

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.45) afforded **2aa** (20.1 mg, 92%) as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.25 (d, J = 5.2 Hz, 1H), 7.06 (d, J = 2.6 Hz, 1H), 7.03–6.98 (m, 1H), 2.71–2.63 (m, 1H), 2.63–2.52 (m, 3H), 2.43 (s, 1H), 1.31 (s, 3H), 0.74 (s, 3H) ppm. **^{13}C**

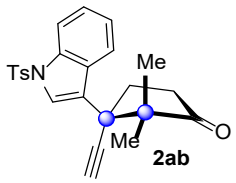
NMR (150 MHz, $CDCl_3$) δ 219.2, 143.8, 126.8, 125.3, 124.7, 86.4, 73.6, 54.4, 49.3, 34.5, 32.5, 20.5, 19.7 ppm. **IR** (KBr): ν_{max} = 3292, 2970, 2925, 1741, 1260, 1082, 801 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{13}H_{14}OS$, $[M+H]^+$, 219.0838; found: 219.0833. **[α]**$_D^{25}$: −152.5 (*c* 0.17, $CHCl_3$). **m.p.**: 76.8–79.1 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 6.511 min (minor), t_R = 9.147 min (major) (86% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.507	BB	0.2241	2555.85864	181.74977	51.8790
2	9.141	BB	0.2245	2370.71631	164.15147	48.1210

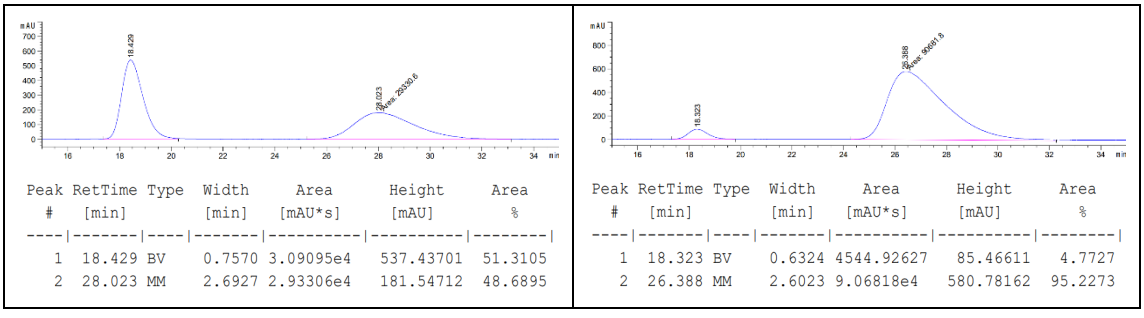
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.511	BB	0.2330	516.52032	34.05431	7.2007
2	9.147	BB	0.3198	6656.71387	329.40317	92.7993

(*S*)-3-ethynyl-2,2-dimethyl-3-(1-tosyl-1*H*-indol-3-yl)cyclopentan-1-one (2ab)



2ab

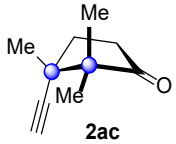
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.24) afforded **2ab** (36.1 mg, 89%) as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.99 (t, *J* = 8.4 Hz, 2H), 7.75 (d, *J* = 8.3 Hz, 2H), 7.48 (s, 1H), 7.32 (t, *J* = 7.6 Hz, 1H), 7.23 (t, *J* = 7.0 Hz, 3H), 2.81–2.53 (m, 3H), 2.52–2.44 (m, 1H), 2.43 (s, 1H), 2.35 (s, 3H), 1.38 (s, 3H), 0.61 (s, 3H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 219.4, 145.3, 135.7, 135.0, 130.1, 129.6, 127.0, 125.0, 123.7, 123.1, 122.8, 121.2, 113.8, 85.5, 74.2, 54.5, 46.8, 34.4, 31.2, 21.7, 21.1, 20.8 ppm. **IR** (KBr): ν_{max} = 3291, 2974, 2873, 1741, 1371, 1179, 1135, 1090, 579 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{24}H_{23}NO_3S$, $[M+Na]^+$, 428.1291; found: 428.1295. **[α]**$_D^{25}$: −52.9 (*c* 0.87, $CHCl_3$). **m.p.**: 182.9–184.2 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 20 : 80, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 18.323 min (minor), t_R = 26.388 min (major) (90% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	18.429	BV	0.7570	3.09095e4	537.43701	51.3105
2	28.023	MM	2.6927	2.93306e4	181.54712	48.6895

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	18.323	BV	0.6324	4544.92627	85.46611	4.7727
2	26.388	MM	2.6023	9.06818e4	580.78162	95.2273

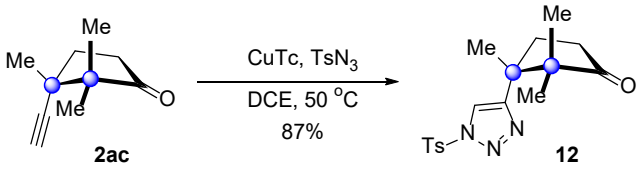
(*S*)-3-ethynyl-2,2,3-trimethylcyclopentan-1-one (2ac)



2ac

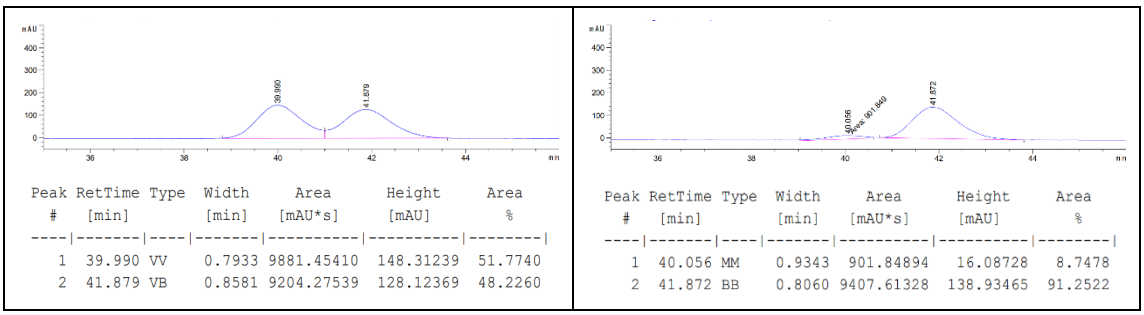
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.45) afforded **2ac** (9.0 mg, 60%) as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 2.50–2.40 (m, 1H), 2.33–2.19 (m, 3H), 1.96–1.88 (m, 1H), 1.23 (s, 3H), 1.14 (s, 3H), 0.94 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 220.9, 88.2, 71.3, 52.2, 42.2, 34.1, 33.2, 22.6, 21.0, 18.6 ppm. **IR** (KBr): ν_{max} = 3251, 2972, 2931, 1732, 1274, 701 cm^{-1}. **[α]**$_D^{25}$: −28 (*c* 0.44, $CHCl_3$). **m.p.**: 52.1–54.8 °C. Ee value of **2ac** was determined to be 83% based on HPLC analysis of its derivative **12**.

Transformation of 2ac to 12:



2ac **12**

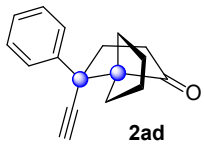
Preparation of (*R*)-2,2,3-trimethyl-3-(1-tosyl-1H-1,2,3-triazol-4-yl)cyclopentan-1-one (12). To a solution of **2ac** (15.0 mg, 0.1 mmol, 1 equiv) in DCE (1.0 mL) was added CuTc (38 mg, 0.2 mmol, 2 equiv) and TsN_3 (39 mg, 0.2 mmol, 2 equiv). The reaction was stirred at 50 °C for 4 h, and the mixture was concentrated in vacuo. The resulting crude product was purified by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.15) to afford **12** (30.2 mg, 87%) as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.99 (d, *J* = 8.4 Hz, 2H), 7.91 (s, 1H), 7.39 (d, *J* = 8.1 Hz, 2H), 2.66–2.51 (m, 2H), 2.47–2.37 (m, 4H), 2.04–1.94 (m, 1H), 1.30 (s, 3H), 1.07 (s, 3H), 0.63 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 221.2, 152.5, 147.5, 133.2, 130.6, 128.8, 120.1, 52.9, 44.4, 33.8, 30.9, 23.2, 22.0, 21.5, 18.8 ppm. **IR** (KBr): ν_{max} = 2972, 2924, 1739, 1390, 1194, 1177, 673 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{17}H_{21}N_3O_3S$, $[M+Na]^+$, 370.1196; found: 370.1196. **[α]**$_D^{25}$: −53.3 (*c* 0.09, $CHCl_3$). **m.p.**: 113.4–116.5 °C. **HPLC** (Chiral pak AD-H, *i*-PrOH/*n*-hexane = 3 : 97, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 40.056 min (minor), t_R = 41.872 min (major) (83% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	39.990	VV	0.7933	9881.45410	148.31239	51.7740
2	41.879	VB	0.8581	9204.27539	128.12369	48.2260

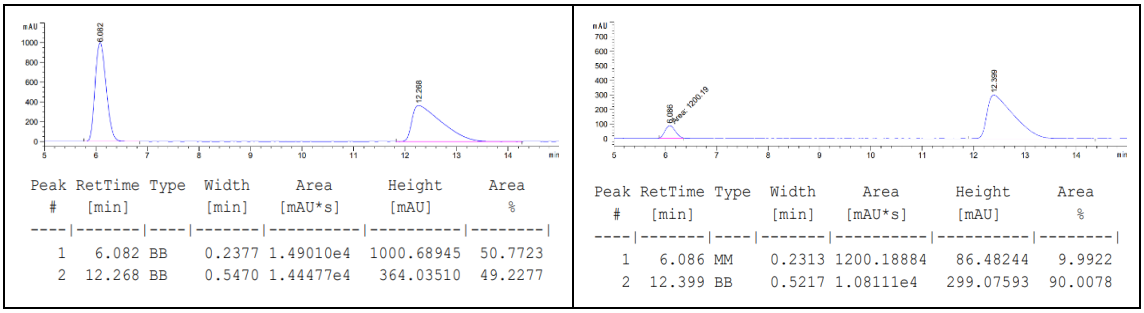
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	40.056	MM	0.9343	901.84894	16.08728	8.7478
2	41.872	BB	0.8060	9407.61328	138.93465	91.2522

(*S*)-4-ethynyl-4-phenylspiro[4.4]nonan-1-one (2ad)



2ad

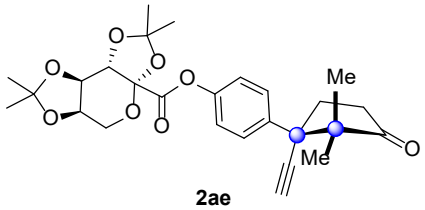
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.6) afforded **2ad** (23.3 mg, 98%) as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.54 (d, J = 7.6 Hz, 2H), 7.36 (t, J = 7.5 Hz, 2H), 7.30 (t, J = 7.2 Hz, 1H), 2.72–2.65 (m, 1H), 2.62–2.49 (m, 2H), 2.40–2.31 (m, 2H), 2.06 (t, J = 7.4 Hz, 2H), 1.71–1.65 (m, 1H), 1.51–1.42 (m, 2H), 1.38–1.32 (m, 1H), 1.27 (q, J = 8.2, 5.7 Hz, 1H), 1.21–1.15 (m, 1H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 219.7, 139.5, 128.3, 127.8, 127.5, 87.7, 72.8, 65.6, 51.2, 34.2, 31.9, 31.3, 26.2, 26.1 ppm. **IR** (KBr): ν_{max} = 3291, 2955, 2869, 1735, 1448, 1084, 1032, 700 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{17}H_{18}O$, $[M+Na]^+$, 261.1250; found: 261.1243. **$[\alpha]_D^{25}$**: −112.5 (*c* 0.51, $CHCl_3$). **m.p.**: 78.3–80.0 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 10 : 90, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 6.086 min (minor), t_R = 12.399 min (major) (80% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.082	BB	0.2377	1.49010e4	1000.68945	50.7723
2	12.268	BB	0.5470	1.44477e4	364.03510	49.2277

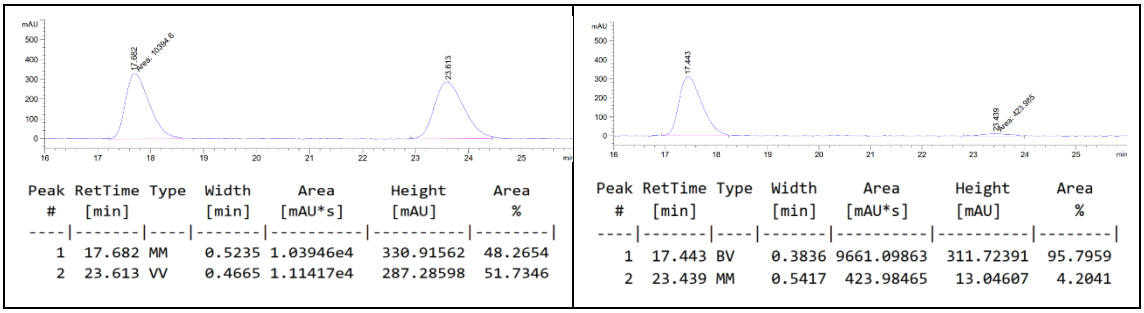
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.086	MM	0.2313	1200.18884	86.48244	9.9922
2	12.399	BB	0.5217	1.08111e4	299.07593	90.0078

4-((*S*)-1-ethynyl-2,2-dimethyl-3-oxocyclopentyl)phenyl (3a*R*,5a*R*,8a*R*,8b*S*)-2,2,7,7-tetramethyltetr-ahydro-3a*H*-bis([1,3]dioxolo)[4,5-*b*:4',5'-*d*]pyran-3a-carboxylate (2ae)



2ae

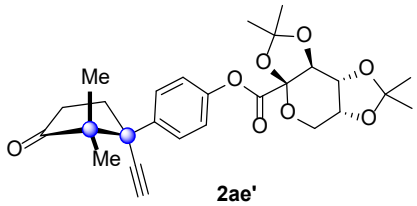
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.32) afforded **2ae** (30.1 mg, 62%) as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.53 (d, J = 8.4 Hz, 2H), 7.15 (d, J = 8.4 Hz, 2H), 4.87 (d, J = 2.5 Hz, 1H), 4.69 (dd, J = 7.9, 2.5 Hz, 1H), 4.31 (d, J = 7.9 Hz, 1H), 4.00–3.92 (m, 2H), 2.77–2.69 (m, 2H), 2.61–2.54 (m, 1H), 2.40–2.31 (m, 2H), 1.61 (s, 3H), 1.51 (d, J = 4.2 Hz, 6H), 1.37 (s, 3H), 1.25 (s, 3H), 0.61 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 219.5, 166.8, 150.1, 136.8, 128.9, 128.7, 121.1, 115.2, 111.0, 109.7, 100.0, 87.1, 73.9, 73.0, 70.5, 70.1, 61.9, 54.3, 51.6, 34.6, 29.9, 26.3, 26.2, 24.7, 24.6, 20.4, 19.8 ppm. **IR** (KBr): ν_{max} = 3291, 2989, 2926, 1742, 1629, 1253, 1073, 548 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{27}H_{32}O_8$, $[M+Na]^+$, 507.1989; found: 507.1994. **[α]$_D^{25}$**: −63.5 (*c* 0.18, $CHCl_3$). **m.p.**: 115.5–117.9 °C. **HPLC** (Chiral pak AD-H, *i*-PrOH/*n*-hexane = 15 : 85, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 17.443 min (major), t_R = 23.439 min (minor) (96 : 4 *dr*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	17.682	MM	0.5235	1.03946e4	330.91562	48.2654
2	23.613	VV	0.4665	1.11417e4	287.28598	51.7346

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	17.443	BV	0.3836	9661.09863	311.72391	95.7959
2	23.439	MM	0.5417	423.98465	13.04607	4.2041

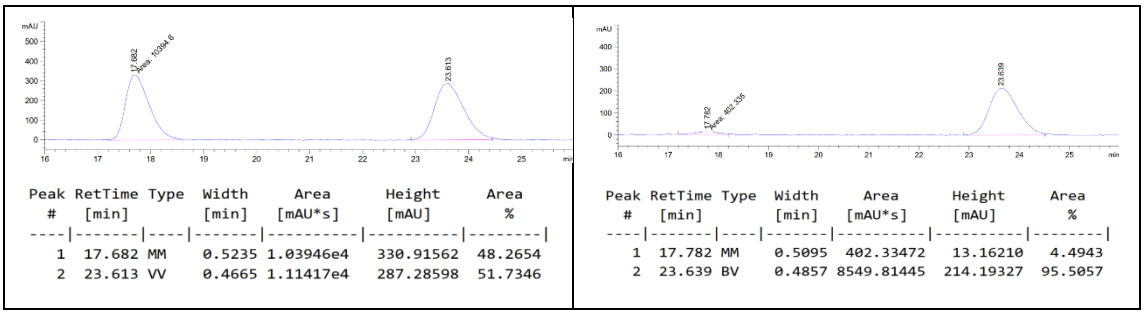
4-((*R*)-1-ethynyl-2,2-dimethyl-3-oxocyclopentyl)phenyl (3a*R*,5a*R*,8a*R*,8b*S*)-2,2,7,7-tetramethyltetr-ahydro-3a*H*-bis([1,3]dioxolo)[4,5-*b*:4',5'-*d*]pyran-3a-carboxylate (2ae')



2ae'

2ae' was prepared following the general procedure using *ent*-**L12**. Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.32) afforded **2ae'** (33 mg, 68%) as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.55–7.50 (m, 2H), 7.15 (d, J = 8.6 Hz, 2H), 4.87 (d, J = 2.5 Hz, 1H), 4.69 (dd, J = 7.9, 2.5 Hz, 1H), 4.31 (d, J = 7.9 Hz, 1H), 3.99–3.93 (m, 2H), 2.77–2.69 (m, 2H), 2.62–2.53 (m, 1H), 2.39 (s, 1H), 2.38–2.32 (m, 1H), 1.61 (s, 3H), 1.51 (d, J = 3.5 Hz, 6H), 1.37 (s, 3H), 1.25 (s, 3H), 0.61 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 219.5, 166.8, 150.1, 136.8, 128.8, 121.1, 111.0, 109.7, 100.0, 87.1, 73.9, 73.0, 70.5, 70.1, 61.9, 54.3, 51.6, 34.6, 29.9, 26.3, 26.2, 24.7, 24.6, 20.4, 19.8 ppm. **IR** (KBr): ν_{max} = 3273, 2984, 2934, 1742, 1507, 1382, 1253, 1073, 873 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{27}H_{32}O_8$, $[M+Na]^+$, 507.1989; found: 507.1989. **[α]$_D^{25}$**: +11.6 (*c*

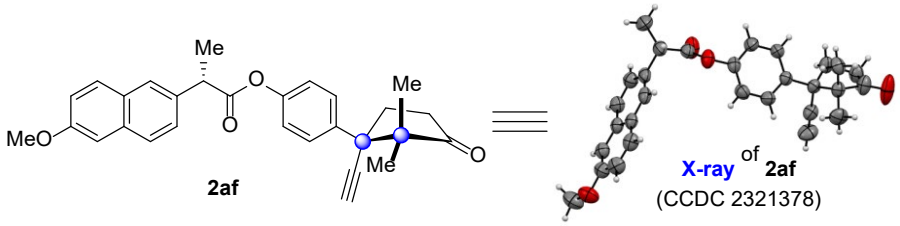
0.08, $CHCl_3$). **m.p.**: 127.4–129.5 °C. **HPLC** (Chiral pak AD-H, *i*-PrOH/*n*-hexane = 15 : 85, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 17.782 min (minor), t_R = 23.639 min (major) (96 : 4 *dr*).



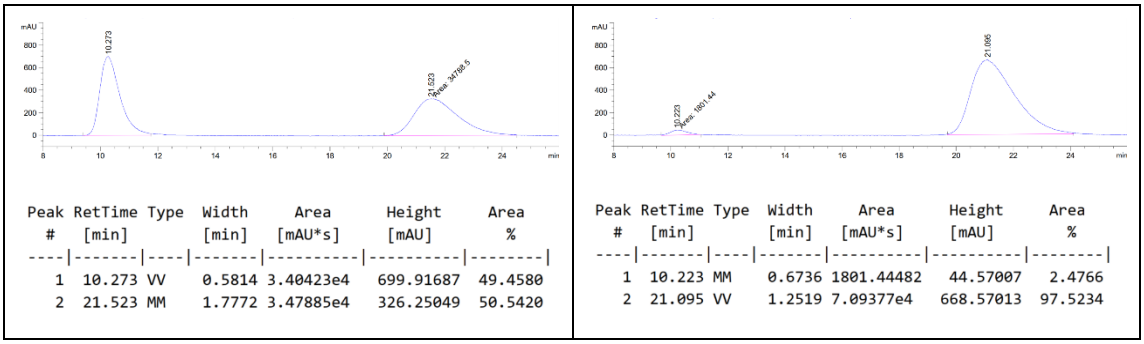
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	17.682	MM	0.5235	1.03946e4	330.91562	48.2654
2	23.613	VV	0.4665	1.11417e4	287.28598	51.7346

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	17.782	MM	0.5095	402.33472	13.16210	4.4943
2	23.639	BV	0.4857	8549.81445	214.19327	95.5057

4-((*S*)-1-ethynyl-2,2-dimethyl-3-oxocyclopentyl)phenyl (*S*)-2-(6-methoxynaphthalen-2-yl)propanoate (2af)



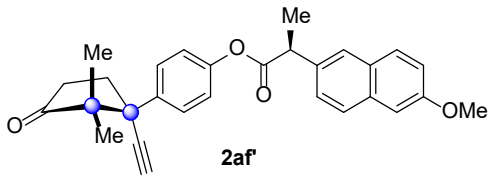
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.25) afforded **2af** (40.1 mg, 91%) as a white solid. The colorless crystal of **2af** for X-ray crystallographic analysis was obtained by slow diffusion of *n*-hexane to a solution of **2af** in EtOAc. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.80–7.72 (m, 3H), 7.50 (d, J = 8.5 Hz, 1H), 7.46 (d, J = 8.4 Hz, 2H), 7.21–7.10 (m, 2H), 7.01 (d, J = 8.5 Hz, 2H), 4.11 (q, J = 7.1 Hz, 1H), 3.92 (s, 3H), 2.77–2.65 (m, 2H), 2.60–2.50 (m, 1H), 2.40–2.28 (m, 2H), 1.70 (d, J = 7.1 Hz, 3H), 1.22 (s, 3H), 0.58 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 219.6, 173.2, 157.9, 150.2, 136.3, 135.2, 134.0, 129.4, 129.1, 128.6, 127.5, 126.3, 126.2, 121.2, 119.3, 105.8, 87.1, 73.7, 55.5, 54.3, 51.5, 45.7, 34.6, 29.8, 20.3, 19.7, 18.6 ppm. **IR** (KBr): ν_{max} = 3293, 2970, 2929, 1744, 1604, 1266, 1171, 852 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{29}H_{28}O_4$, $[M+Na]^+$, 463.1880; found: 463.1872. **$[\alpha]_D^{25}$**: −19.7 (*c* 0.30, $CHCl_3$). **m.p.**: 140.0–141.0 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 30 : 70, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 10.223 min (minor), t_R = 21.095 min (major) (98 : 2 *dr*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	10.273	VV	0.5814	3.40423e4	699.91687	49.4580
2	21.523	MM	1.7772	3.47885e4	326.25049	50.5420

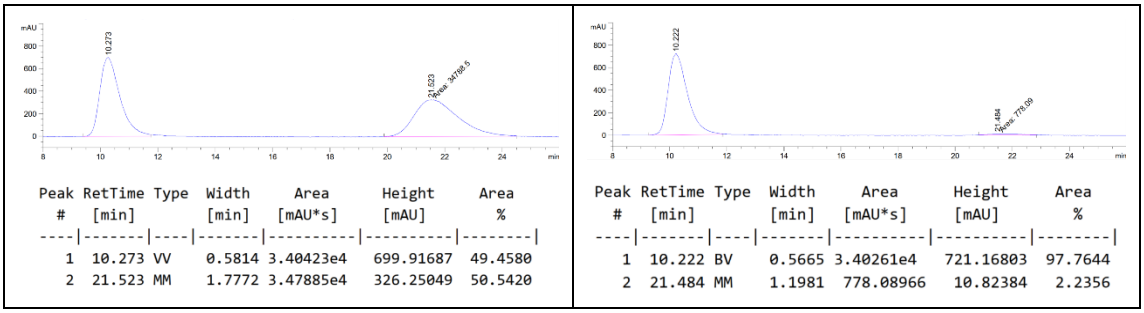
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	10.223	MM	0.6736	1801.44482	44.57007	2.4766
2	21.095	VV	1.2519	7.09377e4	668.57013	97.5234

4-((*R*)-1-ethynyl-2,2-dimethyl-3-oxocyclopentyl)phenyl (*S*)-2-(6-methoxynaphthalen-2-yl)propanoate (2af')

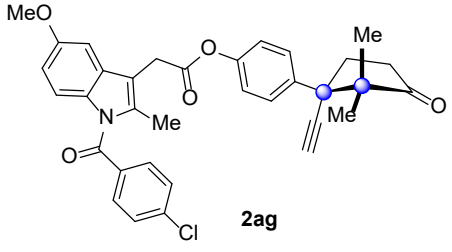


2af'

2af' was prepared following the general procedure using *ent*-**L12**. Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.25) afforded **2af'** (38.9 mg, 88%) as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.79–7.71 (m, 3H), 7.50 (d, J = 8.5 Hz, 1H), 7.46 (d, J = 8.6 Hz, 2H), 7.18–7.12 (m, 2H), 7.01 (d, J = 8.4 Hz, 2H), 4.10 (q, J = 7.1 Hz, 1H), 3.93 (s, 3H), 2.75–2.66 (m, 2H), 2.59–2.51 (m, 1H), 2.39–2.30 (m, 2H), 1.70 (d, J = 7.1 Hz, 3H), 1.22 (s, 3H), 0.58 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 219.6, 173.2, 157.9, 150.3, 136.3, 135.2, 134.0, 129.5, 129.1, 128.6, 127.5, 126.3, 126.2, 121.2, 119.3, 105.8, 87.1, 73.7, 55.5, 54.3, 51.5, 45.7, 34.6, 29.8, 20.4, 19.8, 18.6 ppm. **IR** (KBr): ν_{max} = 3266, 2921, 1737, 1603, 1169, 744 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{29}H_{28}O_4$, $[M+Na]^+$, 463.1880; found: 463.1876. **[α]**$_D^{25}$: +141 (*c* 0.18, $CHCl_3$). **m.p.**: 152.1–153.6 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 30 : 70, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 10.222 min (major), t_R = 21.484 min (minor) (98 : 2 *dr*).



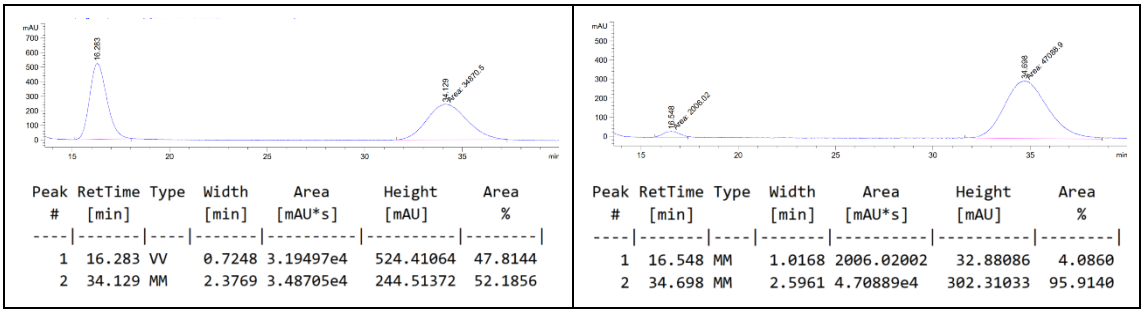
(*S*)-4-(1-ethynyl-2,2-dimethyl-3-oxocyclopentyl)phenyl 2-(1-(4-chlorobenzoyl)-5-methoxy-2-methyl-1H-indol-3-yl)acetate (2ag)



2ag

2ag was prepared using **L12**. Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.32) afforded **2ag** (31.2 mg, 55%) as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.68 (d, J = 8.2 Hz, 2H), 7.49 (dd, J = 11.0, 8.4 Hz, 4H), 7.12–7.05 (m, 3H), 6.89 (d, J = 9.0 Hz, 1H), 6.70 (dd, J = 9.1, 2.5 Hz, 1H), 3.91 (s, 2H), 3.84 (s, 3H), 2.78–2.64 (m, 2H), 2.63–2.51 (m, 1H), 2.46 (s, 3H), 2.38 (s, 1H), 2.37–2.32 (m,

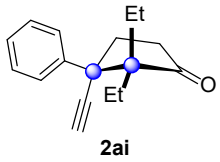
1H), 1.24 (s, 3H), 0.60 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 219.5, 169.3, 168.5, 156.3, 150.1, 139.5, 136.6, 136.4, 134.0, 131.4, 131.0, 130.6, 129.3, 128.7, 121.2, 115.2, 112.1, 111.9, 101.4, 87.1, 73.8, 55.9, 54.3, 51.5, 34.6, 30.8, 29.9, 20.4, 19.8, 13.6 ppm. **IR** (KBr): ν_{max} = 3296, 2926, 2859, 1743, 1684, 1506, 1319, 1128, 737 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{34}H_{30}ClNO_5$, $[M+Na]^+$, 590.1705; found: 590.1708. **$[\alpha]_D^{25}$**: −45.8 (*c* 0.36, $CHCl_3$). **m.p.**: 80.3–81.2 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 35 : 65, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 16.548 min (minor), t_R = 34.698 min (major) (92% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	16.283	VV	0.7248	3.19497e4	524.41064	47.8144
2	34.129	MM	2.3769	3.48705e4	244.51372	52.1856

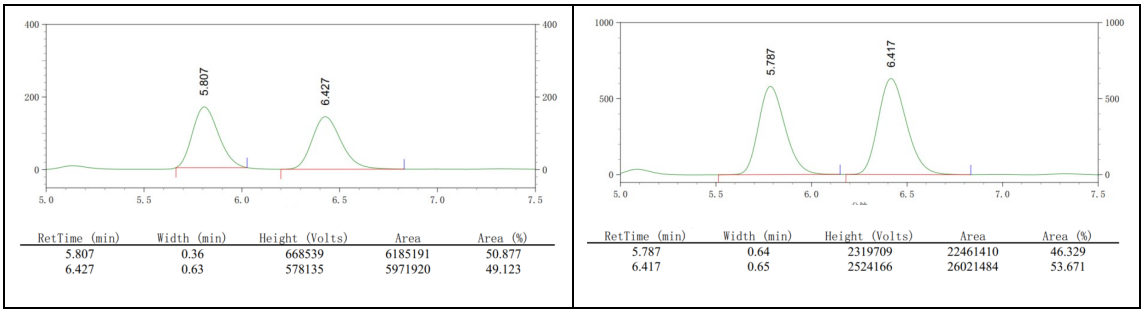
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	16.548	MM	1.0168	2006.02002	32.88086	4.0860
2	34.698	MM	2.5961	4.70889e4	302.31033	95.9140

(*S*)-2,2-diethyl-3-ethynyl-3-phenylcyclopentan-1-one (2ai)



2ai

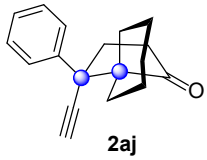
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.66) afforded **2ai** (9.1 mg, 38%) as a colorless oil. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.55 (d, *J* = 7.3 Hz, 2H), 7.32 (q, *J* = 9.0, 8.0 Hz, 3H), 2.75–2.59 (m, 2H), 2.59–2.41 (m, 3H), 2.15 (dq, *J* = 15.0, 7.5 Hz, 1H), 1.80 (dq, *J* = 15.2, 7.6 Hz, 1H), 1.60 (d, *J* = 7.7 Hz, 1H), 0.99 (dq, *J* = 14.7, 7.4 Hz, 1H), 0.71 (td, *J* = 7.5, 1.8 Hz, 6H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 217.0, 141.9, 128.7, 127.4, 126.2, 84.2, 75.7, 62.0, 49.9, 38.1, 36.4, 19.9, 12.8 ppm. **IR** (KBr): ν_{max} = 3449, 2923, 1734, 1640, 1396, 570 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{17}H_{20}O$, $[M+H]^+$, 241.1587; found: 241.1591. **HPLC** (Chiral pak OD-H, *i*-PrOH/*n*-hexane = 5 : 95, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 5.787 min (minor), t_R = 6.417 min (major) (7% *ee*).



RetTime (min)	Width (min)	Height (Volts)	Area	Area (%)
5.807	0.36	668539	6185191	50.877
6.427	0.63	578135	5971920	49.123

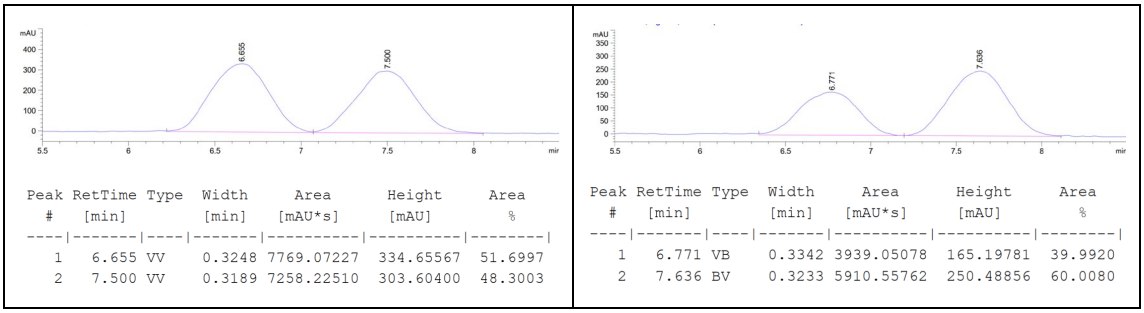
RetTime (min)	Width (min)	Height (Volts)	Area	Area (%)
5.787	0.64	2319709	22461410	46.329
6.417	0.65	2524166	26021484	53.671

(*S*)-4-ethynyl-4-phenylspiro[4.5]decan-1-one (2aj)



2aj

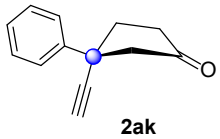
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.66) afforded **2aj** (13.9 mg, 55%) as a colorless oil. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.52 (d, J = 7.3 Hz, 2H), 7.37 (t, J = 7.4 Hz, 2H), 7.34–7.27 (m, 1H), 2.84 (dt, J = 12.3, 9.4 Hz, 1H), 2.69 (dt, J = 19.0, 9.4 Hz, 1H), 2.57–2.46 (m, 1H), 2.41 (s, 1H), 2.29 (ddd, J = 11.9, 9.3, 2.2 Hz, 1H), 2.20 (dd, J = 13.4, 3.3 Hz, 1H), 2.08 (qt, J = 13.2, 4.2 Hz, 1H), 1.52 (qd, J = 13.8, 13.3, 6.2 Hz, 3H), 1.41–1.21 (m, 4H), 0.86–0.76 (m, 1H), 0.68 (ddd, J = 13.2, 10.9, 5.4 Hz, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 219.2, 138.3, 128.4, 128.1, 127.5, 87.2, 73.9, 56.0, 53.2, 35.0, 29.6, 28.8, 28.2, 25.4, 21.8, 21.6 ppm. **IR** (KBr): ν_{max} = 3292, 2929, 2857, 1732, 1452, 699 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{18}H_{20}O$, $[M+H]^+$, 253.1587; found: 253.1589. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 2 : 98, flow rate = 1.0 mL/min, wave length = 220 nm): t_R = 6.771 min (minor), t_R = 7.636 min (major) (20% *ee*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.655	VV	0.3248	7769.07227	334.65567	51.6997
2	7.500	VV	0.3189	7258.22510	303.60400	48.3003

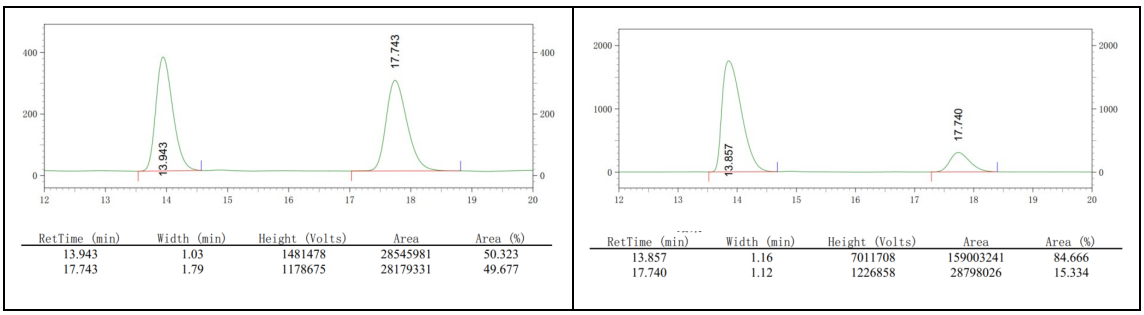
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.771	VB	0.3342	3939.05078	165.19781	39.9920
2	7.636	BV	0.3233	5910.55762	250.48856	60.0080

(*S*)-3-ethynyl-3-phenylcyclopentan-1-one (2ak)

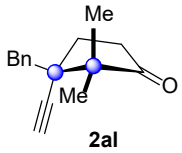


2ak

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.63) afforded **2ak** (17.5 mg, 95%) as a colorless oil. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.52 (d, J = 7.6 Hz, 2H), 7.39 (t, J = 7.6 Hz, 2H), 7.30 (t, J = 7.4 Hz, 1H), 2.86 (d, J = 17.6 Hz, 1H), 2.73–2.65 (m, 2H), 2.62 (td, J = 10.3, 8.5, 2.4 Hz, 1H), 2.47–2.40 (m, 2H), 2.38–2.31 (m, 1H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 215.9, 142.4, 128.9, 127.5, 126.0, 87.8, 72.3, 52.9, 43.9, 38.1, 37.3 ppm. **IR** (KBr): ν_{max} = 3414, 2921, 1743, 1620 1145, 622 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{13}H_{12}O$, $[M+H]^+$, 185.0961; found: 185.0962. **HPLC** (Chiral pak OD-H, *i*-PrOH/*n*-hexane = 5 : 95, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 13.857 min (major), t_R = 17.740 min (minor) (69% *ee*).



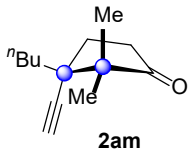
(*R*)-3-benzyl-3-ethynyl-2,2-dimethylcyclopentan-1-one (2al)



2al

The generation of **2al** was not detected under standard conditions.

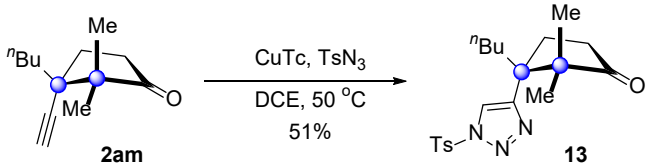
(*S*)-3-butyl-3-ethynyl-2,2-dimethylcyclopentan-1-one (2am)



2am

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.41) afforded **2am** (3 mg, 16%) as a colorless oil. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 2.45 (dt, J = 18.7, 9.2 Hz, 1H), 2.33–2.28 (m, 1H), 2.23–2.14 (m, 2H), 1.90 (dt, J = 12.9, 9.0 Hz, 1H), 1.62–1.57 (m, 1H), 1.53 (dd, J = 12.4, 4.1 Hz, 1H), 1.46–1.41 (m, 1H), 1.38–1.33 (m, 3H), 1.18 (s, 3H), 0.97–0.91 (m, 6H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 221.4, 87.2, 72.8, 52.7, 46.9, 34.4, 34.3, 30.9, 27.5, 23.4, 20.8, 19.0, 14.2 ppm. **IR** (KBr): ν_{max} = 3413, 2922, 1734, 1628, 614 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{13}H_{12}O$, $[M+H]^+$, 185.0961; found: 185.0962. Ee value of **2am** was determined to be 49% based on HPLC analysis of its derivative **13**.

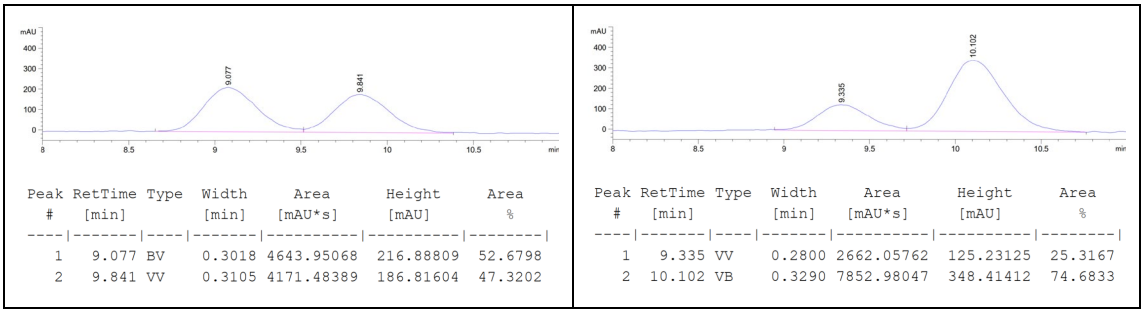
Transformation of 2am to 13:



2am **13**

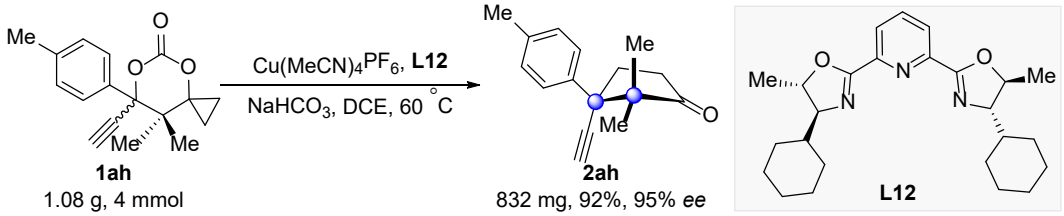
Preparation of (*R*)-3-butyl-2,2-dimethyl-3-(1-tosyl-1H-1,2,3-triazol-4-yl)cyclopentan-1-one (13). To a solution of **2am** (2 mg, 0.01 mmol, 1 equiv) in DCE (0.5 mL) was added CuTc (3.8 mg, 0.02 mmol, 2 equiv) and TsN_3 (3.9 mg, 0.02 mmol, 2 equiv). The reaction was stirred at 50 °C for 4 h, and the mixture was concentrated in vacuo. The

resulting crude product was purified by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.42) to afford **13** (2 mg, 51%) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.97 (d, *J* = 8.3 Hz, 2H), 7.87 (s, 1H), 7.39 (d, *J* = 8.2 Hz, 2H), 2.57–2.49 (m, 1H), 2.46 (s, 3H), 2.42–2.28 (m, 2H), 2.24–2.15 (m, 1H), 1.93–1.85 (m, 1H), 1.40–1.32 (m, 2H), 1.24–1.17 (m, 3H), 1.13 (s, 3H), 0.78 (t, *J* = 7.2 Hz, 3H), 0.59 (s, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 221.3, 151.0, 147.4, 133.2, 130.6, 128.7, 120.9, 53.6, 48.1, 34.1, 33.6, 27.0, 25.7, 23.2, 22.0, 18.3, 14.1. **IR** (KBr): ν_{max} = 3412, 2922, 1622, 1093, 619, 478 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{20}H_{27}N_3O_3S$, $[M+H]^+$, 390.1846; found: 390.1857. **HPLC** (Chiral pak OD-H, *i*-PrOH/*n*-hexane = 15 : 85, flow rate = 1.0 mL/min, wave length = 220 nm): t_R = 9.335 min (minor), t_R = 10.102 min (major) (49% *ee*).



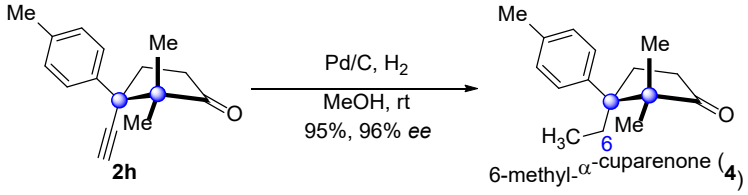
4. Synthetic Applications

4.1 Gram-scale reaction

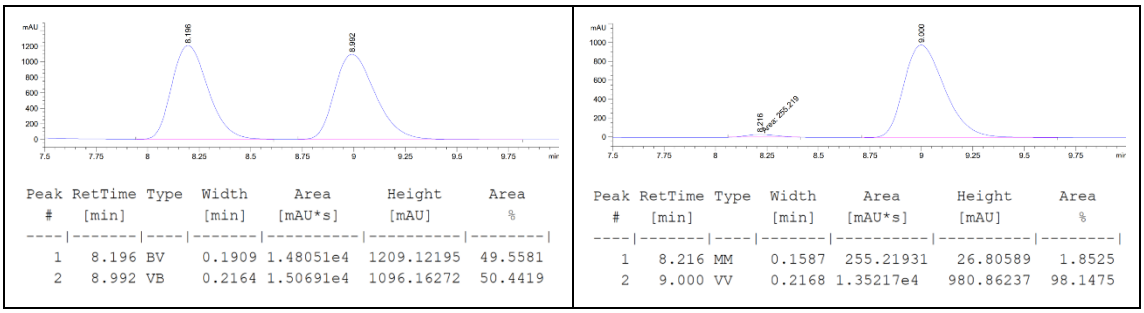


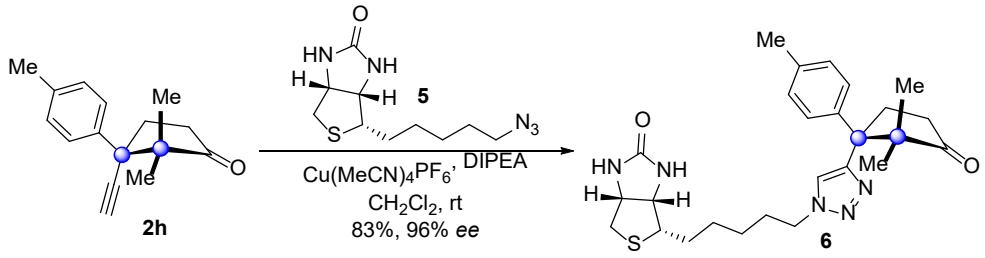
A mixture of $Cu(MeCN)_4PF_6$ (149 mg, 0.4 mmol, 10 mol%) and **L12** (197 mg, 0.48 mmol, 12 mol%) in anhydrous DCE (160 mL) in an a flame-dried flask (500 mL) was stirred at room temperature for 30 min under a nitrogen atmosphere (balloon). Then **1ah** (1.08 g, 4 mmol) and $NaHCO_3$ (336 mg, 4 mmol, 1 equiv) were added. The resulting mixture was stirred at 60 °C for 48 h, until **1ah** was fully consumed as monitored by the TLC analysis. The mixture was concentrated in vacuo, and the crude product was purified by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1) to afford **2ah** (832 mg, 92% yield, 92% *ee*) as a white solid.

4.2 Transformations of compound 2h



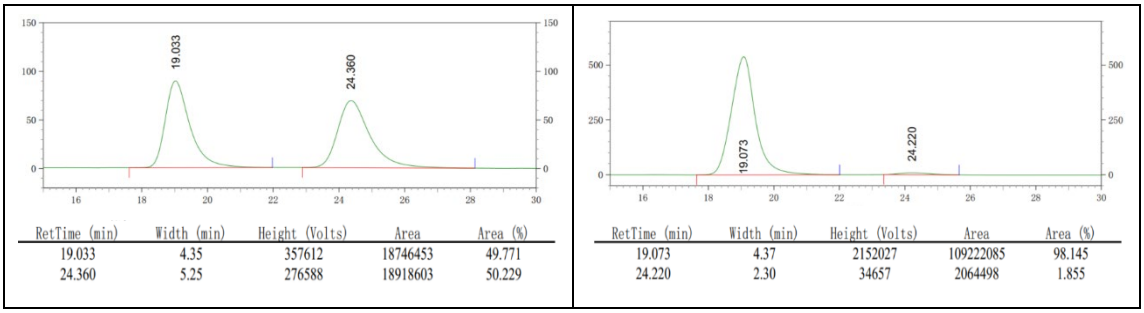
Preparation of (*R*)-6-methyl-*α*-cuparenone (4). To a solution of **2h** (22.6 mg, 0.1 mmol) in MeOH (1 mL) was added 10% Pd/C (10.6 mg, 0.01 mmol), and the reaction mixture was stirred for 4 h at the room temperature under an atmosphere of H_2 (balloon). The reaction mixture was filtered through a pad of celite, and the filtrate was concentrated in vacuo. The crude residue was purified by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.71) to yield **4** (21.9 mg, 95%) as a light yellow oil. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.25–7.09 (m, 4H), 2.51–2.39 (m, 2H), 2.34 (s, 3H), 2.18–2.12 (m, 1H), 1.97–1.88 (m, 1H), 1.35–1.25 (m, 2H), 1.19 (s, 3H), 0.63–0.59 (m, 6H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 222.9, 139.9, 135.8, 129.0, 127.1, 54.1, 52.4, 33.6, 27.7, 23.8, 22.6, 21.0, 18.2, 9.0 ppm. **IR** (KBr): ν_{max} = 2973, 1736, 1460, 1266, 745 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{16}H_{22}O$, $[M+Na]^+$, 253.1563; found: 253.1558. **$[\alpha]_D^{25}$**: −74 (*c* 0.10, $CHCl_3$). **HPLC** (Chiral pak OD-H, *i*-PrOH/*n*-hexane = 0.5 : 99.5, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 8.216 min (minor), t_R = 9.000 min (major) (96% *ee*).

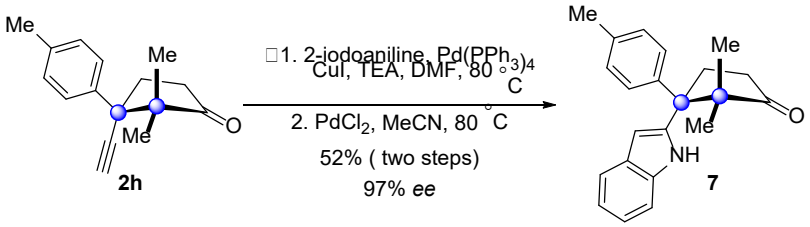




Preparation of (3a*S*,4*S*,6a*R*)-4-(5-(4-((*S*)-2,2-dimethyl-3-oxo-1-(*p*-tolyl)cyclopentyl)-1H-1,2,3-triazol-1-yl) pentyl)tetrahydro-1H-thieno[3,4-d]imidazol-2(3H)-one (6)[1]. A mixture of **2h** (27 mg, 0.12 mmol), **5** (25.5 mg, 0.1 mmol), $Cu(MeCN)_4PF_6$ (7.5 mg, 0.02 mmol) and DIPEA (10 μL, 0.06 mmol) in CH_2Cl_2 (0.5 mL) was stirred at the room temperature overnight and then concentrated in vacuo. The crude residue was purified by flash column

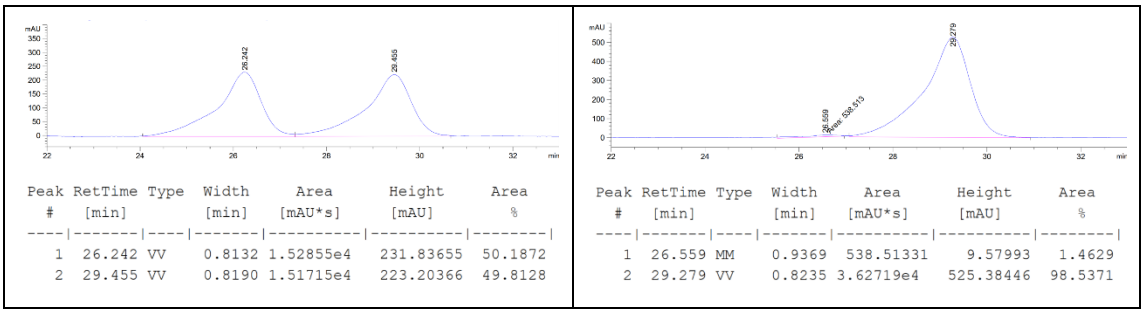
chromatography on silica gel (CH_2Cl_2/MeOH = 10 : 1, R_f = 0.12) to yield **6** (40.0 mg, 83%) as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.27 (d, J = 7.7 Hz, 2H), 7.18 (d, J = 7.8 Hz, 2H), 6.75 (s, 1H), 6.00 (s, 1H), 5.27 (s, 1H), 4.50–4.48 (m, 1H), 4.29–4.27 (m, 1H), 4.24–4.16 (m, 2H), 3.14–3.09 (m, 1H), 2.93–2.87 (m, 2H), 2.80–2.71 (m, 2H), 2.56–2.51 (m, 1H), 2.38–2.34 (m, 4H), 1.87–1.79 (m, 2H), 1.72–1.66 (m, 1H), 1.64–1.57 (m, 1H), 1.44–1.38 (m, 2H), 1.35–1.28 (m, 2H), 1.17 (s, 3H), 0.81 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 221.3, 154.6, 140.1, 136.8, 129.9, 129.2, 127.7, 122.2, 62.2, 60.3, 55.7, 53.8, 53.0, 50.2, 40.7, 34.0, 31.0, 30.0, 28.6, 28.5, 26.6, 22.2, 21.1, 20.6 ppm. **IR** (KBr): ν_{max} = 3250, 2926, 2858, 1737, 1702, 1462, 1265, 735 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{26}H_{35}N_5O_2S$, $[M+Na]^+$, 504.2404; found: 504.2442. **$[\alpha]_D^{25}$**: −21.7 (c 0.13, $CHCl_3$). **m.p.**: 76.4–78.2 °C. **HPLC** (Chiral pak AD-H, i-PrOH/n-hexane = 25 : 75, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 19.073 min (major), t_R = 24.220 min (minor) (96% ee).





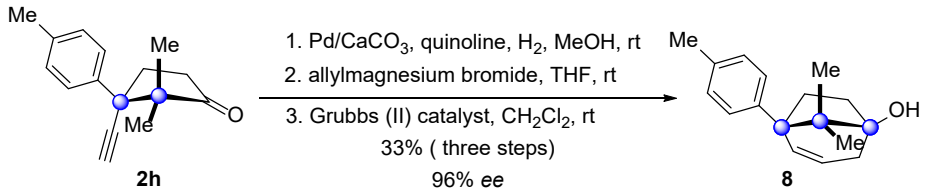
Preparation of (*S*)-3-(1H-indol-2-yl)-2,2-dimethyl-3-(p-tolyl)cyclopentan-1-one (7)[2]. To a flame- dried reaction tube was added 2-iodoaniline (26 mg, 0.12 mmol), $Pd(PPh_3)_4$ (12 mg, 0.01 mmol), CuI (4 mg, 0.02 mmol), and triethylamine (42 μL, 0.3 mmol) under a nitrogen atmosphere (balloon). Then **2h** (23 mg, 0.1 mmol) in anhydrous DMF (1 mL) was added, and the reaction solution was stirred at 80 °C overnight. When **2h** was fully consumed (monitored by TLC), the reaction was quenched by addition of H_2O (2 mL). After extraction of the resulted mixture with EtOAc (3 × 3 mL), the combined organic layers were dried over Na_2SO_4, filtered, and concentrated in vacuo. The crude product was dissolved in MeCN (1 mL), and $PdCl_2$ (3.5 mg, 0.02 mmol, 0.2 equiv) was added under a nitrogen atmosphere (balloon). The reaction solution was stirred at 80 °C for 24 h and then concentrated in vacuo. The crude residue was purified by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.62) to yield **7** (16.5 mg, 52%) as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.55 (d,

J = 7.7 Hz, 1H), 7.39 (s, 1H), 7.19–7.15 (m, 5H), 7.13–7.07 (m, 2H), 6.34 (s, 1H), 2.71–2.66 (m, 1H), 2.60–2.45 (m, 2H), 2.44–2.40 (m, 1H), 2.38 (s, 3H), 1.27 (s, 3H), 0.98 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 221.1, 141.9, 139.0, 137.3, 135.8, 129.4, 128.5, 128.2, 122.0, 120.4, 120.0, 110.7, 102.5, 55.8, 53.6, 33.5, 30.4, 21.8, 21.1, 20.4 ppm. **IR** (KBr): ν_{max} = 2924, 1734, 1457, 1289, 1075, 819, 747 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{22}H_{23}NO$, $[M+Na]^+$, 340.1672; found: 340.1676. **$[\alpha]_D^{25}$**: −41 (c 0.10, $CHCl_3$). **m.p.**: 246.7–249.3 °C. **HPLC** (Chiral pak AD-H, i-PrOH/n-hexane = 1 : 99, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 26.559 min (minor), t_R = 29.279 min (major) (97% *ee*).



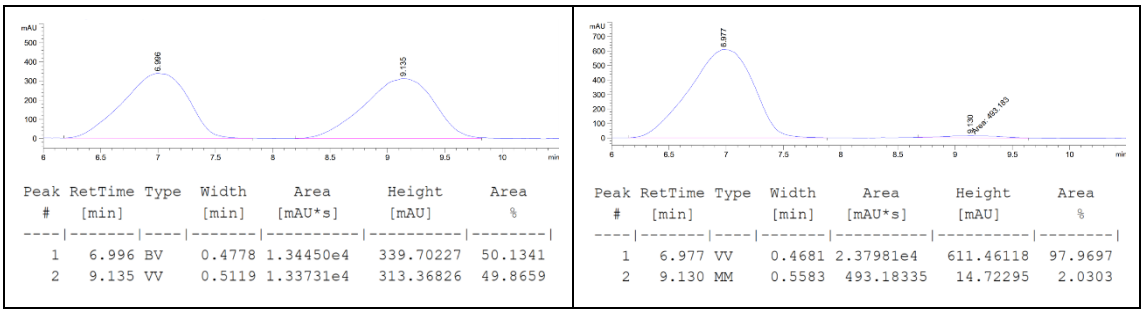
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	26.242	VV	0.8132	1.52855e4	231.83655	50.1872
2	29.455	VV	0.8190	1.51715e4	223.20366	49.8128

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	26.559	MM	0.9369	538.51331	9.57993	1.4629
2	29.279	VV	0.8235	3.62719e4	525.38446	98.5371



Preparation of (1*S*,5*S*)-8,8-dimethyl-5-(*p*-tolyl)bicyclo[3.2.1]oct-3-en-1-ol (8). A mixture of **2h** (22.6 mg, 0.1 mmol), 10% $Pd/CaCO_3$ (10.6 mg, 0.01 mmol), and quinoline (2.6 mg, 0.02 mmol) in MeOH (1 mL) was stirred at the room temperature for 3 h under an atmosphere of H_2 (balloon). The reaction mixture was filtered through a pad of celite, and the filtrate was concentrated in vacuo. The crude residue was purified by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.68) to yield a colorless oil. A solution of the obtained oil (21.9 mg, 0.096 mmol) in anhydrous THF (1 mL) was added with allyl magnesium bromide (0.48 mL, 1 M in THF, 0.5 mmol) at 0 °C. The reaction mixture was stirred 3 h at the room temperature, and then was quenched with a saturated aqueous solution of NH_4Cl (2 mL). The resulting mixture was extracted with EtOAc (3 × 3 mL), and the combined organic phase was washed with brine (1 × 3 mL), dried over Na_2SO_4, filtered, and concentrated in vacuo. The crude residue was purified by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.70) to obtain a pair of inseparable diastereoisomer (dr = 1 : 1) as a colorless oil. A mixture of the resulting oil (22 mg, 0.081 mmol) and Grubbs II catalyst (6.9 mg, 0.0081 mmol) in CH_2Cl_2 (2 mL) was stirred at room temperature for 4 h under a nitrogen atmosphere (balloon) and then concentrated in vacuo. The crude residue was purified by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.34)

to yield **8** (8.0 mg, 33% yield) as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.18–7.13 (m, 4H), 5.80 (d, J = 9.7 Hz, 1H), 5.62–5.60 (m, 1H), 2.68–2.63 (m, 1H), 2.46 (d, J = 16.9 Hz, 1H), 2.34 (s, 3H), 2.23 (d, J = 16.9 Hz, 1H), 2.02–1.93 (m, 2H), 1.80–1.75 (m, 1H), 1.38 (s, 1H), 0.87 (s, 3H), 0.74 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 139.8, 139.3, 135.8, 128.5, 128.0, 123.8, 81.6, 55.1, 46.7, 41.6, 36.6, 33.4, 21.1, 18.5, 17.1 ppm. **IR** (KBr): ν_{max} = 3329, 3025, 2923, 1512, 1267, 1040, 744 cm^{-1}. **HRMS** (APCI) (m/z): Calcd for $C_{17}H_{22}O$, $[M+H]^+$, 243.1743; found: 243.1745. **[α]**$_D^{25}$: −23 (*c* 0.08, $CHCl_3$). **m.p.**: 110.2–111.4 °C. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 3 : 97, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 6.977 min (major), t_R = 9.130 min (minor) (96% *ee*).

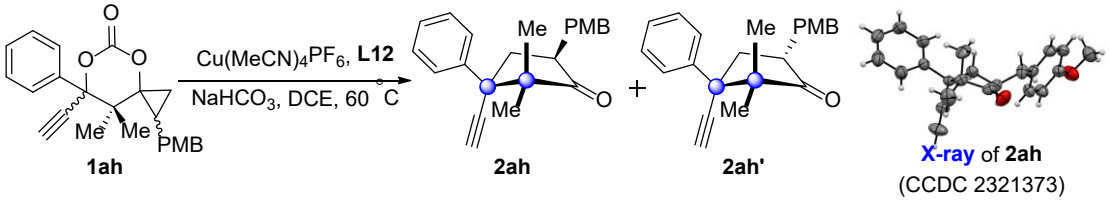


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.996	BV	0.4778	1.34450e4	339.70227	50.1341
2	9.135	VV	0.5119	1.33731e4	313.36826	49.8659

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.977	VV	0.4681	2.37981e4	611.46118	97.9697
2	9.130	MM	0.5583	493.18335	14.72295	2.0303

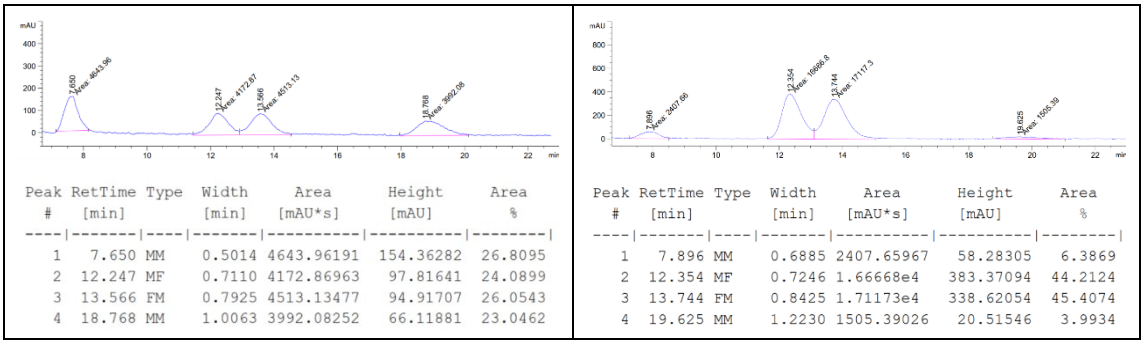
5. Mechanism Studies

5.1 Reaction of 1ah



A mixture of $Cu(MeCN)_4PF_6$ (3.7 mg, 0.01 mmol, 10 mol%) and **L12** (4.9 mg, 0.012 mmol, 10 mol%) in DCE (4 mL) in an oven-dried glass tube was stirred at room temperature for 30 min under a nitrogen atmosphere (balloon). Then **1ah** (37.6 mg, 0.1 mmol) and $NaHCO_3$ (8.4 mg, 0.1 mmol, 1 equiv) was added. The resulting mixture was stirred at 60 °C until **1ah** was fully consumed as indicated by the TLC analysis (48 h). The reaction mixture was concentrated in vacuo, and the resulted crude product was purified by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.34) to afford a pair of inseparable diastereoisomer of **2ah** and **2ah'** (27.3 mg, 82% yield, *dr* = 1 : 1) as a colorless oil. The colorless crystal of **2ah** (preparation through preparative TLC) for X-ray crystallographic analysis was obtained by slow diffusion of *n*-hexane to a solution of **2ah** in EtOAc. Characterization data of the mixture of **2ah**/**2ah'**: **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.44–7.38 (m, 4H), 7.35–7.32 (m, 4H), 7.30–7.27 (m, 2H), 7.15 (d, J = 8.4 Hz, 2H), 6.98 (d, J = 8.4 Hz, 2H), 6.85 (d, J = 8.4 Hz, 2H), 6.78 (d, J = 8.5 Hz, 2H), 3.79 (s, 3H), 3.77 (s, 3H), 3.16–3.09 (m, 2H), 3.07–3.01 (m, 1H), 2.86 (dd, J = 13.7, 7.8 Hz, 1H), 2.74

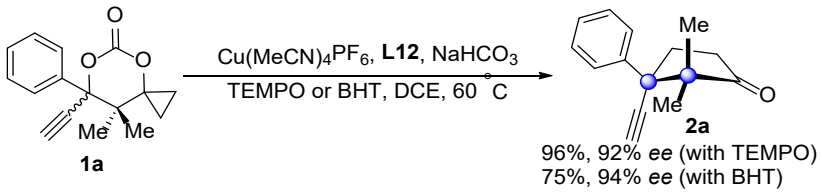
(dd, J = 13.7, 3.5 Hz, 1H), 2.68 (s, 1H), 2.54 (dd, J = 19.8, 9.8 Hz, 1H), 2.48 (t, J = 11.9 Hz, 1H), 2.37–2.34 (m, 2H), 2.27 (dd, J = 19.9, 11.0 Hz, 1H), 1.70–1.66 (m, 1H), 1.36 (s, 3H), 1.30 (s, 3H), 0.91 (s, 3H), 0.30 (s, 3H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 220.4, 220.2, 158.3, 158.2, 138.8, 137.9, 132.5, 131.3, 130.4, 129.7, 128.34, 128.27, 127.52, 127.5, 127.3, 113.99, 113.96, 88.0, 85.2, 75.6, 73.3, 56.3, 55.5, 55.4, 55.4, 54.4, 50.0, 48.5, 47.0, 40.2, 37.2, 35.4, 35.1, 25.5, 20.4, 20.3, 19.1 ppm. **IR** (KBr): ν_{max} = 3286, 2924, 2853, 1737, 1512, 1246, 1035, 701 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{23}H_{24}O_2$, $[M+Na]^+$, 355.1669; found: 355.1673. **HPLC** (Chiral pak AS-H, *i*-PrOH/*n*-hexane = 2 : 98, flow rate = 1.0 mL/min, wave length = 210 nm): t_R = 7.896 min (minor), t_R = 12.354 min (major) (~75% *ee*, ~1 : 1 *dr*).



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.650	MM	0.5014	4643.96191	154.36282	26.8095
2	12.247	MF	0.7110	4172.86963	97.81641	24.0899
3	13.566	FM	0.7925	4513.13477	94.91707	26.0543
4	18.768	MM	1.0063	3992.08252	66.11881	23.0462

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.896	MM	0.6885	2407.65967	58.28305	6.3869
2	12.354	MF	0.7246	1.66668e4	383.37094	44.2124
3	13.744	FM	0.8425	1.71173e4	338.62054	45.4074
4	19.625	MM	1.2230	1505.39026	20.51546	3.9934

5.2 Free radical capture experiments



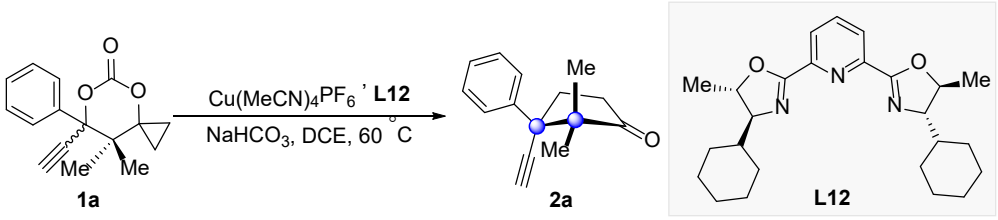
A mixture of $Cu(MeCN)_4PF_6$ (3.7 mg, 0.01 mmol, 10 mol%) and **L12** (4.9 mg, 0.012 mmol, 12 mol%) in anhydrous DCE (4 mL) in an oven-dried glass tube was stirred at room temperature for 30 min under a nitrogen atmosphere (balloon). **1a** (25.6 mg, 0.1 mmol), $NaHCO_3$ (8.4 mg, 0.1 mmol, 1 equiv), and TEMPO (31.3 mg, 0.2 mmol, 2 equiv) or BHT (44.1 mg, 0.2 mmol, 2 equiv) were then added. The mixture was stirred at 60 °C until **1a** was fully consumed as monitored by the TLC analysis (~48 h). The reaction mixture was concentrated in vacuo, and the crude product was purified by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1) to afford **2a** (TEMPO: 20.4 mg, 96% yield, 92% *ee*; BHT: 15.9 mg, 75% yield, 94% *ee*).

5.3 Non-linear effect experiments

A mixture of $Cu(MeCN)_4PF_6$ (3.7 mg, 0.01 mmol, 10 mol%) and **L12** (4.9 mg, 0.012 mmol, 12 mol%) with different optical purities in anhydrous DCE (4 mL) in an oven-dried glass tube was stirred at room temperature for

30 min under a nitrogen atmosphere (balloon). **1a** (25.6 mg, 0.1 mmol) and $NaHCO_3$ (8.4 mg, 0.1 mmol, 1 equiv) were then added. The resulting mixture was stirred at 60 °C until **1a** was fully consumed as monitored by the TLC analysis (48 h). The reaction mixture was concentrated in vacuo, and the crude product was purified by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1) to afford **2a** with different optical purities.

Table S5. Relationship between *ee* values of **L12** and *ee* values of **2a**[a]



entry	*ee* of **L12** (%)[b]	yield (%)[c]	*ee* of **2a** (%)[d]
1	2.5	97	5.3
2	14	95	16
3	25	95	27.5
4	38	96	43
5	57	98	64
6	74	95	79
7	86	96	88
8	100	95	95

[a] Conditions: **1a** (0.1 mmol), $Cu(CH_3CN)_4PF_6$ (10 mol %), **L12** (12 mol %), $NaHCO_3$ (1 equiv), DCE (4 mL), 60 °C, 48 h; [b] Enantiomeric excesses of **L12** (mixture of **L12** and *ent*-**L12** in different ratios) were determined by chiral HPLC analysis; [c] Isolated yields of **2a**; [d] Enantiomeric excesses of **2a** were determined by chiral HPLC analysis.

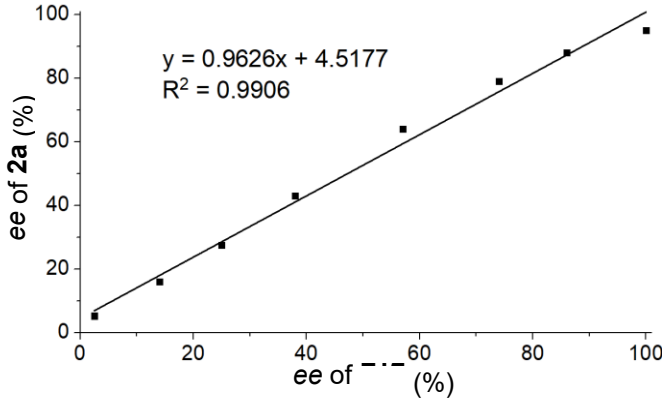


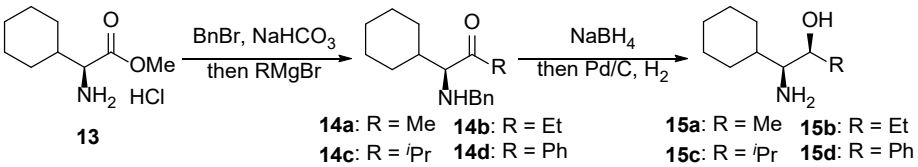
Figure S1. Relationship between *ee* values of **L12** and *ee* values of **2a**.

6. Preparation and Characterization Data of Ligands

Ligands **L1**–**L10** were purchased from commercial suppliers and used without further purification unless otherwise noted. Ligand **L11** were prepared according to the literature procedures[3].

General procedure for the synthesis of Cy-PyBox ligands **L12**–**L15** was as follows:

6.1 Preparation of 15

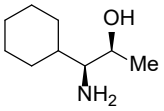


To a 50 mL round-bottom flask was added **13** (415 mg, 2 mmol), $NaHCO_3$ (370 mg, 4.4 mmol), MeCN (20 mL), and BnBr (0.29 mL, 2.4 mmol). The resulting mixture was stirred at 80 °C for 4 h and filtered through a pad of silica gel. The filtrate was concentrated, and the residue was used next step without further purification. To a solution of the crude product (1 equiv) in dry THF (0.1 M) was added RMgBr (1.5 equiv) dropwise at –20 °C. The reaction mixture was stirred at –20 °C for 6 h and then quenched with a saturated aqueous solution of NH_4Cl. The resulting mixture was extracted with EtOAc, and the combined organic phase was washed with brine, dried over Na_2SO_4, filtered, and concentrated in vacuo. The crude product was purified by column chromatography on silica gel to afford **14** (**14a**, 79% yield; **14b**, 81% yield; **14c**, 70% yield; **14d**, 68% yield).

To a solution of **14** (1 equiv) in MeOH (0.1 M) was added $NaBH_4$ (2 equiv) at −40 °C. The mixture was stirred at 0 °C for 8 h and then quenched with water. The resulting mixture was extracted with EtOAc. The combined organic phase was washed with brine, dried over Na_2SO_4, filtered, and concentrated in vacuo. The crude product was purified by column chromatography on silica gel to afford alcohol[4]. A mixture of alcohol (1 equiv) and 10% Pd/C (0.1 equiv) in MeOH (0.1 M) was stirred at 50 °C for 4 h under an atmosphere of H_2 (balloon). The reaction mixture was then filtered through a pad of celite. The filtrate was concentrated in vacuo and the resulted crude residue was purified by flash column chromatography on silica gel to afford **15** (**15a**, 70% yield; **15b**, 56% yield; **15c**, 72% yield; **15d**, 77% yield).

6.2 Characterization data of 15

(1*S*,2*S*)-1-amino-1-cyclohexylpropan-2-ol (15a)

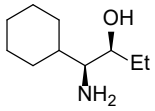


15a

Purification by flash column chromatography on silica gel (CH_2Cl_2/MeOH = 10 : 1, R_f = 0.10) afforded **15a** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 3.70–3.64 (m, 1H), 3.21 (s, 3H), 2.41 (s, 1H), 1.77 (d, J = 12.0 Hz, 2H),

1.63 (dd, J = 26.9, 12.1 Hz, 3H), 1.47 (d, J = 12.0 Hz, 1H), 1.34–0.99 (m, 9H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 67.1, 62.6, 39.3, 31.1, 26.6, 26.5, 26.4, 26.3, 20.4 ppm. **IR** (KBr): ν_{max} = 3370, 2962, 2923, 2850, 1259, 1087, 796 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_9H_{19}NO$, $[M+H]^+$, 158.1539; found: 158.1556. **[α]**$_D^{25}$: −10.2 (c 0.1, $CHCl_3$). **m.p.**: 97.4–99.6 °C.

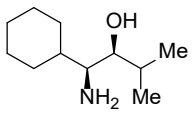
(1*S*,2*S*)-1-amino-1-cyclohexylbutan-2-ol (15b)



15b

Purification by flash column chromatography on silica gel (CH_2Cl_2/MeOH = 10 : 1, R_f = 0.11) afforded **15b** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 3.51 (d, J = 9.6 Hz, 1H), 2.46 (dd, J = 7.7, 4.9 Hz, 1H), 1.93 (d, J = 12.6 Hz, 1H), 1.76–1.60 (m, 4H), 1.48–1.39 (m, 1H), 1.26–1.18 (m, 4H), 1.06–0.94 (m, 6H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 72.7, 60.6, 41.1, 30.1, 29.8, 26.6, 26.3, 26.2, 23.3, 10.8 ppm. **IR** (KBr): ν_{max} = 3387, 2924, 2853, 1452, 970 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{10}H_{21}NO$, $[M+H]^+$, 172.1696; found: 172.1707. **[α]**$_D^{25}$: −10.5 (c 0.09, $CHCl_3$). **m.p.**: 71.3–73.5 °C.

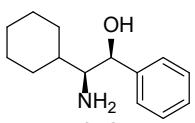
(1*S*,2*S*)-1-amino-1-cyclohexyl-3-methylbutan-2-ol (15c)



15c

Purification by flash column chromatography on silica gel (CH_2Cl_2/MeOH = 10 : 1, R_f = 0.13) afforded **15c** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 3.31 (dd, J = 6.7, 4.4 Hz, 1H), 2.57 (dd, J = 6.7, 4.2 Hz, 1H), 1.86–1.73 (m, 4H), 1.69–1.50 (m, 4H), 1.27–1.09 (m, 4H), 0.94 (d, J = 6.9 Hz, 3H), 0.89 (d, J = 6.8 Hz, 3H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 76.7, 58.2, 39.1, 31.4, 29.2, 27.2, 26.8, 26.7, 26.4, 20.5, 16.5 ppm. **IR** (KBr): ν_{max} = 3382, 2924, 2851, 1449, 893 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{11}H_{23}NO$, $[M+H]^+$, 186.1852; found: 186.1889. **[α]**$_D^{25}$: −15.1 (c 0.08, $CHCl_3$). **m.p.**: 90.3–92.8 °C.

(1*S*,2*S*)-2-amino-2-cyclohexyl-1-phenylethan-1-ol (15d)

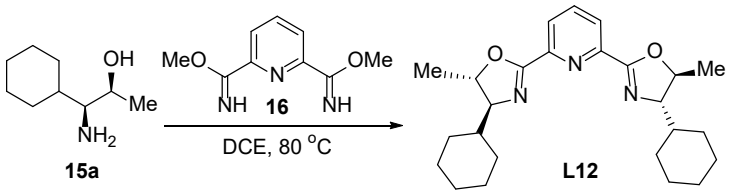


15d

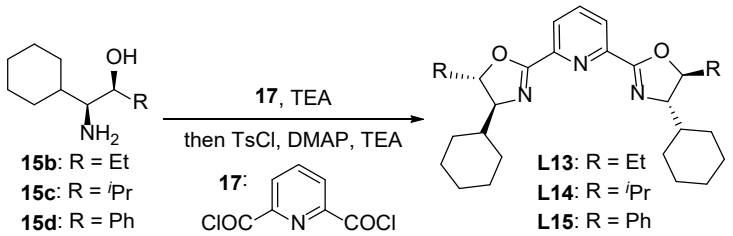
Purification by flash column chromatography on silica gel (CH_2Cl_2/MeOH = 10 : 1, R_f = 0.13) afforded **15d** as a

white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.38–7.27 (m, 5H), 4.72 (d, J = 5.3 Hz, 1H), 2.79 (t, J = 5.3 Hz, 1H), 2.38 (s, 3H), 1.77–1.71 (m, 4H), 1.34–0.95 (m, 7H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 141.8, 128.4, 127.7, 127.0, 74.1, 61.4, 39.2, 31.2, 27.9, 26.6, 26.3, 26.2 ppm. **IR** (KBr): ν_{max} = 3333, 2923, 2850, 1265, 1043, 699 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{14}H_{21}NO$, $[M+H]^+$, 220.1696; found: 220.1721. **$[\alpha]_D^{25}$**: −9.1 (*c* 0.1, MeOH). **m.p.**: 134.4–136.8 °C.

6.3 Preparation of L12–L15



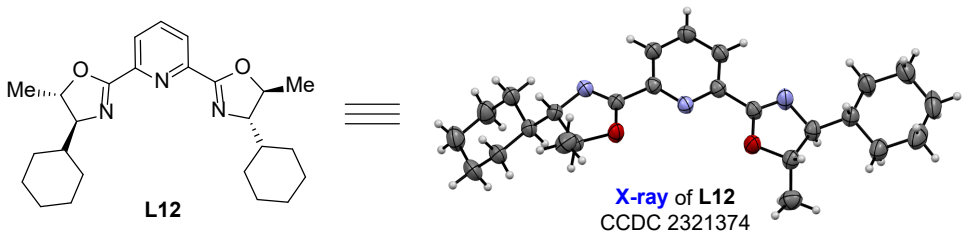
A mixture of **15a** (157 mg, 1 mmol) and **16** (97 mg, 0.5 mmol) in anhydrous DCE (5 mL) was stirred at 80 °C for 12 h. The reaction solution was then concentrated in vacuo and the crude residue was purified by flash column chromatography on silica gel to afford **L12** (75% yield) as a white solid[5].



To a solution of **15** (1 mmol) and TEA (0.35 mL, 2.5 mmol) in CH_2Cl_2 (5 mL) was added a solution of **17** (204 mg, 0.5 mmol) in CH_2Cl_2 (1 mL) dropwise at 0 °C. The reaction mixture was stirred at room temperature for 8 h and then concentrated under a reduced pressure. The crude residue was purified by flash column chromatography on silica gel to afford amide. To a solution of amide (1 equiv), DMAP (5 equiv), and TEA (5 equiv) in CH_2Cl_2 (0.1 M) was added a solution of TsCl (1 equiv) in CH_2Cl_2 dropwise at 0 °C. The reaction mixture was stirred at room temperature for 12 h and then concentrated under a reduced pressure. The crude residue was purified by flash column chromatography on silica gel to afford **L13**, **L14**, **or L15** as a white solid (**L13**, 62% yield; **L14**, 50% yield; **L15**, 68% yield)[6].

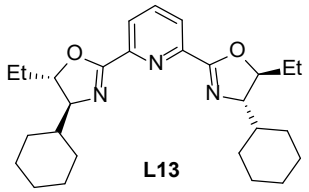
6.4 Characterization data of L12–L15

2,6-bis((4*S*,5*S*)-4-cyclohexyl-5-methyl-4,5-dihydrooxazol-2-yl)pyridine (L12)



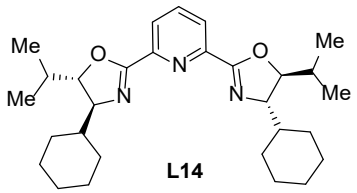
Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 1 : 1, R_f = 0.41) afforded **L12** as a white solid. The colorless crystal of **L12** for X-ray crystallographic analysis was obtained by slow diffusion of *n*-hexane to a solution of **L12** in CH_2Cl_2. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 8.13 (d, J = 7.8 Hz, 2H), 7.82 (t, J = 7.9 Hz, 1H), 4.64–4.60 (m, 2H), 3.62 (t, J = 7.2 Hz, 2H), 1.98 (d, J = 13.0 Hz, 2H), 1.78–1.74 (m, 4H), 1.69–1.64 (m, 4H), 1.55–1.48 (m, 2H), 1.44 (d, J = 6.2 Hz, 6H), 1.27–1.16 (m, 6H), 1.11–1.03 (m, 4H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 161.4, 147.4, 137.2, 125.7, 80.1, 79.1, 42.6, 29.8, 29.0, 26.7, 26.2, 22.0 ppm. **IR** (KBr): ν_{max} = 2924, 2852, 1643, 1450, 1264, 744 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{25}H_{35}N_3O_2$, $[M+H]^+$, 410.2802; found: 410.2807. **[α]**$_D^{25}$: −91.6 (*c* 0.14, $CHCl_3$). **m.p.**: 161.1–163.7 °C.

2,6-bis((4*S*,5*S*)-4-cyclohexyl-5-ethyl-4,5-dihydrooxazol-2-yl)pyridine (L13)



Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 1 : 1, R_f = 0.47) afforded **L13** as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 8.09 (d, J = 7.8 Hz, 2H), 7.83 (t, J = 7.8 Hz, 1H), 4.45 (q, J = 6.4 Hz, 2H), 3.71 (t, J = 6.7 Hz, 2H), 1.96 (d, J = 13.0 Hz, 2H), 1.78–1.73 (m, 6H), 1.69–1.65 (m, 6H), 1.53–1.47 (m, 2H), 1.27–1.17 (m, 6H), 1.11–1.05 (m, 4H), 1.03 (t, J = 7.4 Hz, 6H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 161.4, 147.4, 137.2, 125.6, 84.8, 76.7, 42.7, 29.6, 29.1, 28.9, 26.6, 26.3, 26.2, 9.6 ppm. **IR** (KBr): ν_{max} = 2925, 2852, 1664, 1453, 1261, 941, 745 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{27}H_{39}N_3O_2$, $[M+H]^+$, 438.3115; found: 438.1120. **[α]**$_D^{25}$: −103 (*c* 0.06, $CHCl_3$). **m.p.**: 79.3–81.7 °C.

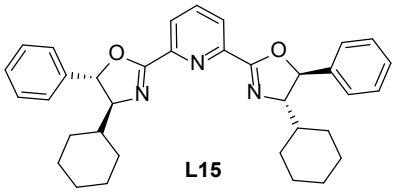
2,6-bis((4*S*,5*S*)-4-cyclohexyl-5-isopropyl-4,5-dihydrooxazol-2-yl)pyridine (L14)



Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 1 : 1, R_f = 0.48) afforded **L14**

as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 8.09 (d, J = 7.8 Hz, 2H), 7.85 (t, J = 7.8 Hz, 1H), 4.40 (t, J = 8.1 Hz, 2H), 4.01 (dd, J = 8.8, 5.0 Hz, 2H), 2.36 (s, 4H), 2.16–2.13 (m, 2H), 1.94 (d, J = 13.2 Hz, 2H), 1.77 (d, J = 13.0 Hz, 2H), 1.70–1.68 (m, 4H), 1.64 (d, J = 12.6 Hz, 2H), 1.47–1.40 (m, 2H), 1.32–1.22 (m, 4H), 1.20–1.14 (m, 2H), 1.10 (d, J = 6.4 Hz, 6H), 1.06 (d, J = 6.6 Hz, 6H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 162.7, 147.3, 137.4, 125.4, 89.6, 72.8, 38.2, 32.3, 29.1, 27.9, 26.8, 26.4, 26.1, 20.8, 19.5 ppm. **IR** (KBr): ν_{max} = 2963, 2924, 2852, 1666, 1450, 1342, 938, 745 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{29}H_{43}N_3O_2$, $[M+H]^+$, 466.3428; found: 466.3425. **[α]**$_D^{25}$: −95.8 (*c* 0.08, $CHCl_3$). **m.p.**: 213.7–215.2 °C.

2,6-bis((4*S*,5*S*)-4-cyclohexyl-5-phenyl-4,5-dihydrooxazol-2-yl)pyridine (L15)



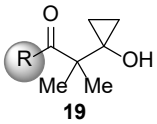
L15

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 1 : 1, R_f = 0.68) afforded **L15** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.18 (d, J = 7.8 Hz, 2H), 7.88 (t, J = 7.9 Hz, 1H), 7.37–7.28 (m, 10H), 5.40 (d, J = 7.4 Hz, 2H), 4.10 (t, J = 7.0 Hz, 2H), 2.06–2.00 (m, 2H), 1.80–1.62 (m, 10H), 1.31–1.07 (m, 10H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 161.3, 147.1, 141.1, 137.4, 128.8, 128.4, 126.5, 125.9, 85.0, 80.7, 43.0, 29.6, 29.3, 26.6, 26.2, 26.2 ppm. **IR** (KBr): ν_{max} = 2925, 2852, 1645, 1452, 1263, 963, 742 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{35}H_{39}N_3O_2$, $[M+H]^+$, 534.3115; found: 534.3116. **[α]**$_D^{25}$: −25 (*c* 0.05, $CHCl_3$). **m.p.**: 263.4–267.9 °C.

7. Preparation and Characterization Data of 1

7.1 Preparation of 19

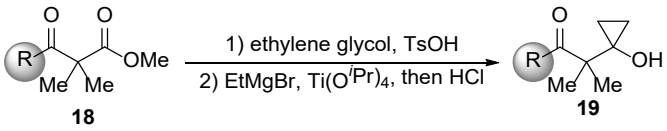
Compounds **19a**, **19b**, **19e**, **19f**, **19g**, **19h**, **19i**, **19j**, **19k**, **19m**, **19o**, **19v**, **19w**, **19aa**, **19ac**, **19ak**, **19al** and **19am** were prepared by **Method A**; Compounds **19c, 19d**, **19l**, **19n**, **19p**, **19q**, **19r**, **19s**, **19t**, **19u**, **19x**, **19y**, **19z**, **19ab**, **19ad**, **19ai** and **19aj** were prepared by **Method B**; Compounds **19ae**, **19af**, and **19ag** were prepared by **Method C**; Compound **19ah** was prepared by **Method D**.



19

19a: R = Ph
19b: R = 4-$MeOC_6H_4$
19c: R = 4-$TBSOC_6H_4$
19d: R = 4-morpholineyl-C_6H_4
19e: R = 4-FC_6H_4
19f: R = 4-ClC_6H_4
19g: R = 4-BrC_6H_4
19h: R = 4-MeC_6H_4
19i: R = 4-$CF_3C_6H_4$
19j: R = 4-PhC_6H_4
19k: R = 3-$MeOC_6H_4$
19l: R = 3-FC_6H_4
19m: R = 3-ClC_6H_4
19n: R = 3-BrC_6H_4
19o: R = 3-MeC_6H_4
19p: R = 2-FC_6H_4
19q: R = 3-MeO-4-ClC_6H_3
19r: R = 3,4-diClC_6H_3
19s: R = 3-Me-4-BrC_6H_3
19t: R = piperonyl
19u: R = 3,5-di^{t}BuC_6H_3
19v: R = 3,4,5-triMeC_6H_2
19w: R = 2-naphthyl
19x: R = dihydrobenzofuranyl
19y: R = 3-furyl
19z: R = 3-thienyl
19aa: R = 2-thienyl
19ab: R = *N*-Ts-3-indolyl
19ac: R = Me

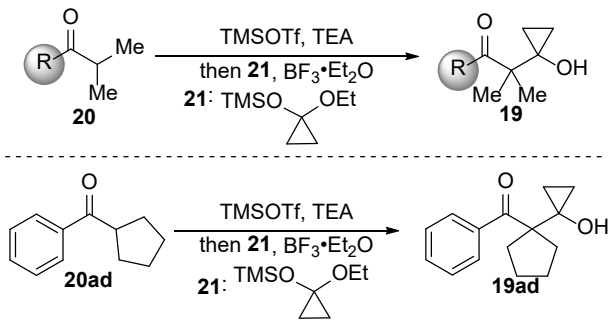
Method A:



18 **19**

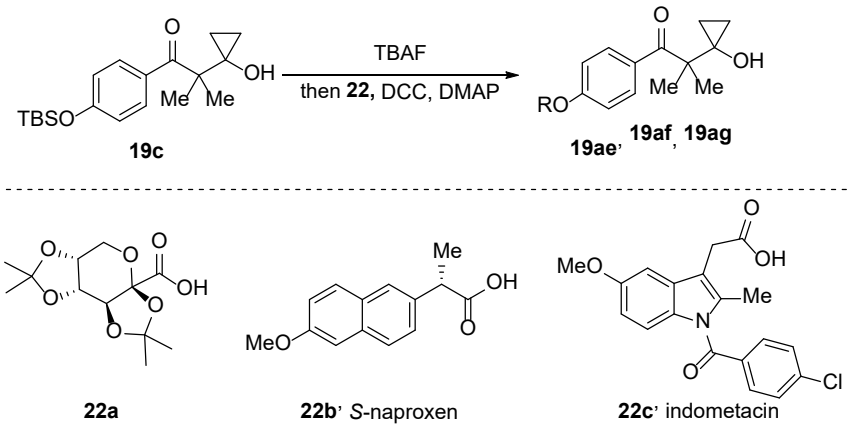
A round-bottomed flask equipped with a Dean-Stark Trap was charged with **18** (compounds **18a**, **18b**, **18e**, **18f**, **18g**, **18h**, **18i**, **18j**, **18k**, **18m**, **18o**, **18v**, **18w**, **18aa**, **18al**, and **18am** were synthesized following the reported procedure[7], compound **18ac** and **18ak** was commercially available) (5 mmol), ethylene glycol (2.8 mL, 50 mmol), and TsOH (86 mg, 0.5 mmol) in toluene (50 mL). The reaction mixture was stirred at 140 °C for 24 h and then quenched with a saturated aqueous solution of $NaHCO_3$ (20 mL). After separation of the organic phase, the aqueous phase was extracted with EtOAc (2 × 30 mL). The combined organic phase was concentrated in vacuo. The crude product was filtered through a pad of silica gel to afford the protected crude esters. To a solution of the crude esters (1 equiv) and Ti(O^{i}Pr)$_4$ (0.4 equiv) in THF (0.1 M) was added EtMgBr (2 equiv) dropwise at 0 °C. The reaction mixture was stirred for an additional 2 h and then quenched with a saturated aqueous solution of NH_4Cl. The resulting mixture was extracted with EtOAc, and the combined organic phase was washed with brine, dried over Na_2SO_4, filtered, and concentrated in vacuo. The crude product was used directly in the next step without further purification. To a solution of the above crude cyclopropanol (1 equiv) in THF (0.1 M) was added a 2 N aqueous HCl solution (50% volume ratio). The resulting mixture was stirred at 60 °C for 8 h and then extracted with EtOAc. The combined organic phase was washed with brine, dried over Na_2SO_4, filtered, and concentrated in vacuo. The crude product was purified by column chromatography on silica gel to afford **19** (**19a**, 65% yield; **19b**, 29% yield; **19e**, 45% yield; **19f**, 30% yield; **19g**, 32% yield; **19h**, 39% yield; **19i**, 23% yield; **19j**, 54% yield; **19k**, 27% yield; **19m**, 21% yield; **19o**, 41% yield; **19v**, 30% yield; **19w**, 16% yield; **19aa**, 47% yield; **19ac**, 52% yield; **19ak**, 65% yield; **19al**, 50% yield; **19am**, 58% yield).

Method B:



To a solution of **20** (compounds **20c, 20d**, **20l**, **20n**, **20p**, **20q**, **20r**, **20s**, **20t**, **20u**, **20x**, **20y**, **20z**, **20ab** and **20al** were synthesized following the reported procedure[8], compound **20ad** and **20aj** is commercially available) (2 mmol) and TEA (1.1 mL, 8 mmol) in CH_2Cl_2 (20 mL) was added TMSOTf (0.54 mL, 3 mmol) dropwise at 0 °C. The reaction mixture was stirred overnight at room temperature before being quenched with a saturated aqueous solution of $NaHCO_3$ (20 mL). The resulting mixture was extracted with CH_2Cl_2 (2 × 20 mL), and the combined organic phase was dried over Na2SO4, filtered, and concentrated in vacuo. The crude product was filtered through a pad of silica gel and then concentrated. To a solution of the crude silyl ether (2 equiv) and **21** (1 equiv) in CH_2Cl_2 (0.1 M) was added BF_3•Et_2O (1.6 equiv) dropwise at −78 °C. The reaction temperature was then elevated to 0 °C after 2 h. The reaction was stirred for additional 2 h at room temperature. The resulting solution was quenched with a saturated aqueous solution of $NaHCO_3$ and extracted with CH_2Cl_2. The combined organic phase was dried over Na2SO4, filtered, and concentrated in vacuo. The crude product was purified by flash column chromatography on silica gel to afford **19** (**19c**, 62% yield; **19d**, 50% yield; **19l**, 51% yield; **19n**, 42% yield; **19p**, 65% yield; **19q**, 65% yield; **19r**, 32% yield; **19s**, 59% yield; **19t**, 70% yield; **19u**, 77% yield; **19x**, 63% yield; **19y**, 60% yield; **19z**, 65% yield; **19ab**, 62% yield; **19ad**, 56% yield; **19aj**, 75% yield; **19al**, 52% yield).

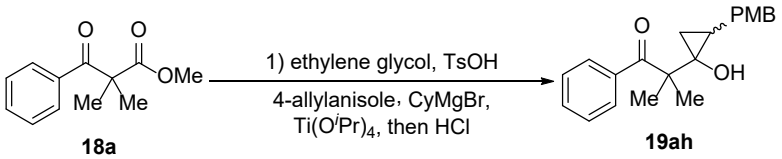
Method C:



To a solution of **19c** (670 mg, 2 mmol) in dry THF (20 mL) was added TBAF (1 M in THF, 4 mL, 4 mmol) at 0 °C. The reaction mixture was stirred at room temperature for 4 h. Water (15 mL) was then added to quench the reaction.

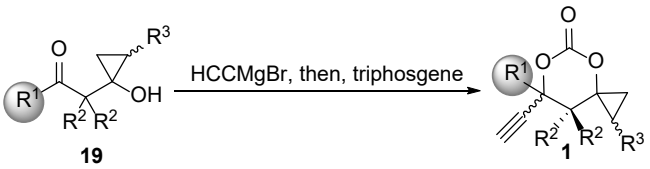
The resulting mixture was extracted with EtOAc (3 × 20 mL). The combined organic phase was washed with brine (1 × 20 mL), dried over Na_2SO_4, filtered, and concentrated in vacuo. The crude product was used directly in the next step without further purification. A mixture of the obtained crude (1 equiv), **22** (1.2 equiv), DCC (1.2 equiv), and DMAP (0.1 equiv) in CH_2Cl_2 (0.2 M) was stirred at room temperature overnight. Water was then added to quench the reaction. The resulting mixture was extracted with CH_2Cl_2. The combined organic phase was dried over Na_2SO_4, filtered, and concentrated in vacuo. The crude product was purified by column chromatography on silica gel to afford **19ae**–**19ag** (**19ae**, 63% yield; **19af**, 84% yield; **19ag**, 85% yield).

Method D:



A round-bottomed flask equipped with a Dean-Stark Trap was charged with **18a** (1 g, 5 mmol), ethylene glycol (2.8 mL, 50 mmol), and TsOH (86 mg, 0.5 mmol) in toluene (50 mL). The reaction mixture was stirred at 140 °C for 24 h and then quenched with a saturated aqueous solution of $NaHCO_3$ (20 mL). After separation of the organic phase, the aqueous phase was extracted with EtOAc (2 × 30 mL). The combined organic phase was concentrated in vacuo. The crude product was filtered through a pad of silica gel and then concentrated. To a solution of the crude esters (1 equiv) and 4-allylanisole (1.5 equiv) in THF (0.1 M) was added Ti(O^{i}Pr)$_4$ (1 equiv) and CyMgBr (4 equiv) successively at 0 °C. The reaction mixture was stirred for an additional 2 h and then quenched with a saturated aqueous solution of NH_4Cl. The resulting mixture was extracted with EtOAc, and the combined organic phase was washed with brine, dried over Na_2SO_4, filtered, and concentrated in vacuo. The crude cyclopropanol was dissolved in THF (0.1 M) and then added with a 2 N aqueous solution of HCl (50% volume ratio). The reaction mixture was stirred at 60 °C for 8 h, and the resulting mixture was extracted with EtOAc. The combined organic phase was washed with brine, dried over Na_2SO_4, filtered, and concentrated in vacuo. The crude product was purified by column chromatography on silica gel to afford **19ah** (30% yield) as a colorless oil.

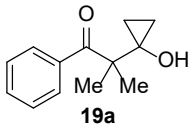
7.2 Preparation of 1



To a solution of **19** (2 mmol) in THF (20 mL) was added ethynylmagnesium bromide (0.5 M in THF, 10 mL, 5 mmol) dropwise at 0 °C. The reaction mixture was stirred 2 h at room temperature before being quenched with a saturated aqueous solution of NH4Cl (20 mL). The resulting mixture was extracted with EtOAc (3 × 20 mL). The combined organic phase was washed with brine (2 × 20 mL), dried over Na2SO4, filtered, and concentrated in vacuo afford the crude propargyl alcohol without further purification. To a solution of the crud propargyl alcohol (1 equiv) and pyridine (5 equiv) in CH_2Cl_2 (0.05 M) was added a solution of triphosgene (1 equiv) in CH_2Cl_2 (0.05 M) dropwise at 0 °C. The reaction mixture was stirred for 3 h at room temperature before being quenched with a saturated aqueous solution of NH4Cl. The resulting mixture was extracted with CH_2Cl_2. The combined organic phase was washed with brine, dried over Na2SO4, filtered, and concentrated in vacuo. The crude product was purified by column chromatography on silica gel to afford substrates **1** (**1a**, 79% yield; **1b**, 51% yield; **1c**, 66% yield; **1d**, 61% yield; **1e**, 66% yield; **1f**, 54% yield; **1g**, 36% yield; **1h**, 55% yield; **1i**, 66% yield; **1j**, 47% yield; **1k**, 67% yield; **1l**, 45% yield; **1m**, 65% yield; **1n**, 67% yield; **1o**, 31% yield; **1p**, 40% yield; **1q**, 56% yield; **1r**, 83% yield; **1s**, 60% yield; **1t**, 47% yield; **1u**, 53% yield; **1v**, 46% yield; **1w**, 61% yield; **1x**, 35% yield; **1y**, 42% yield; **1z**, 37% yield; **1aa**, 43% yield; **1ab**, 54% yield; **1ac**, 62% yield; **1ad**, 40% yield; **1ae**, 47% yield; **1af**, 57% yield; **1ag**, 52% yield; **1ah**, 65% yield, dr = 1 : 1; **1ai**, 50% yield; **1aj**, 42% yield; **1ak**, 55% yield; **1al**, 62% yield; **1am**, 65% yield).

7.3 Characterization data of 19 and 1

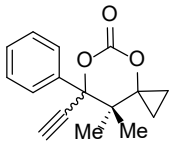
2-(1-hydroxycyclopropyl)-2-methyl-1-phenylpropan-1-one (19a)



19a

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.48) afforded **19a** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.85–7.59 (m, 1H), 7.50–7.44 (m, 1H), 7.42–7.38 (m, 1H), 1.28 (s, 4H), 0.85–0.72 (m, 3H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 209.9, 139.2, 131.1, 128.3, 127.8, 60.9, 51.5, 23.2, 11.6 ppm. **IR** (KBr): ν_{max} = 3461, 3058, 2979, 1680, 1617, 1237, 1019, 702 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{13}H_{16}O_2$, $[M+H]^+$, 205.1223; found: 205.1214. **m.p.**: 46.9–48.0 °C.

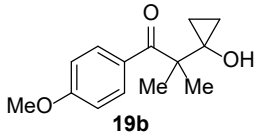
7-ethynyl-8,8-dimethyl-7-phenyl-4,6-dioxaspiro[2.5]octan-5-one (1a)



1a

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.26) afforded **1a** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.58–7.55 (m, 2H), 7.41–7.37 (m, 3H), 2.89 (s, 1H), 1.32–1.21 (m, 2H), 0.99–0.90 (m, 7H), 0.75–0.69 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 148.4, 136.0, 129.0, 127.8, 127.3, 86.3, 81.1, 78.3, 70.3, 38.0, 19.8, 19.6, 12.2, 7.5 ppm. **IR** (KBr): ν_{max} = 3253, 2984, 2925, 1755, 1270, 1072, 762 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{16}H_{16}O_3$, $[M+Na]^+$, 279.0992; found: 279.0987. **m.p.**: 117.4–119.5 °C.

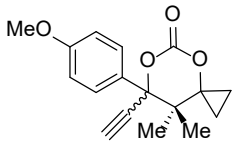
2-(1-hydroxycyclopropyl)-1-(4-methoxyphenyl)-2-methylpropan-1-one (19b)



19b

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.25) afforded **19b** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.92 (d, J = 8.9 Hz, 2H), 6.91 (d, J = 8.9 Hz, 2H), 3.86 (s, 3H), 3.09 (s, 1H), 1.32 (s, 6H), 0.86–0.74 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 206.7, 162.4, 131.0, 130.6, 113.6, 61.3, 55.5, 51.2, 23.6, 11.8 ppm. **IR** (KBr): ν_{max} = 3308, 2979, 1664, 1600, 1506, 1255, 1168, 840 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{14}H_{18}O_3$, $[M+Na]^+$, 257.1148; found: 257.1137. **m.p.**: 60.2–61.0 °C.

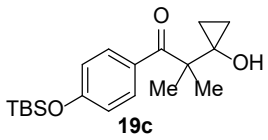
7-ethynyl-7-(4-methoxyphenyl)-8,8-dimethyl-4,6-dioxaspiro[2.5]octan-5-one(1b)



1b

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.28) afforded **1b** as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.48 (d, J = 8.9 Hz, 2H), 6.90 (d, J = 8.9 Hz, 2H), 3.83 (s, 3H), 2.88 (s, 1H), 1.29–1.22 (m, 2H), 0.98–0.94 (m, 4H), 0.88 (s, 3H), 0.76–0.70 (m, 1H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 160.0, 148.5, 128.7, 128.1, 113.1, 86.2, 81.3, 78.1, 70.2, 55.5, 38.2, 19.8, 19.6, 12.2, 7.5 ppm. **IR** (KBr): ν_{max} = 3523, 3290, 1752, 1512, 1255, 1076, 831 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{17}H_{18}O_4$, $[M+H]^+$, 287.1205; found: 287.1278. **m.p.**: 168.3–171.6 °C.

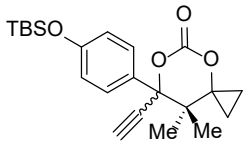
1-(4-((*tert*-butyldimethylsilyl)oxy)phenyl)-2-(1-hydroxycyclopropyl)-2-methylpropan-1-one (19c)



19c

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.42) afforded **19c** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.83 (d, J = 8.3 Hz, 2H), 6.84 (d, J = 8.3 Hz, 2H), 3.22 (s, 1H), 1.29 (s, 6H), 0.98 (s, 9H), 0.82–0.74 (m, 4H), 0.22 (s, 6H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 206.9, 159.0, 131.2, 130.8, 119.6, 61.1, 51.2, 25.7, 23.5, 18.3, 11.8, −4.3 ppm. **IR** (KBr): ν_{max} = 3310, 2956, 2933, 2860, 1598, 1506, 1262, 913, 843 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{19}H_{30}O_3Si$, $[M+Na]^+$, 357.1856; found: 357.1853. **m.p.**: 59.7–61.4 °C.

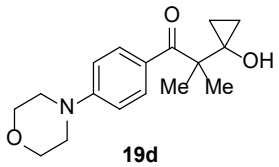
7-(4-((*tert*-butyldimethylsilyl)oxy)phenyl)-7-ethynyl-8,8-dimethyl-4,6-dioxaspiro[2.5]octan-5-one (1c)



1c

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.46) afforded **1c** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.40 (d, J = 8.7 Hz, 2H), 6.82 (d, J = 8.7 Hz, 2H), 2.87 (s, 1H), 1.28–1.17 (m, 2H), 0.97–0.89 (m, 13H), 0.86 (s, 3H), 0.73–0.66 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 156.2, 148.4, 128.6, 119.2, 86.2, 81.2, 78.1, 70.2, 38.1, 25.7, 19.8, 19.6, 18.3, 12.1, 7.5, −4.3 ppm. **IR** (KBr): ν_{max} = 3291, 2955, 2859, 1758, 1509, 1263, 914, 839 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{22}H_{30}O_4Si$, $[M+Na]^+$, 409.1806; found: 409.1802. **m.p.**: 136.2–137.4 °C.

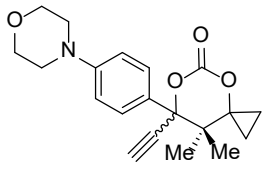
2-(1-hydroxycyclopropyl)-2-methyl-1-(4-morpholinophenyl)propan-1-one (19d)



19d

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.18) afforded **19d** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.91 (d, J = 8.5 Hz, 2H), 6.81 (d, J = 8.6 Hz, 2H), 3.80 (t, J = 4.9 Hz, 3H), 3.41 (s, 1H), 3.23 (t, J = 4.9 Hz, 3H), 1.28 (s, 6H), 0.80–0.73 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 205.4, 153.2, 131.0, 127.7, 113.1, 66.5, 61.1, 50.9, 47.5, 23.5, 11.8 ppm. **IR** (KBr): ν_{max} = 3331, 2972, 1553, 1169, 1118, 1020 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{17}H_{23}NO_3$, $[M+H]^+$, 290.1750; found: 290.1741. **m.p.**: 80.3–81.4 °C.

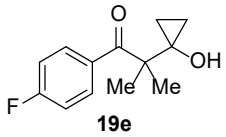
7-ethynyl-8,8-dimethyl-7-(4-morpholinophenyl)-4,6-dioxaspiro[2.5]octan-5-one (1d)



1d

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.2) afforded **1d** as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.44 (d, J = 8.4 Hz, 2H), 6.88 (d, J = 8.4 Hz, 2H), 3.86 (t, J = 4.7 Hz, 4H), 3.19 (t, J = 4.7 Hz, 4H), 2.86 (s, 1H), 1.29–1.18 (m, 2H), 0.97–0.93 (m, 4H), 0.88 (s, 3H), 0.73–0.69 (m, 1H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 151.4, 148.6, 128.4, 126.9, 114.2, 86.3, 81.4, 78.0, 70.2, 66.9, 48.8, 38.3, 19.9, 19.6, 12.2, 7.5 ppm. **IR** (KBr): ν_{max} = 3285, 2979, 1751, 1516, 1343, 1171 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{20}H_{23}NO_4$, $[M+H]^+$, 342.1700; found: 342.1690. **m.p.**: 198.8–202.6 °C.

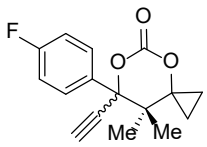
1-(4-fluorophenyl)-2-(1-hydroxycyclopropyl)-2-methylpropan-1-one (19e)



19e

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.17) afforded **19e** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.87–7.82 (m, 2H), 7.11–7.06 (m, 2H), 3.01 (s, 1H), 1.26 (s, 6H), 0.83–0.75 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 207.5, 164.5 (d, J_{CF} = 252.5 Hz), 134.9 (d, J_{CF} = 3.4 Hz), 130.7 (d, J_{CF} = 8.8 Hz), 115.3 (d, J_{CF} = 21.6 Hz), 60.9, 51.4, 23.2, 11.9 ppm. **^{19}F NMR** (564 MHz, $CDCl_3$) δ −114.79 (s, 1F) ppm. **IR** (KBr): ν_{max} = 3504, 2978, 2947, 1675, 1599, 1235, 845 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{13}H_{15}FO_2$, $[M+Na]^+$, 245.0948; found: 245.0942. **m.p.**: 57.6–60.1 °C.

7-ethynyl-7-(4-fluorophenyl)-8,8-dimethyl-4,6-dioxaspiro[2.5]octan-5-one (1e)

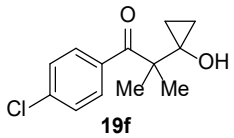


1e

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.33) afforded **1e** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.51 (dd, J = 8.7, 5.3 Hz, 2H), 7.03 (t, J = 8.6 Hz, 2H), 2.91 (s, 1H), 1.26–1.19 (m, 2H), 0.93–0.89 (m, 4H), 0.83 (s, 3H), 0.73–0.68 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 162.9 (d, J_{CF} = 248.6 Hz), 148.0, 131.8 (d, J_{CF} = 2.9 Hz), 129.2 (d, J_{CF} = 8.3 Hz), 114.7 (d, J_{CF} = 21.8 Hz), 85.7,

80.7, 78.6, 70.2, 38.0, 19.6, 19.4, 12.2, 7.3 ppm. **^{19}F NMR** (564 MHz, $CDCl_3$) δ −112.94 (s, 1F) ppm. **IR** (KBr): ν_{max} = 3293, 2984, 2947, 2115, 1753, 1474, 1344, 791 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{16}H_{15}FO_3$, $[M+Na]^+$, 297.0897; found: 297.0892. **m.p.**: 145.5–148.3 °C.

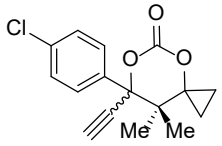
1-(4-chlorophenyl)-2-(1-hydroxycyclopropyl)-2-methylpropan-1-one (19f)



19f

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.48) afforded **19f** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.69 (d, J = 8.5 Hz, 2H), 7.33 (d, J = 8.6 Hz, 2H), 3.29 (s, 1H), 1.18 (s, 6H), 0.79–0.70 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 208.1, 137.2, 129.4, 128.3, 60.6, 51.4, 23.0, 11.8 ppm. **IR** (KBr): ν_{max} = 3311, 1757, 2980, 1676, 1589, 1264, 1092, 836 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{13}H_{15}ClO_2$, $[M+Na]^+$, 261.0653; found: 261.0641. **m.p.**: 53.4–54.4 °C.

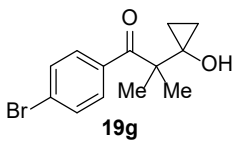
7-(4-chlorophenyl)-7-ethynyl-8,8-dimethyl-4,6-dioxaspiro[2.5]octan-5-one (1f)



1f

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.22) afforded **1f** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.48 (d, J = 8.7 Hz, 2H), 7.34 (d, J = 8.7 Hz, 2H), 2.91 (s, 1H), 1.30–1.18 (m, 2H), 0.97–0.90 (m, 4H), 0.85 (s, 3H), 0.77–0.68 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 148.0, 135.0, 134.5, 128.7, 128.0, 85.7, 80.6, 78.7, 70.3, 38.0, 19.6, 19.5, 12.3, 7.4 ppm. **IR** (KBr): ν_{max} = 3294, 2984, 1757, 1680, 1266, 1077, 825 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{16}H_{15}ClO_3$, $[M+Na]^+$, 313.0602; found: 313.0592. **m.p.**: 122.6–123.7 °C.

1-(4-bromophenyl)-2-(1-hydroxycyclopropyl)-2-methylpropan-1-one (19g)

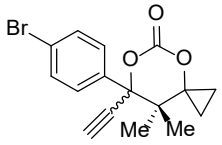


19g

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.48) afforded **19g** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.62 (d, J = 8.3 Hz, 2H), 7.52 (d, J = 8.2 Hz, 2H), 3.09 (s, 1H), 1.21 (s, 6H), 0.81–0.72 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 208.3, 137.8, 131.4, 129.6, 125.8, 60.8, 51.5,

29.8, 23.0, 11.9 ppm. **IR** (KBr): ν_{max} = 3329, 2979, 1680, 1254, 1174, 1150, 984, 742 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{13}H_{15}BrO_2$, $[M+Na]^+$, 305.0148; found: 305.0150. **m.p.**: 65.4–69.4 °C.

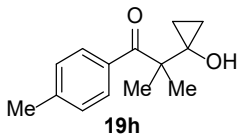
7-(4-bromophenyl)-7-ethynyl-8,8-dimethyl-4,6-dioxaspiro[2.5]octan-5-one (1g)



1g

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.26) afforded **1g** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.51 (d, J = 8.6 Hz, 2H), 7.43 (d, J = 8.6 Hz, 2H), 2.91 (s, 1H), 1.30–1.21 (m, 2H), 0.95 (s, 4H), 0.87 (s, 3H), 0.76–0.70 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 148.0, 135.1, 131.0, 129.0, 123.4, 85.8, 80.6, 78.7, 70.3, 38.0, 19.7, 19.5, 12.3, 7.4 ppm. **IR** (KBr): ν_{max} = 3291, 2984, 1757, 1472, 1265, 1076, 822 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{16}H_{15}BrO_3$, $[M+Na]^+$, 357.0097; found: 357.0089. **m.p.**: 196.4–198.5 °C.

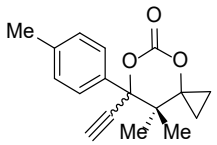
2-(1-hydroxycyclopropyl)-2-methyl-1-(*p*-tolyl)propan-1-one (19h)



19h

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.48) afforded **19h** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.71 (d, J = 8.2 Hz, 2H), 7.21 (d, J = 8.0 Hz, 2H), 3.15 (s, 1H), 2.38 (s, 3H), 1.29 (s, 6H), 0.83–0.74 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 208.9, 141.9, 135.9, 128.9, 128.3, 61.0, 51.3, 23.3, 21.6, 11.7 ppm. **IR (KBr)**: ν_{max} = 3310, 2979, 1672, 1468, 1267, 1238, 828 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{14}H_{18}O_2$, $[M+Na]^+$, 241.1199; found: 241.1189. **m.p.**: 52.7–54.6 °C.

7-ethynyl-8,8-dimethyl-7-(*p*-tolyl)-4,6-dioxaspiro[2.5]octan-5-one (1h)

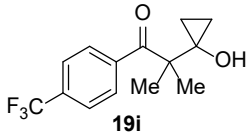


1h

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.30) afforded **1h** as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.43 (d, J = 8.0 Hz, 2H), 7.18 (d, J = 7.9 Hz, 2H), 2.87 (s, 1H), 2.36 (s, 3H), 1.29–1.19 (m, 2H), 0.96–0.92 (m, 4H), 0.88 (s, 3H), 0.73–0.69 (m, 1H) ppm. **^{13}C NMR** (150 MHz,

$CDCl_3$) δ 148.5, 138.8, 133.1, 128.4, 127.2, 86.3, 81.2, 78.1, 70.2, 38.0, 21.2, 19.8, 19.6, 12.2, 7.5 ppm. **IR** (KBr): ν_{max} = 3287, 1753, 1268, 1077, 815 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{17}H_{18}O_3$, $[M+Na]^+$, 293.1148; found: 293.1143. **m.p.**: 136.0–137.3 °C.

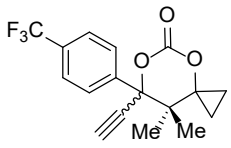
2-(1-hydroxycyclopropyl)-2-methyl-1-(4-(trifluoromethyl)phenyl)propan-1-one (19i)



19i

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.48) afforded **19i** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.77 (d, J = 8.1 Hz, 2H), 7.64 (d, J = 8.2 Hz, 2H), 3.09 (s, 1H), 1.20 (s, 6H), 0.82–0.70 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 209.3, 142.9, 132.3 (q, J_{CF} = 33.0 Hz), 127.8, 125.2 (q, J_{CF} = 3.5 Hz), 122.5 (q, J_{CF} = 271 Hz), 60.6, 51.7, 22.7, 11.7 ppm. **^{19}F NMR** (564 MHz, $CDCl_3$) δ −62.54 (s, 3F) ppm. **IR** (KBr): ν_{max} = 3308, 2978, 1678, 1263, 1235, 832 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{14}H_{15}F_3O_2$, $[M+Na]^+$, 295.0916; found: 295.0924. **m.p.**: 55.1–56.2 °C.

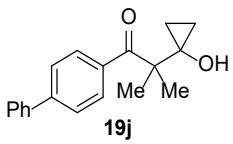
7-ethynyl-8,8-dimethyl-7-(4-(trifluoromethyl)phenyl)-4,6-dioxaspiro[2.5]octan-5-one (1i)



1i

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.26) afforded **1i** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.66 (d, J = 8.2 Hz, 2H), 7.60 (d, J = 8.3 Hz, 2H), 2.96 (s, 1H), 1.27–1.17 (m, 2H), 0.92–0.83 (m, 7H), 0.75–0.66 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 147.7, 139.9, 130.9 (q, J_{CF} = 32.7 Hz), 127.7, 124.7 (q, J_{CF} = 3.4 Hz), 122.4 (q, J_{CF} = 271 Hz), 85.6, 80.2, 79.0, 70.3, 37.9, 19.4, 19.3, 12.52, 7.2 ppm. **^{19}F NMR** (564 MHz, $CDCl_3$) δ −62.76 (s, 3F) ppm. **IR** (KBr): ν_{max} = 3302, 2987, 1760, 1328, 1126, 1073, 836 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{17}H_{15}F_3O_3$, $[M+Na]^+$, 347.0866; found: 347.0858. **m.p.**: 146.2–148.7 °C.

1-([1,1'-biphenyl]-4-yl)-2-(1-hydroxycyclopropyl)-2-methylpropan-1-one (19j)

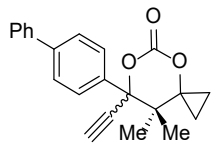


19j

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.46) afforded **19j**

as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.90 (d, J = 8.4 Hz, 2H), 7.64 (dd, J = 9.9, 8.1 Hz, 4H), 7.47 (t, J = 7.5 Hz, 2H), 7.40 (t, J = 7.3 Hz, 1H), 3.14 (s, 1H), 1.34 (s, 6H), 0.89–0.78 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 208.9, 144.0, 140.1, 137.4, 129.0, 128.7, 128.1, 127.3, 126.9, 61.0, 51.5, 23.3, 11.8 ppm. **IR** (KBr): ν_{max} = 3327, 2979, 1671, 1603, 1264, 1237, 977, 847 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{19}H_{20}O_2$, $[M+Na]^+$, 303.1356; found: 303.1342. **m.p.**: 80.8–81.2 °C.

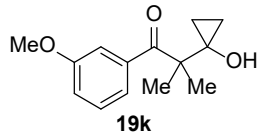
7-([1,1'-biphenyl]-4-yl)-7-ethynyl-8,8-dimethyl-4,6-dioxaspiro[2.5]octan-5-one (1j)



1j

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.19) afforded **1j** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.66–7.58 (m, 6H), 7.46 (t, J = 7.5 Hz, 2H), 7.37 (t, J = 7.3 Hz, 1H), 2.92 (s, 1H), 1.35–1.24 (m, 2H), 1.02–0.94 (m, 7H), 0.79–0.72 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 148.4, 141.7, 140.1, 134.9, 129.0, 127.8, 127.8, 127.2, 126.4, 86.2, 81.0, 78.4, 70.3, 38.1, 19.8, 19.6, 12.3, 7.5 ppm. **IR** (KBr): ν_{max} = 3288, 2984, 1754, 1272, 1077, 764 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{22}H_{20}O_3$, $[M+Na]^+$, 355.1305; found: 355.1296. **m.p.**: 176.7–177.6 °C.

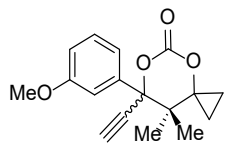
2-(1-hydroxycyclopropyl)-1-(3-methoxyphenyl)-2-methylpropan-1-one (19k)



19k

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.43) afforded **19k** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.33–7.23 (m, 3H), 6.97 (d, J = 7.8 Hz, 1H), 3.78 (s, 3H), 3.24 (s, 1H), 1.22 (s, 6H), 0.79–0.72 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 209.3, 159.2, 140.3, 129.1, 120.0, 116.8, 113.0, 60.7, 55.3, 51.4, 23.0, 11.7 ppm. **IR** (KBr): ν_{max} = 3443, 2976, 2938, 1678, 1240, 991 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{14}H_{18}O_3$, $[M+Na]^+$, 257.1148; found: 257.1137. **m.p.**: 60.3–61.2 °C.

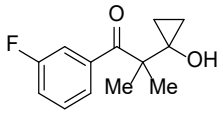
7-ethynyl-7-(3-methoxyphenyl)-8,8-dimethyl-4,6-dioxaspiro[2.5]octan-5-one (1k)



1k

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.19) afforded **1k** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.24 (t, J = 8.0 Hz, 1H), 7.12–7.00 (m, 2H), 6.85 (d, J = 8.0 Hz, 1H), 3.75 (s, 3H), 2.88 (s, 1H), 1.25–1.14 (m, 2H), 0.92–0.84 (m, 7H), 0.74–0.64 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 158.8, 148.2, 137.3, 128.6, 119.6, 113.5, 85.9, 80.8, 78.3, 70.2, 55.3, 37.8, 19.6, 19.5, 12.1, 7.3 ppm. **IR** (KBr): ν_{max} = 3284, 2984, 1755, 1605, 1271, 1241, 1075 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{17}H_{18}O_4$, $[M+H]^+$, 287.1278; found: 287.1273. **m.p.**: 207.4–209.5 °C.

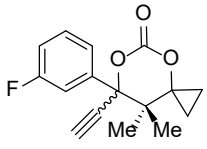
1-(3-fluorophenyl)-2-(1-hydroxycyclopropyl)-2-methylpropan-1-one (19l)



19l

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.21) afforded **19l** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.50 (d, J = 7.8 Hz, 1H), 7.43 (dt, J = 9.6, 2.0 Hz, 1H), 7.35 (td, J = 8.0, 5.6 Hz, 1H), 7.14 (td, J = 8.3, 2.6 Hz, 1H), 3.16 (s, 1H), 1.21 (s, 6H), 0.81–0.72 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 208.2, 162.3 (d, J_{CF} = 247.2 Hz), 141.1 (d, J_{CF} = 6.1 Hz), 129.9 (d, J_{CF} = 7.8 Hz), 123.5 (d, J_{CF} = 3.1 Hz), 117.9 (d, J_{CF} = 21.1 Hz), 114.9 (d, J_{CF} = 23.1 Hz), 60.6, 51.6, 22.9, 11.8 ppm. **^{19}F NMR** (564 MHz, $CDCl_3$) δ −112.09 (s, 1F) ppm. **IR** (KBr): ν_{max} = 3309, 2978, 1687, 1584, 1478, 1270 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{13}H_{15}FO_2$, $[M+Na]^+$, 245.0948; found: 245.0945. **m.p.**: 61.8–63.4 °C.

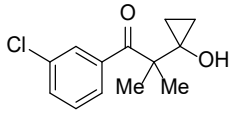
7-ethynyl-7-(3-fluorophenyl)-8,8-dimethyl-4,6-dioxaspiro[2.5]octan-5-one (1l)



1l

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.4) afforded **1l** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.39–7.34 (m, 2H), 7.30–7.27 (m, 1H), 7.12–7.05 (m, 1H), 2.92 (s, 1H), 1.33–1.21 (m, 2H), 1.00–0.94 (m, 4H), 0.90 (s, 3H), 0.78–0.71 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 162.2 (d, J_{CF} = 246.2 Hz), 148.0, 138.5 (d, J_{CF} = 7.2 Hz), 129.4 (d, J_{CF} = 8.1 Hz), 123.1 (d, J_{CF} = 2.9 Hz), 116.0 (d, J_{CF} = 21.0 Hz), 114.8 (d, J_{CF} = 24.2 Hz), 85.6, 80.6, 78.6, 70.3, 38.1, 19.7, 19.6, 12.4, 7.4 ppm. **^{19}F NMR** (564 MHz, $CDCl_3$) δ −112.53 (s, 1F) ppm. **IR** (KBr): ν_{max} = 3294, 2986, 1759, 1592, 1238, 1026 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{16}H_{15}FO_3$, $[M+Na]^+$, 297.0897; found: 297.0896. **m.p.**: 136.7–141.6 °C.

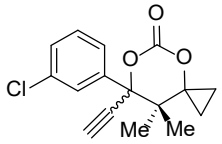
1-(3-chlorophenyl)-2-(1-hydroxycyclopropyl)-2-methylpropan-1-one (19m)



19m

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.33) afforded **19m** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.70 (t, J = 1.9 Hz, 1H), 7.60 (d, J = 7.7 Hz, 1H), 7.44 (d, J = 8.1 Hz, 1H), 7.34 (t, J = 7.9 Hz, 1H), 2.91 (s, 1H), 1.24 (s, 6H), 0.84–0.74 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 208.4, 140.8, 134.4, 131.0, 129.6, 127.9, 125.8, 60.7, 51.7, 23.0, 11.8 ppm. **IR** (KBr): ν_{max} = 3476, 2976, 2944, 1689, 1566, 1471, 1263, 991, 743 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{13}H_{15}ClO_2$, $[M+Na]^+$, 261.0653; found: 261.0641. **m.p.**: 83.0–84.2 °C.

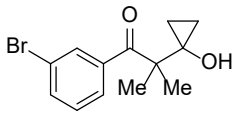
7-(3-chlorophenyl)-7-ethynyl-8,8-dimethyl-4,6-dioxaspiro[2.5]octan-5-one (1m)



1m

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.33) afforded **1m** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.54 (d, J = 2.3 Hz, 1H), 7.46–7.43 (m, 1H), 7.38–7.27 (m, 2H), 2.92 (s, 1H), 1.31–1.19 (m, 2H), 0.98–0.94 (m, 4H), 0.88 (s, 3H), 0.77–0.70 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 147.9, 137.9, 134.0, 129.2, 129.1, 127.5, 125.6, 85.6, 80.4, 78.8, 70.3, 38.0, 19.6, 19.5, 12.3, 7.4 ppm. **IR** (KBr): ν_{max} = 3293, 2984, 2947, 2115, 1753, 1474, 1416, 1344, 760 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{16}H_{15}ClO_3$, $[M+Na]^+$, 313.0602; found: 313.0595. **m.p.**: 159.3–162.4 °C.

1-(3-bromophenyl)-2-(1-hydroxycyclopropyl)-2-methylpropan-1-one (19n)

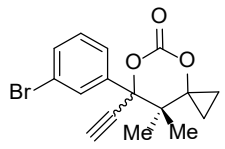


19n

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.25) afforded **19n** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.86 (s, 1H), 7.65 (d, J = 7.7 Hz, 1H), 7.60 (d, J = 7.3 Hz, 1H), 7.29 (t, J = 8.0 Hz, 1H), 2.93–2.81 (m, 1H), 1.24 (s, 6H), 0.85–0.74 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 1208.2, 141.1, 133.9, 130.8, 129.8, 126.2, 122.5, 60.8, 51.7, 23.0, 11.8 ppm. **IR** (KBr): ν_{max} = 3323, 2979, 1680, 1563, 1468, 1254, 1150 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{13}H_{15}BrO_2$, $[M+Na]^+$, 305.0148; found: 305.0136.

m.p.: 67.4–69.3 °C.

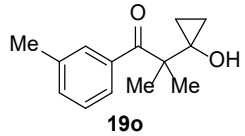
7-(3-bromophenyl)-7-ethynyl-8,8-dimethyl-4,6-dioxaspiro[2.5]octan-5-one (1n)



1n

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.28) afforded **1n** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.71 (s, 1H), 7.52–7.49 (m, 2H), 7.30–7.25 (m, 1H), 2.93 (s, 1H), 1.32–1.21 (m, 2H), 1.00–0.95 (m, 4H), 0.89 (s, 3H), 0.79–0.71 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 147.8, 138.1, 132.0, 130.2, 129.3, 126.0, 121.9, 85.4, 80.4, 78.7, 70.2, 37.9, 19.6, 19.5, 12.2, 7.3 ppm. **IR** (KBr): ν_{max} = 3291, 2983, 1758, 1472, 1265, 1104 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{16}H_{15}BrO_3$, $[M+Na]^+$, 357.0097; found: 357.0093. **m.p.**: 105.4–106.3 °C.

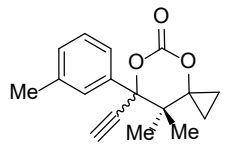
2-(1-hydroxycyclopropyl)-2-methyl-1-(*m*-tolyl)propan-1-one (19o)



19o

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.51) afforded **19o** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.60–7.46 (m, 2H), 7.27 (d, J = 5.4 Hz, 2H), 3.22 (s, 1H), 2.37 (s, 3H), 1.25 (s, 6H), 0.82–0.71 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 210.1, 139.2, 137.9, 131.7, 128.3, 128.0, 124.7, 60.71 51.4, 23.1, 21.5, 11.6 ppm. **IR** (KBr): ν_{max} = 3515, 2977, 2928, 1676, 1467, 1272, 1142, 981 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{14}H_{18}O_2$, $[M+Na]^+$, 241.1199; found: 241.1191. **m.p.**: 53.4–54.4 °C.

7-ethynyl-8,8-dimethyl-7-(*m*-tolyl)-4,6-dioxaspiro[2.5]octan-5-one (1o)

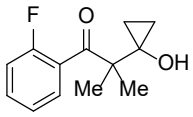


1o

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.35) afforded **1o** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.32 (d, J = 8.8 Hz, 2H), 7.22 (t, J = 7.6 Hz, 1H), 7.14 (d, J = 7.5 Hz, 1H), 2.87 (s, 1H), 2.34 (s, 3H), 1.25–1.18 (m, 2H), 0.93–0.84 (m, 7H), 0.71–0.67 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 148.3, 137.3, 135.7, 129.5, 127.6, 127.5, 124.4, 86.2, 81.0, 78.2, 70.1, 37.8, 21.5, 19.6, 19.5,

12.1, 7.3 ppm. **IR** (KBr): ν_{max} = 3526, 3286, 1756, 1268, 1076 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{17}H_{18}O_3$, $[M+Na]^+$, 293.1148; found: 293.1142. **m.p.**: 123.4–125.7 °C.

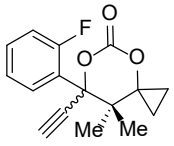
1-(2-fluorophenyl)-2-(1-hydroxycyclopropyl)-2-methylpropan-1-one (19p)



19p

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.46) afforded **19p** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.40–7.29 (m, 2H), 7.15 (t, J = 7.5 Hz, 1H), 7.08 (t, J = 9.0 Hz, 1H), 3.07 (s, 1H), 1.17 (s, 6H), 0.75–0.65 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 210.2, 158.0 (d, J_{CF} = 246.5 Hz), 131.0 (d, J_{CF} = 8.0 Hz), 129.1 (d, J_{CF} = 19.2 Hz), 127.8 (d, J_{CF} = 4.1 Hz), 123.9 (d, J_{CF} = 3.2 Hz), 115.9 (d, J_{CF} = 21.8 Hz), 60.1, 52.1, 21.6, 10.7 ppm. **^{19}F NMR** (564 MHz, $CDCl_3$) δ −113.71 (s, 1F) ppm. **IR** (KBr): ν_{max} = 3303, 3051, 1700, 1492, 1483 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{13}H_{15}FO_2$, $[M+Na]^+$, 245.0948; found: 245.0941. **m.p.**: 36.0–37.1 °C.

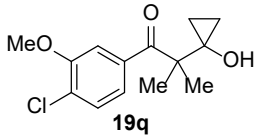
7-ethynyl-7-(2-fluorophenyl)-8,8-dimethyl-4,6-dioxaspiro[2.5]octan-5-one (1p)



1p

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.26) afforded **1p** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.59 (t, J = 7.8 Hz, 1H), 7.38 (q, J = 6.8 Hz, 1H), 7.19 (t, J = 7.6 Hz, 1H), 7.10 (dd, J = 11.9, 8.4 Hz, 1H), 2.88 (s, 1H), 1.29–1.18 (m, 2H), 1.05–0.92 (m, 7H), 0.74–0.67 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 159.3 (d, J_{CF} = 251.5 Hz), 147.9, 131.0 (d, J_{CF} = 8.9 Hz), 129.7 (d, J_{CF} = 2.0 Hz), 123.7 (d, J_{CF} = 3.5 Hz), 123.2 (d, J_{CF} = 8.6 Hz), 116.9 (d, J_{CF} = 23.8 Hz), 79.6, 77.91, 77.88, 69.5, 38.9, 20.00, 19.96, 19.7, 11.6, 7.4 ppm. **^{19}F NMR** (564 MHz, $CDCl_3$) δ −105.77 (s, 1F) ppm. **IR** (KBr): ν_{max} = 3298, 3055, 2982, 1755, 1492, 1269 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{16}H_{15}FO_3$, $[M+Na]^+$, 297.0897; found: 297.0892. **m.p.**: 194.6–196.3 °C.

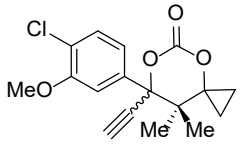
1-(4-chloro-3-methoxyphenyl)-2-(1-hydroxycyclopropyl)-2-methylpropan-1-one (19q)



19q

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.6) afforded **19q** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.34 (s, 3H), 3.87 (s, 3H), 3.19 (s, 1H), 1.18 (s, 6H), 0.82–0.70 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 207.5, 154.8, 138.3, 129.6, 125.7, 120.8, 111.9, 60.7, 56.2, 51.5, 23.1, 12.1 ppm. **IR** (KBr): ν_{max} = 3329, 2978, 1677, 1468, 1268, 1243, 1069 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{14}H_{17}ClO_3$, $[M+H]^+$, 269.0939; found: 269.0929. **m.p.**: 78.9–80.1 °C.

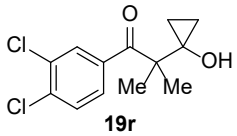
7-(4-chloro-3-methoxyphenyl)-7-ethynyl-8,8-dimethyl-4,6-dioxaspiro[2.5]octan-5-one (1q)



1q

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.48) afforded **1q** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.32 (d, J = 8.9 Hz, 1H), 7.06 (d, J = 6.8 Hz, 2H), 3.87 (s, 3H), 2.92 (s, 1H), 1.28−1.18 (m, 2H), 0.94–0.84 (m, 7H), 0.75−0.68 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 154.3, 147.9, 135.9, 129.3, 123.3, 120.4, 111.1, 85.6, 80.5, 78.6, 70.3, 56.3, 38.0, 19.6, 19.5, 12.3, 7.3 ppm. **IR** (KBr): ν_{max} = 3290, 2983, 1757, 1490, 1468, 1268, 1243, 1069 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{17}H_{17}ClO_4$, $[M+Na]^+$, 343.0708; found: 343.0712. **m.p.**: 171.2–174.7 °C.

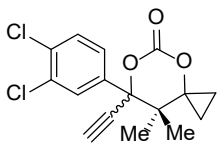
1-(3,4-dichlorophenyl)-2-(1-hydroxycyclopropyl)-2-methylpropan-1-one (19r)



19r

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.31) afforded **19r** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.87 (d, J = 1.8 Hz, 1H), 7.61 (dd, J = 8.3, 1.9 Hz, 1H), 7.49 (d, J = 8.4 Hz, 1H), 2.76 (s, 1H), 1.23 (s, 6H), 0.86–0.77 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 206.8, 138.6, 135.5, 132.8, 130.3, 130.2, 127.2, 60.8, 51.7, 23.0, 12.1 ppm. **IR** (KBr): ν_{max} = 3306, 2981, 1681, 1467, 1271 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{13}H_{14}Cl_2O_2$, $[M+Na]^+$, 295.0263; found: 295.0258. **m.p.**: 93.2–96.4 °C.

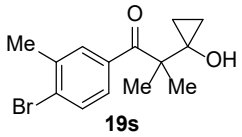
7-(3,4-dichlorophenyl)-7-ethynyl-8,8-dimethyl-4,6-dioxaspiro[2.5]octan-5-one (1r)



1r

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.32) afforded **1r** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.66 (s, 1H), 7.47 (d, J = 8.4 Hz, 1H), 7.41 (d, J = 8.5 Hz, 1H), 2.94 (s, 1H), 1.34–1.21 (m, 2H), 1.01–0.94 (m, 4H), 0.88 (s, 3H), 0.79–0.72 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 147.7, 136.2, 133.5, 132.4, 129.8, 129.4, 126.7, 85.2, 80.2, 79.1, 70.4, 38.1, 19.64, 19.56, 12.4, 7.4 ppm. **IR** (KBr): ν_{max} = 3298, 2984, 1758, 1471, 1264 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{16}H_{14}Cl_2O_3$, $[M+Na]^+$, 347.0212; found: 347.0207. **m.p.**: 86.2–88.4 °C.

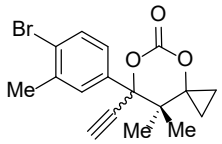
1-(4-bromo-3-methylphenyl)-2-(1-hydroxycyclopropyl)-2-methylpropan-1-one (19s)



19s

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.4) afforded **19s** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.58 (s, 1H), 7.52 (d, J = 8.3 Hz, 1H), 7.42 (dd, J = 8.3, 2.2 Hz, 1H), 3.20 (s, 1H), 2.39 (s, 3H), 1.20 (s, 6H), 0.79–0.72 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 208.5, 138.1, 138.0, 132.0, 130.2, 128.1, 126.6, 60.6, 51.5, 23.0, 23.0, 11.8 ppm. **IR** (KBr): ν_{max} = 3387, 3087, 2980, 1676, 1470, 1257, 1026, 820 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{14}H_{17}BrO_2$, $[M+H]^+$, 297.0485; found: 297.0472. **m.p.**: 63.1–64.1 °C.

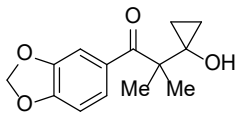
7-(4-bromo-3-methylphenyl)-7-ethynyl-8,8-dimethyl-4,6-dioxaspiro[2.5]octan-5-one (1s)



1s

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.31) afforded **1s** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.49 (d, J = 8.4 Hz, 1H), 7.38 (s, 1H), 7.21 (d, J = 10.1 Hz, 1H), 2.91 (s, 1H), 2.39 (s, 3H), 1.28–1.17 (m, 2H), 0.94–0.84 (m, 7H), 0.74–0.68 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 148.0, 137.4, 135.2, 131.6, 129.4, 126.3, 125.6, 85.7, 80.6, 78.6, 70.2, 37.8, 23.1, 19.6, 19.5, 12.2, 7.3 ppm. **IR** (KBr): ν_{max} = 3291, 2984, 1758, 1626, 1343, 1267, 1064, 757 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{17}H_{17}BrO_3$, $[M+Na]^+$, 371.0253; found: 371.0255. **m.p.**: 161.5–163.4 °C.

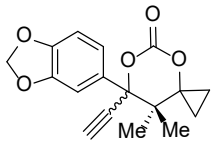
1-(benzo[d][1,3]dioxol-5-yl)-2-(1-hydroxycyclopropyl)-2-methylpropan-1-one (19t)



19t

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.22) afforded **19t** as a colorless oil. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.50 (d, J = 8.2 Hz, 1H), 7.37 (s, 1H), 6.81 (d, J = 8.2 Hz, 1H), 6.00 (s, 2H), 3.09 (s, 1H), 1.27 (s, 6H), 0.83–0.77 (m, 4H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 206.3, 150.4, 147.7, 132.3, 124.2, 109.1, 107.8, 101.7, 61.2, 51.3, 23.5, 12.0 ppm. **IR** (KBr): ν_{max} = 3306, 2925, 1664, 1485, 1435, 1254, 1037, 930 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{14}H_{16}O_4$, $[M+Na]^+$, 271.0941; found: 271.0928.

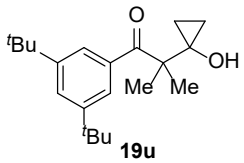
7-(benzo[d][1,3]dioxol-5-yl)-7-ethynyl-8,8-dimethyl-4,6-dioxaspiro[2.5]octan-5-one (1t)



1t

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.15) afforded **1t** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.04 (d, J = 7.6 Hz, 2H), 6.80 (d, J = 8.2 Hz, 1H), 5.99 (s, 2H), 2.88 (s, 1H), 1.28–1.19 (m, 2H), 0.98 (s, 4H), 0.87 (s, 3H), 0.76–0.70 (m, 1H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 148.3, 148.1, 147.3, 129.8, 121.3, 108.2, 107.5, 101.6, 86.1, 81.1, 78.2, 70.3, 38.2, 19.8, 19.7, 12.3, 7.4 ppm. **IR** (KBr): ν_{max} = 3289, 2986, 1753, 1490, 1243, 1076, 814 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{17}H_{16}O_5$, $[M+Na]^+$, 323.0890; found: 323.0883. **m.p.**: 176.2–178.1 °C.

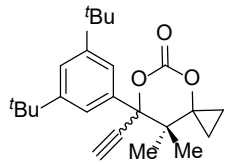
1-(3,5-di-*tert*-butylphenyl)-2-(1-hydroxycyclopropyl)-2-methylpropan-1-one (19u)



19u

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.8) afforded **19u** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.64 (s, 2H), 7.55 (s, 1H), 3.04 (s, 1H), 1.35–1.30 (m, 24H), 0.85–0.78 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 210.1, 150.7, 138.3, 125.4, 122.2, 61.0, 51.4, 35.1, 31.6, 31.5, 23.4, 11.8 ppm. **IR** (KBr): ν_{max} = 3312, 2963, 1674, 1472, 1246, 758 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{21}H_{32}O_2$, $[M+Na]^+$, 339.2295; found: 339.2284. **m.p.**: 56.2–58.1 °C.

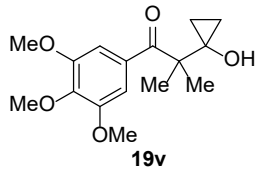
7-(3,5-di-*tert*-butylphenyl)-7-ethynyl-8,8-dimethyl-4,6-dioxaspiro[2.5]octan-5-one (1u)



1u

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.71) afforded **1u** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.40 (s, 1H), 7.37 (d, J = 1.3 Hz, 2H), 2.87 (s, 1H), 1.32 (s, 18H), 1.27–1.20 (m, 2H), 0.96–0.87 (m, 7H), 0.73–0.67 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 150.0, 148.6, 134.8, 122.5, 121.7, 86.7, 81.3, 78.0, 70.2, 37.9, 35.0, 31.5, 19.8, 19.5, 12.1, 7.5 ppm. **IR** (KBr): ν_{max} = 3275, 2962, 1759, 1266, 1071, 830 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{24}H_{32}O_3$, $[M+Na]^+$, 391.2244; found: 391.2226. **m.p.**: 187.4–199.2 °C.

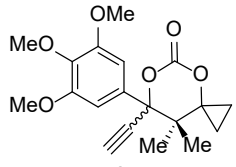
2-(1-hydroxycyclopropyl)-2-methyl-1-(3,4,5-trimethoxyphenyl)propan-1-one (19v)



19v

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.10) afforded **19v** as a yellow liquid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.16 (s, 2H), 3.87 (s, 9H), 2.97 (s, 1H), 1.26 (s, 6H), 0.88–0.81 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 206.8, 152.7, 141.0, 133.4, 106.1, 61.1, 61.0, 56.3, 51.5, 23.6, 12.4 ppm. **IR** (KBr): ν_{max} = 3475, 3418, 3279, 1740, 1630, 1590, 1409, 1126 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{16}H_{22}O_5$, $[M+Na]^+$, 317.1359; found: 317.1358.

7-ethynyl-8,8-dimethyl-7-(3,4,5-trimethoxyphenyl)-4,6-dioxaspiro[2.5]octan-5-one (1v)

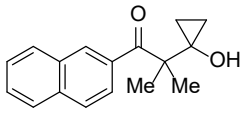


1v

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.22) afforded **1v** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 6.77 (s, 2H), 3.87 (d, J = 3.7 Hz, 9H), 2.91 (s, 1H), 1.32–1.23 (m, 2H), 1.06–0.87 (m, 7H), 0.79–0.72 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 152.6, 148.3, 138.6, 131.3, 105.1, 86.1, 81.1, 78.3, 70.4, 61.0, 56.5, 38.2, 19.9, 19.8, 12.5, 7.5 ppm. **IR** (KBr): ν_{max} = 3268, 2941, 1757, 1249, 1129, 1076 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{19}H_{22}O_6$, $[M+Na]^+$, 369.1309; found: 369.1307. **m.p.**:

194.6–196.3 °C.

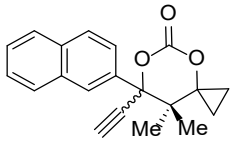
2-(1-hydroxycyclopropyl)-2-methyl-1-(naphthalen-2-yl)propan-1-one (19w)



19w

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.18) afforded **19w** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.32 (s, 1H), 7.91 (d, J = 7.9 Hz, 1H), 7.88–7.80 (m, 3H), 7.55 (dt, J = 19.0, 7.1 Hz, 2H), 3.14 (s, 1H), 1.35 (s, 6H), 0.88–0.81 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 209.5, 136.3, 134.5, 132.4, 129.2, 128.5, 128.0, 127.9, 127.8, 126.8, 124.7, 61.0, 51.7, 23.3, 11.8 ppm. **IR** (KBr): ν_{max} = 3441, 3329, 2977, 1674, 1627, 1467, 1276 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{17}H_{18}O_2$, $[M+Na]^+$, 277.1199; found: 277.1188. **m.p.**: 78.3–79.1 °C.

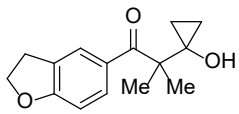
7-ethynyl-8,8-dimethyl-7-(naphthalen-2-yl)-4,6-dioxaspiro[2.5]octan-5-one (1w)



1w

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.21) afforded **1w** as a light pink solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.06 (s, 1H), 7.96–7.75 (m, 3H), 7.65 (d, J = 7.7 Hz, 1H), 7.59–7.42 (m, 2H), 2.95 (s, 1H), 1.34–1.23 (m, 2H), 0.99–0.83 (m, 7H), 0.77–0.69 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 148.4, 133.3, 133.1, 132.3, 128.5, 127.5, 127.3, 127.0, 126.8, 126.6, 124.6, 86.3, 81.0, 78.5, 70.3, 38.2, 19.8, 19.6, 12.2, 7.4 ppm. **IR** (KBr): ν_{max} = 3289, 2983, 1754, 1273, 1079 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{20}H_{18}O_3$, $[M+Na]^+$, 329.1148; found: 329.1141. **m.p.**: 156.8–157.7 °C.

1-(2,3-dihydrobenzofuran-5-yl)-2-(1-hydroxycyclopropyl)-2-methylpropan-1-one (19x)

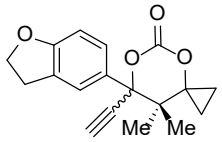


19x

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.35) afforded **19x** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.79 (d, J = 7.4 Hz, 2H), 6.76 (d, J = 8.5 Hz, 1H), 4.62 (t, J = 8.7 Hz, 2H), 3.28–3.17 (m, 3H), 1.30 (s, 6H), 0.86–0.73 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 206.6, 163.2, 130.7, 130.3, 127.3, 126.3, 108.7, 72.1, 61.2, 51.1, 29.3, 23.7, 11.8 ppm. **IR** (KBr): ν_{max} = 3320, 2978, 1659,

1627, 1241, 1098, 939 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{15}H_{18}O_3$, $[M+Na]^+$, 269.1148; found: 269.1147. **m.p.**: 47.2–49.8 °C.

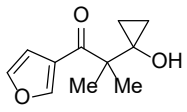
7-(2,3-dihydrobenzofuran-5-yl)-7-ethynyl-8,8-dimethyl-4,6-dioxaspiro[2.5]octan-5-one (1x)



1x

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.25) afforded **1x** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.37 (s, 1H), 7.28 (d, J = 8.4 Hz, 1H), 6.74 (d, J = 8.4 Hz, 1H), 4.58 (t, J = 8.7 Hz, 2H), 3.21 (t, J = 8.7 Hz, 2H), 2.87 (s, 1H), 1.27–1.19 (m, 2H), 0.98–0.84 (m, 7H), 0.75–0.68 (m, 1H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 160.7, 148.6, 128.1, 127.8, 126.8, 124.0, 108.4, 86.4, 81.5, 78.1, 71.8, 70.3, 38.2, 29.8, 19.9, 19.7, 12.3, 7.5 ppm. **IR** (KBr): ν_{max} = 3283, 2982, 2930, 1753, 1493, 1271, 1241, 1075 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{18}H_{18}O_4$, $[M+Na]^+$, 321.1097; found: 321.1094. **m.p.**: 182.5–184.6 °C.

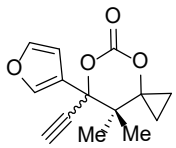
1-(furan-3-yl)-2-(1-hydroxycyclopropyl)-2-methylpropan-1-one (19y)



19y

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.20) afforded **19y** as a light yellow oil. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.11 (s, 1H), 7.40 (s, 1H), 6.82 (d, J = 1.2 Hz, 1H), 3.19 (s, 1H), 1.25 (s, 6H), 0.81–0.72 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 201.1, 147.1, 143.1, 125.2, 110.5, 60.5, 51.2, 23.0, 11.4 ppm. **IR** (KBr): ν_{max} = 3311, 2980, 1658, 1463, 1285, 1239, 1023, 764 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{11}H_{14}O_3$, $[M+Na]^+$, 217.0835; found: 217.0826.

7-ethynyl-7-(furan-3-yl)-8,8-dimethyl-4,6-dioxaspiro[2.5]octan-5-one (1y)

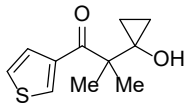


1y

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.30) afforded **1y** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.52 (s, 1H), 7.39 (t, J = 1.8 Hz, 1H), 6.43 (s, 1H), 2.85 (s, 1H), 1.23–1.11 (m, 2H), 1.06 (s, 3H), 0.97–0.89 (m, 4H), 0.76–0.69 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ

148.0, 143.1, 141.5, 123.3, 109.9, 82.3, 80.2, 77.6, 37.7, 19.7, 19.5, 11.8, 7.6 ppm. **IR** (KBr): ν_{max} = 3290, 2985, 1754, 1274 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{14}H_{14}O_4$, $[M+Na]^+$, 269.0784; found: 269.0789. **m.p.**: 90.6–93.2 °C.

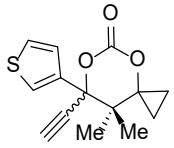
2-(1-hydroxycyclopropyl)-2-methyl-1-(thiophen-3-yl)propan-1-one (19z)



19z

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.28) afforded **19z** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.11 (s, 1H), 7.55 (d, J = 5.1 Hz, 1H), 7.24 (dd, J = 4.7, 3.0 Hz, 1H), 3.37 (s, 1H), 1.25 (s, 6H), 0.81–0.72 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 201.0, 140.0, 131.8, 128.6, 125.1, 60.6, 51.1, 23.0, 11.7 ppm. **IR** (KBr): ν_{max} = 3328, 2980, 1660, 1234, 855 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{11}H_{14}O_2S$, $[M+Na]^+$, 233.0607; found: 233.0597. **m.p.**: 66.5–69.5 °C.

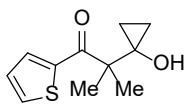
7-ethynyl-8,8-dimethyl-7-(thiophen-3-yl)-4,6-dioxaspiro[2.5]octan-5-one (1z)



1z

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.22) afforded **1z** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.45–7.35 (m, 1H), 7.29 (dd, J = 5.0, 3.1 Hz, 1H), 7.12 (d, J = 5.0 Hz, 1H), 2.88 (s, 1H), 1.24–1.16 (m, 2H), 0.99 (s, 3H), 0.96–0.89 (s, 4H), 0.73–0.67 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 148.1, 137.5, 127.0, 125.4, 124.3, 84.5, 80.7, 78.0, 70.0, 38.0, 19.8, 19.6, 11.9, 7.85 ppm. **IR** (KBr): ν_{max} = 3285, 2983, 1752, 1274, 1076 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{14}H_{14}O_3S$, $[M+Na]^+$, 285.0556; found: 285.05502. **m.p.**: 136.4–139.5 °C

7-ethynyl-8,8-dimethyl-7-(thiophen-2-yl)-4,6-dioxaspiro[2.5]octan-5-one (19aa)

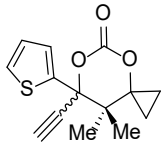


19aa

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.19) afforded **19aa** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.89 (d, J = 3.8 Hz, 1H), 7.59 (d, J = 4.9 Hz, 1H), 7.11 (t, J = 4.4 Hz, 1H), 3.21 (s, 1H), 1.36 (s, 6H), 0.85–0.75 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 198.9, 142.8,

133.2, 132.5, 128.0, 60.8, 51.2, 23.5, 11.7 ppm. **IR** (KBr): ν_{max} = 3440, 2983, 2937, 1632, 1412, 1234, 1020, 743 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{14}H_{14}O_3S$, $[M+Na]^+$, 233.0607; found: 233.0611. **m.p.**: 105.0–106.0 °C.

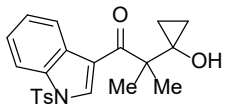
7-ethynyl-8,8-dimethyl-7-(thiophen-2-yl)-4,6-dioxaspiro[2.5]octan-5-one (1aa)



1aa

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.27) afforded **1aa** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.34 (d, J = 5.1 Hz, 1H), 7.19 (d, J = 3.5 Hz, 1H), 7.01 (t, J = 4.3 Hz, 1H), 2.92 (s, 1H), 1.28–1.20 (m, 2H), 1.10 (s, 3H), 1.01 (s, 3H), 0.99–0.96 (m, 1H), 0.78–0.74 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 147.6, 139.5, 127.6, 126.5, 126.5, 84.7, 80.7, 78.3, 70.2, 38.5, 19.91, 19.89, 12.1, 7.8 ppm. **IR** (KBr): ν_{max} = 2983, 2117, 1754, 1273, 1073, 759 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{14}H_{14}O_3S$, $[M+Na]^+$, 285.0556; found: 285.0551. **m.p.**: 86.0–87.0 °C.

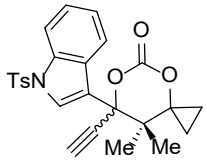
2-(1-hydroxycyclopropyl)-2-methyl-1-(1-tosyl-1H-indol-3-yl)propan-1-one (19ab)



19ab

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 4 : 1, R_f = 0.23) afforded **19ab** as a light yellow oil. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.44 (s, 1H), 8.31 (d, J = 7.5 Hz, 1H), 7.93 (d, J = 7.8 Hz, 1H), 7.81 (d, J = 8.2 Hz, 2H), 7.38–7.30 (m, 2H), 7.26 (d, J = 8.1 Hz, 2H), 3.02 (s, 1H), 2.35 (s, 3H), 1.36 (s, 6H), 0.91–0.83 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 202.4, 146.0, 134.6, 134.2, 131.0, 130.3, 129.5, 127.2, 125.8, 124.9, 123.4, 118.5, 113.0, 61.0, 51.9, 23.7, 21.8, 12.0 ppm. **IR** (KBr): ν_{max} = 3330, 2980, 1660, 1375, 1268, 1175, 750 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{22}H_{23}NO_4S$, $[M+Na]^+$, 420.1240; found: 420.1246.

7-ethynyl-8,8-dimethyl-7-(1-tosyl-1H-indol-3-yl)-4,6-dioxaspiro[2.5]octan-5-one(1ab)

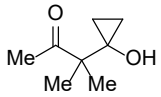


1ab

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 4 : 1, R_f = 0.27) afforded **1ab** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.98 (d, J = 8.4 Hz, 1H), 7.84–7.71 (m, 4H), 7.32 (t, J = 7.8 Hz,

1H), 7.26–7.21 (m, 3H), 2.96 (s, 1H), 2.34 (s, 3H), 1.34–1.24 (m, 2H), 1.09–0.93 (m, 7H), 0.79–0.72 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 148.0, 145.6, 135.0, 134.7, 130.2, 128.0, 127.1, 126.3, 125.0, 123.6, 122.3, 118.4, 113.6, 83.6, 80.1, 78.8, 70.2, 39.0, 21.7, 20.3, 20.0, 12.4, 7.3 ppm. **IR** (KBr): ν_{max} = 3290, 2925, 1756, 1374, 1271, 1174, 746, 576 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{25}H_{23}NO_5S$, $[M+H]^+$, 450.1370; found: 450.1358. **m.p.**: 103.7–105.8 °C.

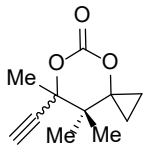
3-(1-hydroxycyclopropyl)-3-methylbutan-2-one (19ac)



19ac

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.25) afforded **19ac** as a light yellow oil. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 3.42 (s, 1H), 2.17 (s, 3H), 0.99 (s, 6H), 0.70–0.61 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 214.7, 59.9, 51.0, 26.0, 21.4, 10.7 ppm. **IR** (KBr): ν_{max} = 3331, 2979, 1704, 1468, 1357, 1260, 1234 ,1124 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{11}H_{14}O_3$, $[M+Na]^+$, 165.0887; found: 165.0886.

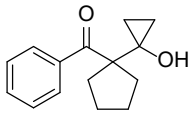
7-ethynyl-7,8,8-trimethyl-4,6-dioxaspiro[2.5]octan-5-one (1ac)



1ac

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.29) afforded **1ac** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 2.68 (s, 1H), 1.59 (s, 3H), 1.08–0.93 (m, 7H), 0.84–0.90 (m, 1H), 0.72–0.79 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 148.0, 82.5, 81.2, 76.5, 69.7, 36.2, 23.6, 19.8, 19.0, 10.9, 7.6 ppm. **IR** (KBr): ν_{max} = 3270, 2984, 1753, 1282, 1250, 1070 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{11}H_{14}O_3$, $[M+Na]^+$, 217.0835; found: 217.0858. **m.p.**: 85.4–87.2 °C.

(1-(1-hydroxycyclopropyl)cyclopentyl)(phenyl)methanone (19ad)

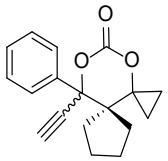


19ad

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.18) afforded **19ad** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.78 (d, J = 7.2 Hz, 2H), 7.46 (t, J = 7.3 Hz, 1H), 7.39

(t, J = 7.4 Hz, 2H), 2.79 (s, 1H), 2.37–2.27 (m, 2H), 1.68–1.56 (m, 6H), 0.83–0.73 (m, 4H) ppm **^{13}C NMR** (100 MHz, $CDCl_3$) δ 207.8, 138.6, 131.3, 128.3, 128.1, 63.7, 59.8, 34.1, 25.8, 13.0 ppm. **IR** (KBr): ν_{max} = 3329, 2955, 2871, 1671, 1449, 1235, 1017, 701 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{15}H_{18}O_2$, $[M+Na]^+$, 253.1199; found: 253.1189. **m.p.**: 56.1–57.2 °C.

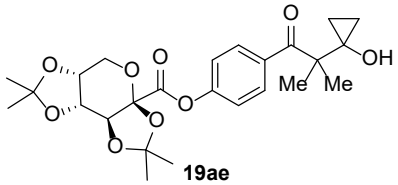
9-ethynyl-9-phenyl-10,12-dioxadispiro[2.0.4^4.4^3]dodecan-11-one (1ad)



1ad

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 10 : 1, R_f = 0.20) afforded **1ad** as a light yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.62 (d, J = 6.5 Hz, 2H), 7.38 (d, J = 5.7 Hz, 3H), 2.85 (s, 1H), 2.08–2.01 (m, 2H), 1.62–1.55 (m 1H), 1.42–1.37 (m, 2H), 1.30–1.15 (m, 4H), 0.99–0.83 (m, 2H), 0.70–0.64 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 148.9, 136.9, 129.0, 128.0, 127.4, 86.5, 81.9, 77.6, 69.8, 50.0, 31.9, 31.0, 26.5, 26.3, 12.2, 8.1 ppm. **IR** (KBr): ν_{max} = 3290, 2960, 2875, 1755, 1267, 1065, 702 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{18}H_{18}O_3$, $[M+Na]^+$, 305.1148; found: 305.1142. **m.p.**: 144.6–145.8 °C.

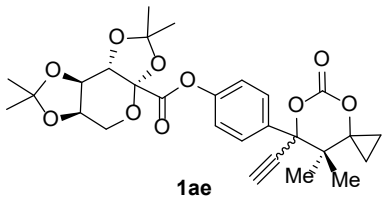
4-(2-(1-hydroxycyclopropyl)-2-methylpropanoyl)phenyl (3a*R*,5a*R*,8a*R*,8b*S*)-2,2,7,7-tetramethyltetrahydro-3a*H*-bis([1,3]dioxolo)[4,5-*b*:4',5'-*d*]pyran-3a-carboxylate (19ae)



19ae

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.21) afforded **19ae** as a colorless oil. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.84 (d, J = 8.4 Hz, 2H), 7.20 (d, J = 8.3 Hz, 2H), 4.86 (d, J = 2.5 Hz, 1H), 4.69 (dd, J = 7.9, 2.5 Hz, 1H), 4.31 (d, J = 7.9 Hz, 1H), 3.99–3.93 (m, 2H), 2.89 (s, 1H), 1.61 (s, 3H), 1.51 (s, 3H), 1.49 (s, 3H), 1.37 (s, 3H), 1.28 (s, 6H), 0.83–0.77 (m, 4H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 208.0, 166.5, 152.8, 136.8, 129.8, 121.2, 111.1, 109.7, 99.9, 73.0, 70.4, 70.1, 61.9, 61.0, 51.6, 26.3, 26.1, 24.7, 24.6, 23.2, 11.8 ppm. **IR** (KBr): ν_{max} = 3308, 2989, 2937, 1767, 1676, 1383, 1253, 1164, 926 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{25}H_{32}O_9$, $[M+Na]^+$, 499.1939; found: 499.1943.

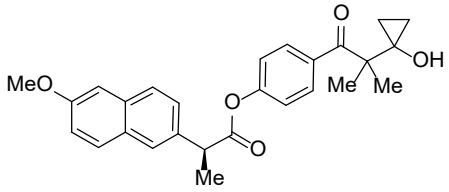
4-(7-ethynyl-8,8-dimethyl-5-oxo-4,6-dioxaspiro[2.5]octan-7-yl)phenyl (3a*R*,5a*R*,8a*R*,8b*S*)-2,2,7,7-tetramethyltetrahydro-3a*H*-bis([1,3]dioxolo)[4,5-*b*:4',5'-*d*]pyran-3a-carboxylate (1ae)



1ae

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.13) afforded **1ae** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.58 (d, J = 8.5 Hz, 2H), 7.16 (d, J = 8.4 Hz, 2H), 4.84 (s, 1H), 4.67 (dd, J = 7.9, 2.6 Hz, 1H), 4.29 (d, J = 7.9 Hz, 1H), 3.98–3.90 (m, 2H), 2.90 (s, 1H), 1.59 (s, 3H), 1.48 (d, J = 6.3 Hz, 6H), 1.35 (s, 3H), 1.29–1.19 (m, 2H), 0.98–0.91 (m, 4H), 0.87 (s, 3H), 0.75–0.69 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 166.6, 166.6, 151.0, 148.1, 133.9, 128.6, 120.6, 111.0, 109.6, 99.8, 85.9, 80.8, 78.60, 73.0, 72.9, 70.4, 70.3, 70.0, 61.8, 38.1, 26.3, 26.1, 24.7, 24.5, 19.7, 19.5, 12.3, 7.4 ppm. **IR** (KBr): ν_{max} = 3293, 2989, 1760, 1506, 1252, 1074, 739 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{28}H_{32}O_{10}$, $[M+Na]^+$, 551.1888; found: 551.1884. **m.p.**: 130.7–131.4 °C.

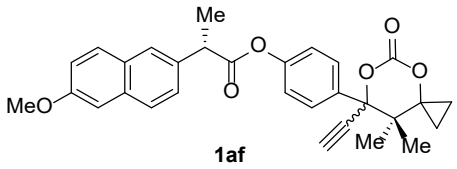
4-(2-(1-hydroxycyclopropyl)-2-methylpropanoyl)phenyl (*S*)-2-(6-methoxynaphthalen-2-yl)propanoate (19af)



19af

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.13) afforded **19af** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.81–7.71 (m, 5H), 7.51 (d, J = 8.5 Hz, 1H), 7.19–7.15 (m, 2H), 7.06 (d, J = 8.4 Hz, 2H), 4.12 (q, J = 7.1 Hz, 1H), 3.91 (s, 3H), 3.08 (s, 1H), 1.71 (d, J = 7.2 Hz, 3H), 1.24 (s, 6H), 0.82–0.74 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 207.8, 172.8, 157.8, 153.0, 136.1, 134.9, 133.9, 129.6, 129.4, 129.0, 127.5, 126.2, 126.1, 121.2, 119.3, 105.7, 60.8, 55.4, 51.4, 45.6, 23.1, 18.5, 11.8 ppm. **IR** (KBr): ν_{max} = 3330, 2979, 1755, 1675, 1603, 1266, 1165, 978, 853 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{27}H_{28}O_5$, $[M+Na]^+$, 455.1829; found: 455.1830. **m.p.**: 99.4–100.7 °C.

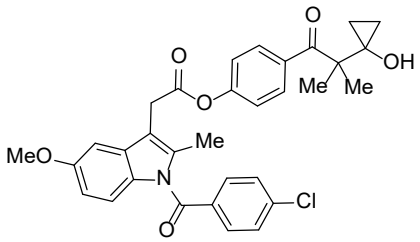
4-(7-ethynyl-8,8-dimethyl-5-oxo-4,6-dioxaspiro[2.5]octan-7-yl)phenyl (2*S*)-2-(6-methoxynaphthalen-2-yl)propanoate (1af)



1af

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.11) afforded **1af** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.77–7.73 (m, 3H), 7.53–7.48 (m, 3H), 7.18–7.14 (m, 2H), 7.04 (d, J = 8.3 Hz, 2H), 4.11 (q, J = 7.1 Hz, 1H), 3.92 (s, 3H), 2.87 (s, 1H), 1.70 (d, J = 7.1 Hz, 3H), 1.31–1.19 (m, 2H), 0.99–0.92 (m, 4H), 0.86 (s, 3H), 0.75–0.68 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 173.1, 157.9, 151.3, 148.2, 135.0, 134.0, 133.4, 129.4, 129.1, 128.5, 127.6, 126.3, 126.2, 120.8, 119.3, 105.8, 85.9, 80.9, 78.5, 70.3, 55.5, 45.7, 38.1, 19.7, 19.6, 18.6, 12.3, 7.5 ppm. **IR** (KBr): ν_{max} = 3290, 2985, 1755, 1603, 1505, 1268, 1170, 1076, 739 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{30}H_{28}O_6$, $[M+Na]^+$, 507.1778; found: 507.1773. **m.p.**: 176.2–178.7 °C.

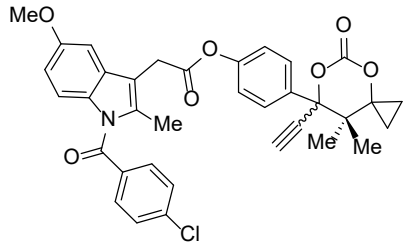
4-(2-(1-hydroxycyclopropyl)-2-methylpropanoyl)phenyl 2-(1-(4-chlorobenzoyl)-5-methoxy-2-methyl-1H-indol-3-yl)acetate (19ag)



19ag

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.13) afforded **19ag** as a yellow solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.82 (d, J = 8.4 Hz, 2H), 7.68 (d, J = 6.6 Hz, 2H), 7.48 (d, J = 6.6 Hz, 2H), 7.13 (d, J = 8.5 Hz, 2H), 7.05 (s, 1H), 6.89 (d, J = 10.5 Hz, 1H), 6.70 (d, J = 9.0 Hz, 1H), 3.92 (s, 2H), 3.84 (s, 3H), 2.95 (s, 1H), 2.46 (s, 3H), 1.26 (s, 6H), 0.84–0.76 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 207.9, 169.0, 168.4, 156.3, 152.8, 139.5, 136.5, 133.9, 131.3, 131.0, 130.5, 129.7, 129.3, 121.3, 115.2, 111.9, 111.8, 101.3, 60.9, 55.9, 51.5, 30.7, 23.2, 13.6, 11.9 ppm. **IR** (KBr): ν_{max} = 3301, 3058, 2980, 1755, 1681, 1478, 1320, 1222, 754, 555 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{32}H_{30}ClNO_6$, $[M+H]^+$, 560.1834; found: 560.1834. **m.p.**: 59.8–61.5 °C.

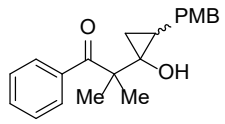
4-(7-ethynyl-8,8-dimethyl-5-oxo-4,6-dioxaspiro[2.5]octan-7-yl)phenyl 2-(1-(4-chlorobenzoyl)-5-methoxy-2-methyl-1H-indol-3-yl)acetate (1ag)



1ag

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 3 : 1, R_f = 0.13) afforded **1ag** as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.68 (d, J = 8.5 Hz, 2H), 7.58–7.54 (m, 2H), 7.48 (d, J = 8.4 Hz, 2H), 7.11 (d, J = 8.8 Hz, 2H), 7.05 (d, J = 2.5 Hz, 1H), 6.89 (d, J = 9.0 Hz, 1H), 6.70 (dd, J = 9.0, 2.5 Hz, 1H), 3.92 (s, 2H), 3.84 (s, 3H), 2.89 (s, 1H), 2.46 (s, 3H), 1.30–1.22 (m, 2H), 0.99–0.94 (m, 4H), 0.88 (s, 3H), 0.75–0.71 (m, 1H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 169.1, 168.4, 156.3, 151.2, 148.2, 139.5, 136.4, 133.9, 133.7, 131.3, 131.0, 130.6, 129.3, 128.6, 120.8, 115.2, 111.9, 101.4, 85.9, 80.9, 78.5, 70.3, 55.9, 38.1, 30.7, 19.7, 19.6, 13.6, 12.3, 7.5 ppm. **IR** (KBr): ν_{max} = 3439, 2985, 1756, 1682, 1505, 1265, 1220, 1073, 754 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{35}H_{30}ClNO_7$, $[M+Na]^+$, 634.1603; found: 634.1601. **m.p.**: 93.4–95.9 °C.

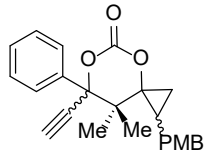
2-(1-hydroxy-2-(4-methoxybenzyl)cyclopropyl)-2-methyl-1-phenylpropan-1-one (19ah)



19ah

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.26) afforded **19ah** as a colorless oil. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.75 (d, J = 7.9 Hz, 2H), 7.48 (t, J = 7.3 Hz, 1H), 7.41 (t, J = 7.5 Hz, 2H), 7.15 (d, J = 8.1 Hz, 2H), 6.85 (d, J = 8.1 Hz, 2H), 3.80 (s, 3H), 2.95 (dd, J = 14.6, 4.3 Hz, 1H), 2.85 (s, 1H), 2.45 (dd, J = 14.6, 10.5 Hz, 1H), 1.47–1.43 (m, 4H), 1.41 (s, 3H), 1.08 (dd, J = 10.5, 5.9 Hz, 1H), 0.86 (t, J = 6.8 Hz, 1H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 209.3, 158.1, 139.1, 133.8, 131.1, 129.2, 128.3, 128.0, 114.0, 63.8, 55.4, 52.2, 34.3, 30.0, 25.1, 23.7, 19.0 ppm. **IR** (KBr): ν_{max} = 3483, 2928, 1677, 1512, 1248, 1035, 744 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{21}H_{24}O_3$, $[M+Na]^+$, 347.1618; found: 347.1619.

7-ethynyl-1-(4-methoxybenzyl)-8,8-dimethyl-7-phenyl-4,6-dioxaspiro[2.5]octan-5-one (1ah)

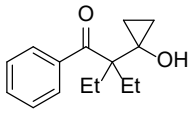


1ah

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.29) afforded **1ah**

as a white solid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.60–7.57 (m, 4H), 7.42–7.38 (m, 6H), 7.13 (dd, J = 18.9, 8.2 Hz, 4H), 6.85 (dd, J = 12.9, 8.3 Hz, 4H), 3.79 (d, J = 8.2 Hz, 6H), 3.35 (dd, J = 14.3, 3.3 Hz, 1H), 2.95 (s, 1H), 2.89 (s, 1H), 2.77 (dd, J = 14.7, 5.0 Hz, 1H), 2.56–2.46 (m, 2H), 1.80–1.70 (m, 1H), 1.63–1.59 (m, 1H), 1.50 (dd, J = 11.2, 7.0 Hz, 1H), 1.23–1.19 (m, 2H), 1.16 (d, J = 9.4 Hz, 6H), 1.07 (s, 3H), 1.02 (s, 3H), 0.68–0.65 (m, 1H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 158.33, 158.32, 148.4, 148.2, 136.2, 135.5, 132.9, 132.5, 129.2, 129.1, 129.02, 129.00, 127.9, 127.8, 127.5, 114.2, 114.1, 86.5, 86.4, 82.0, 81.2, 78.2, 77.7, 73.2, 73.0, 55.41, 55.38, 40.9, 39.0, 35.4, 33.4, 29.4, 25.7, 21.4, 21.2, 19.2, 18.5, 16.0 ppm. **IR** (KBr): ν_{max} = 2960, 2935, 2355, 1751, 1511, 1264, 761 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{24}H_{24}O_4$, $[M+Na]^+$, 399.1567; found: 399.1567. **m.p.**: 134.4–136.1 °C.

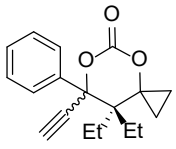
2-ethyl-2-(1-hydroxycyclopropyl)-1-phenylbutan-1-one (19ai)



19ai

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.43) afforded **19ai** as a yellow oily liquid. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.75 (d, J = 7.4 Hz, 2H), 7.45 (t, J = 7.3 Hz, 1H), 7.39 (t, J = 7.5 Hz, 2H), 2.28 (s, 1H), 1.74–1.68 (m, 2H), 1.67–1.62 (m, 2H), 0.91 (t, J = 7.5 Hz, 6H), 0.86–0.83 (m, 2H), 0.78–0.75 (m, 2H) ppm. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 208.6, 140.7, 130.7, 128.2, 127.5, 58.7, 57.9, 25.4, 12.3, 9.2 ppm. **IR** (KBr): ν_{max} = 3470, 2969, 1644, 1268, 754 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{15}H_{20}O_2$, $[M+H]^+$, 233.1536; found: 233.1539.

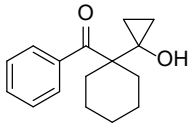
8,8-diethyl-7-ethynyl-7-phenyl-4,6-dioxaspiro[2.5]octan-5-one (1ai)



1ai

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.38) afforded **1ai** as a colorless oil. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.59 (dd, J = 6.5, 3.2 Hz, 2H), 7.42–7.32 (m, 3H), 2.93 (s, 1H), 1.96 (dq, J = 14.9, 7.4 Hz, 1H), 1.60–1.51 (m, 1H), 1.41 (dt, J = 15.1, 7.6 Hz, 1H), 1.23 (dt, J = 14.2, 7.1 Hz, 1H), 1.12–0.93 (m, 6H), 0.78–0.72 (m, 1H), 0.60 (t, J = 7.5 Hz, 3H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 148.7, 136.9, 129.1, 128.0, 127.7, 88.5, 82.1, 79.0, 67.0, 42.1, 22.1, 20.8, 9.2, 9.2, 8.7, 8.5 ppm. **IR** (KBr): ν_{max} = 3256, 2960, 1755, 1269, 1066, 757 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{18}H_{20}O_3$, $[M+H]^+$, 285.1485; found: 285.1488.

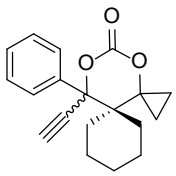
(1-(1-hydroxycyclopropyl)cyclohexyl)(phenyl)methanone (19aj)



19aj

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.28) afforded **19aj** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.77 (d, J = 7.1 Hz, 2H), 7.50–7.30 (m, 3H), 2.43–2.26 (m, 3H), 1.65–1.53 (m, 3H), 1.31–1.19 (m, 2H), 1.15–1.01 (m, 3H), 0.93–0.81 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 208.7, 140.6, 130.6, 128.1, 127.3, 61.9, 55.3, 31.5, 25.9, 23.2, 12.8 ppm. **IR** (KBr): ν_{max} = 3413, 2923, 1626, 1454, 1229, 616 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{16}H_{20}O_2$, $[M+Na]^+$, 267.1356; found: 267.1357. **m.p.**: 72.5–73.9 °C.

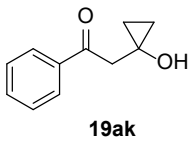
10-ethynyl-10-phenyl-11,13-dioxadispiro[2.0.5^4.4^3]tridecan-12-one (1aj)



1aj

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.40) afforded **1aj** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.59–7.53 (m, 2H), 7.40–7.33 (m, 3H), 2.89 (s, 1H), 1.80–1.73 (m, 1H), 1.68–1.59 (m, 1H), 1.57–1.45 (m, 3H), 1.44–1.37 (m, 1H), 1.35–1.25 (m, 3H), 1.23–1.00 (m, 4H), 0.99–0.87 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 148.7, 136.4, 128.9, 128.3, 127.6, 88.4, 81.7, 78.6, 68.2, 39.2, 27.5, 27.0, 24.5, 21.4, 20.5, 11.7, 10.5 ppm. **IR** (KBr): ν_{max} = 3417, 2943, 2865, 1754, 1271, 1070, 755 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{19}H_{20}O_3$, $[M+H]^+$, 297.1485; found: 297.1488. **m.p.**: 124.4–126.8 °C.

2-(1-hydroxycyclopropyl)-1-phenylethan-1-one (19ak)

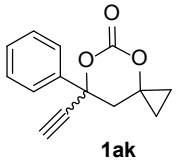


19ak

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.40) afforded **19ak** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.92 (d, J = 7.7 Hz, 2H), 7.57 (t, J = 7.3 Hz, 1H), 7.45 (t, J = 7.6 Hz, 2H), 4.01 (s, 1H), 3.24 (s, 2H), 0.96–0.85 (m, 2H), 0.55–0.42 (m, 2H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 200.8, 136.5, 133.7, 128.8, 128.1, 52.2, 46.1, 12.9 ppm. **IR** (KBr): ν_{max} = 3007, 1677, 1597, 1450, 1284, 1213,

979, 731 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{11}H_{12}O_2$, $[M+Na]^+$, 199.0731; found: 199.0730. **m.p.**: 37.0–38.2 °C.

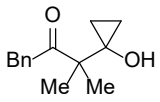
7-ethynyl-7-phenyl-4,6-dioxaspiro[2.5]octan-5-one (1ak)



1ak

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.27) afforded **1al** as a yellow oil. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 77.59 (d, J = 7.7 Hz, 2H), 7.45–7.34 (m, 3H), 2.90 (s, 1H), 2.75 (dd, J = 14.4, 1.6 Hz, 1H), 2.21 (d, J = 14.4 Hz, 1H), 1.38–1.32 (m, 1H), 1.14–1.01 (m, 2H), 0.69–0.62 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 148.5, 139.5, 129.2, 128.8, 125.0, 81.2, 79.6, 77.9, 61.6, 41.6, 13.5, 9.8 ppm. **IR** (KBr): ν_{max} = 3418, 1753, 1295, 1218, 1059, 752 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{14}H_{12}O_3$, $[M+Na]^+$, 251.0679; found: 251.0684.

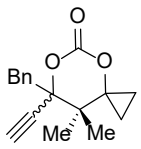
3-(1-hydroxycyclopropyl)-3-methyl-1-phenylbutan-2-one (19al)



19al

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.37) afforded **19al** as a colorless liquid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.33 (t, J = 7.3 Hz, 2H), 7.26 (t, J = 7.2 Hz, 1H), 7.21 (d, J = 7.3 Hz, 2H), 3.93 (s, 2H), 3.01 (s, 1H), 1.14 (s, 6H), 0.81–0.73 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 213.3, 134.7, 129.8, 128.4, 126.7, 60.1, 51.4, 44.4, 21.6, 10.8 ppm. **IR** (KBr): ν_{max} = 3470, 2980, 1712, 1455, 1246, 1049, 702 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{14}H_{18}O_2$, $[M+H]^+$, 219.1380; found: 219.1371.

7-benzyl-7-ethynyl-8,8-dimethyl-4,6-dioxaspiro[2.5]octan-5-one (1al)

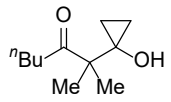


1al

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.27) afforded **1al** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.46–7.16 (m, 5H), 3.24 (d, J = 13.9 Hz, 1H), 2.92 (d, J = 13.9 Hz, 1H), 2.62 (s, 1H), 1.24 (s, 3H), 1.17–1.01 (m, 5H), 0.98–0.91 (m, 1H), 0.87–0.82 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 147.7, 134.1, 131.1, 127.8, 127.0, 85.1, 79.3, 79.0, 69.9, 41.2, 36.8, 20.0, 19.3, 11.1, 7.8 ppm. **IR**

(KBr): ν_{max} = 3417, 2980, 1751, 1276, 1071, 697 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{17}H_{18}O_3$, $[M+Na]^+$, 293.1148; found:293.1155. **m.p.**: 155.9–157.4 °C.

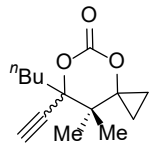
2-(1-hydroxycyclopropyl)-2-methylheptan-3-one (19am)



19am

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.48) afforded **19am** as a colorless liquid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 3.19 (s, 1H), 2.53 (t, J = 7.3 Hz, 2H), 1.51 (p, J = 7.4 Hz, 2H), 1.26 (h, J = 7.4 Hz, 2H), 1.02 (d, J = 1.8 Hz, 6H), 0.86 (t, J = 7.4 Hz, 3H), 0.70–0.59 (m, 4H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 216.6, 60.0, 50.8, 37.5, 25.9, 22.4, 21.6, 14.0, 10.6 ppm. **IR** (KBr): ν_{max} = 3476, 2962, 2872, 1702, 1246, 1048 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{11}H_{20}O_2$, $[M+H]^+$, 185.1536; found: 185.1535.

7-butyl-7-ethynyl-8,8-dimethyl-4,6-dioxaspiro[2.5]octan-5-one (1am)



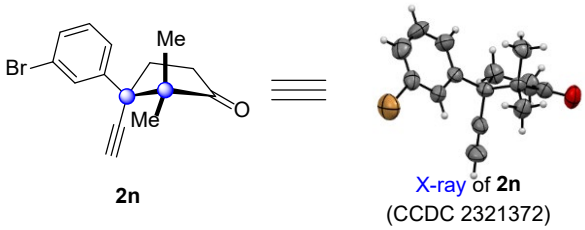
1am

Purification by flash column chromatography on silica gel (petroleum ether/EtOAc = 5 : 1, R_f = 0.41) afforded **1am** as a white solid. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 2.68 (s, 1H), 1.85–1.76 (m, 1H), 1.70–1.58 (m, 3H), 1.37–1.26 (m, 2H), 1.14–0.99 (m, 5H), 0.96 (s, 3H), 0.91–0.85 (m, 4H), 0.79–0.73 (m, 1H) ppm. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 148.2, 85.6, 79.8, 77.8, 70.0, 36.7, 34.9, 25.7, 22.7, 20.0, 19.3, 14.0, 11.2, 7.6 ppm. **IR** (KBr): ν_{max} = 3418, 2960, 1753, 1277, 1068, 753 cm^{-1}. **HRMS** (ESI) (m/z): Calcd for $C_{14}H_{20}O_3$, $[M+H]^+$, 237.1485; found: 237.1490. **m.p.**: 101.1–102.7 °C.

8. Crystallographic Data

Crystallographic data for the structures reported in this article have been deposited at the Cambridge Crystallographic Data Centre under deposition numbers CCDC 2321372 (**2n**), CCDC 2321378 (**2af**), CCDC 2321373 (**2ah**), and CCDC 2321374 (**L12**). Copies of the data can be obtained free of charge via https://www.ccdc.cam.ac.uk/data_request/cif.

8.1 Crystallographic data of 2n

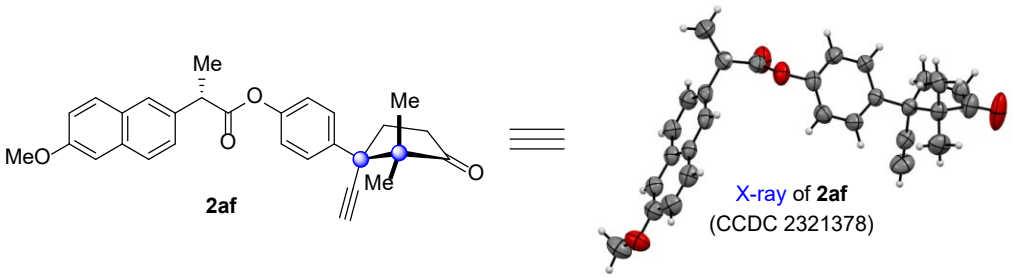


2n

X-ray of **2n**
(CCDC 2321372)

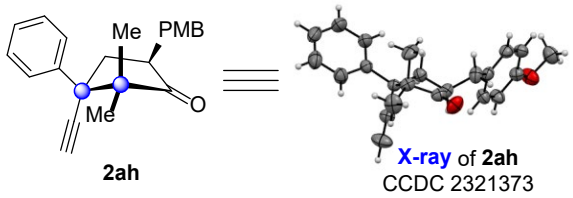
Identification code	**2n**
Empirical formula	$C_{15}H_{15}BrO$
Formula weight	291.18
Temperature/K	293(2)
Crystal system	orthorhombic
Space group	$P2_12_12_1$
a/Å	9.0877(6)
b/Å	10.7172(12)
c/Å	14.3707(11)
α/°	90
β/°	90
γ/°	90
Volume/Å^3	1399.6(2)
Z	4
ρ_{calc}g/cm^3	1.382
μ/mm^{-1}	2.919
F(000)	592.0
Crystal size/mm^3	0.32 × 0.3 × 0.28
Radiation	Mo Kα (λ = 0.71073)
2Θ range for data collection/°	4.742 to 58.178
Index ranges	$-9 \le h \le 12$, $-10 \le k \le 14$, $-18 \le l \le 18$
Reflections collected	5784
Independent reflections	3195 [R_{int} = 0.0288, R_{sigma} = 0.0611]
Data/restraints/parameters	3195/0/156
Goodness-of-fit on F^2	1.016
Final R indexes [I>=2σ (I)]	R_1 = 0.0565, wR_2 = 0.1135
Final R indexes [all data]	R_1 = 0.1258, wR_2 = 0.1420
Largest diff. peak/hole / e Å^{-3}	0.62/-0.49
Flack parameter	-0.006(9)

8.2 Crystallographic data of 2af



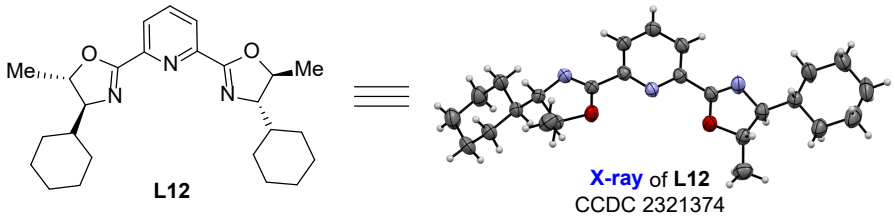
Identification code	**2af**
Empirical formula	$C_{29}H_{28}O_4$
Formula weight	440.51
Temperature/K	293(2)
Crystal system	monoclinic
Space group	$P2_1$
a/Å	12.4747(4)
b/Å	6.58280(10)
c/Å	15.4889(4)
α/°	90
β/°	110.054(3)
γ/°	90
Volume/Å^3	1194.81(6)
Z	2
ρ_{calc}g/cm^3	1.224
μ/mm^{-1}	0.643
F(000)	468.0
Crystal size/mm^3	0.34 × 0.26 × 0.24
Radiation	Cu Kα (λ = 1.54184)
2Θ range for data collection/°	6.074 to 141.076
Index ranges	$-15 \le h \le 15$, $-8 \le k \le 8$, $-18 \le l \le 18$
Reflections collected	20099
Independent reflections	4544 [R_{int} = 0.0311, R_{sigma} = 0.0196]
Data/restraints/parameters	4544/1/302
Goodness-of-fit on F^2	1.039
Final R indexes [I>=2σ (I)]	R_1 = 0.0364, wR_2 = 0.0964
Final R indexes [all data]	R_1 = 0.0387, wR_2 = 0.0999
Largest diff. peak/hole / e Å^{-3}	0.18/-0.17
Flack parameter	-0.06(8)

8.3 Crystallographic data of 2ah



Identification code	**2ah**
Empirical formula	$C_{23}H_{24}O_2$
Formula weight	332.42
Temperature/K	293
Crystal system	orthorhombic
Space group	$P2_12_12_1$
a/Å	6.6478(3)
b/Å	10.5086(5)
c/Å	26.9042(15)
α/°	90
β/°	90
γ/°	90
Volume/Å^3	1879.50(16)
Z	4
ρ_{calc}g/cm^3	1.175
μ/mm^{-1}	0.073
F(000)	712.0
Crystal size/mm^3	0.31 × 0.27 × 0.22
Radiation	Mo Kα (λ = 0.71073)
2Θ range for data collection/°	6.836 to 57.732
Index ranges	$-8 \le h \le 8$, $-8 \le k \le 14$, $-33 \le l \le 33$
Reflections collected	6986
Independent reflections	4231 [R_{int} = 0.0309, R_{sigma} = 0.0591]
Data/restraints/parameters	4231/0/229
Goodness-of-fit on F^2	1.065
Final R indexes [I>=2σ (I)]	R_1 = 0.0556, wR_2 = 0.1219
Final R indexes [all data]	R_1 = 0.0800, wR_2 = 0.1392
Largest diff. peak/hole / e Å^{-3}	0.18/-0.17
Flack parameter	-1.3(10)

8.4 Crystallographic data of L12



Identification code	**L12**
Empirical formula	$C_{25}H_{35}N_3O_2$
Formula weight	409.56
Temperature/K	293(2)
Crystal system	monoclinic
Space group	$P2_1$
a/Å	6.5199(3)
b/Å	8.9739(5)
c/Å	19.7834(10)
α/°	90
β/°	96.520(5)
γ/°	90
Volume/Å^3	1150.02(10)
Z	2
ρ_{calc}g/cm^3	1.183
μ/mm^{-1}	0.075
F(000)	444.0
Crystal size/mm^3	0.31 × 0.28 × 0.25
Radiation	Mo Kα (λ = 0.71073)
2Θ range for data collection/°	6.842 to 58.346
Index ranges	$-8 \le h \le 8$, $-11 \le k \le 11$, $-25 \le l \le 24$
Reflections collected	16343
Independent reflections	5469 [R_{int} = 0.0352, R_{sigma} = 0.0444]
Data/restraints/parameters	5469/1/273
Goodness-of-fit on F^2	1.141
Final R indexes [I>=2σ (I)]	R_1 = 0.0498, wR_2 = 0.1328
Final R indexes [all data]	R_1 = 0.0748, wR_2 = 0.1471
Largest diff. peak/hole / e Å^{-3}	0.16/-0.20
Flack parameter	0.3(6)

9. References

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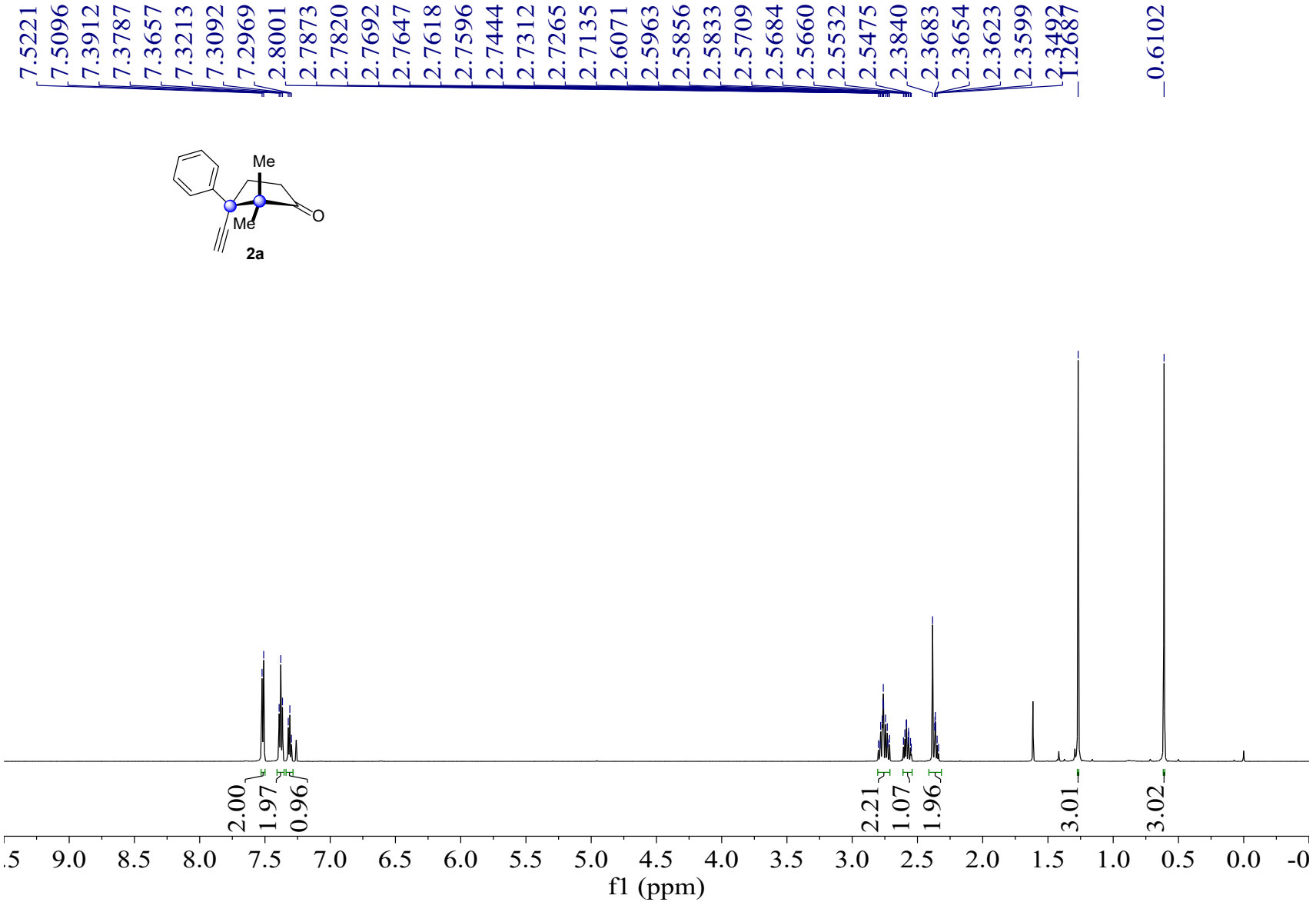
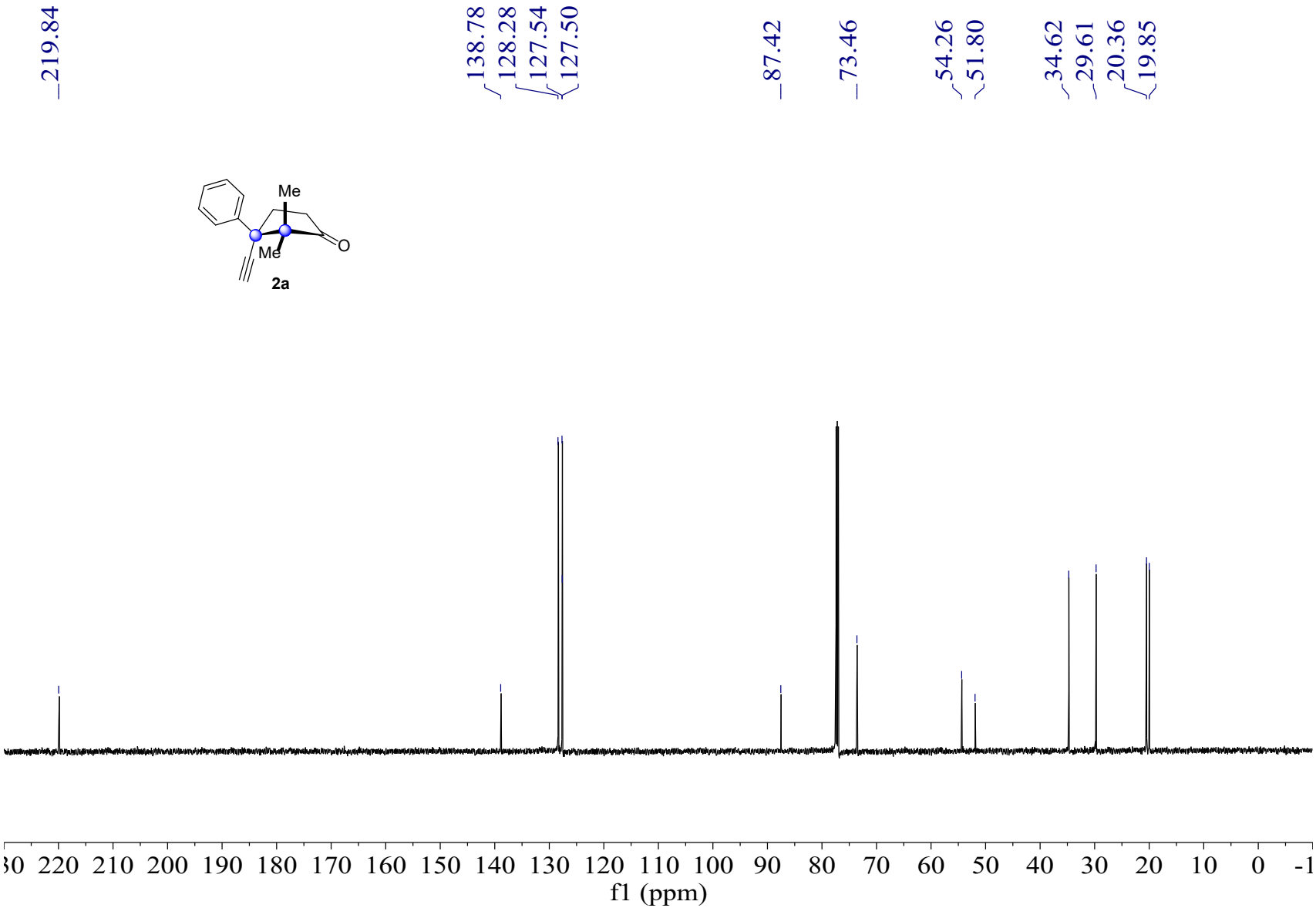
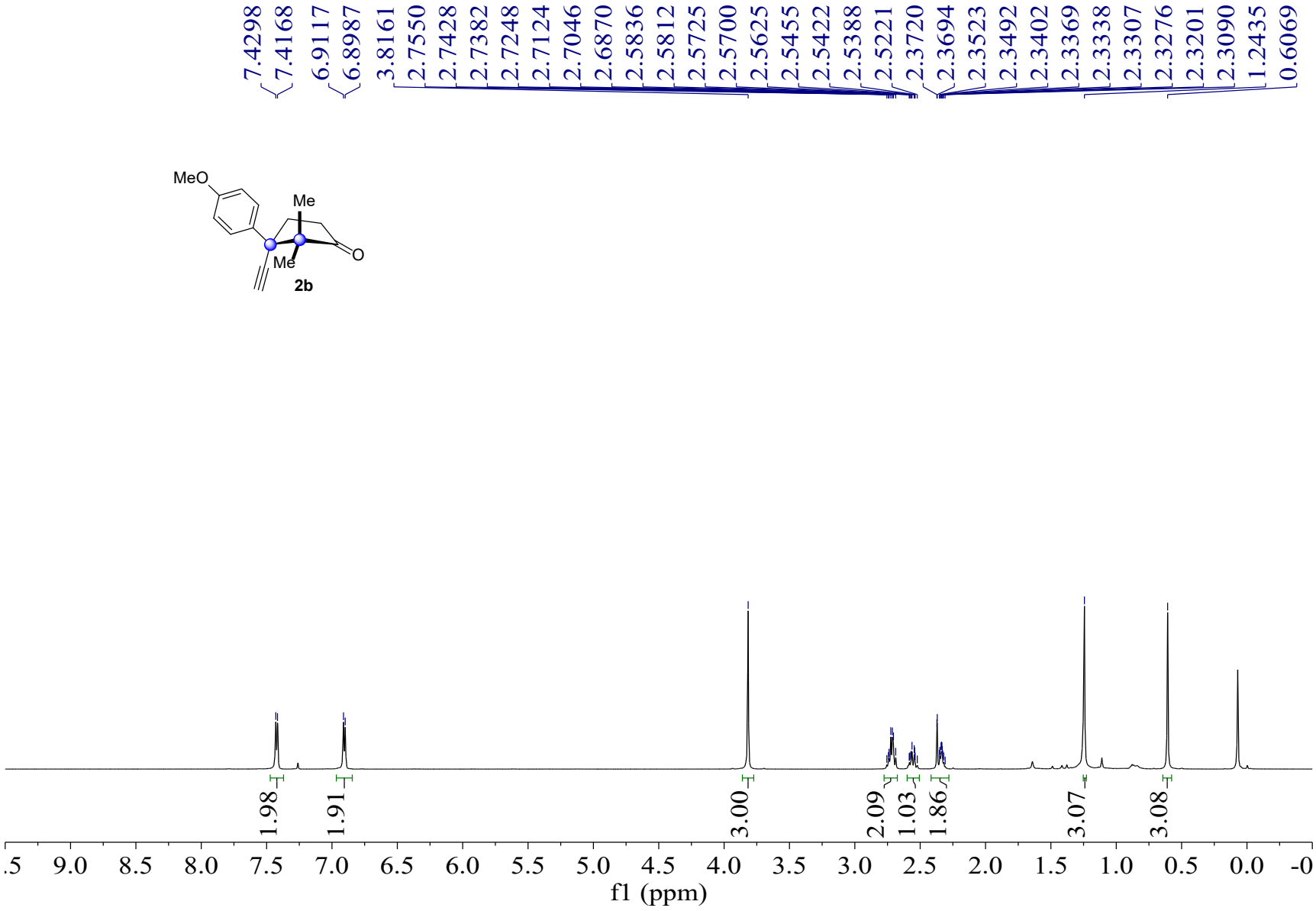
10. NMR Spectra



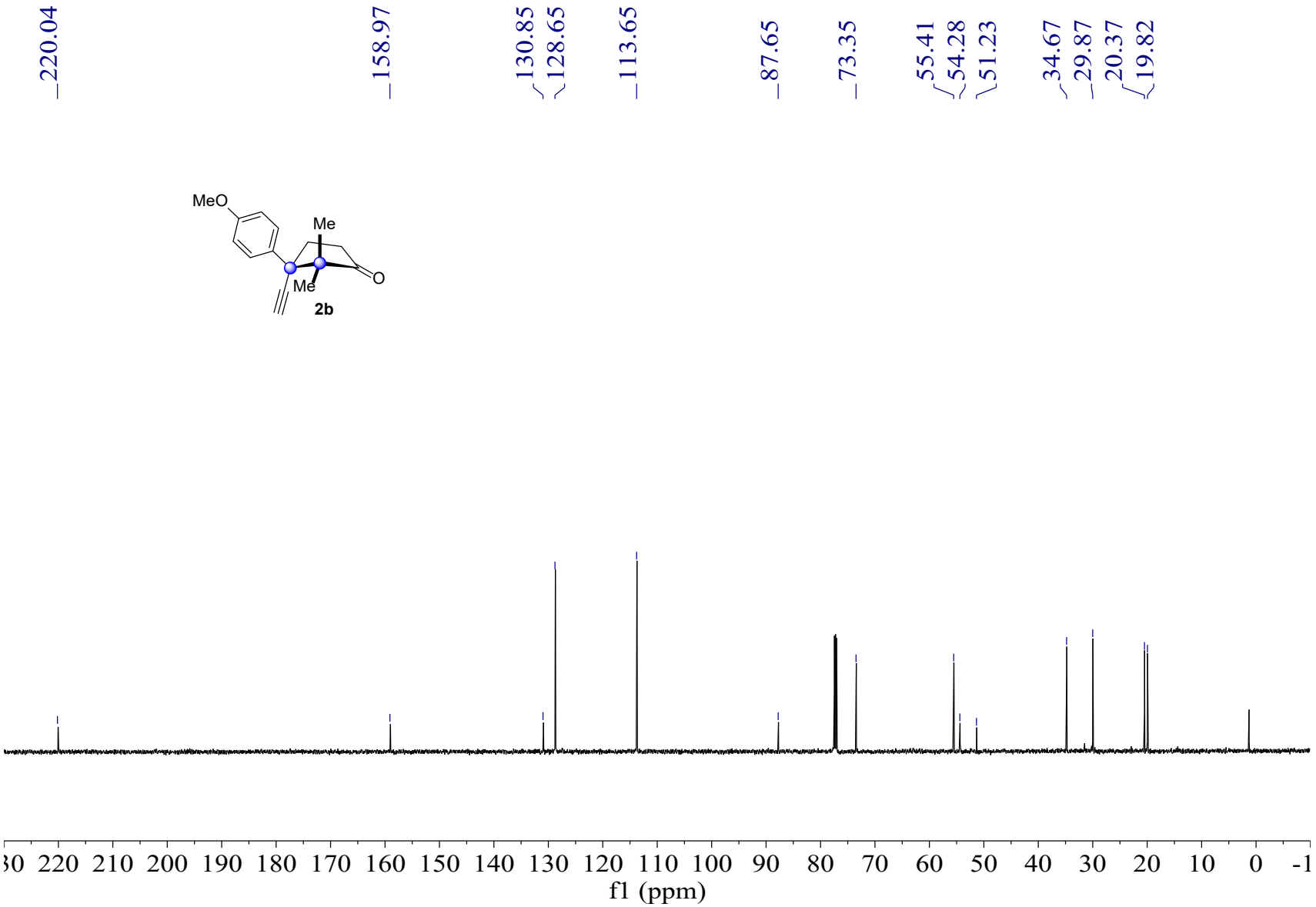
^{1}H NMR spectrum of compound **2a**



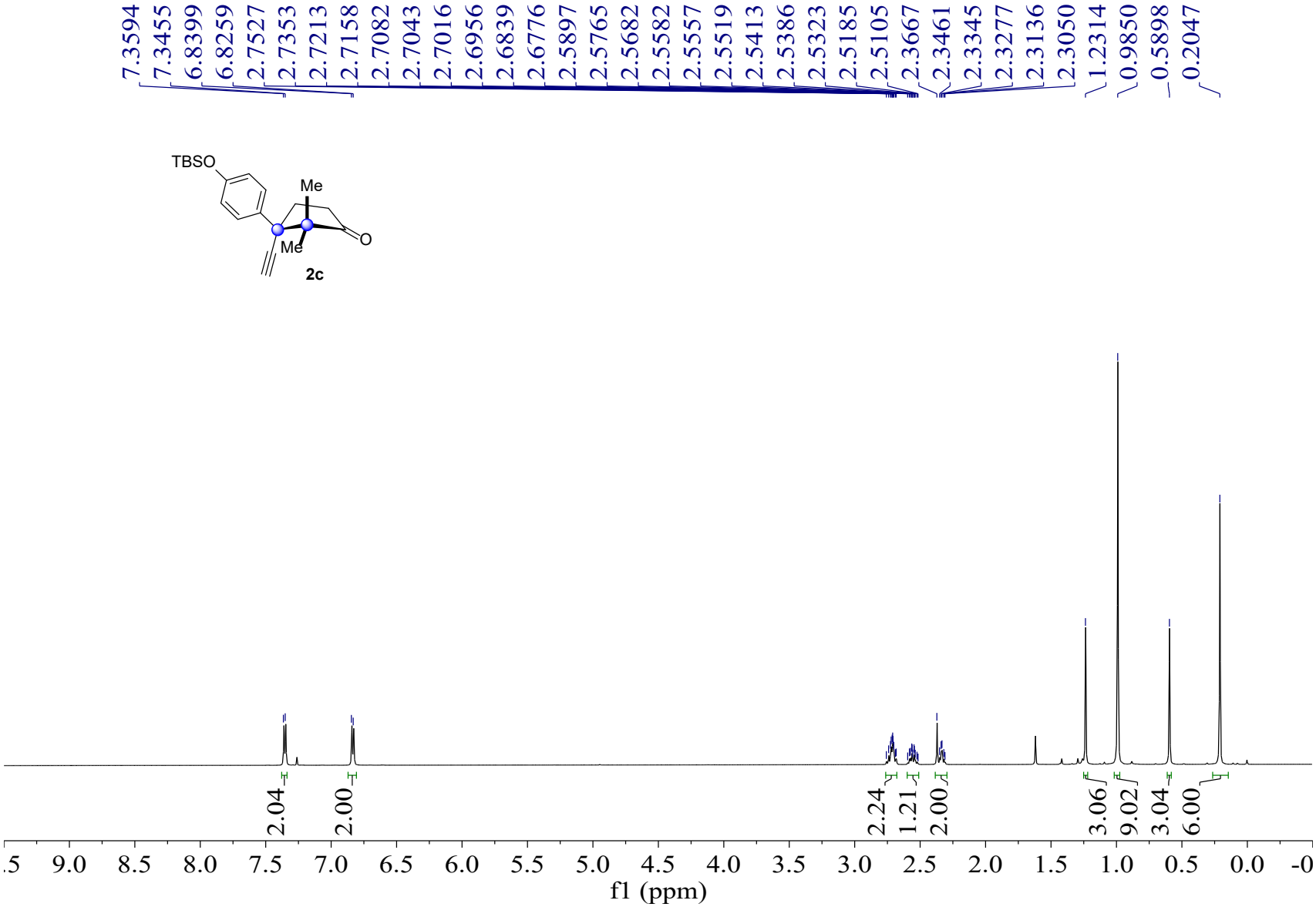
^{13}C NMR spectrum of compound **2a**



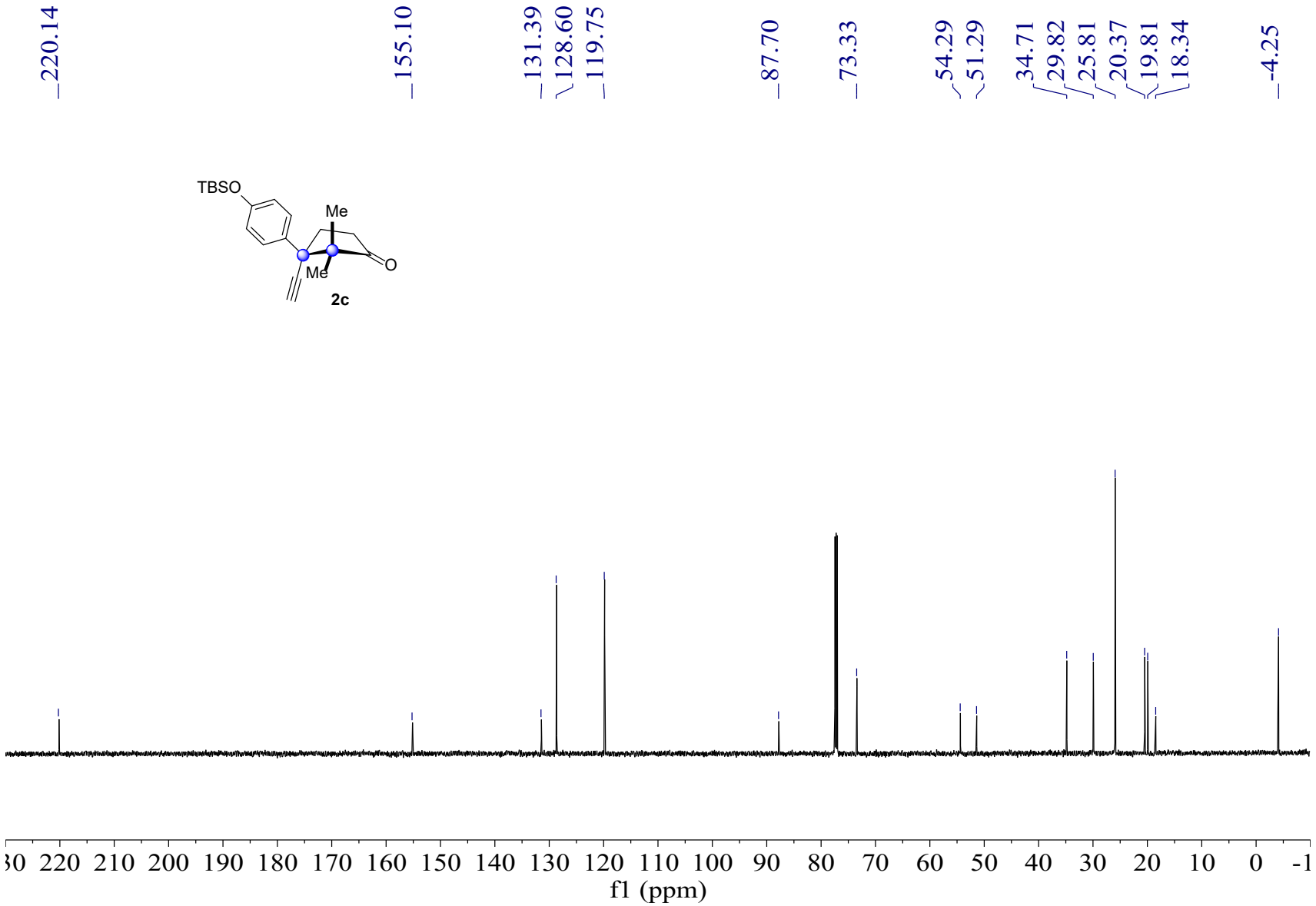
^{1}H NMR spectrum of compound **2b**



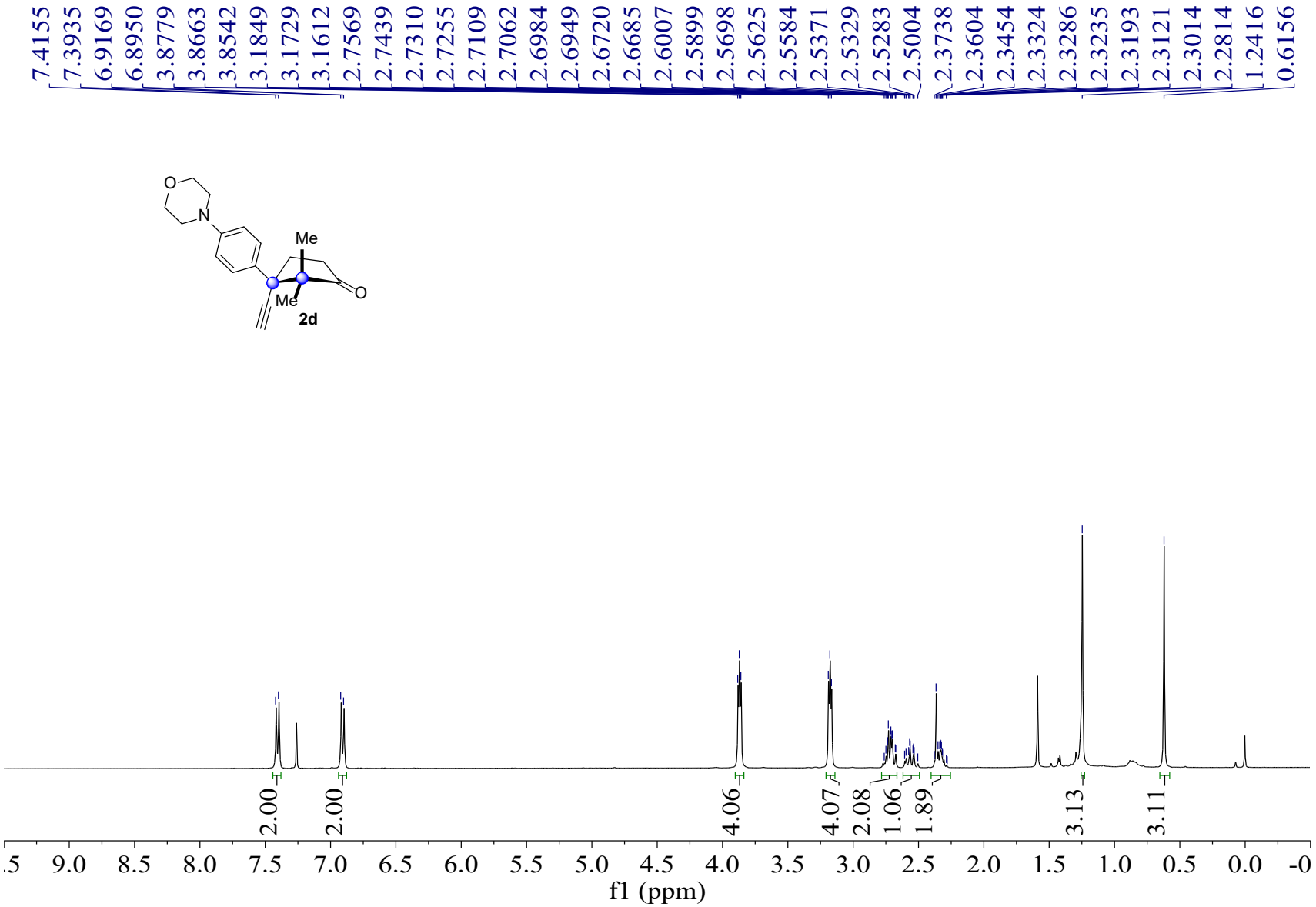
^{13}C NMR spectrum of compound **2b**



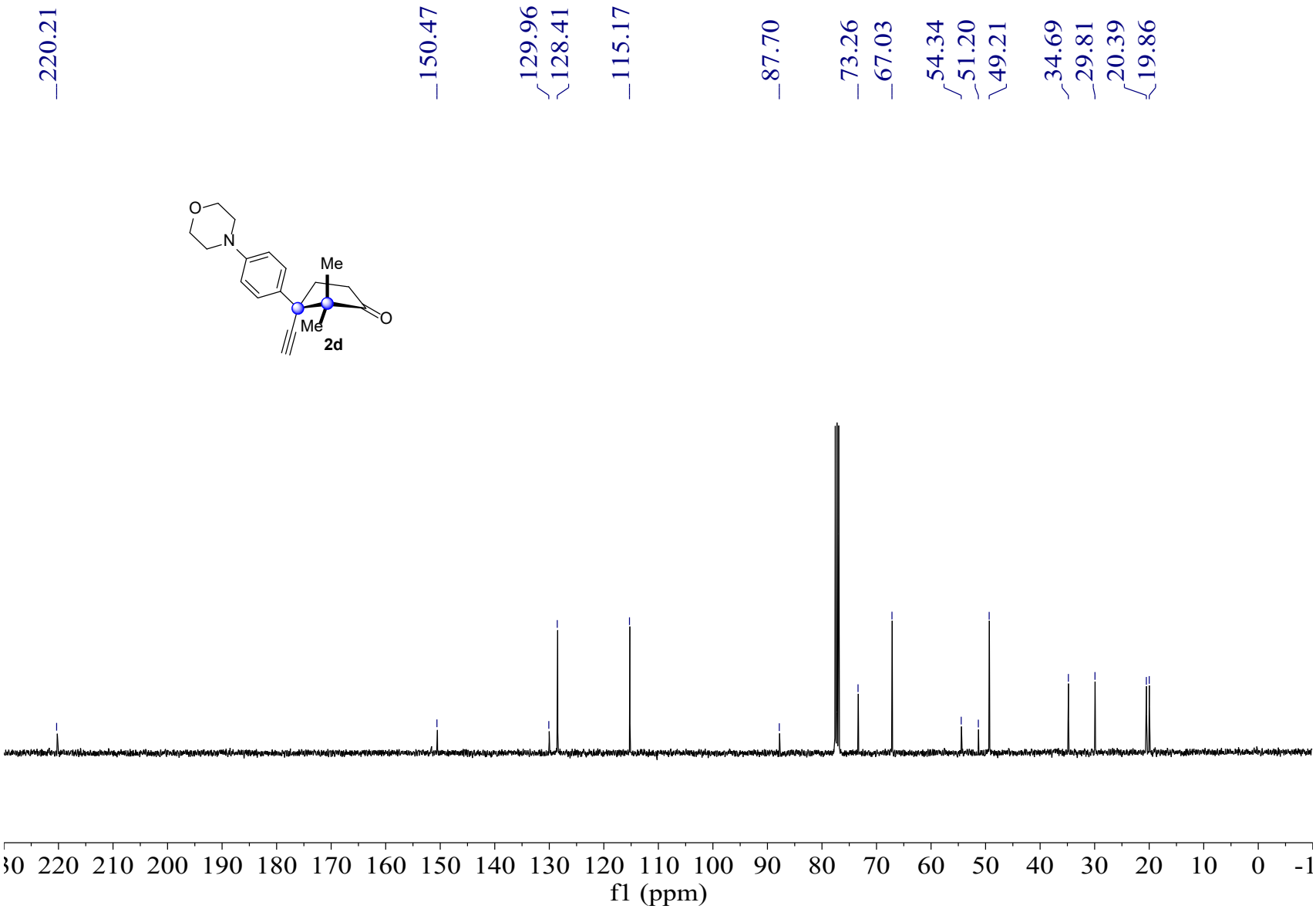
^{1}H NMR spectrum of compound **2c**



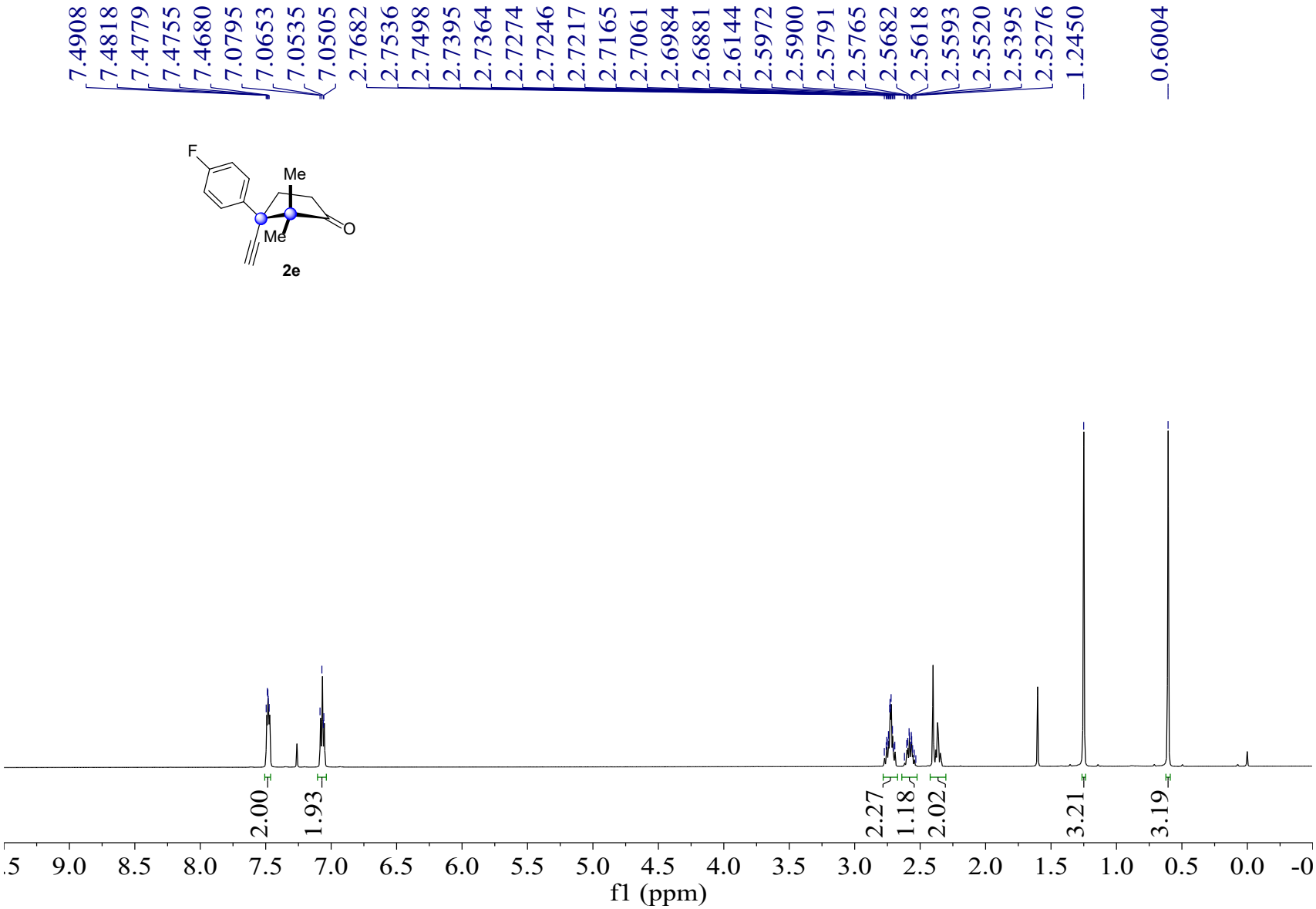
^{13}C NMR spectrum of compound **2c**



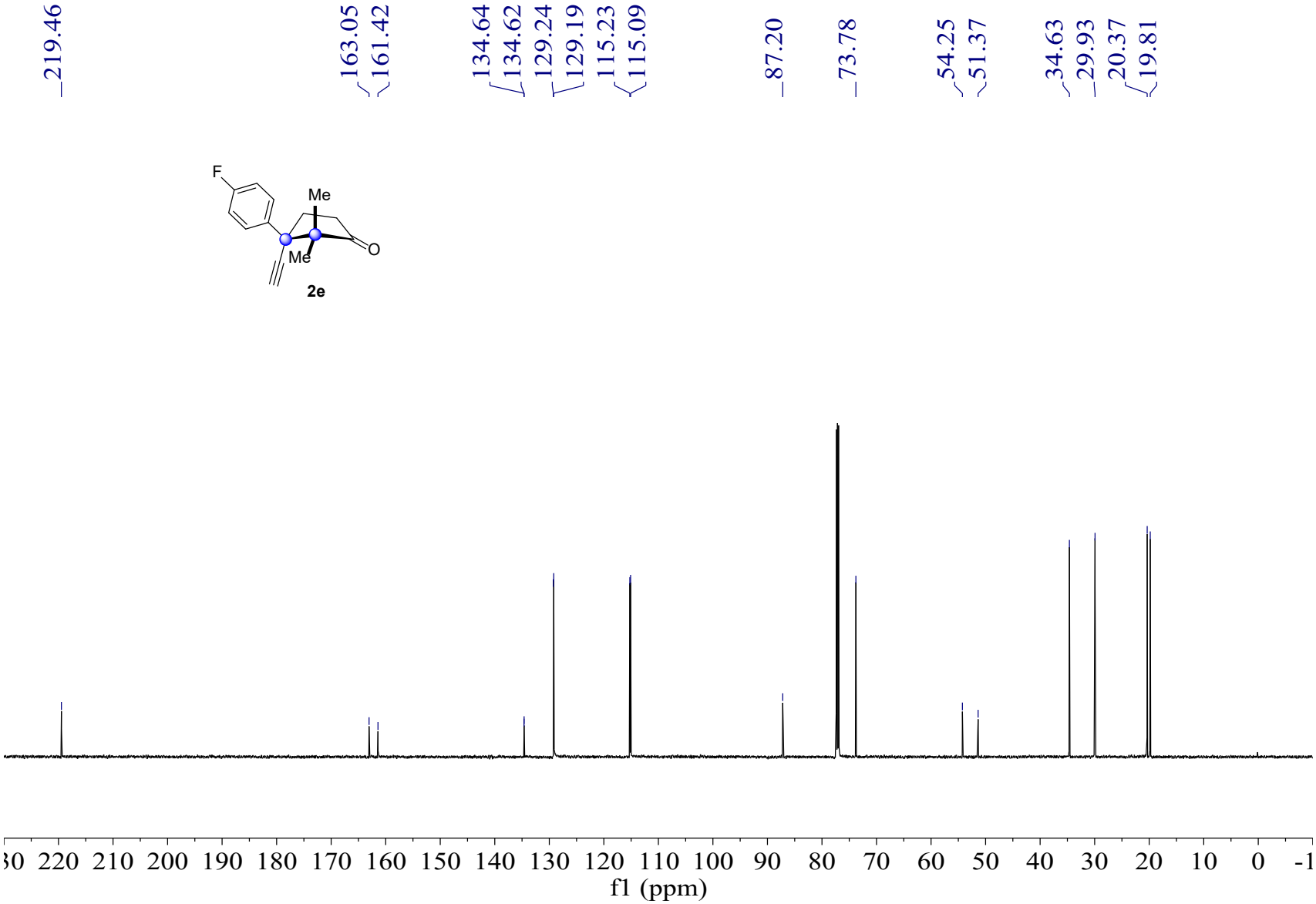
^{1}H NMR spectrum of compound **2d**



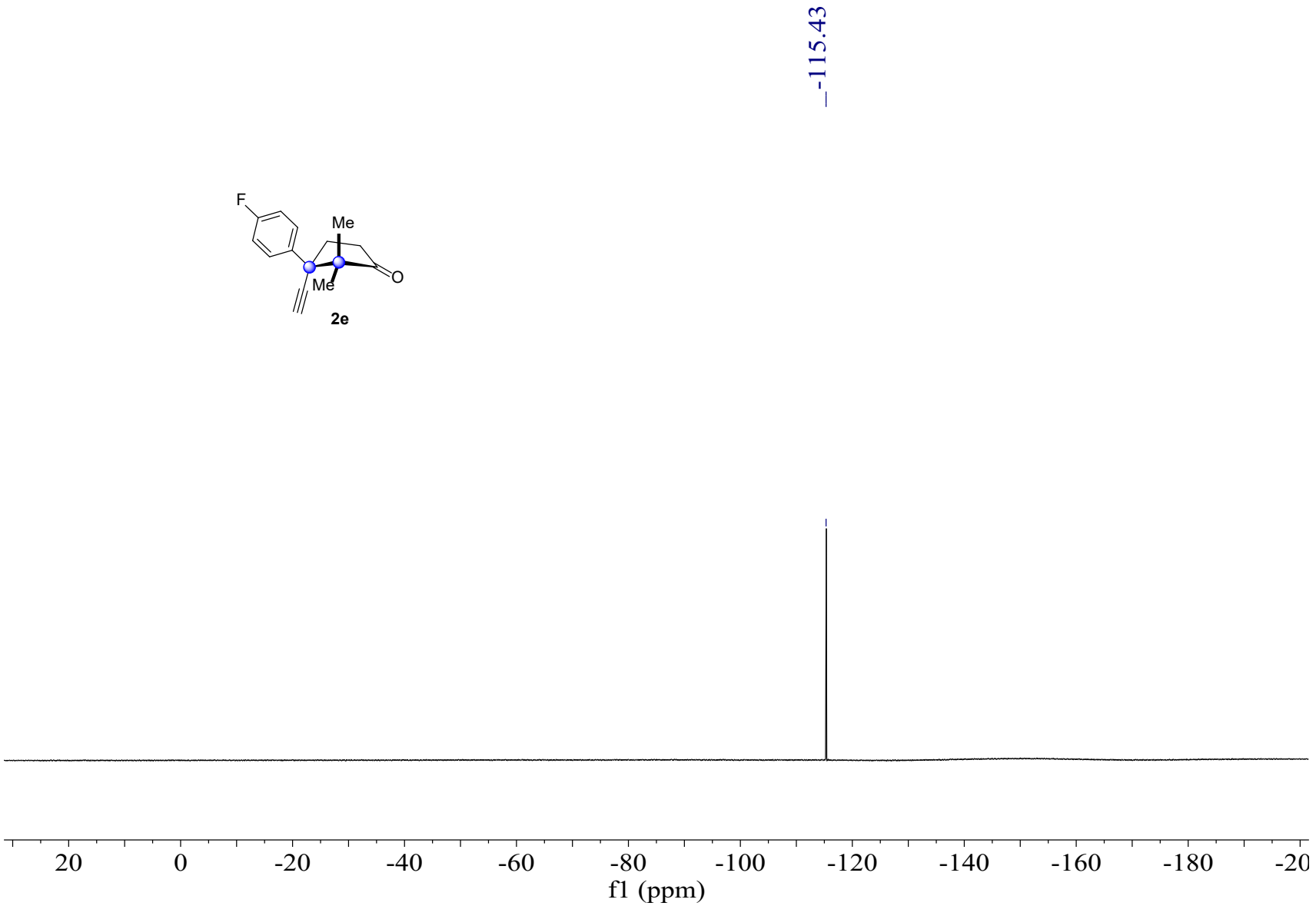
^{13}C NMR spectrum of compound **2d**



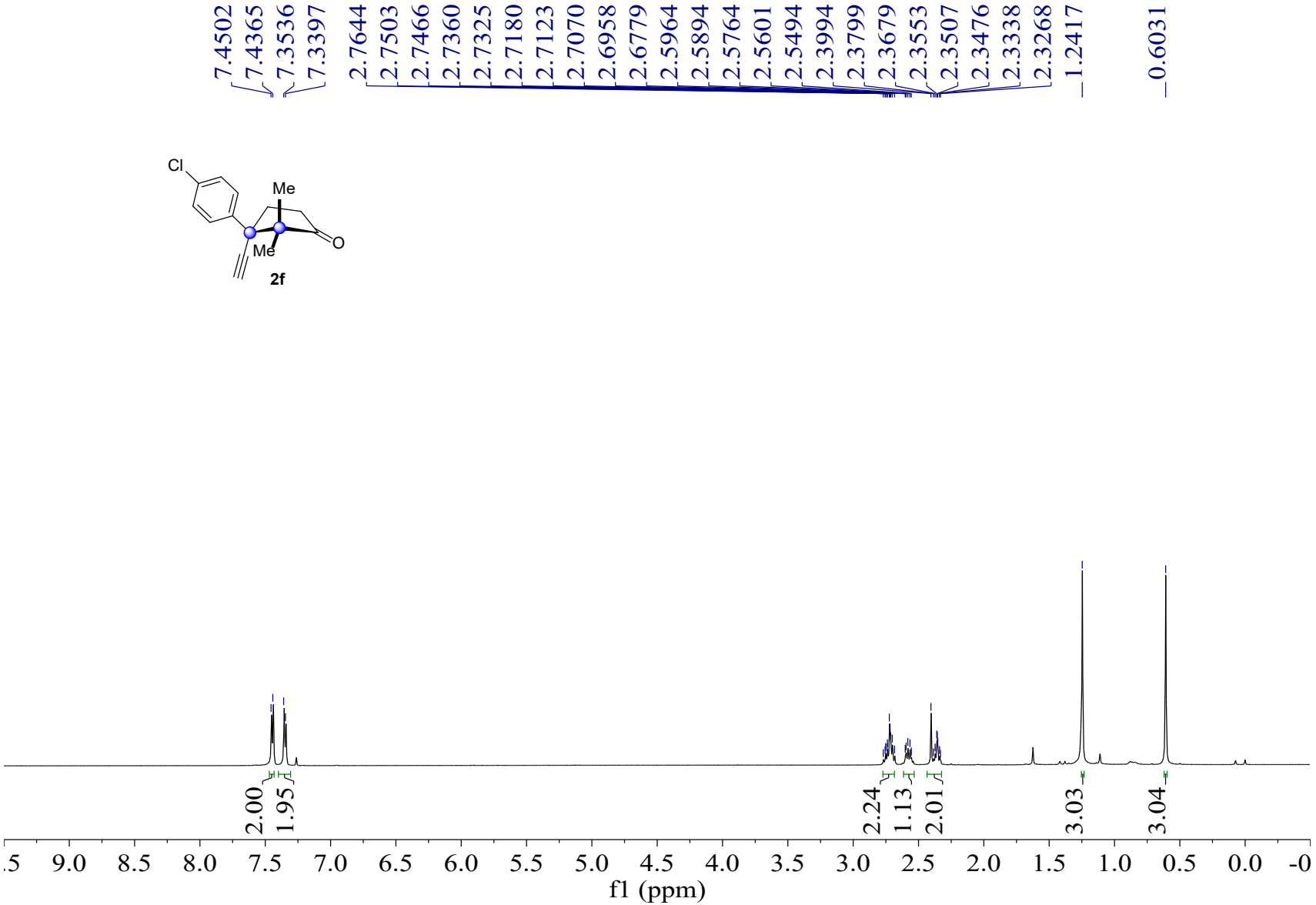
^{1}H NMR spectrum of compound **2e**



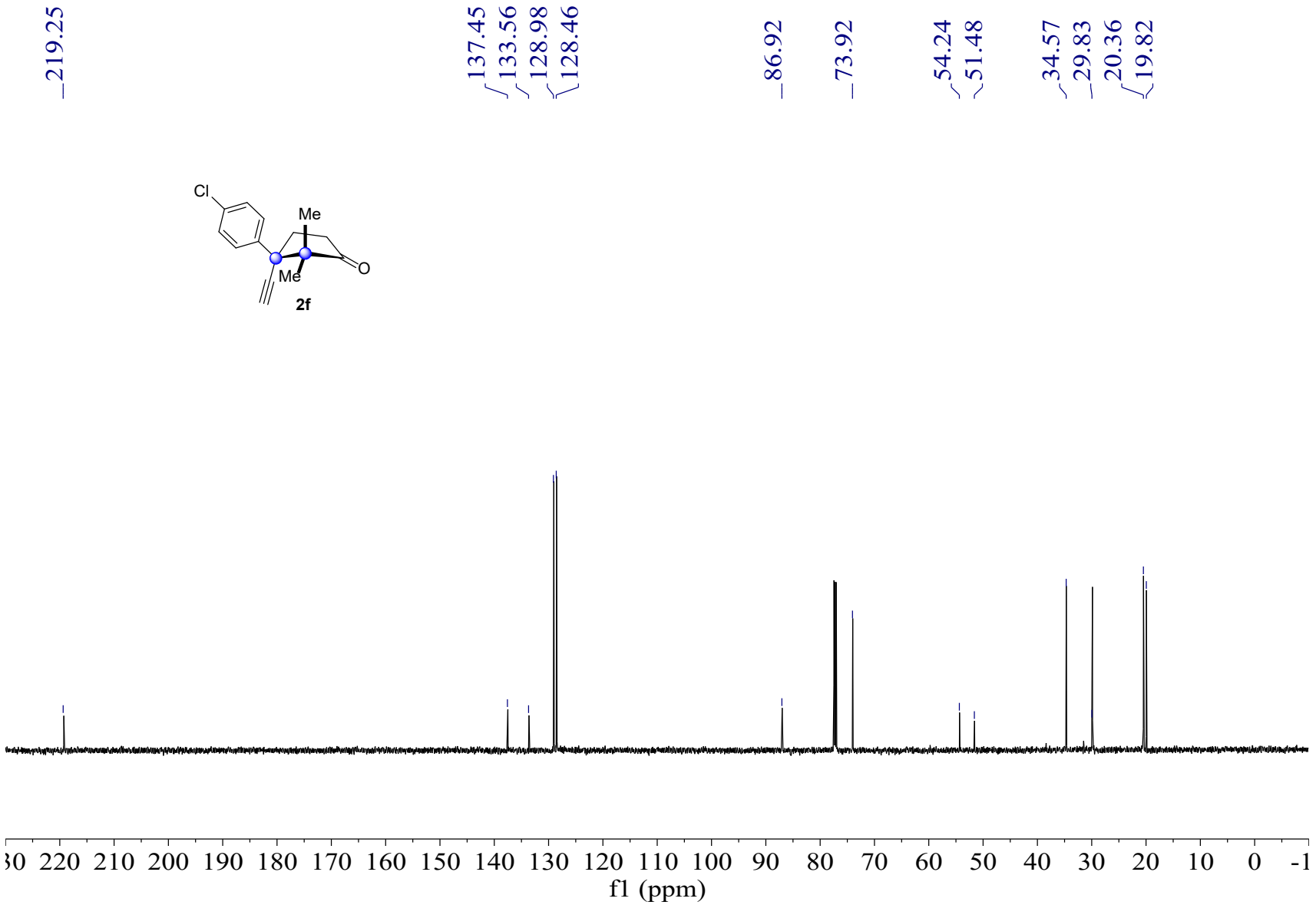
^{13}C NMR spectrum of compound **2e**



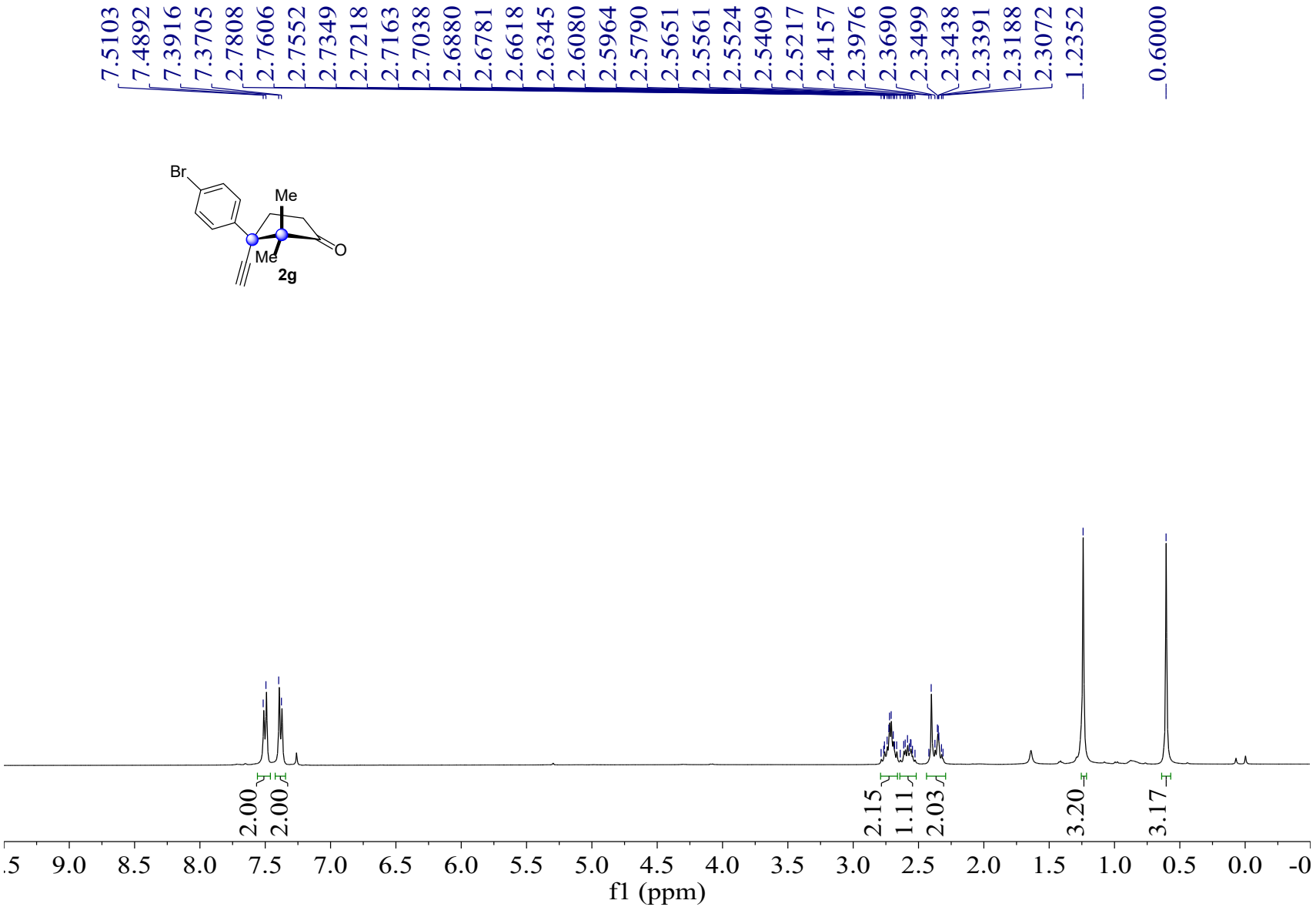
^{19}F NMR spectrum of compound **2e**



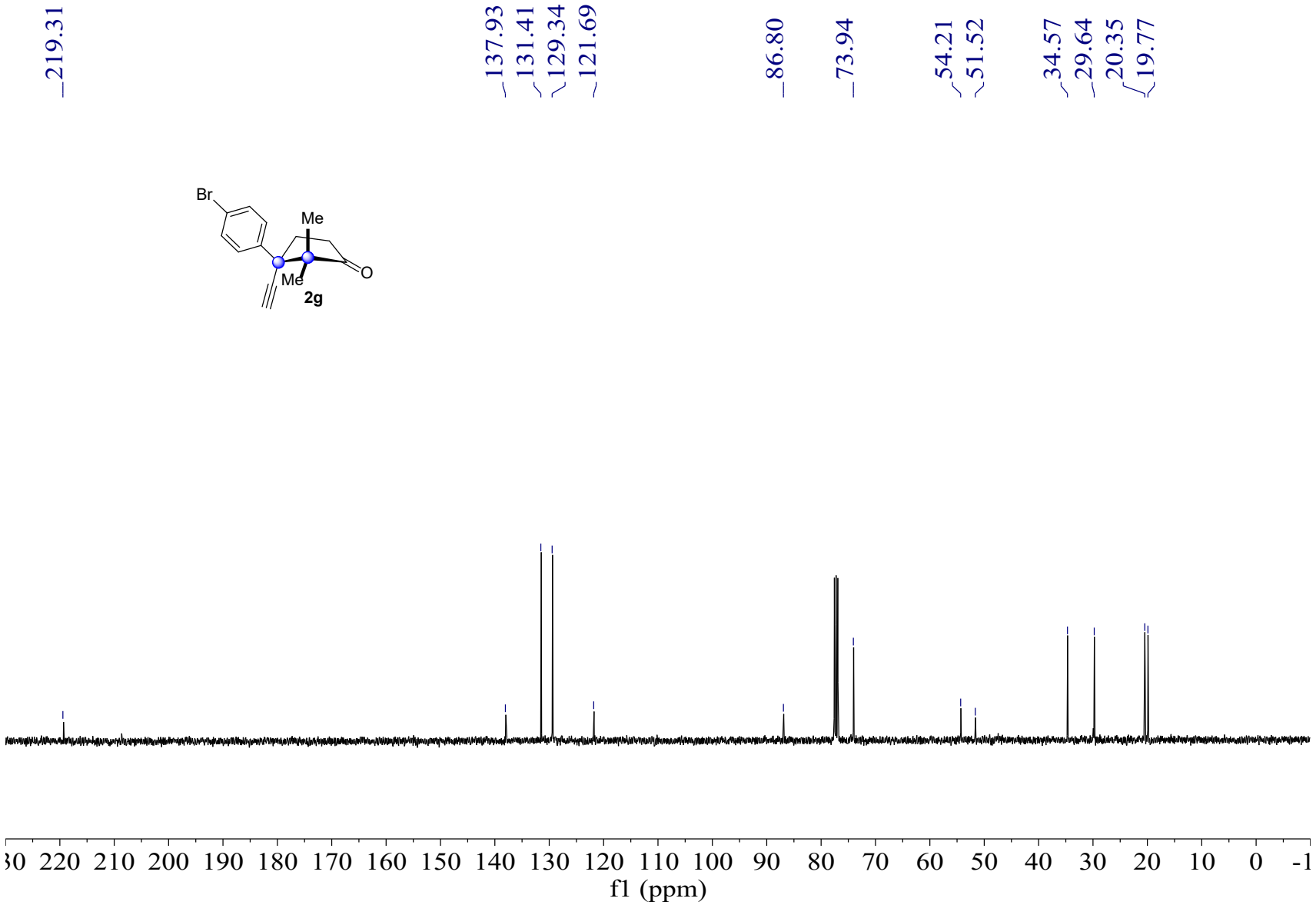
^{1}H NMR spectrum of compound **2f**



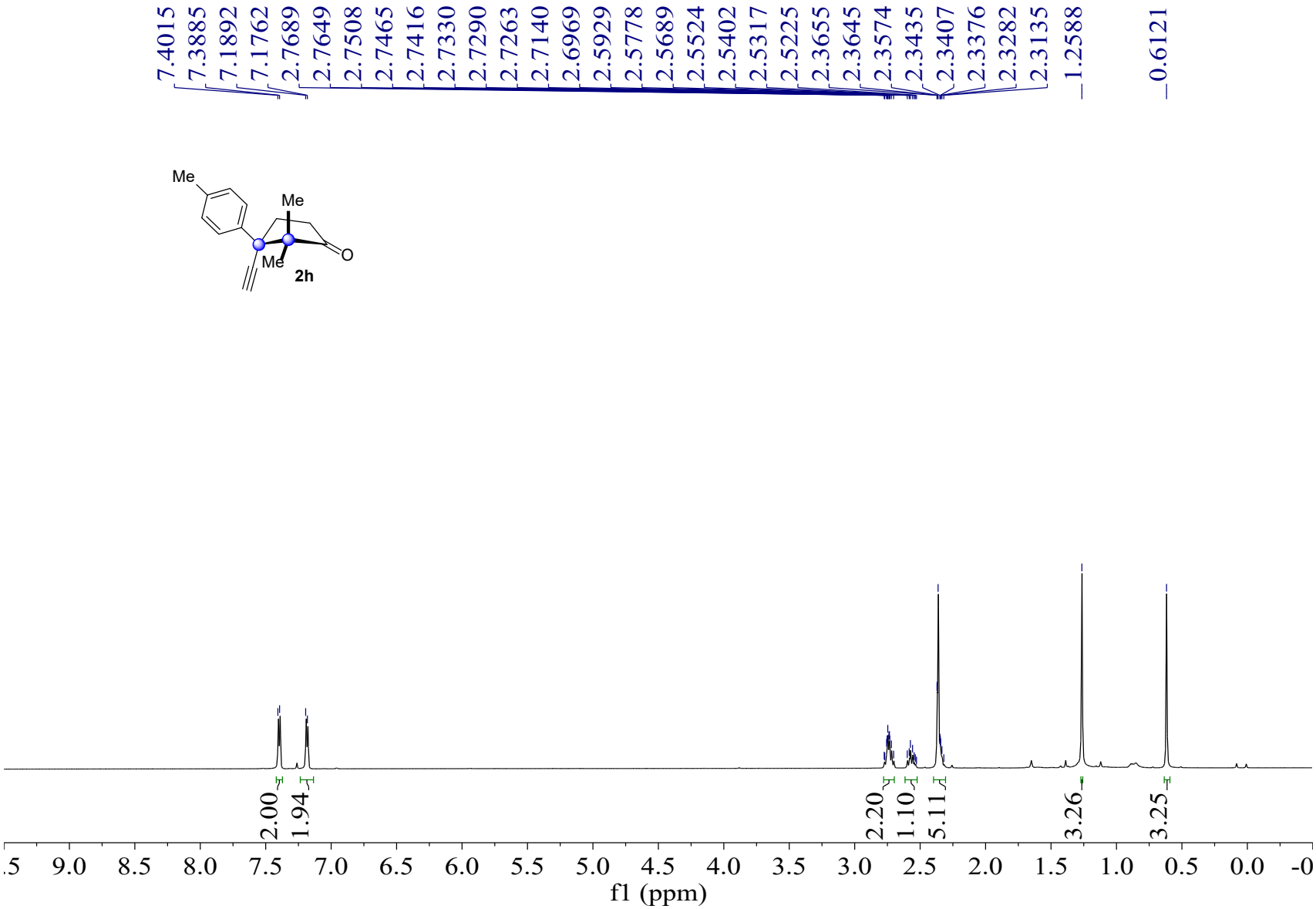
^{13}C NMR spectrum of compound **2f**



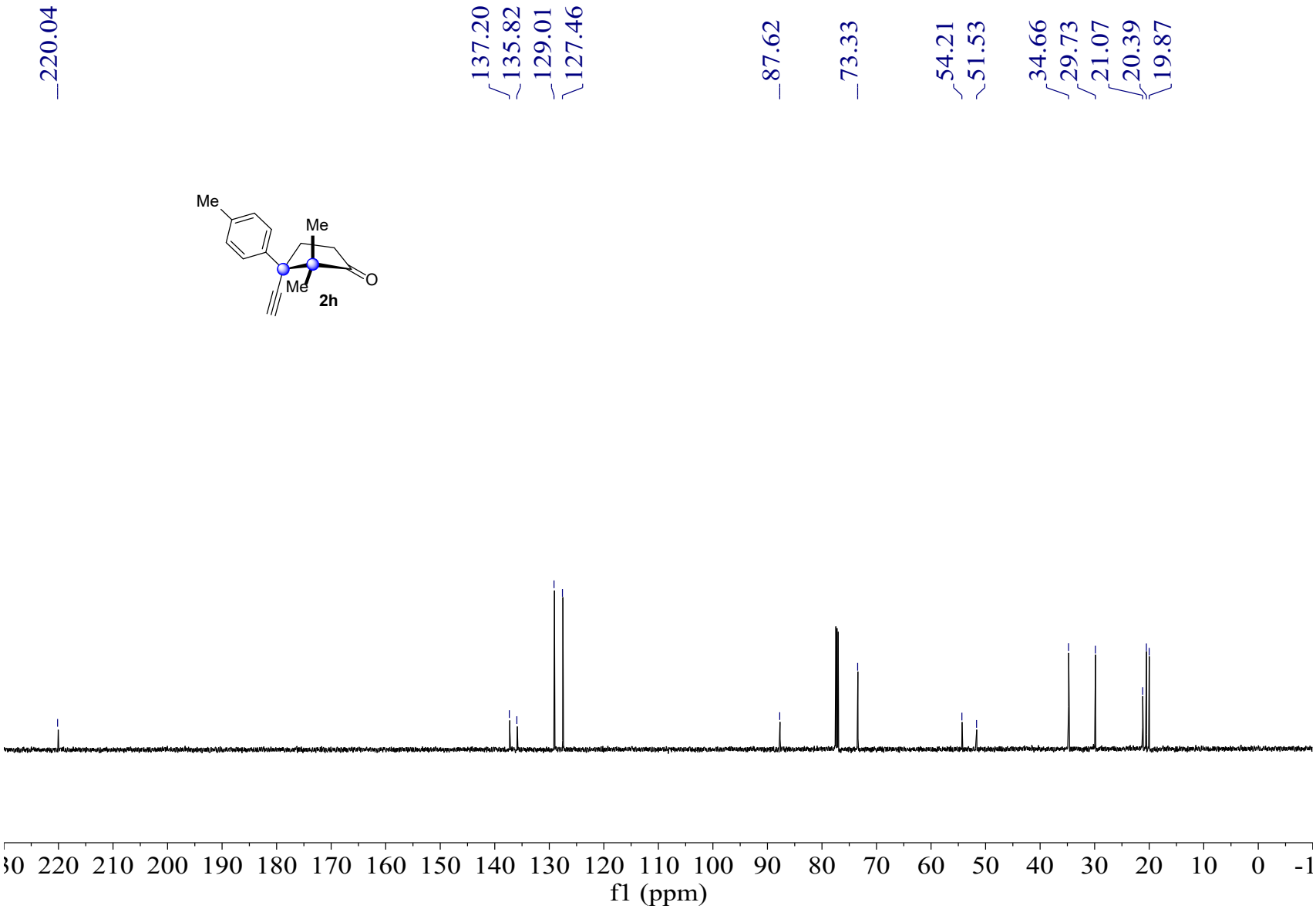
^{1}H NMR spectrum of compound **2g**



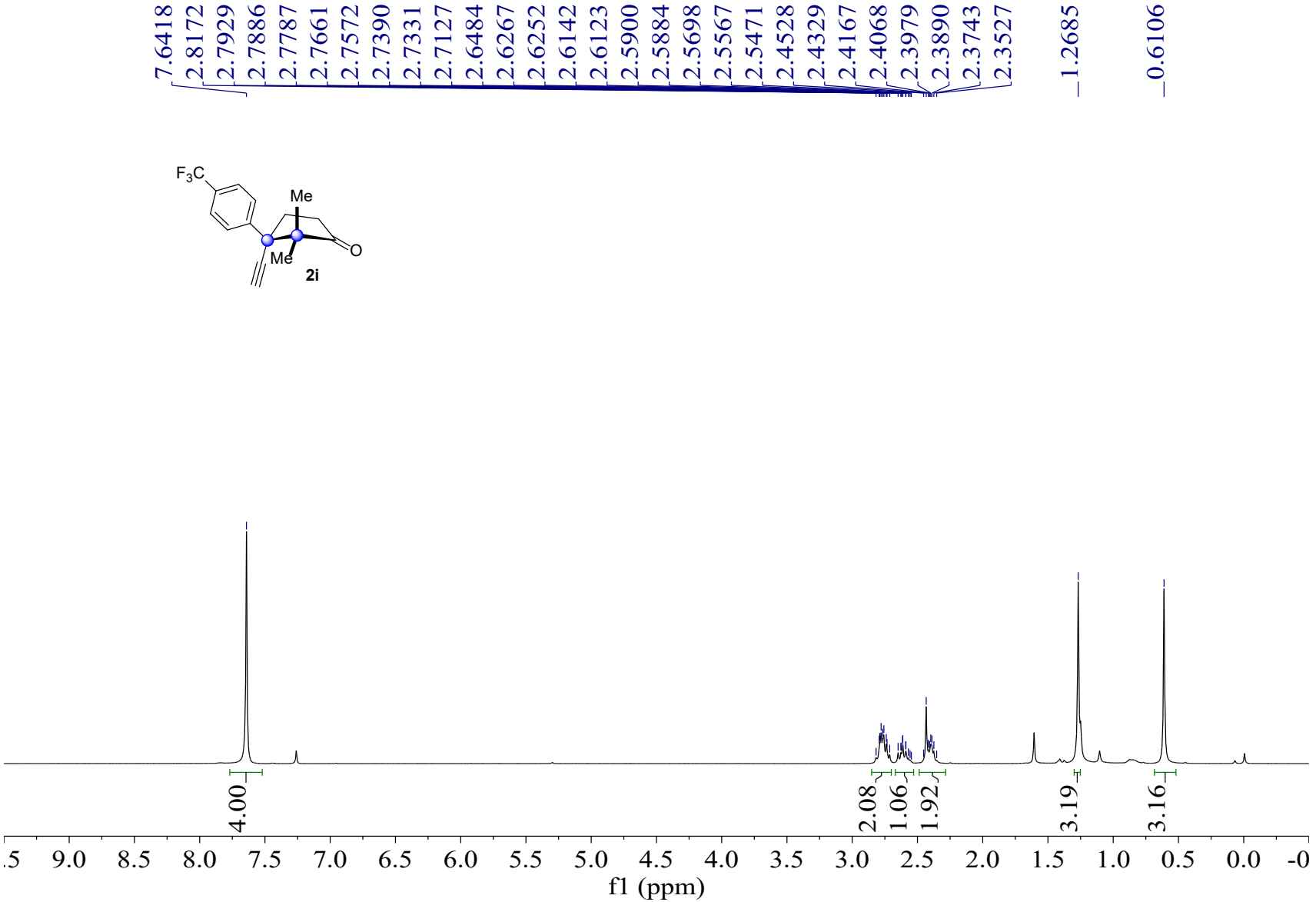
^{13}C NMR spectrum of compound **2g**



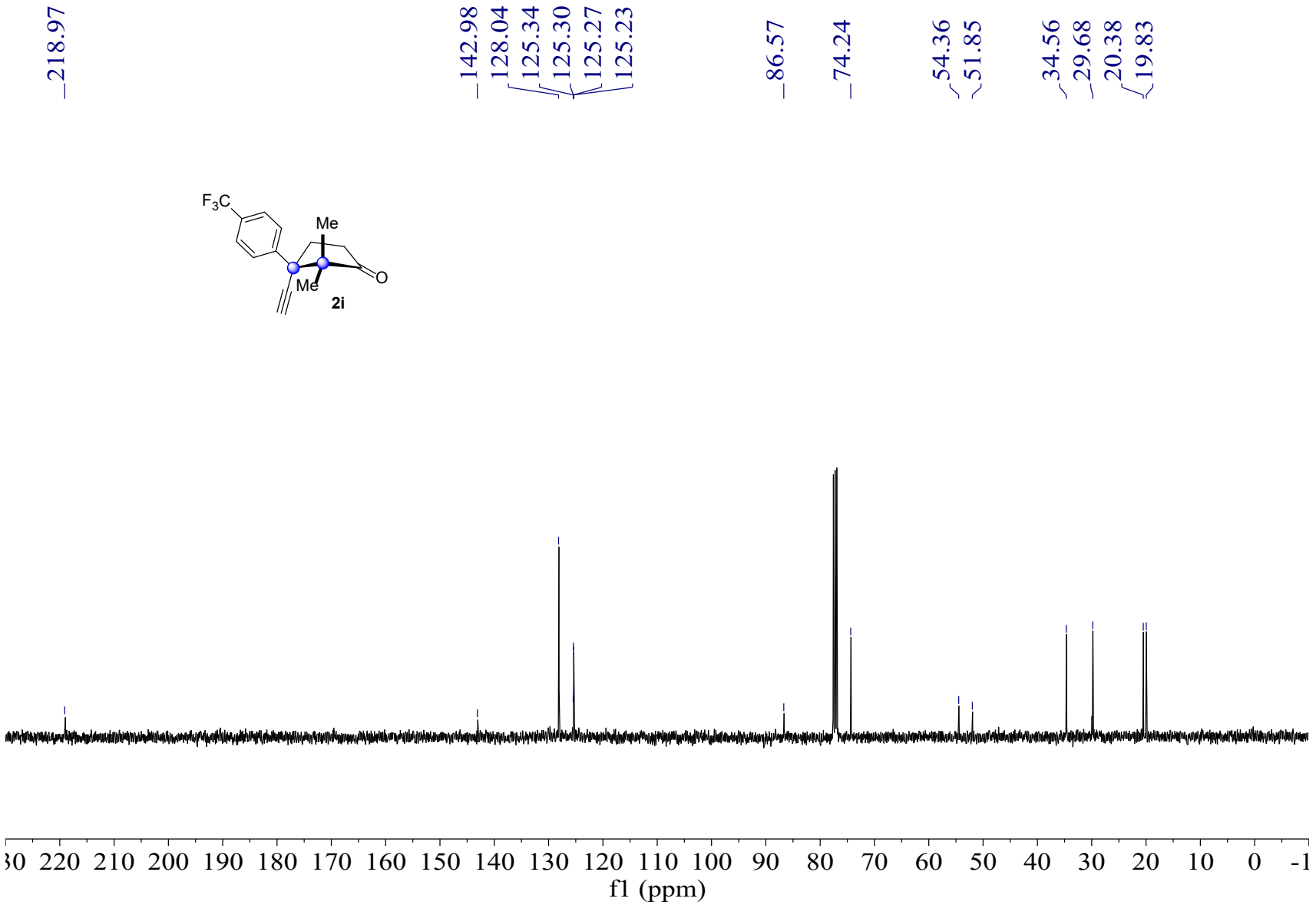
^{1}H NMR spectrum of compound **2h**



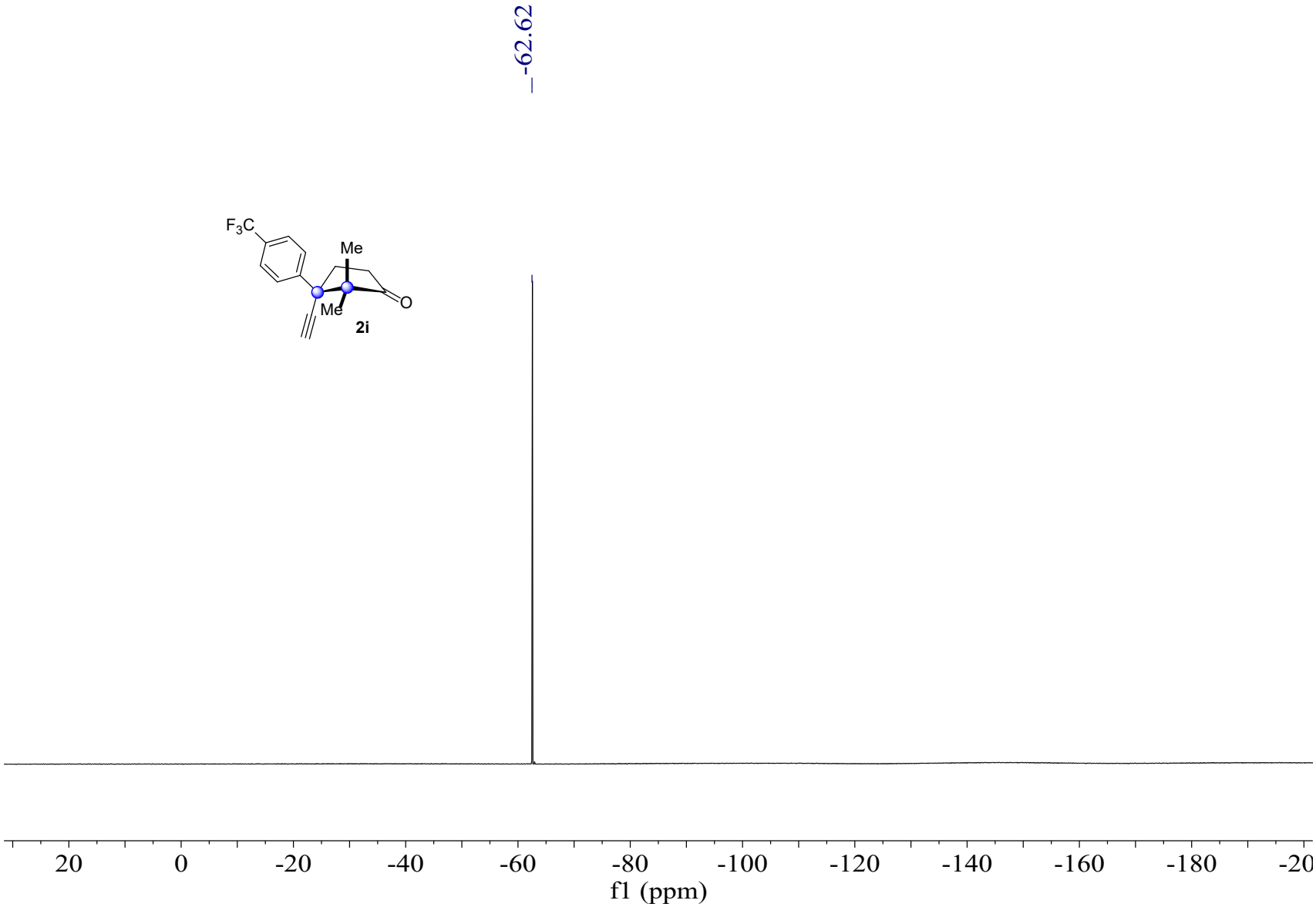
^{13}C NMR spectrum of compound **2h**



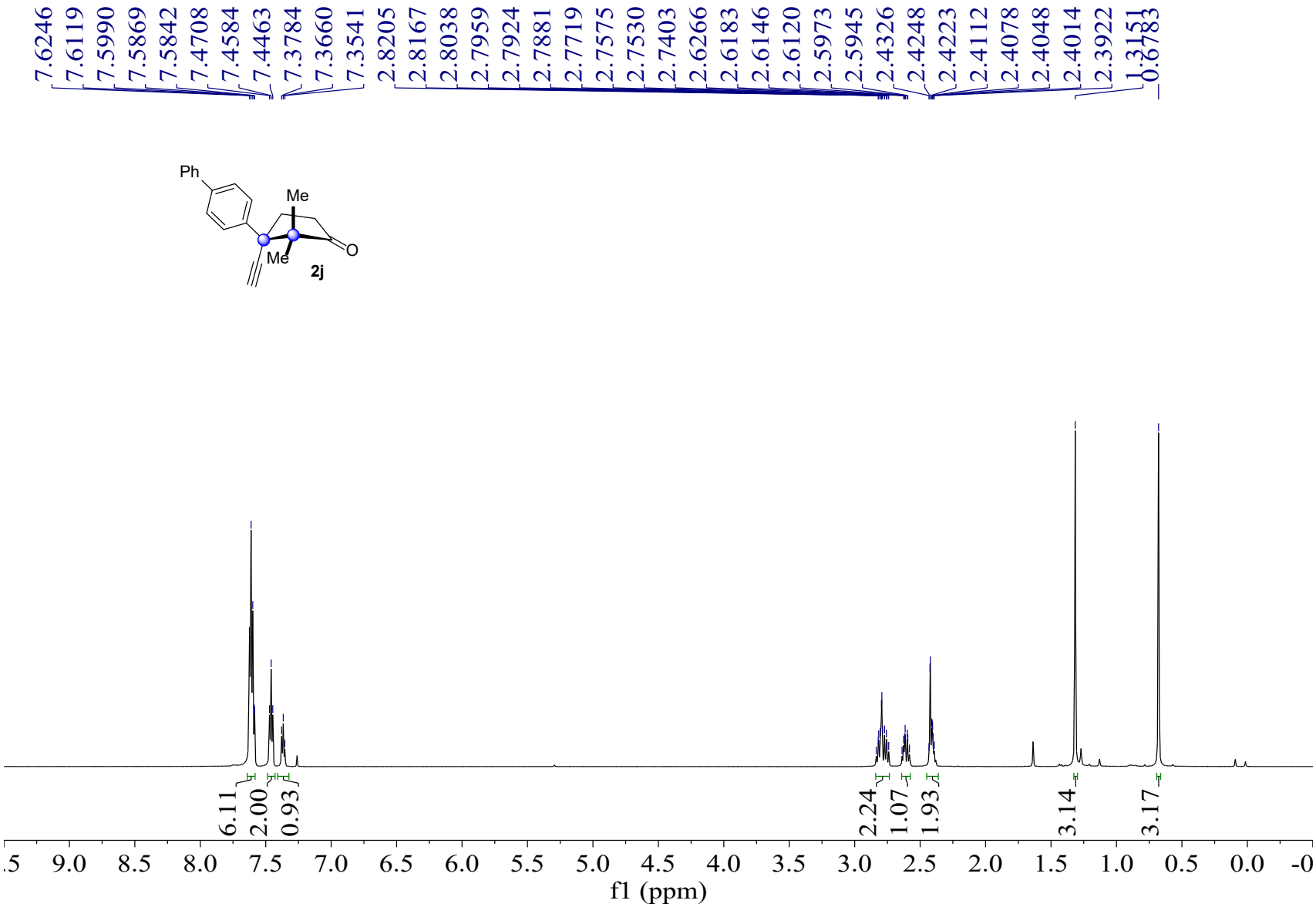
^{1}H NMR spectrum of compound **2i**



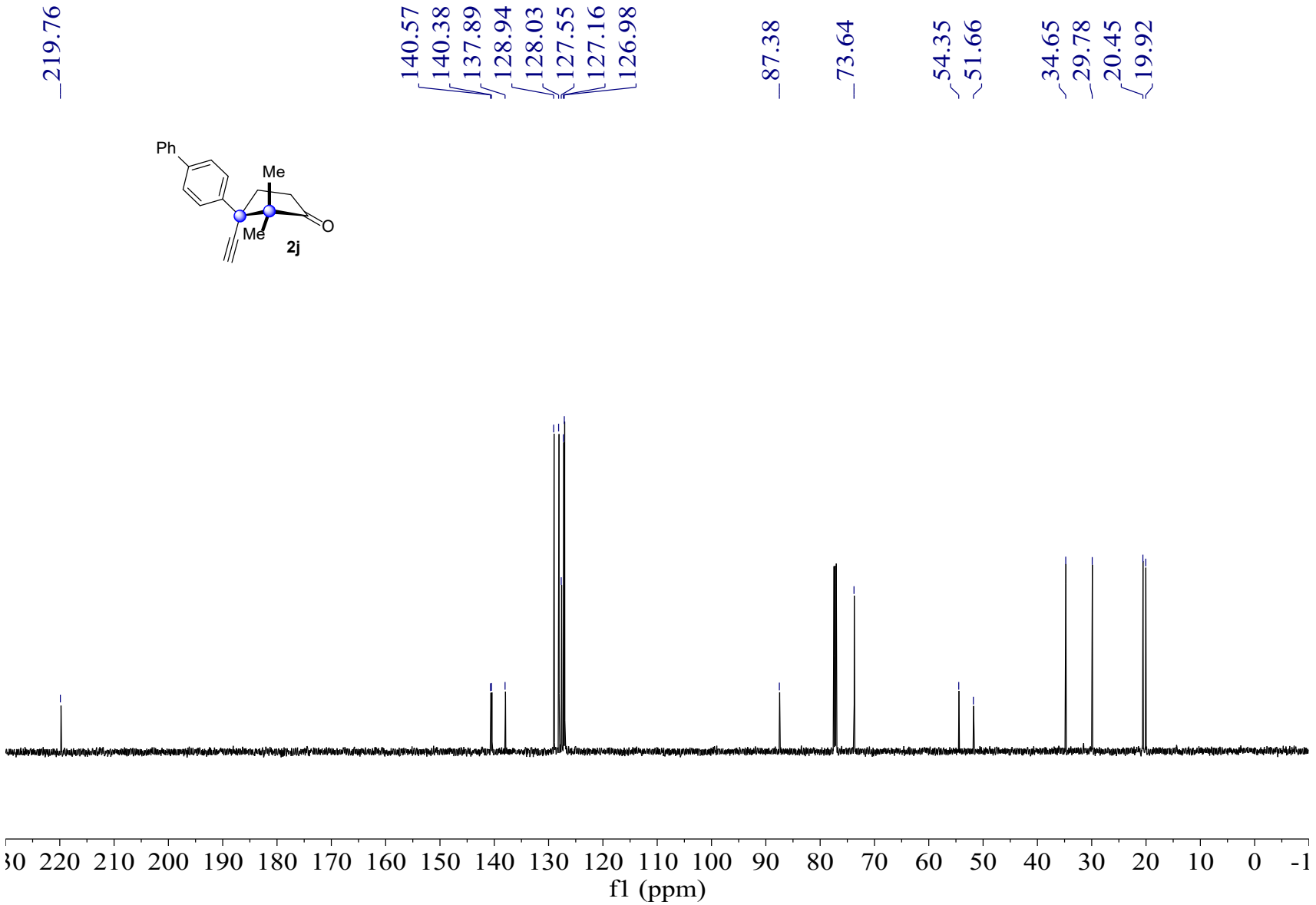
^{13}C NMR spectrum of compound **2i**



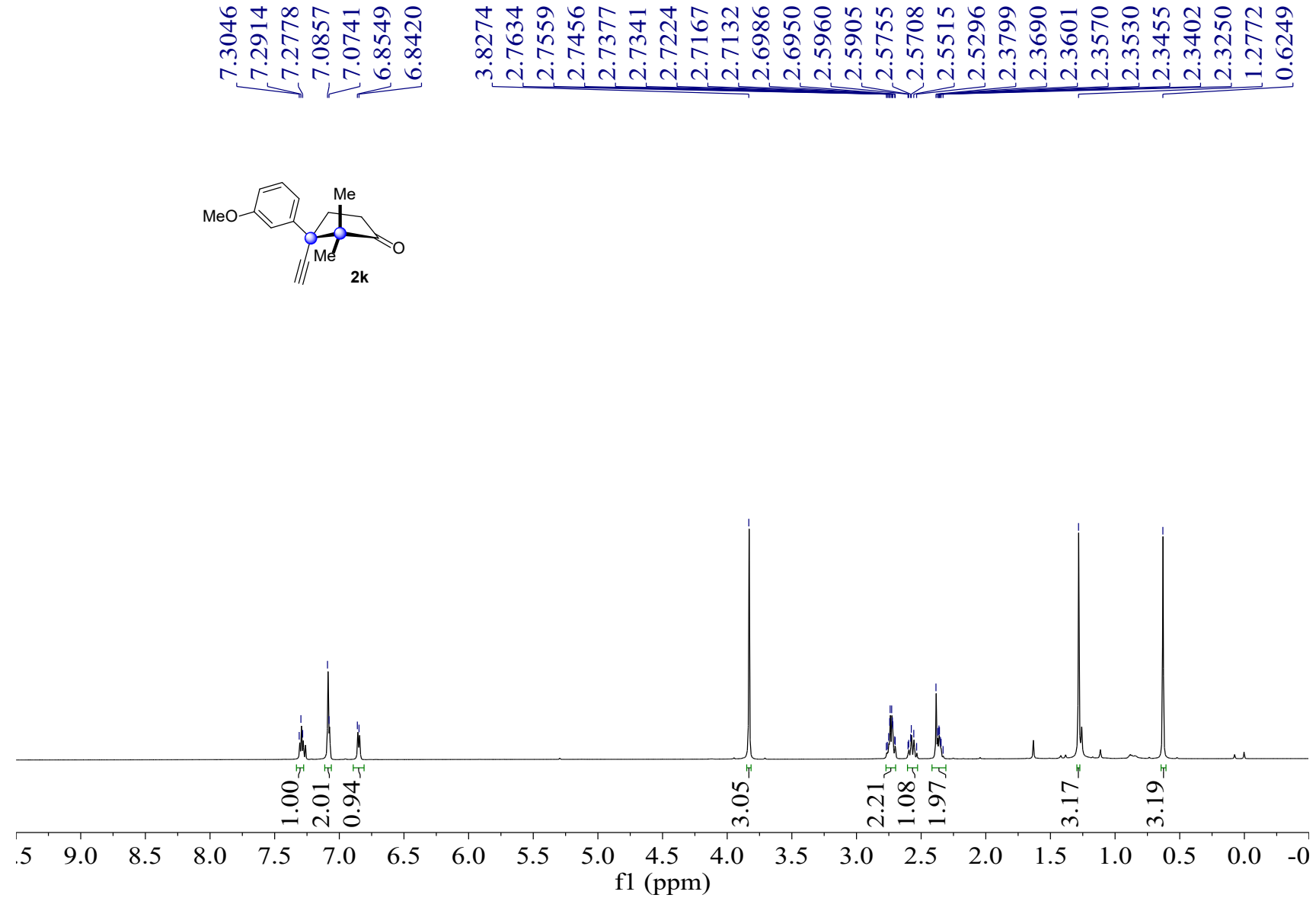
^{19}F NMR spectrum of compound **2i**



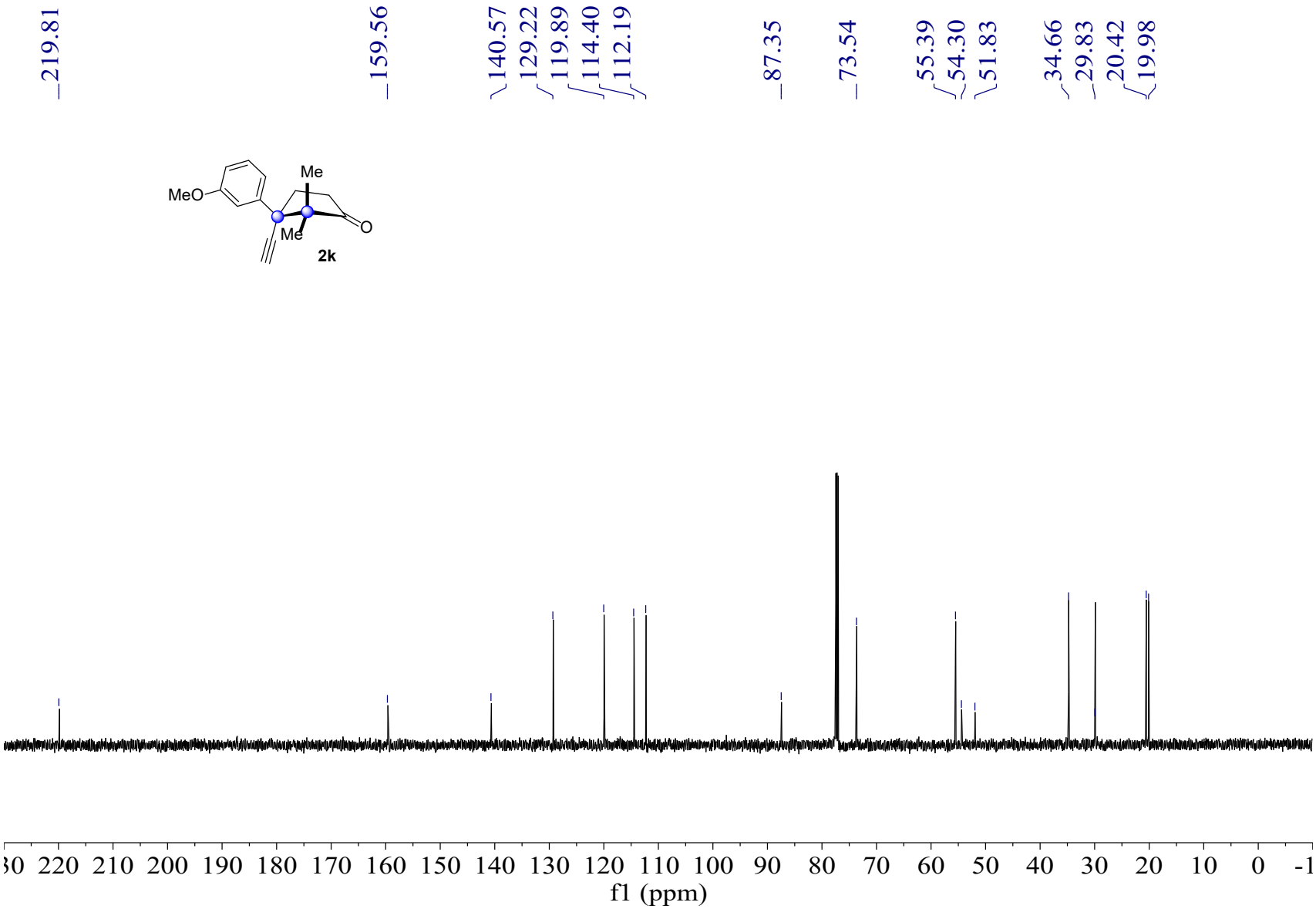
^{1}H NMR spectrum of compound **2j**



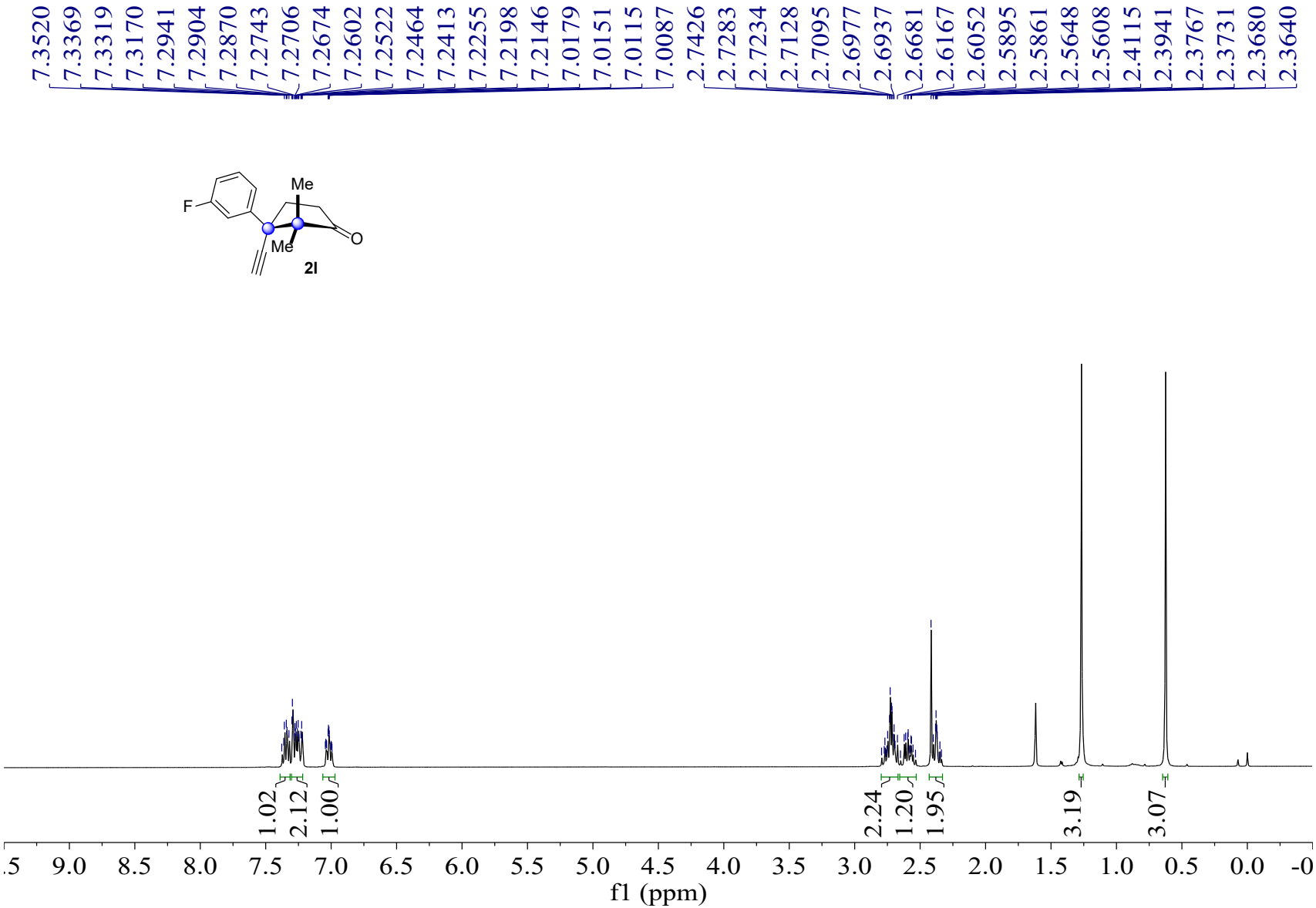
^{13}C NMR spectrum of compound **2j**



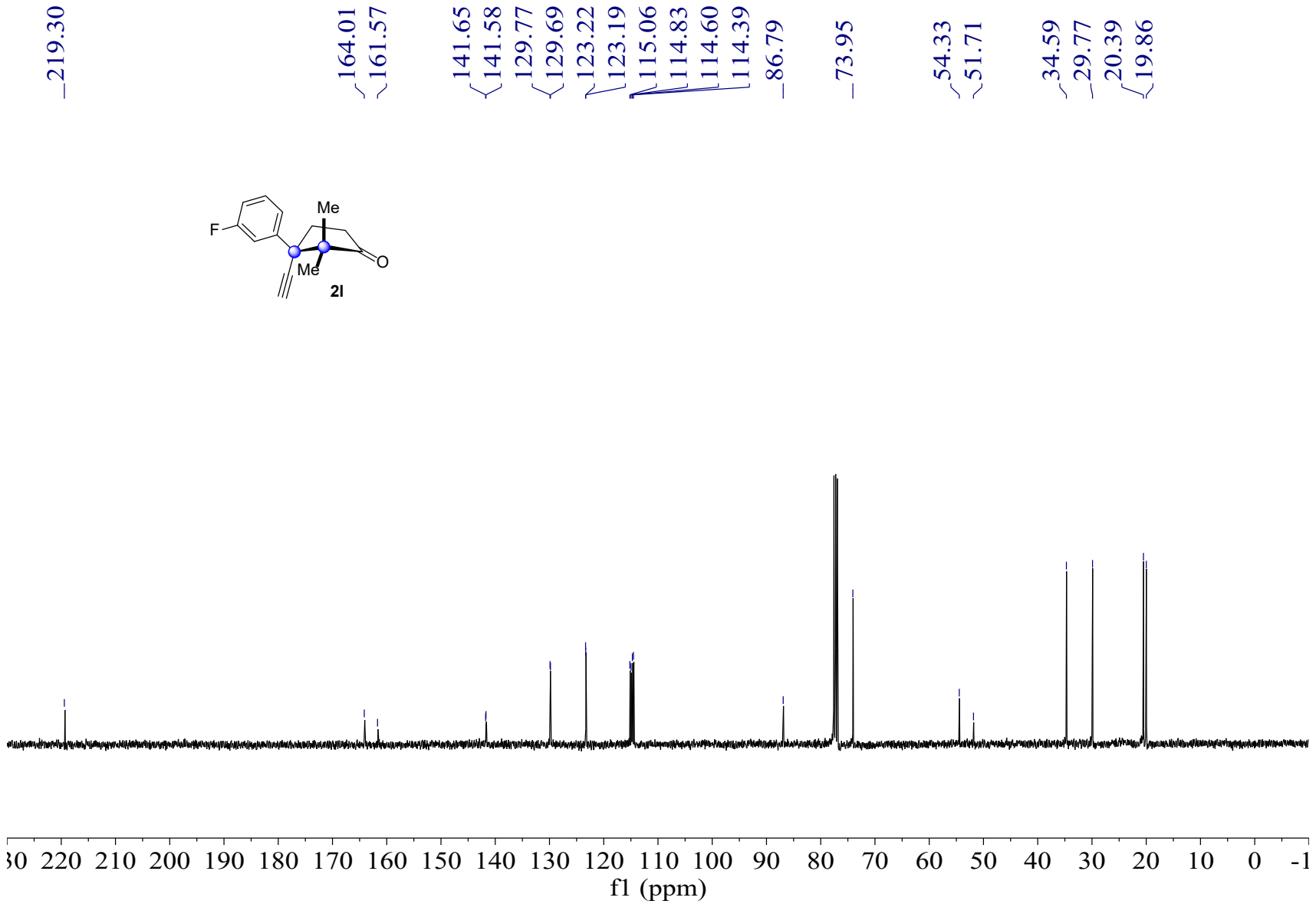
^{1}H NMR spectrum of compound **2k**



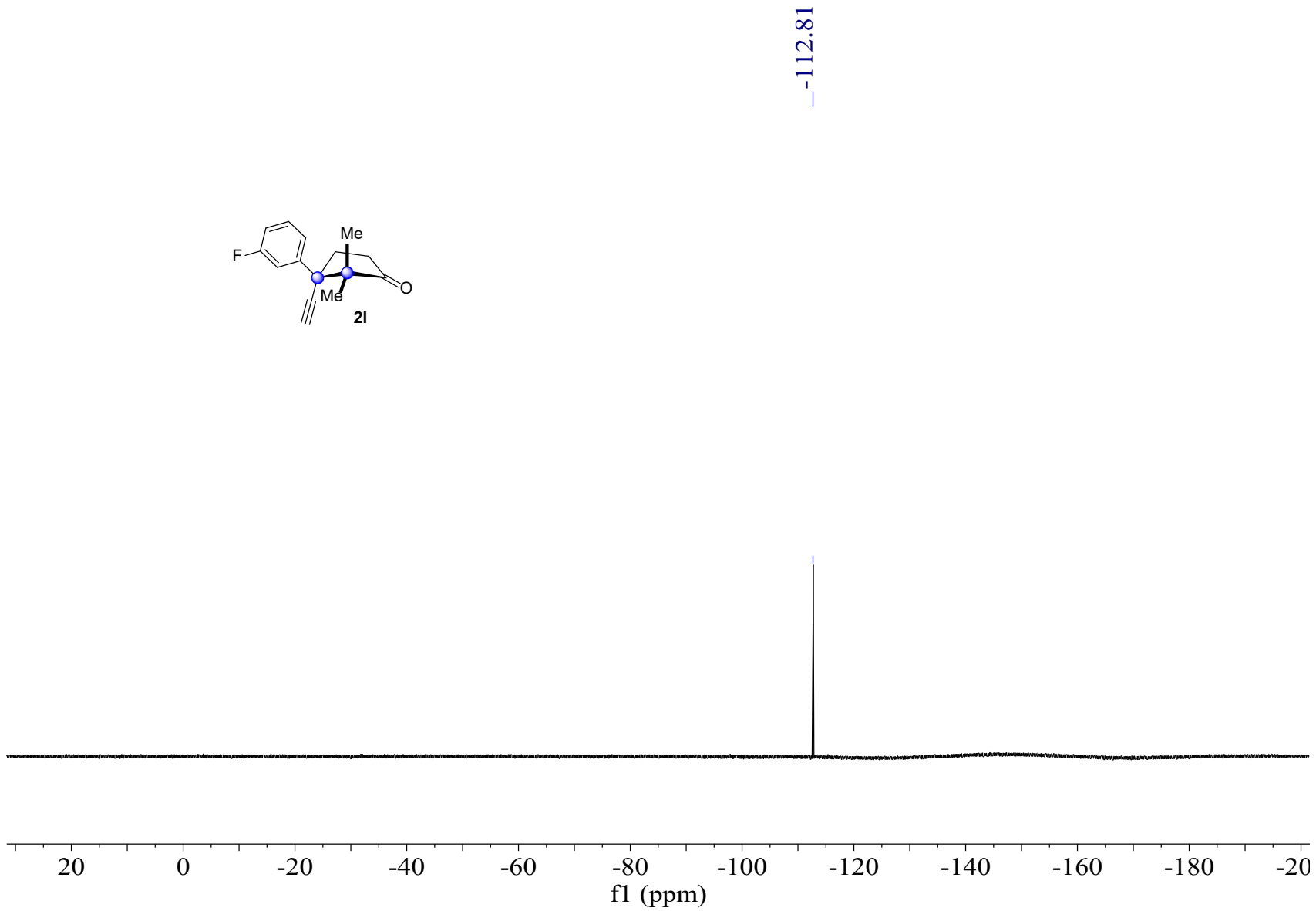
^{13}C NMR spectrum of compound **2k**



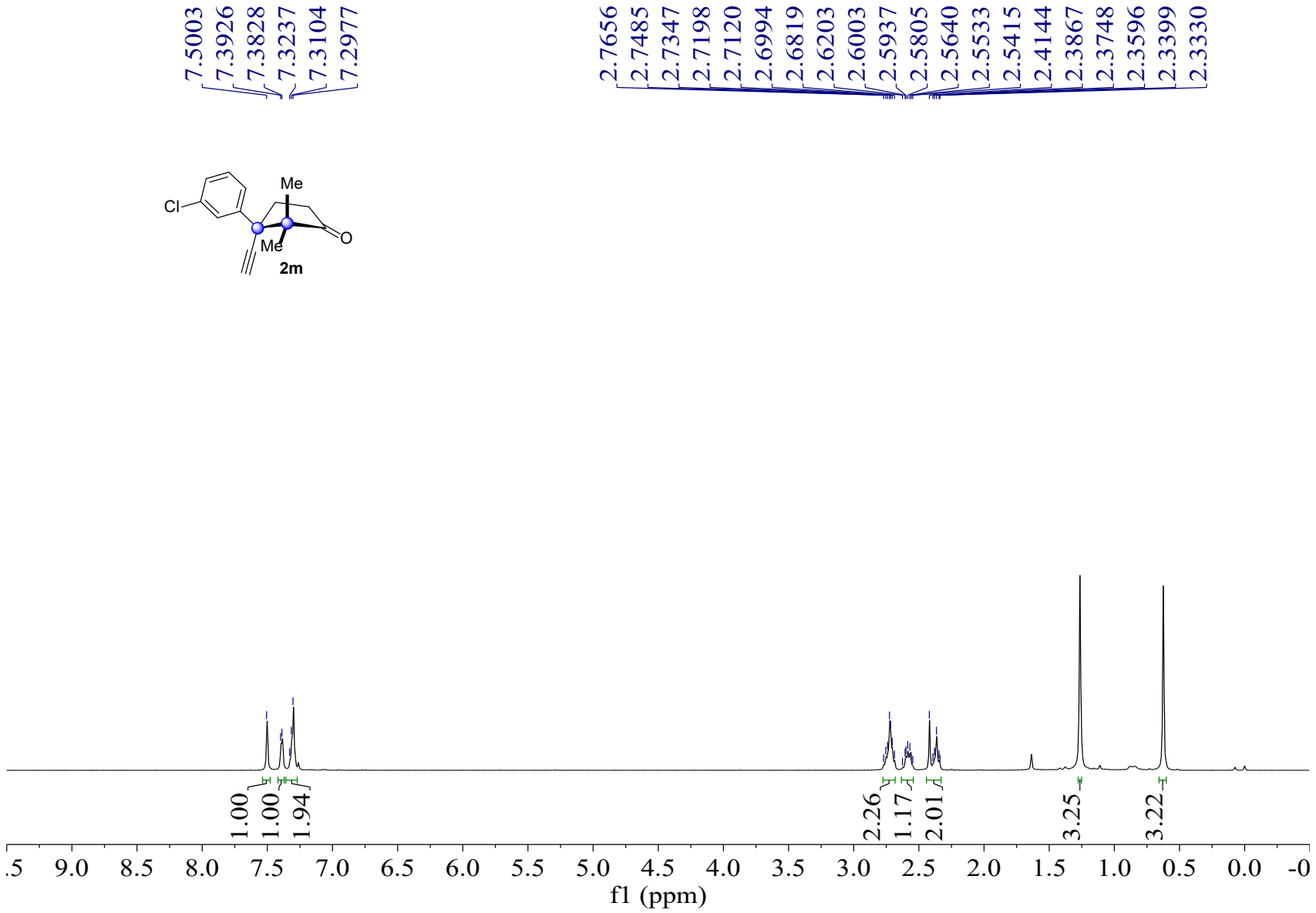
^{1}H NMR spectrum of compound **2l**



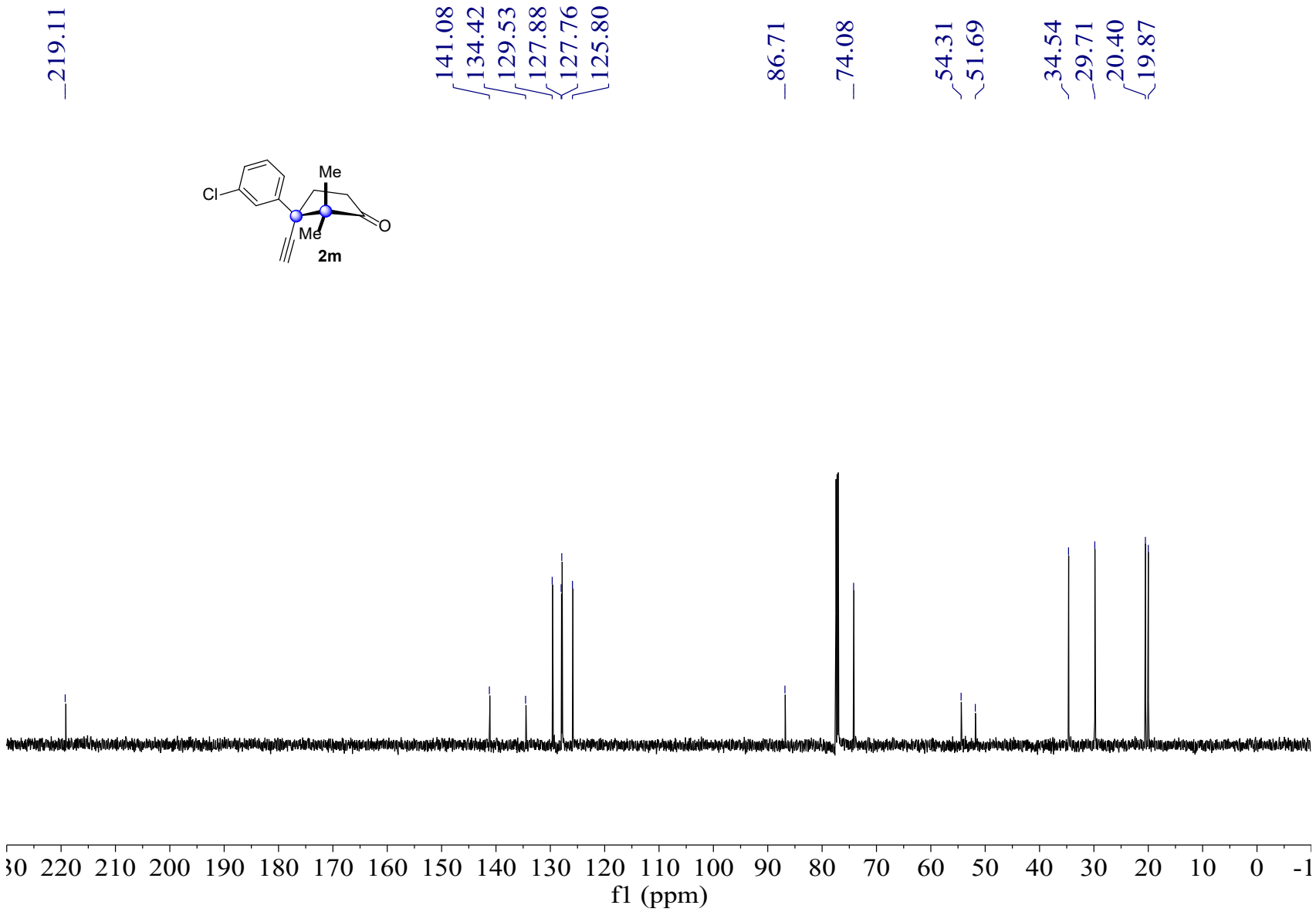
^{13}C NMR spectrum of compound **2l**



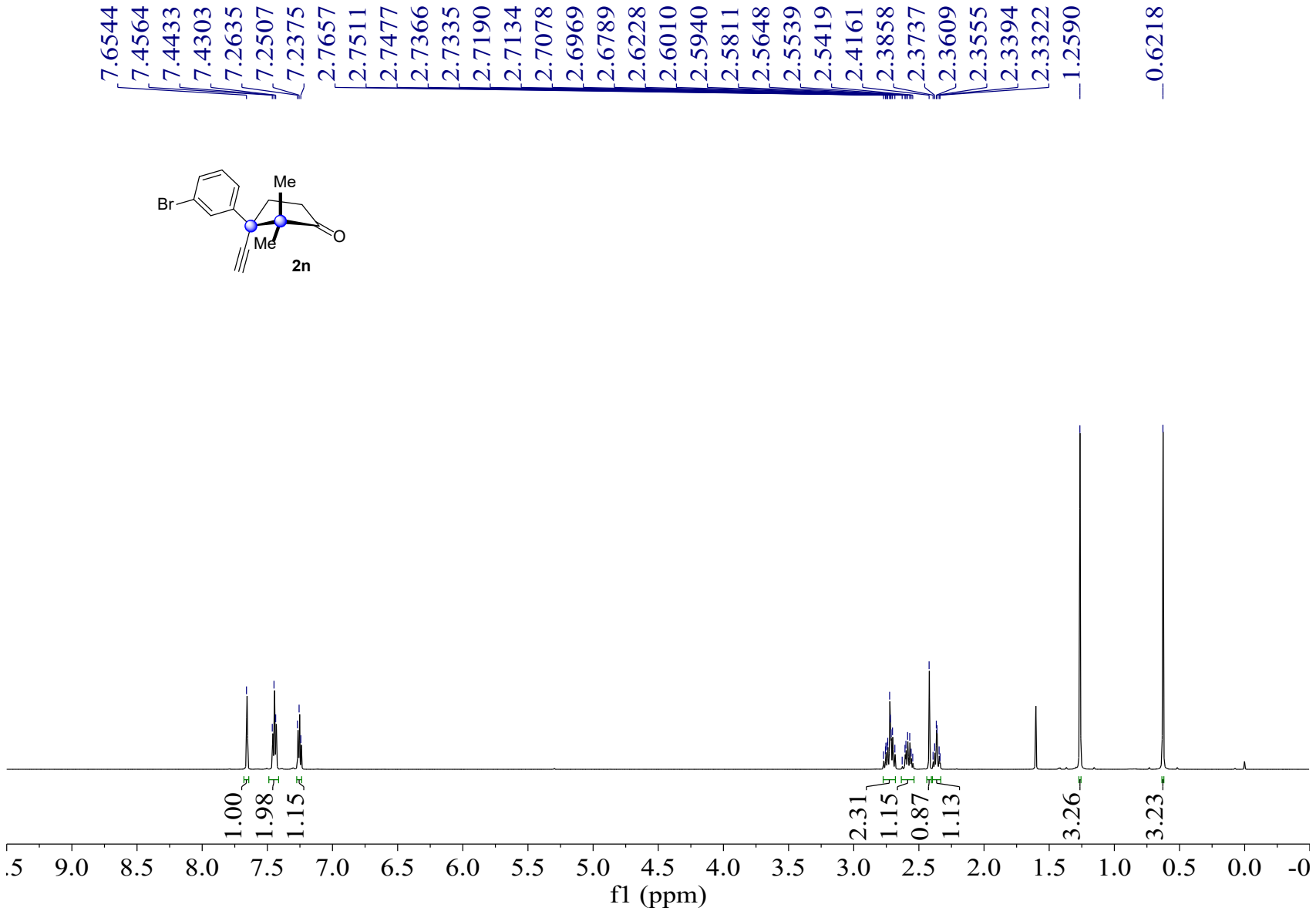
^{19}F NMR spectrum of compound **2l**



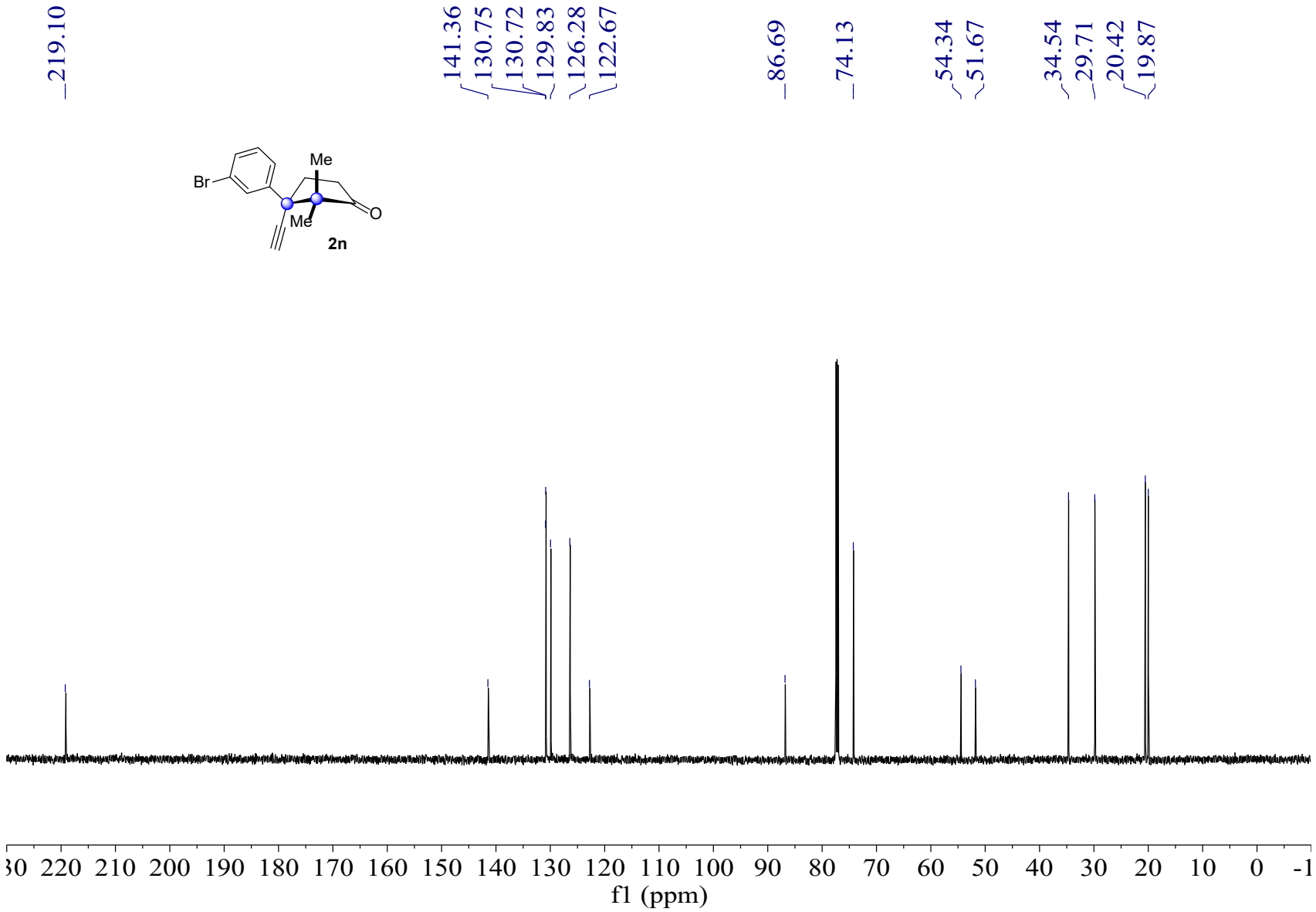
^{1}H NMR spectrum of compound **2m**



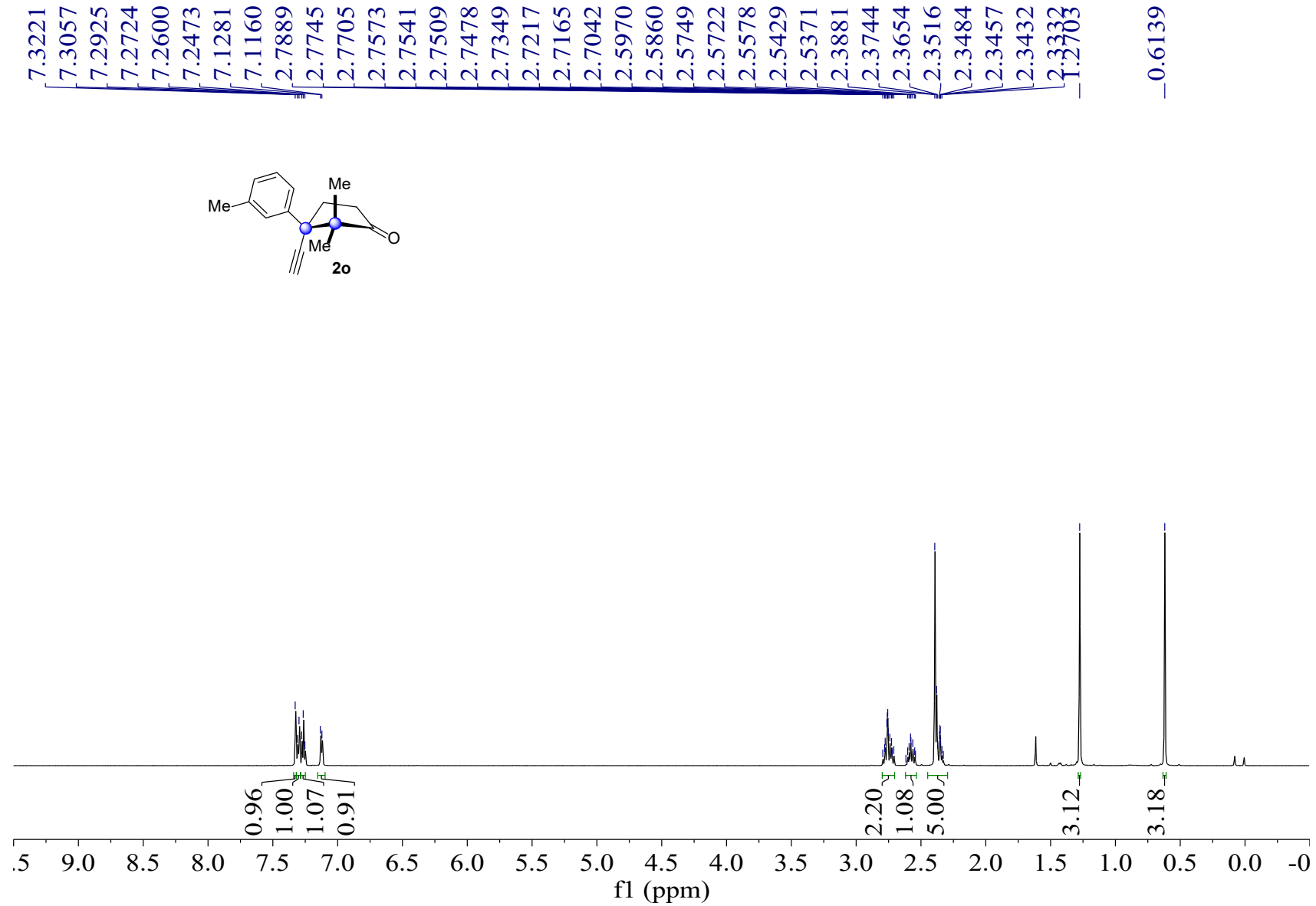
^{13}C NMR spectrum of compound **2m**



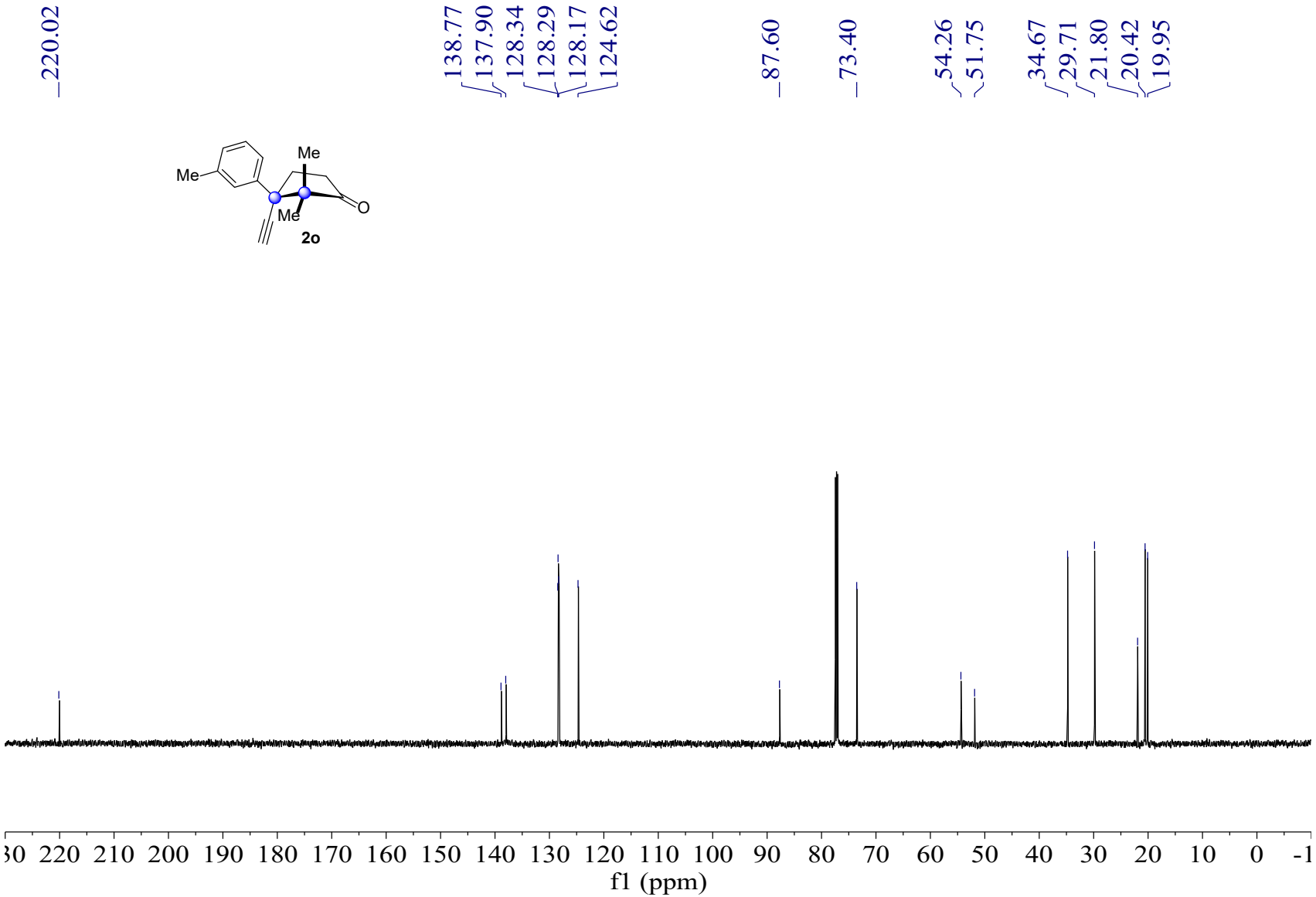
^{1}H NMR spectrum of compound **2n**



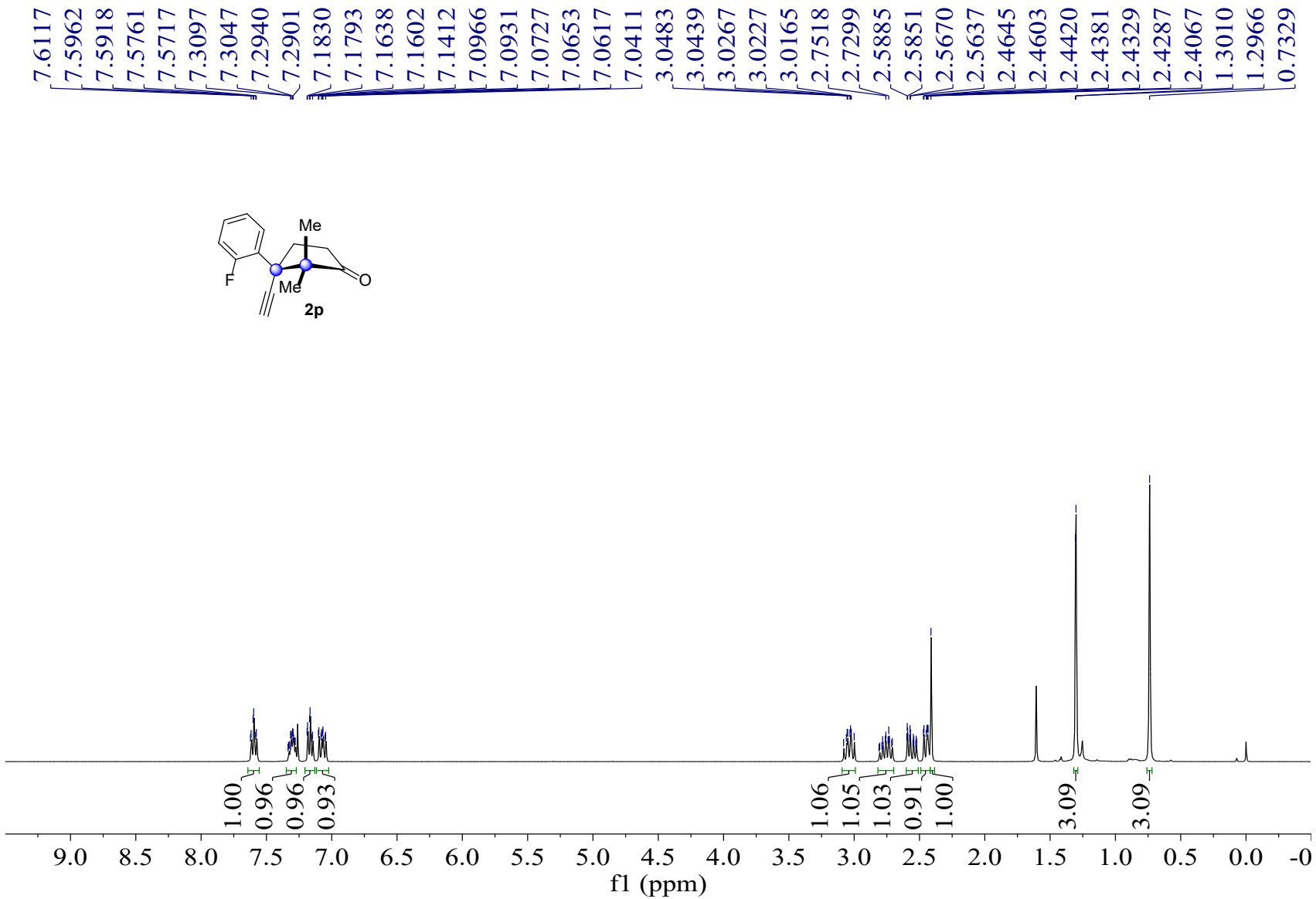
^{13}C NMR spectrum of compound **2n**



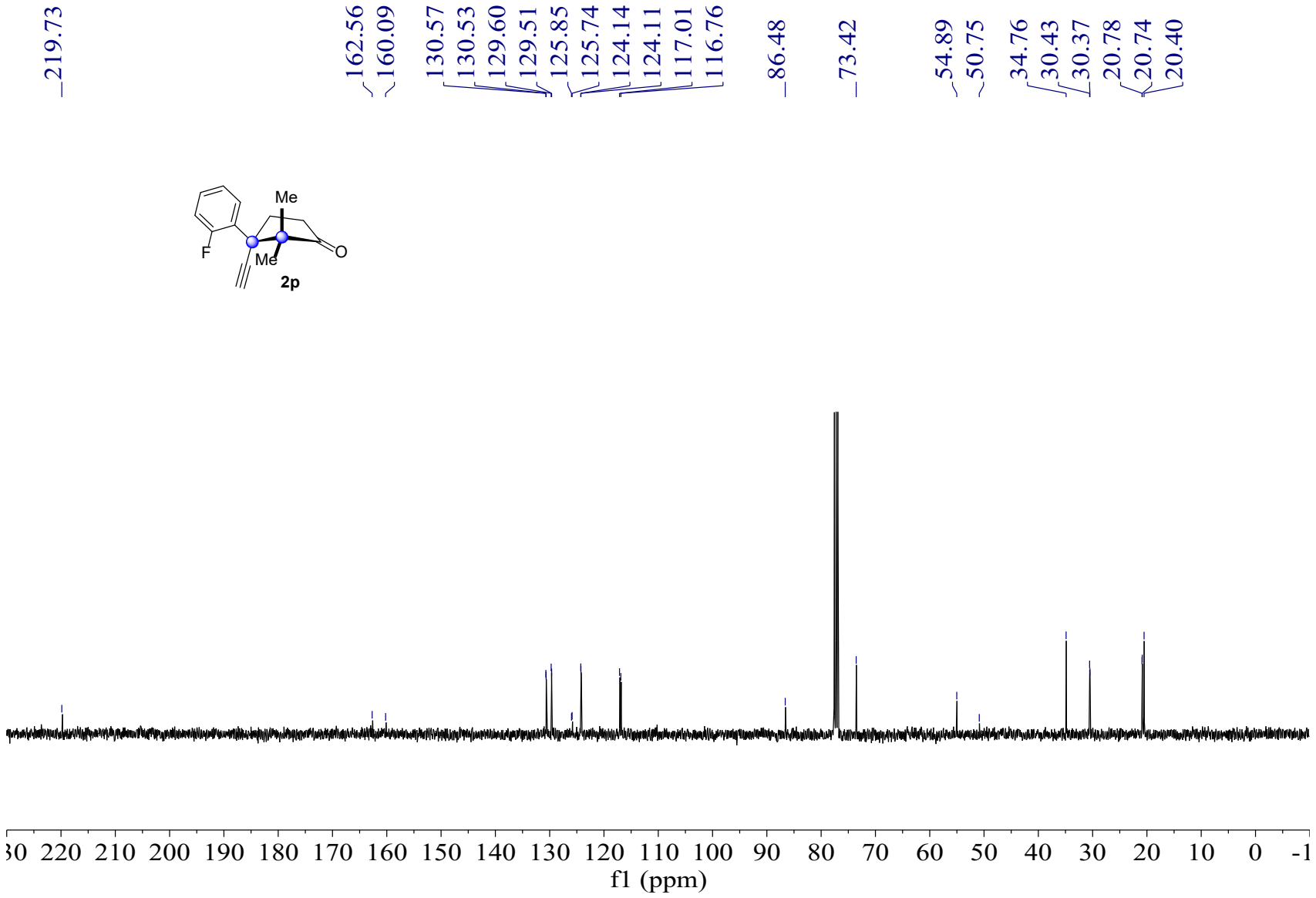
^{1}H NMR spectrum of compound **2o**



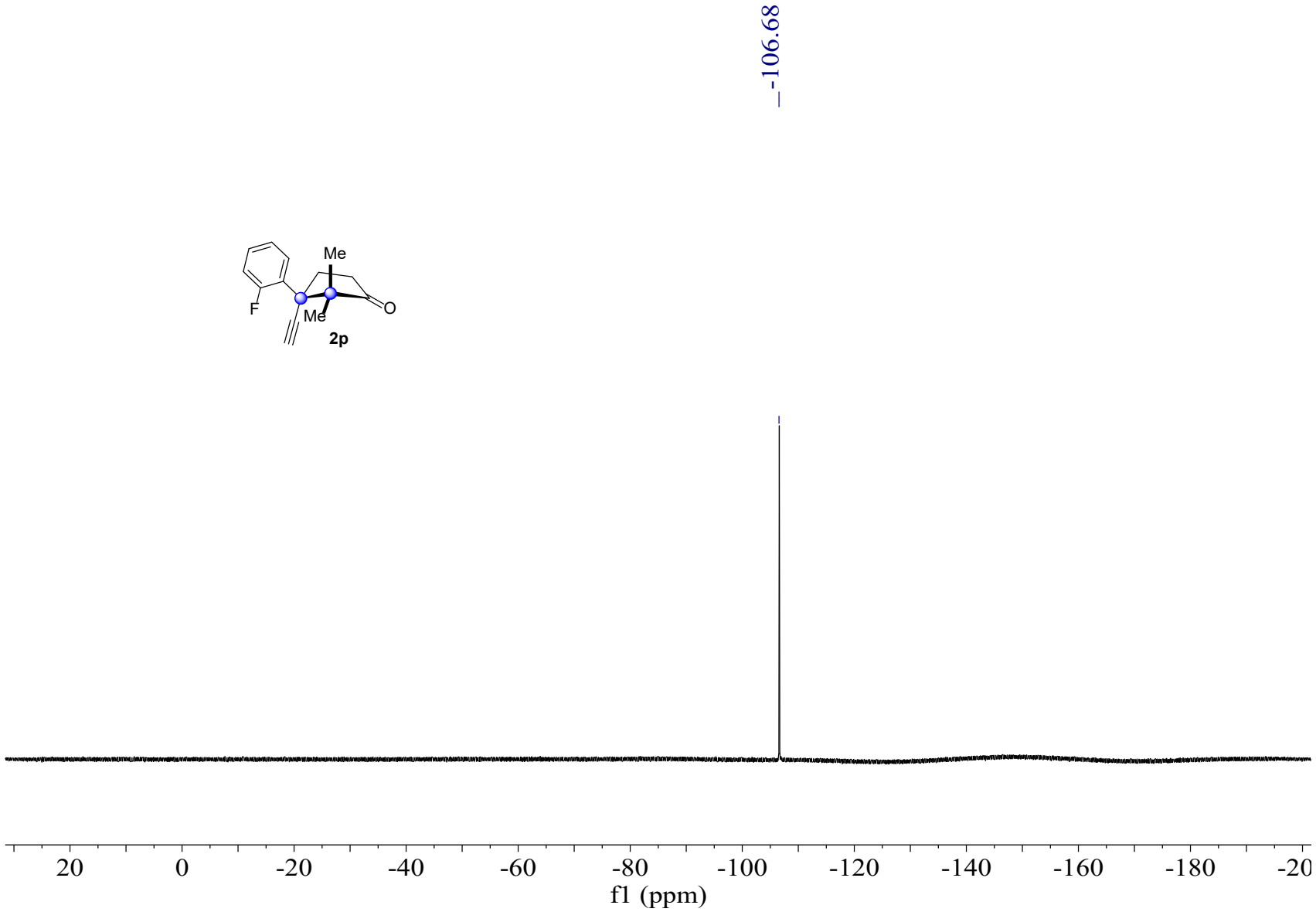
^{13}C NMR spectrum of compound **2o**



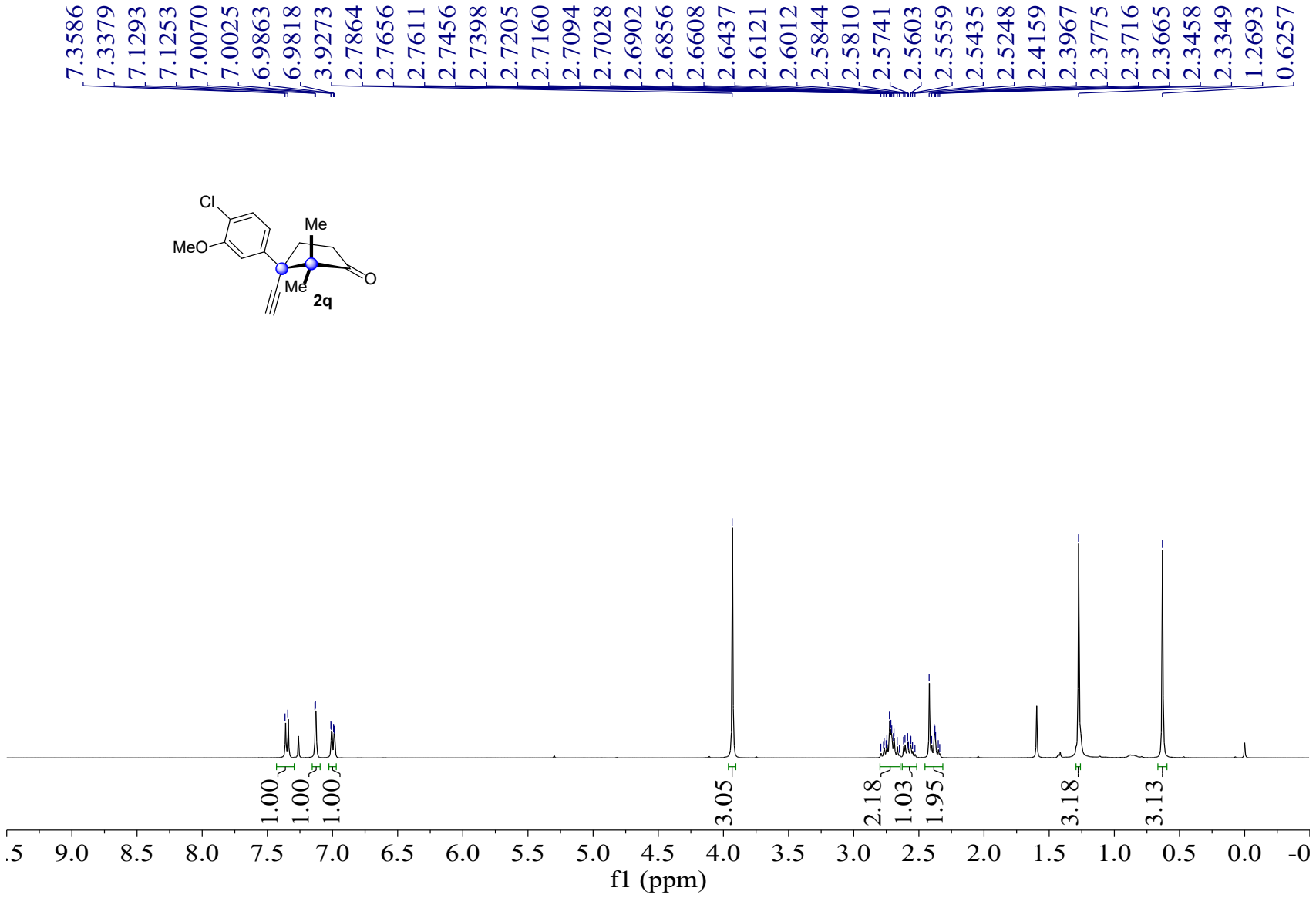
^{1}H NMR spectrum of compound **2p**



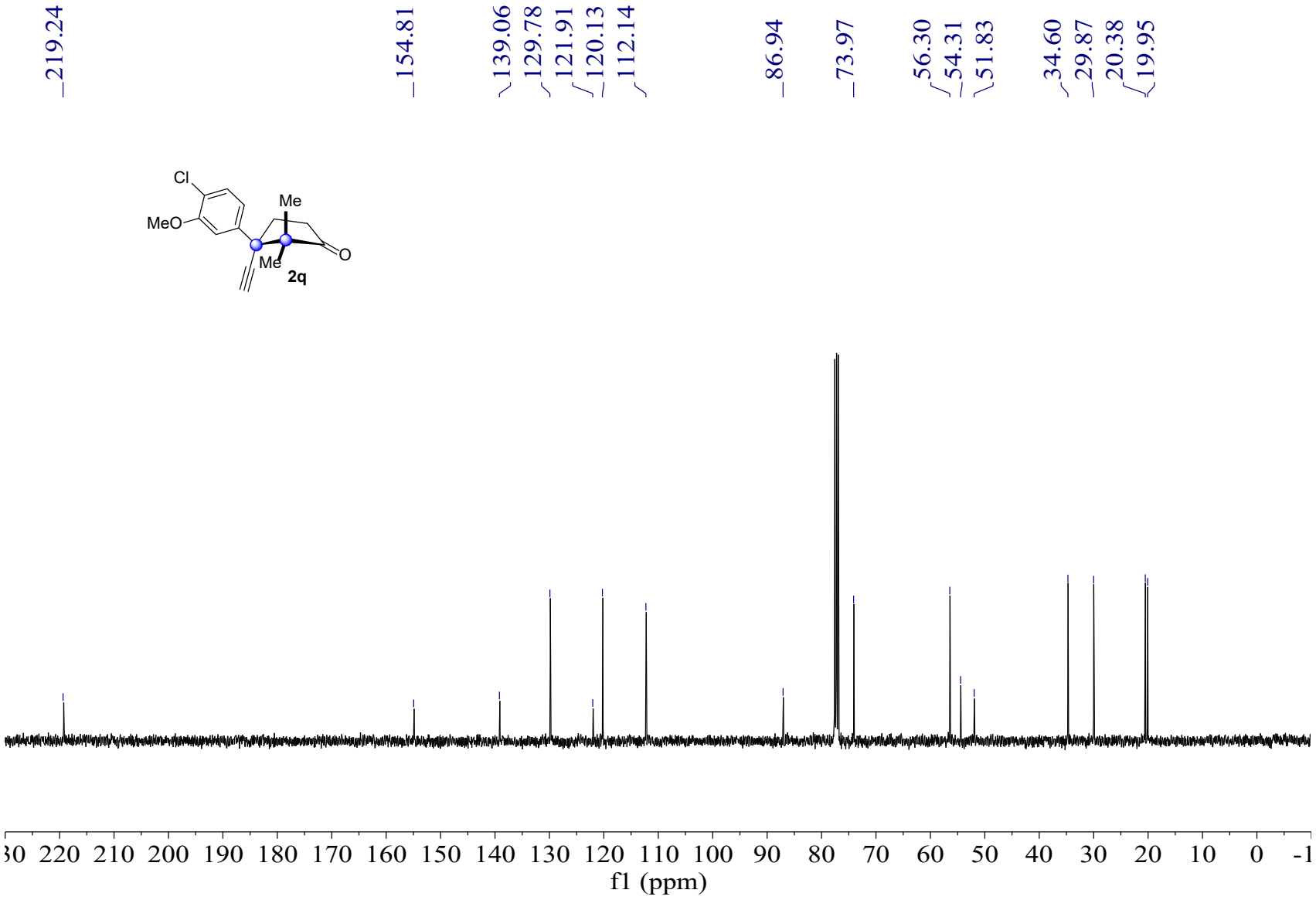
^{13}C NMR spectrum of compound **2p**



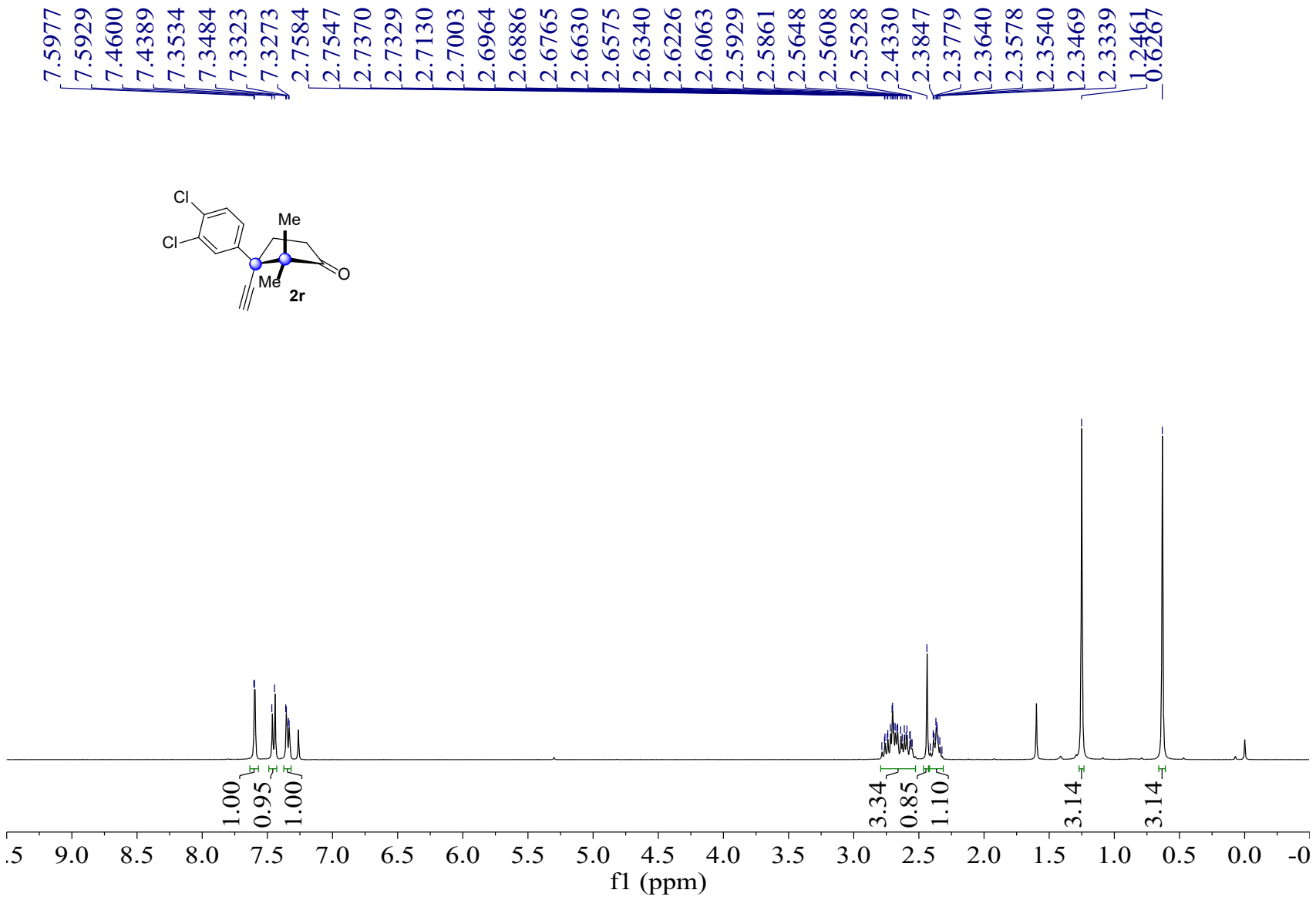
^{19}F NMR spectrum of compound **2p**



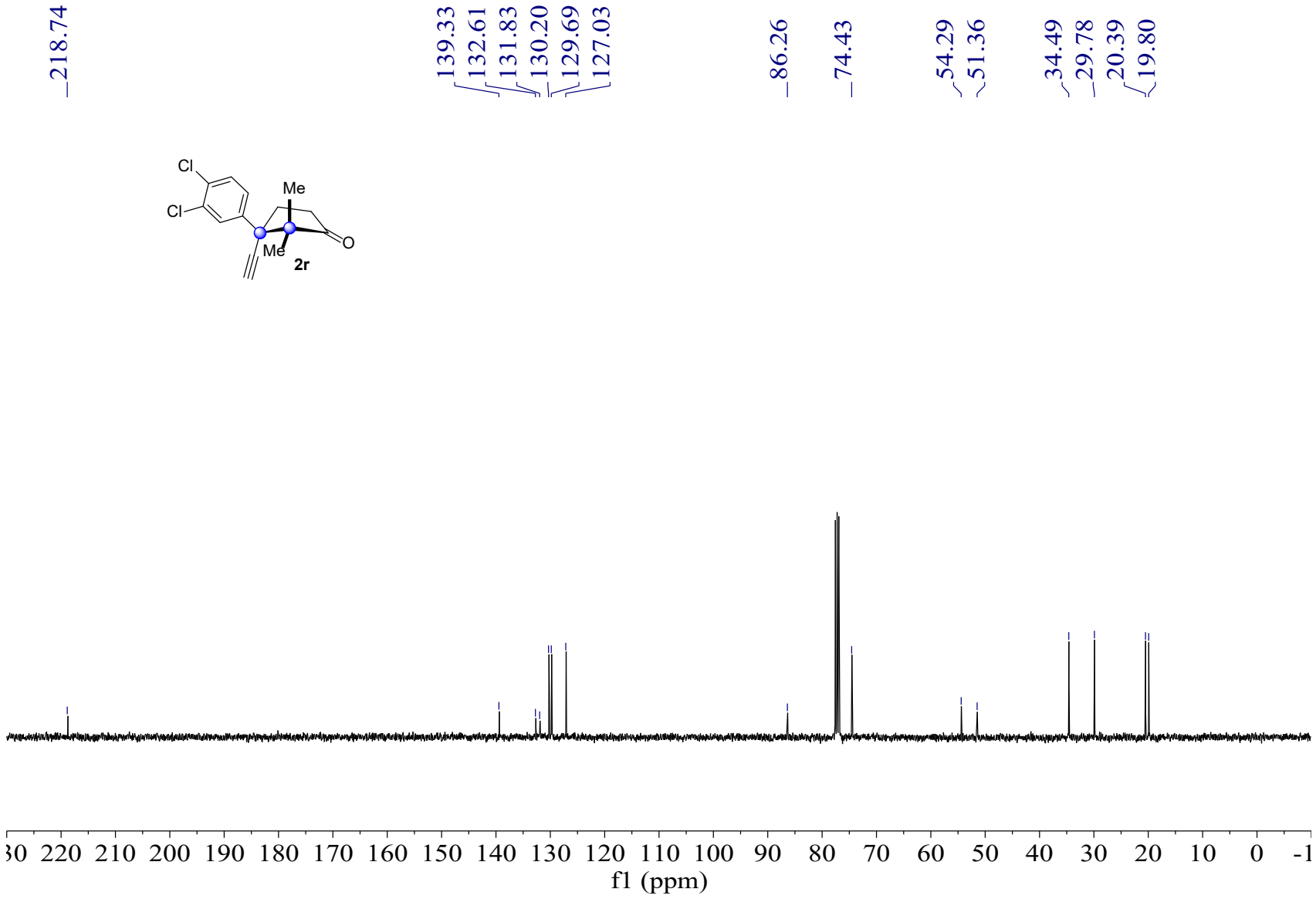
^{1}H NMR spectrum of compound **2q**



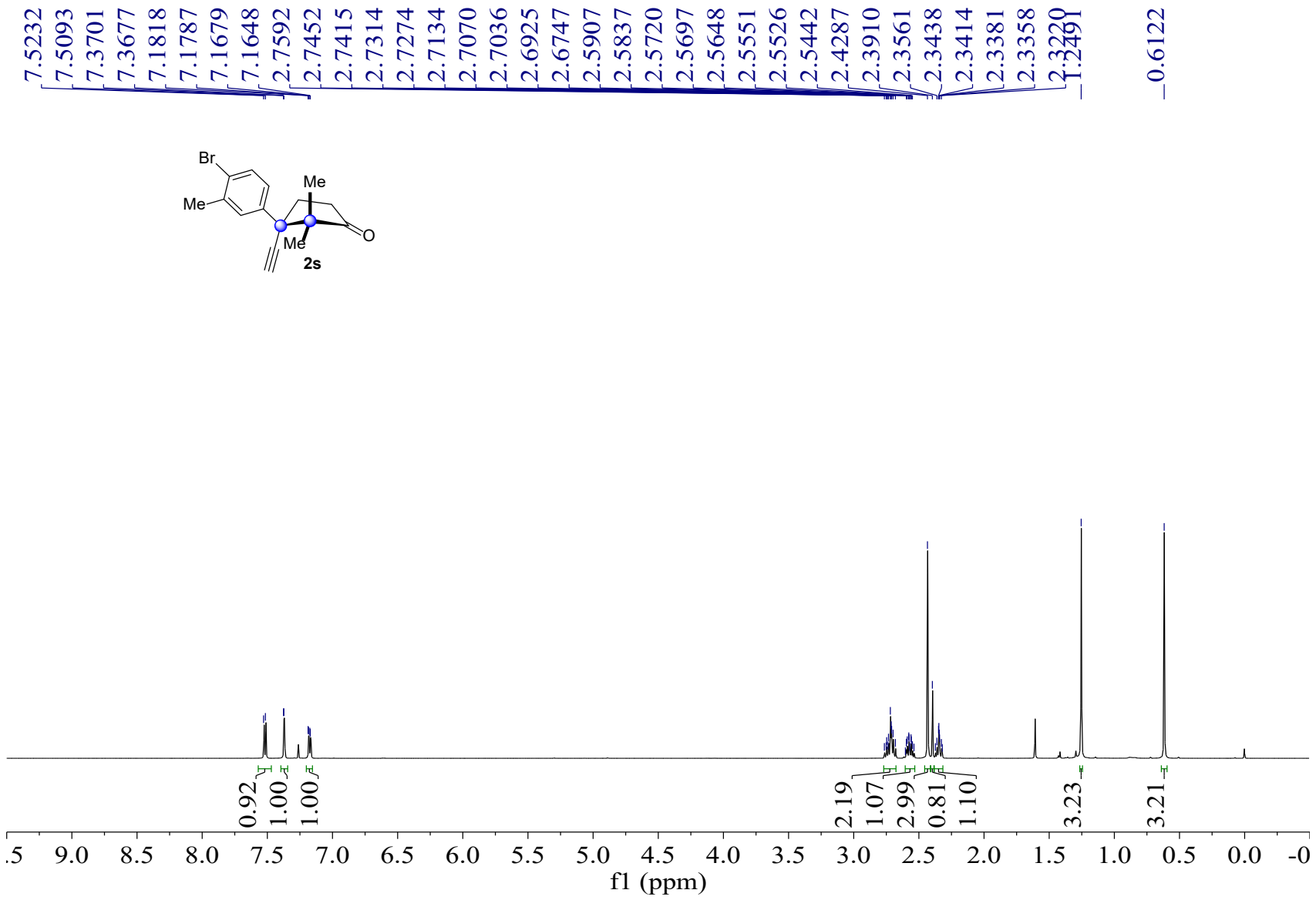
^{13}C NMR spectrum of compound **2q**



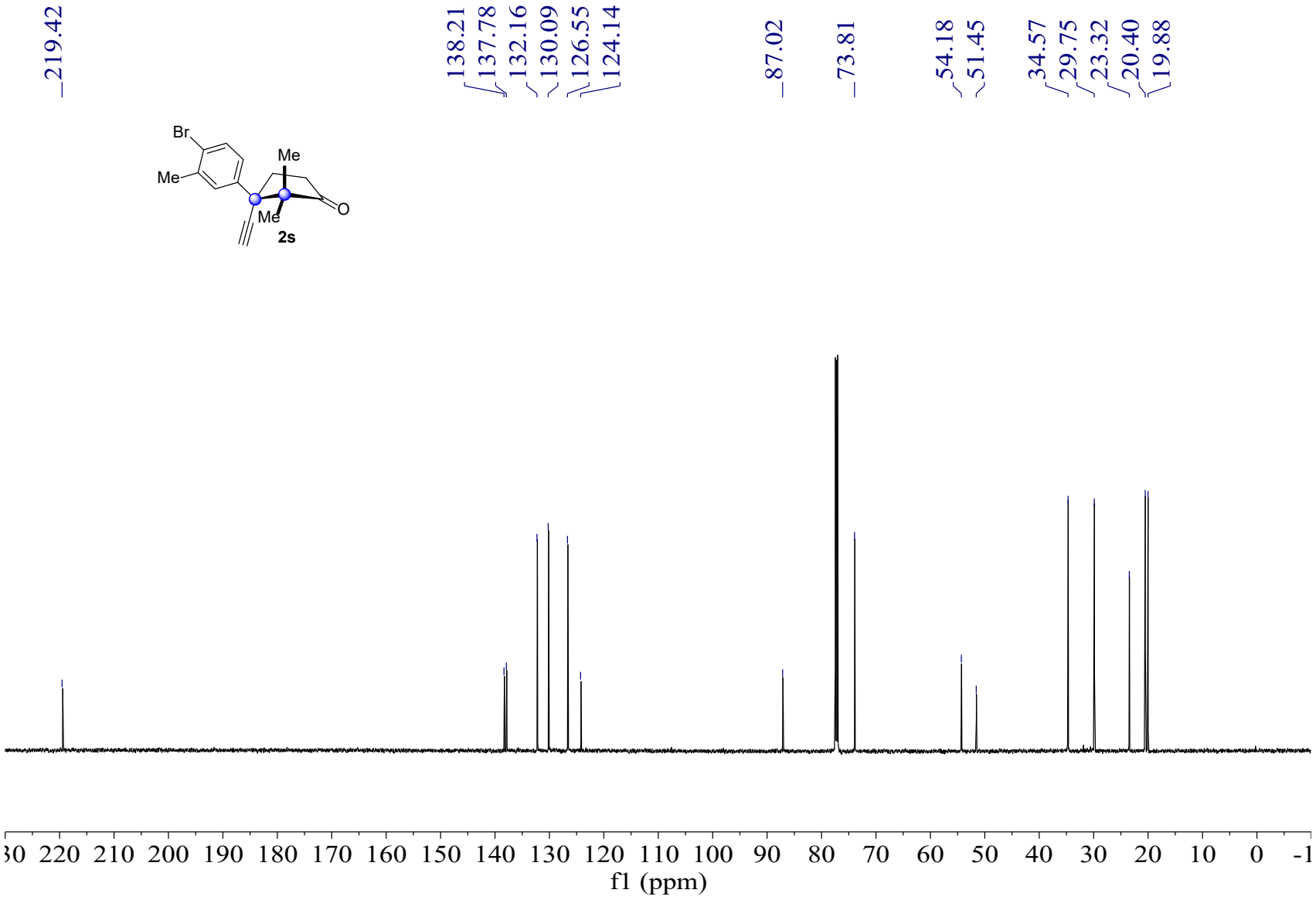
^{1}H NMR spectrum of compound **2r**



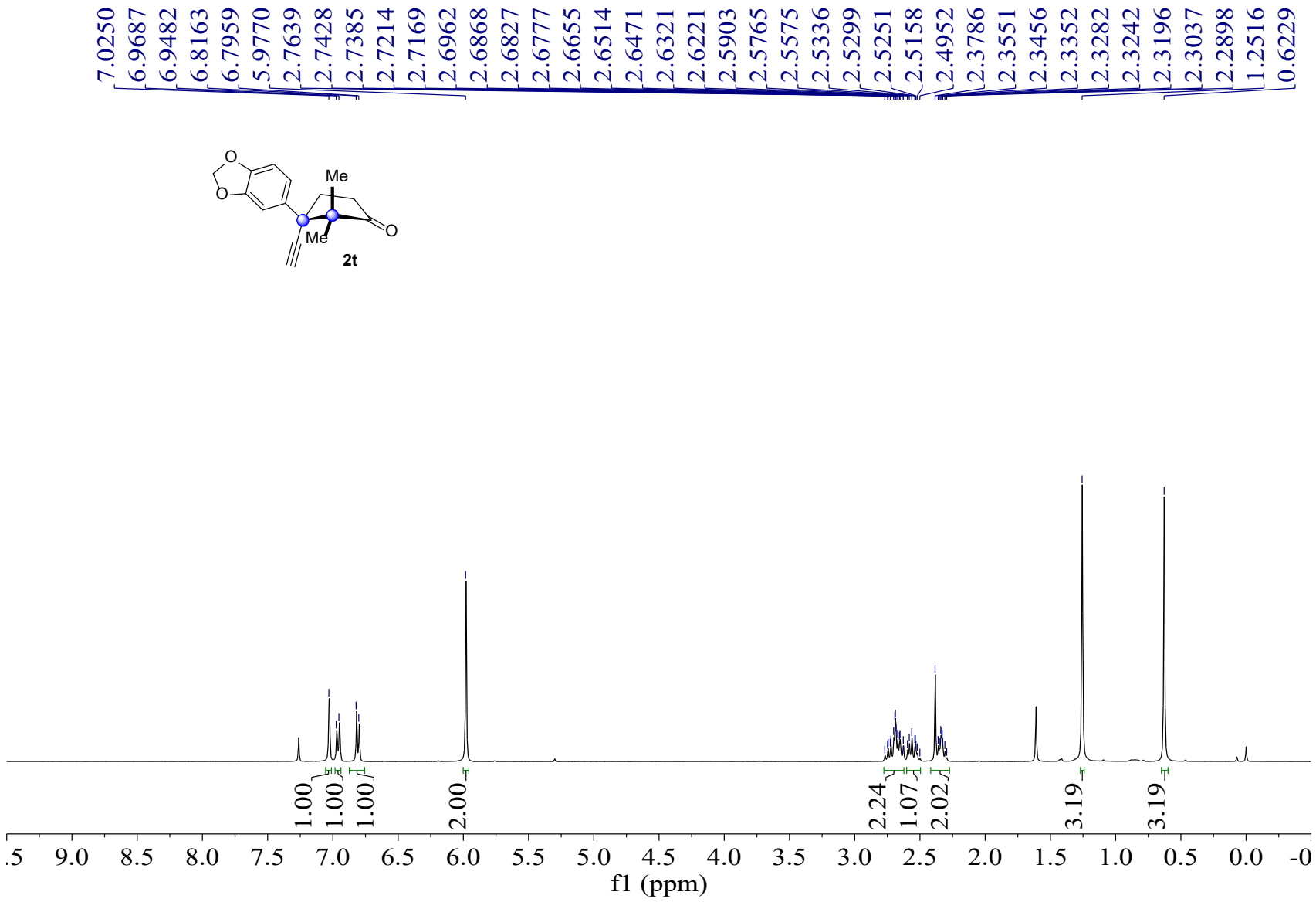
^{13}C NMR spectrum of compound **2r**



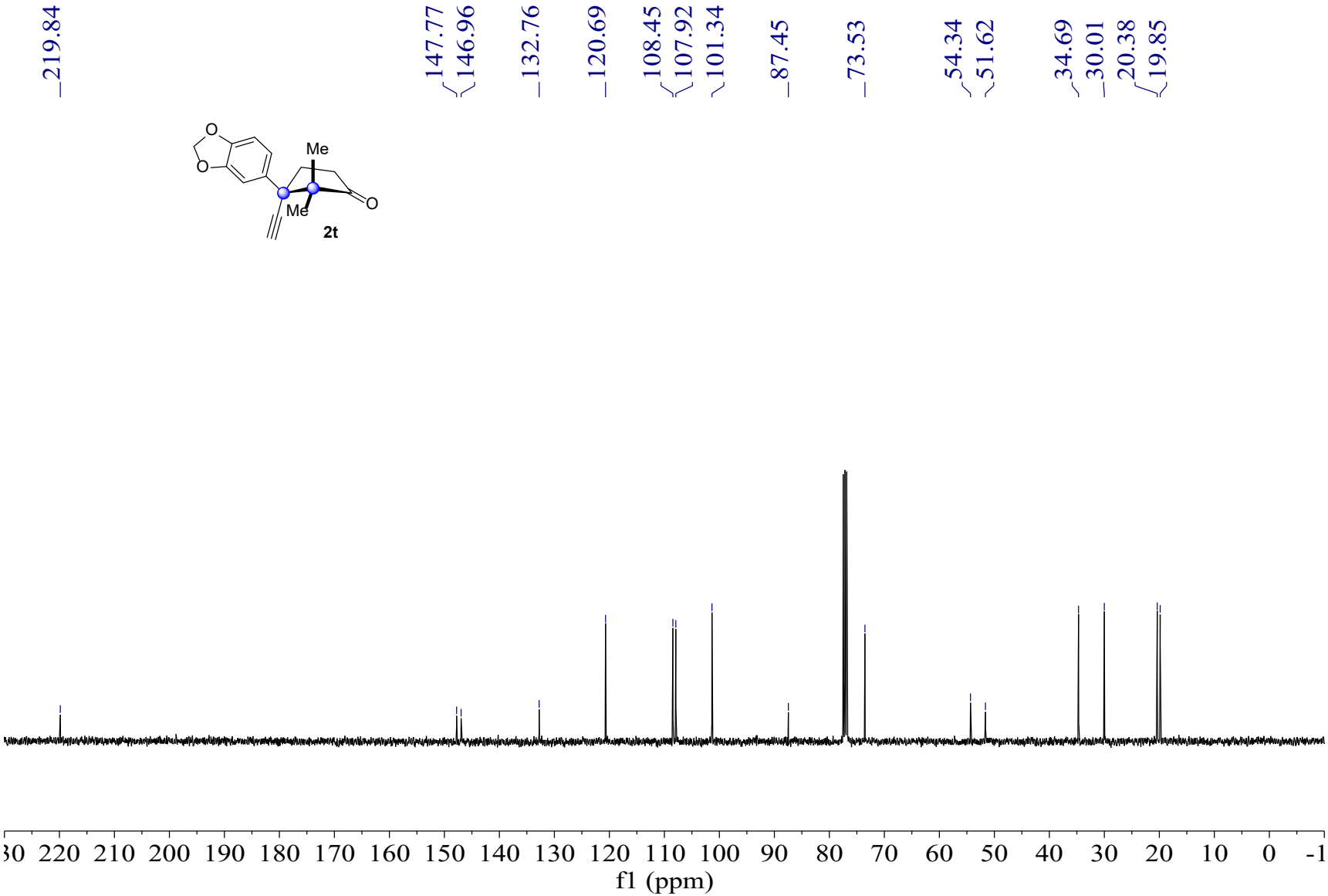
^{1}H NMR spectrum of compound **2s**



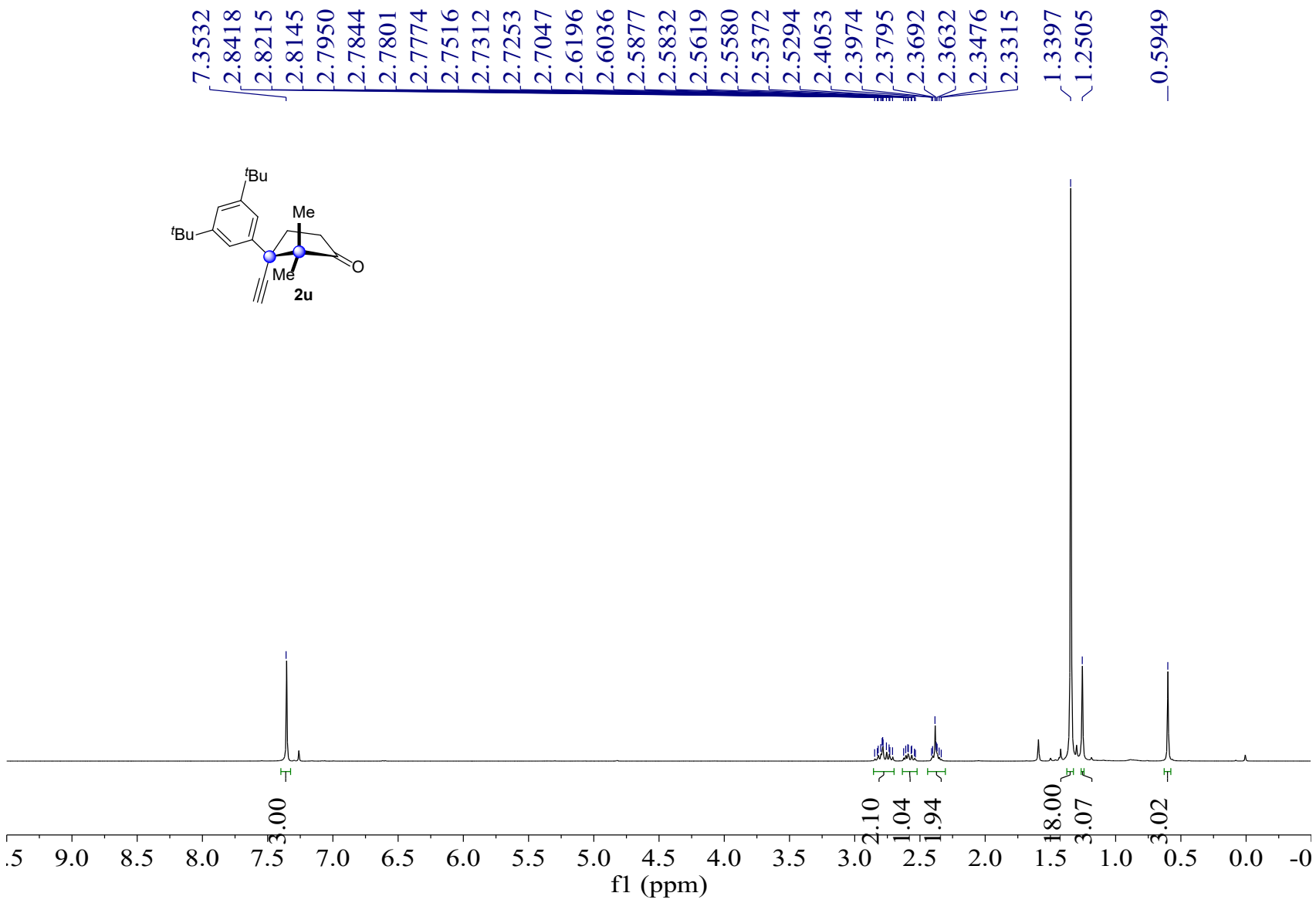
^{13}C NMR spectrum of compound **2s**



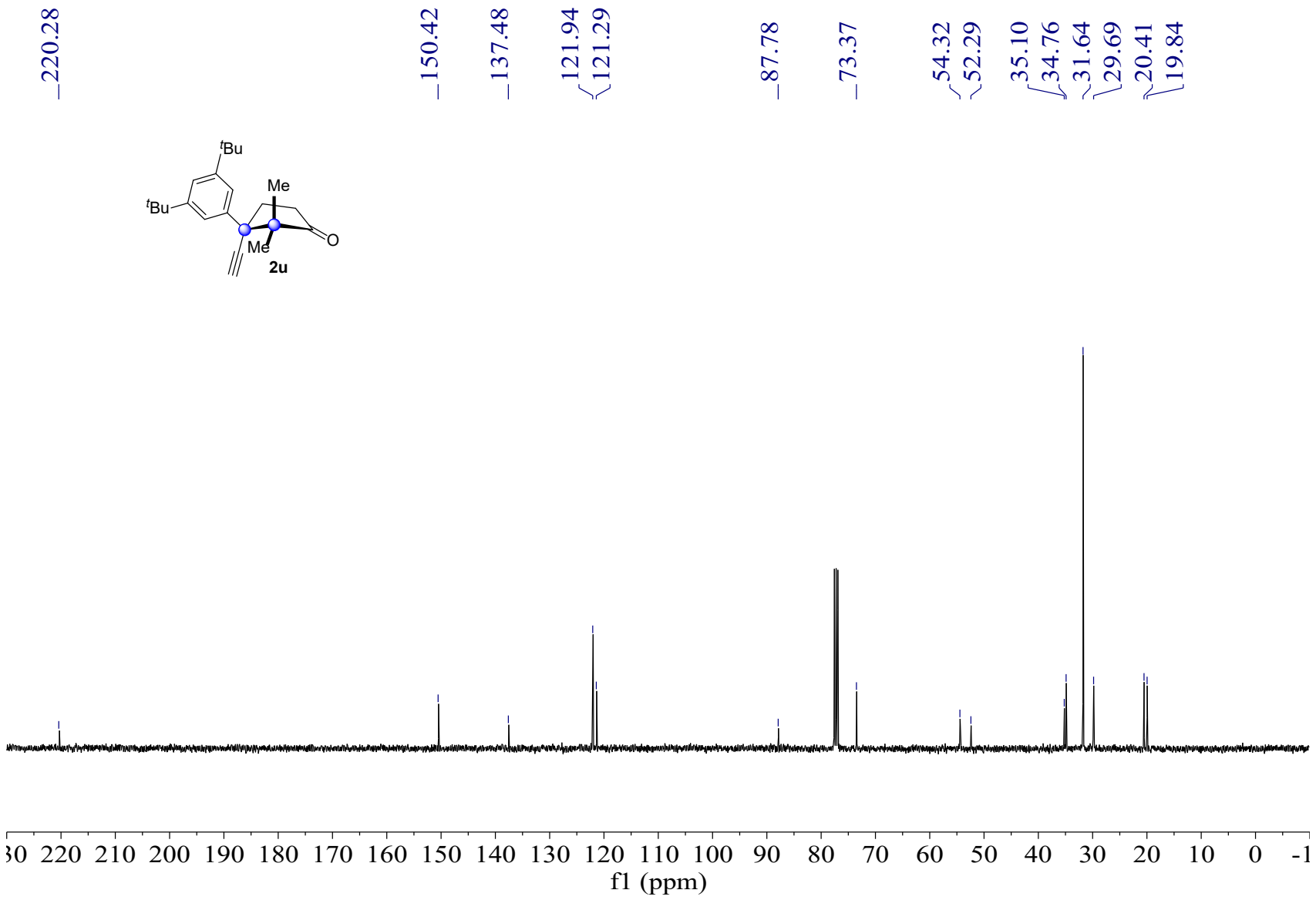
^{1}H NMR spectrum of compound **2t**



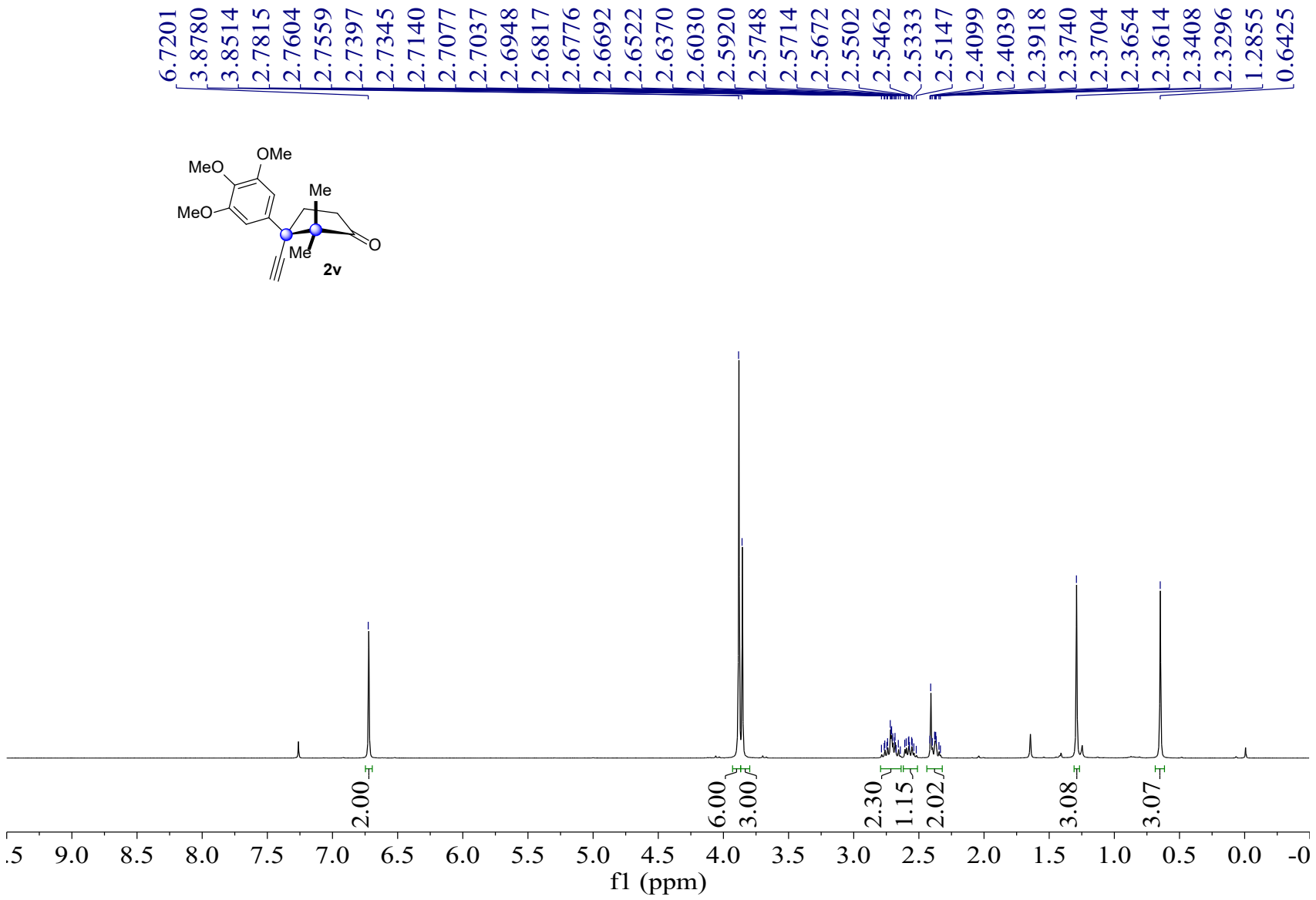
^{13}C NMR spectrum of compound **2t**



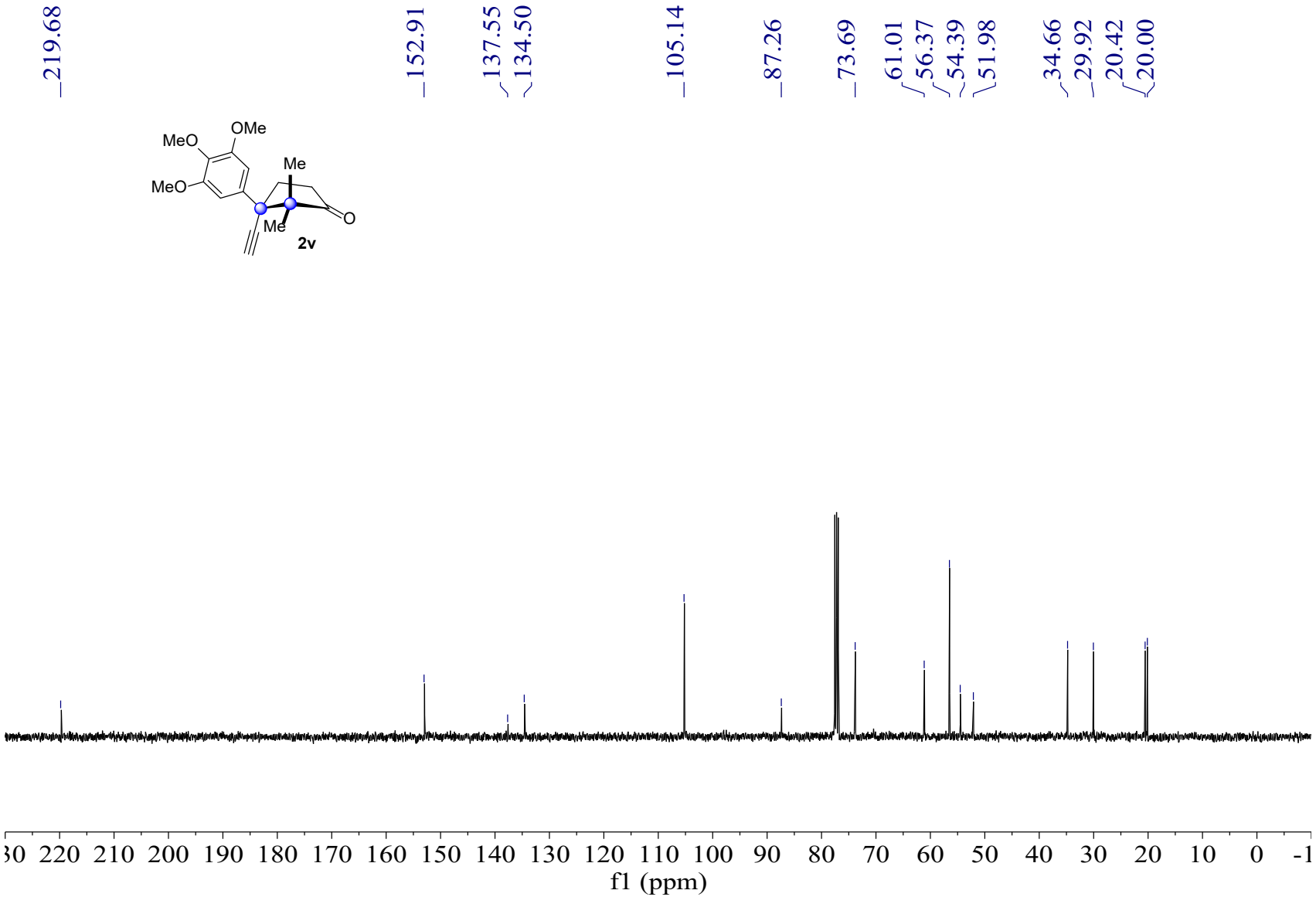
^{1}H NMR spectrum of compound **2u**



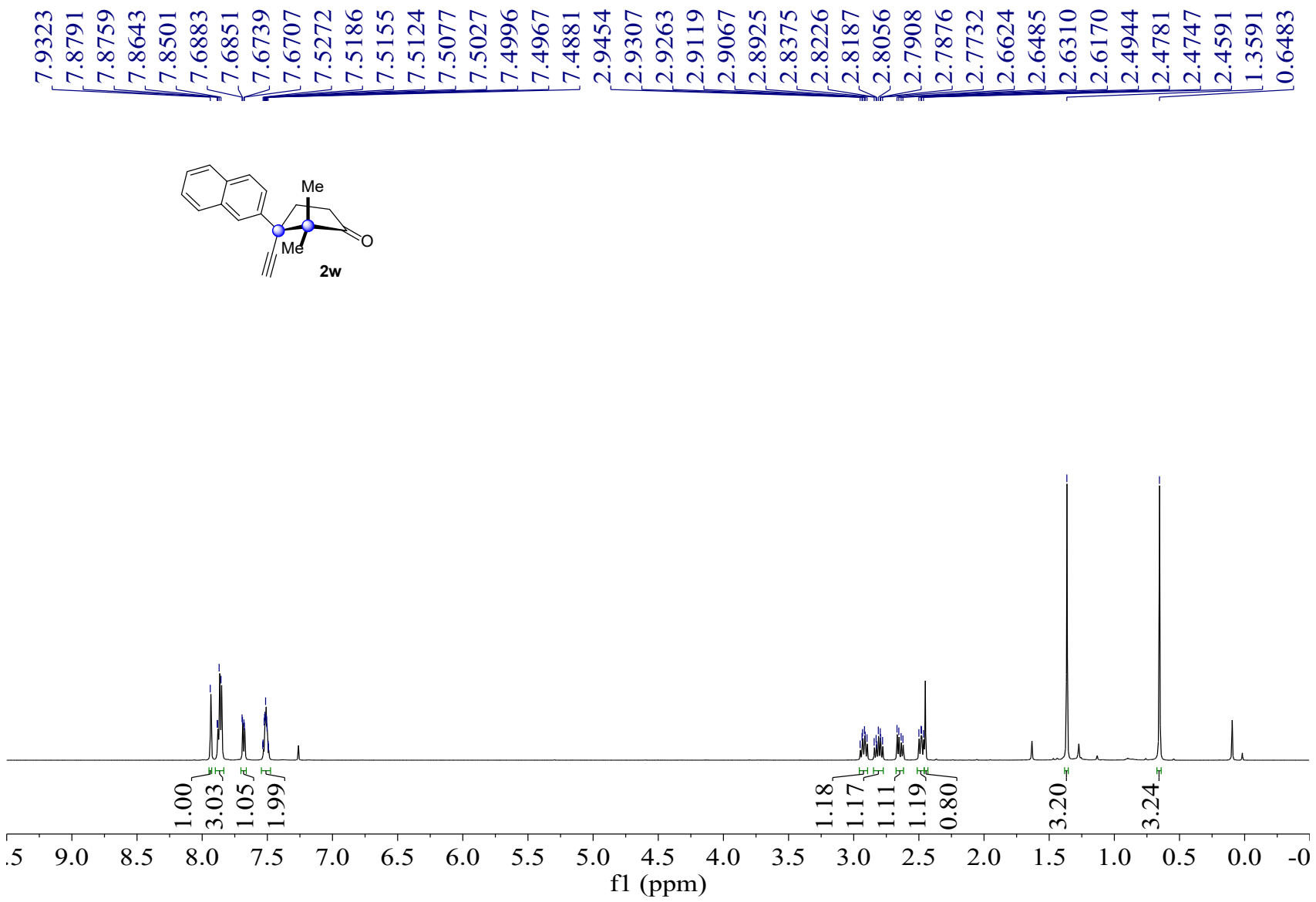
^{13}C NMR spectrum of compound **2u**



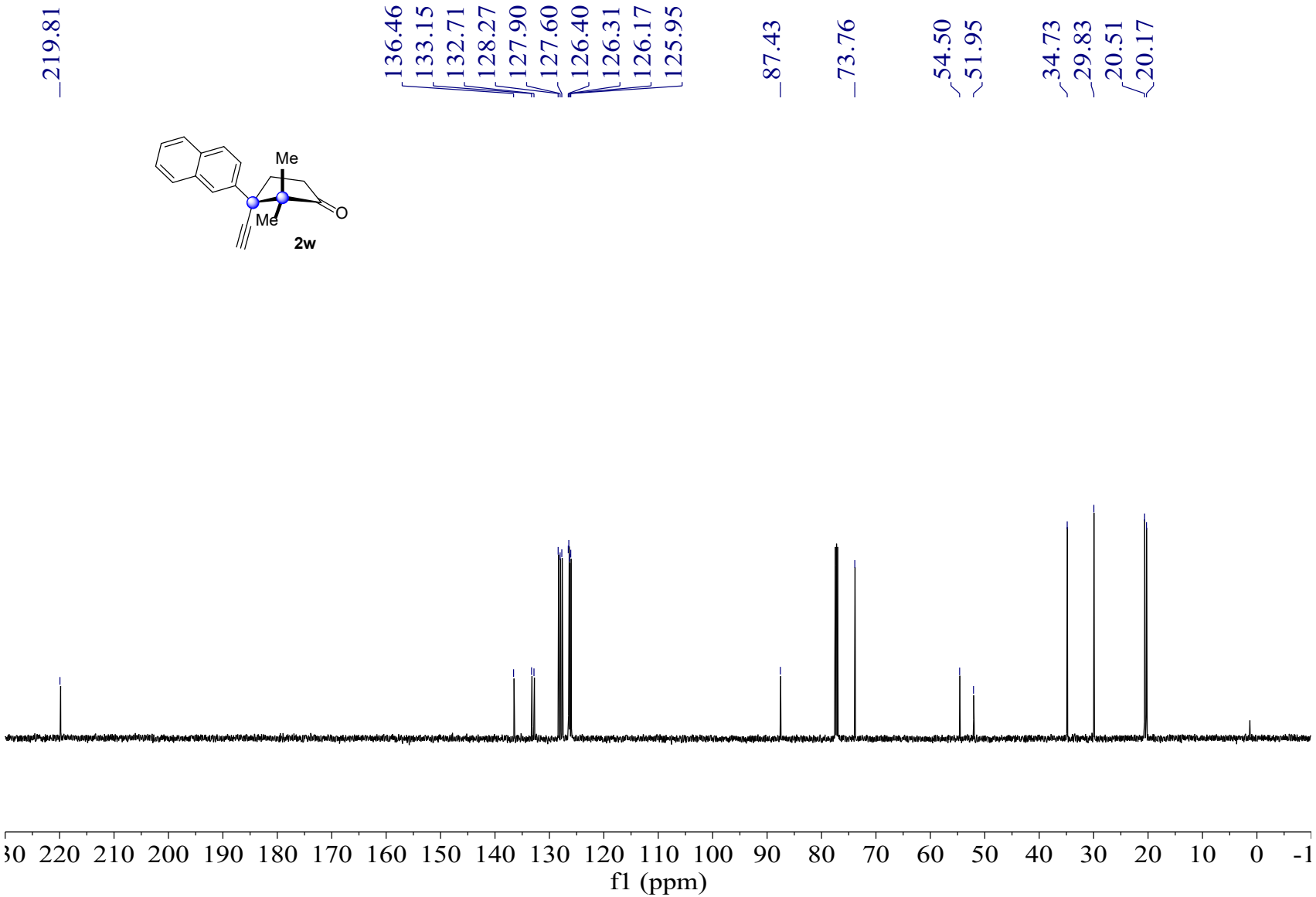
^{1}H NMR spectrum of compound **2v**



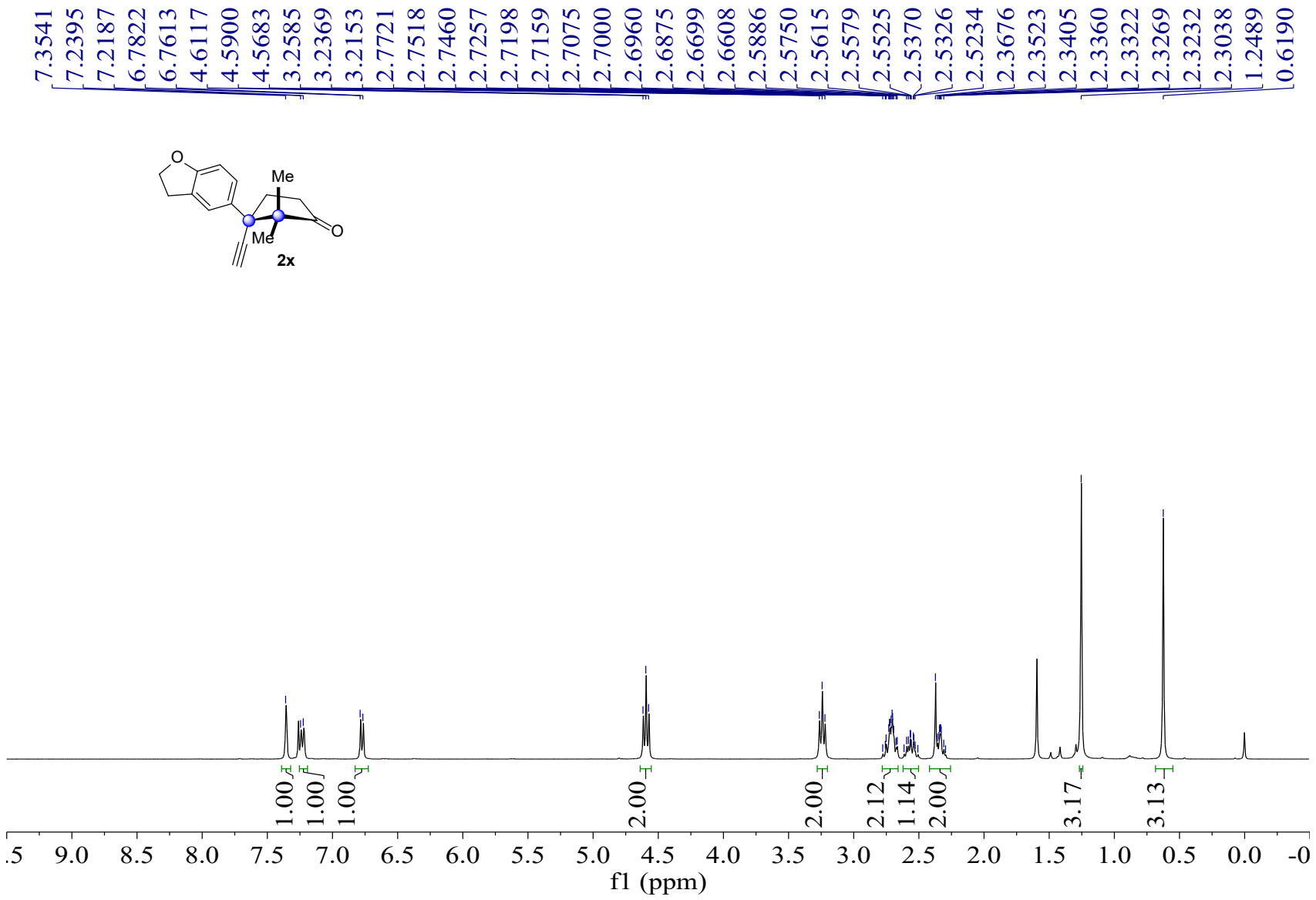
^{13}C NMR spectrum of compound **2v**



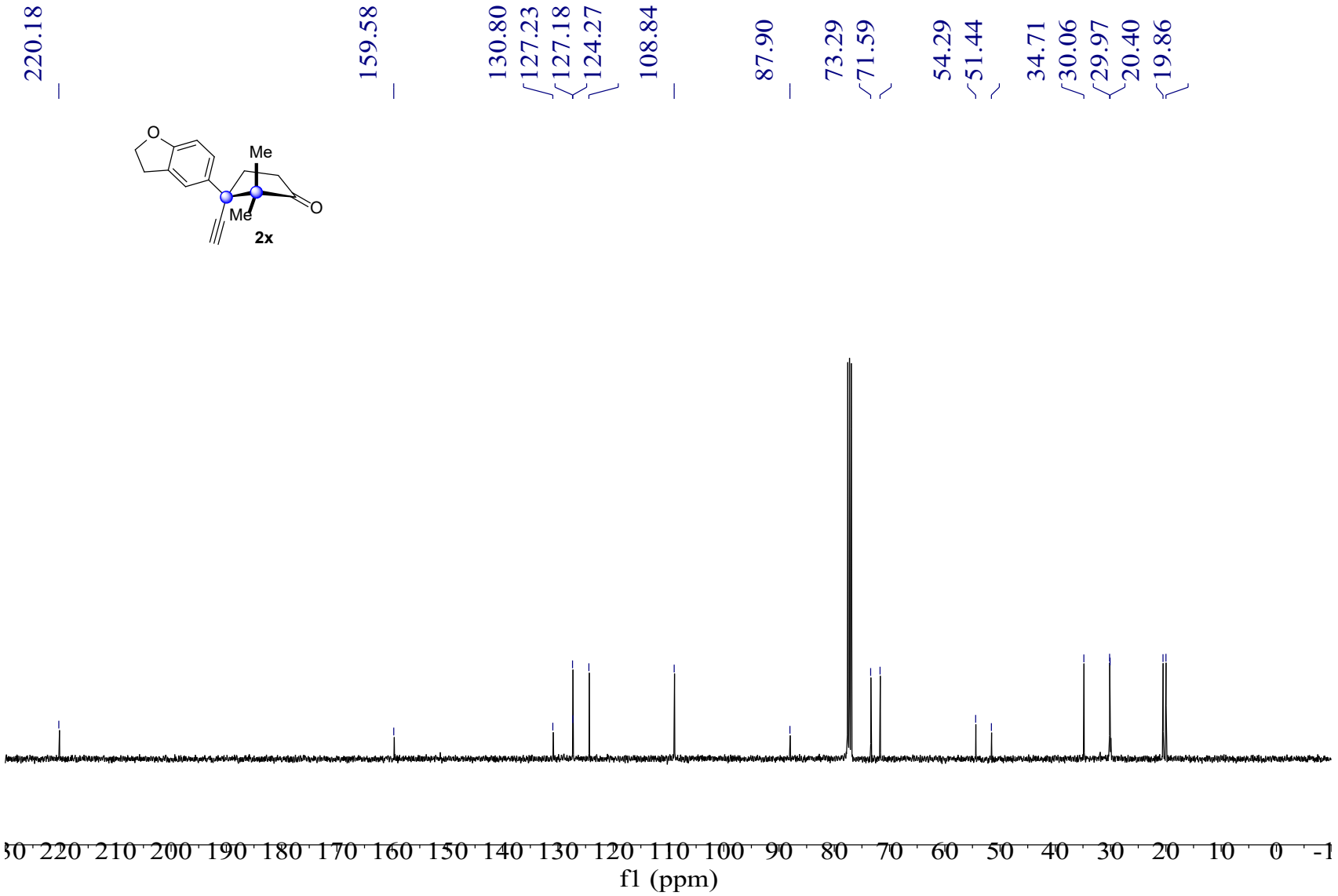
^{1}H NMR spectrum of compound **2w**



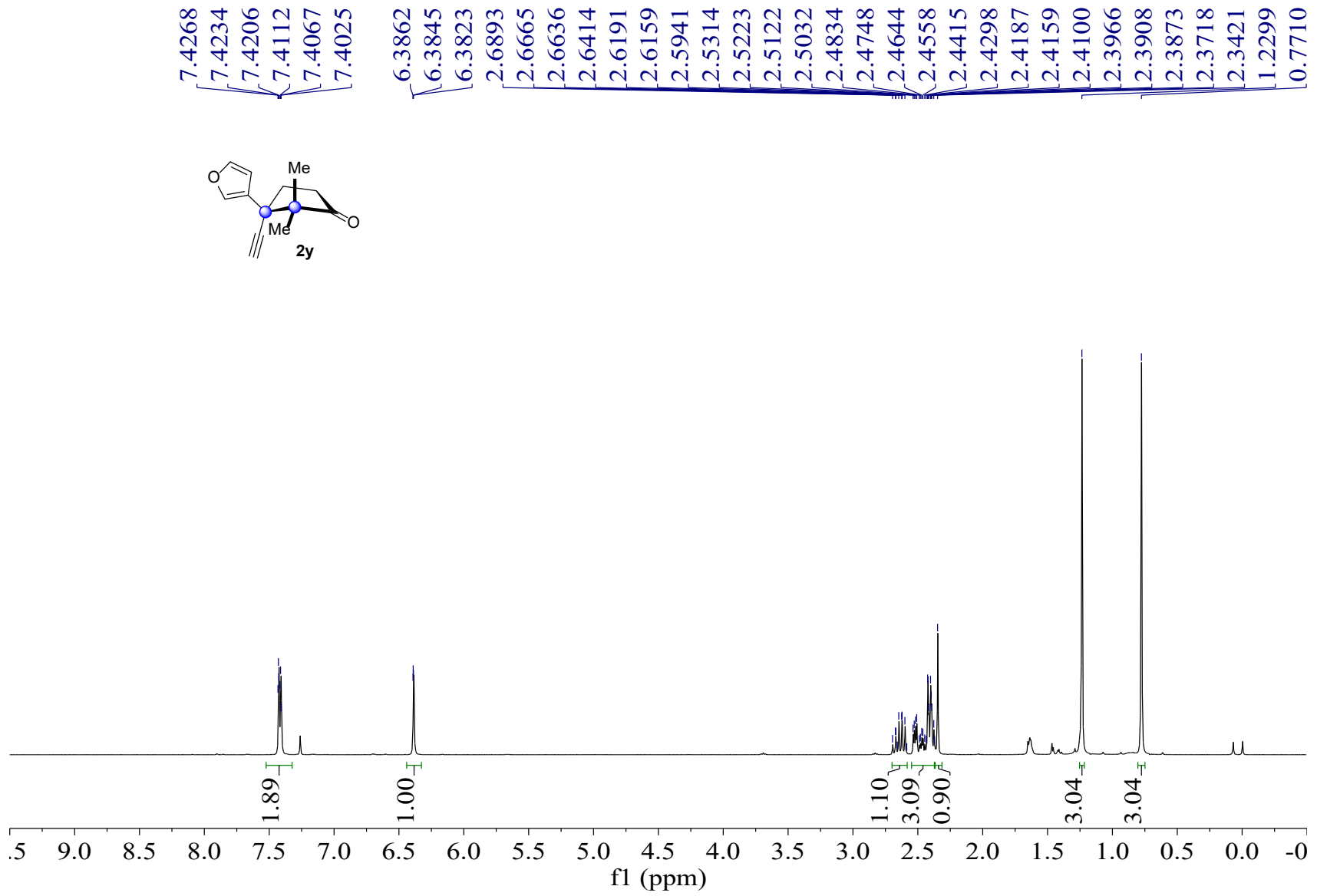
^{13}C NMR spectrum of compound **2w**



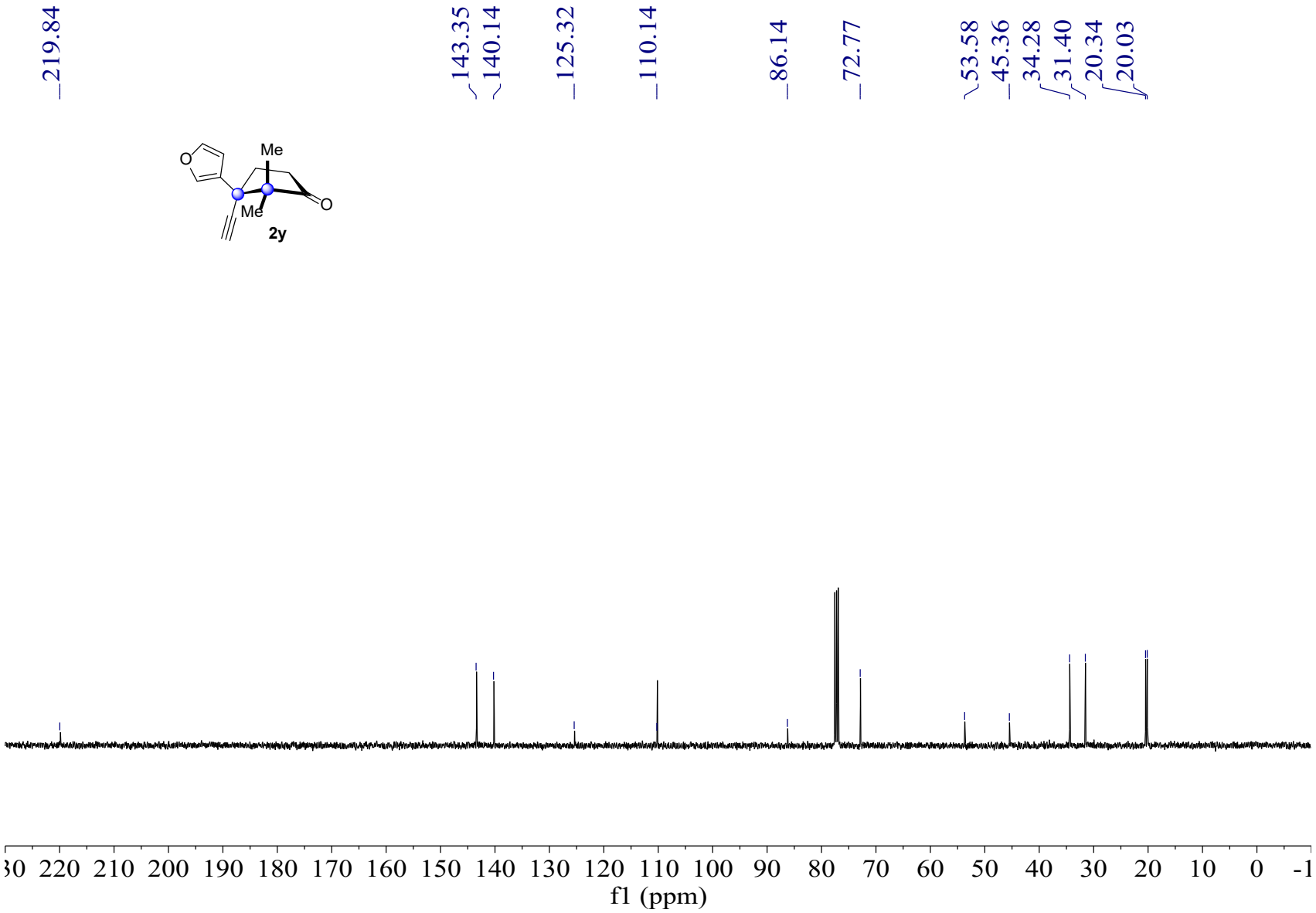
^{1}H NMR spectrum of compound **2x**



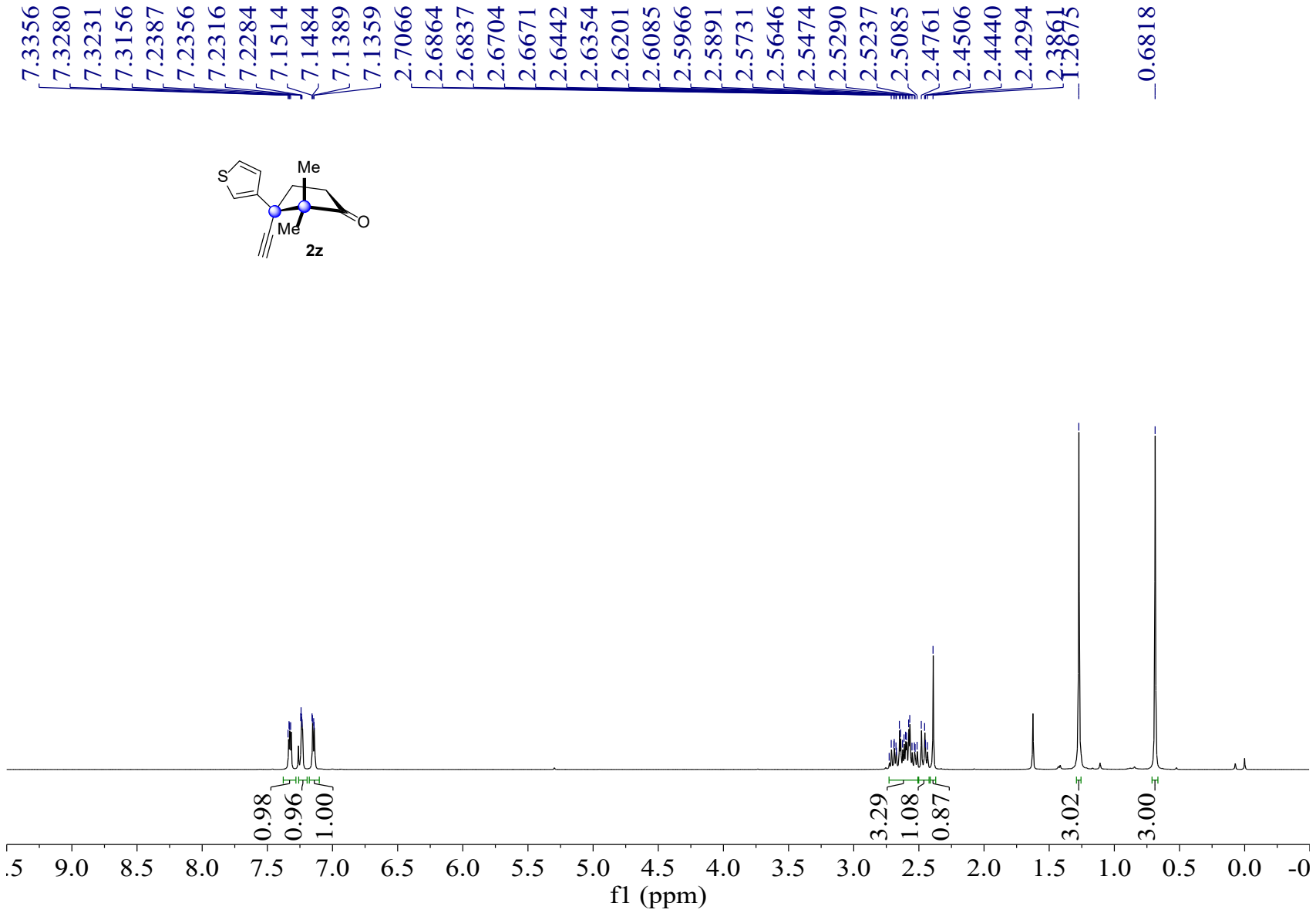
^{13}C NMR spectrum of compound **2x**



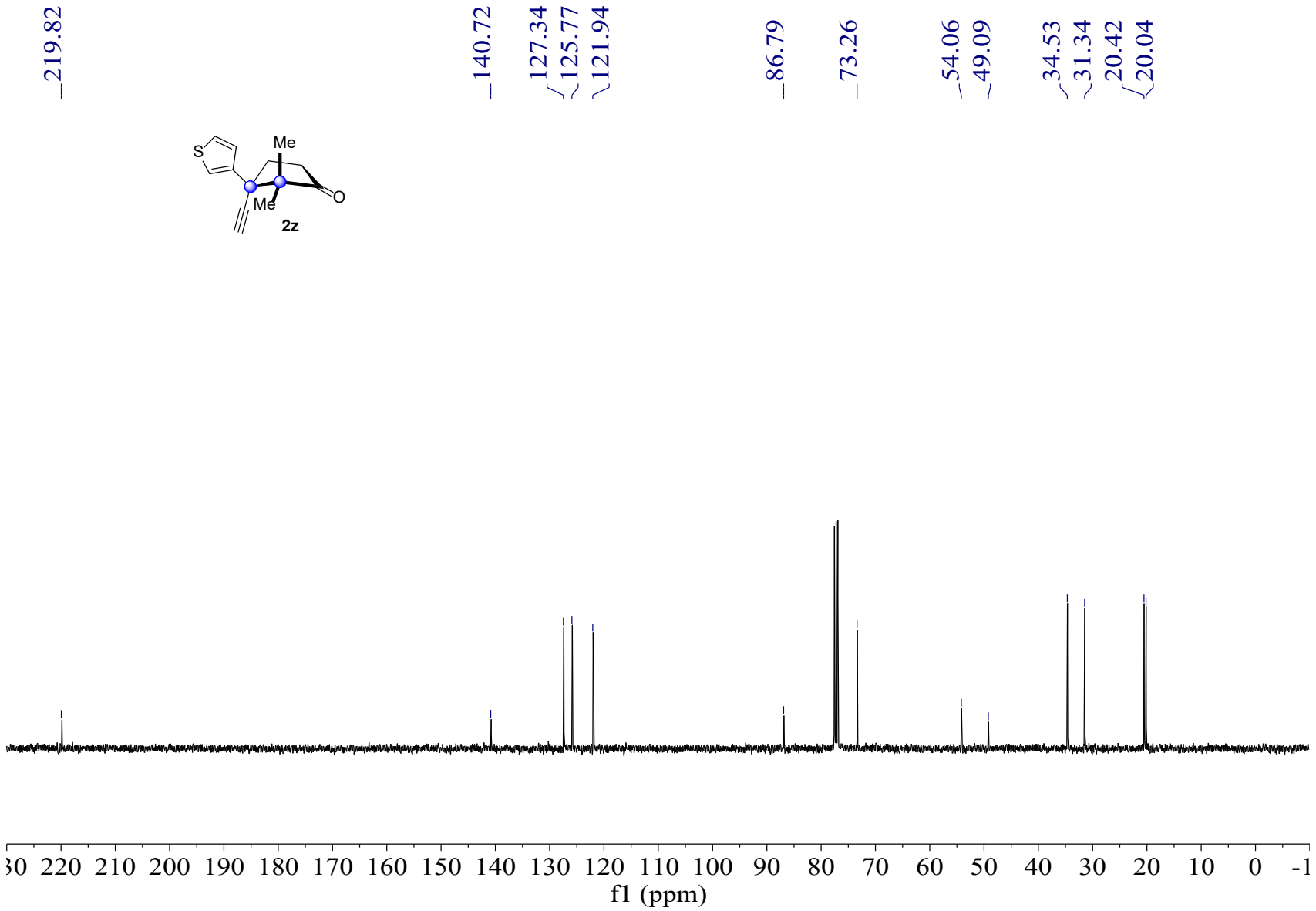
^{1}H NMR spectrum of compound **2y**



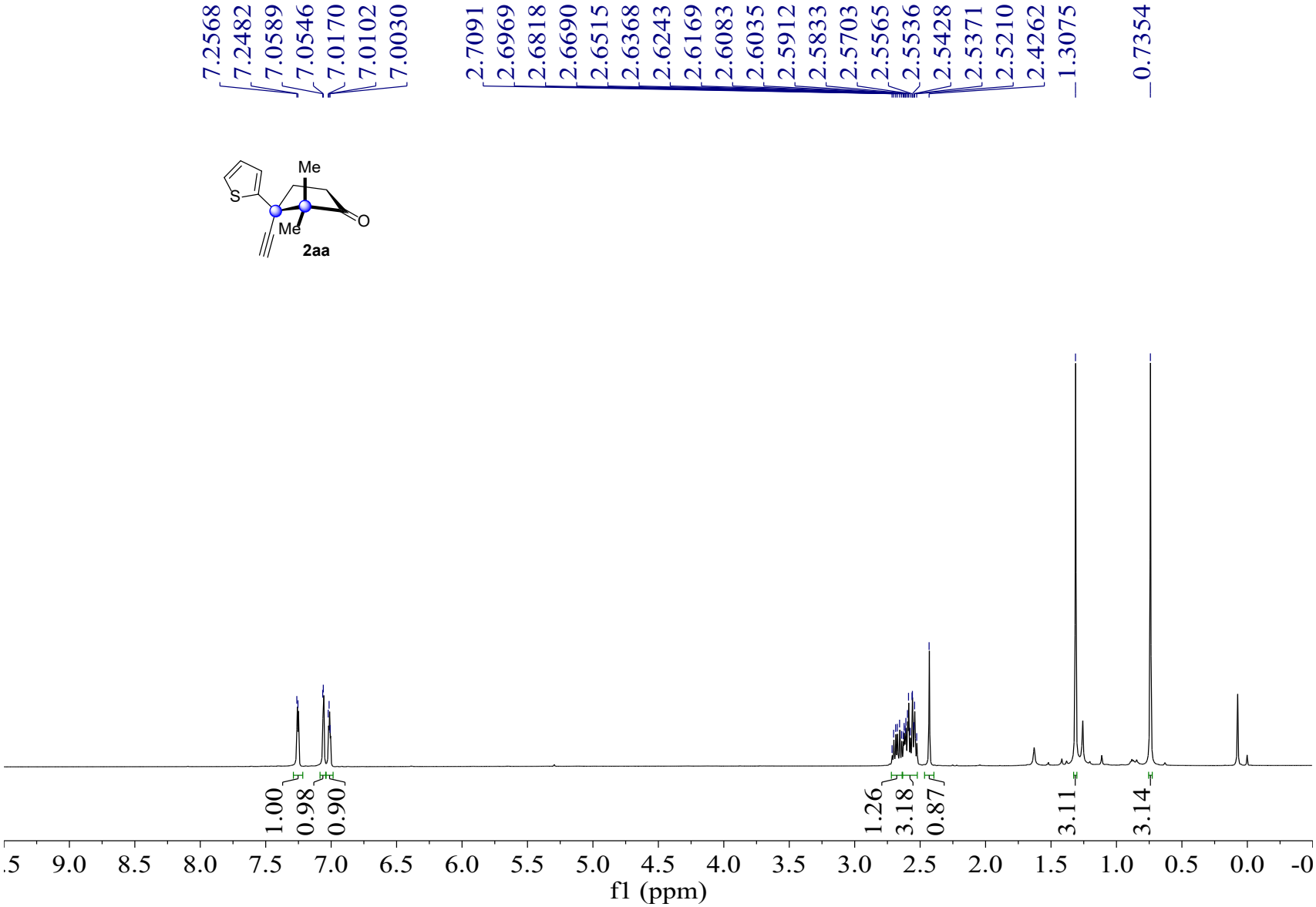
^{13}C NMR spectrum of compound **2y**



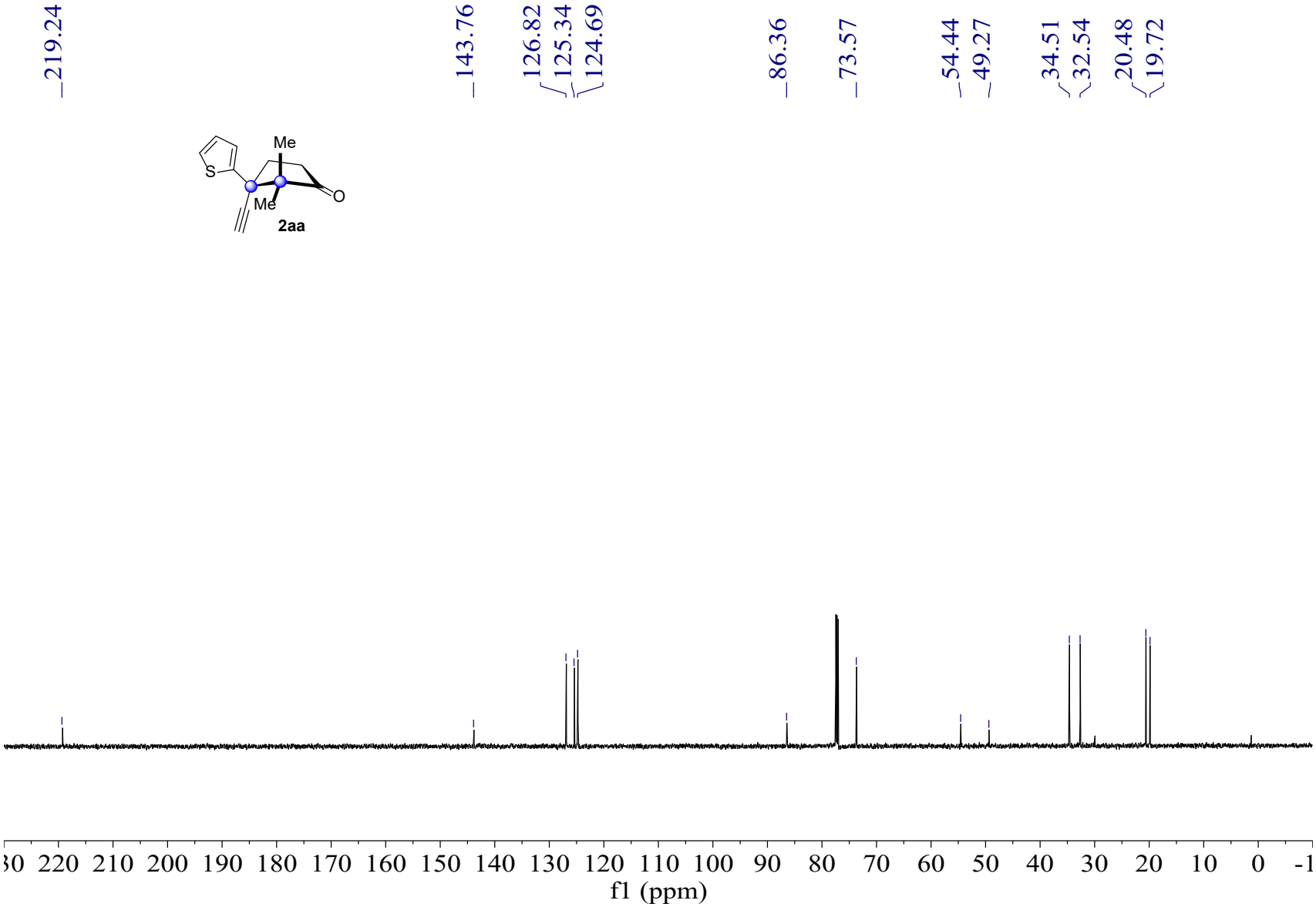
^{1}H NMR spectrum of compound **2z**



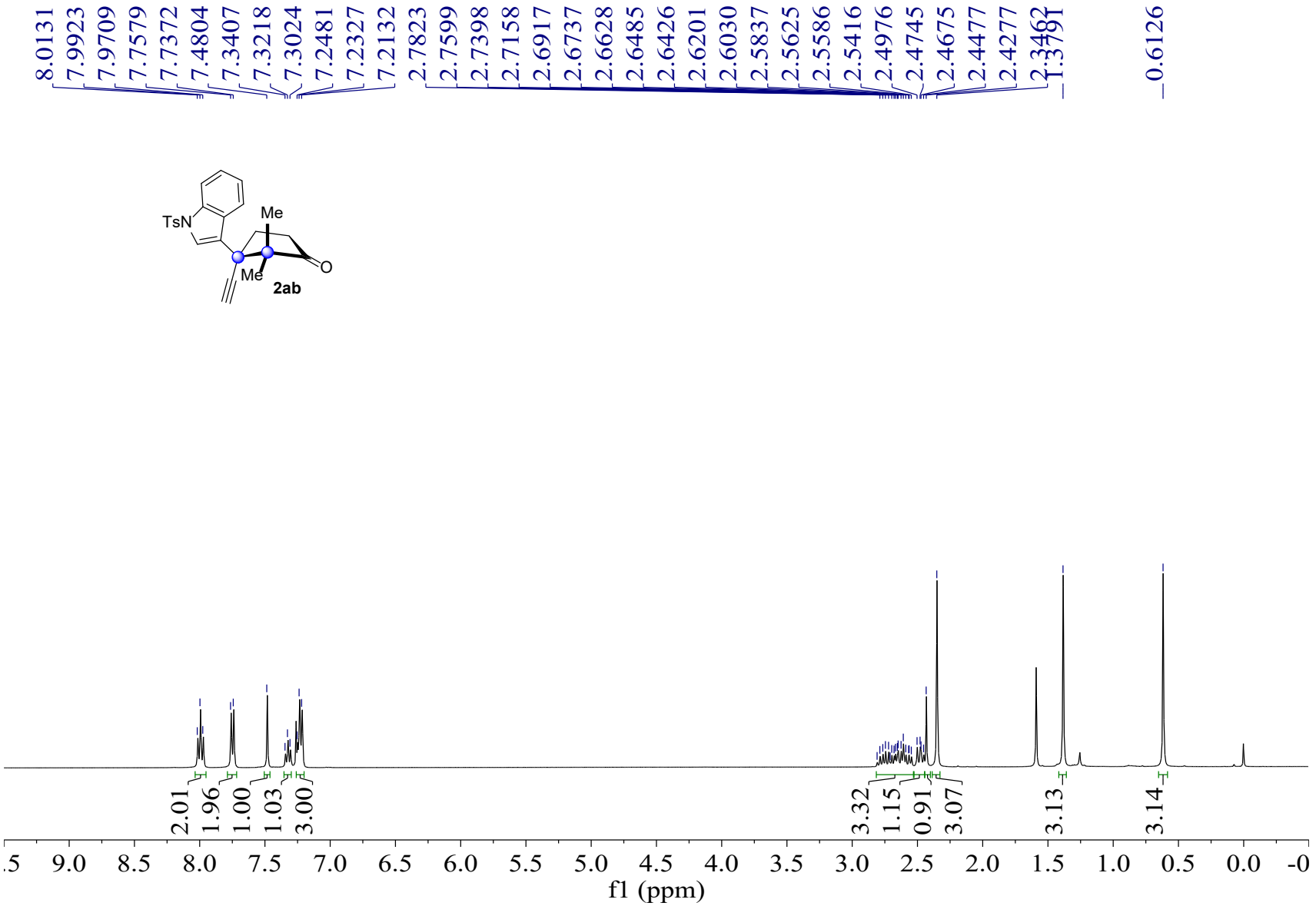
^{13}C NMR spectrum of compound **2z**



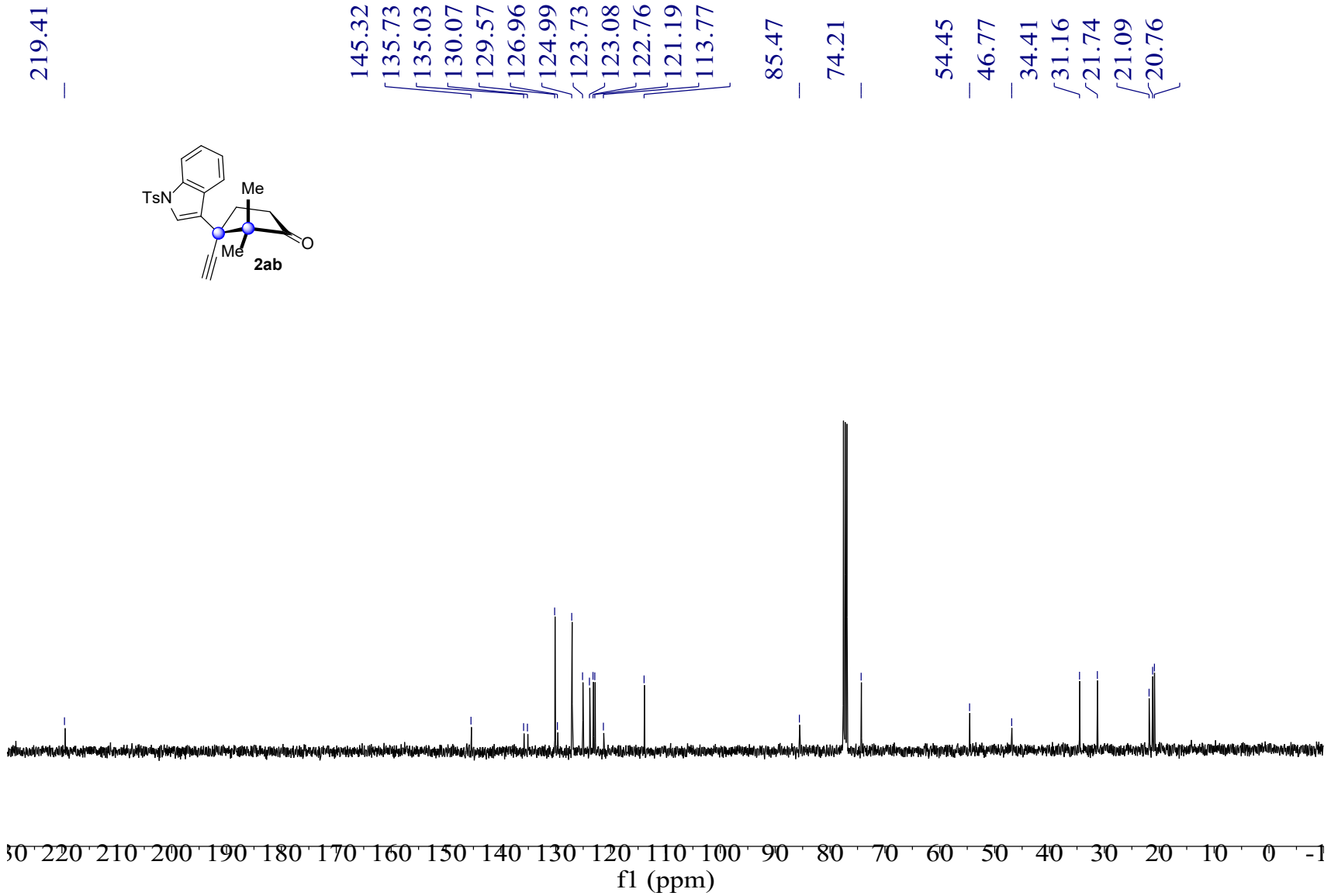
^{1}H NMR spectrum of compound **2aa**



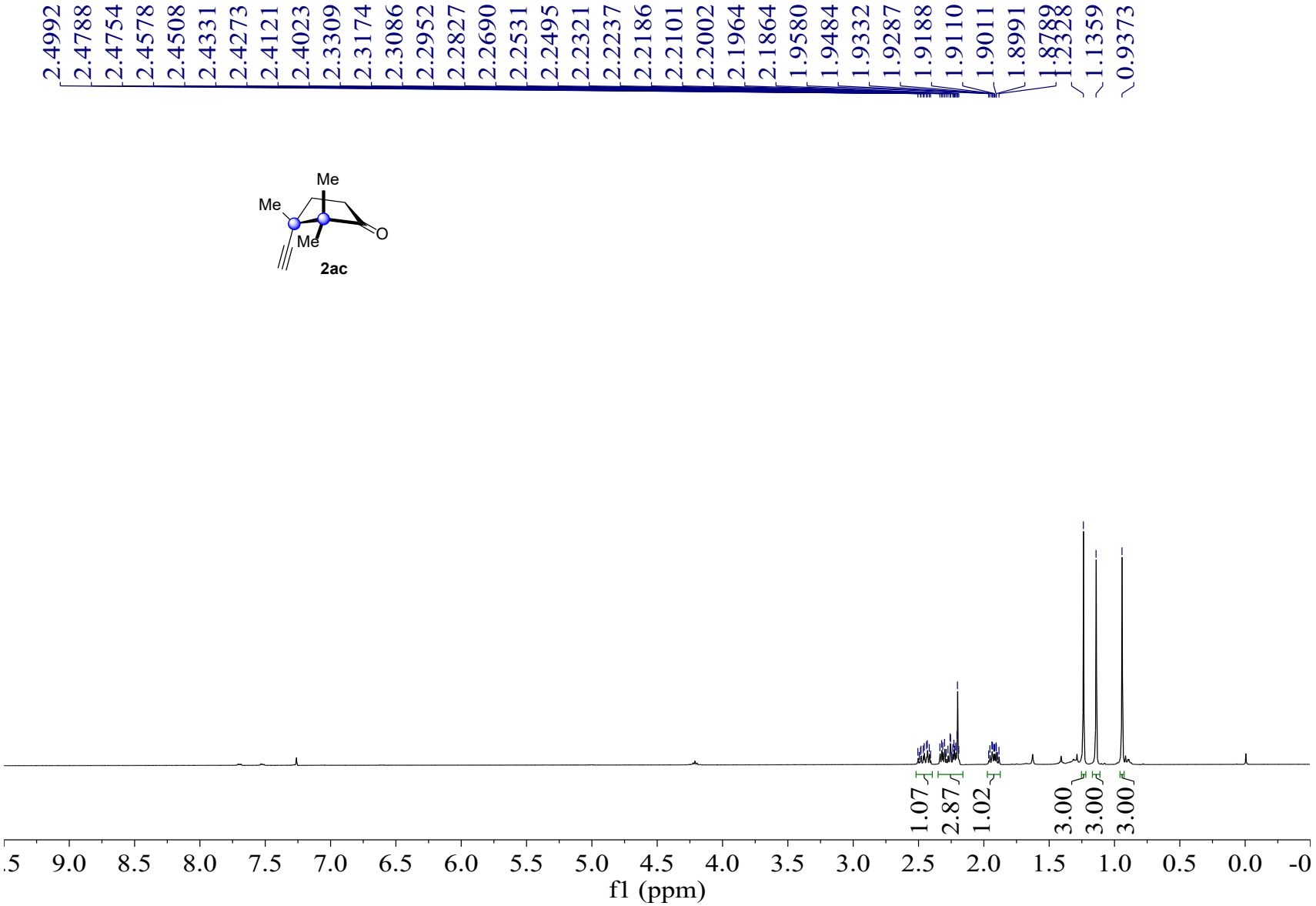
^{13}C NMR spectrum of compound **2aa**



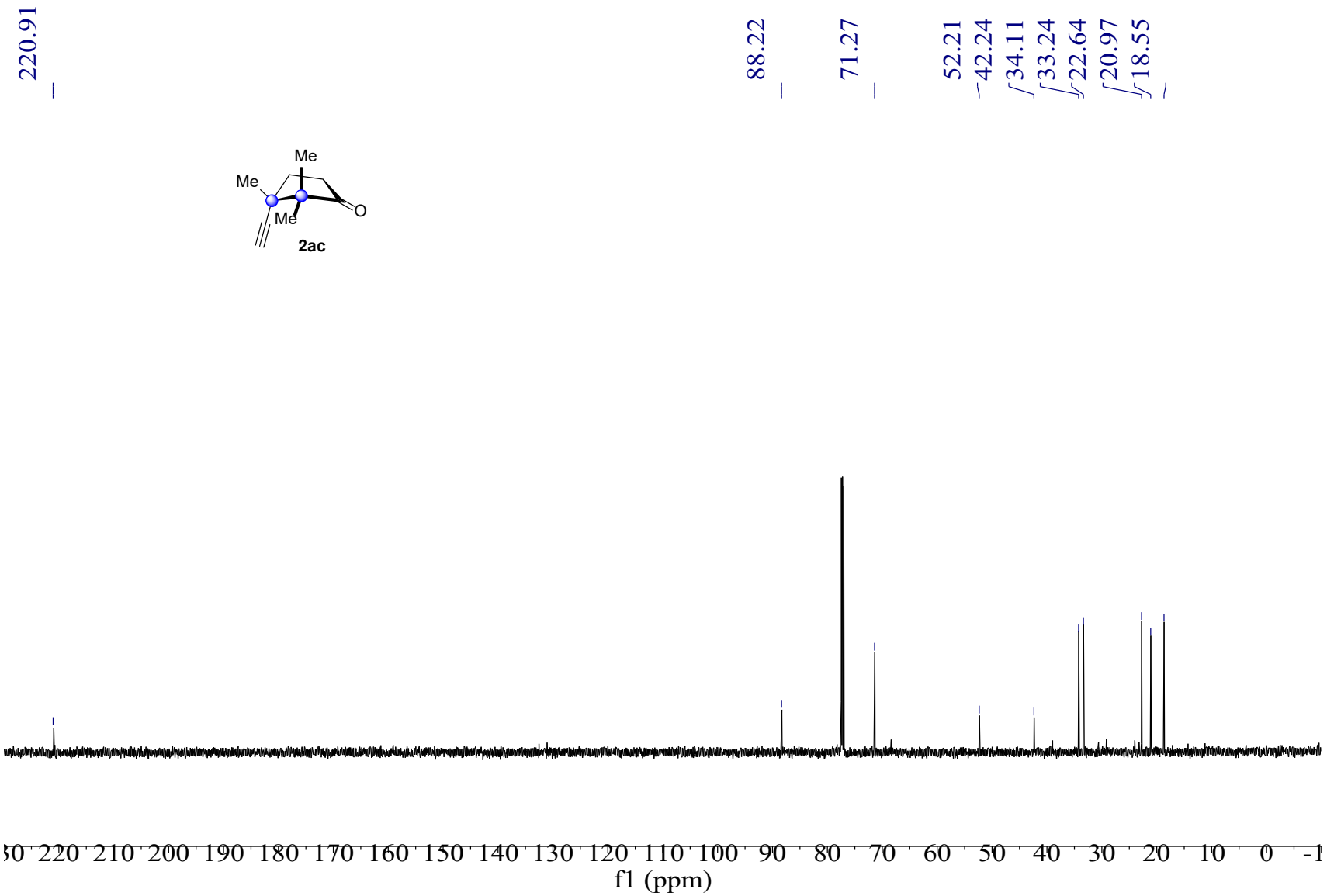
^{1}H NMR spectrum of compound **2ab**



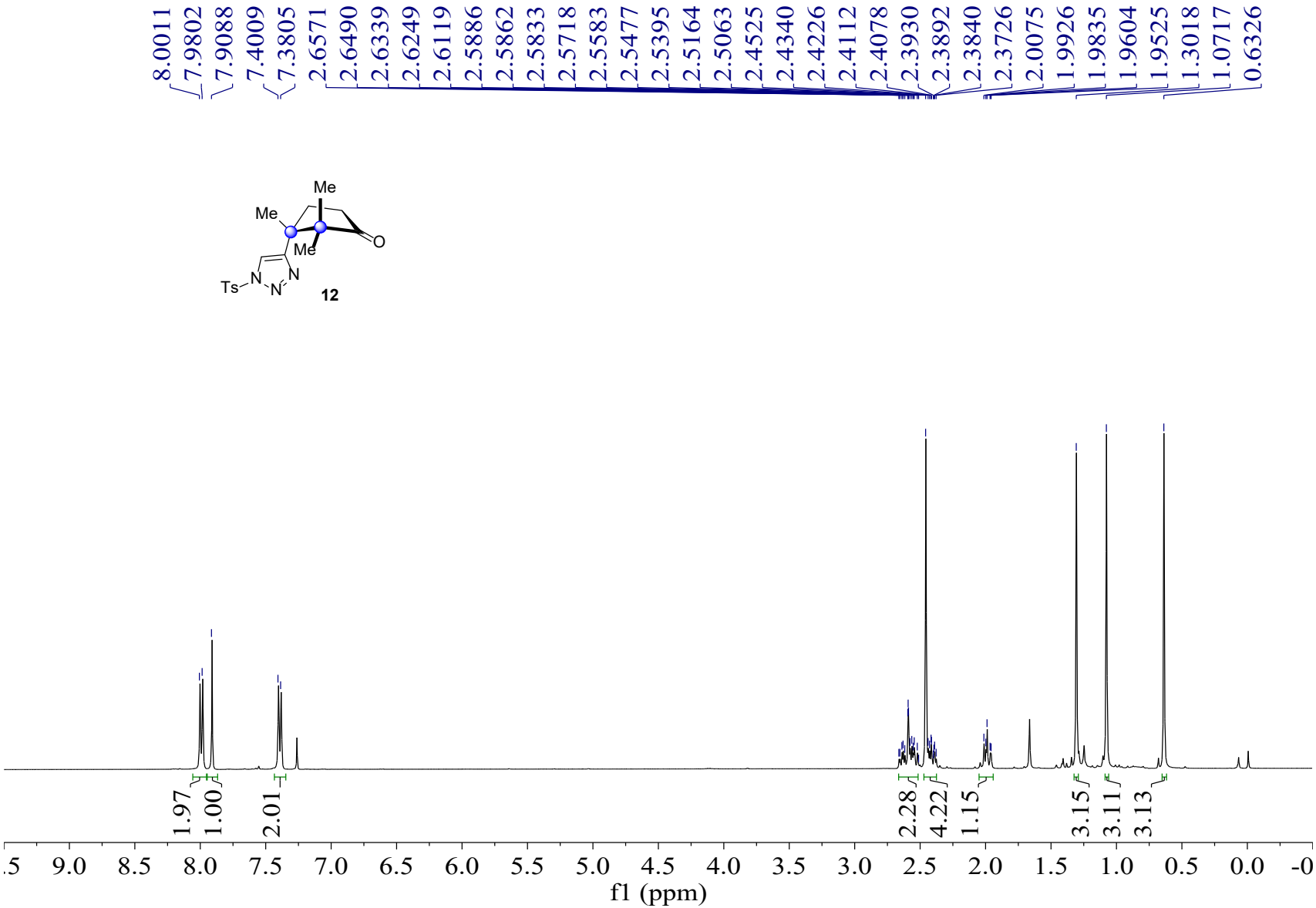
^{13}C NMR spectrum of compound **2ab**



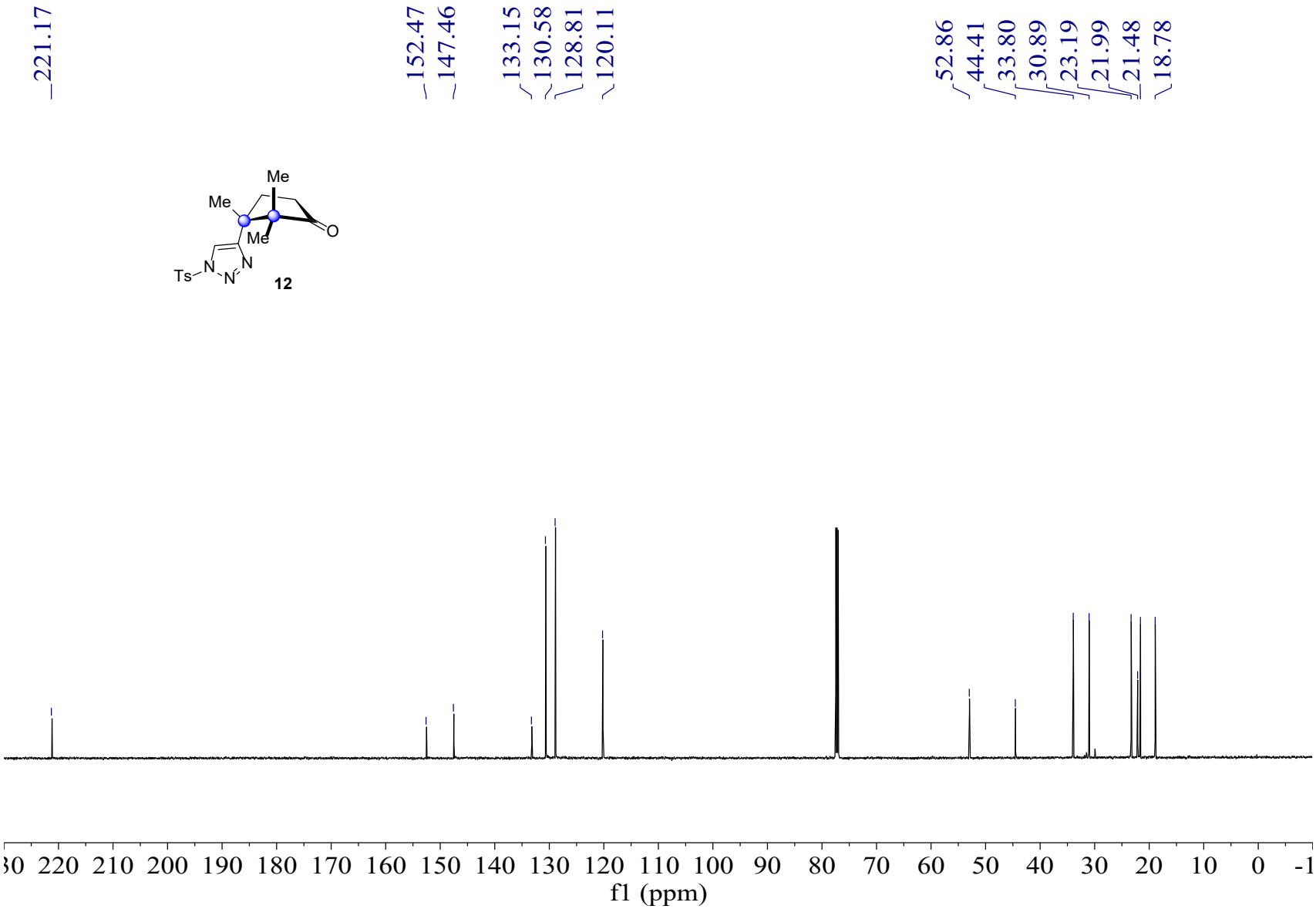
^{1}H NMR spectrum of compound **2ac**



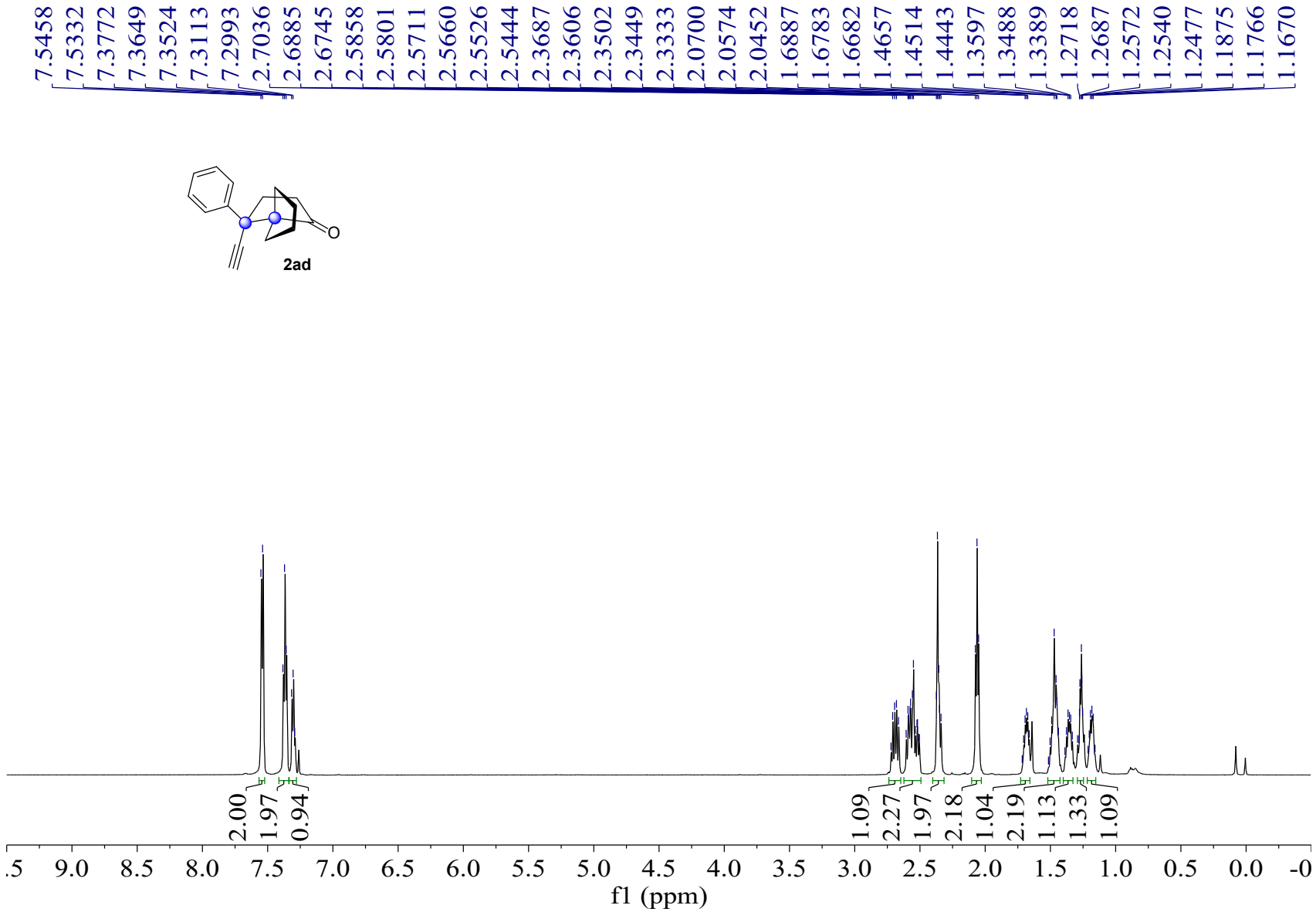
^{13}C NMR spectrum of compound **2ac**



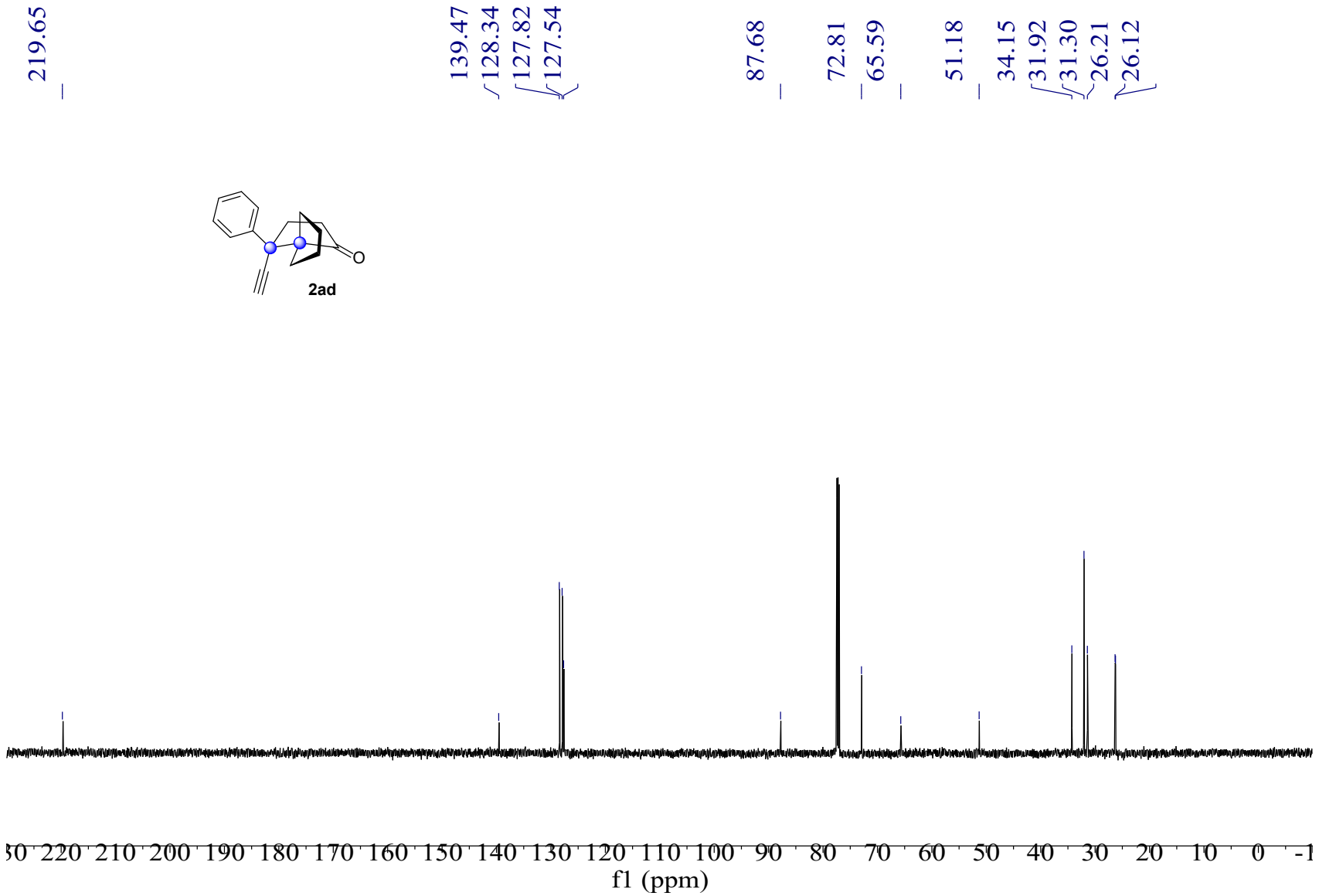
^{1}H NMR spectrum of compound **12**



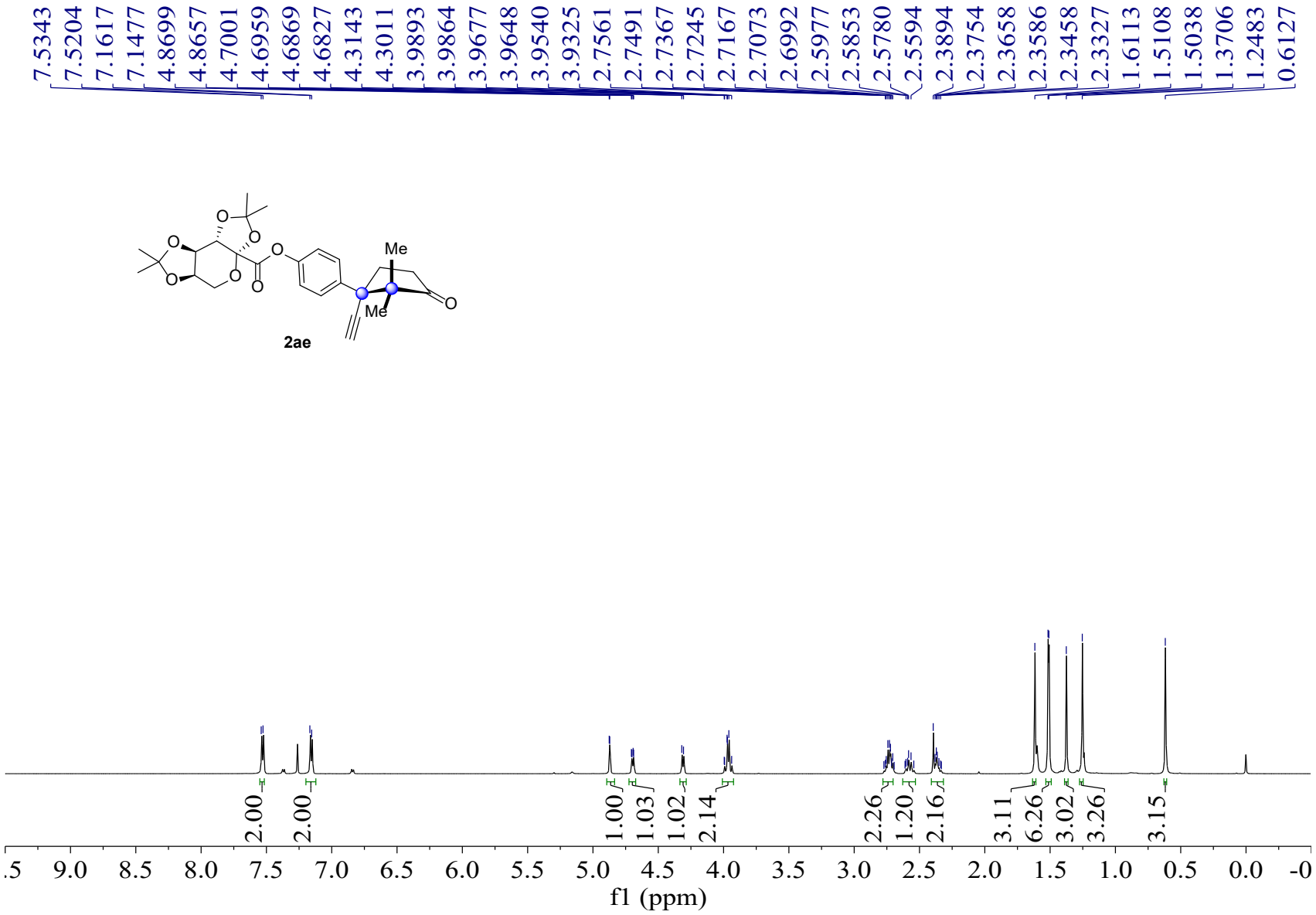
^{13}C NMR spectrum of compound **12**



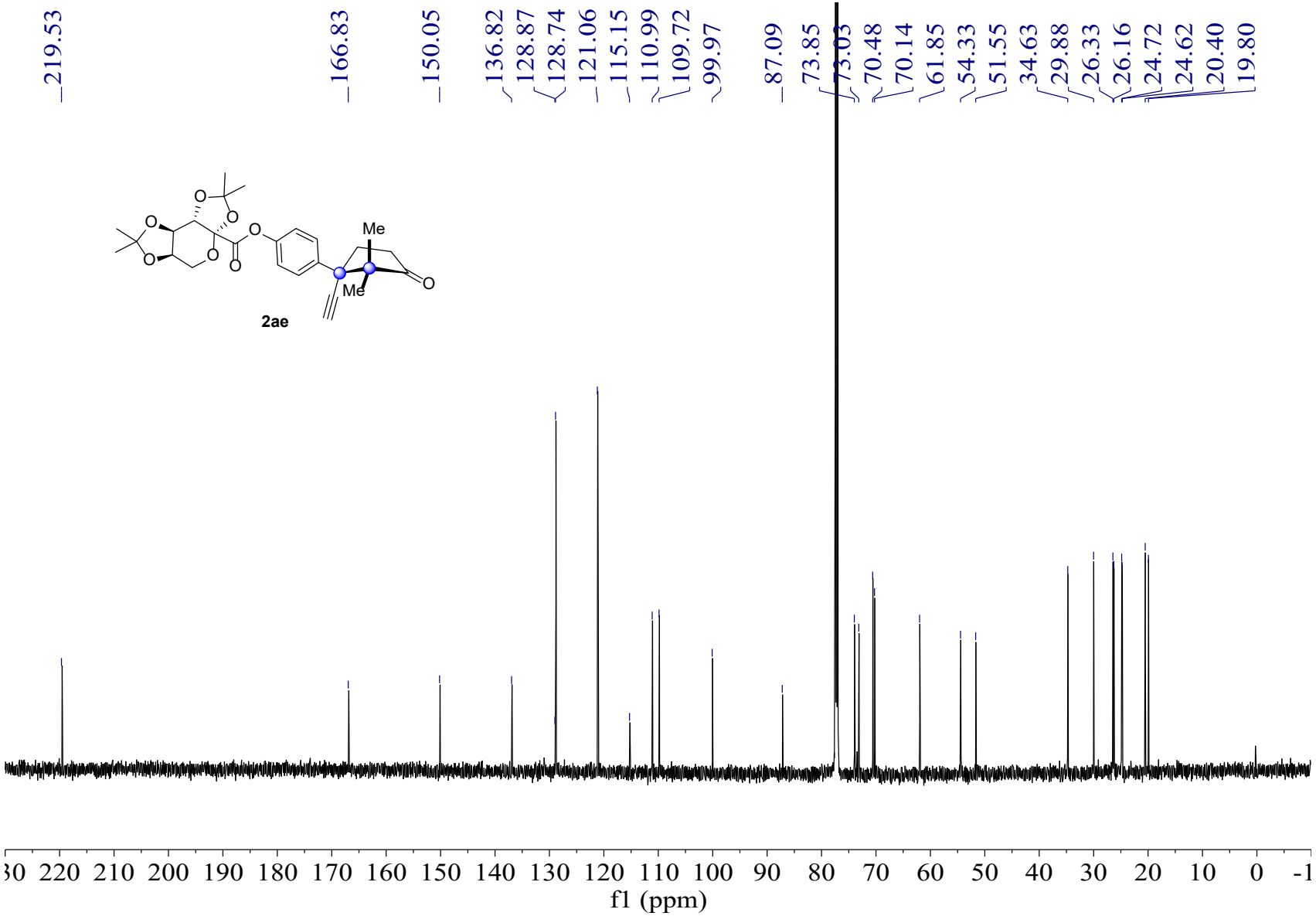
^{1}H NMR spectrum of compound **2ad**



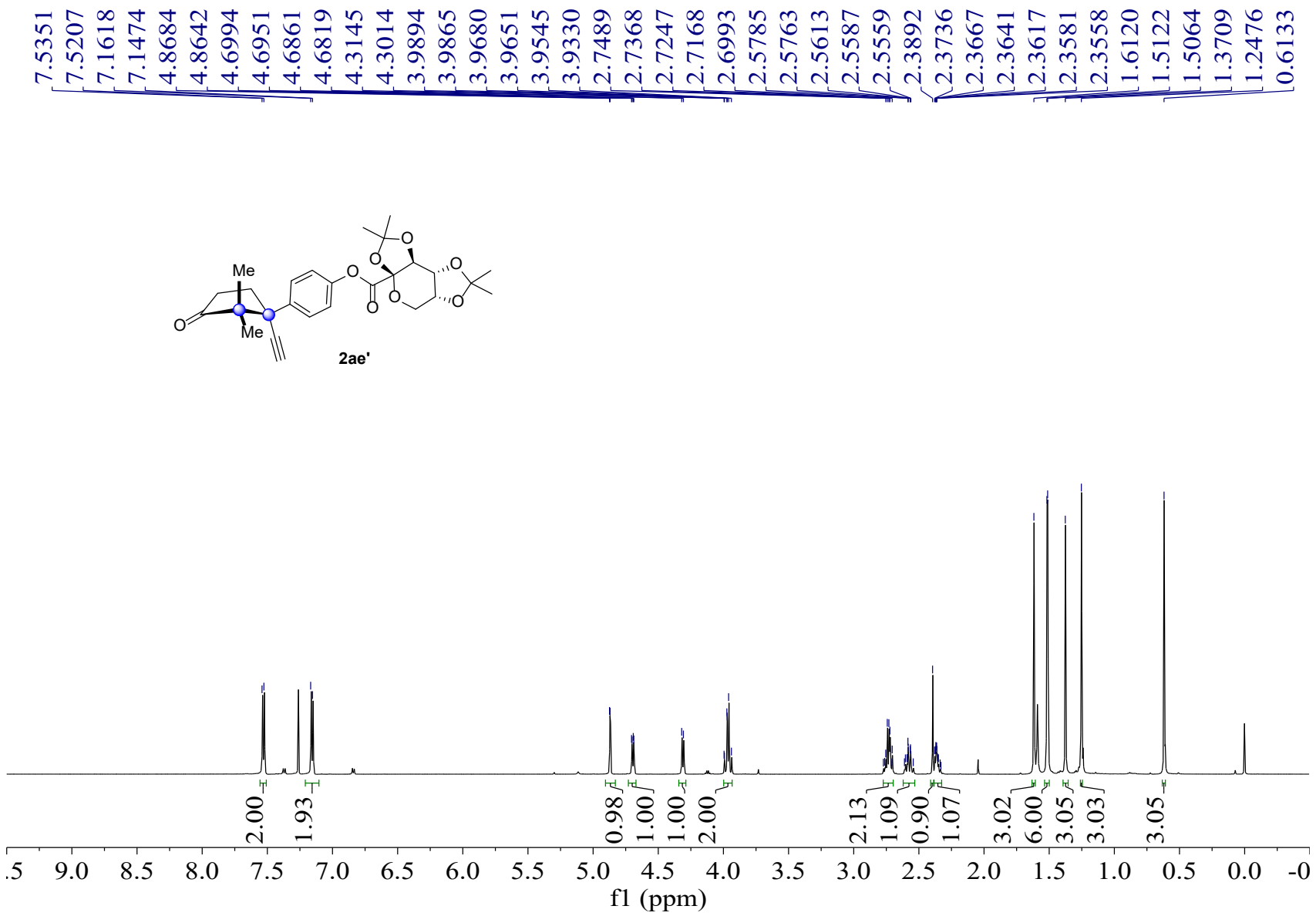
^{13}C NMR spectrum of compound **2ad**



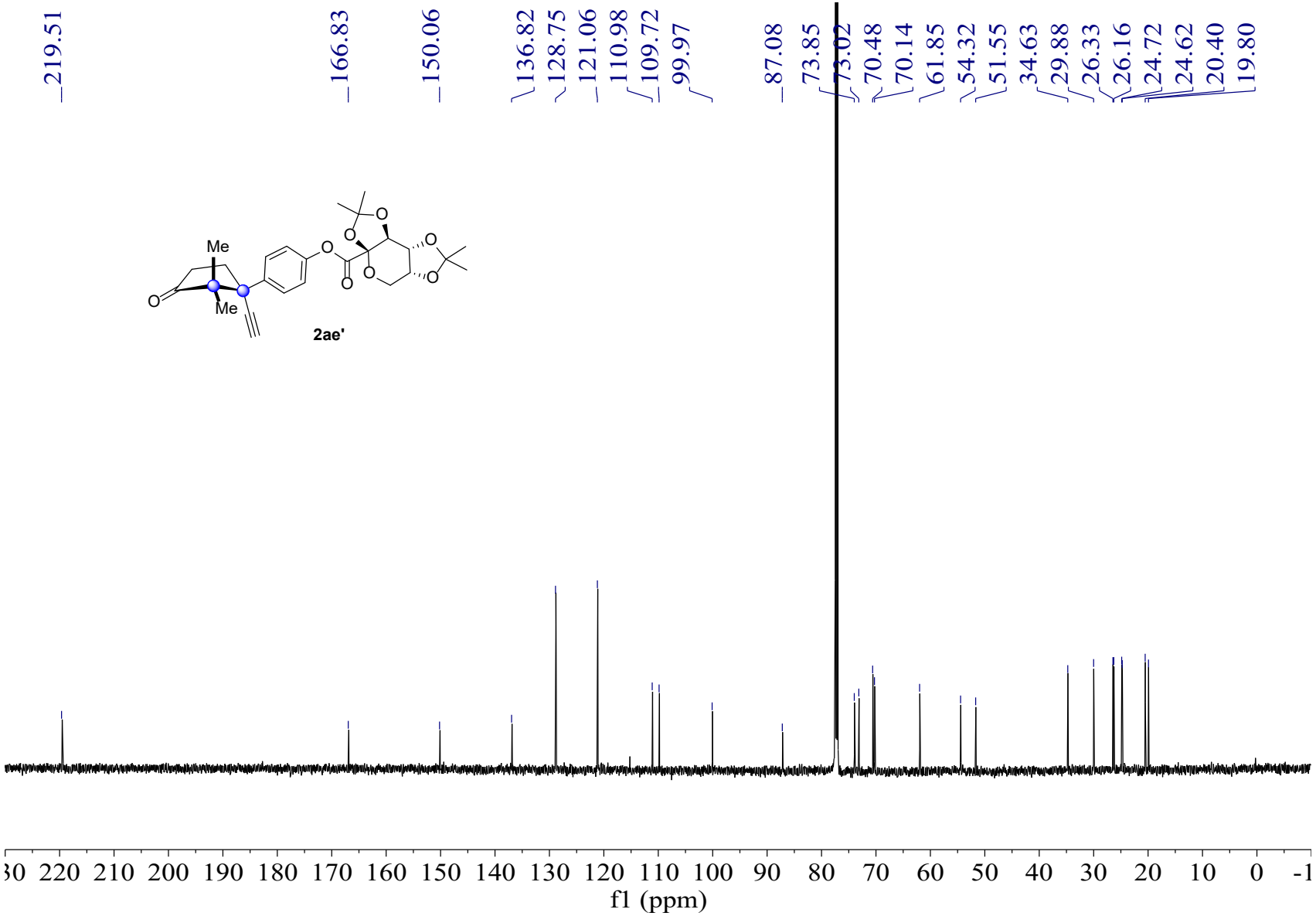
^{1}H NMR spectrum of compound **2ae**



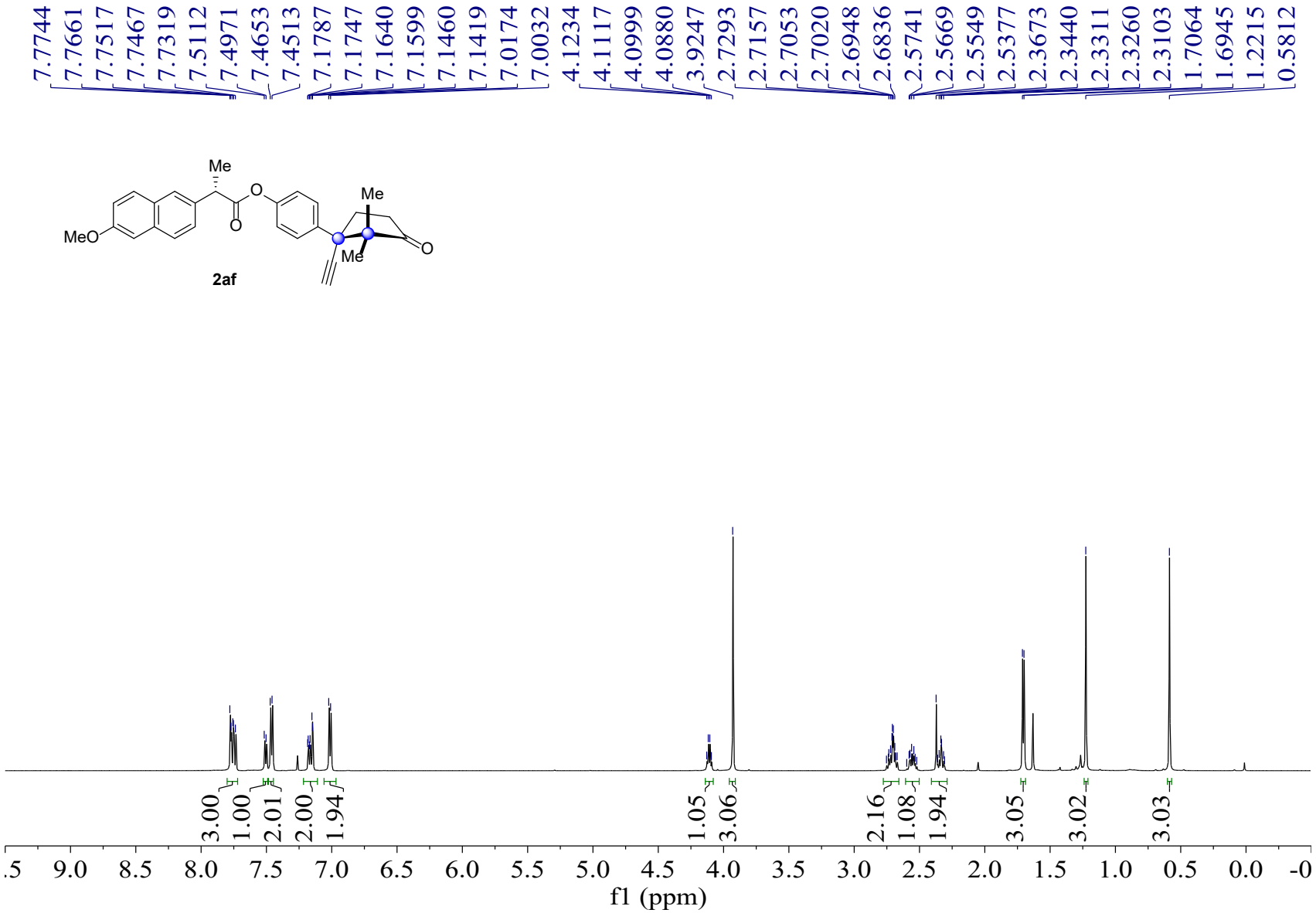
^{13}C NMR spectrum of compound **2ae**



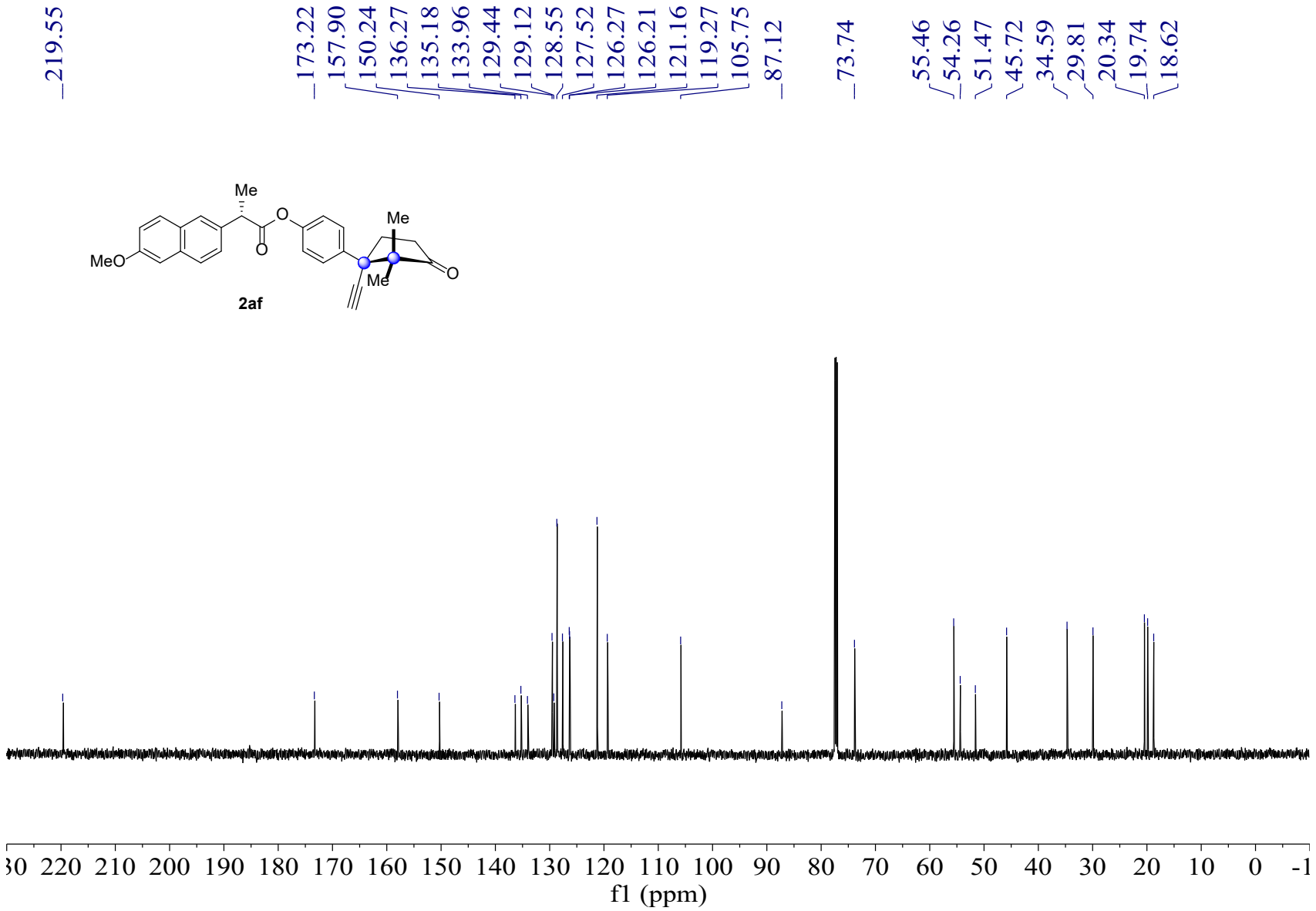
^{1}H NMR spectrum of compound **2ae'**



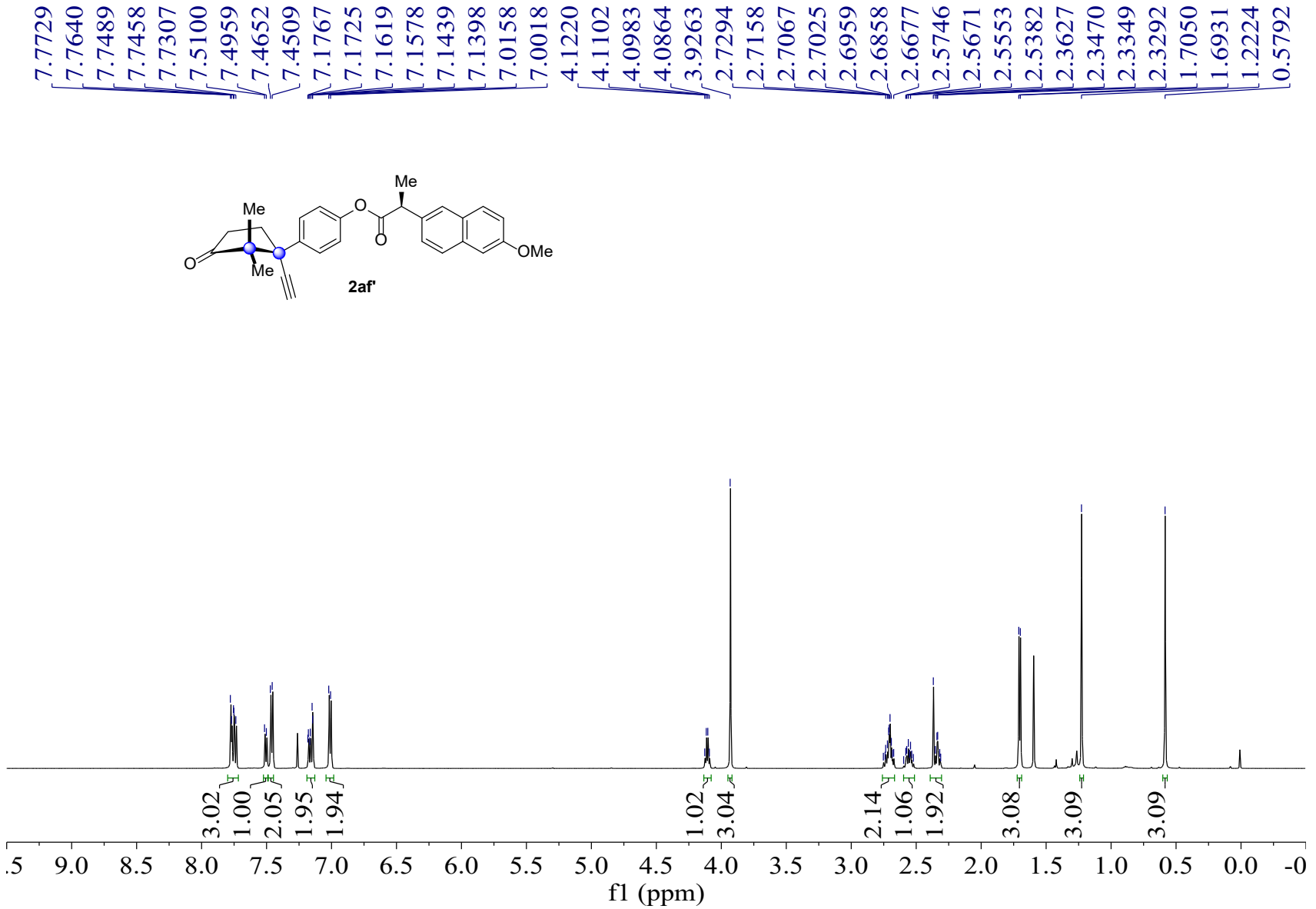
^{13}C NMR spectrum of compound **2ae'**



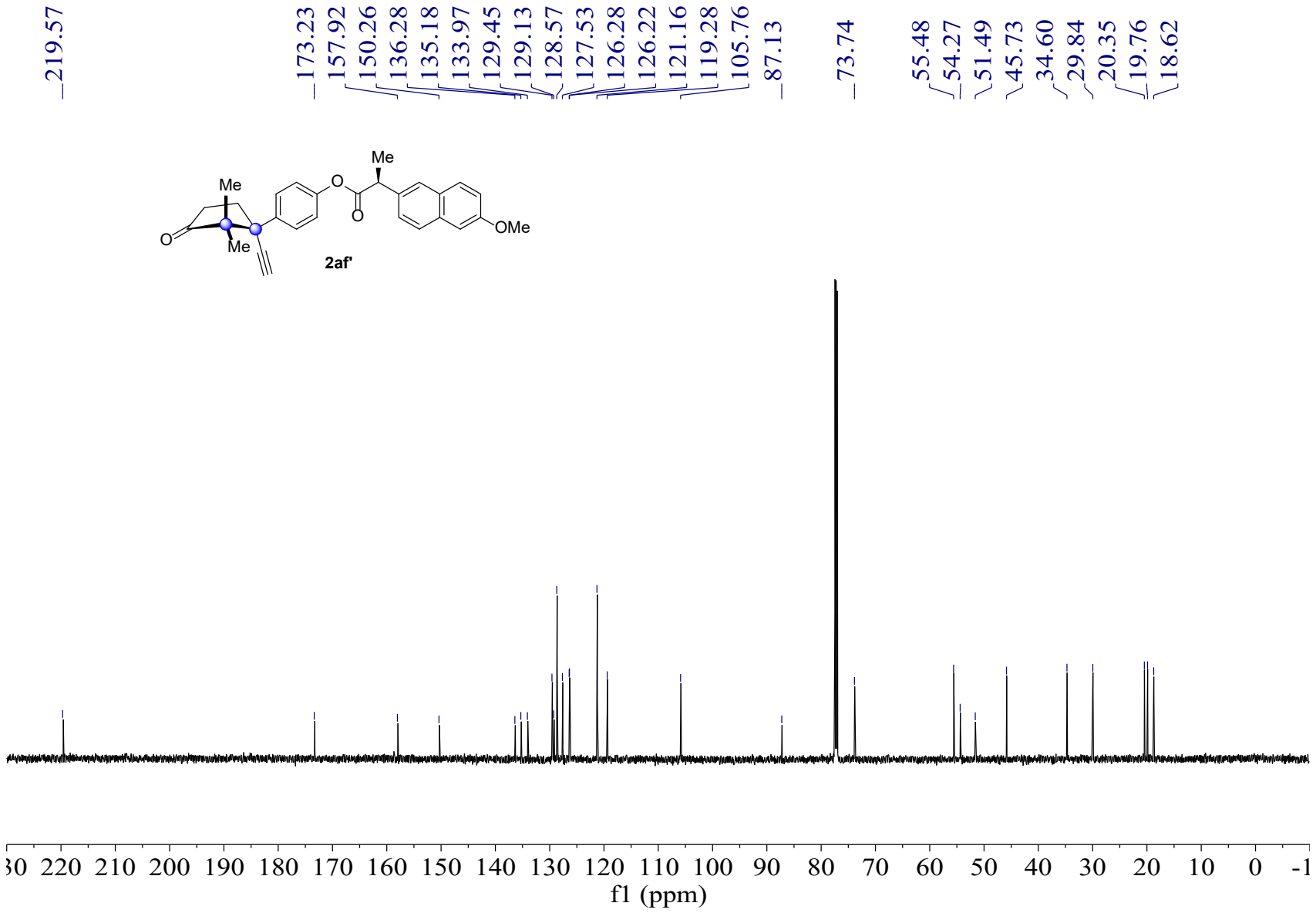
^{1}H NMR spectrum of compound **2af**



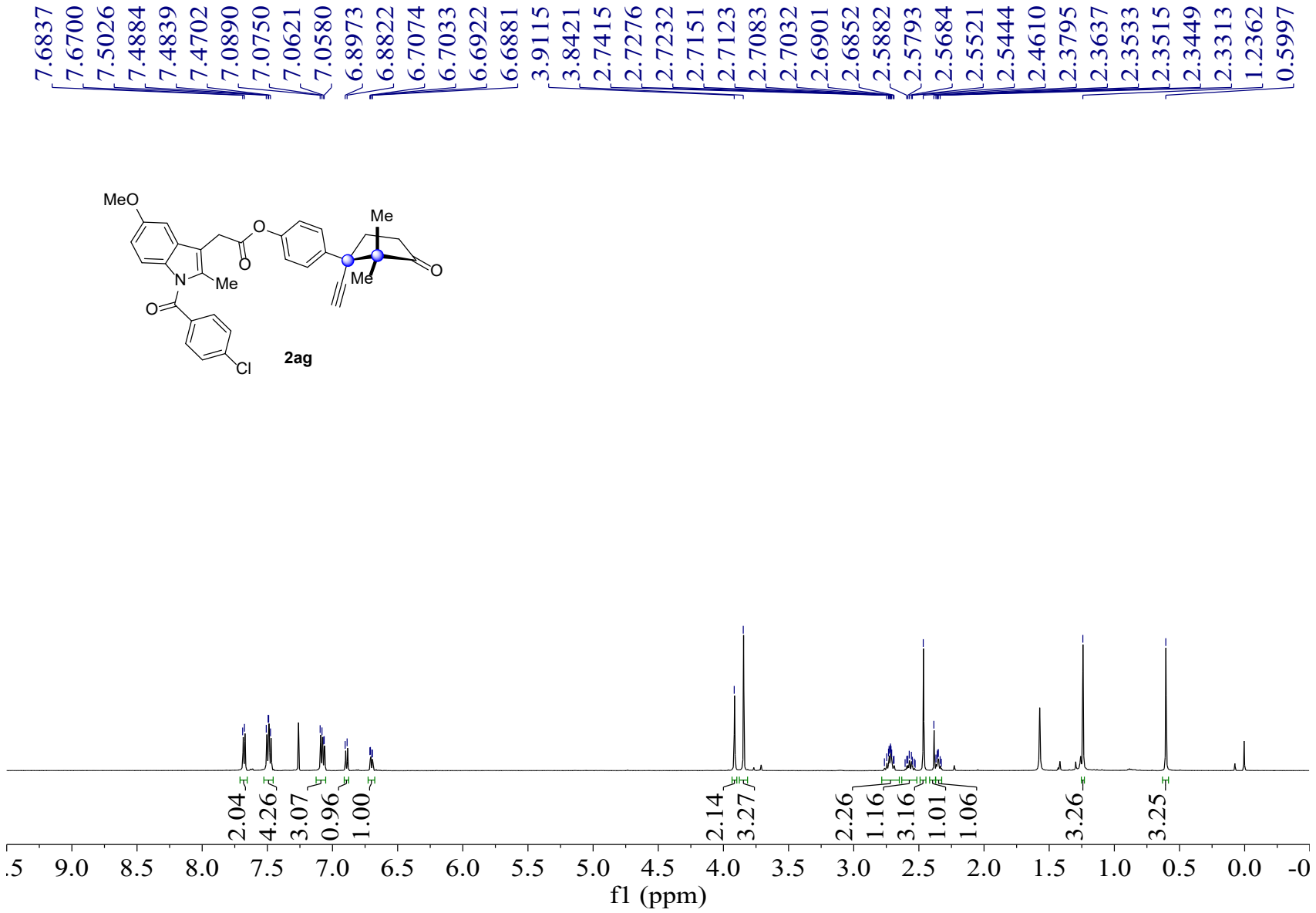
^{13}C NMR spectrum of compound **2af**



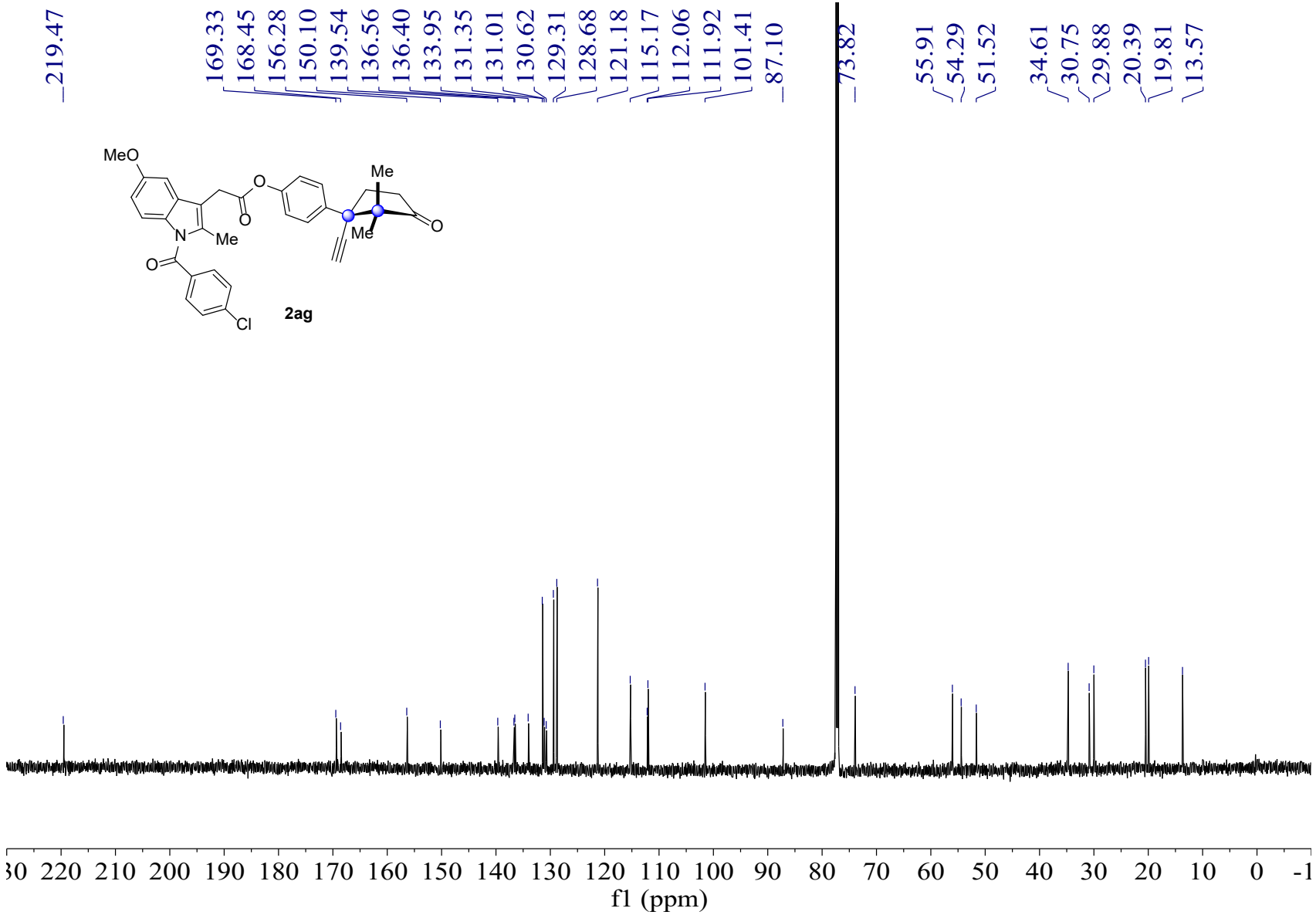
^{1}H NMR spectrum of compound **2af'**



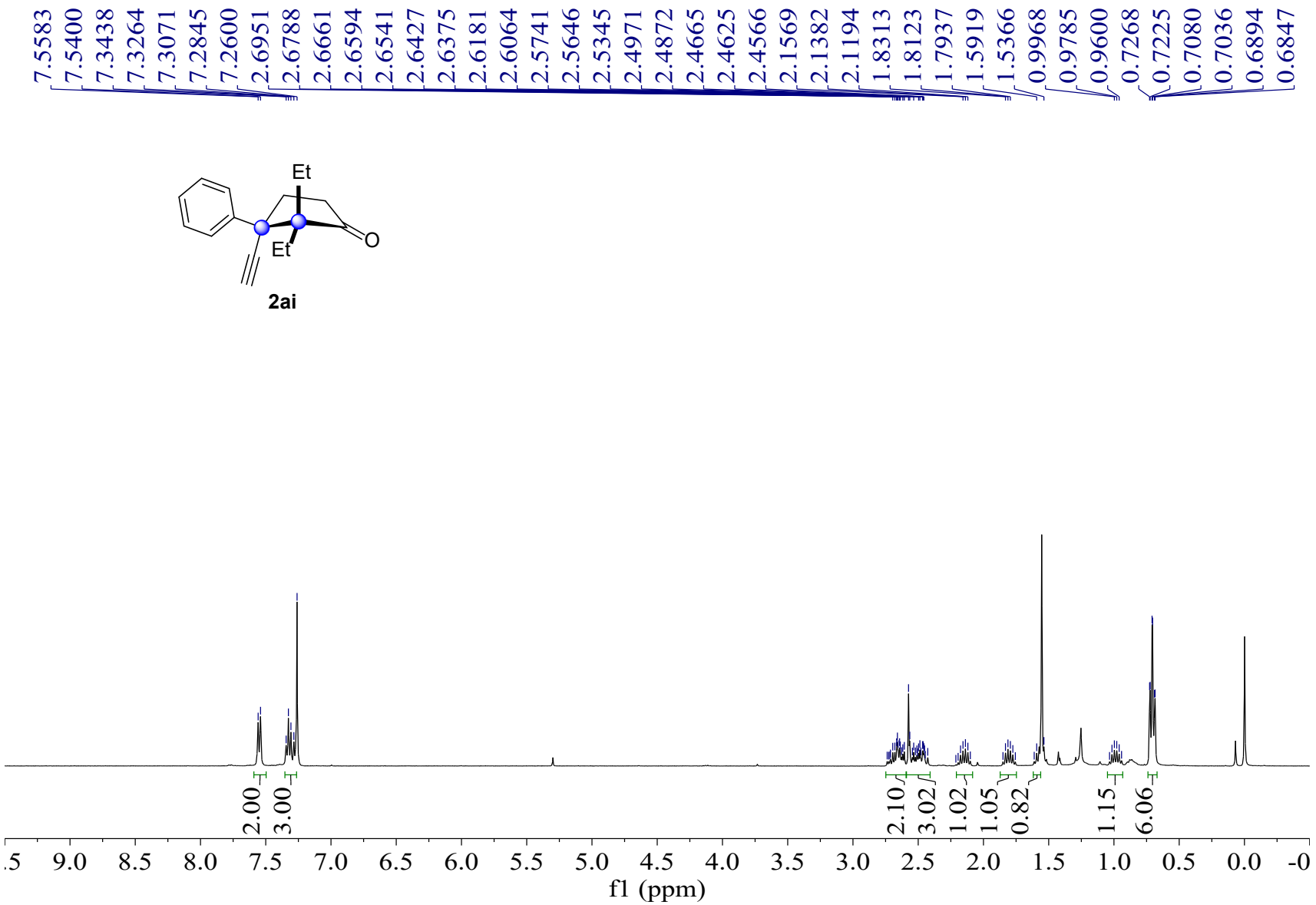
^{13}C NMR spectrum of compound **2af'**



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

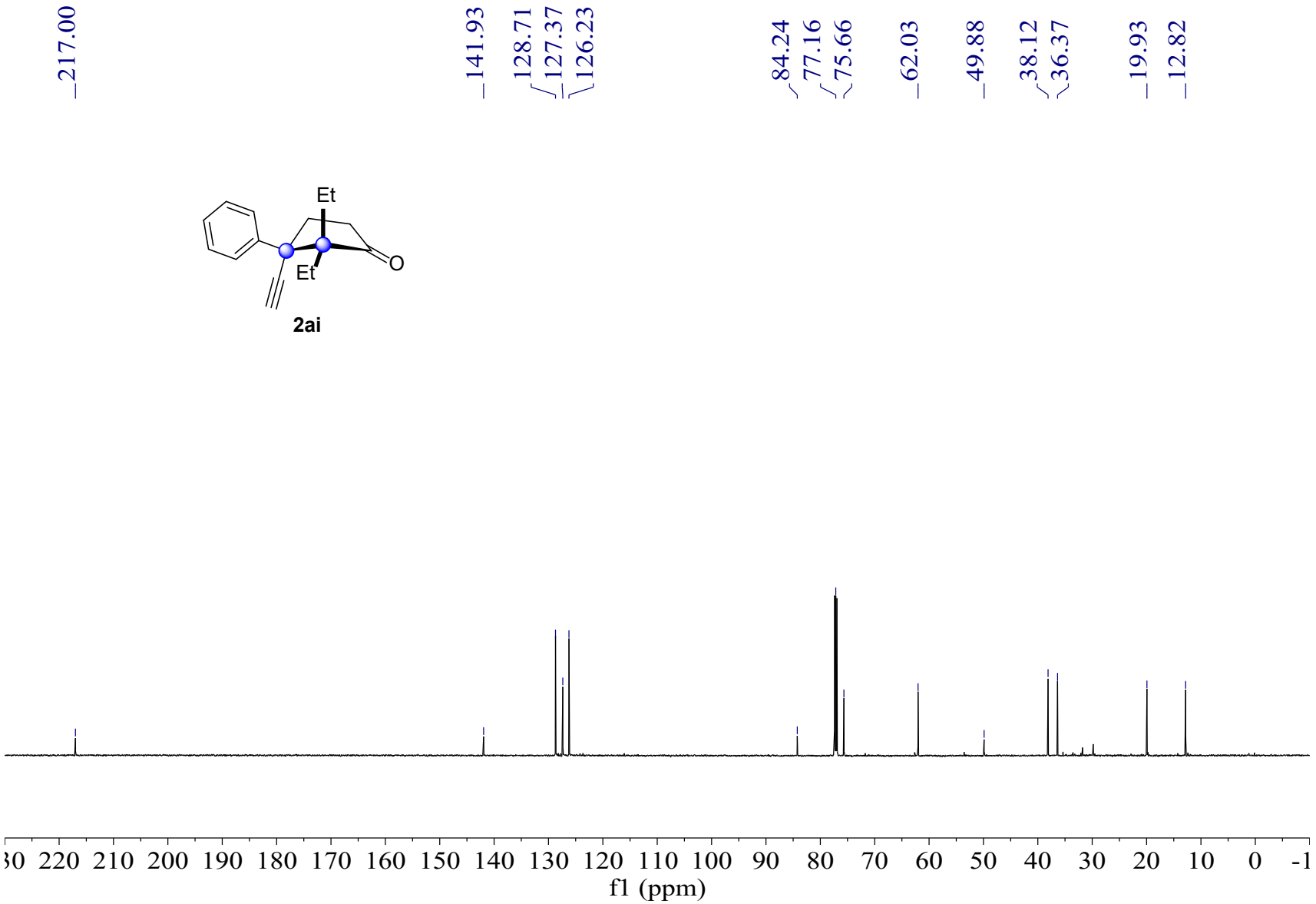


^{13}C NMR spectrum of compound **2ag**

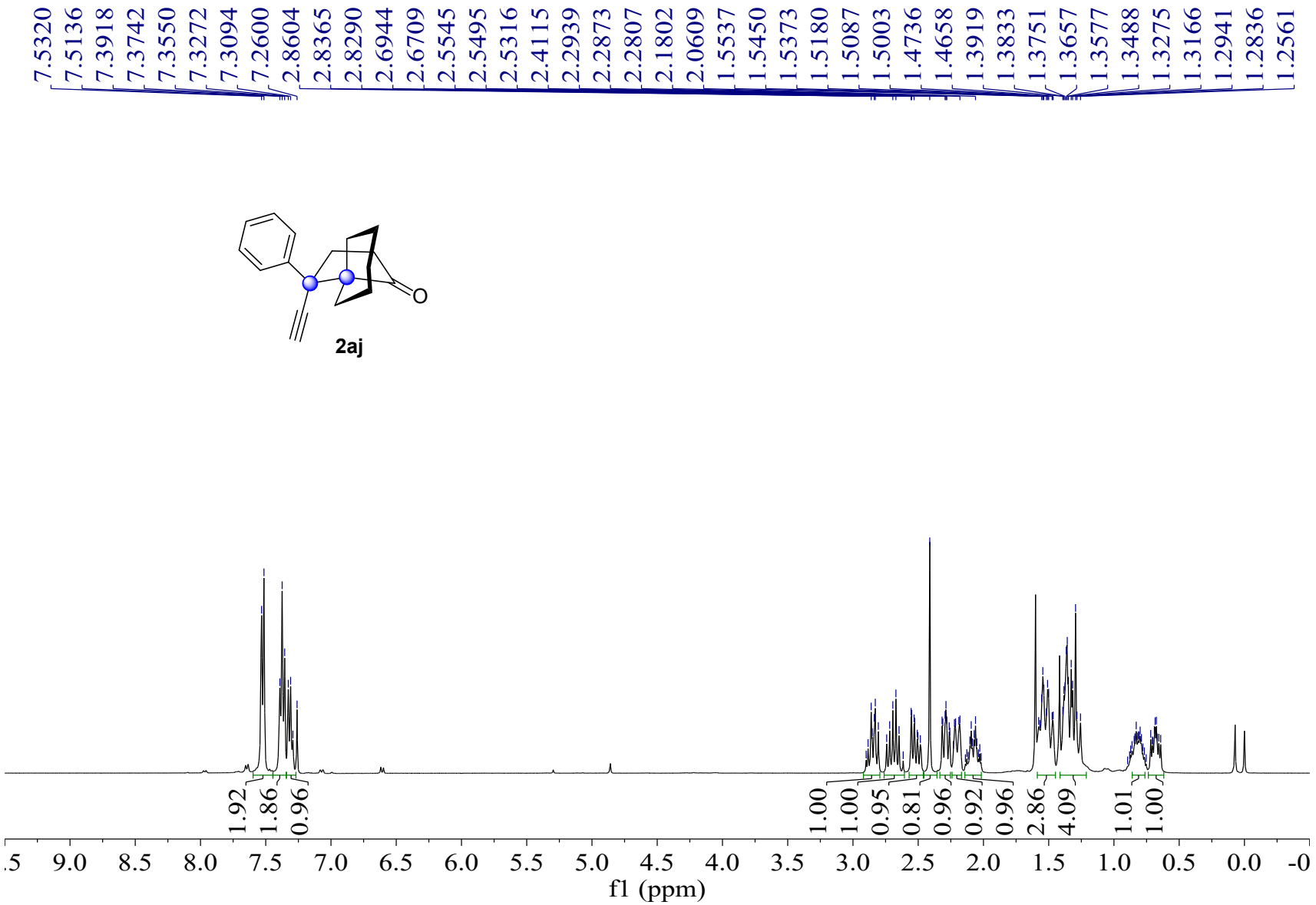


2ai

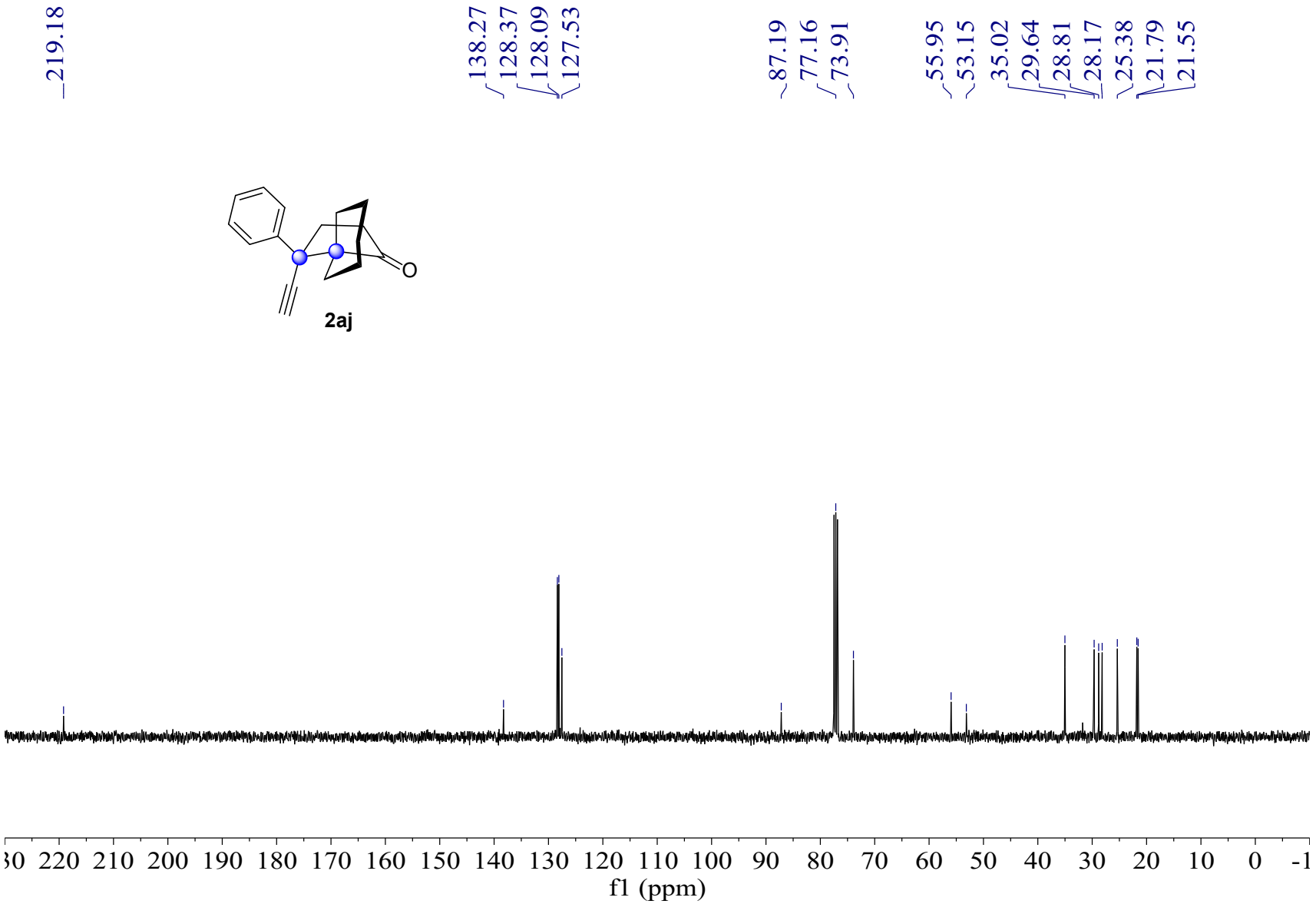
^{1}H NMR spectrum of compound **2ai**



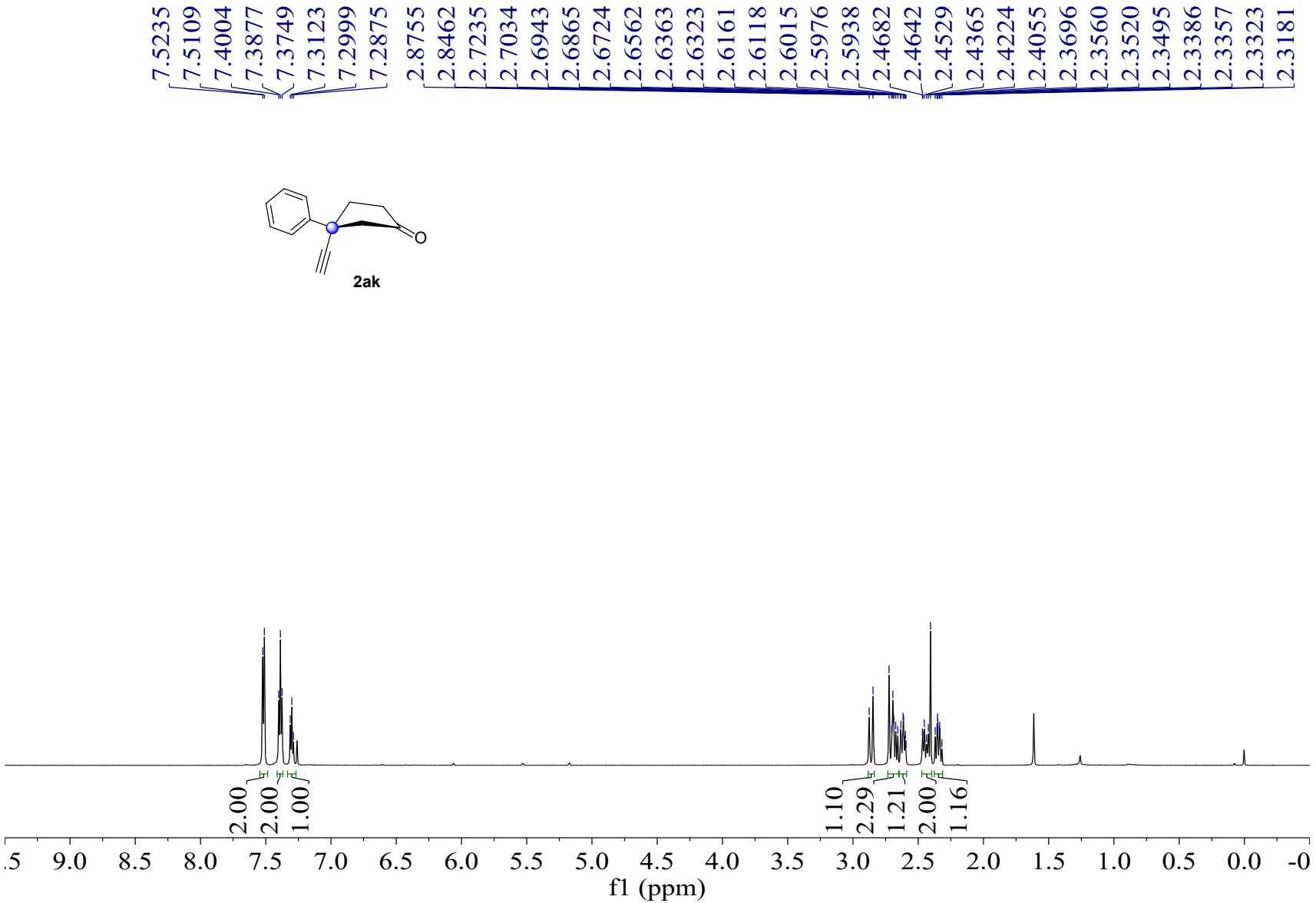
^{13}C NMR spectrum of compound **2ai**



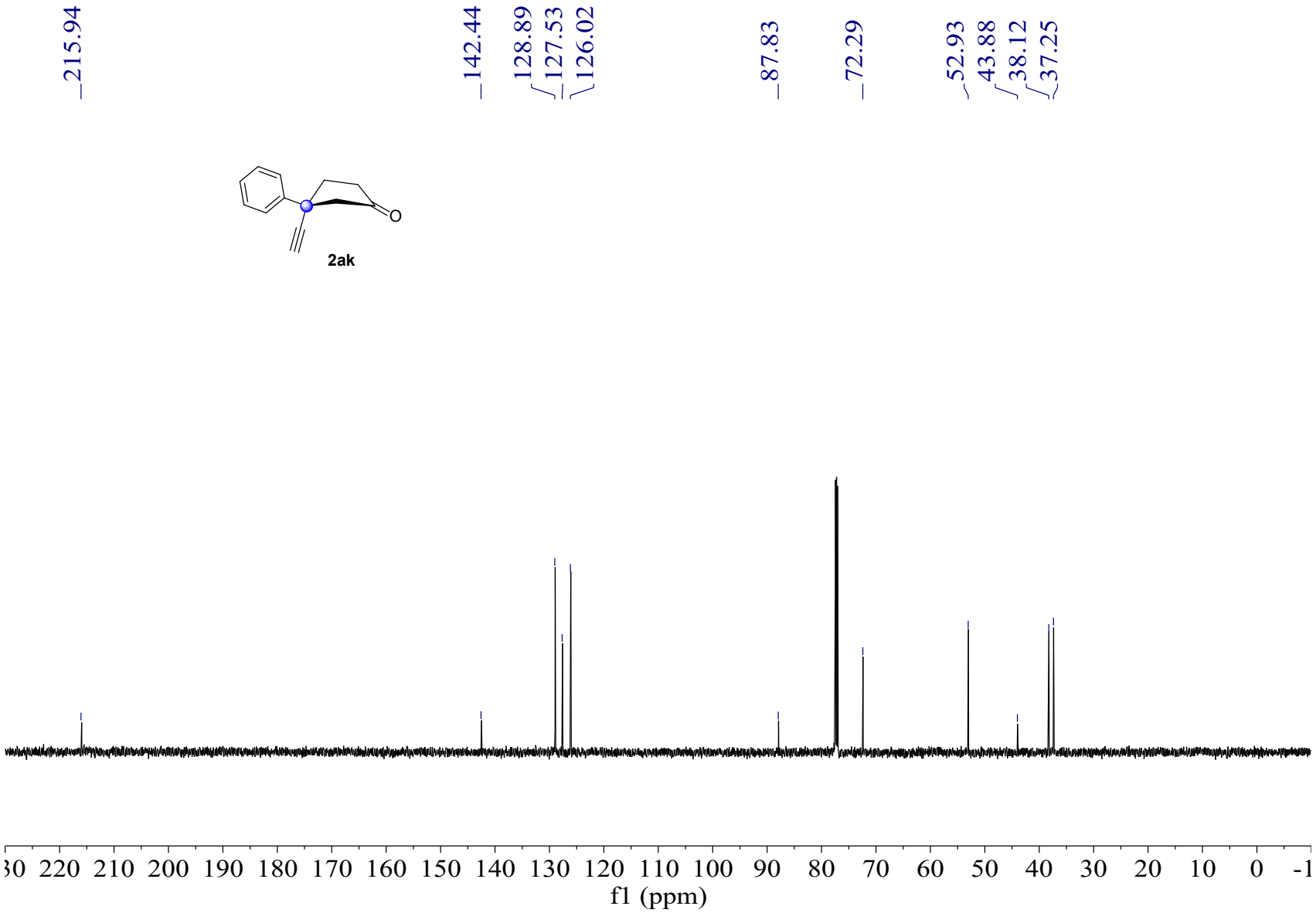
^{1}H NMR spectrum of compound **2aj**



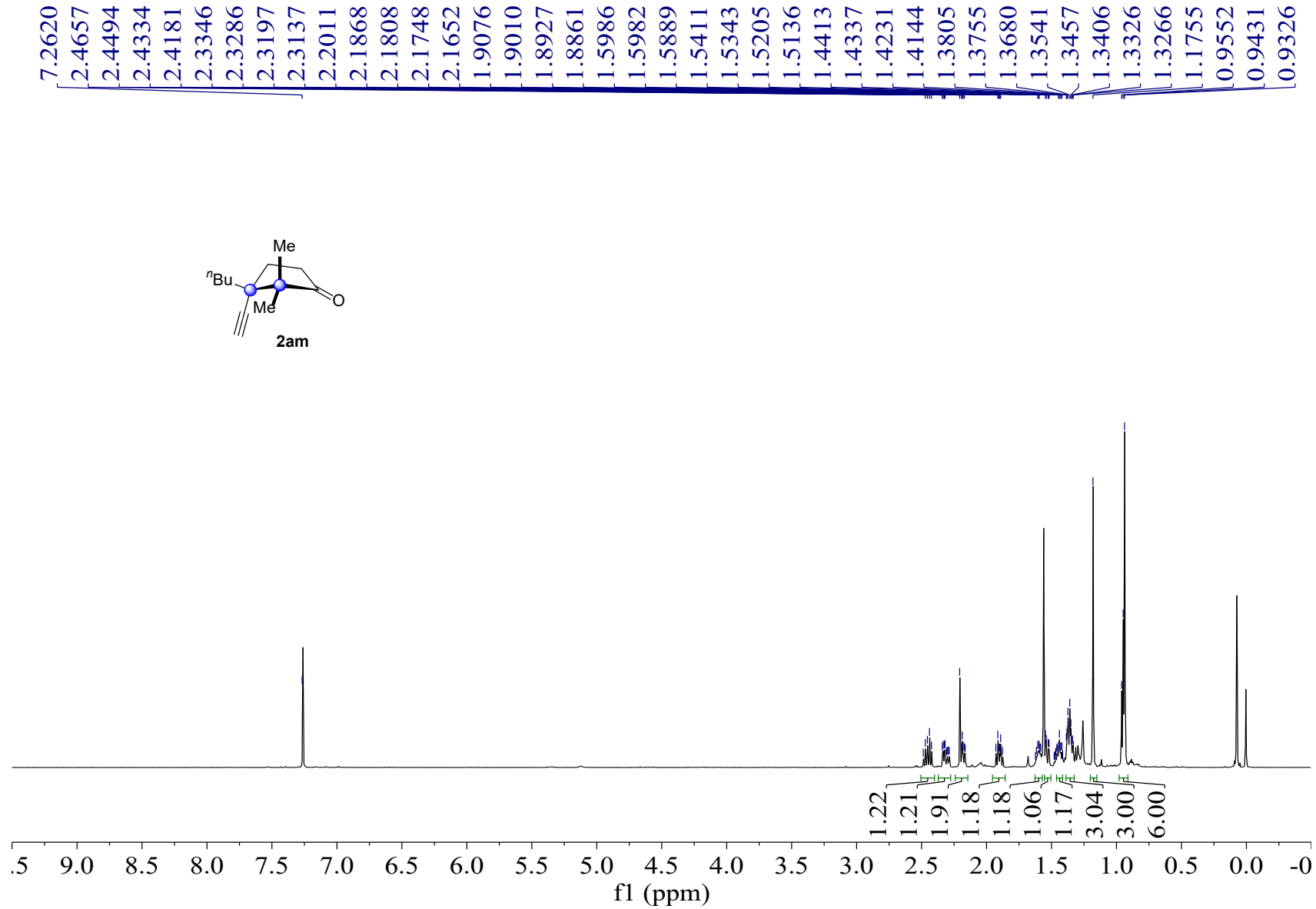
^{13}C NMR spectrum of compound **2aj**



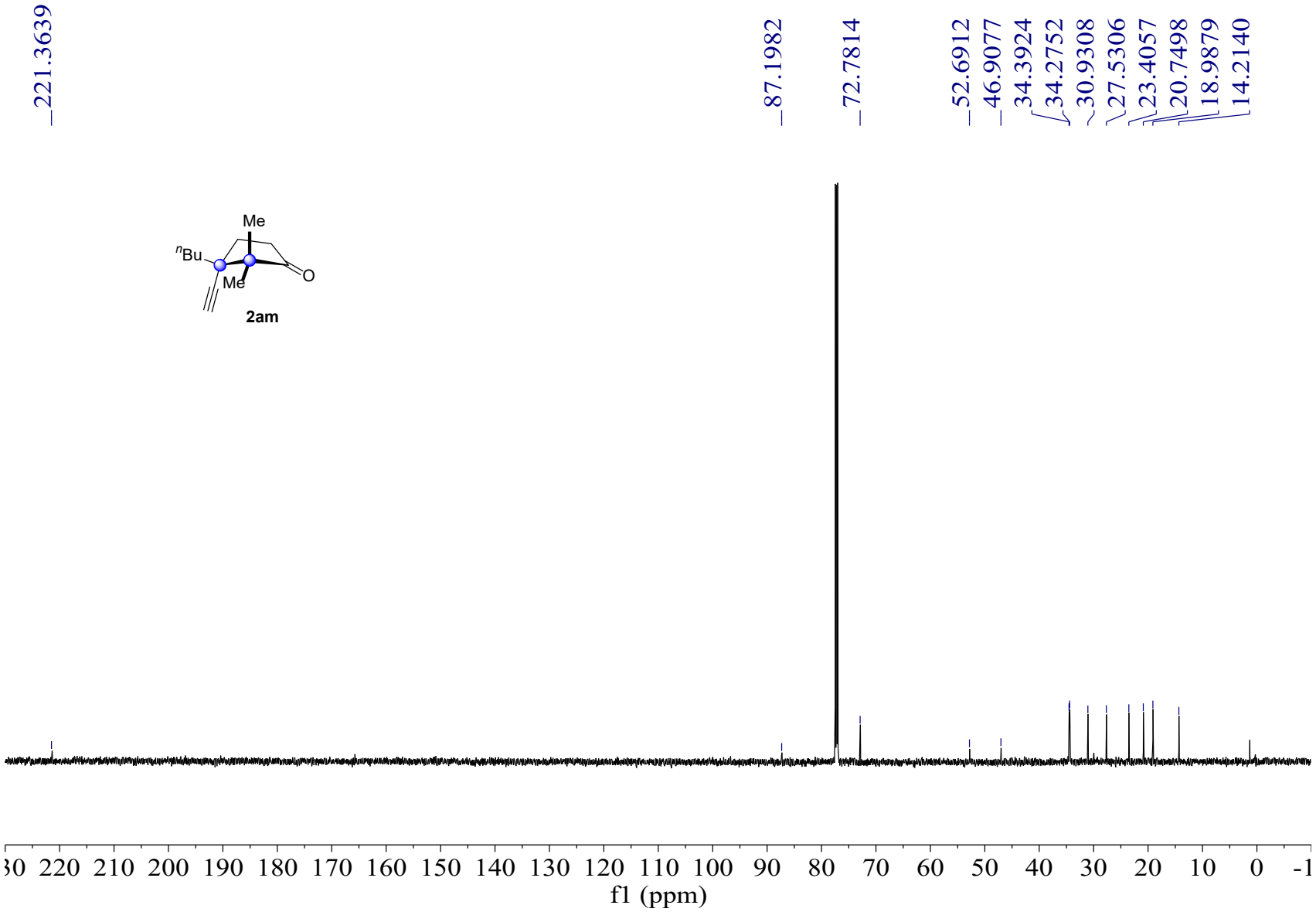
^{1}H NMR spectrum of compound **2ak**



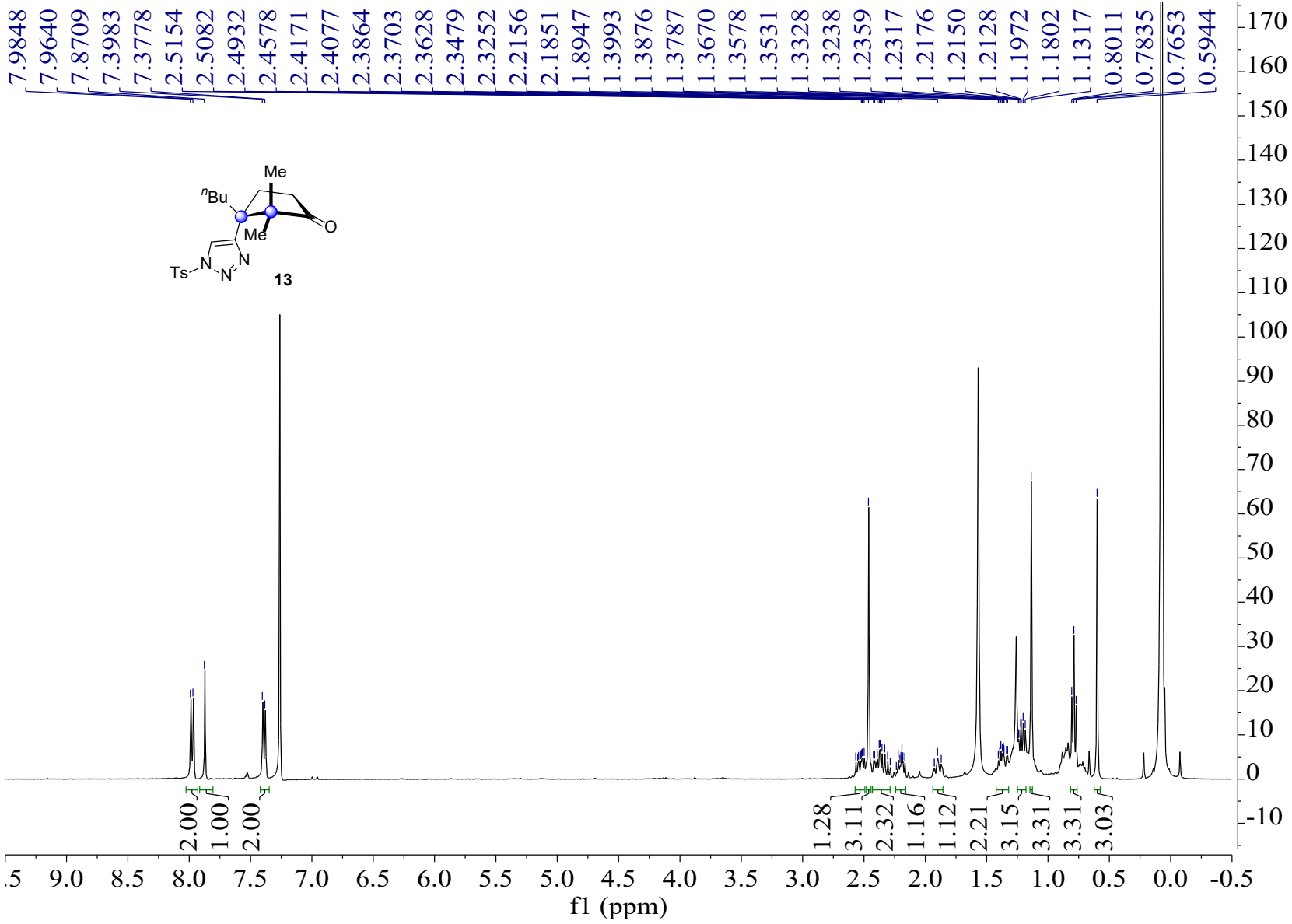
^{13}C NMR spectrum of compound **2ak**



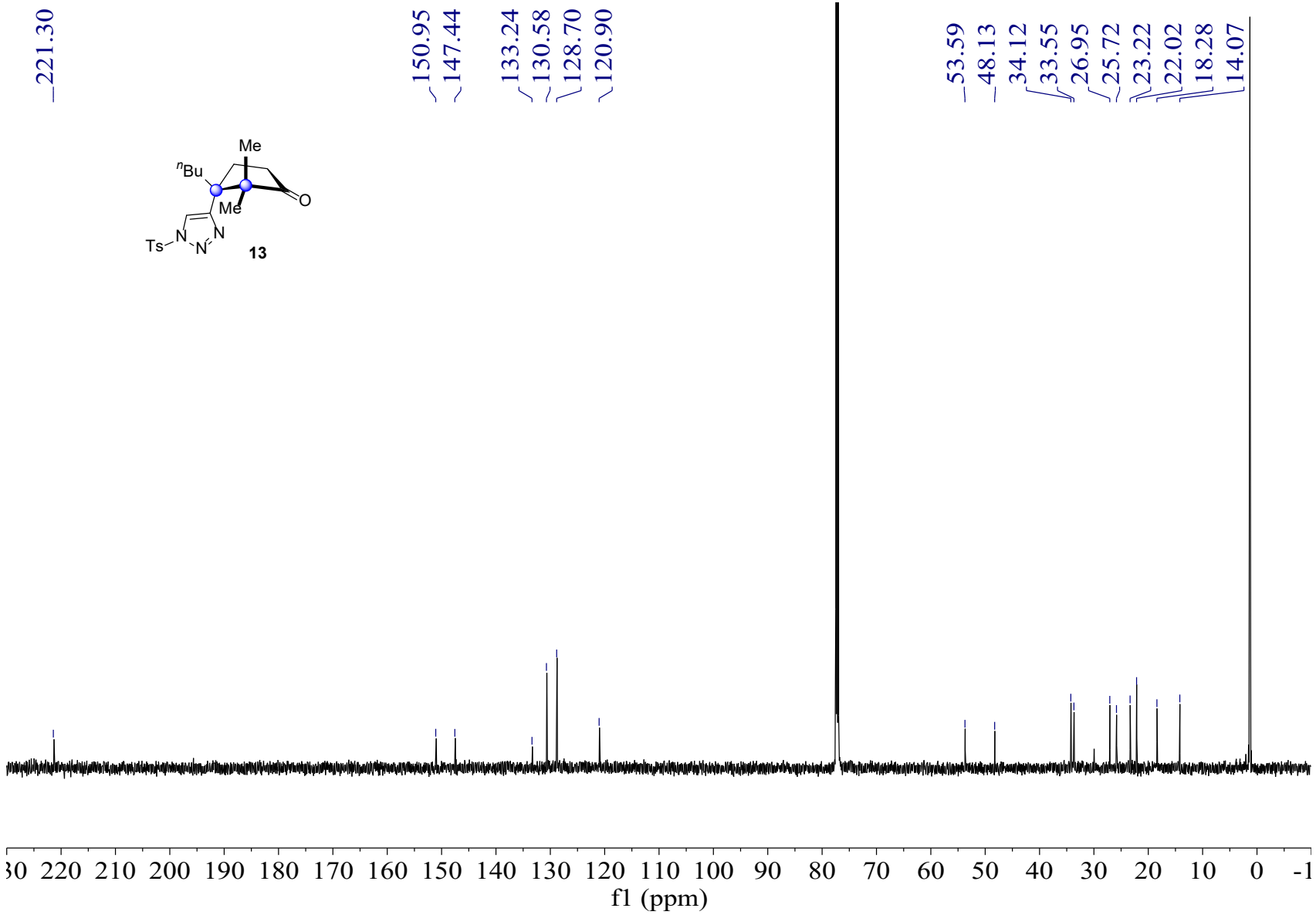
^{1}H NMR spectrum of compound **2am**



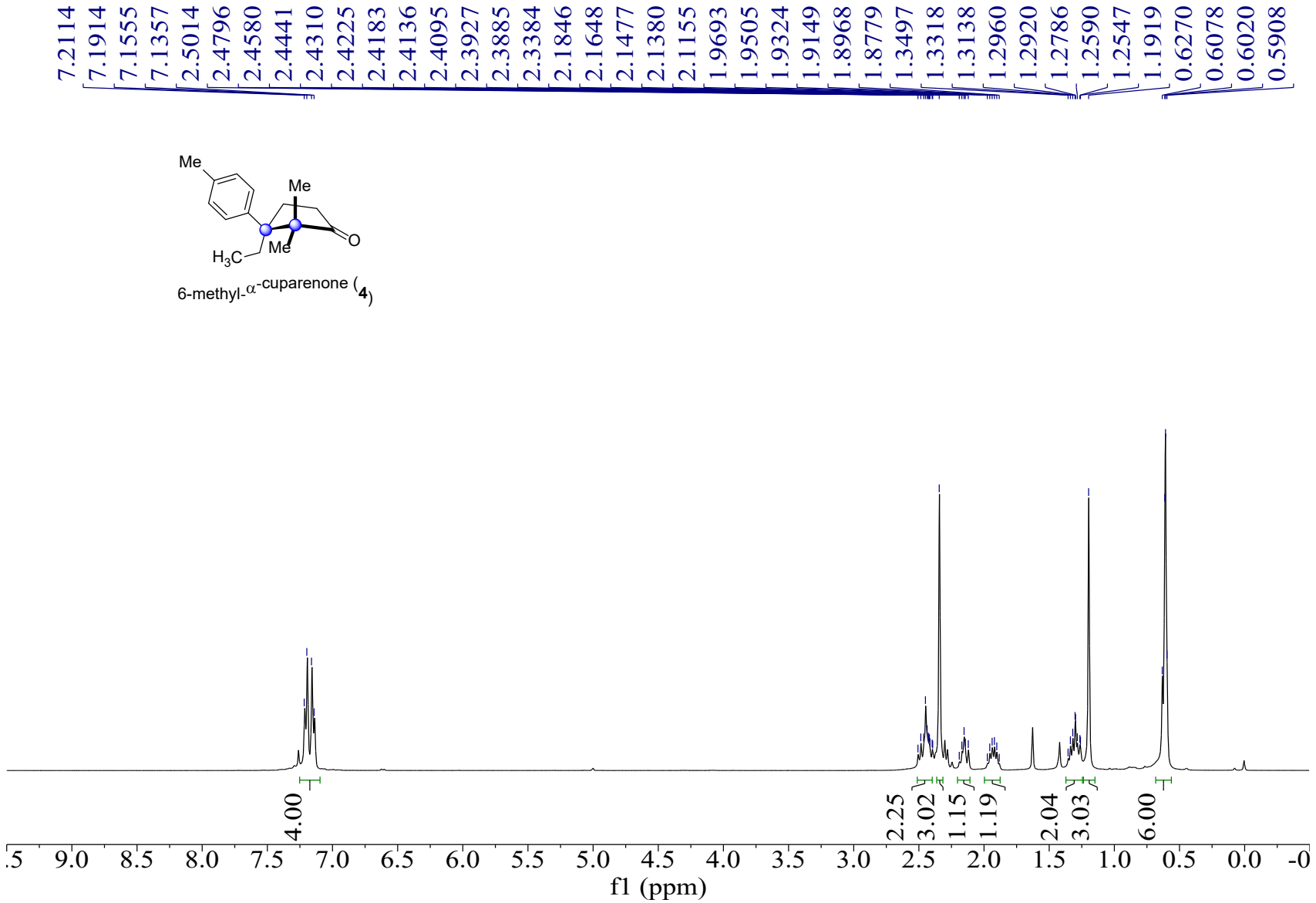
^{13}C NMR spectrum of compound **2am**



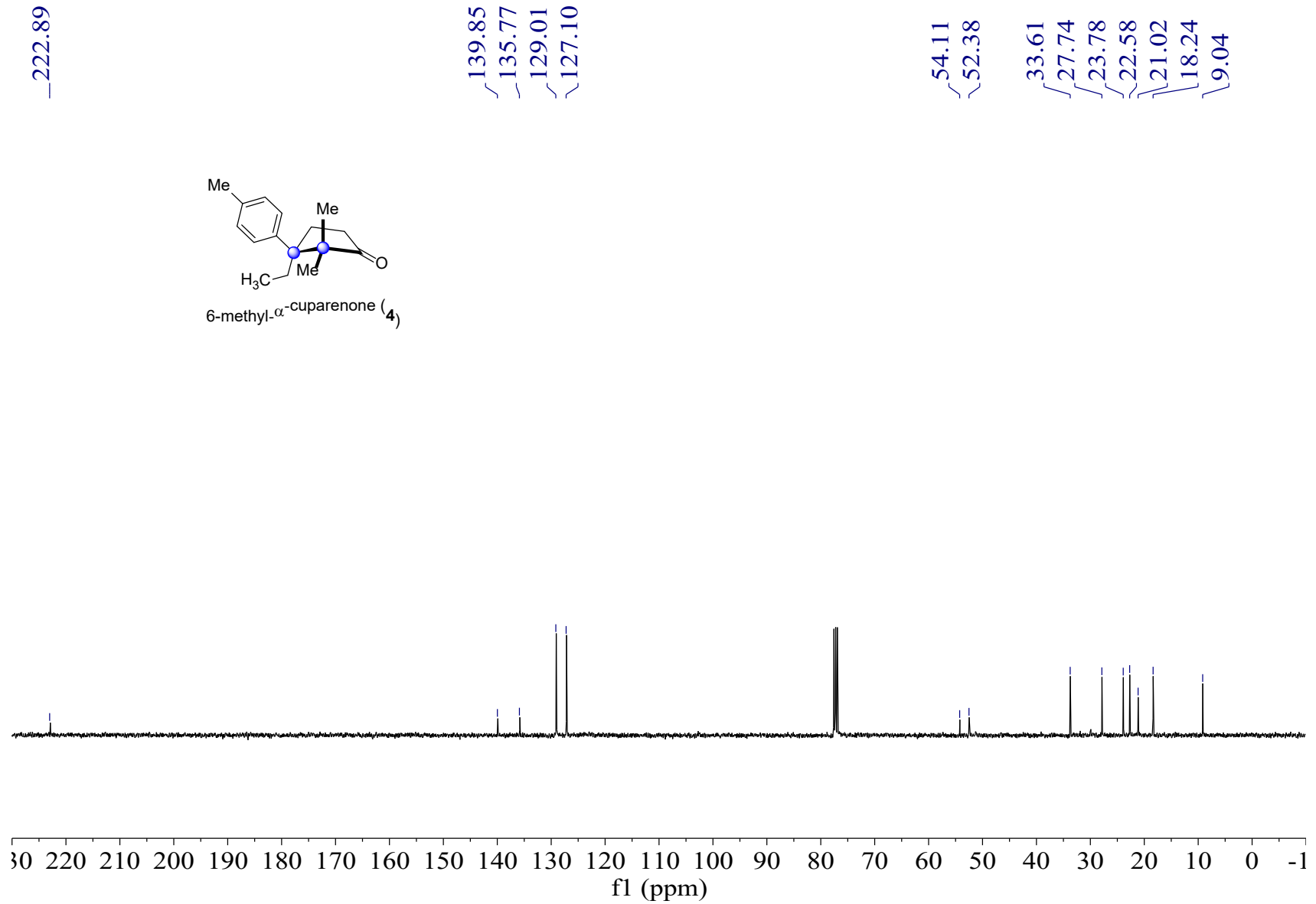
^{1}H NMR spectrum of compound **13**



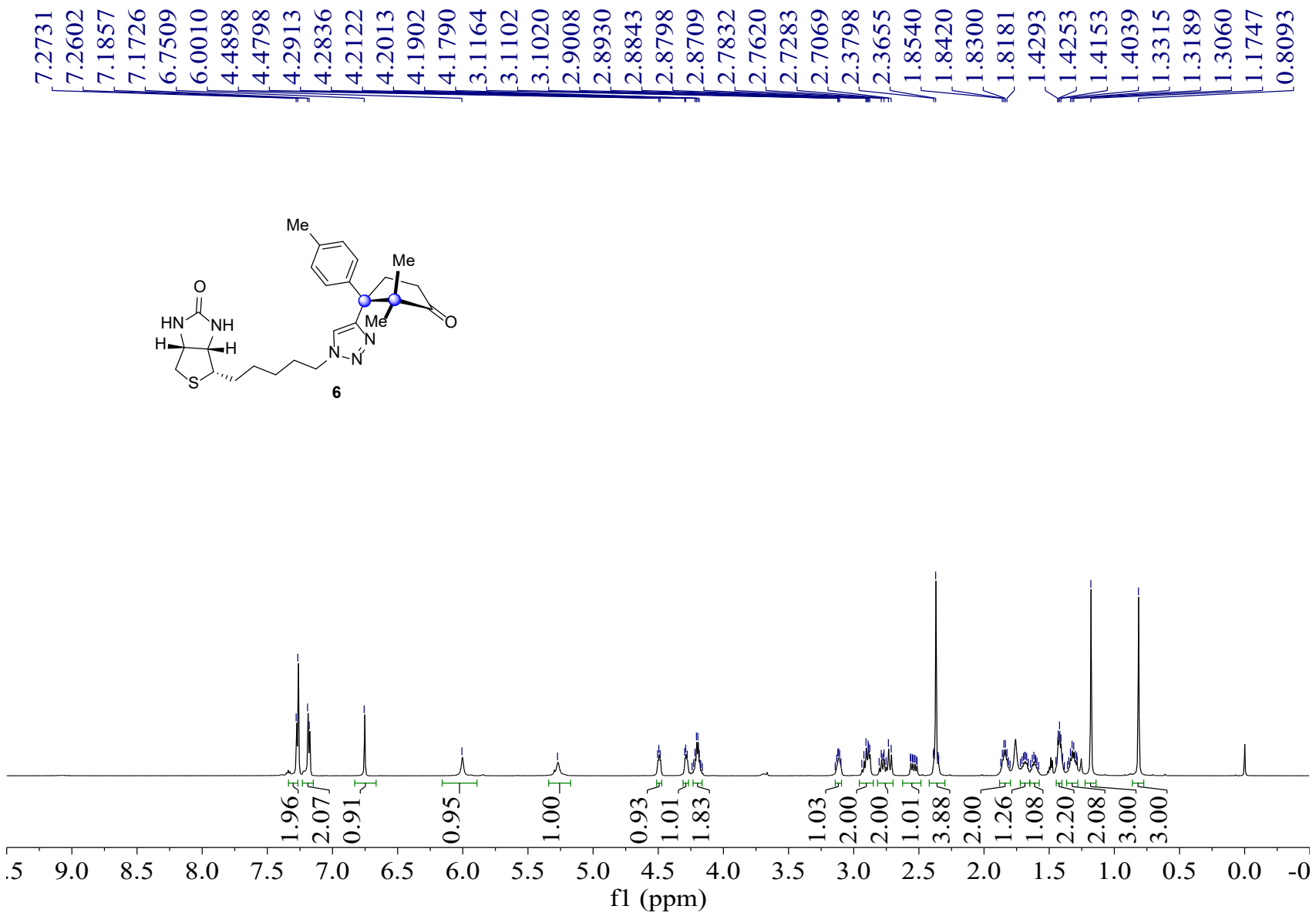
^{13}C NMR spectrum of compound **13**



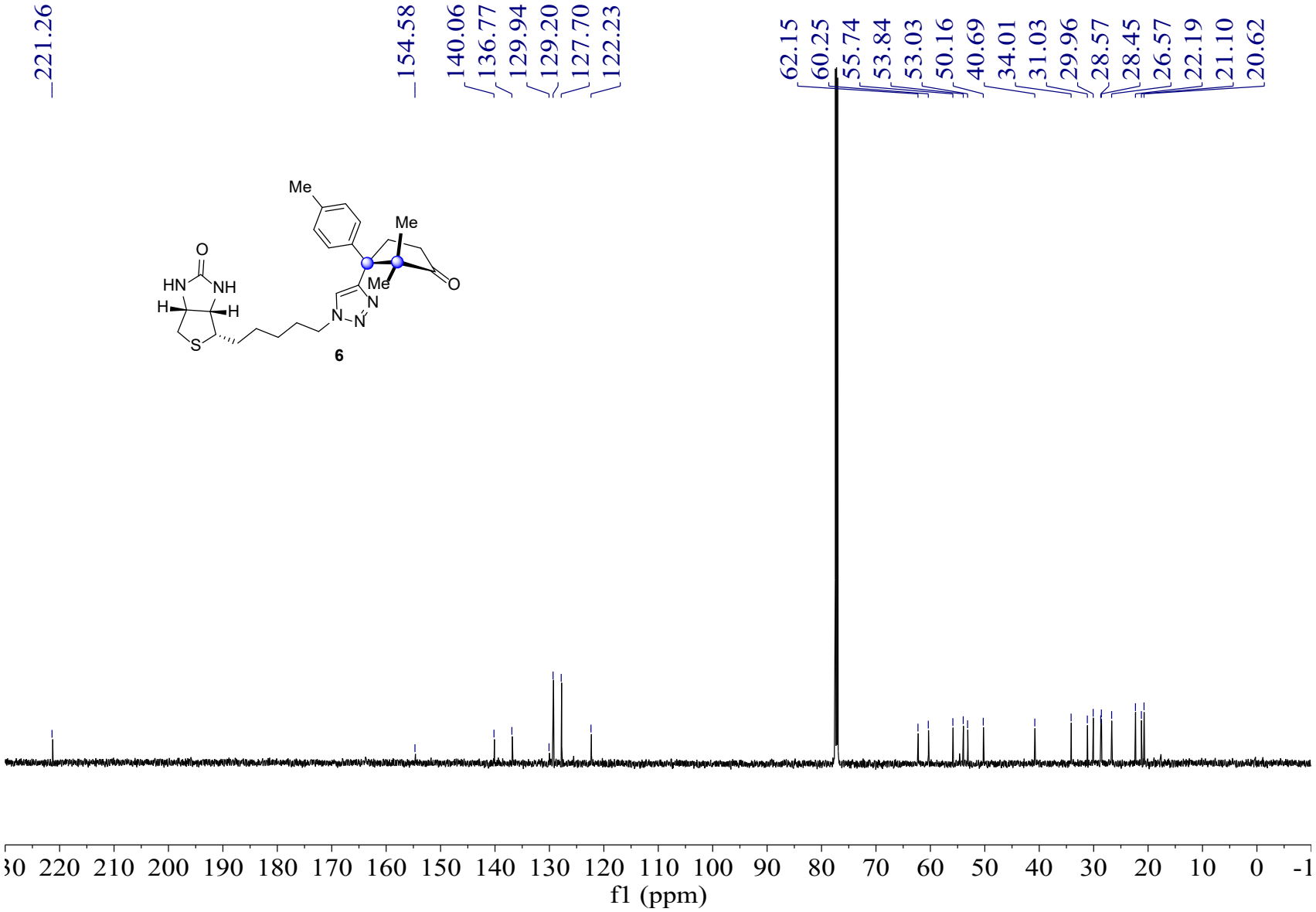
^{1}H NMR spectrum of compound **4**



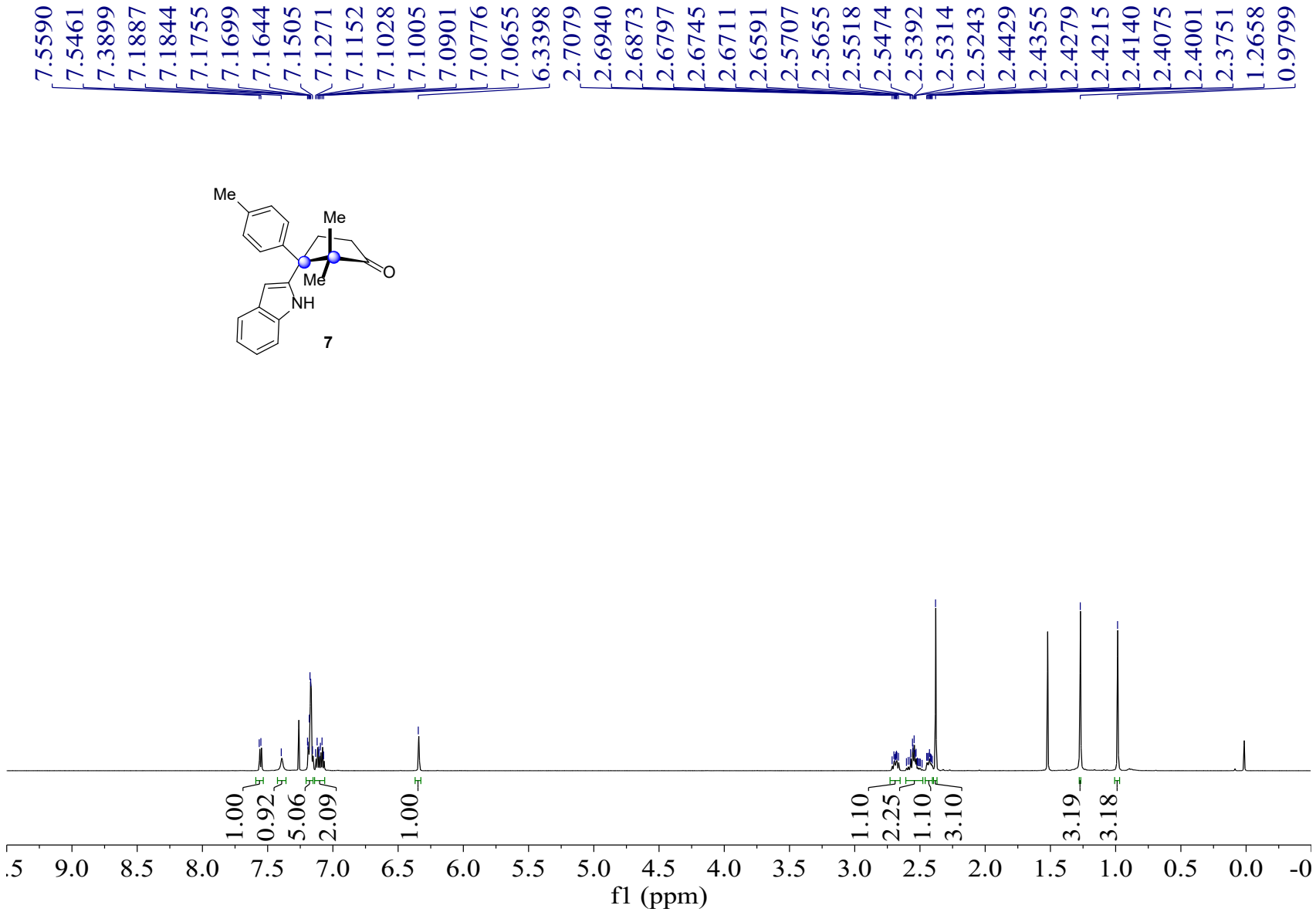
^{13}C NMR spectrum of compound **4**



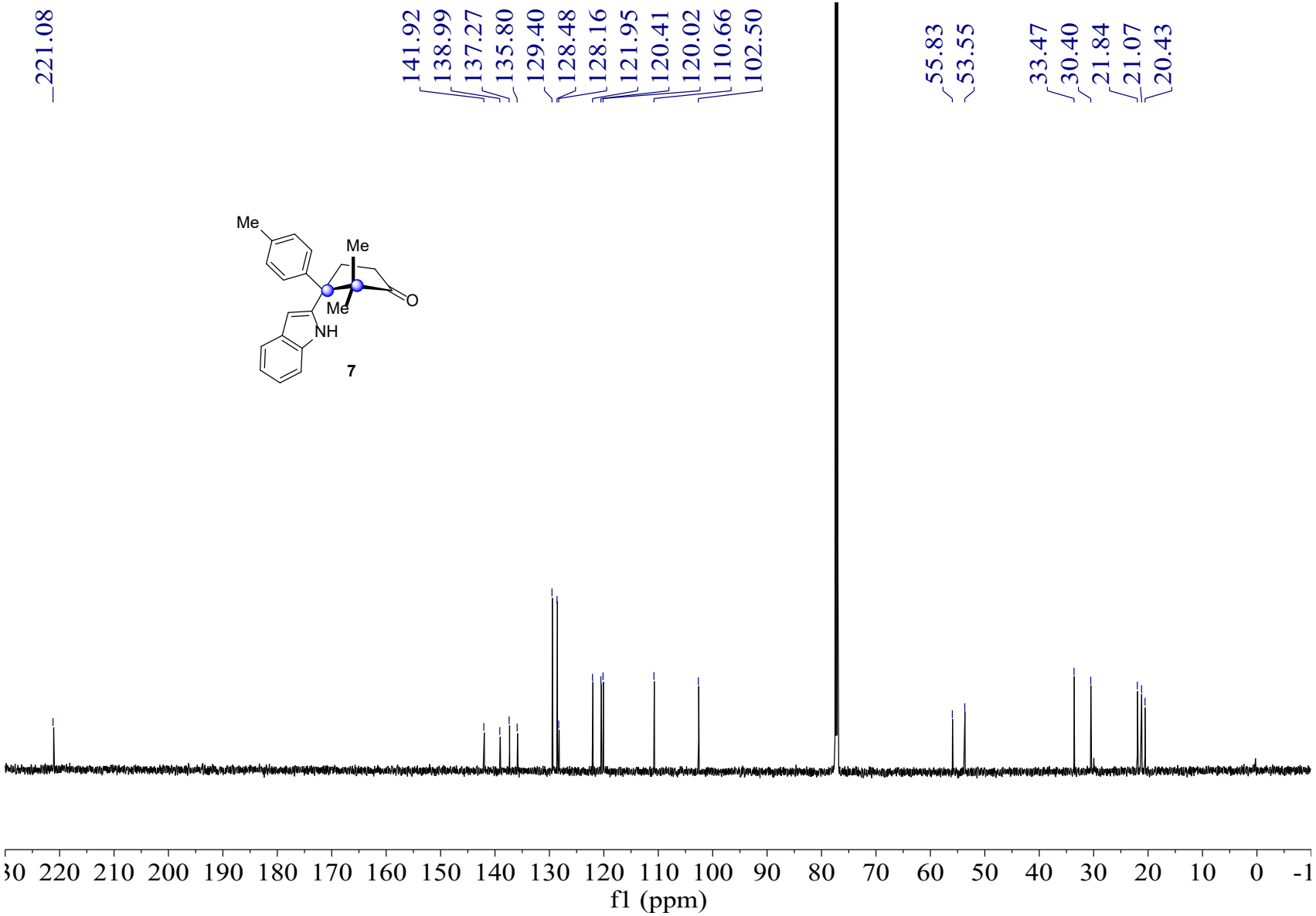
^{1}H NMR spectrum of compound **6**



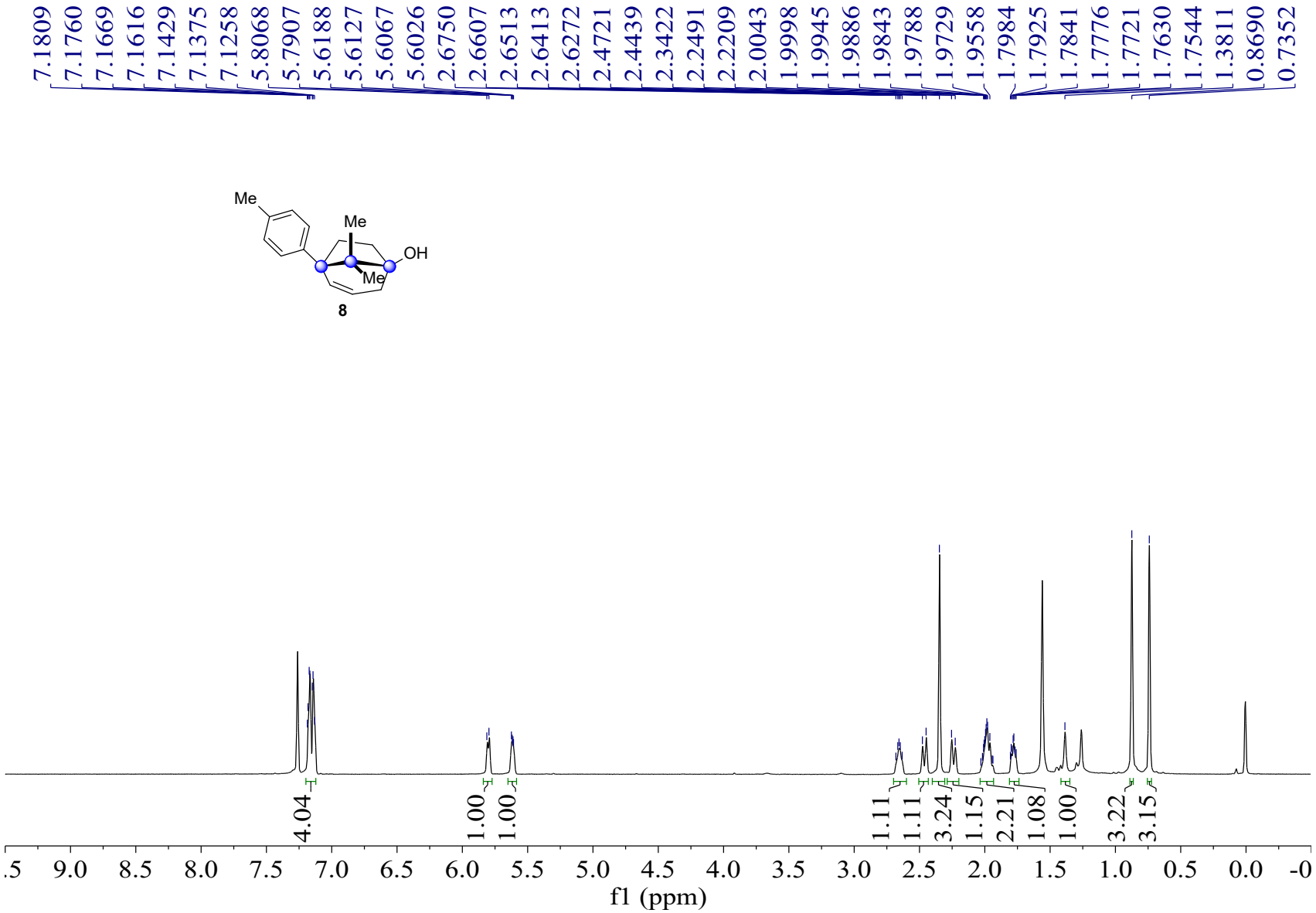
^{13}C NMR spectrum of compound **6**



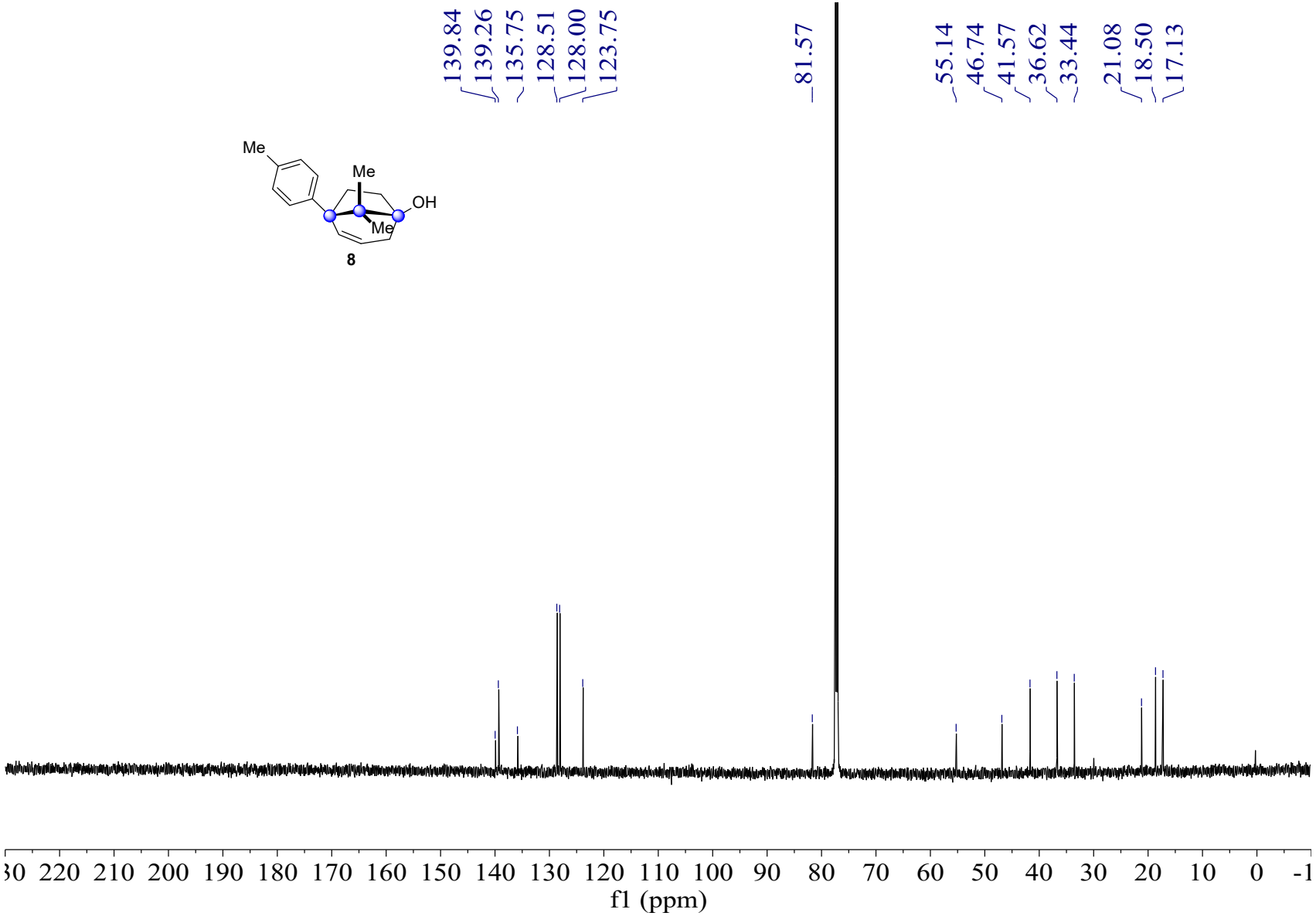
^{1}H NMR spectrum of compound **7**



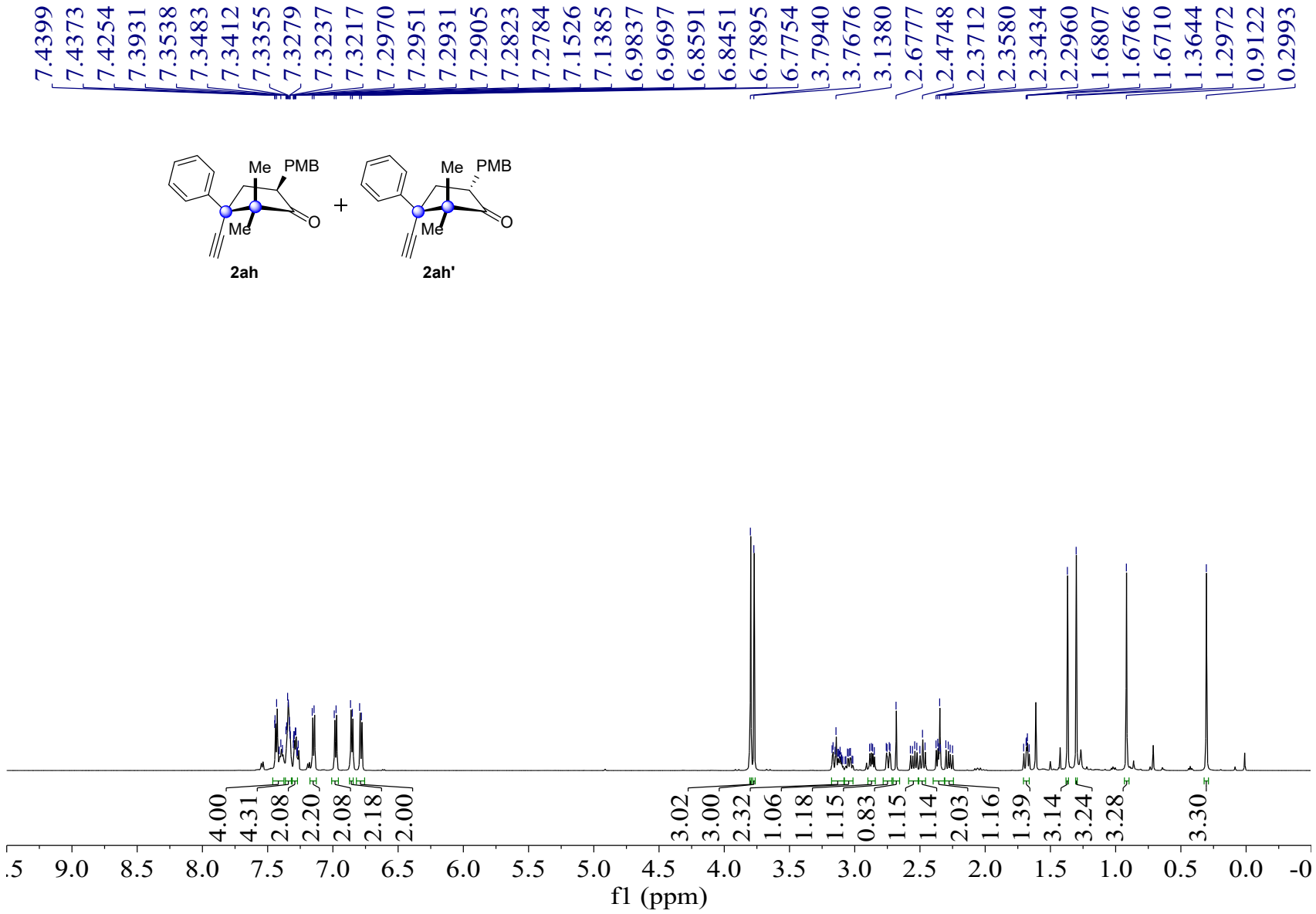
^{13}C NMR spectrum of compound **7**



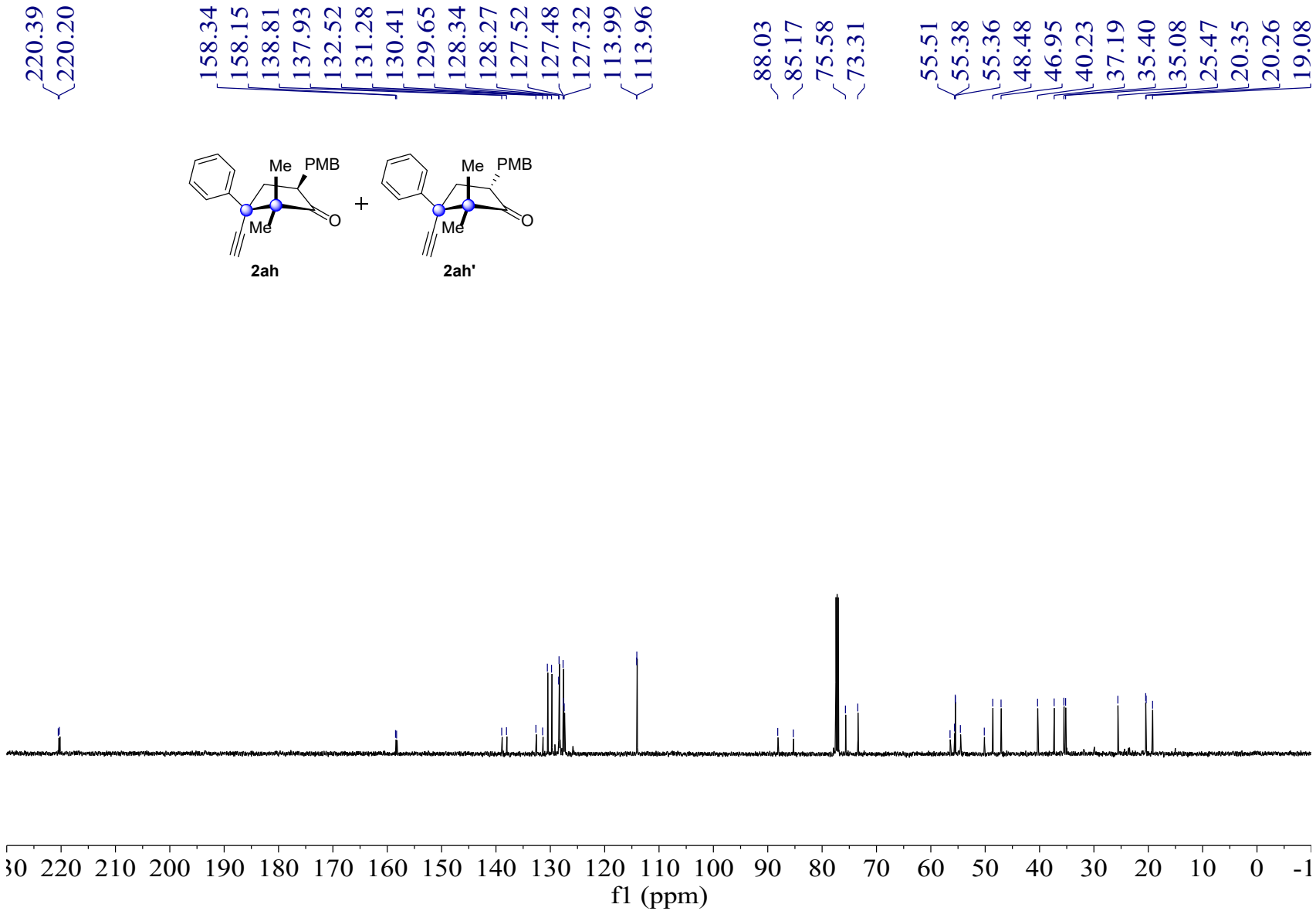
^{1}H NMR spectrum of compound **8**



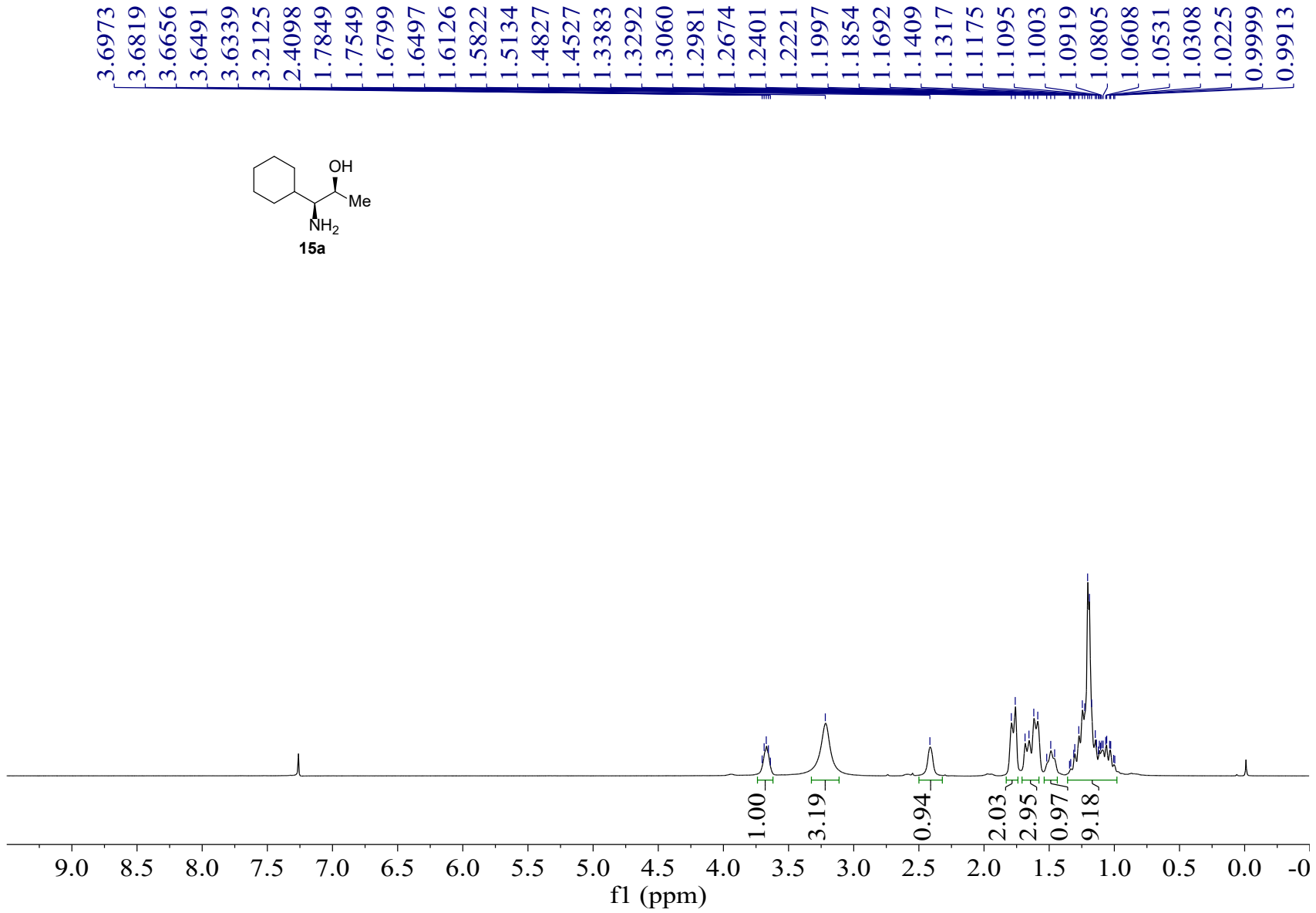
^{13}C NMR spectrum of compound **8**



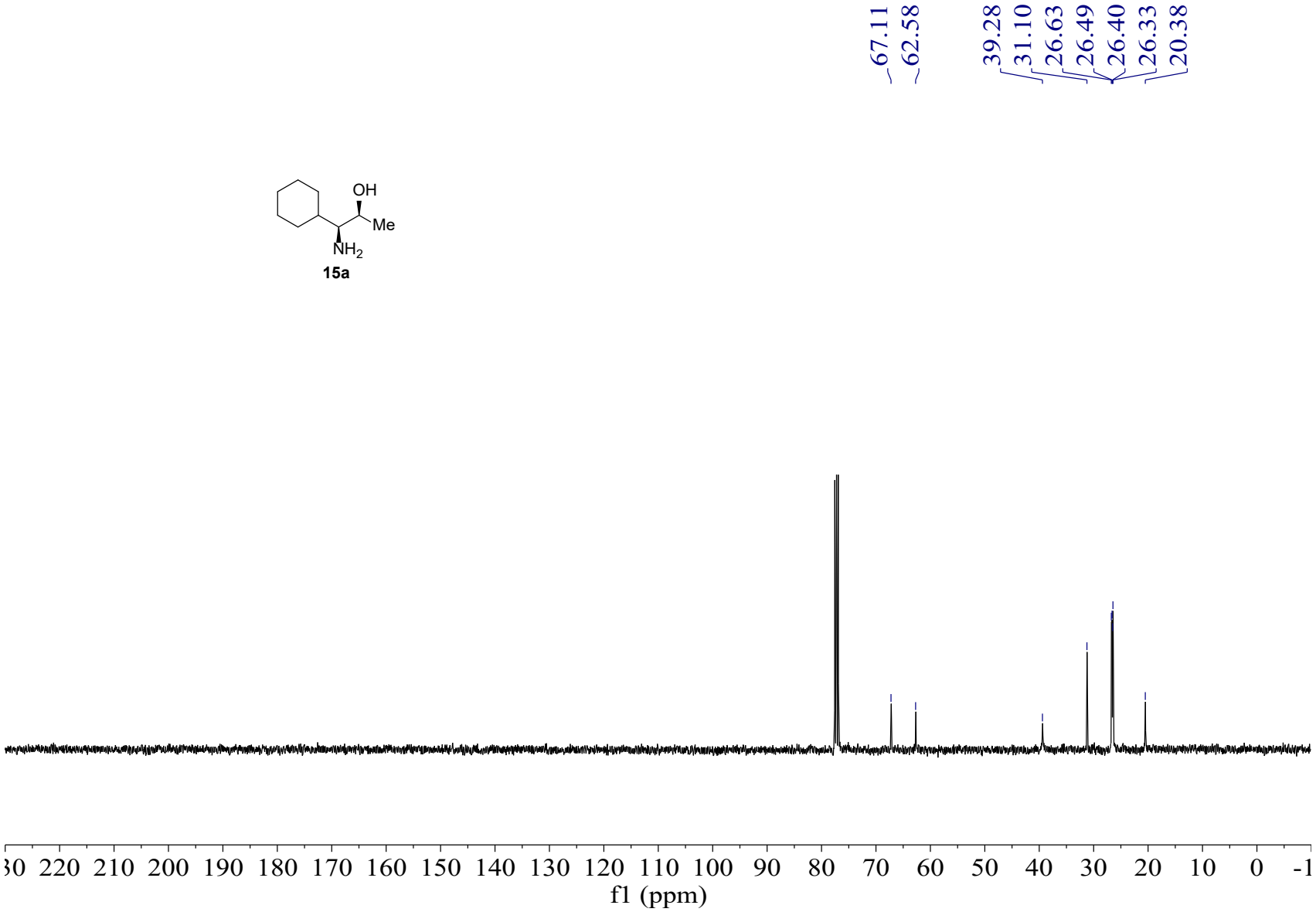
^{1}H NMR spectrum of the mixture of **2ah** and **2ah'**



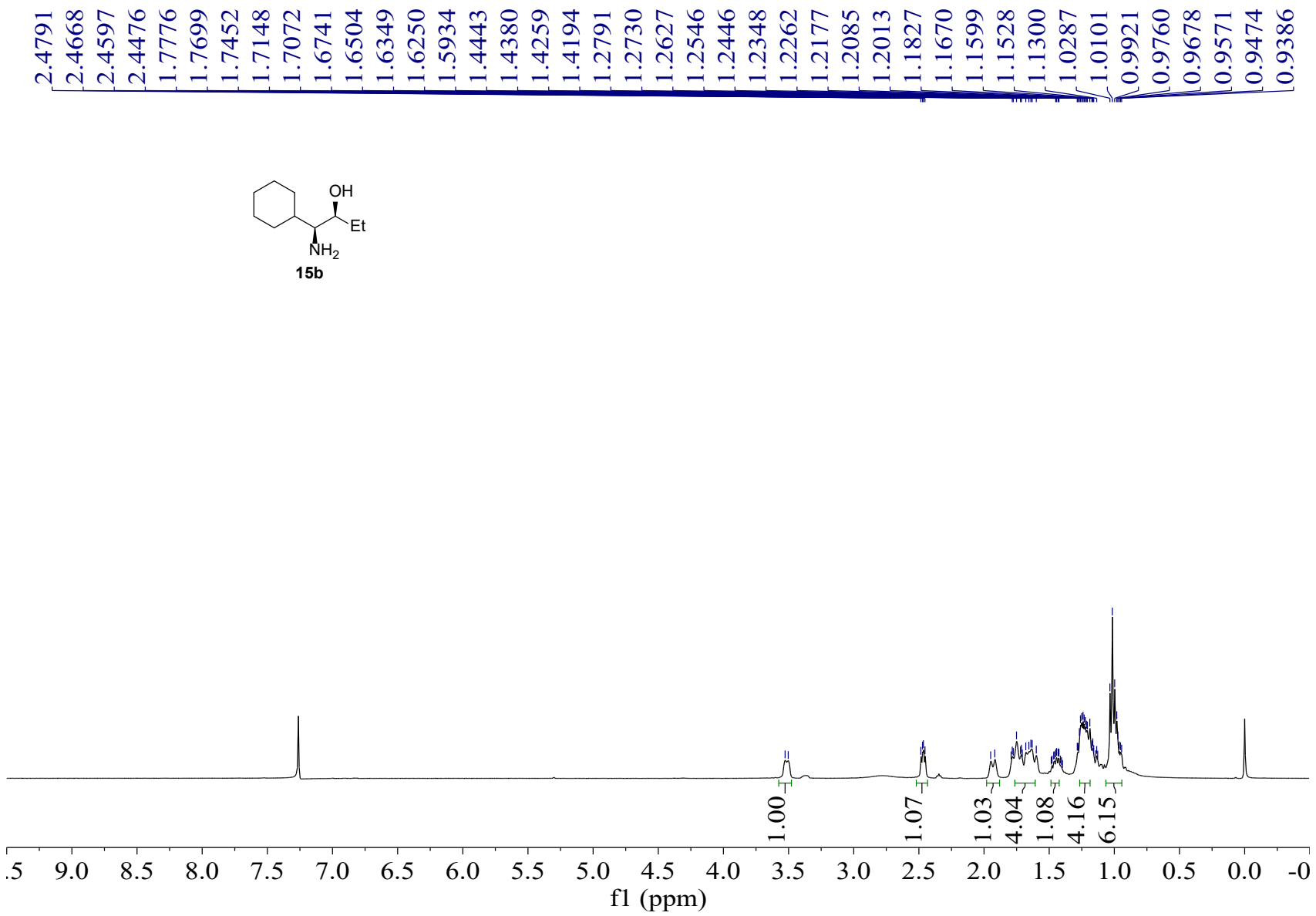
^{13}C NMR spectrum of the mixture of **2ah** and **2ah'**



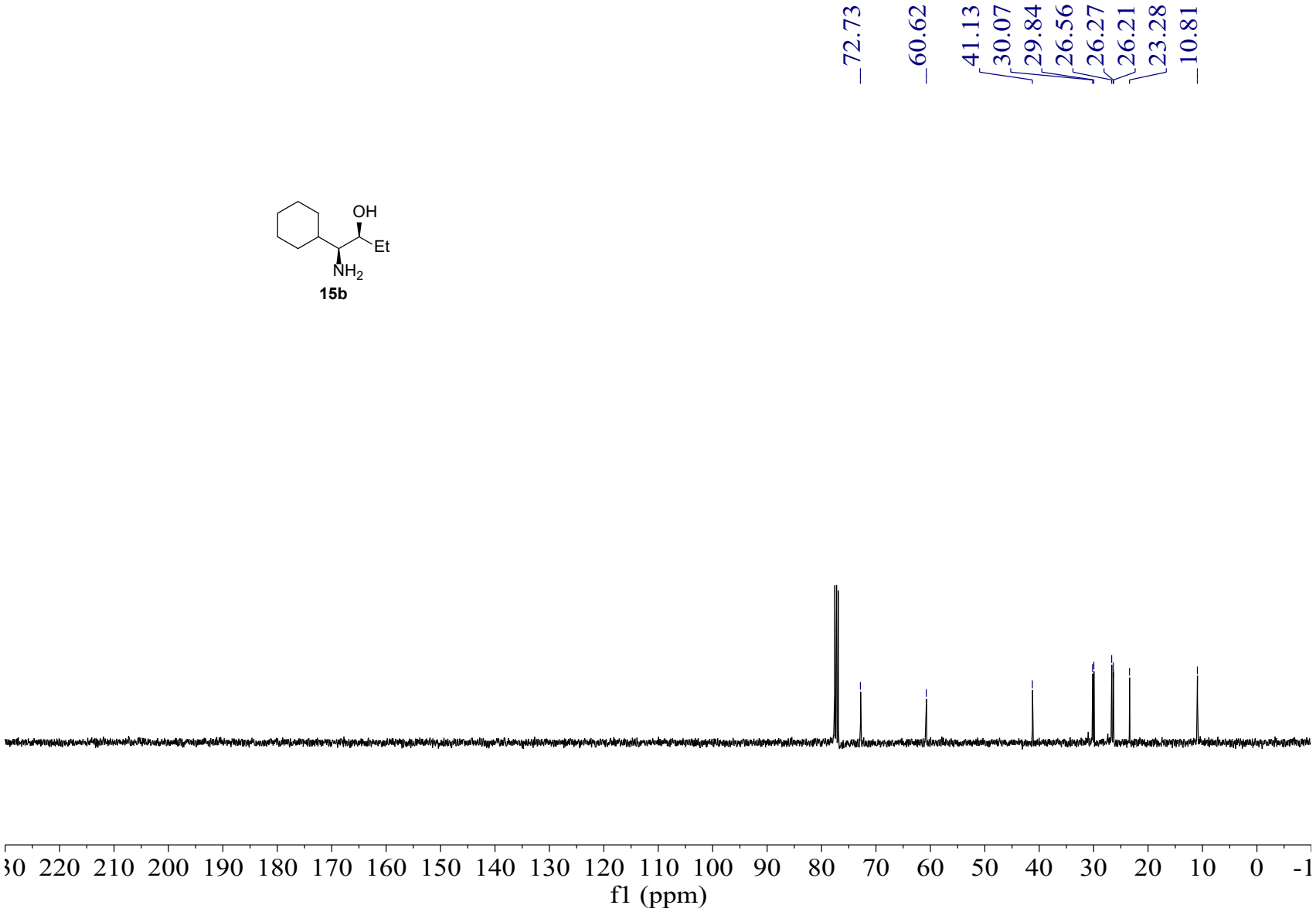
^{1}H NMR spectrum of compound **15a**



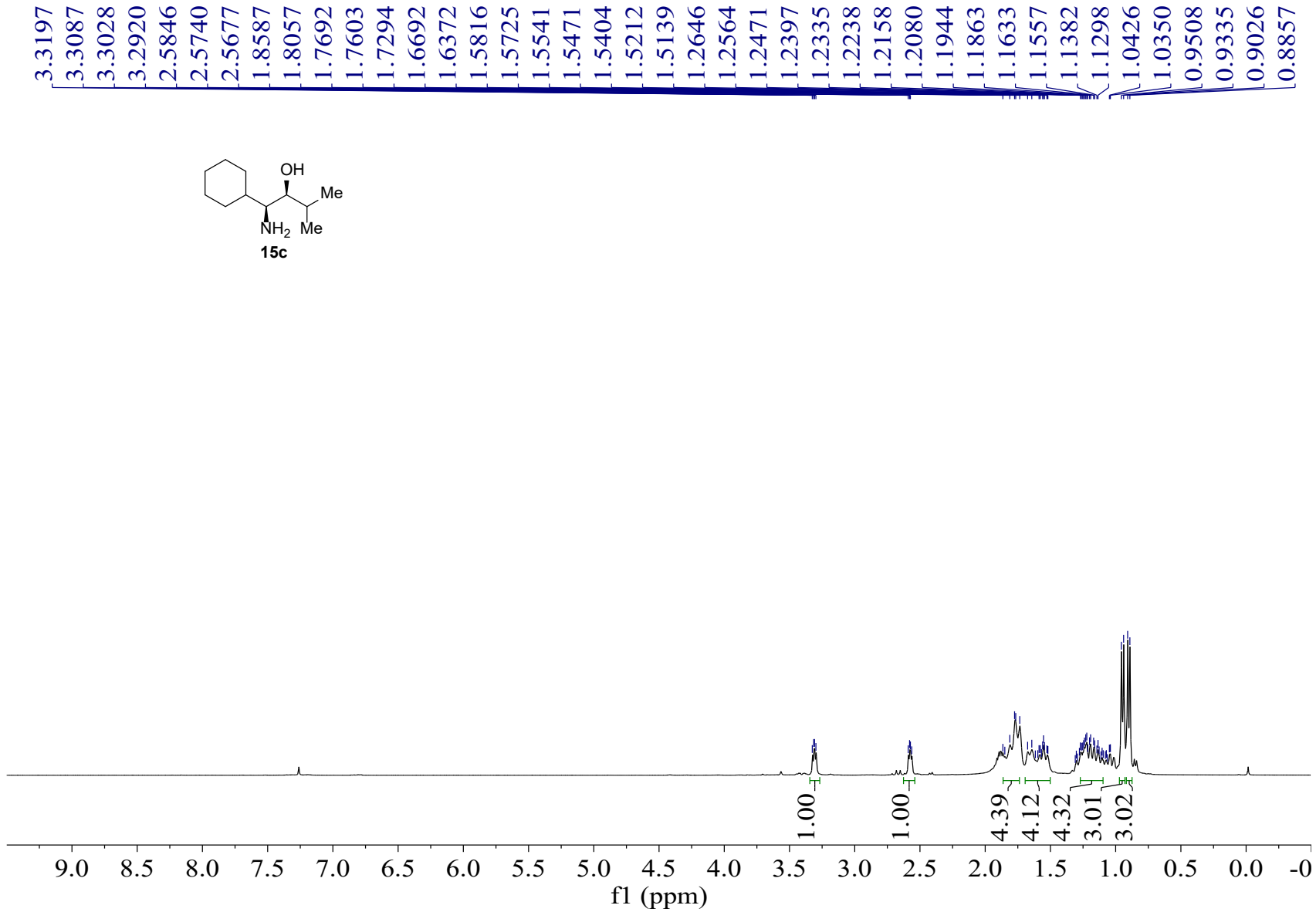
^{13}C NMR spectrum of compound **15a**



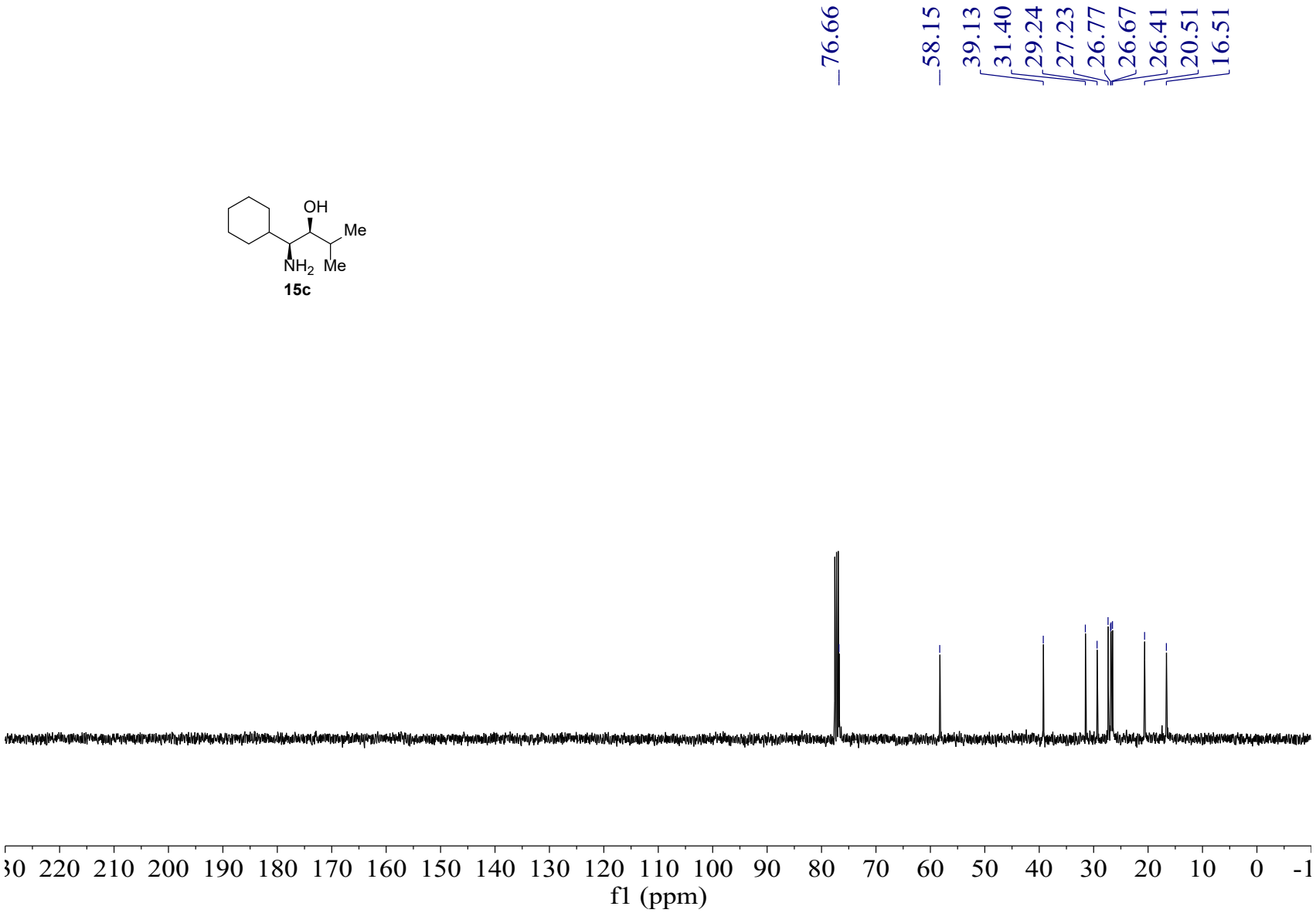
^{1}H NMR spectrum of compound **15b**



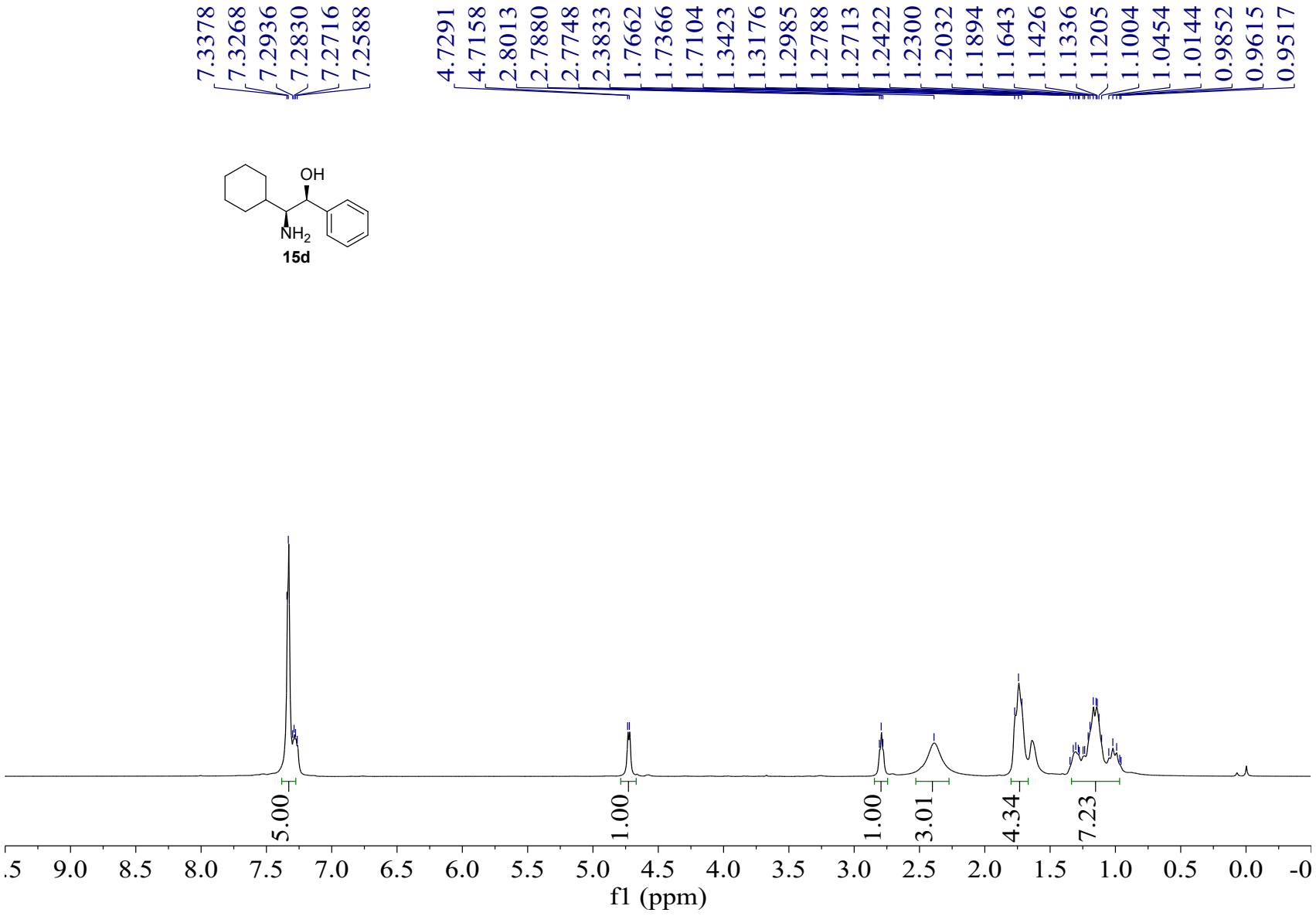
^{13}C NMR spectrum of compound **15b**



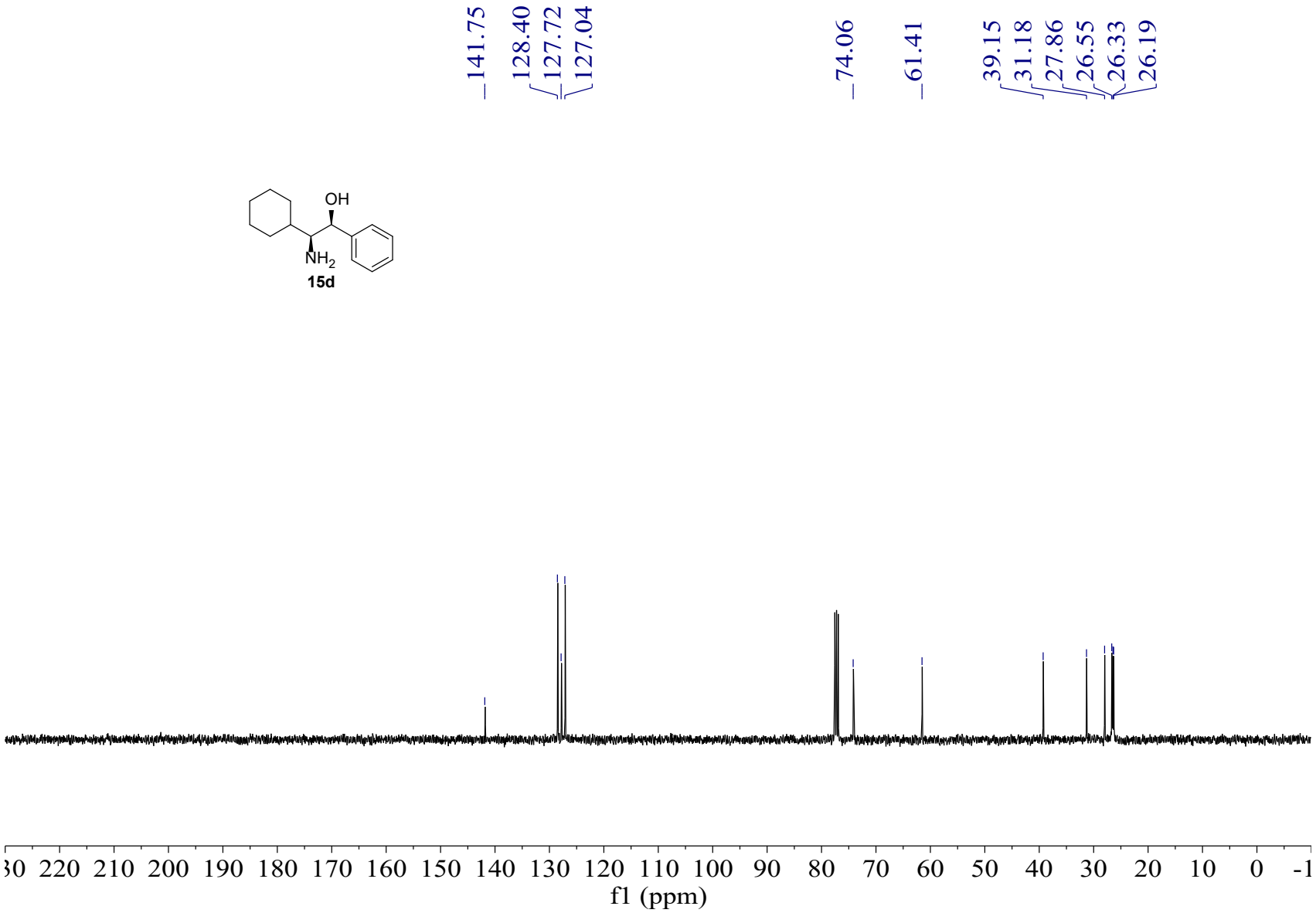
^{1}H NMR spectrum of compound **15c**



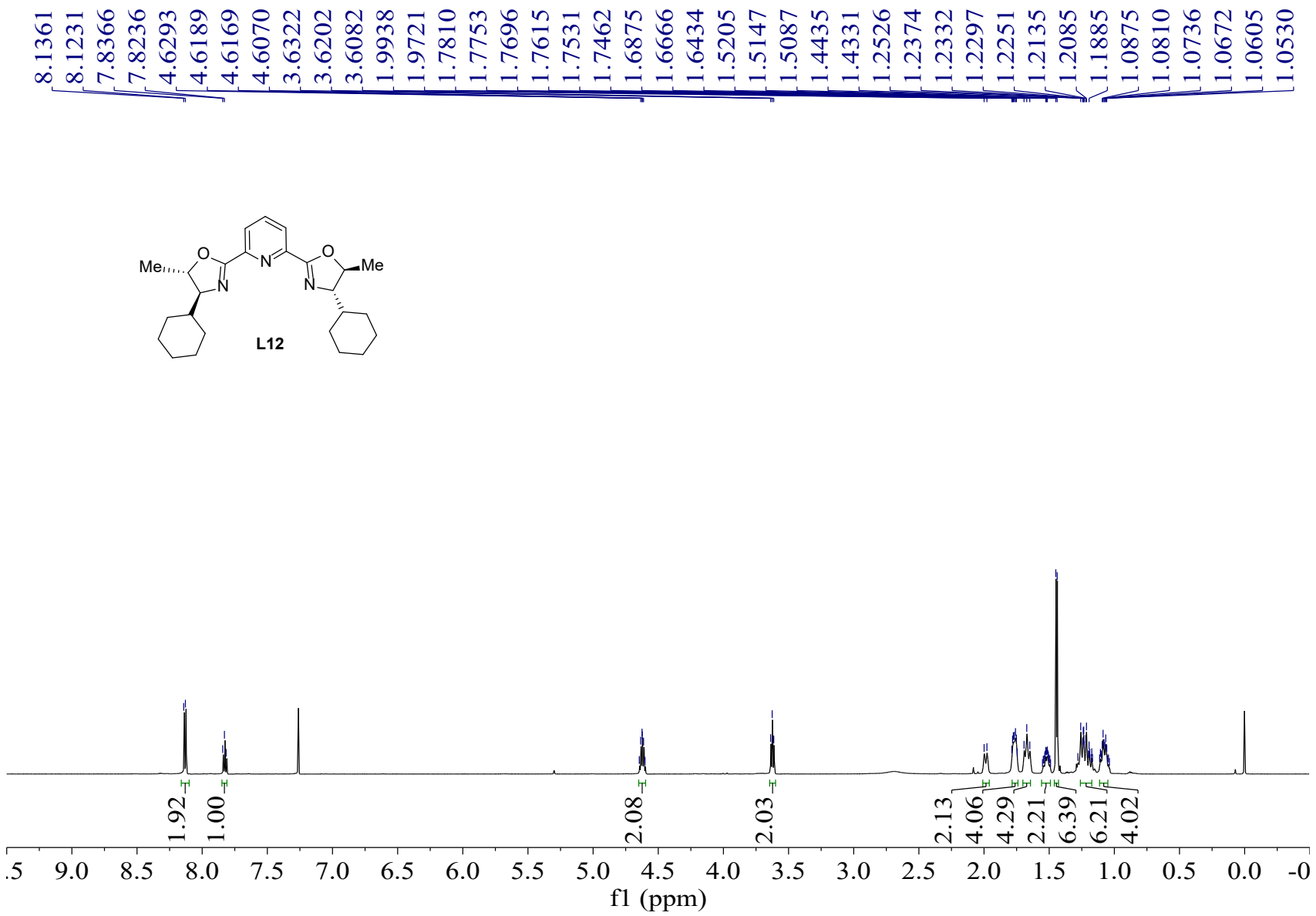
^{13}C NMR spectrum of compound **15c**



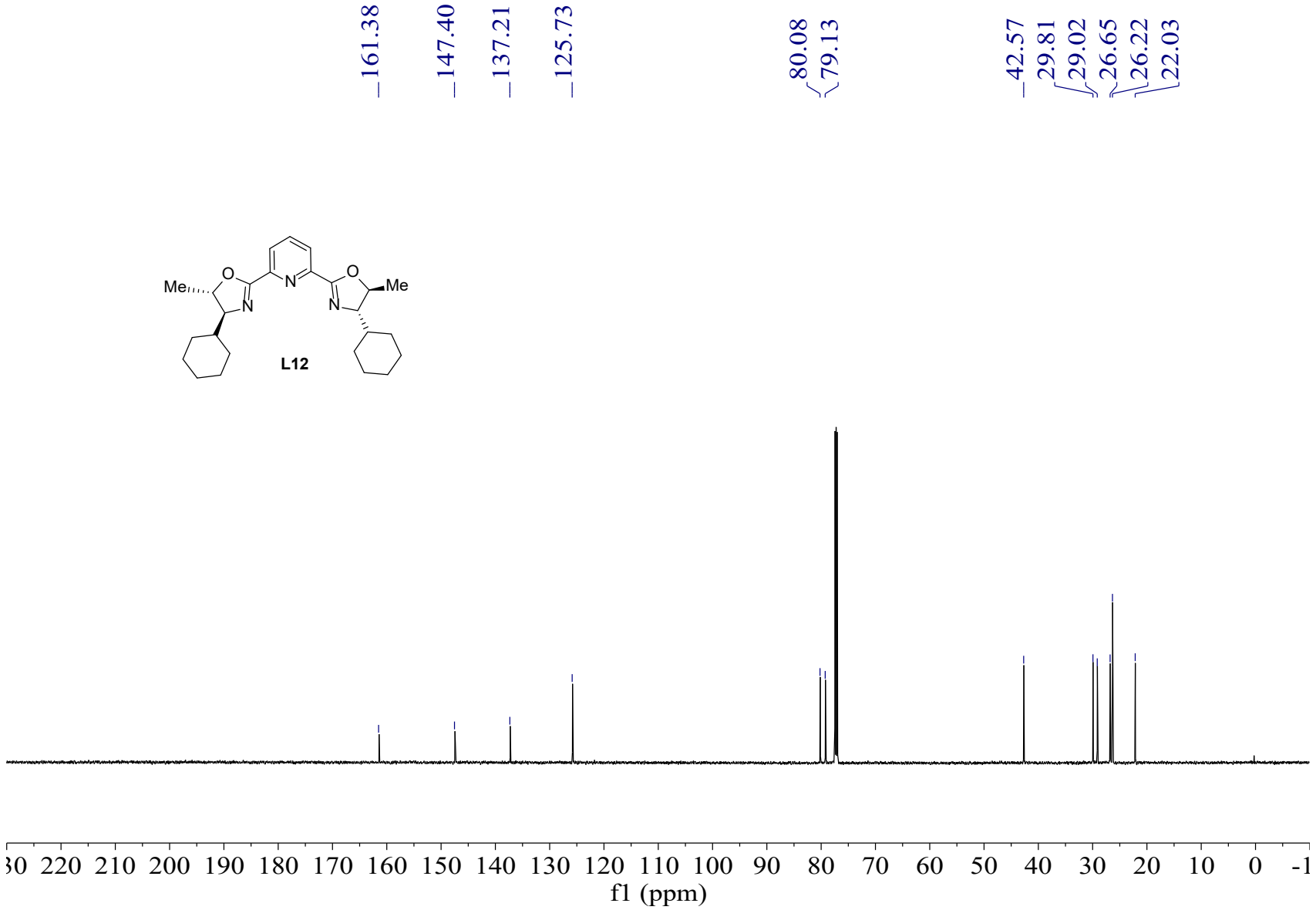
^{1}H NMR spectrum of compound **15d**



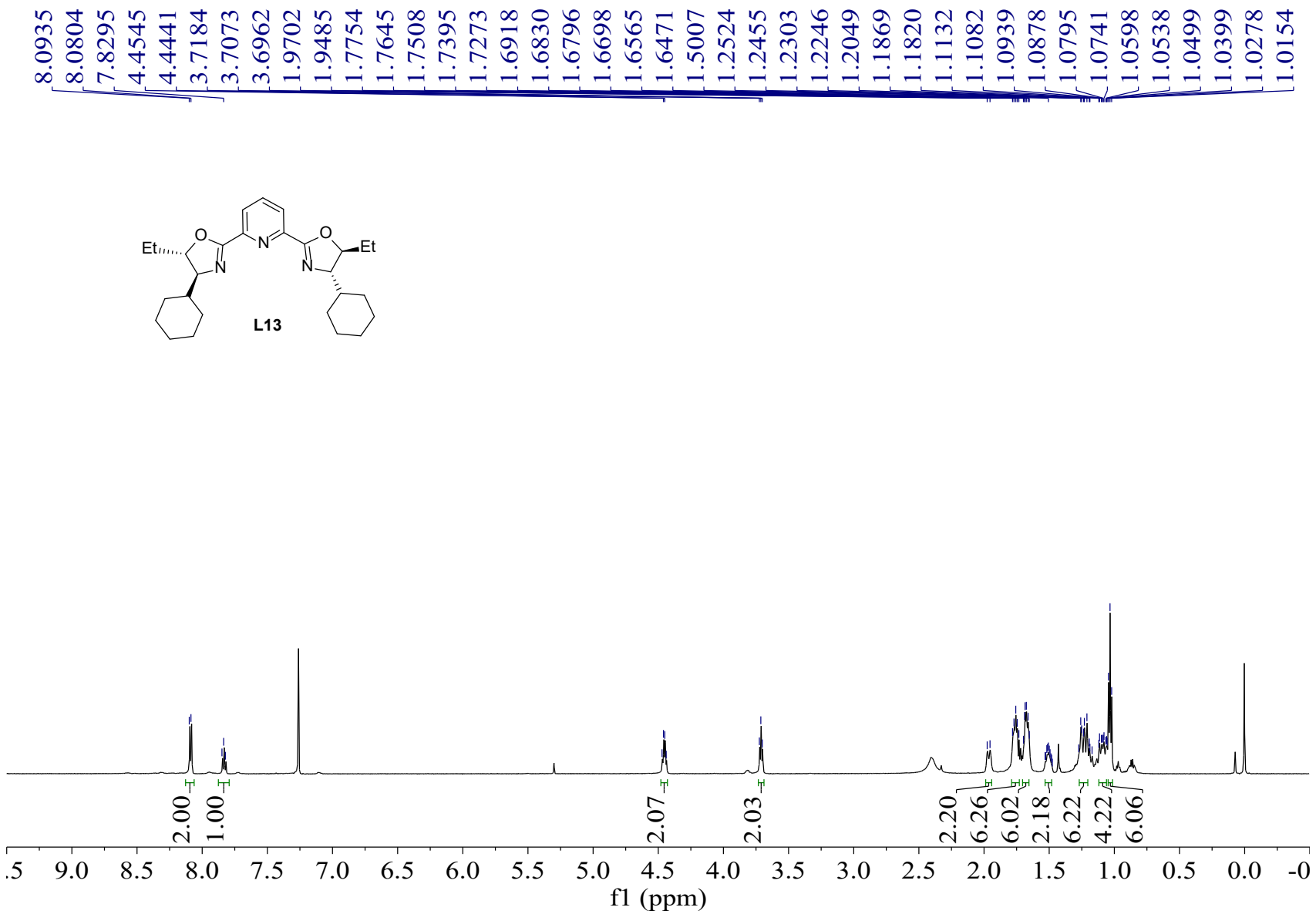
^{13}C NMR spectrum of compound **15d**



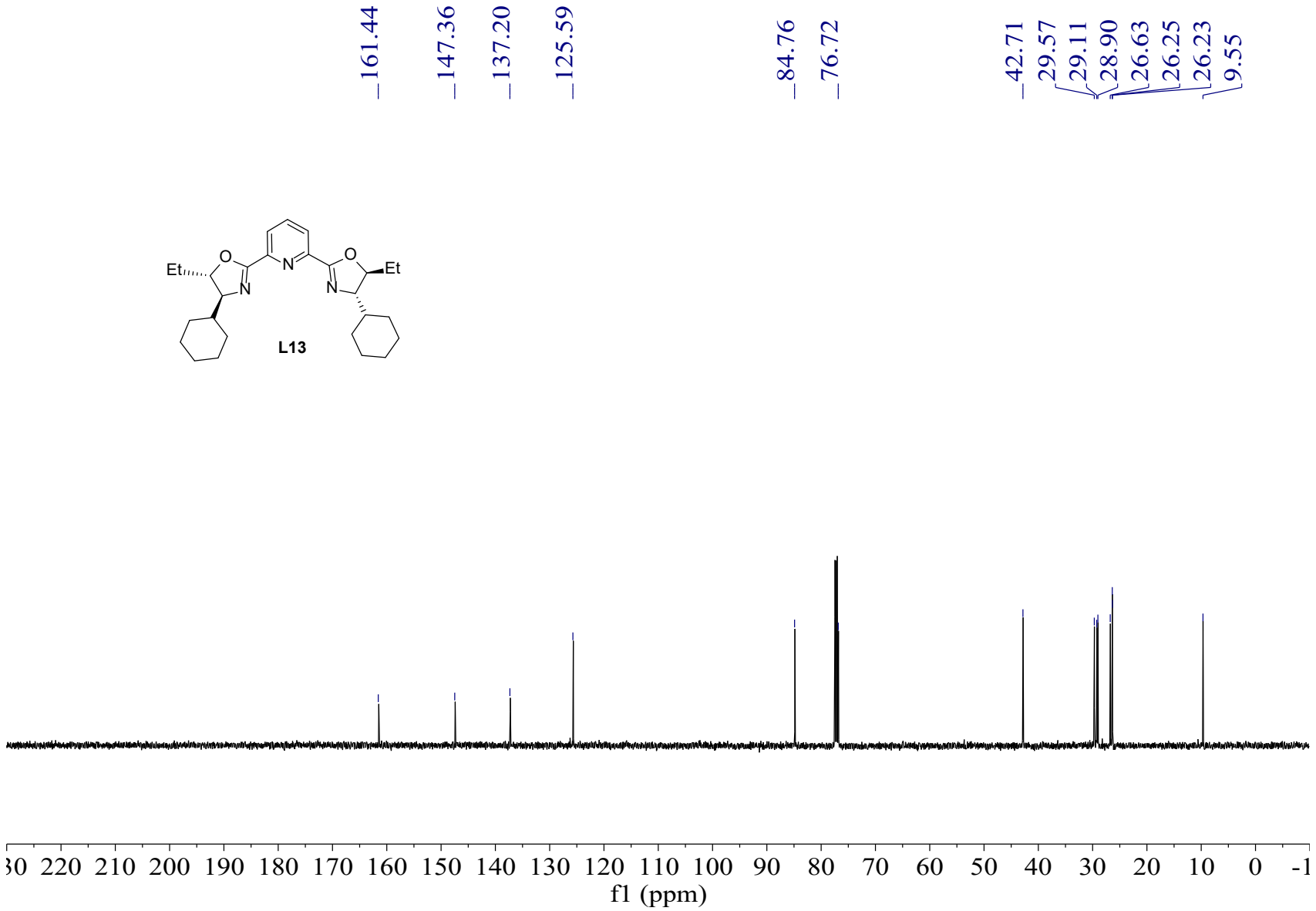
^{1}H NMR spectrum of compound **L12**



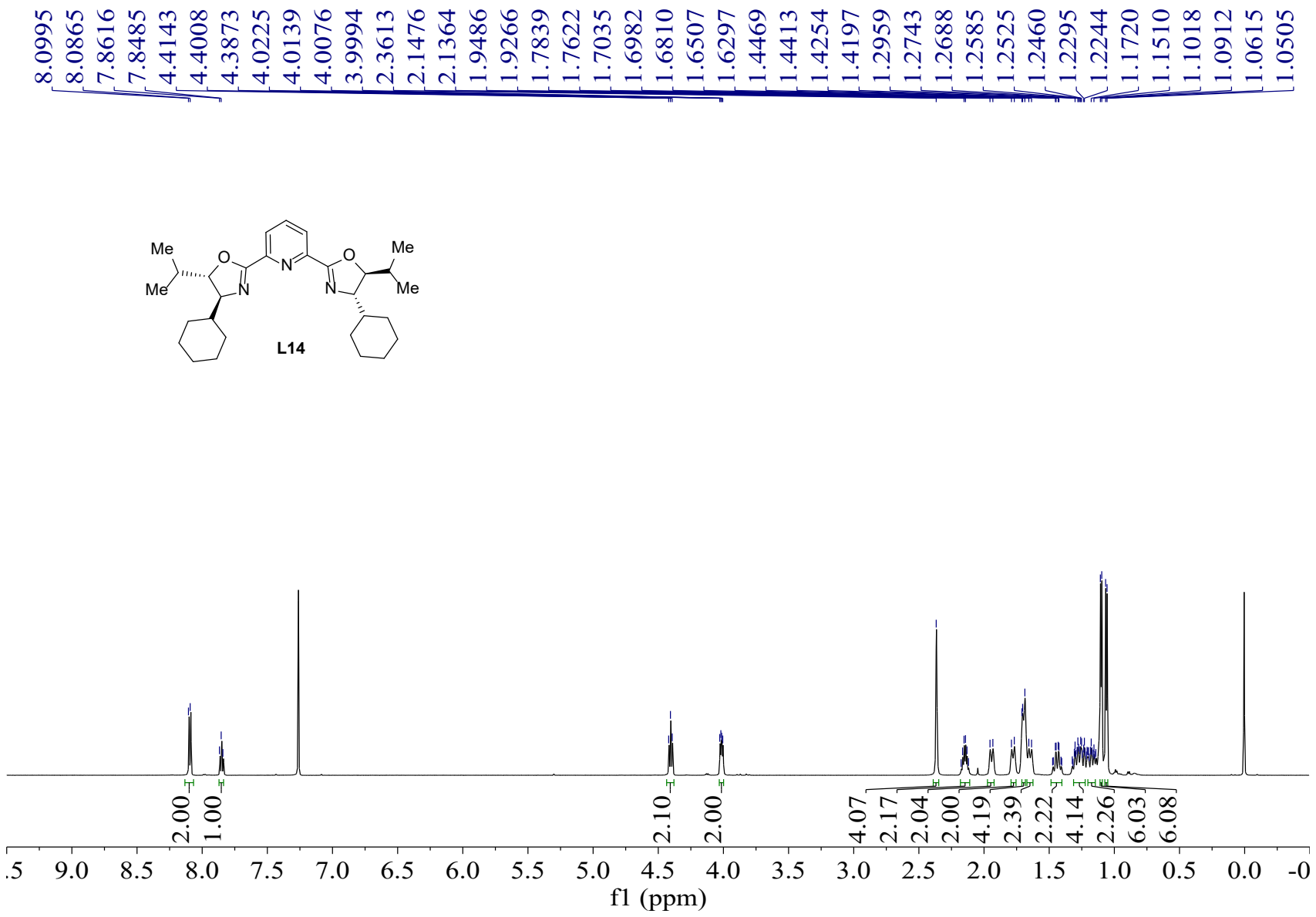
^{13}C NMR spectrum of compound **L12**



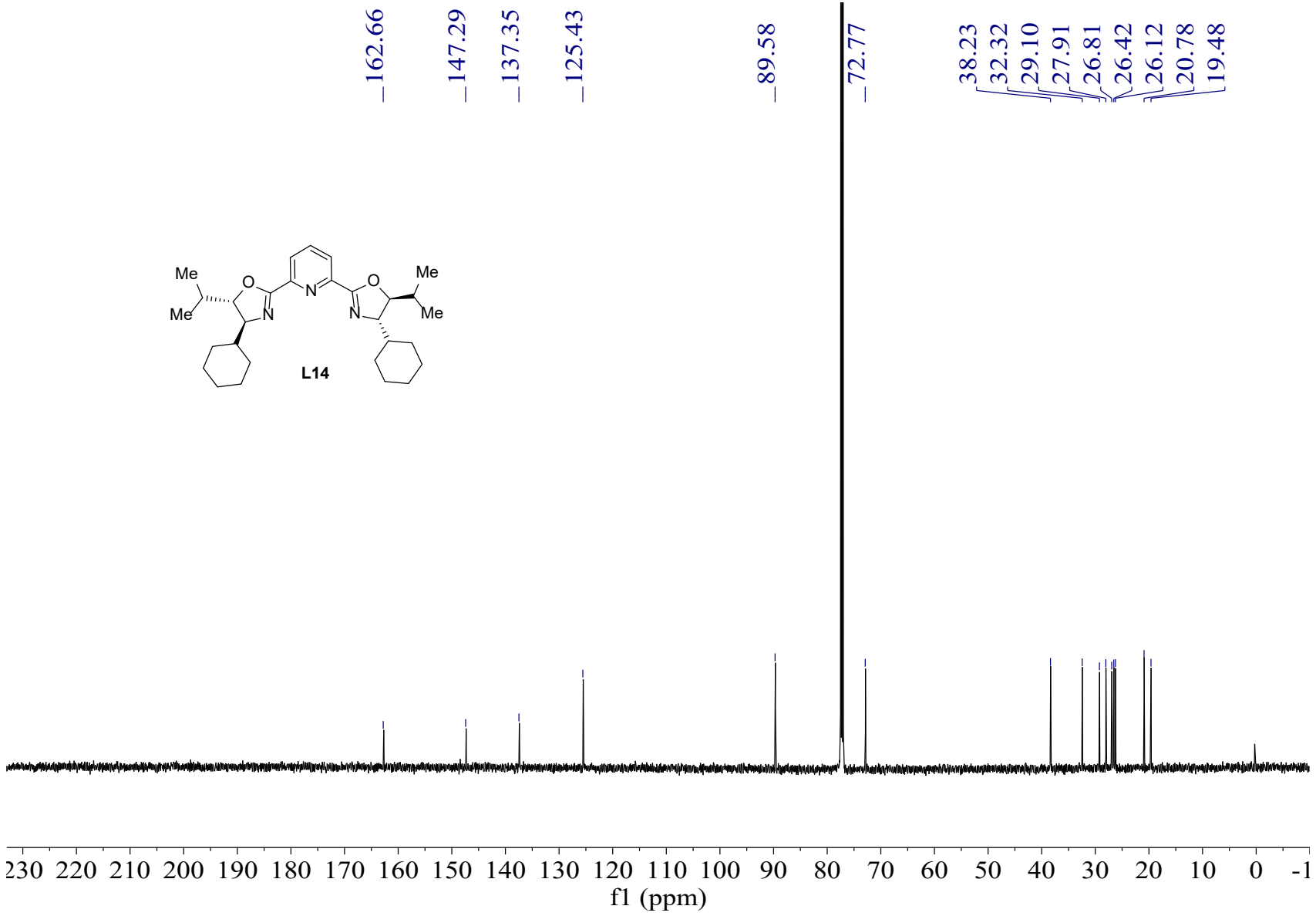
^{1}H NMR spectrum of compound **L13**



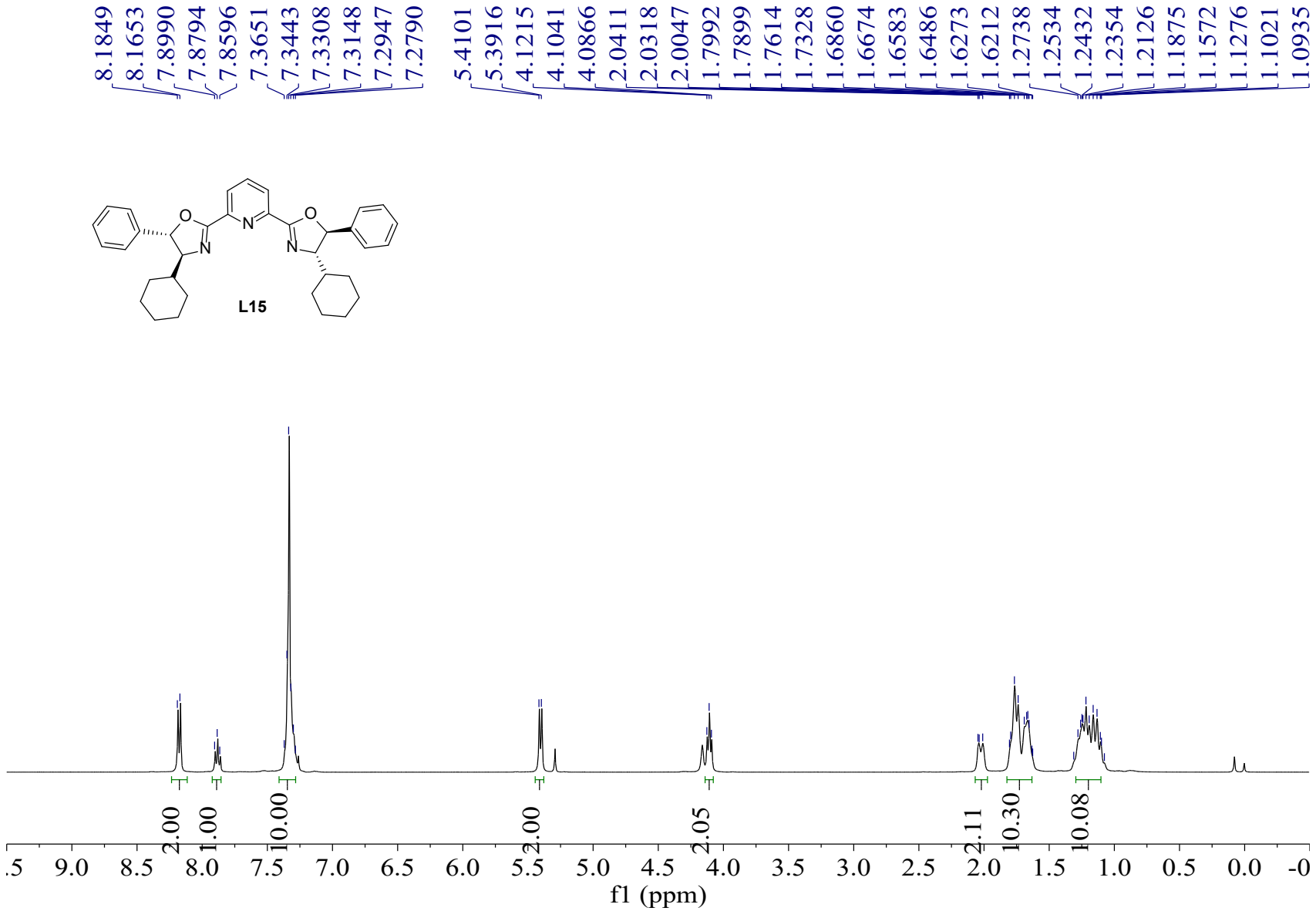
^{13}C NMR spectrum of compound **L13**



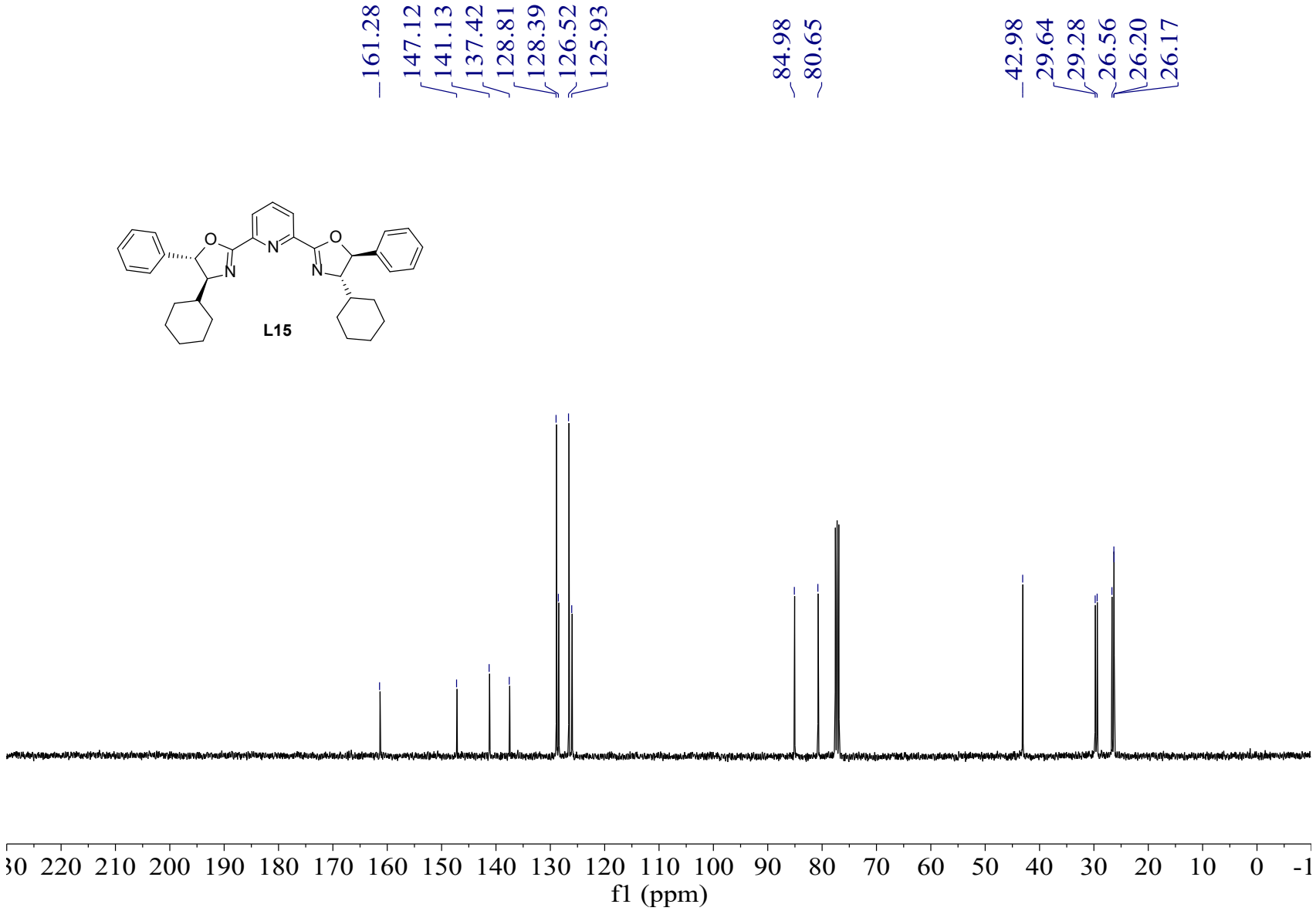
^{1}H NMR spectrum of compound **L14**



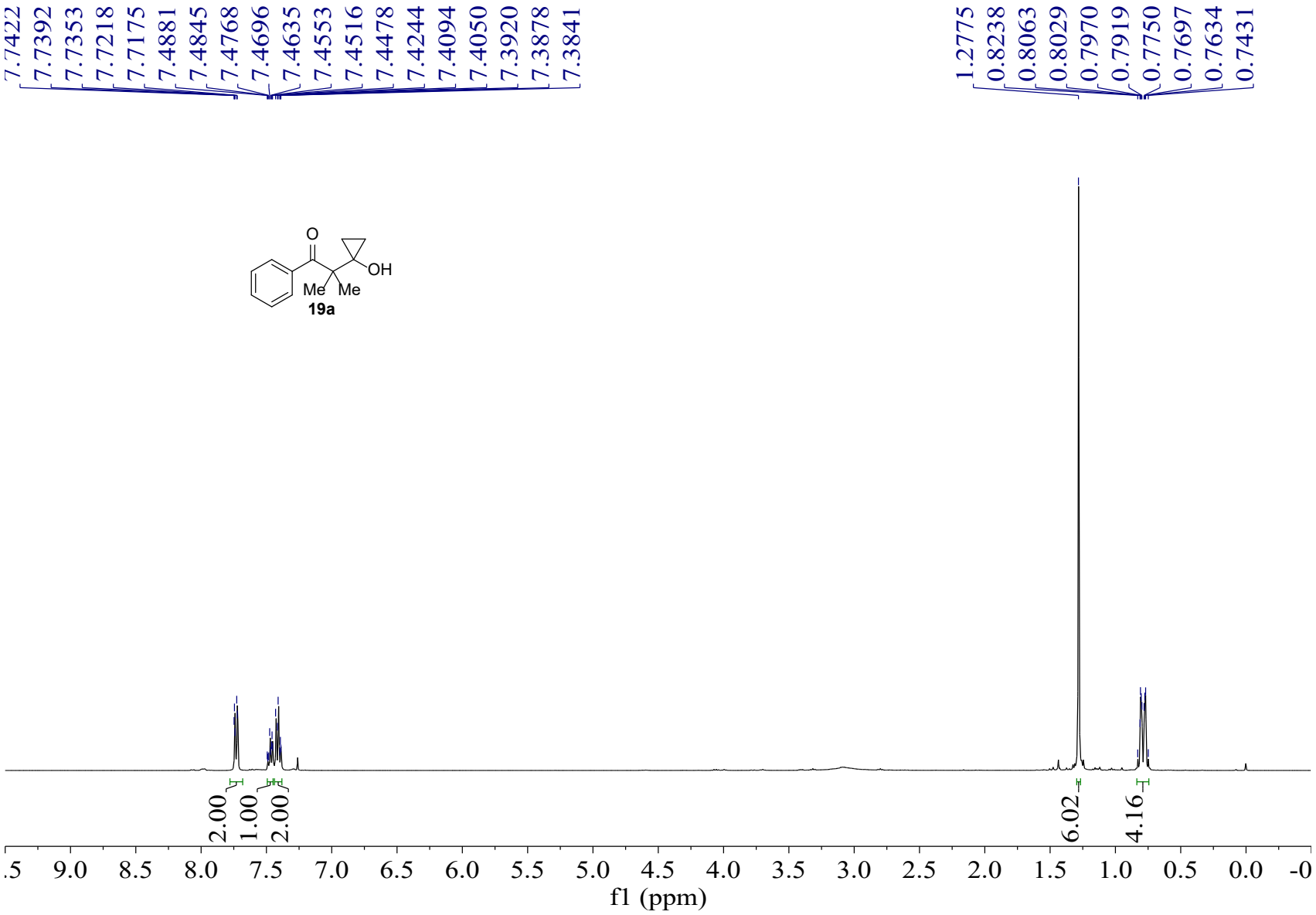
^{13}C NMR spectrum of compound **L14**



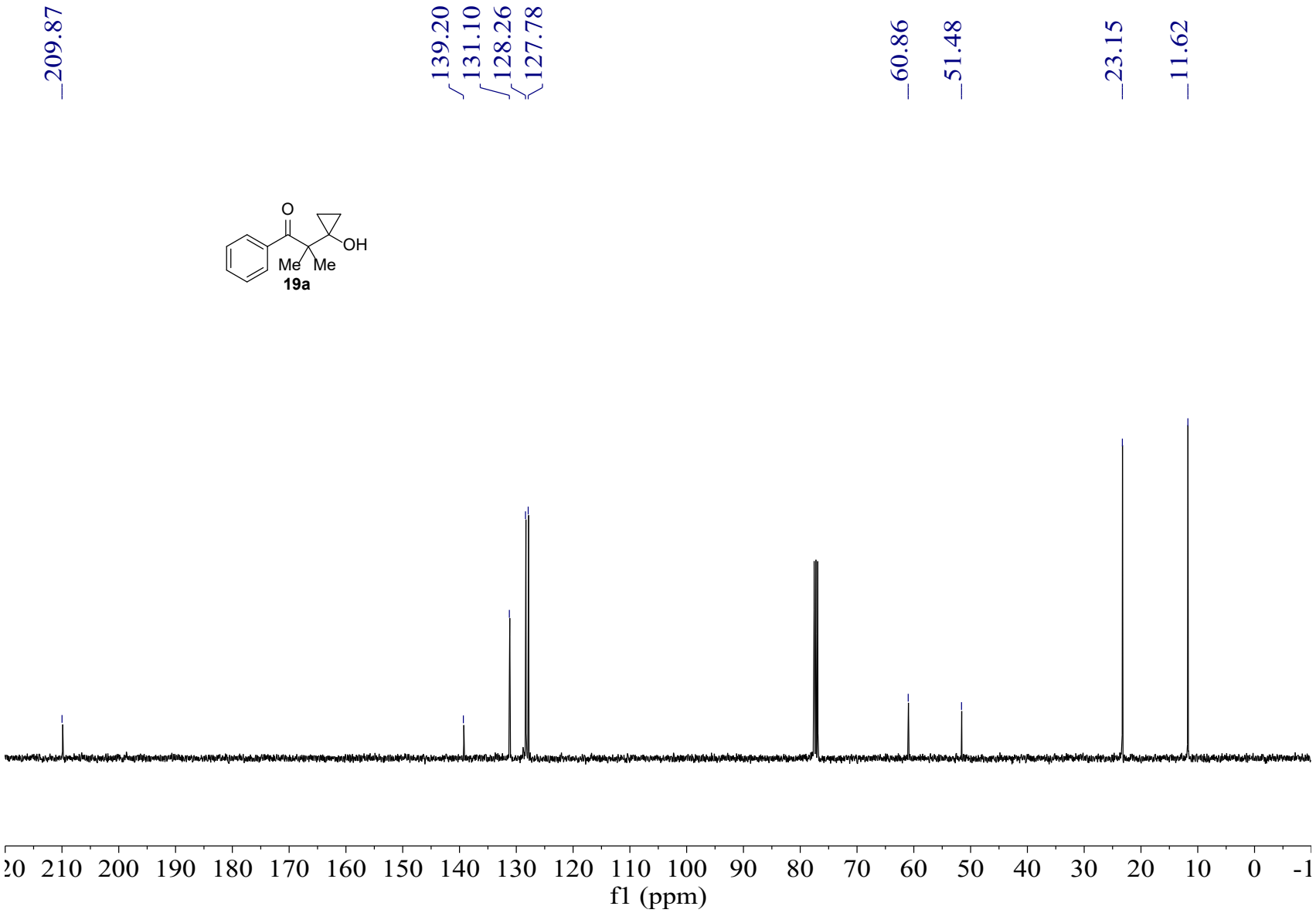
^{1}H NMR spectrum of compound **L15**



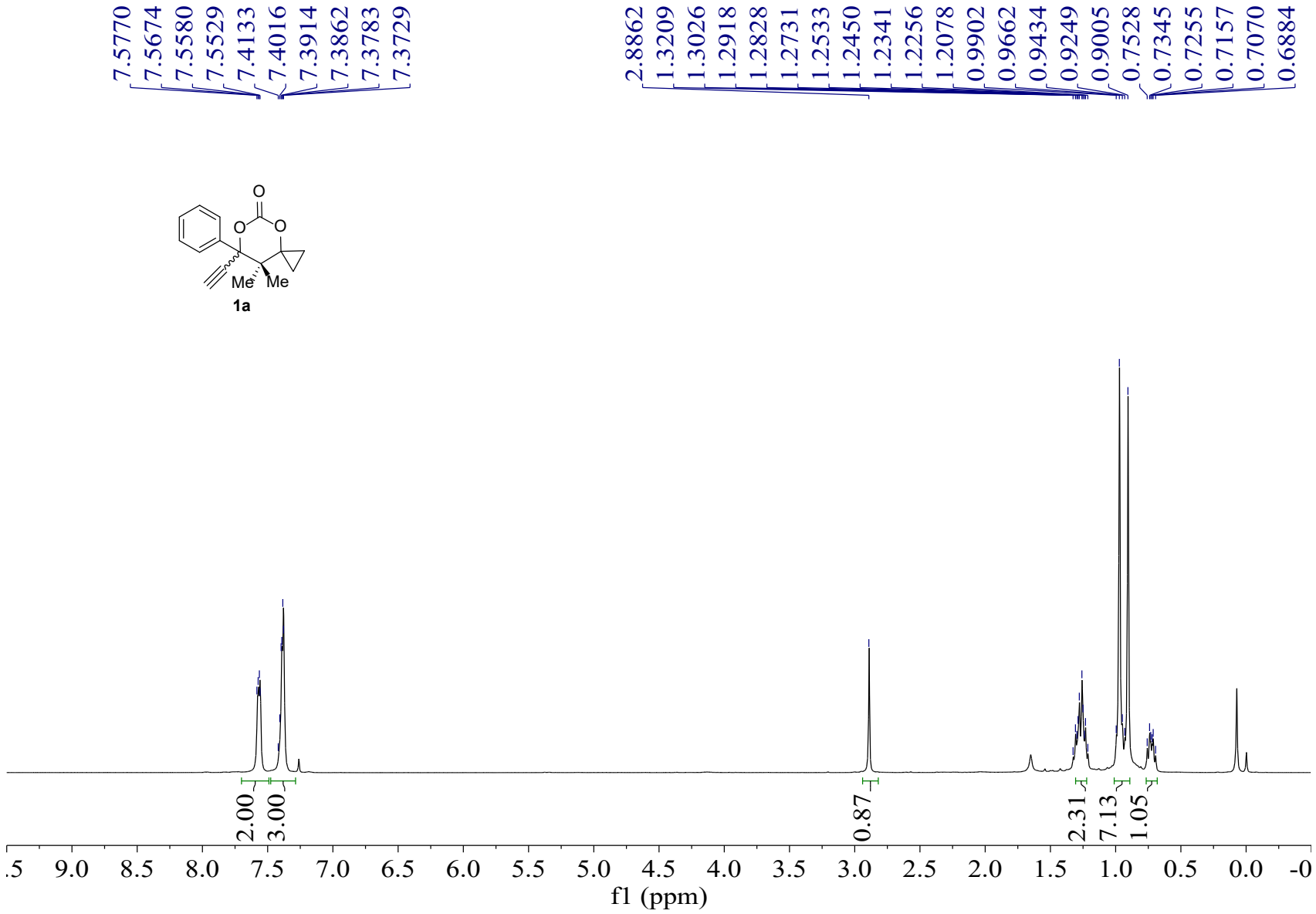
^{13}C NMR spectrum of compound **L15**



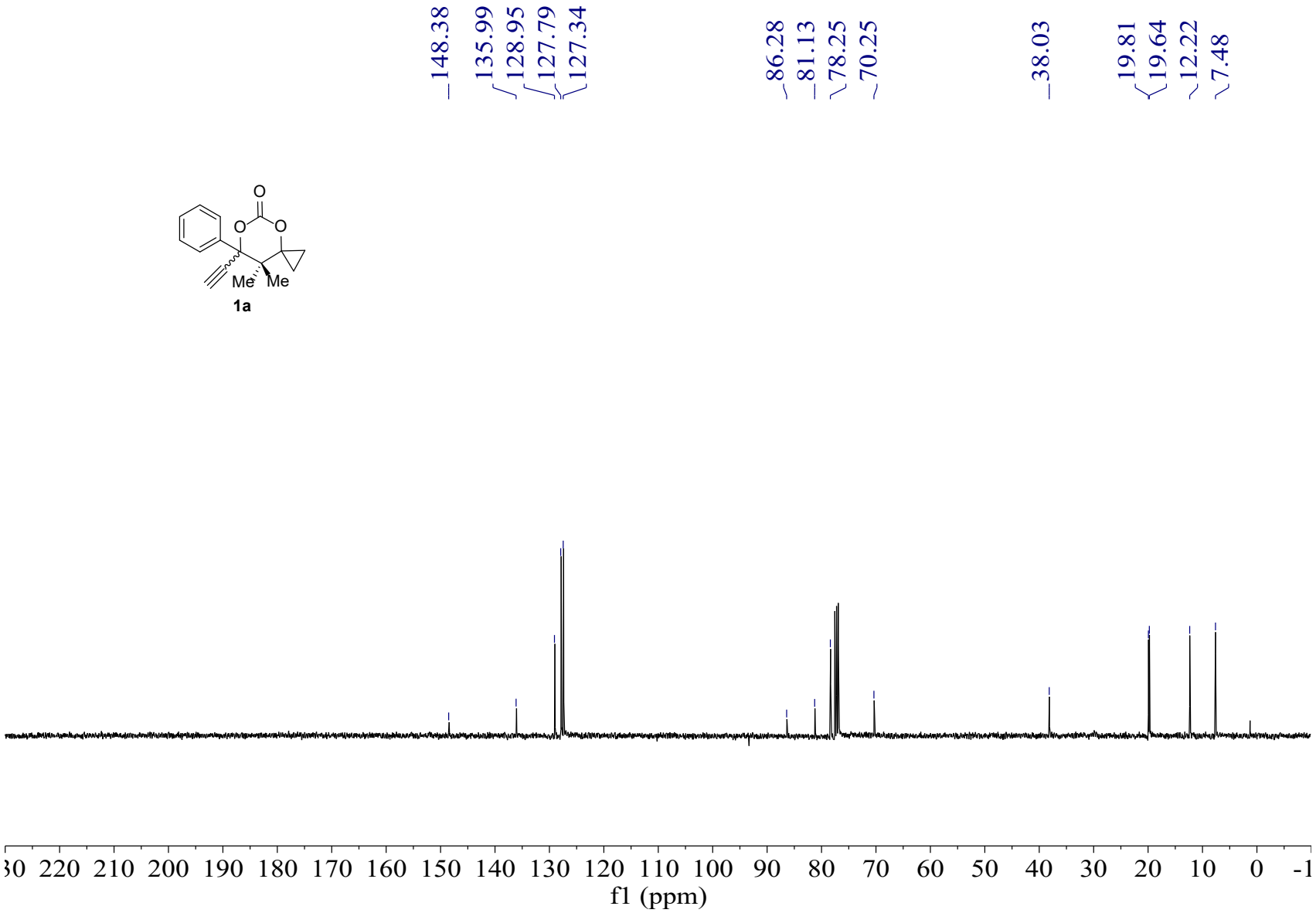
^{1}H NMR spectrum of compound **19a**



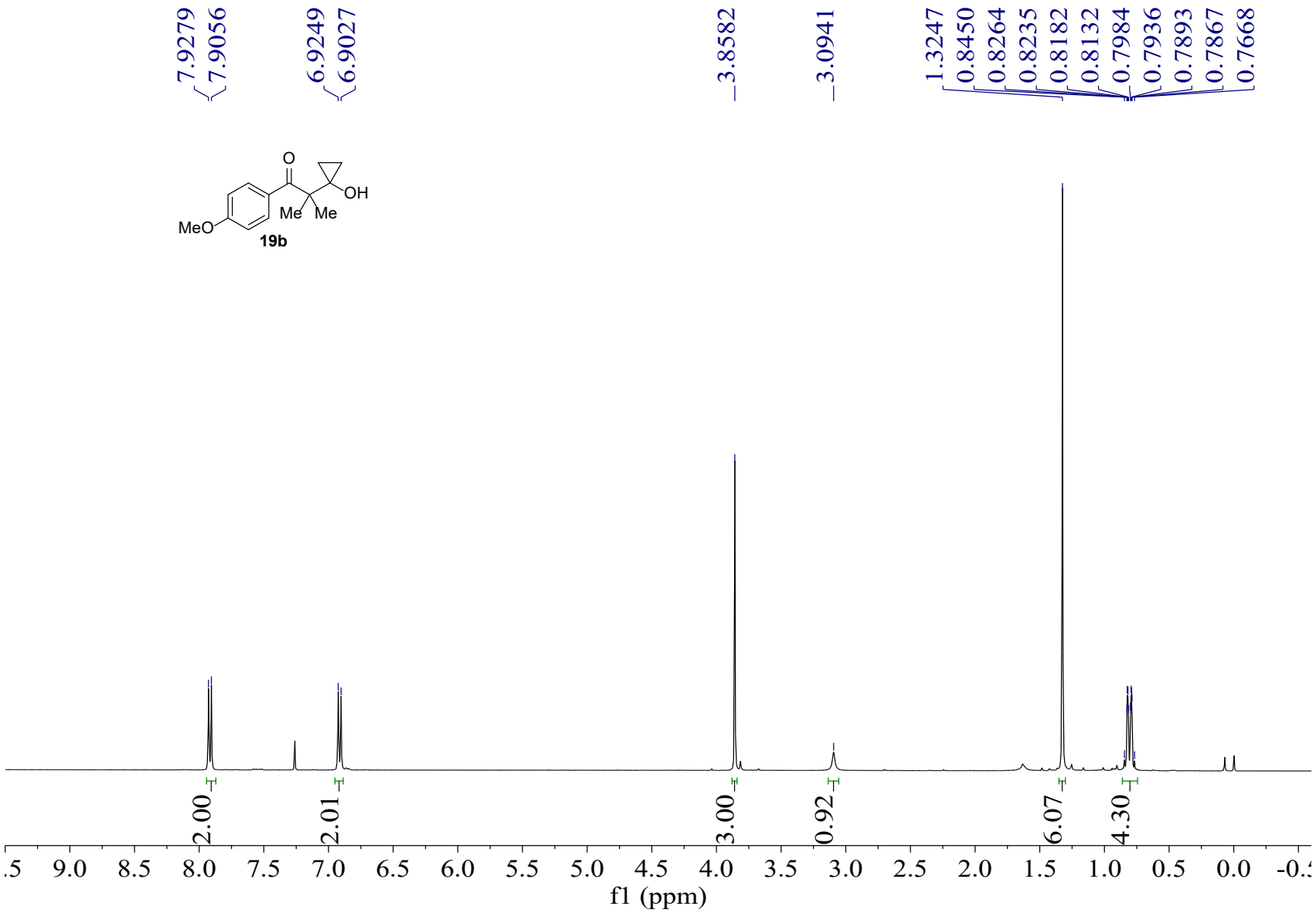
^{13}C NMR spectrum of compound **19a**



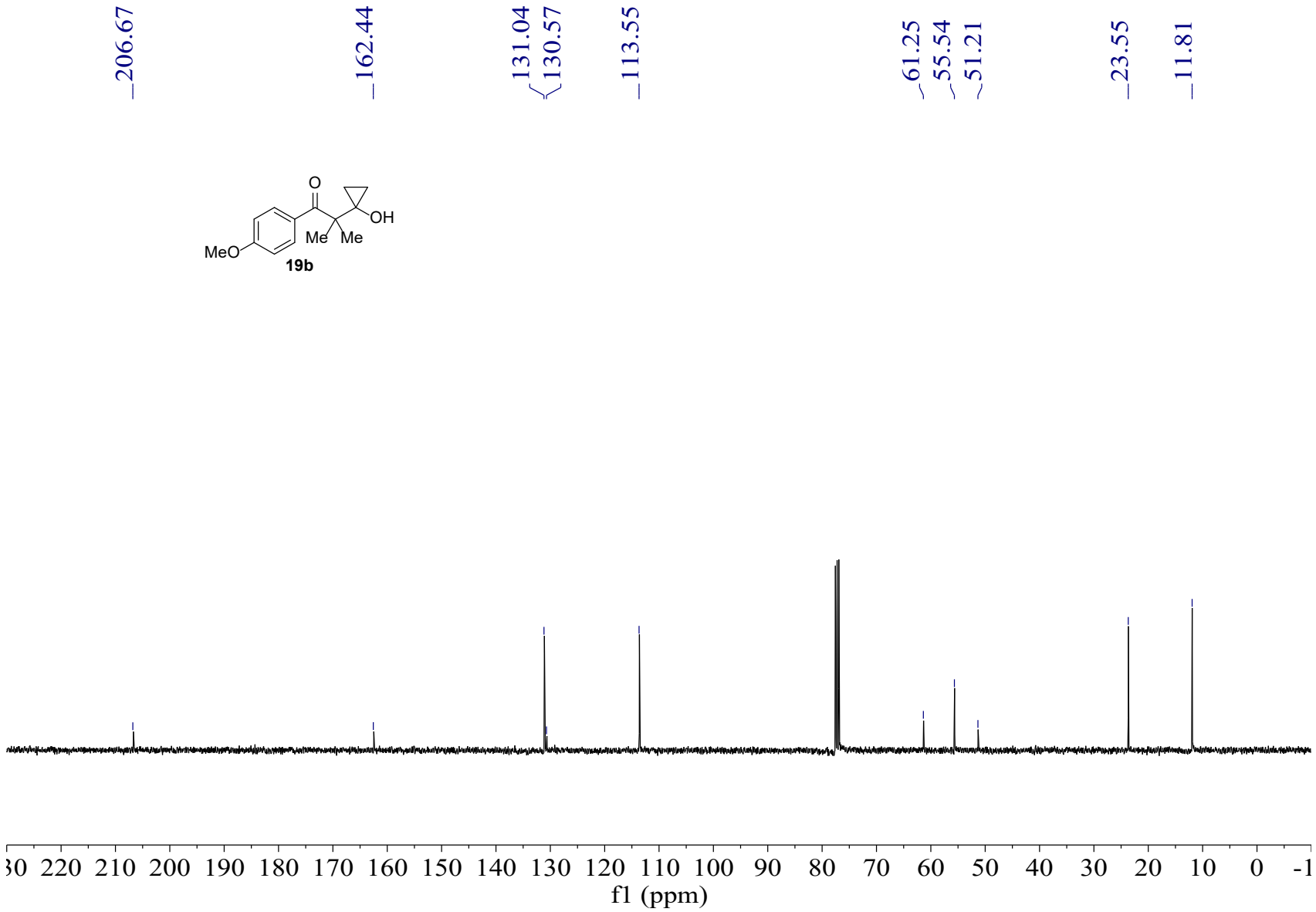
^{1}H NMR spectrum of compound **1a**



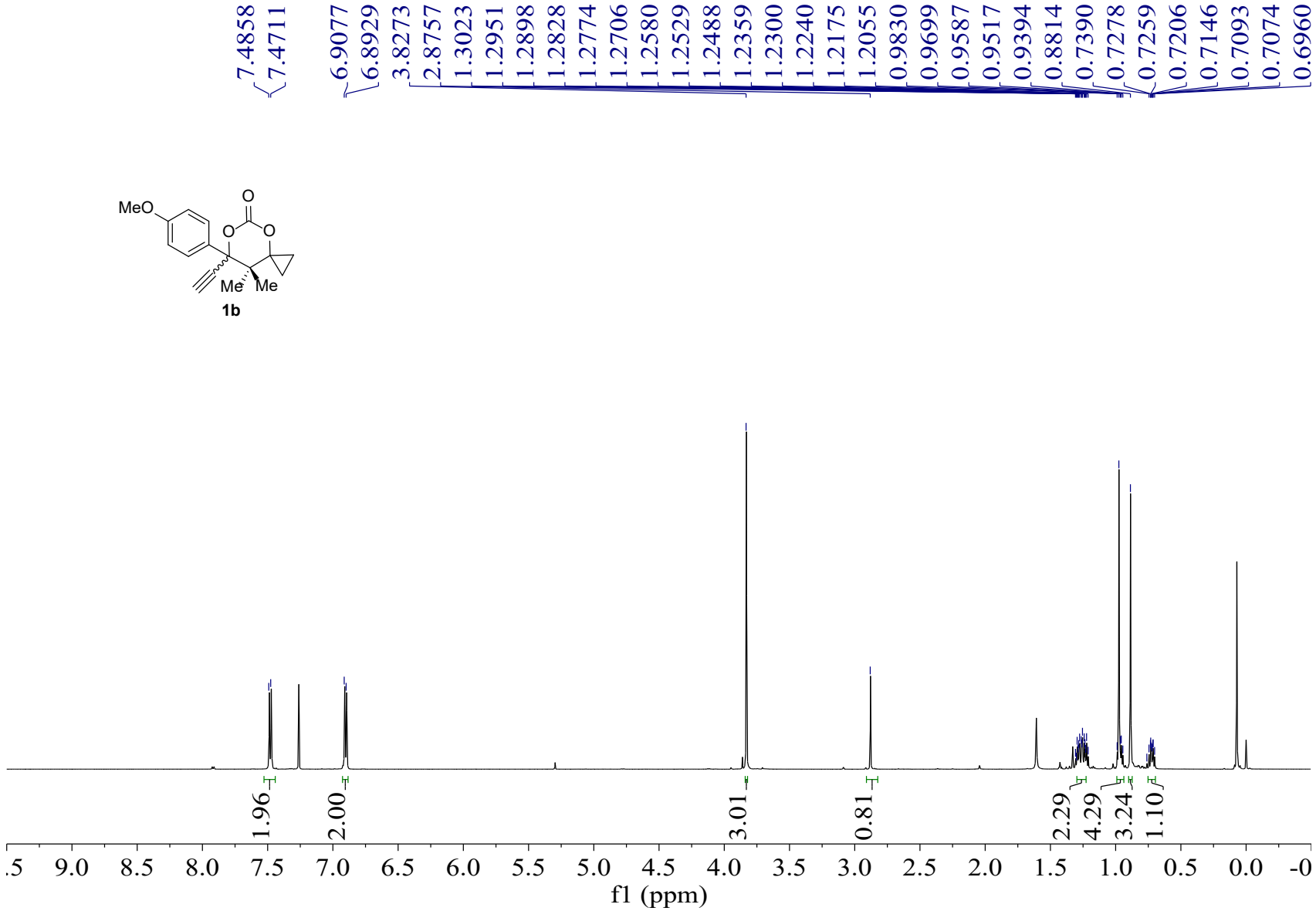
^{13}C NMR spectrum of compound **1a**



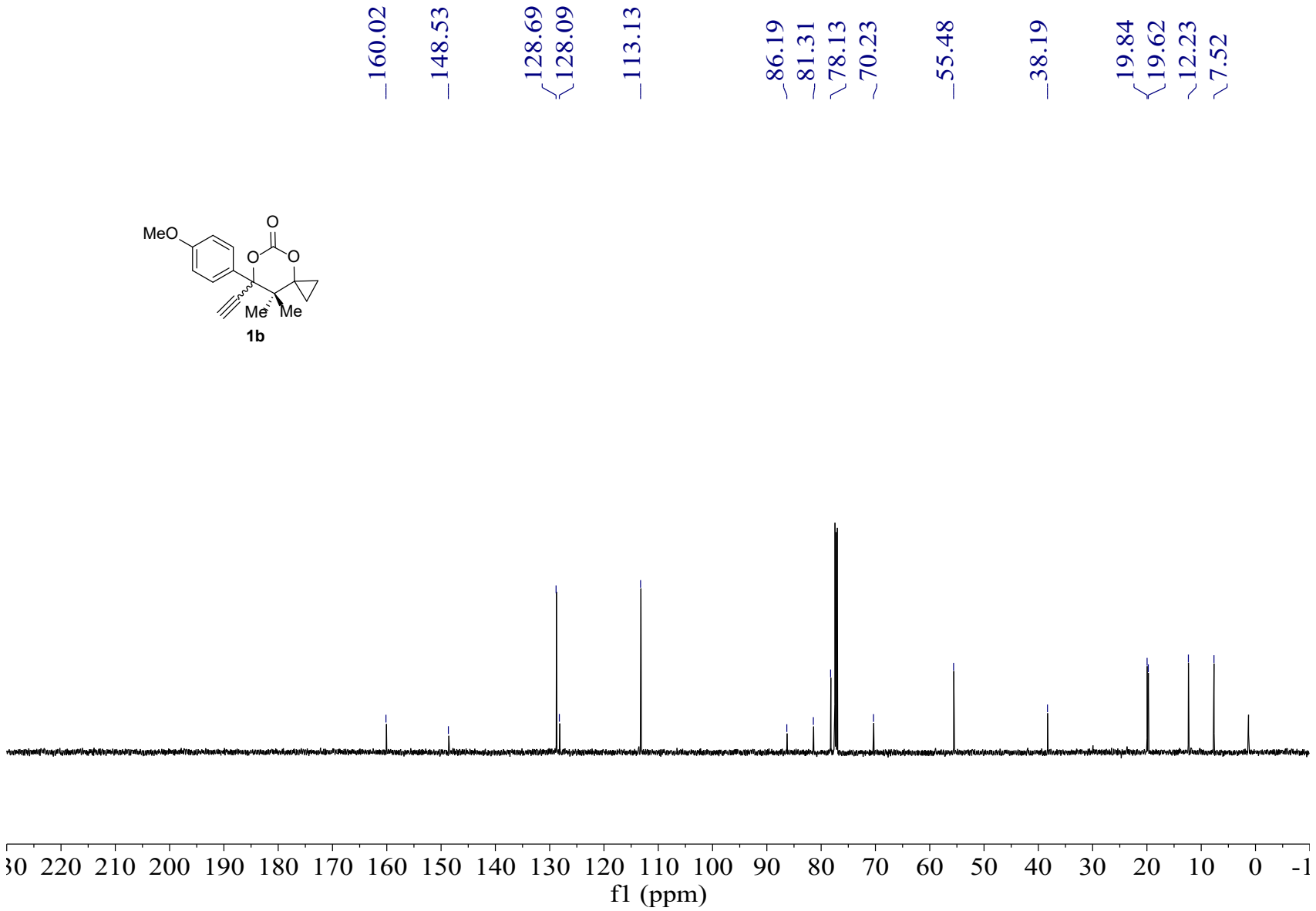
^{1}H NMR spectrum of compound **19b**



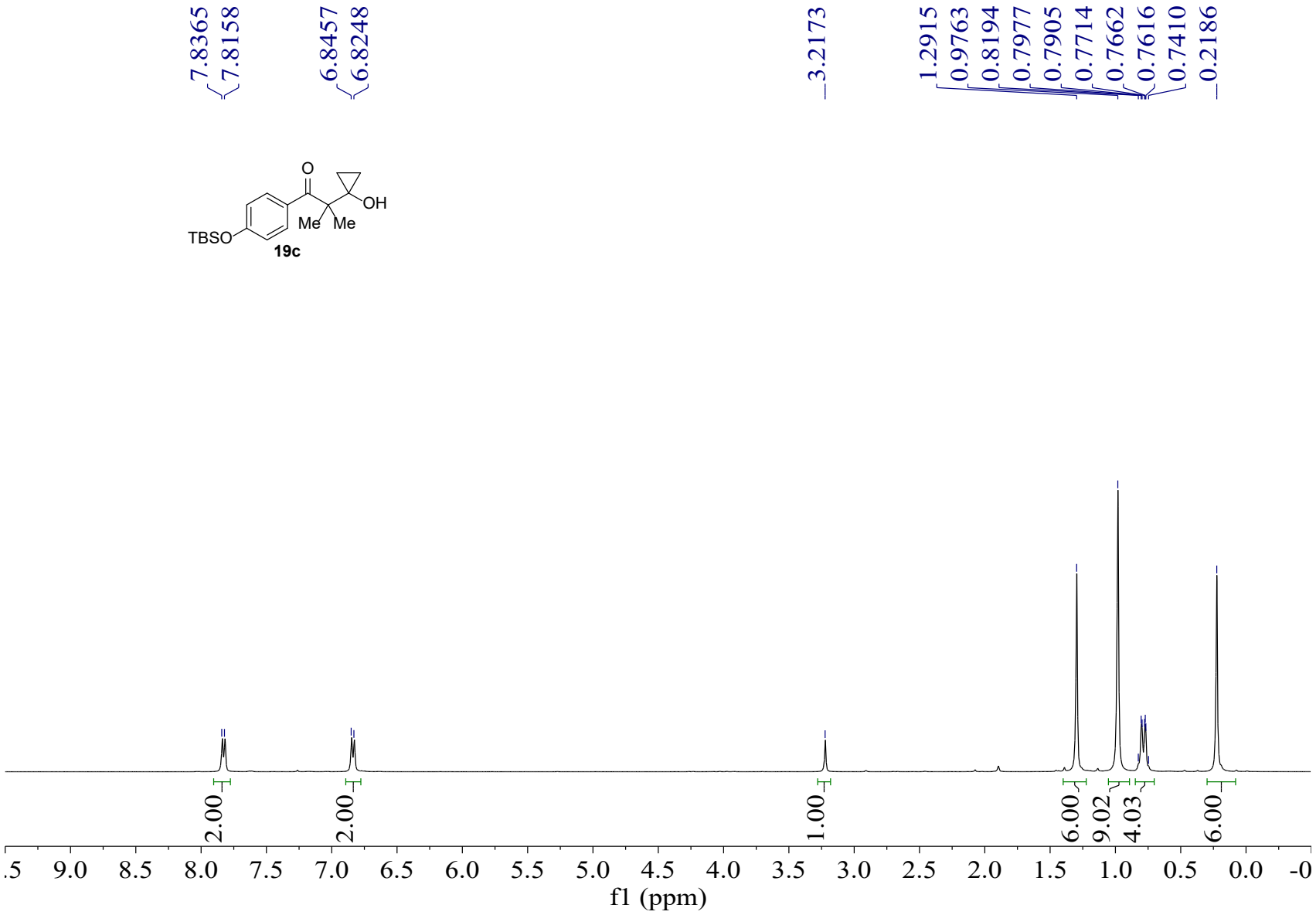
^{13}C NMR spectrum of compound **19b**



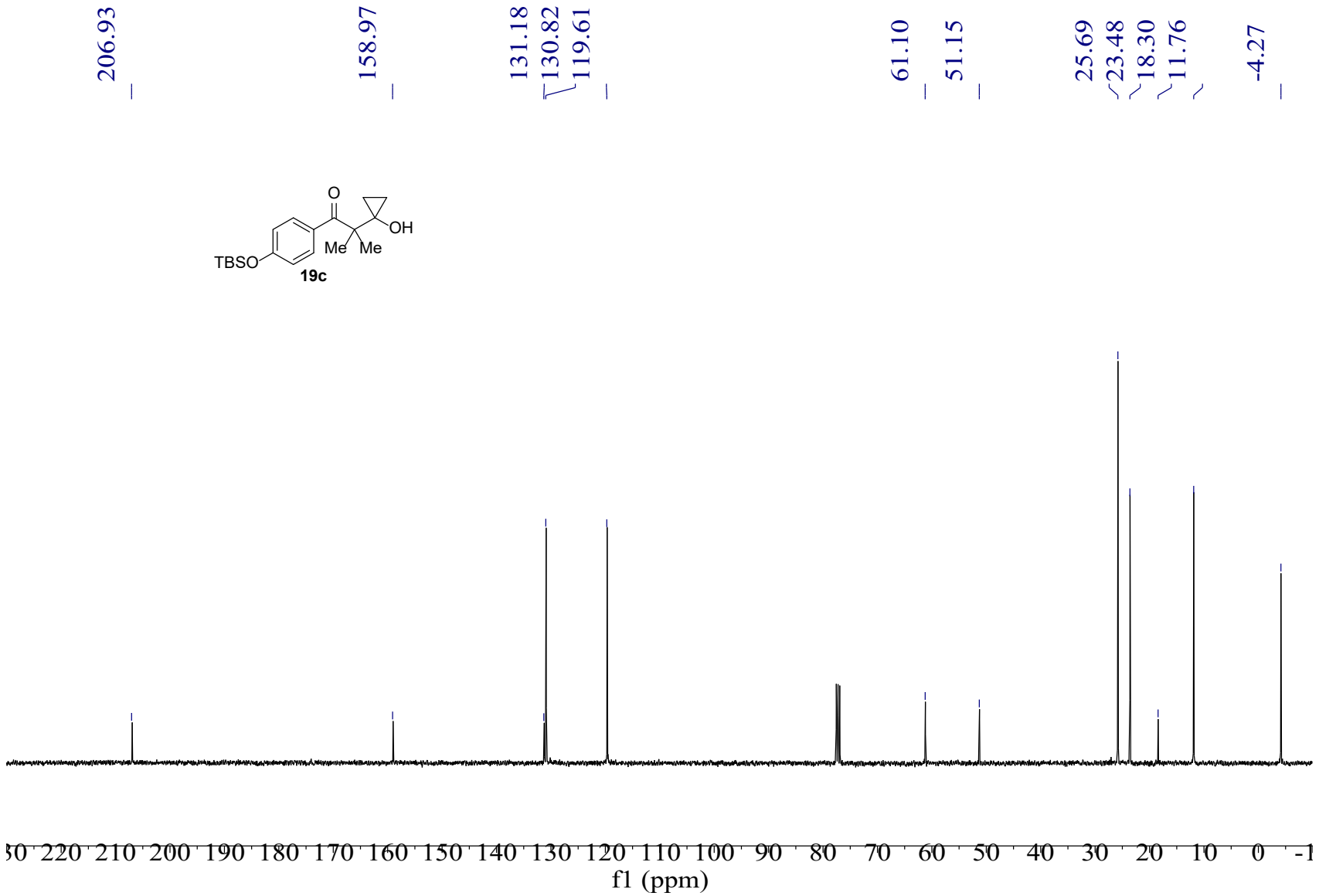
^{1}H NMR spectrum of compound **1b**



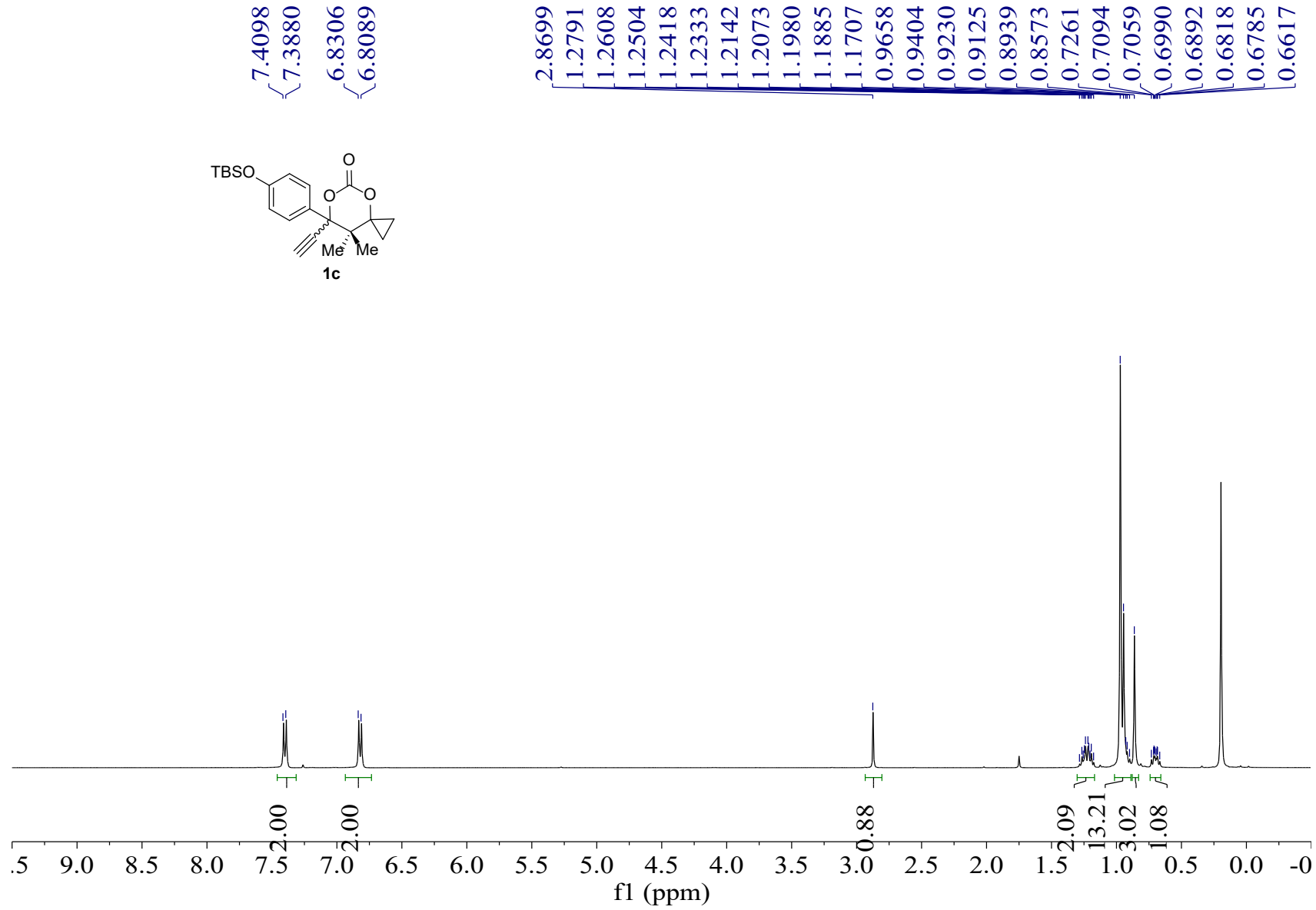
^{13}C NMR spectrum of compound **1b**



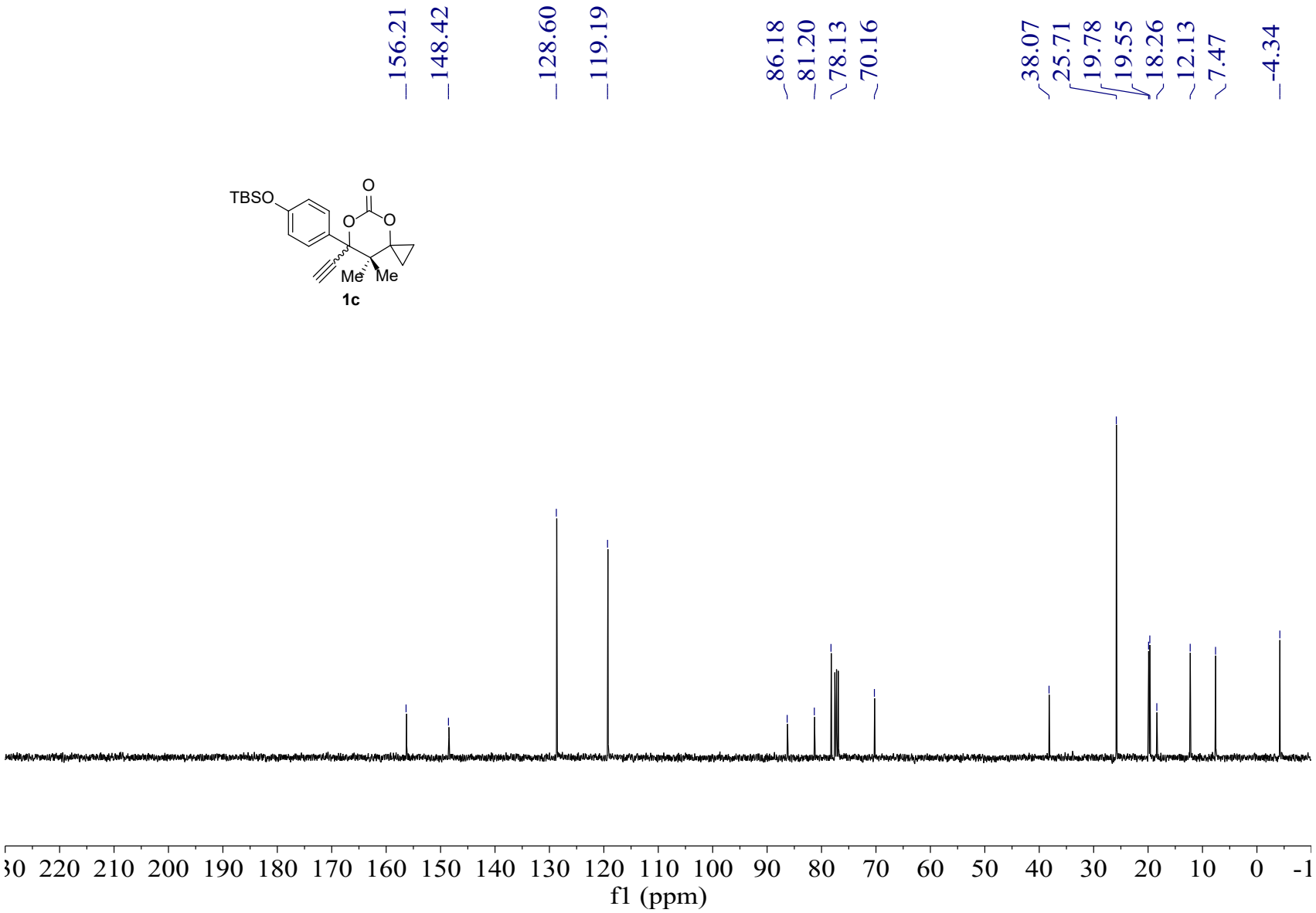
^{1}H NMR spectrum of compound **19c**



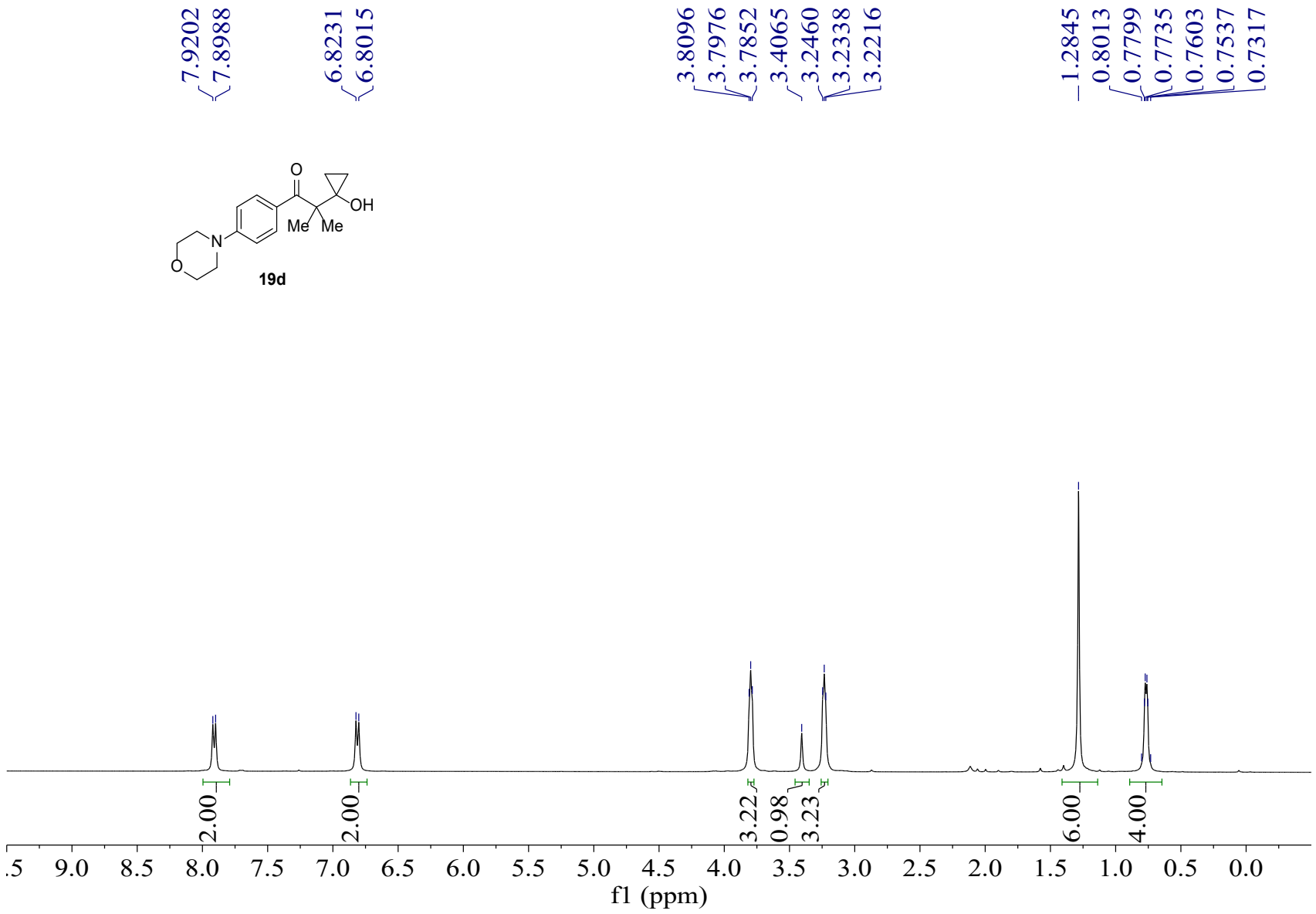
^{13}C NMR spectrum of compound **19c**



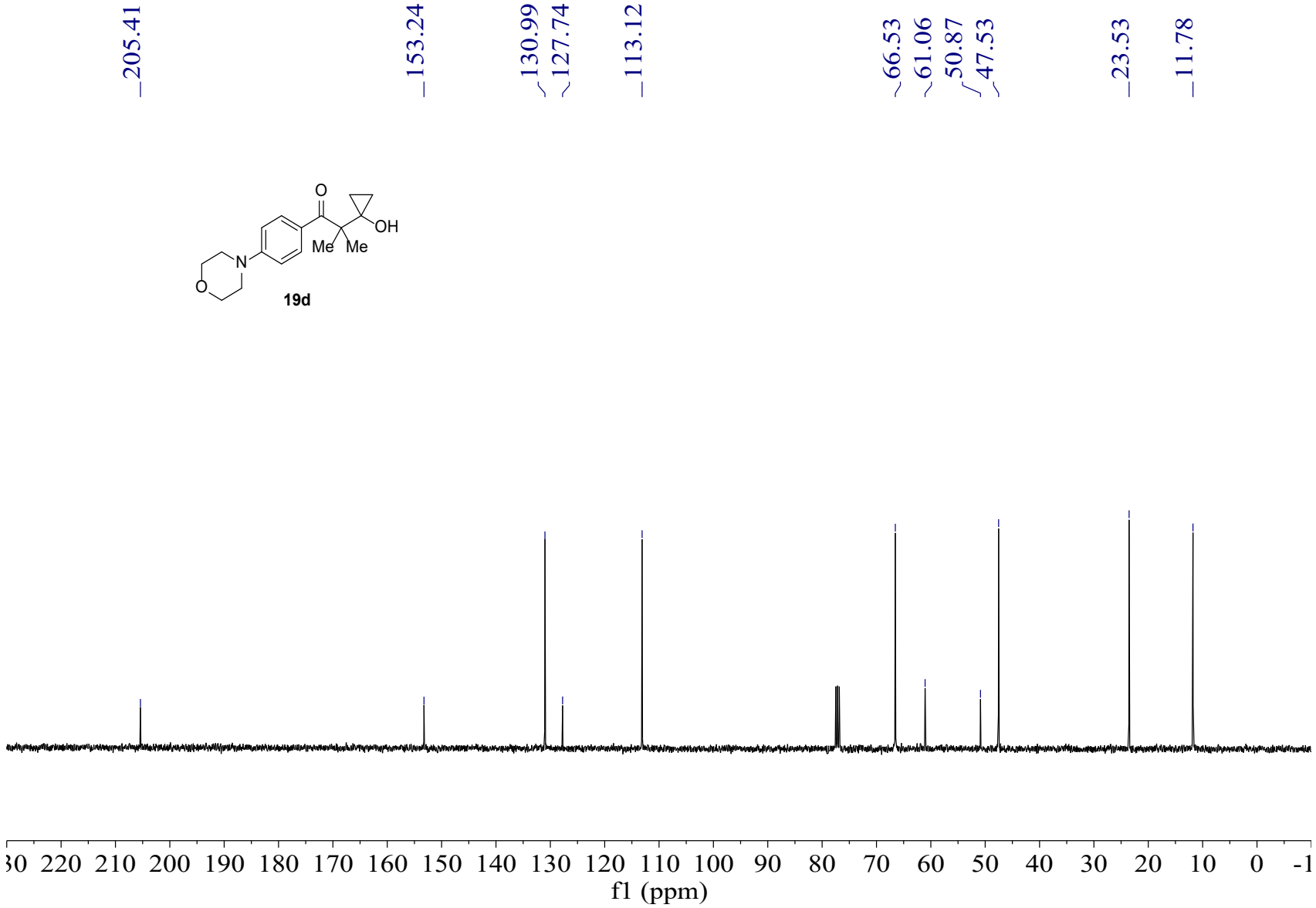
^{1}H NMR spectrum of compound **1c**



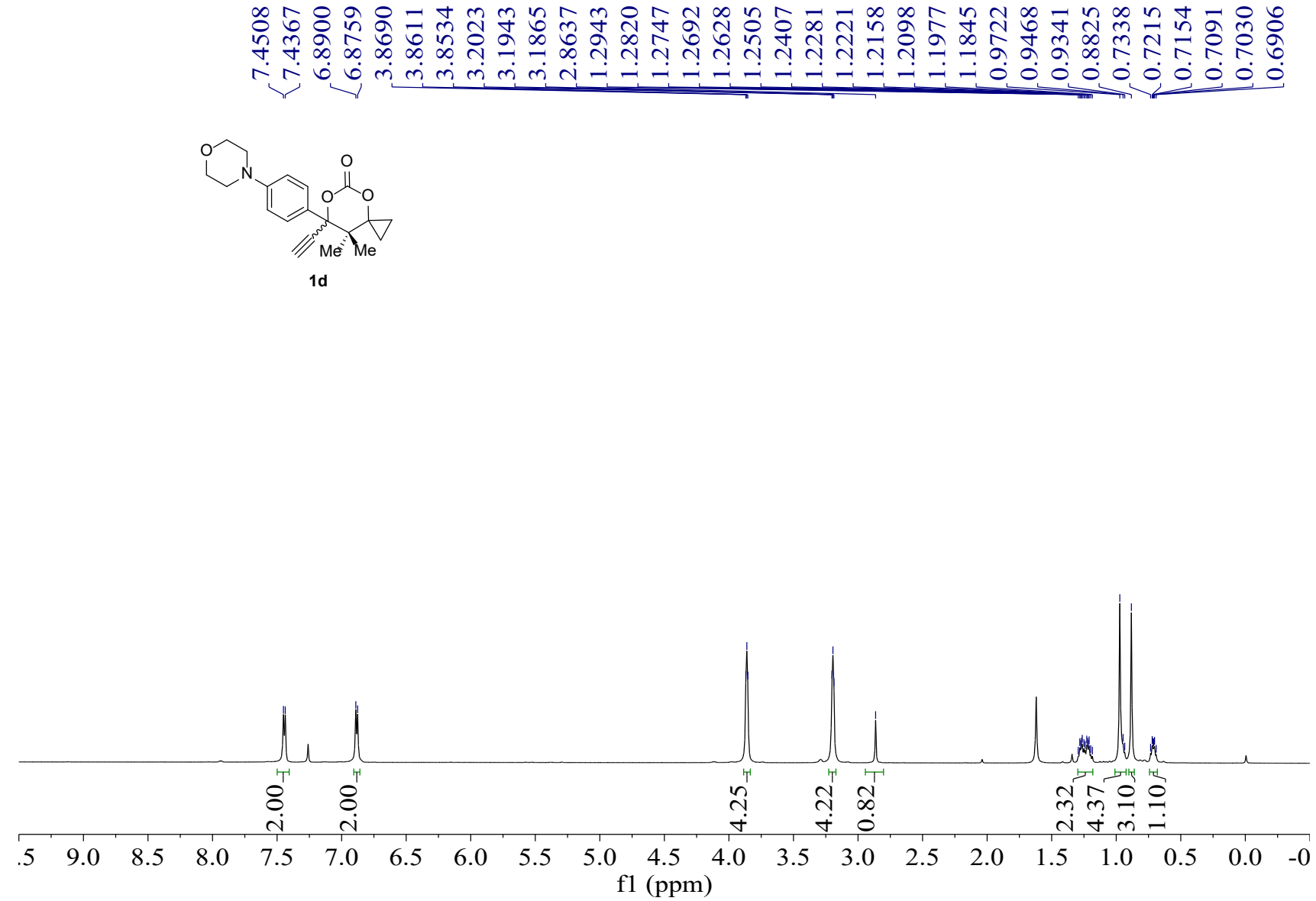
^{13}C NMR spectrum of compound **1c**



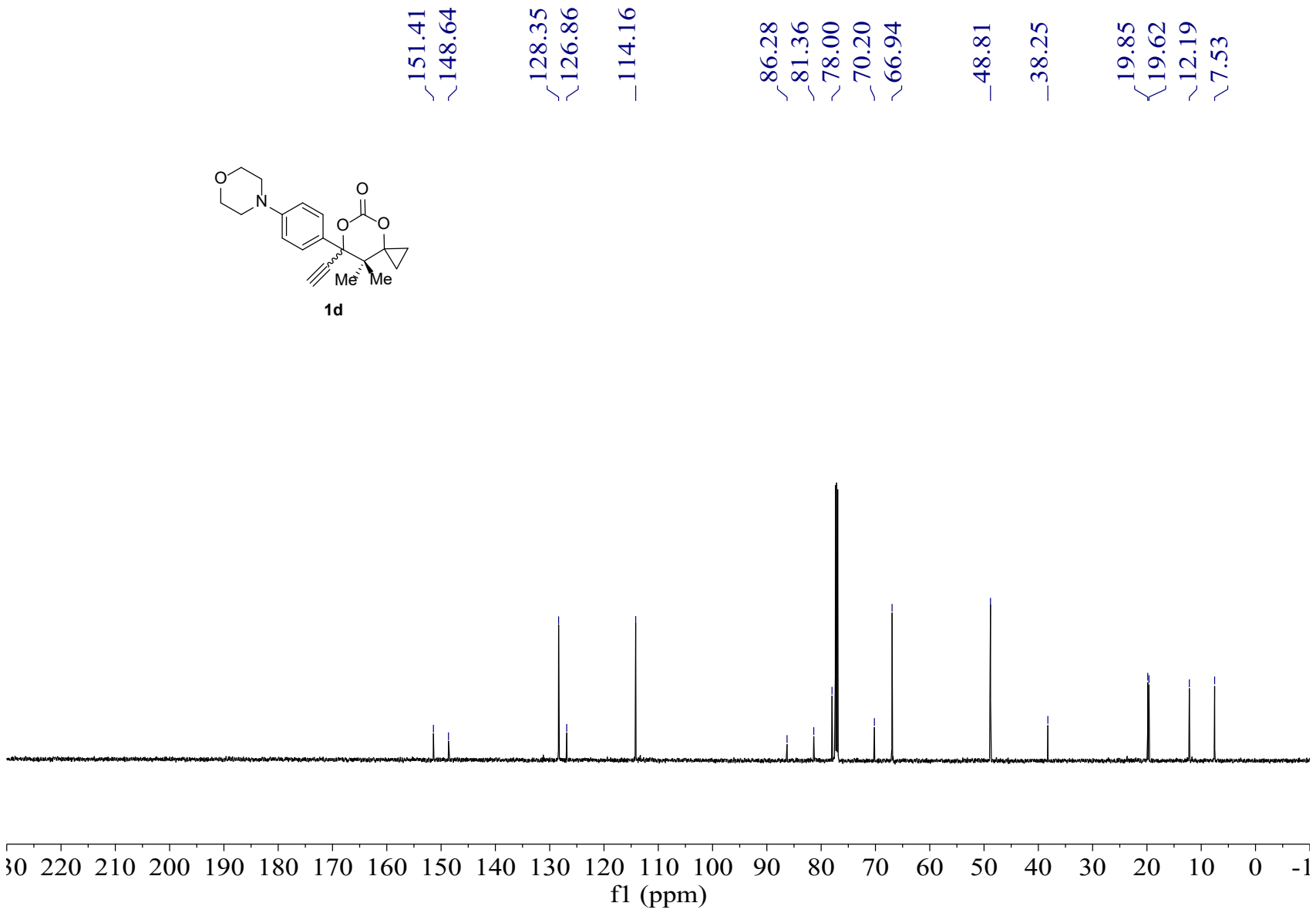
^{1}H NMR spectrum of compound **19d**



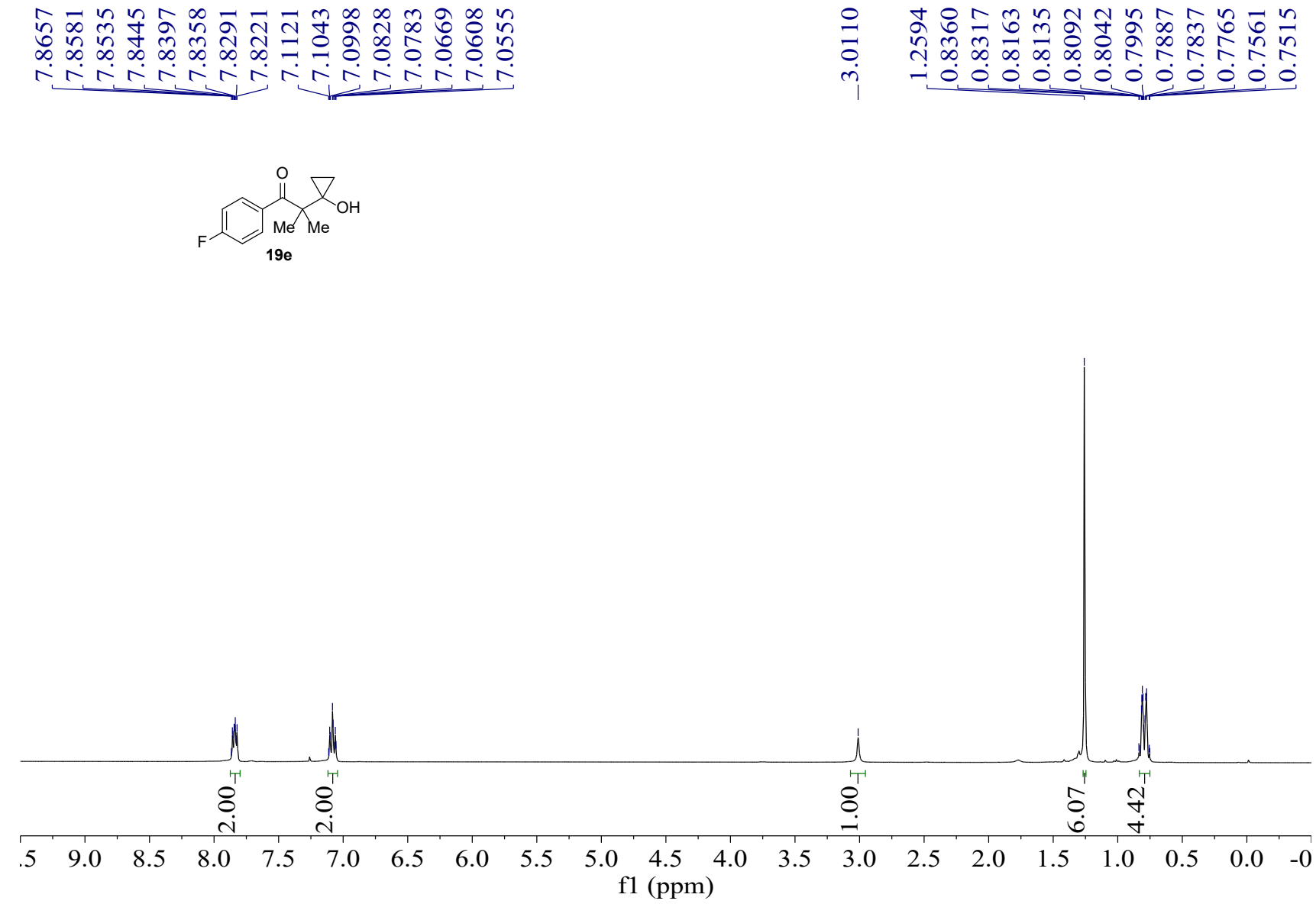
^{13}C NMR spectrum of compound **19d**



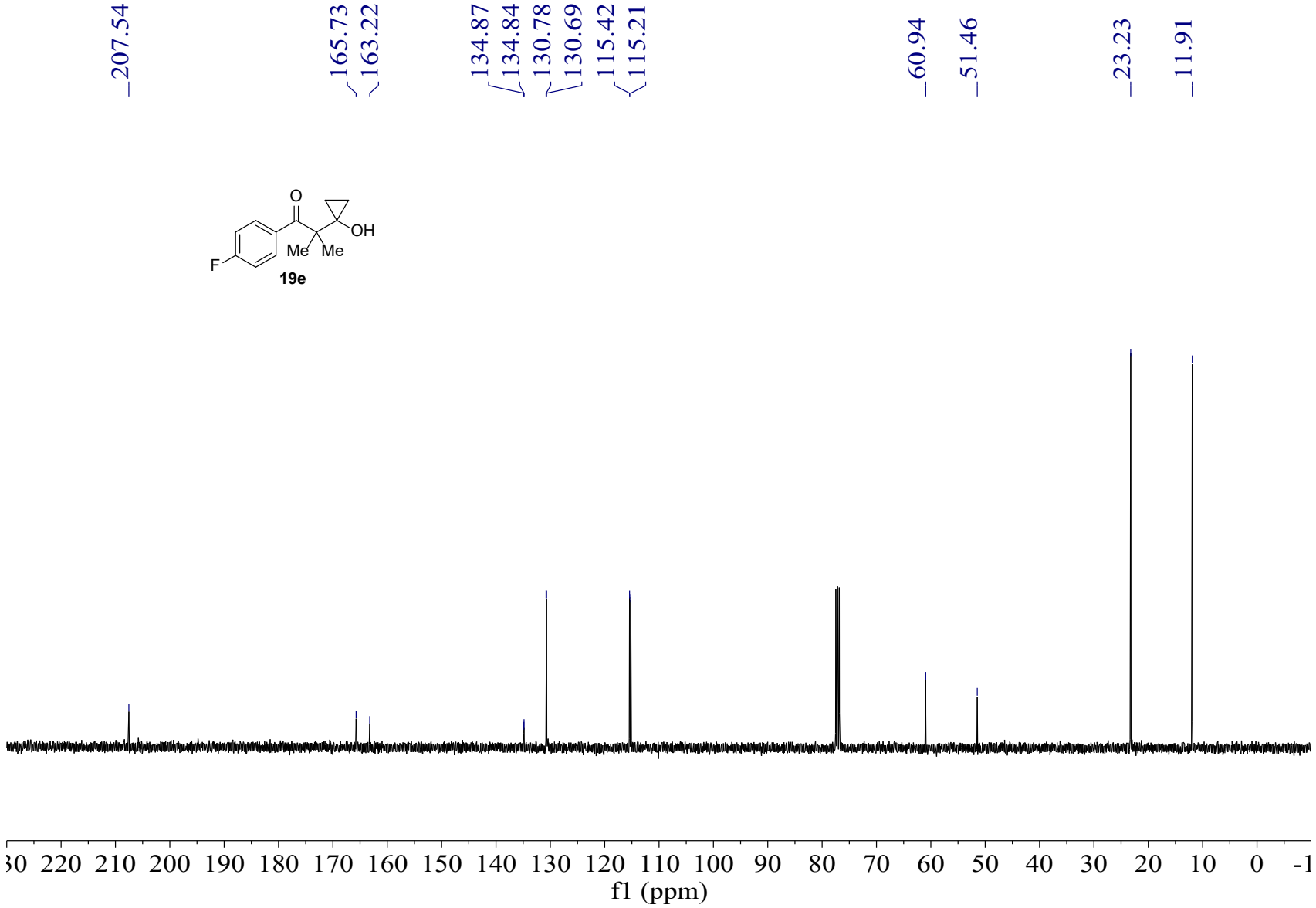
^{1}H NMR spectrum of compound **1d**



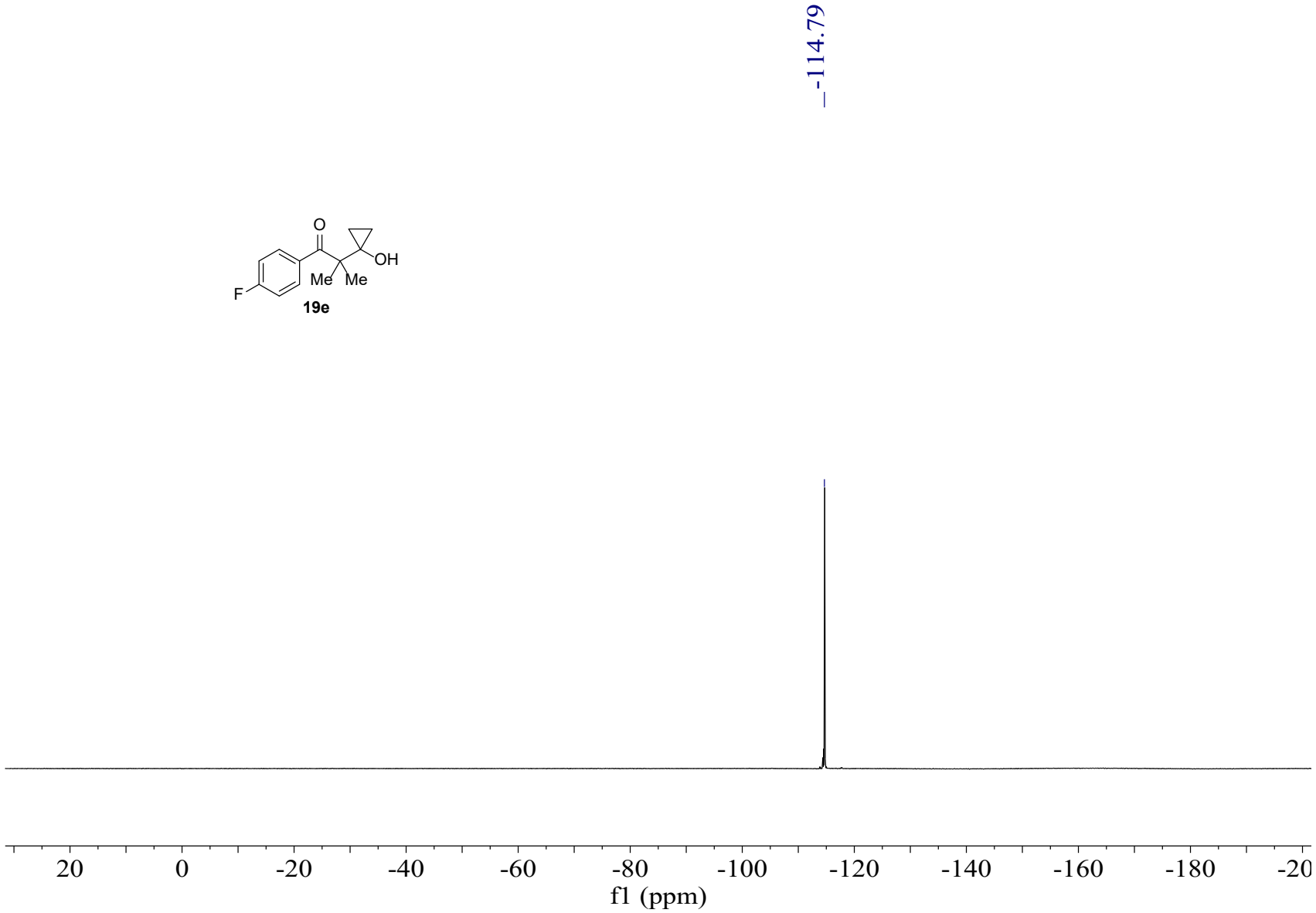
^{13}C NMR spectrum of compound **1d**



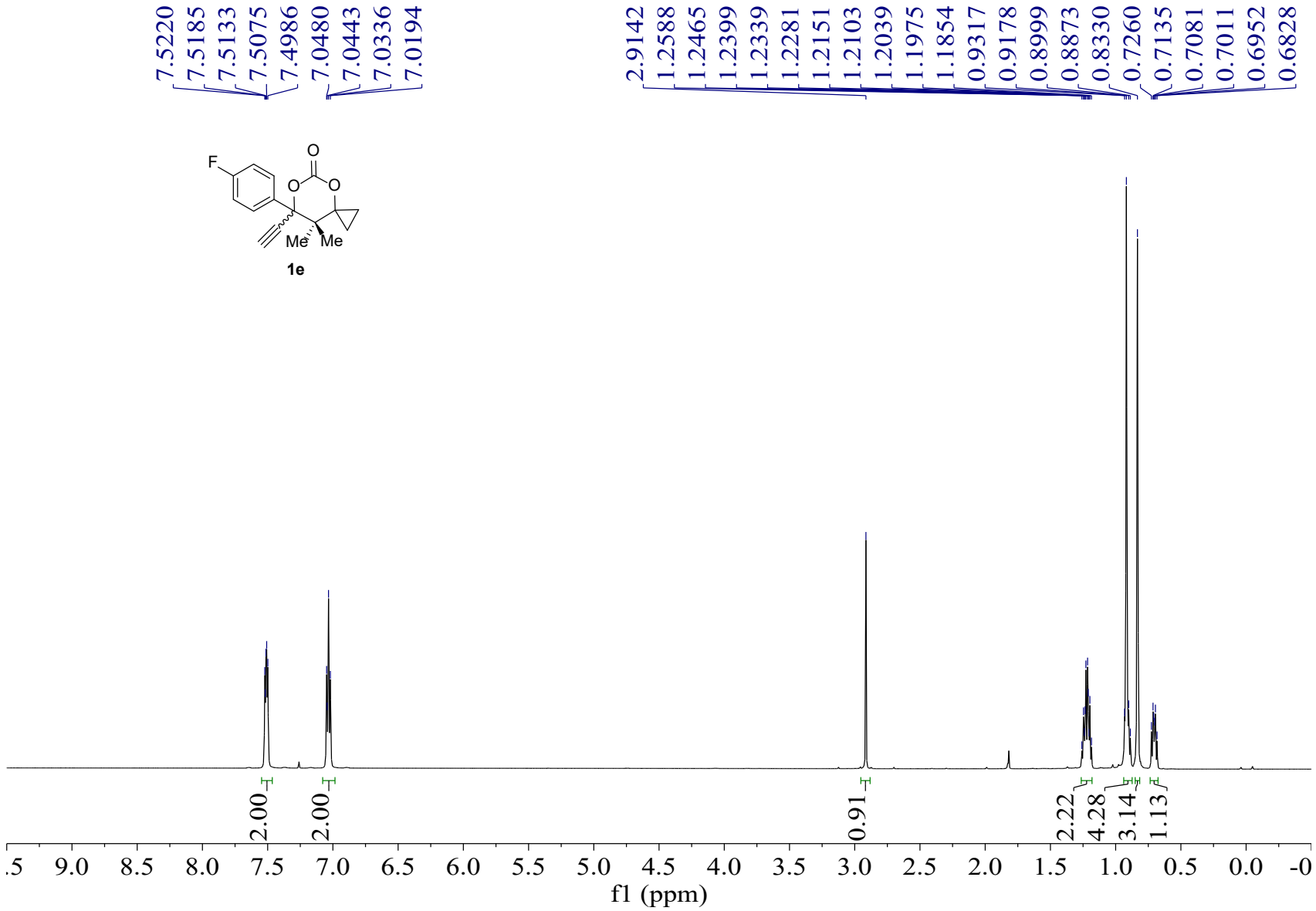
^{1}H NMR spectrum of compound **19e**



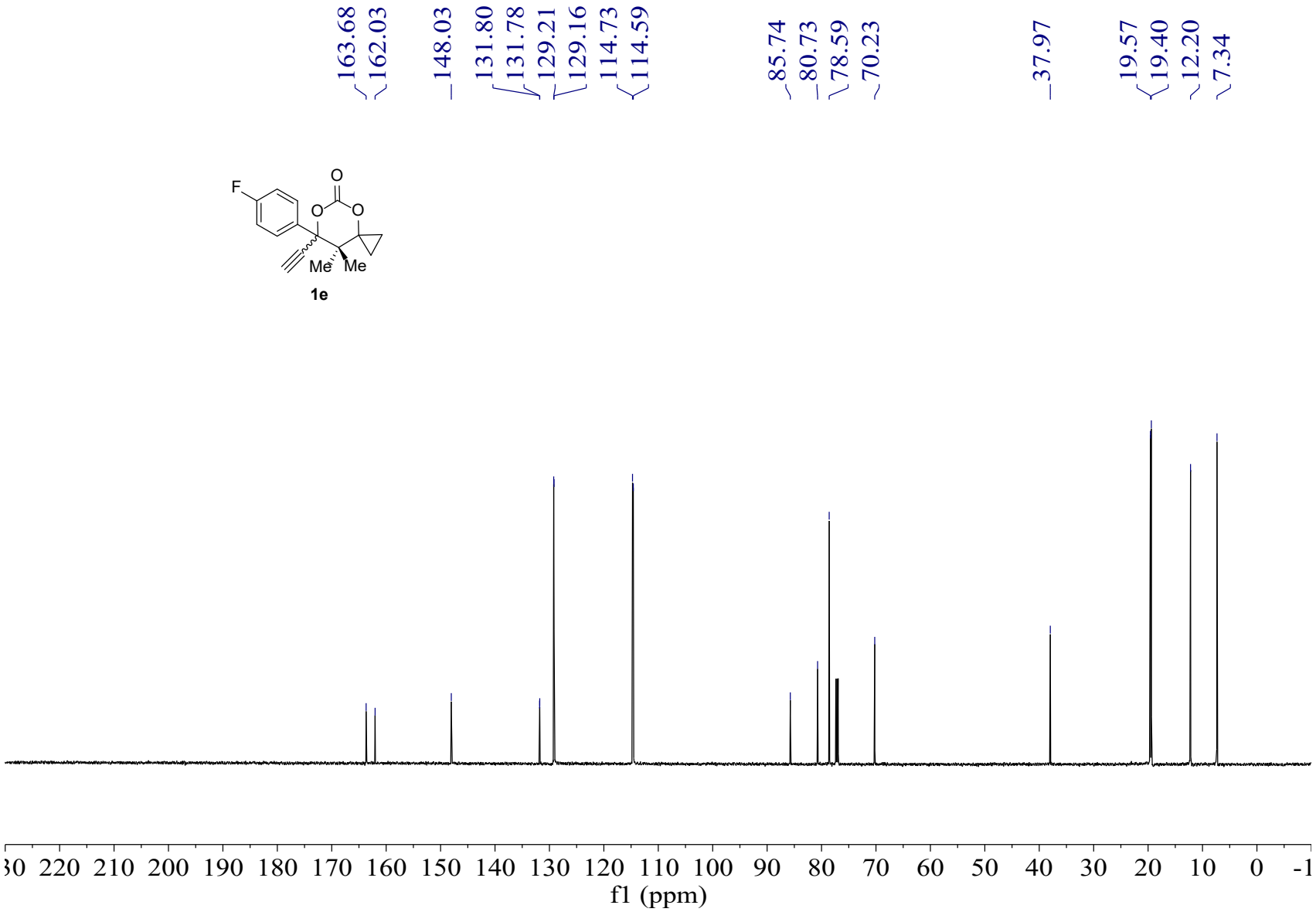
^{13}C NMR spectrum of compound **19e**



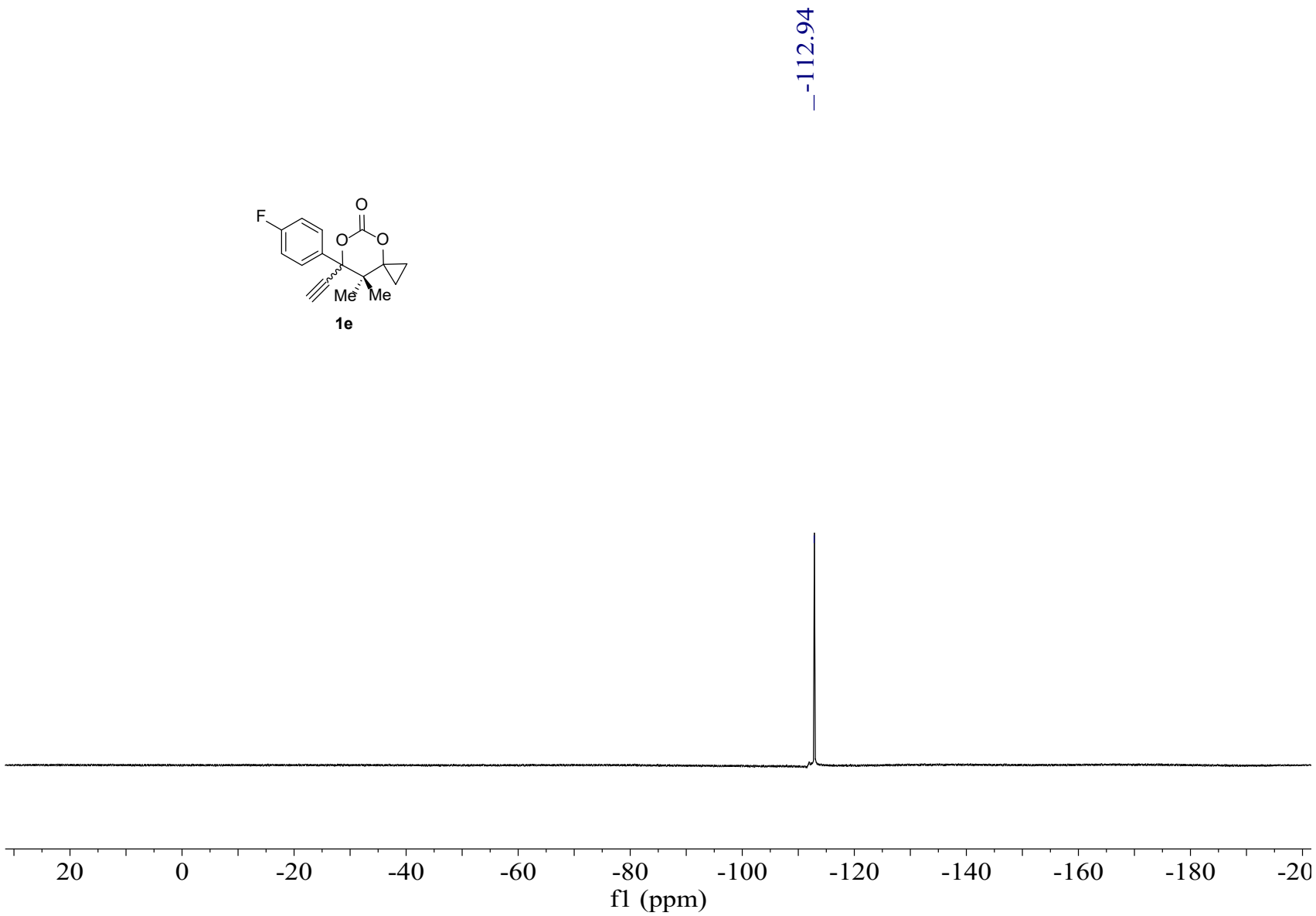
^{19}F NMR spectrum of compound **19e**



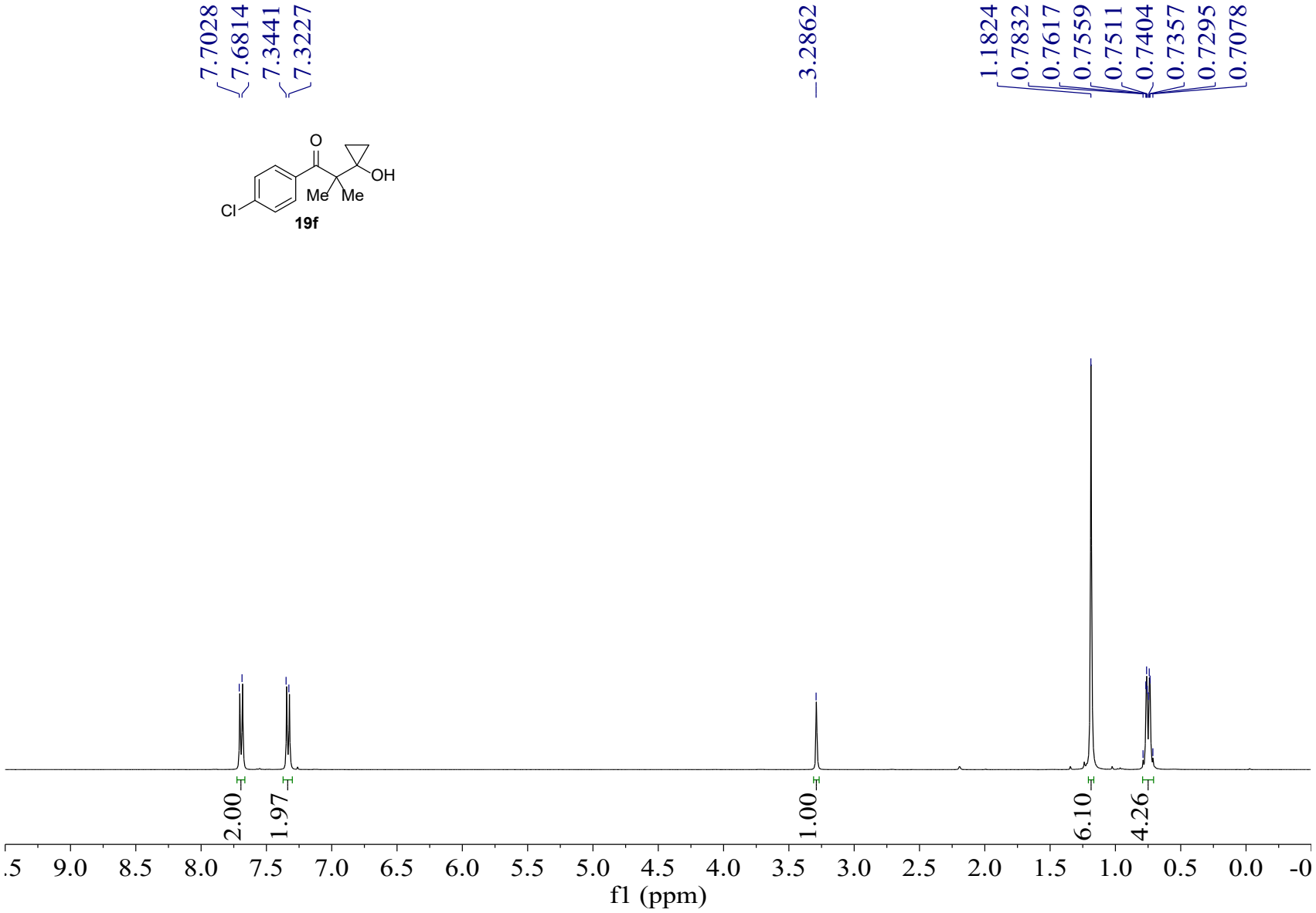
^{1}H NMR spectrum of compound **1e**



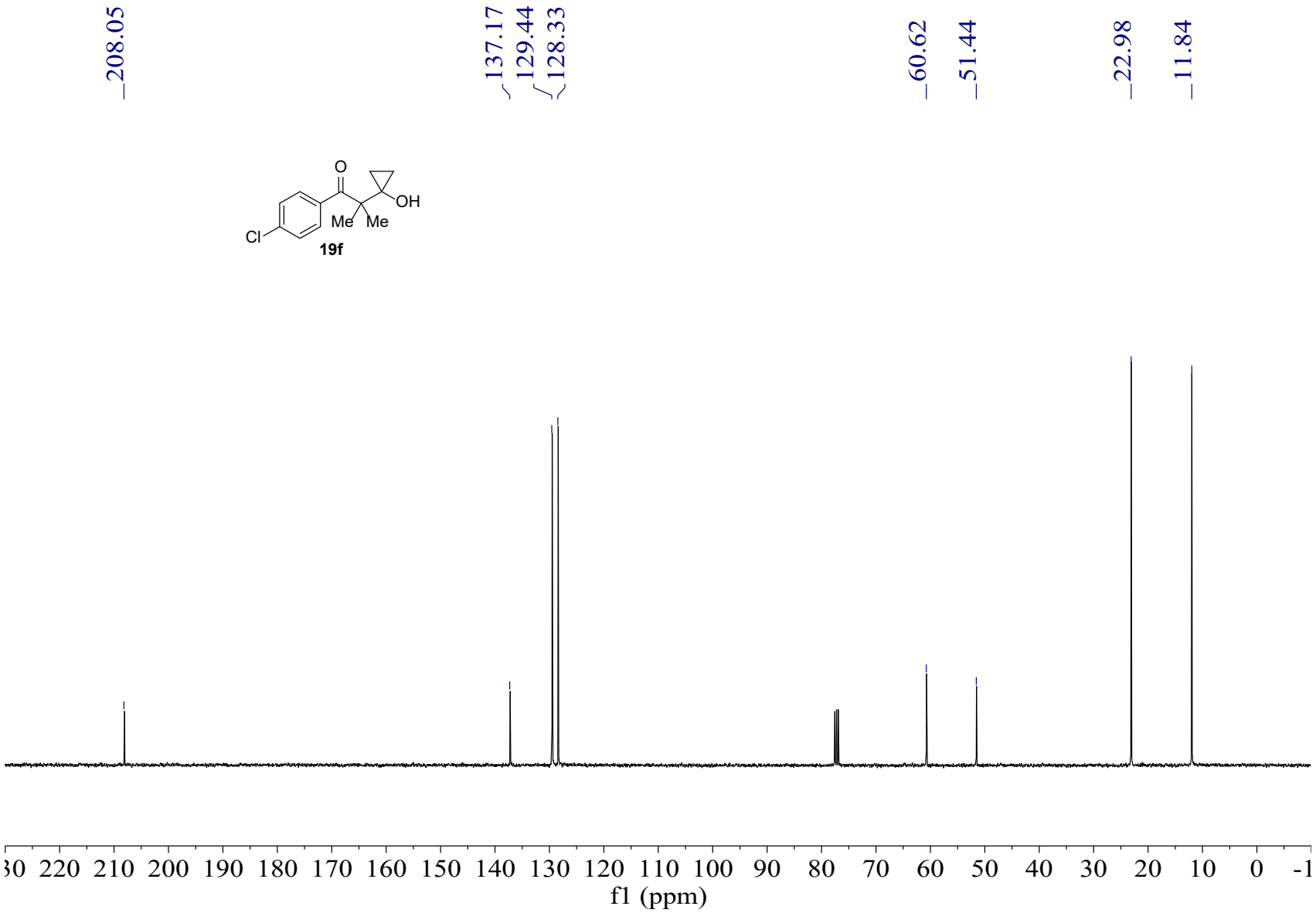
^{13}C NMR spectrum of compound **1e**



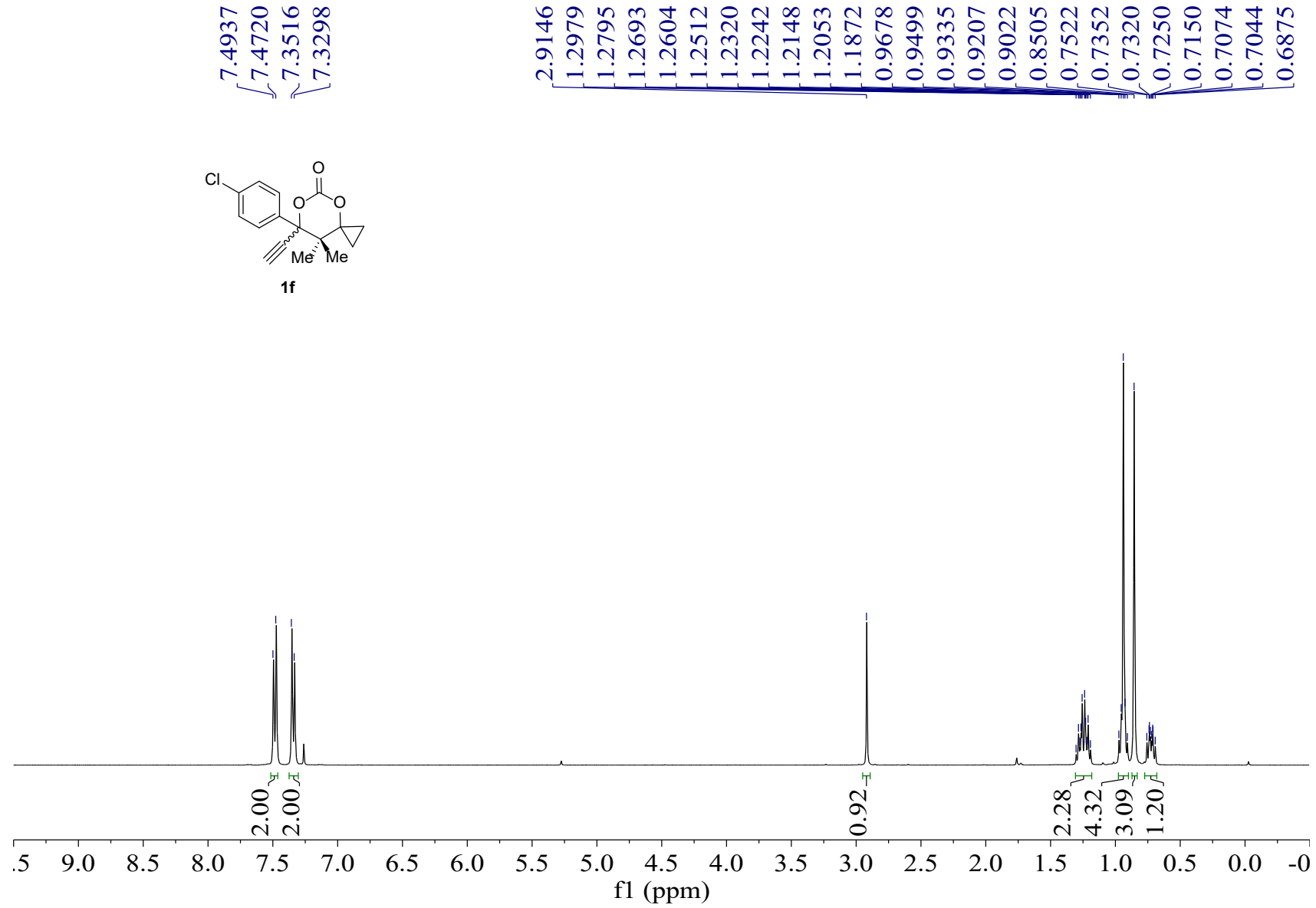
^{19}F NMR spectrum of compound **1e**



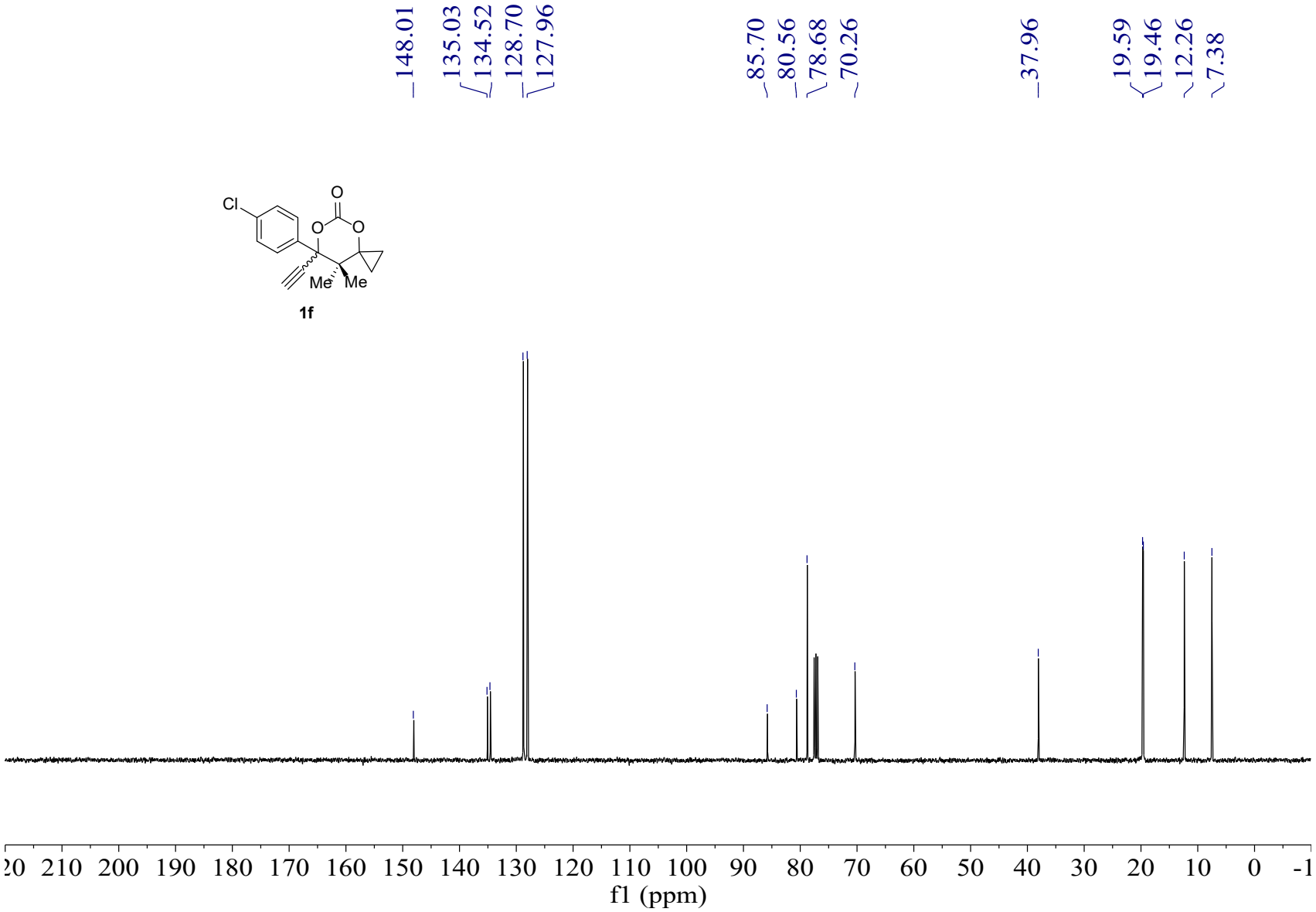
^{1}H NMR spectrum of compound **19f**



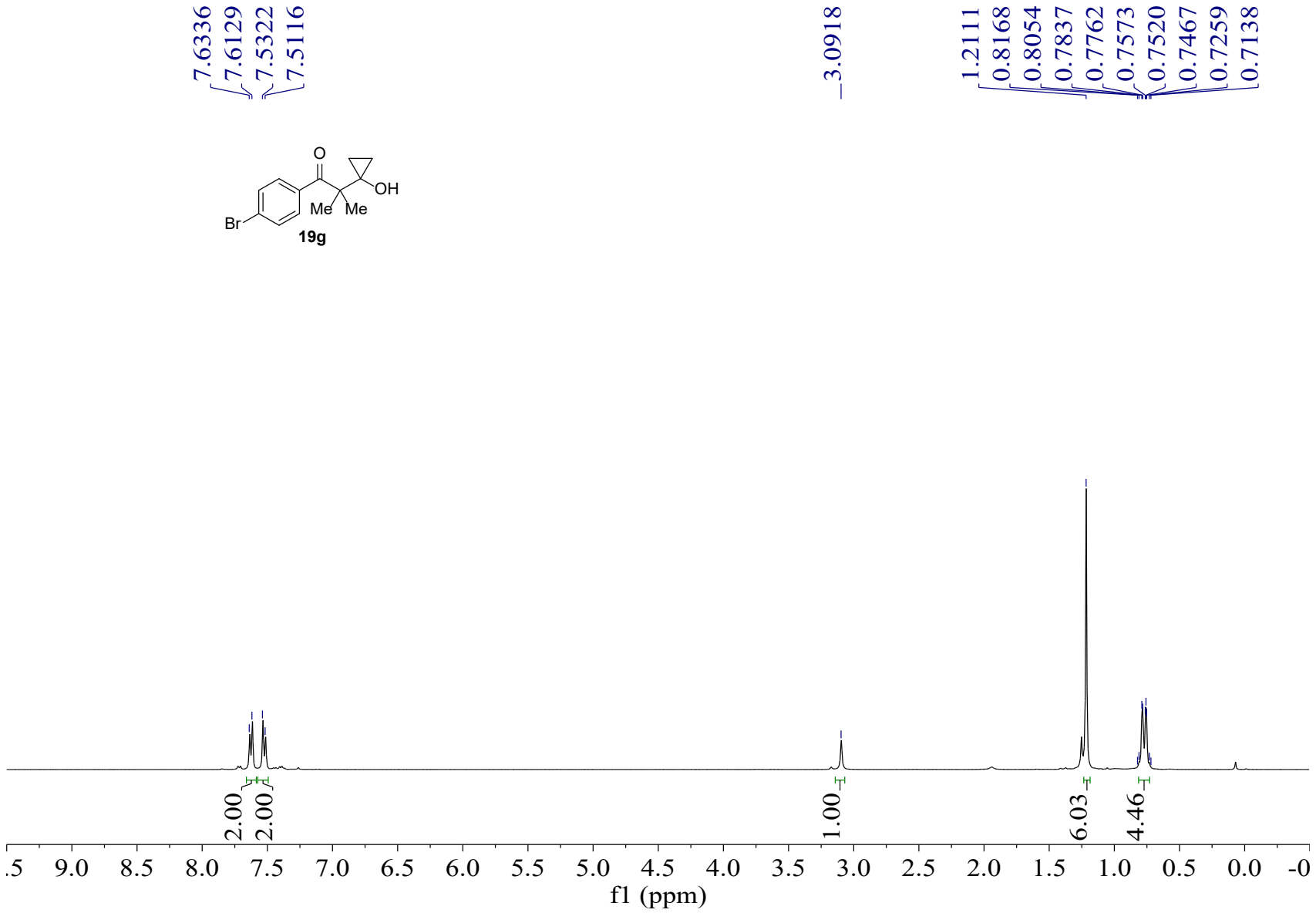
^{13}C NMR spectrum of compound **19f**



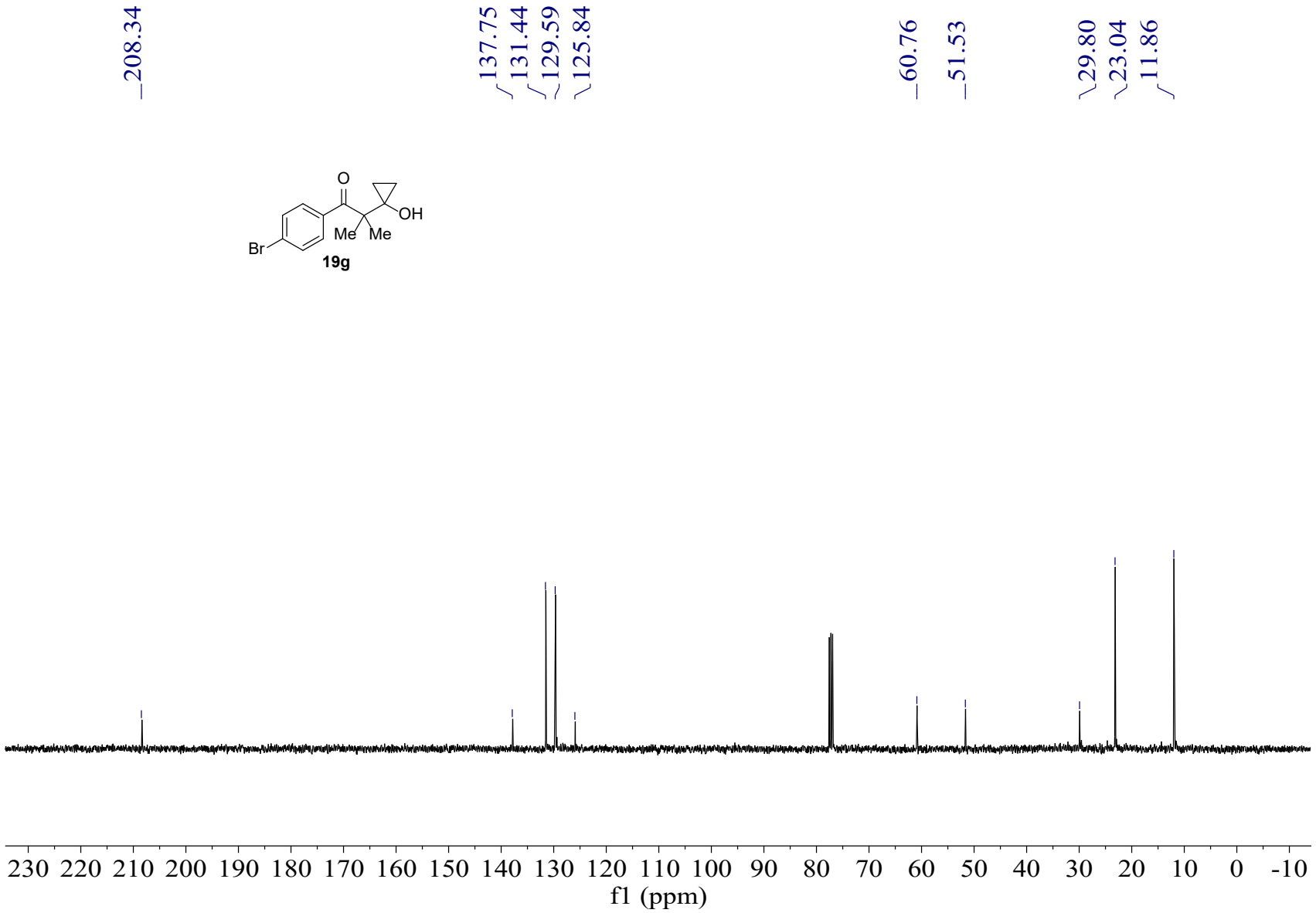
^{1}H NMR spectrum of compound **1f**



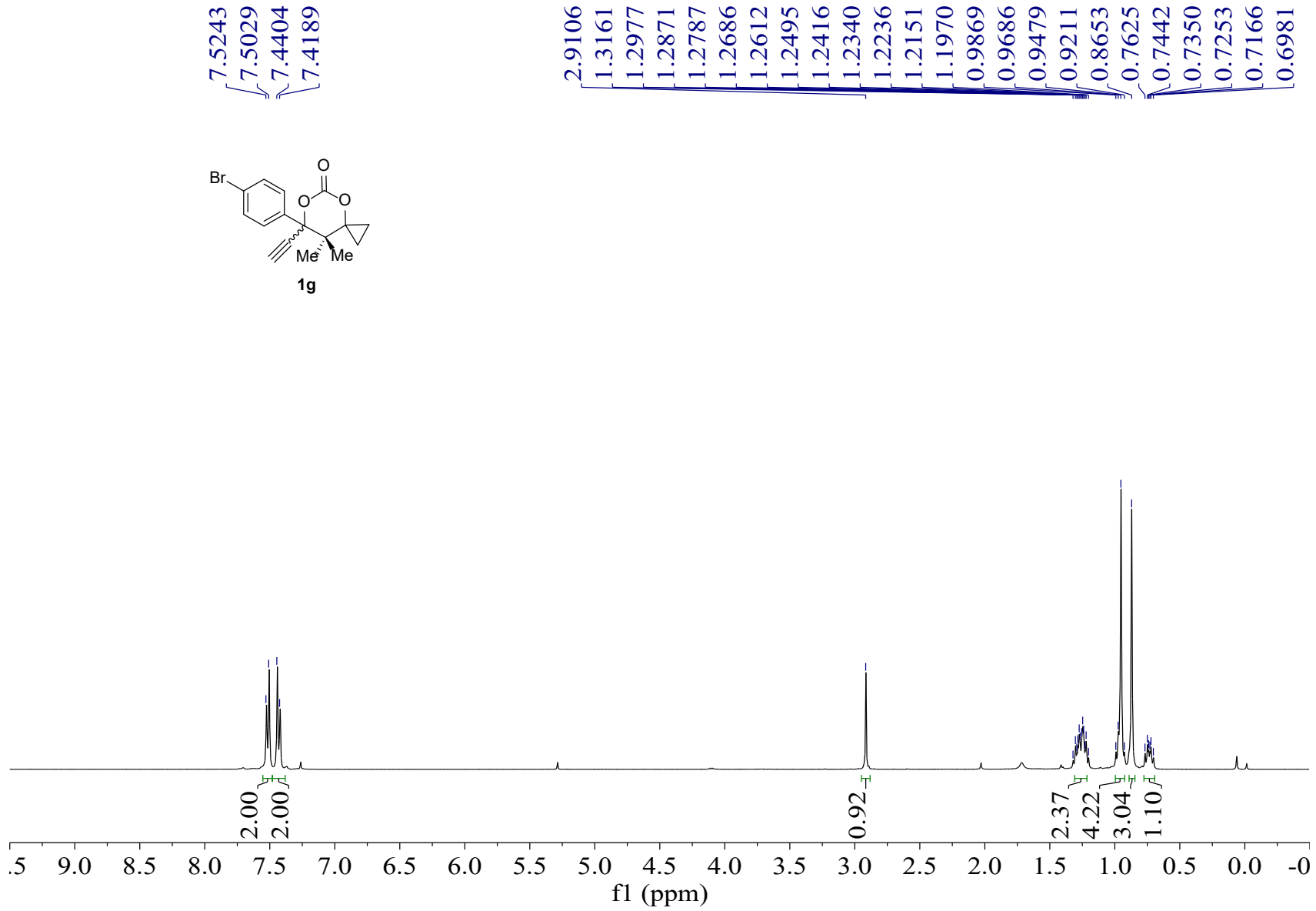
^{13}C NMR spectrum of compound **1f**



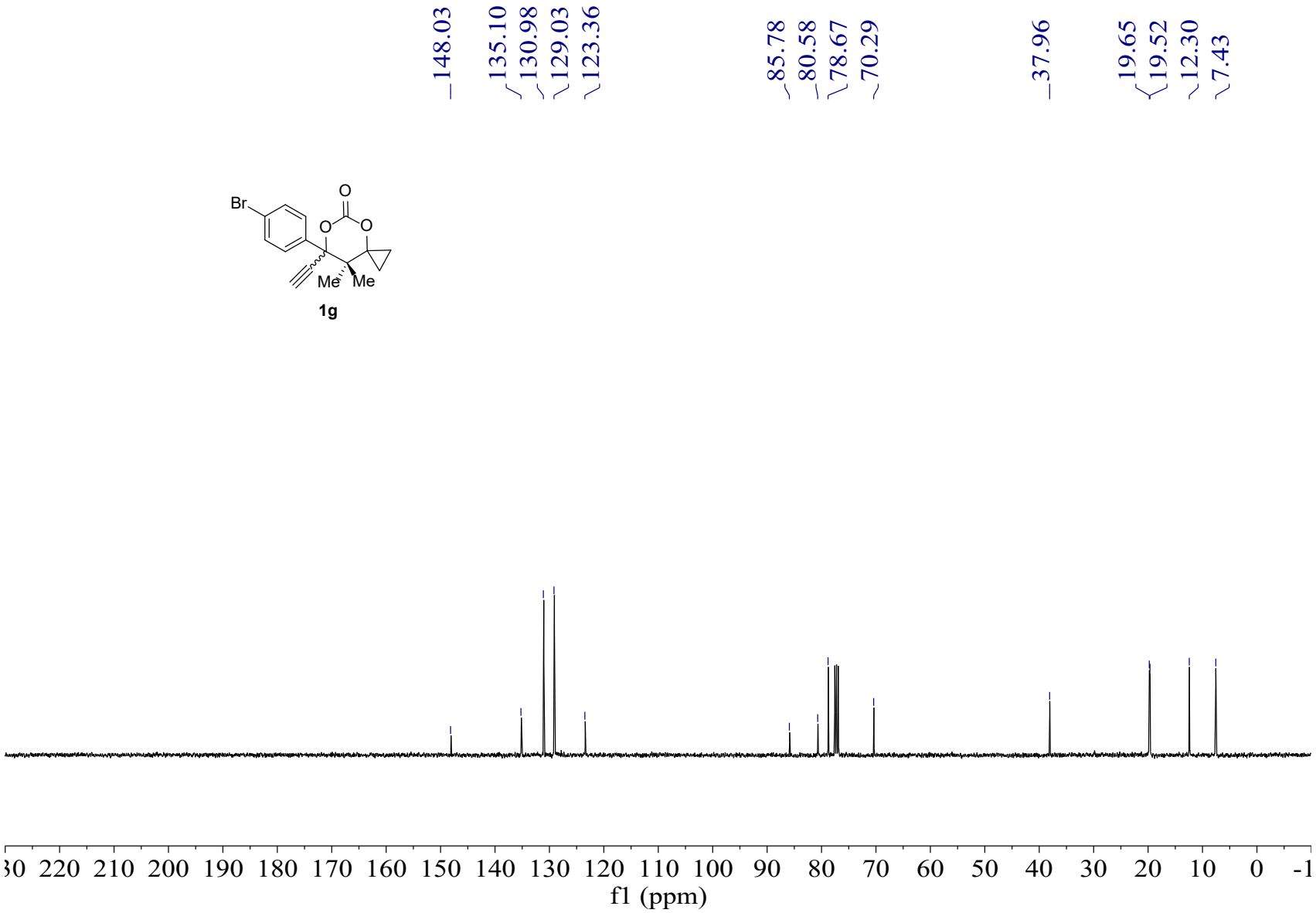
^{1}H NMR spectrum of compound **19g**



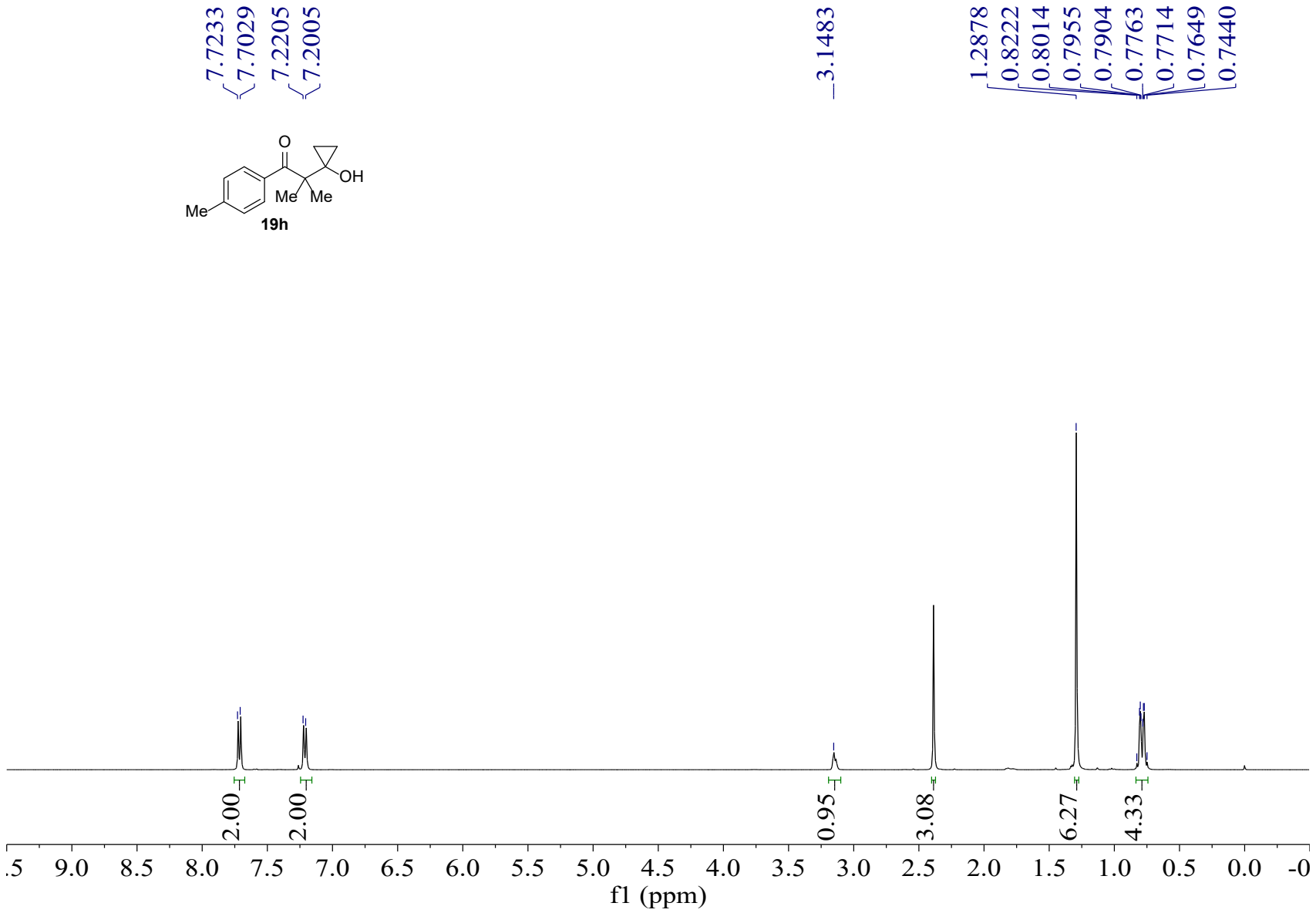
^{13}C NMR spectrum of compound **19g**



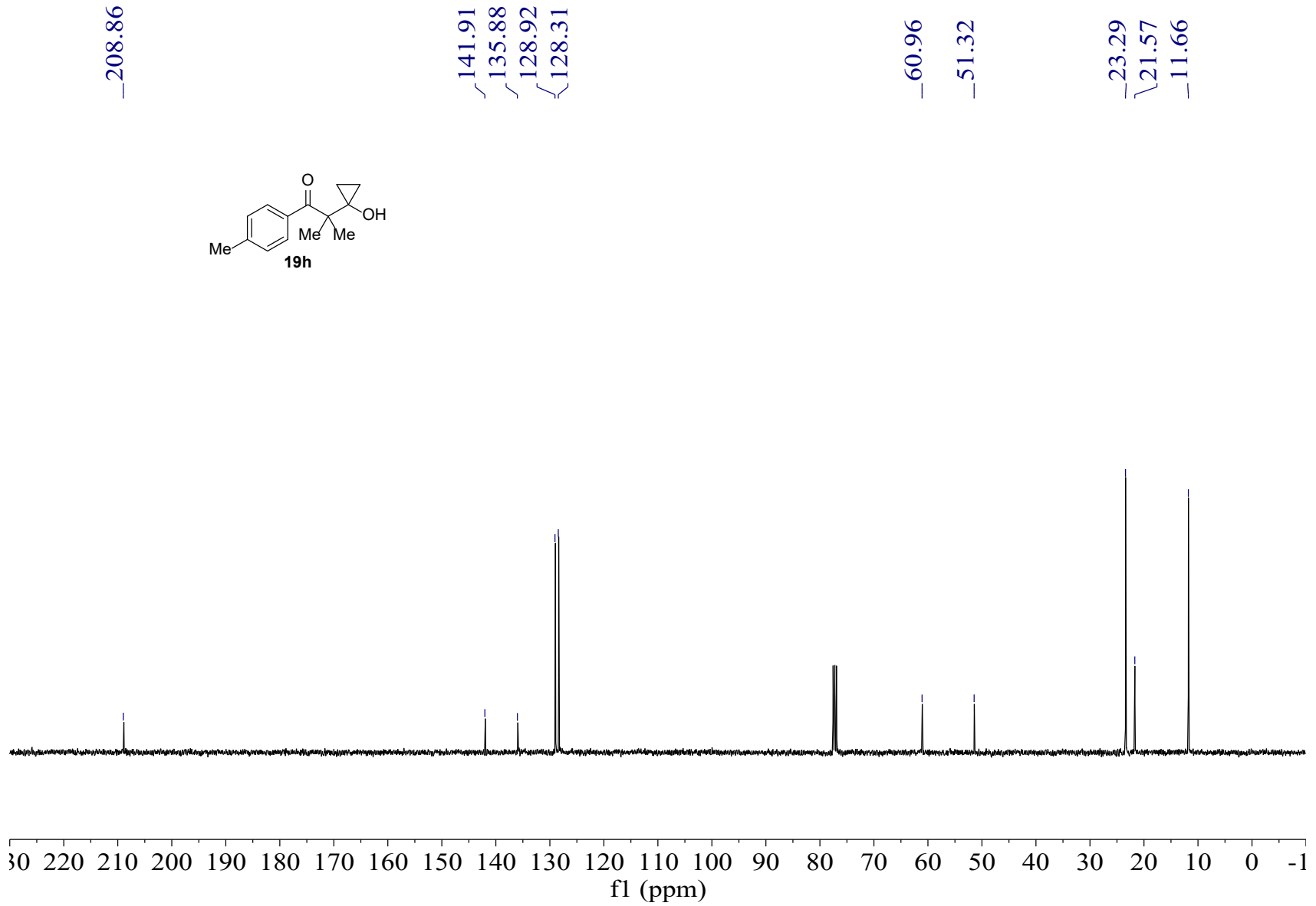
^{1}H NMR spectrum of compound **1g**



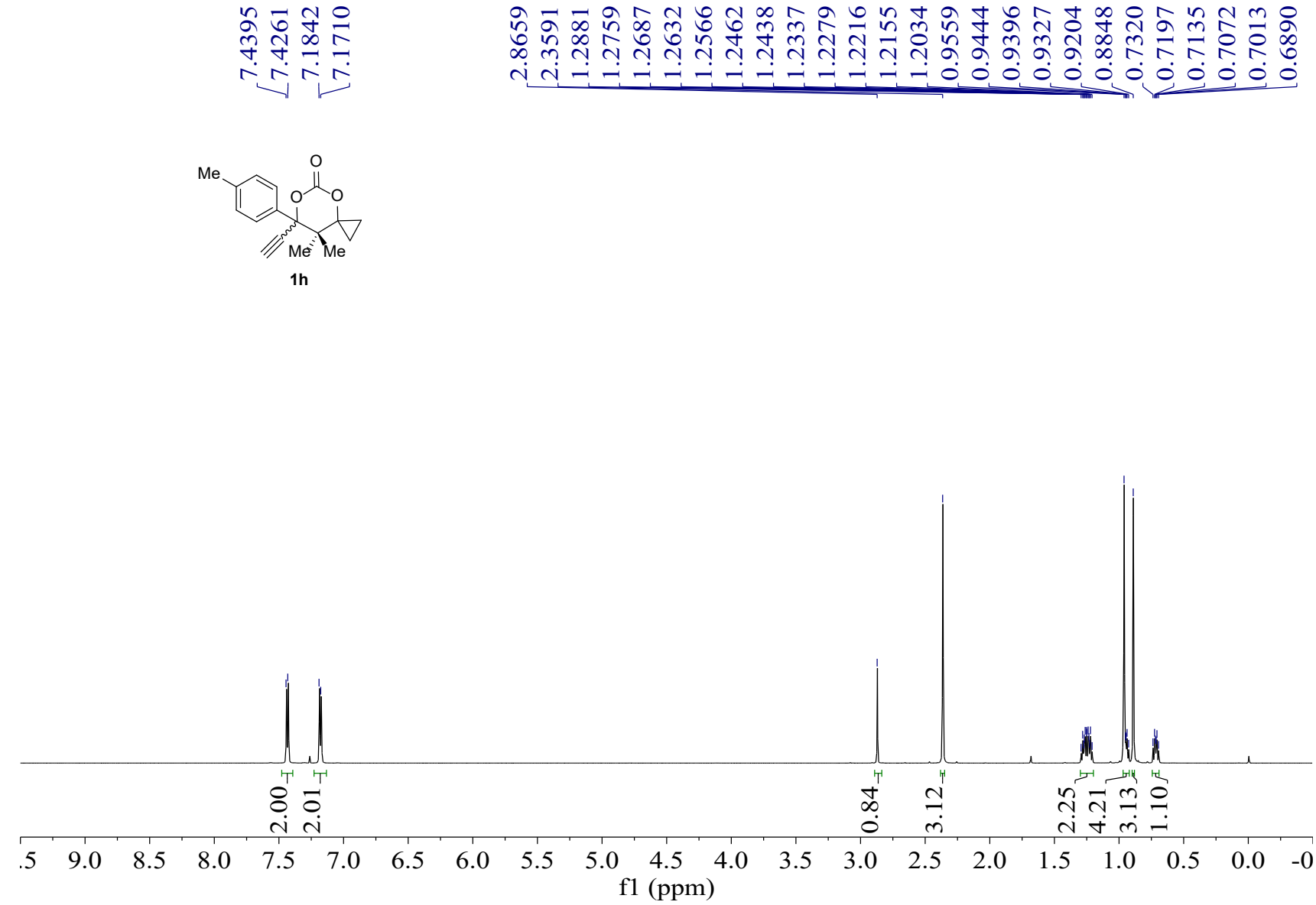
^{13}C NMR spectrum of compound **1g**



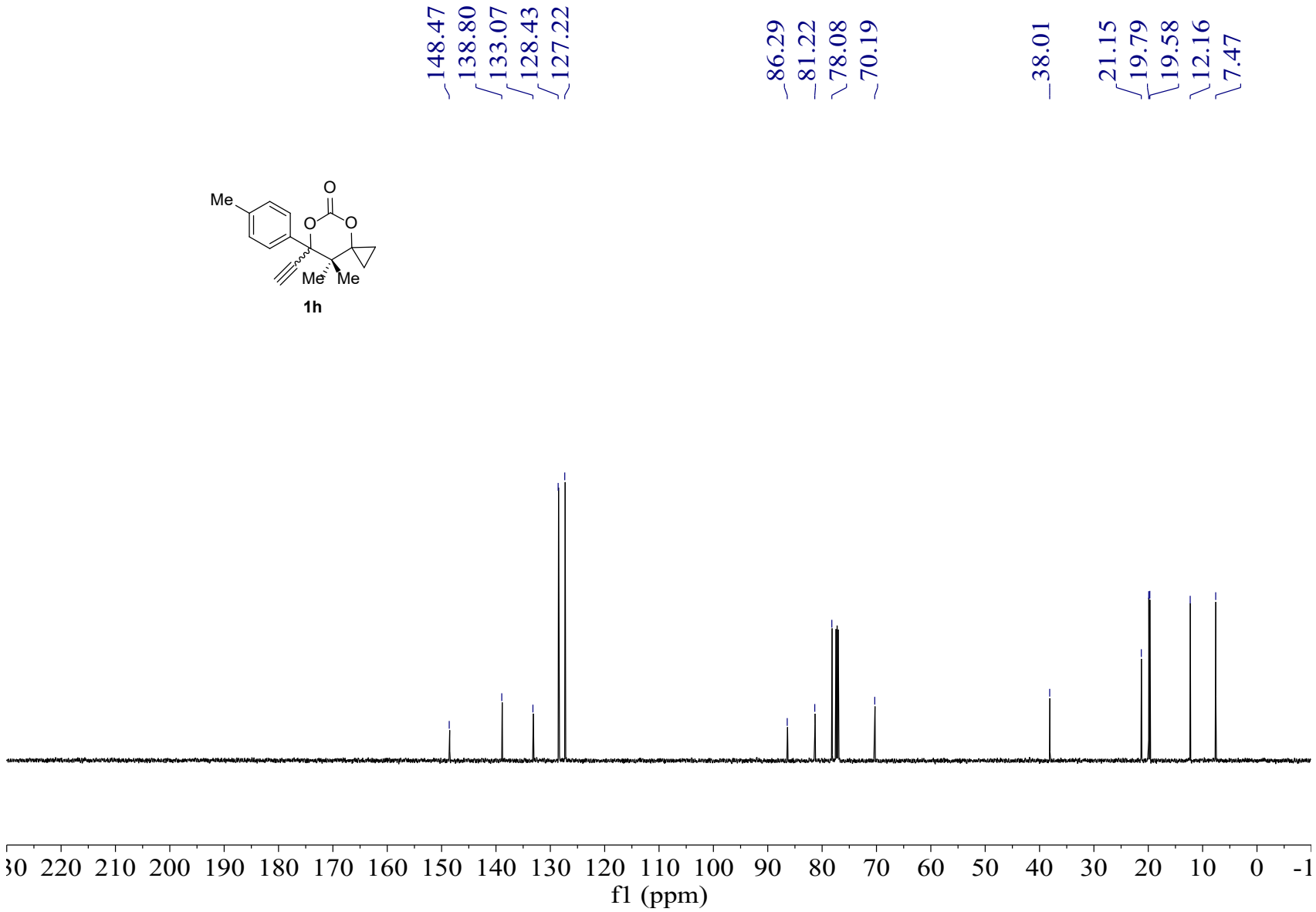
^{1}H NMR spectrum of compound **19h**



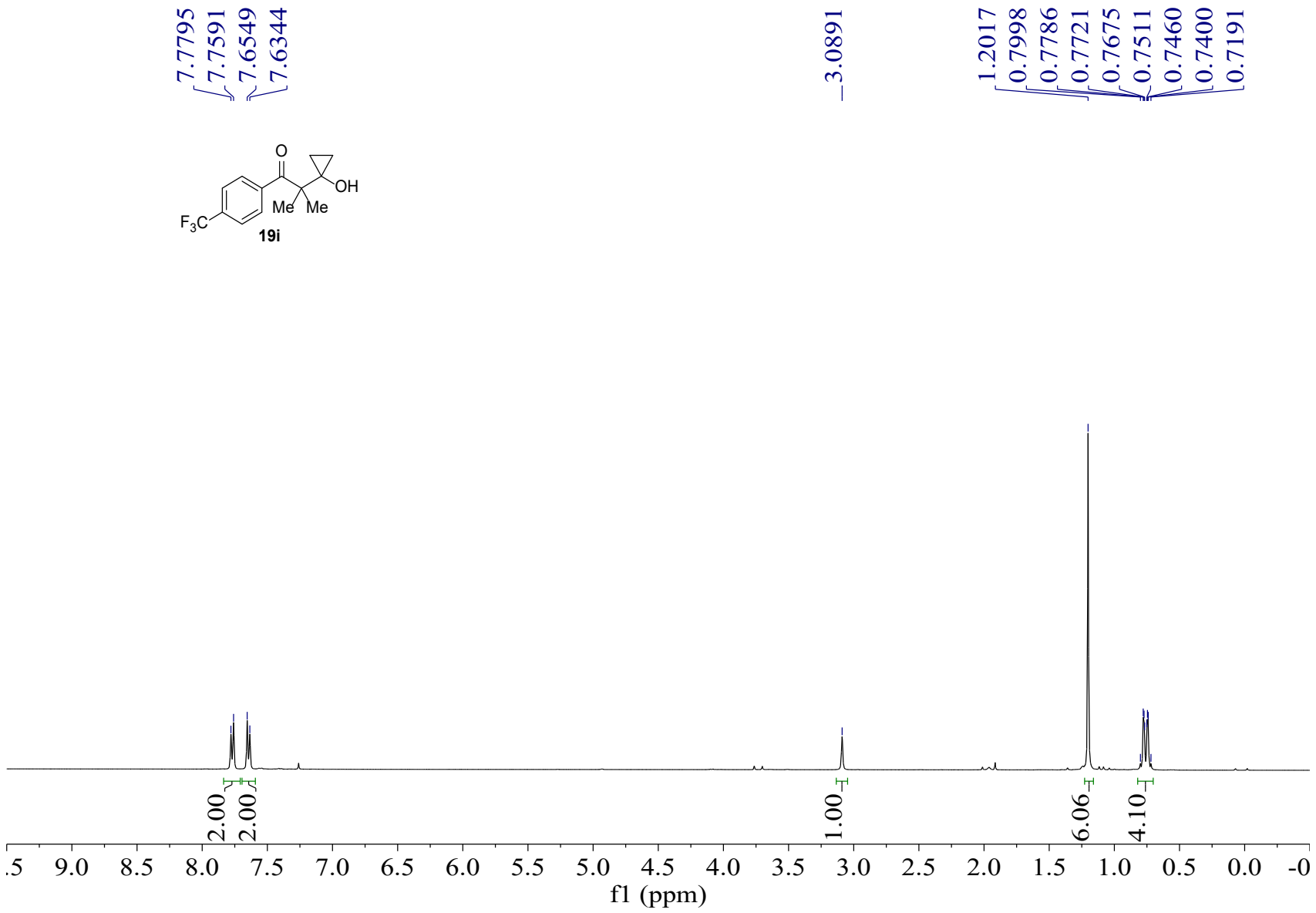
^{13}C NMR spectrum of compound **19h**



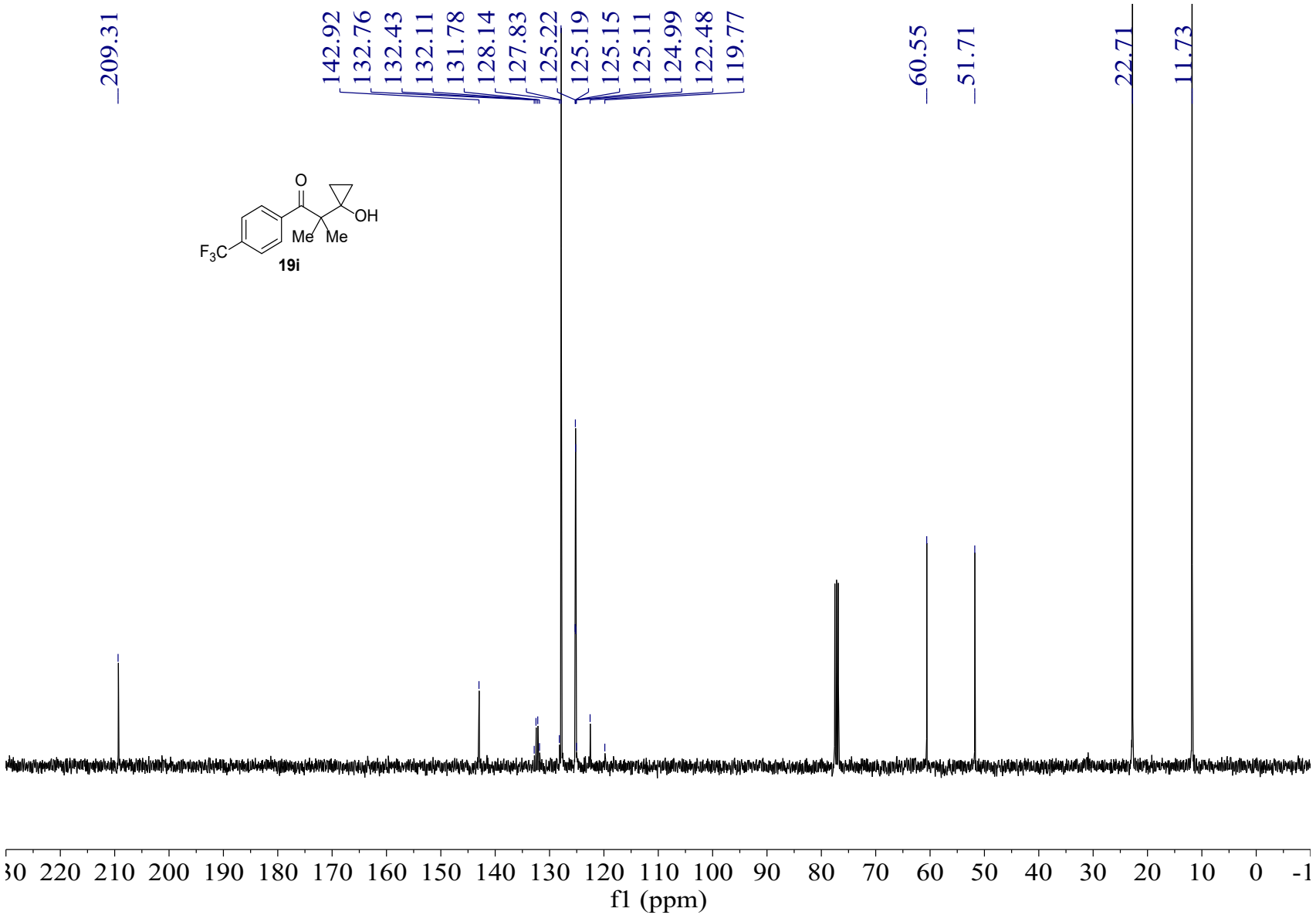
^{1}H NMR spectrum of compound **1h**



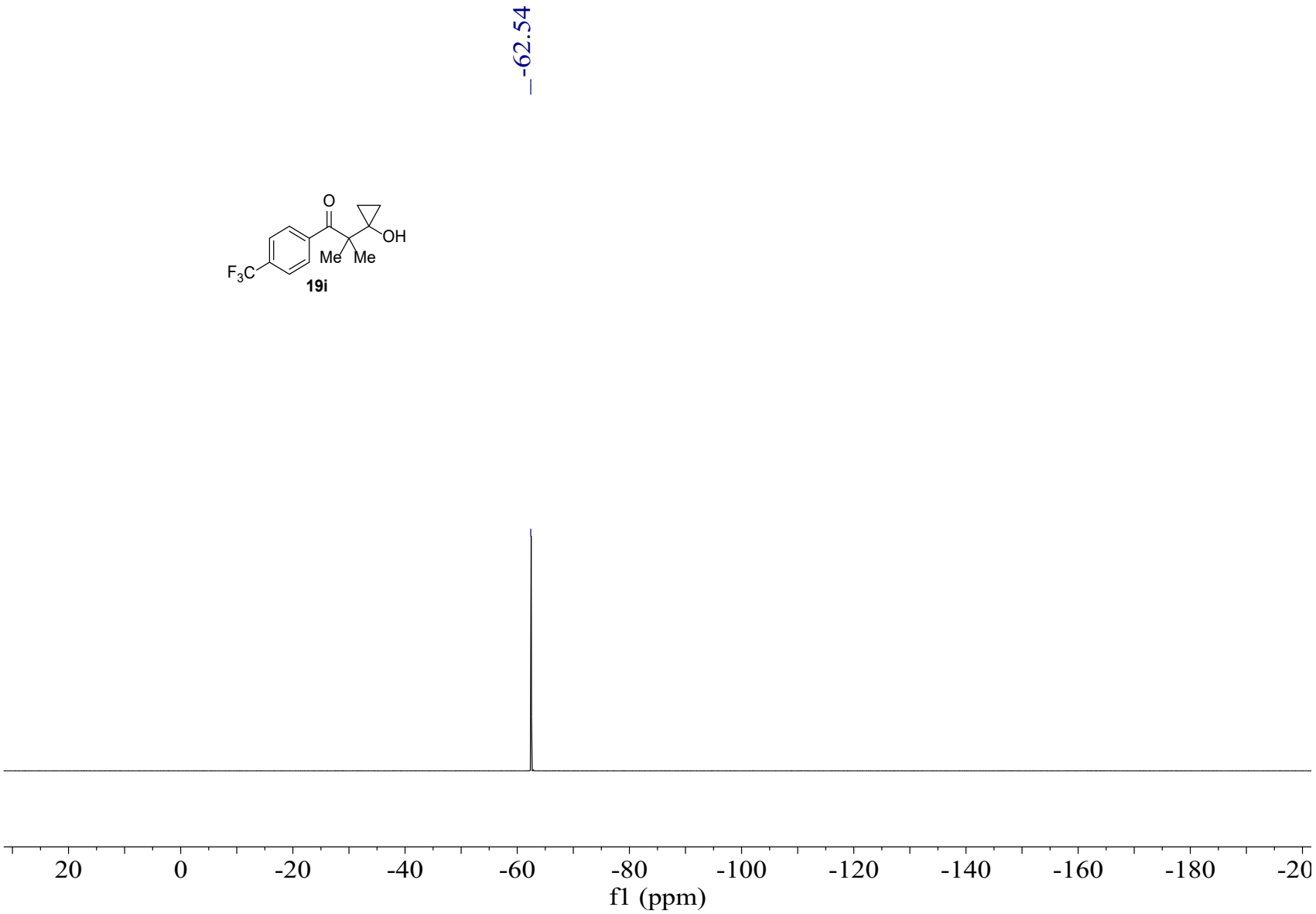
^{13}C NMR spectrum of compound **1h**



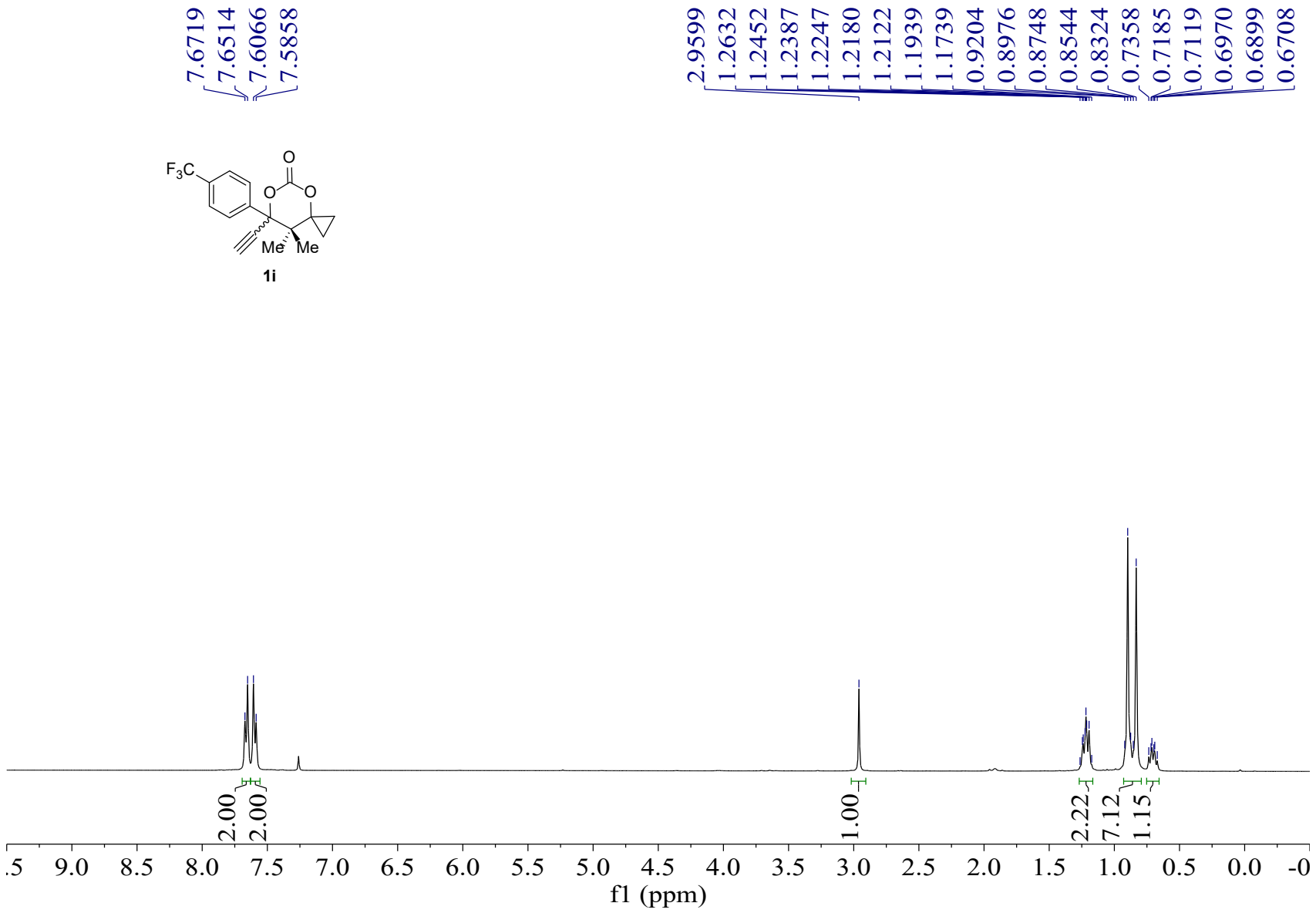
^{1}H NMR spectrum of compound **19i**



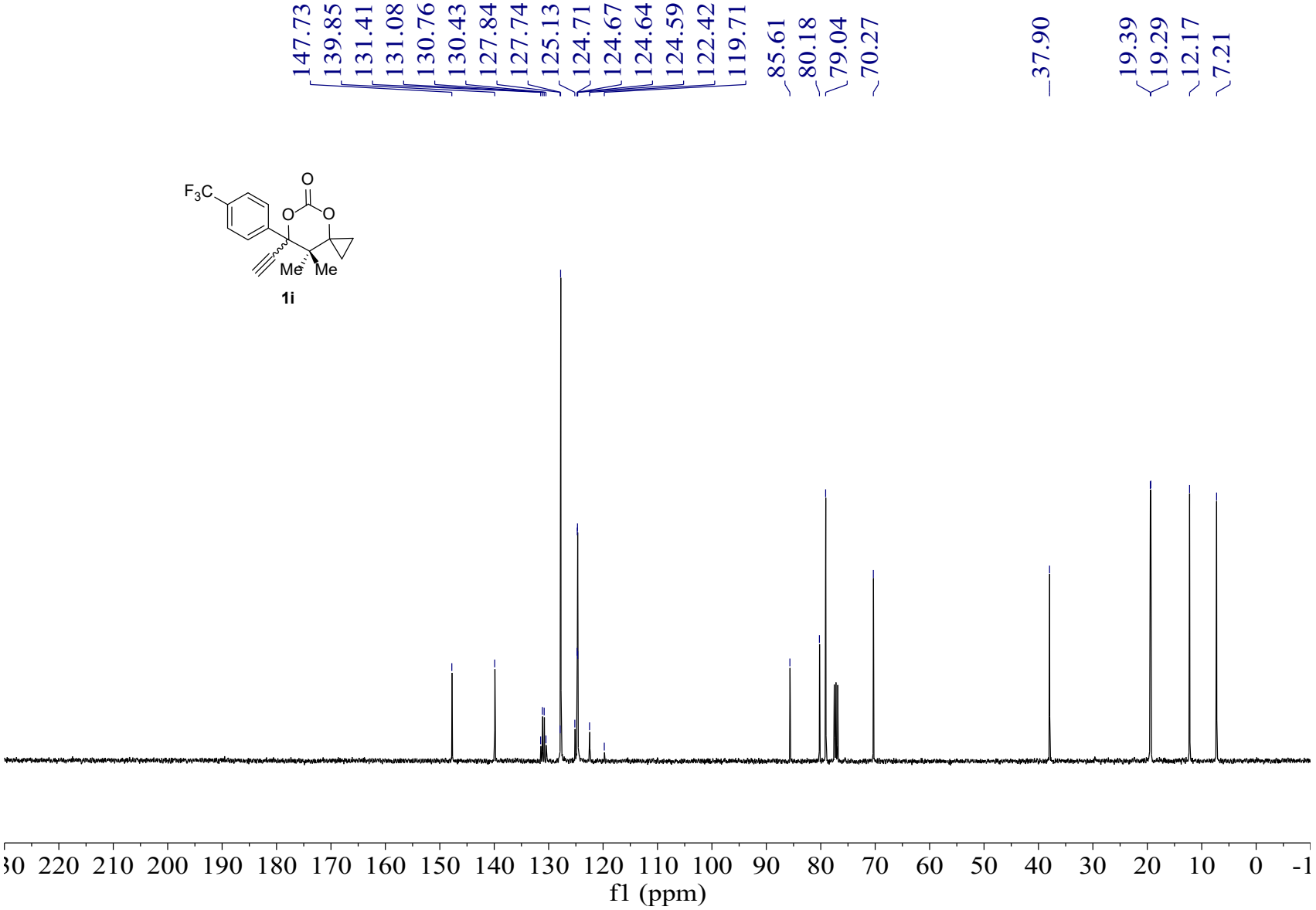
^{13}C NMR spectrum of compound **19i**



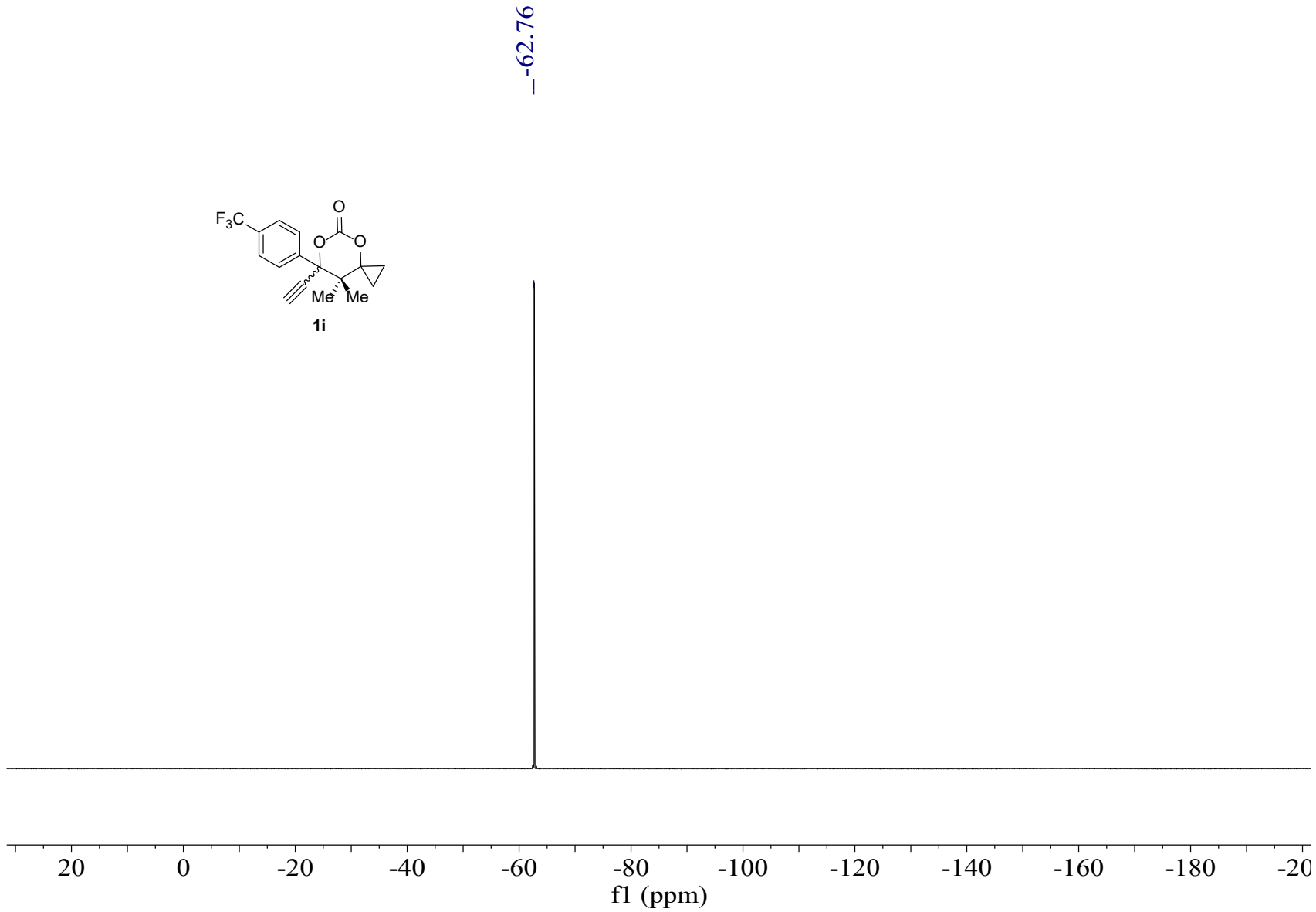
^{19}F NMR spectrum of compound **19i**



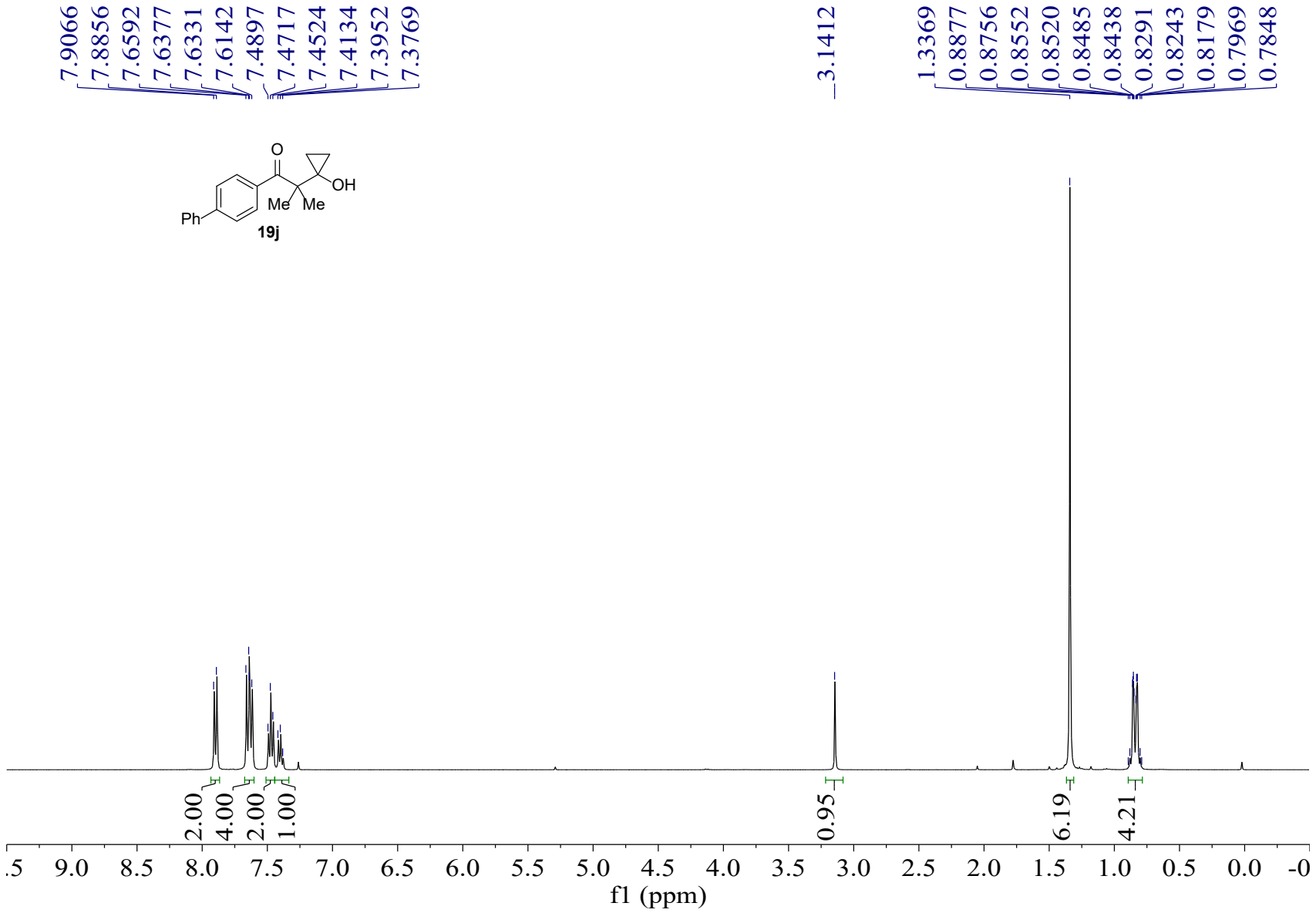
^{1}H NMR spectrum of compound **1i**



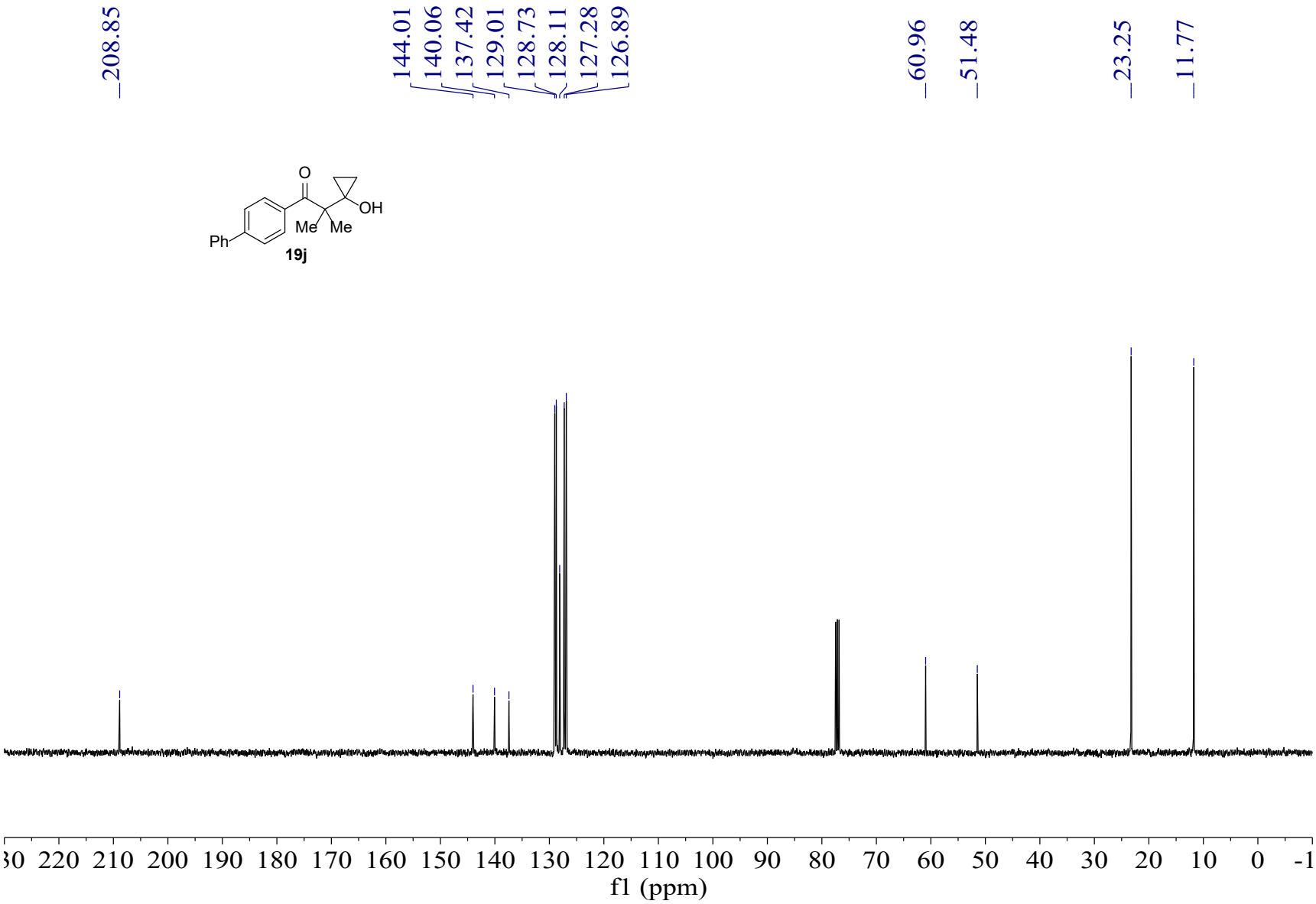
^{13}C NMR spectrum of compound **1i**



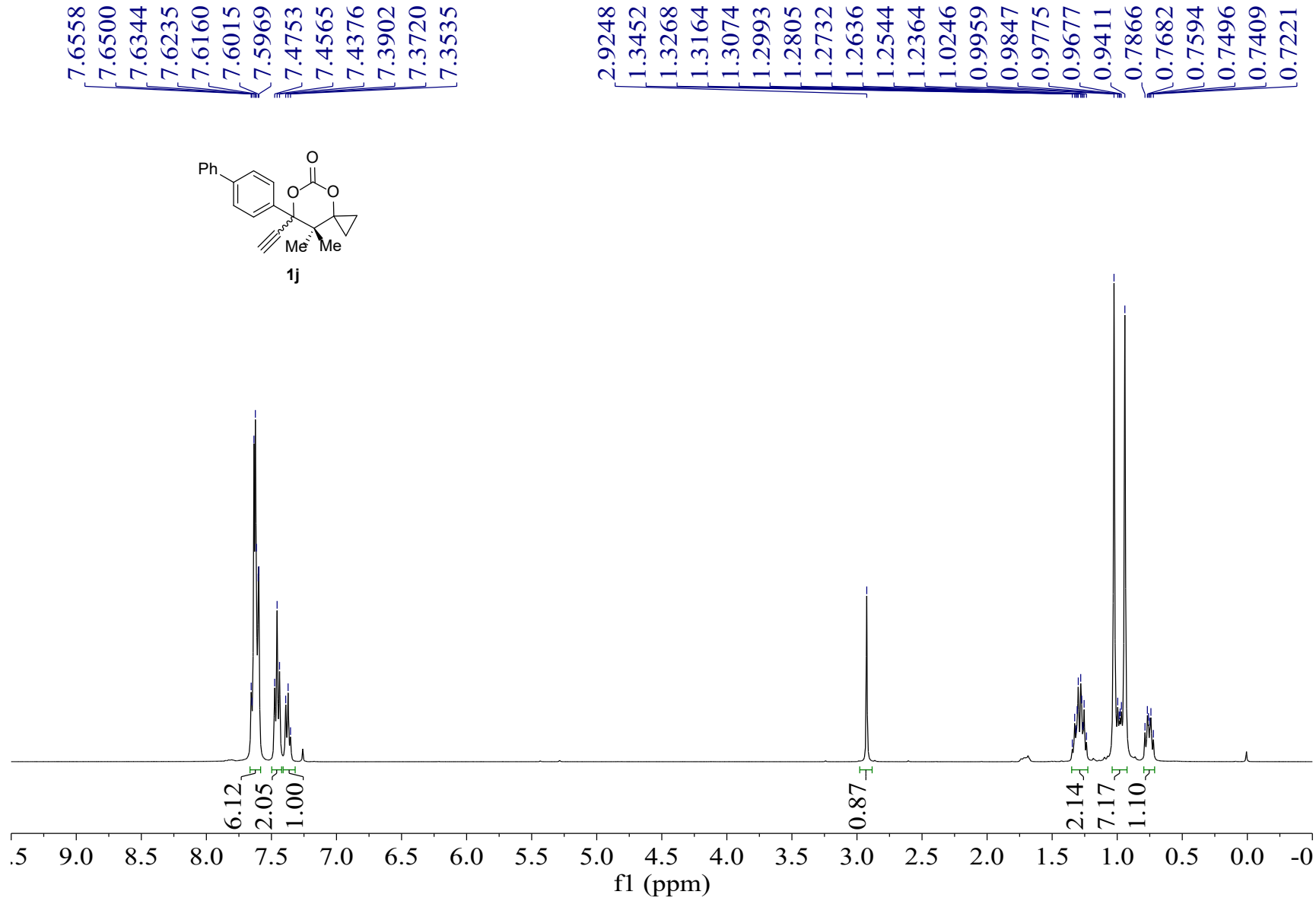
^{19}F NMR spectrum of compound **1i**



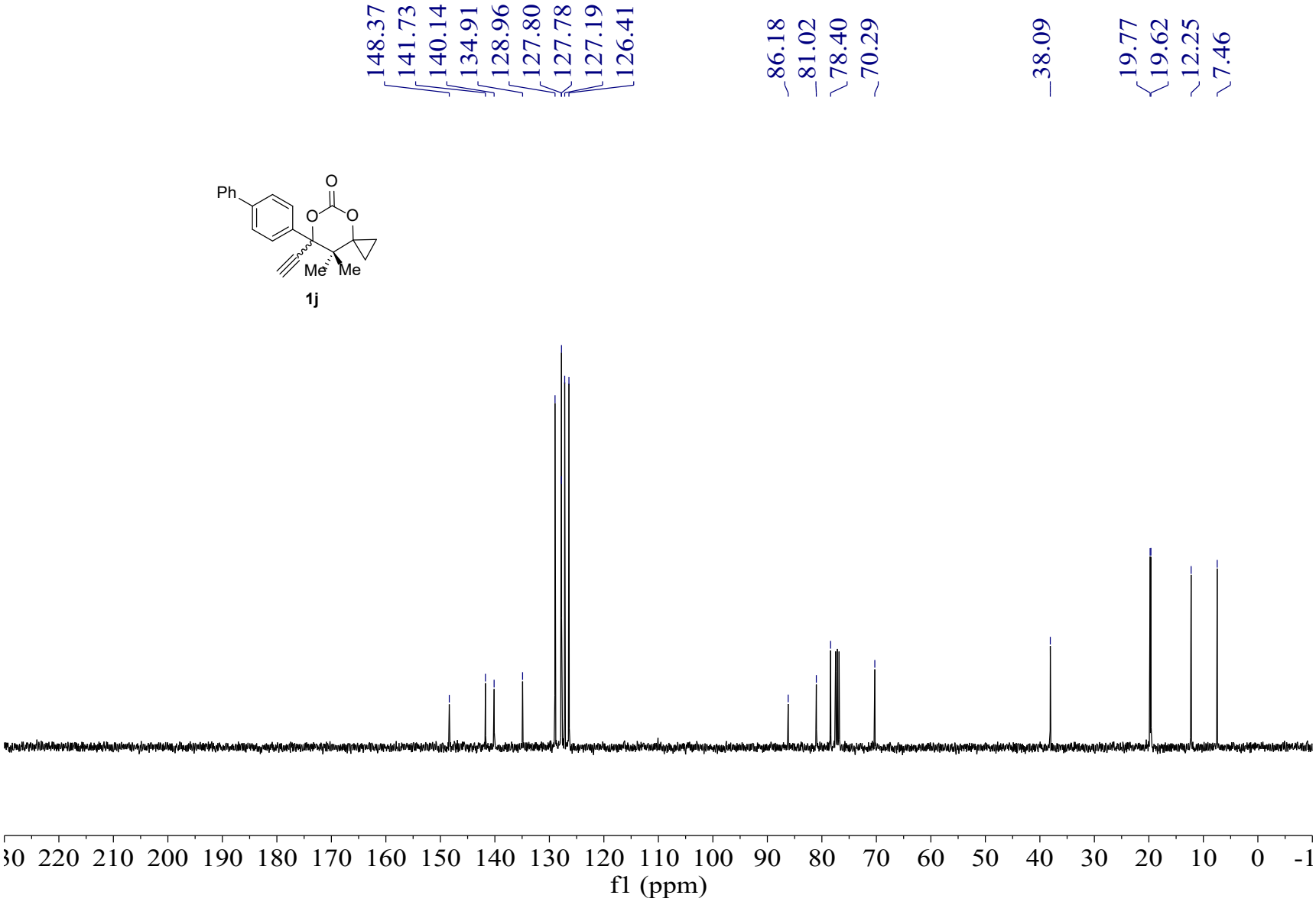
^{1}H NMR spectrum of compound **19j**



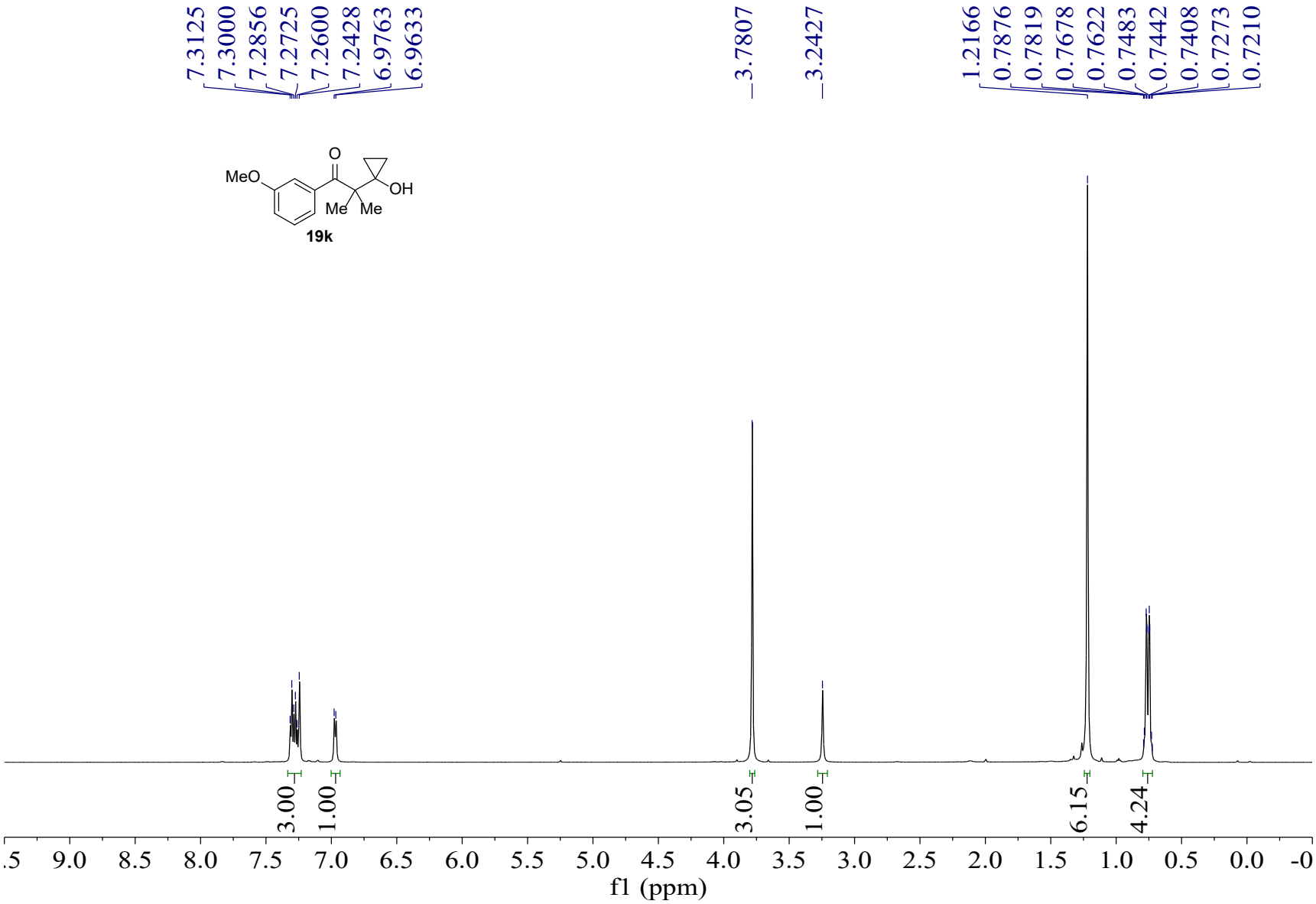
^{13}C NMR spectrum of compound **19j**



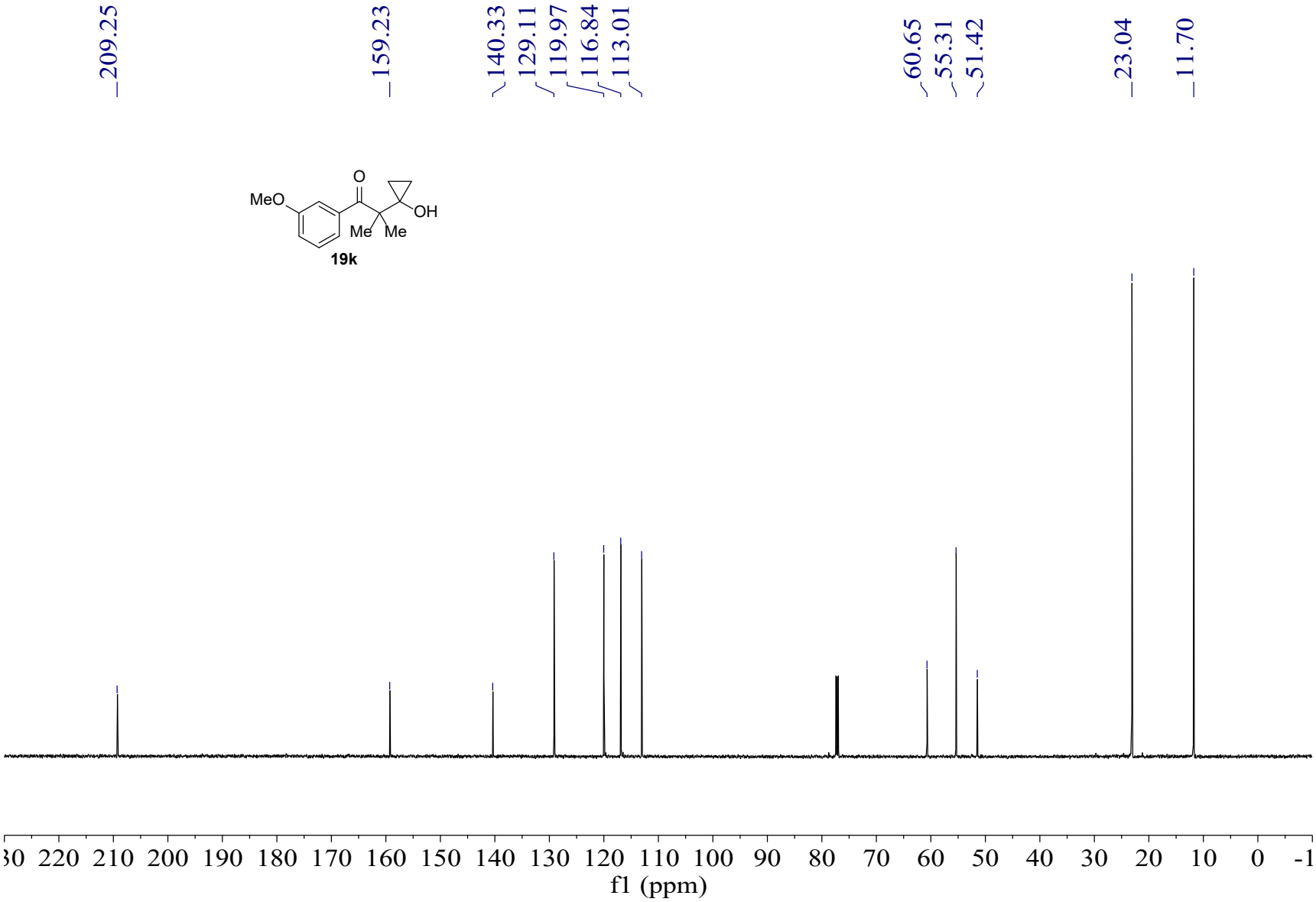
^{1}H NMR spectrum of compound **1j**



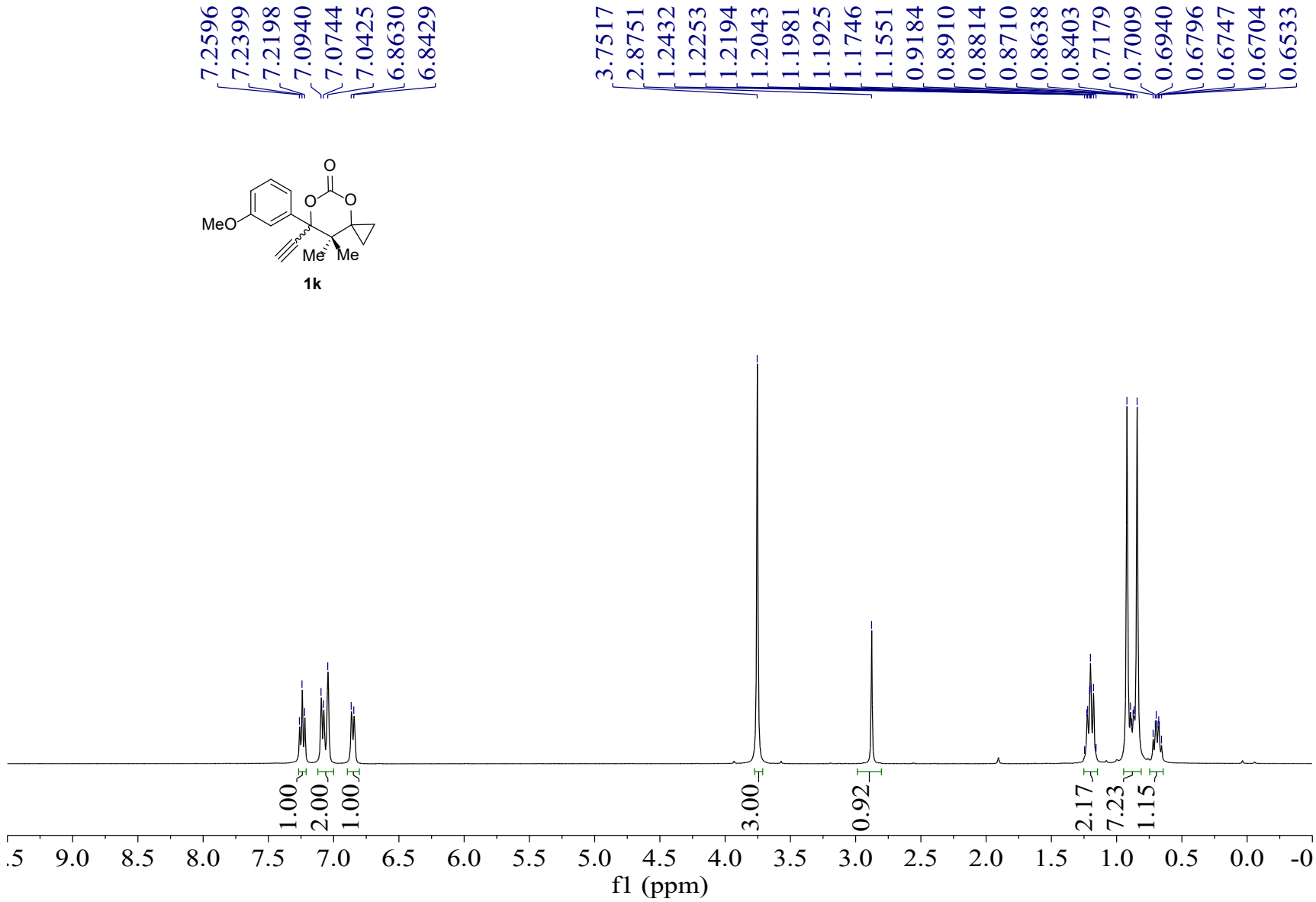
^{13}C NMR spectrum of compound **1j**



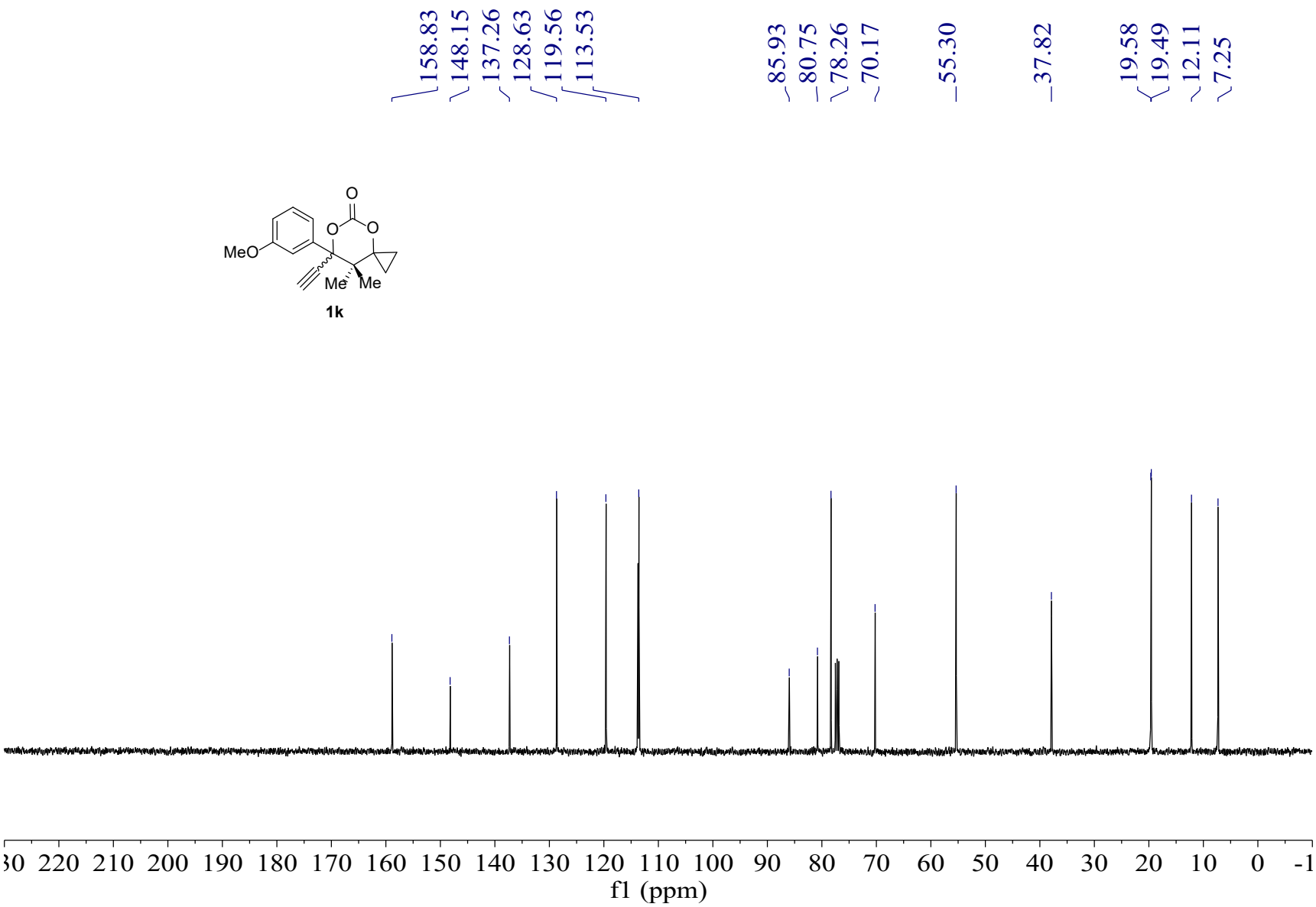
^{1}H NMR spectrum of compound **19k**



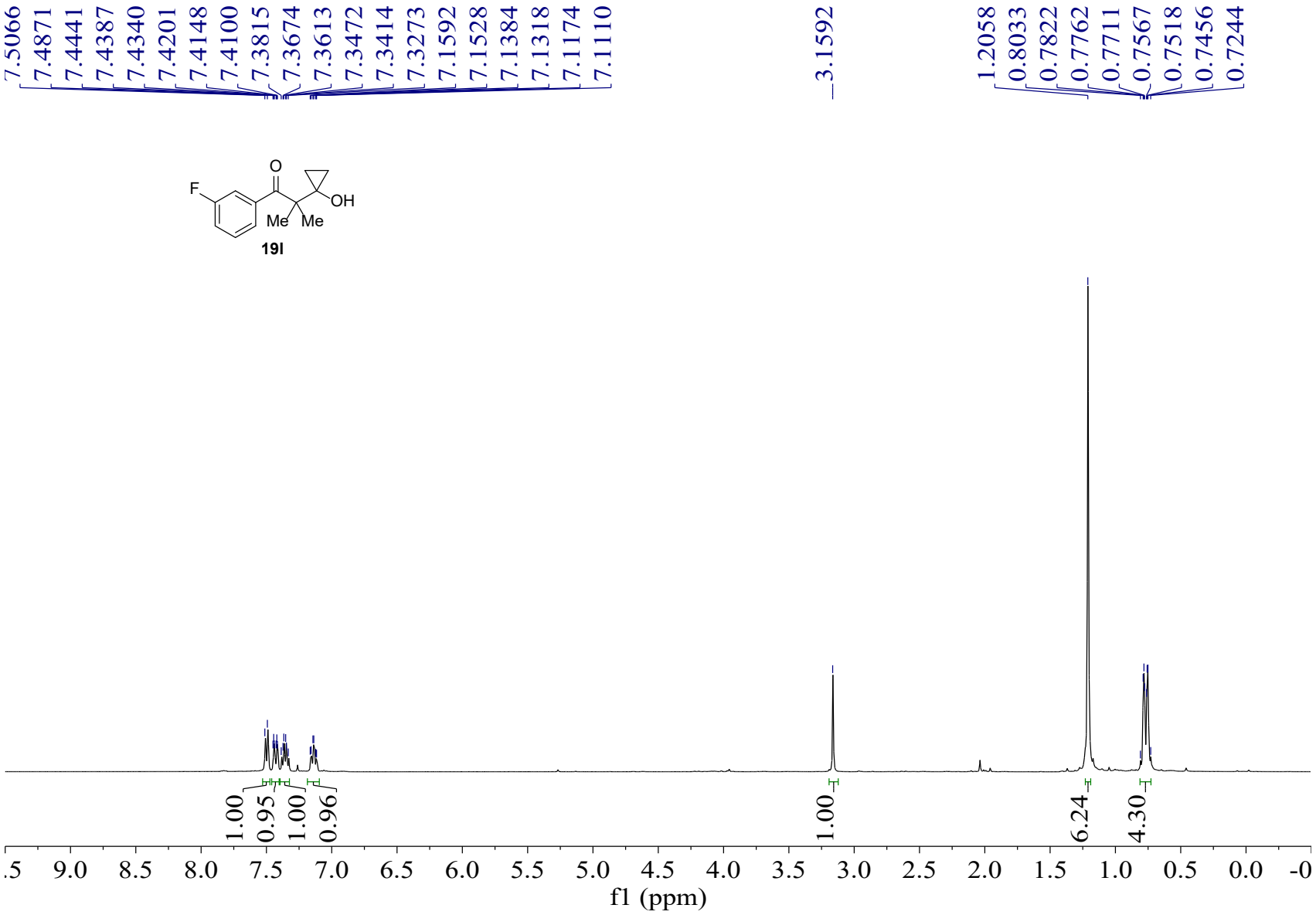
^{13}C NMR spectrum of compound **19k**



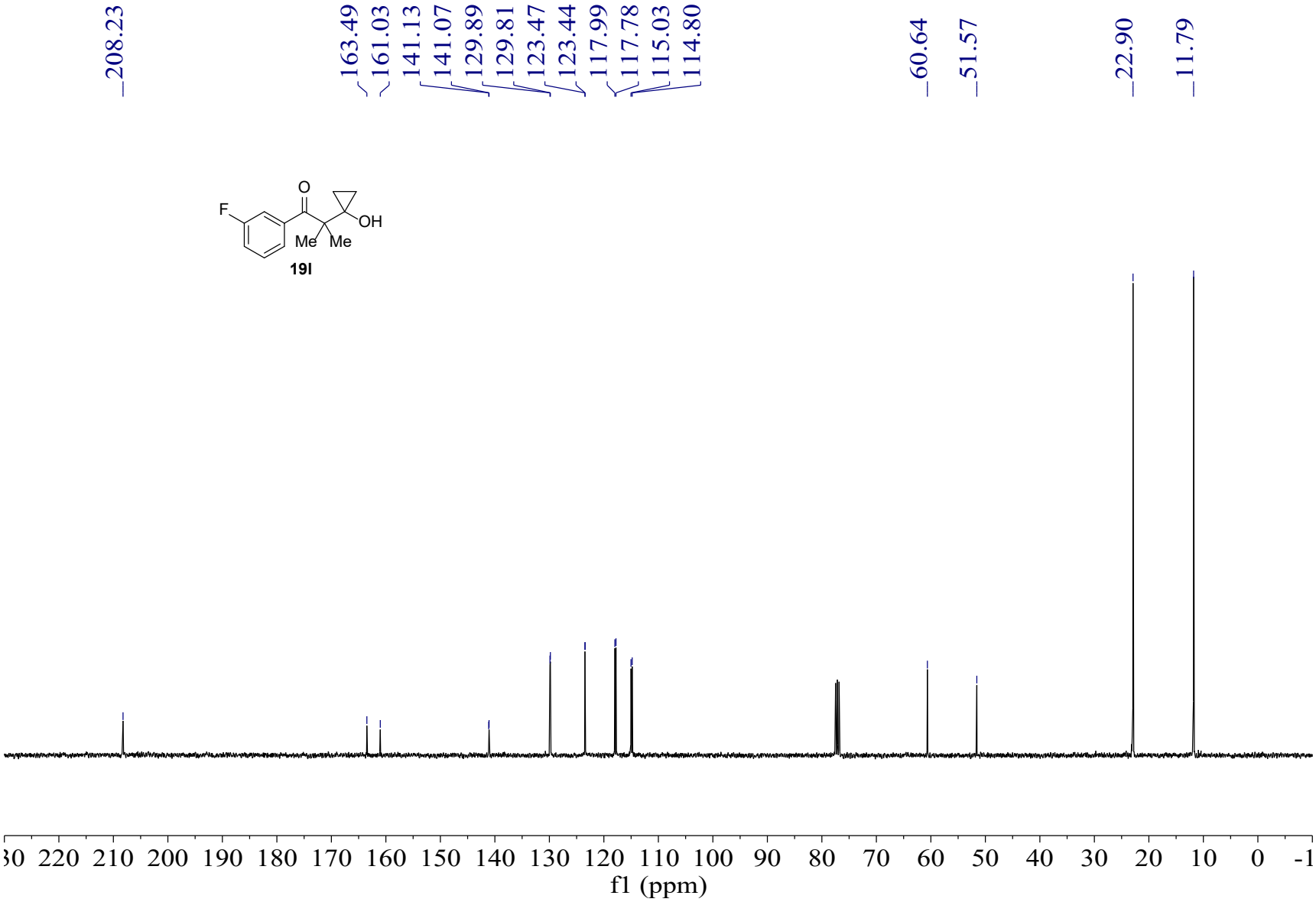
^{1}H NMR spectrum of compound **1k**



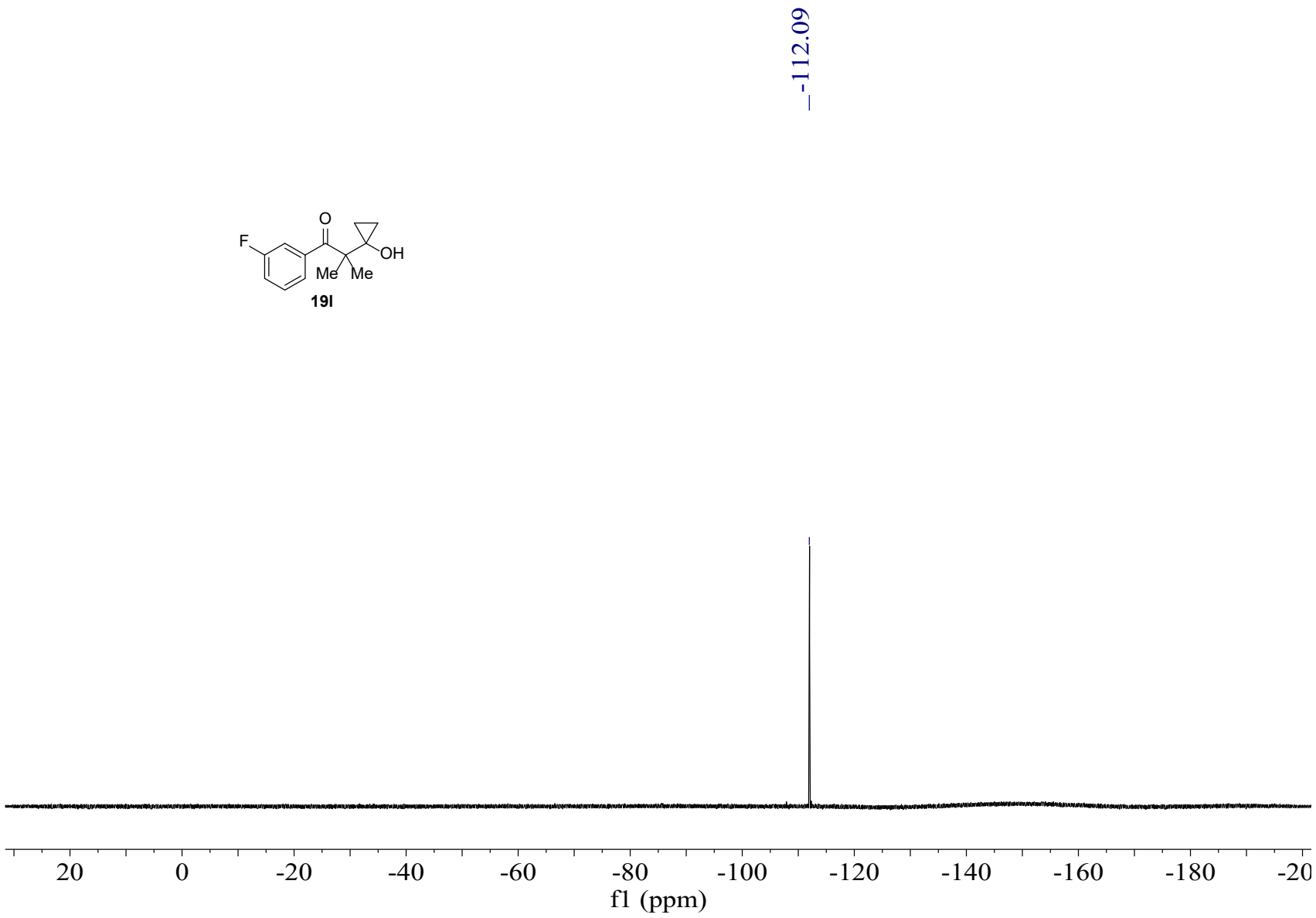
^{13}C NMR spectrum of compound **1k**



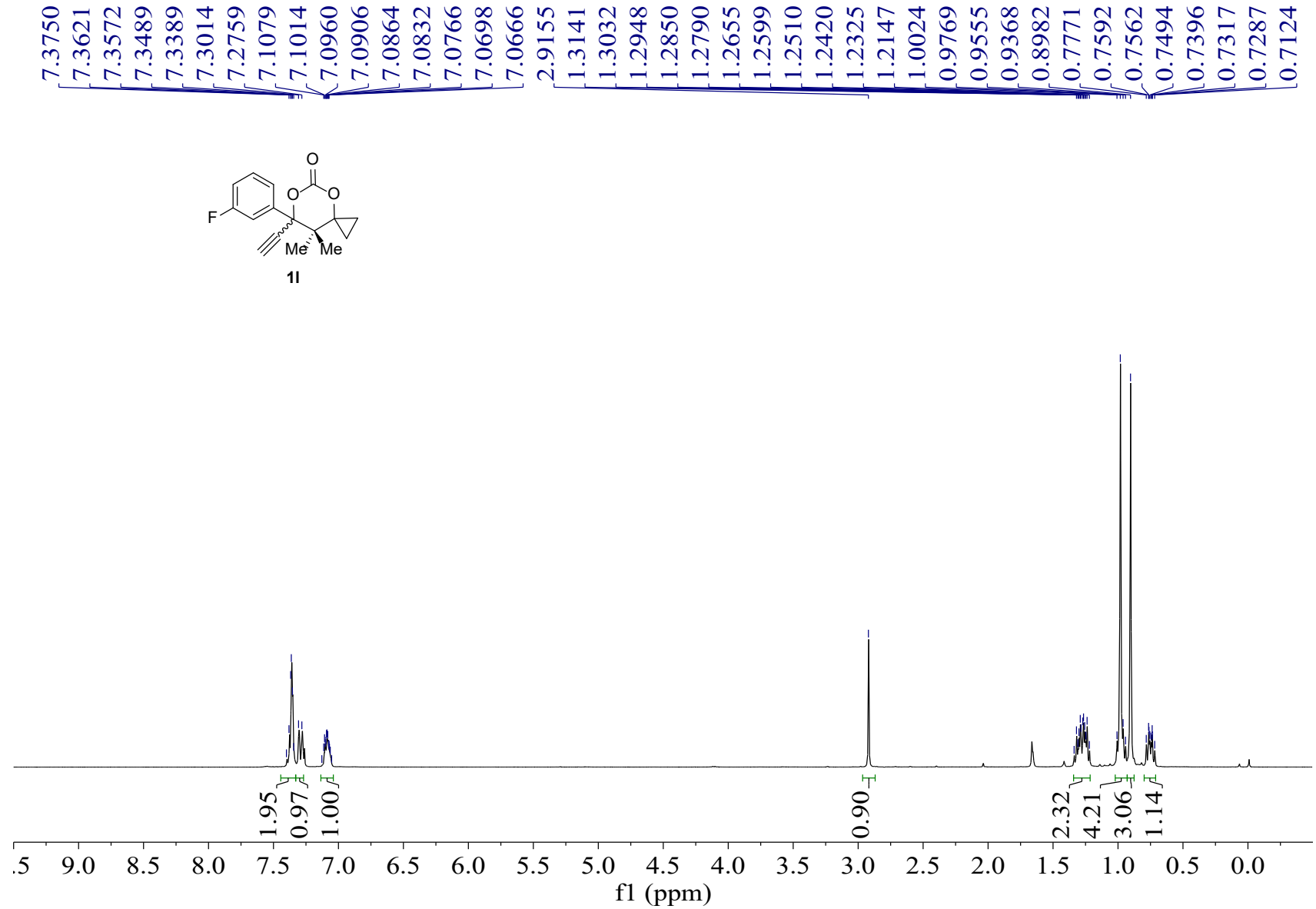
^{1}H NMR spectrum of compound **19l**



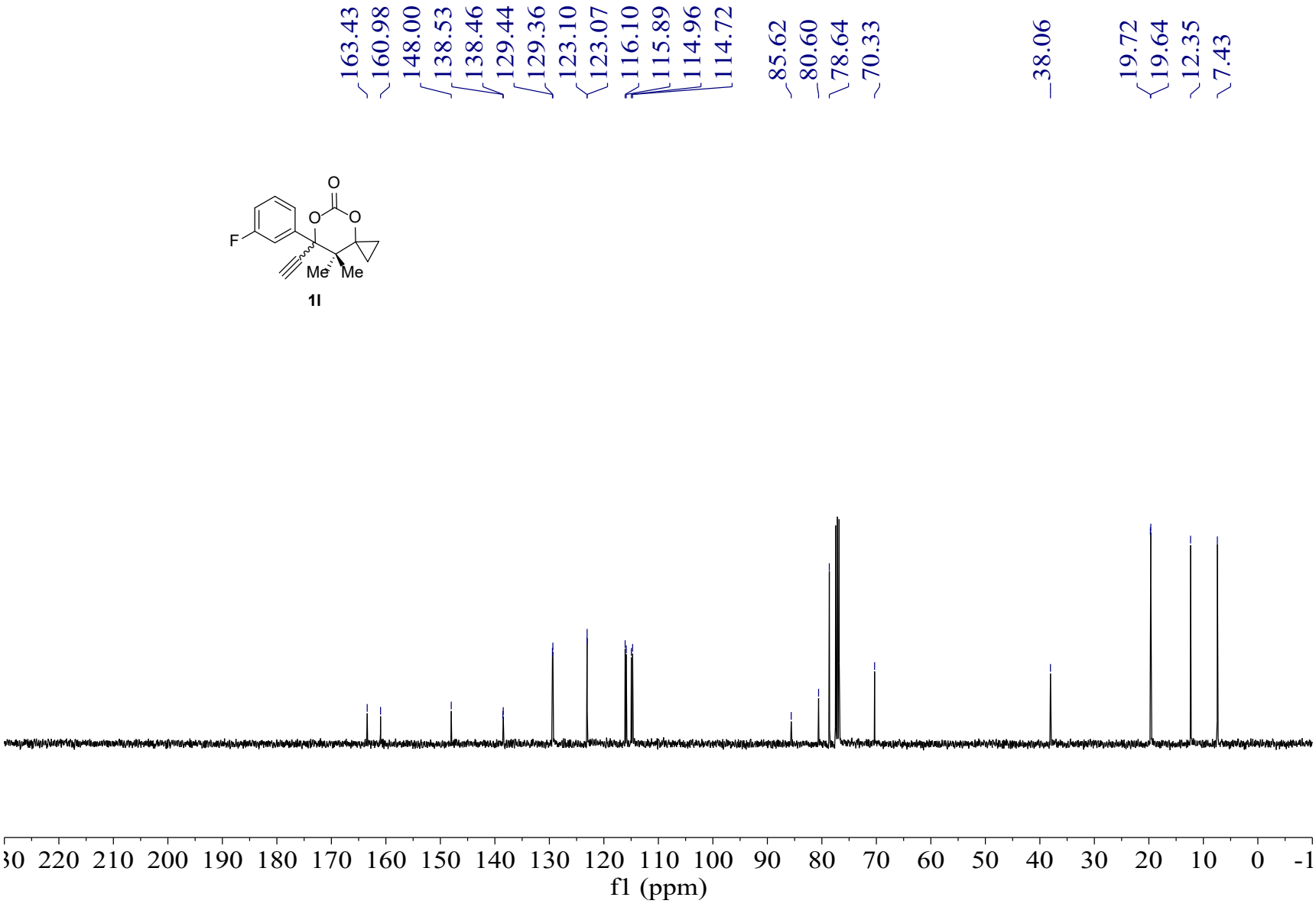
^{13}C NMR spectrum of compound **19l**



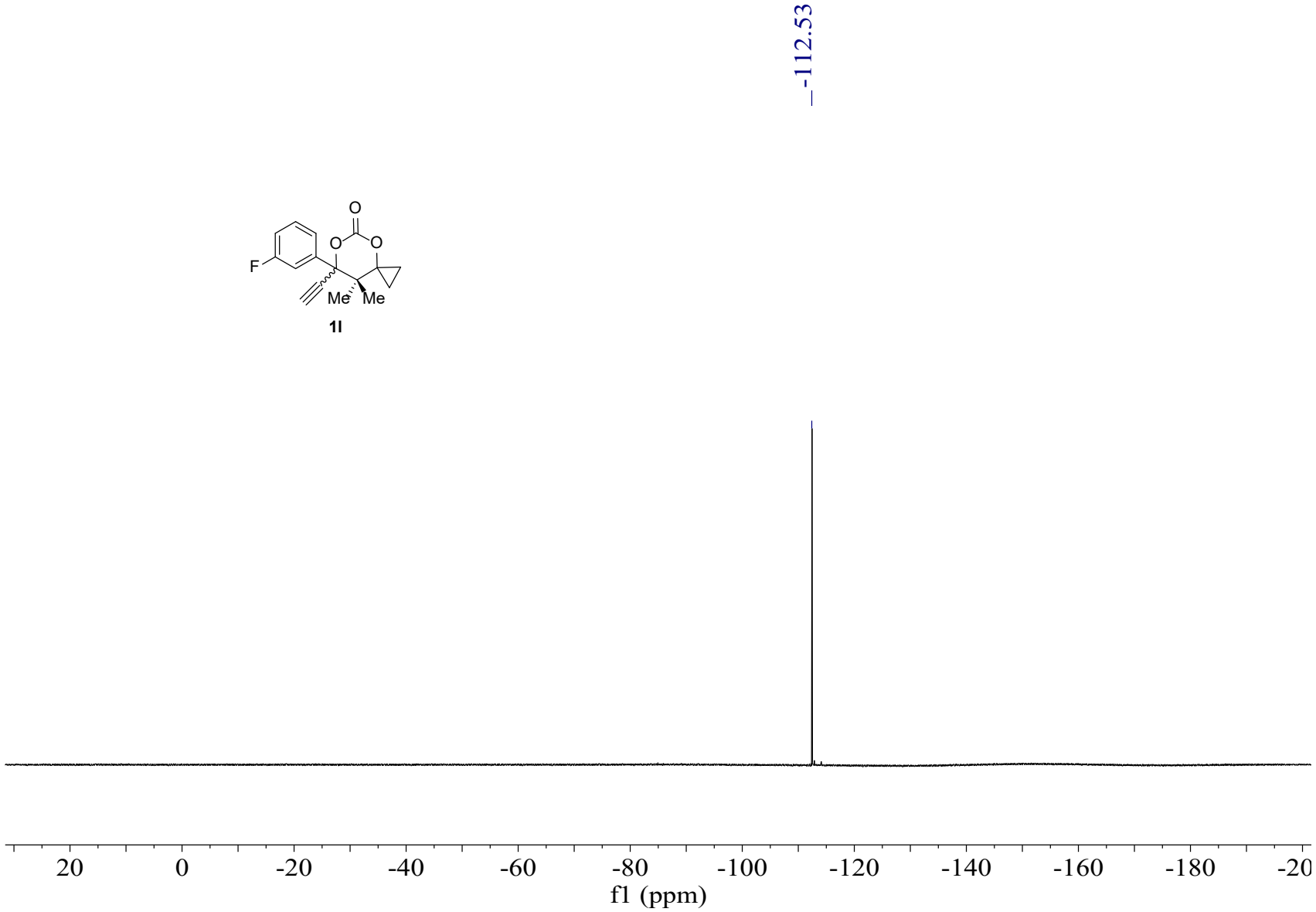
^{19}F NMR spectrum of compound **19l**



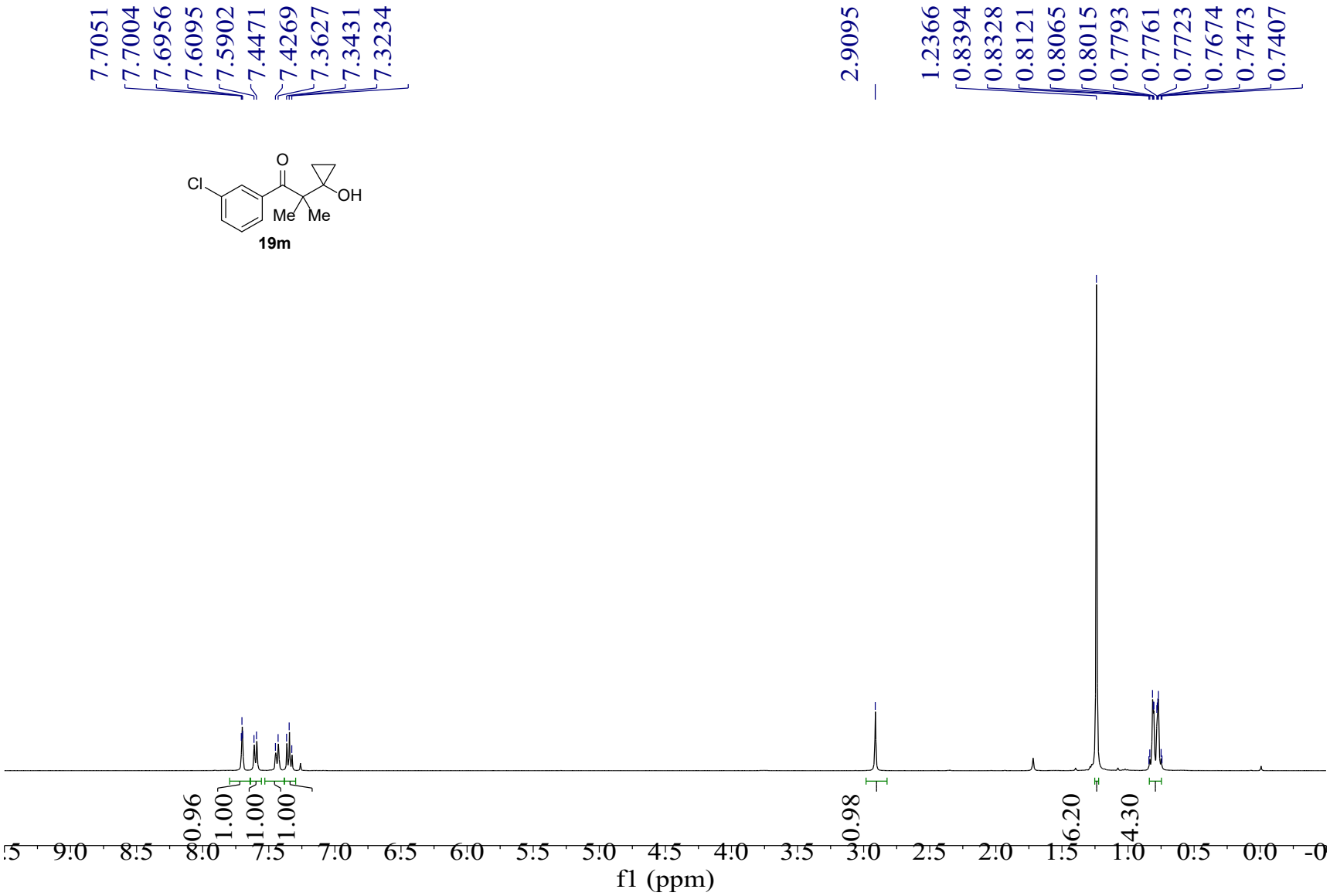
^{1}H NMR spectrum of compound **1l**



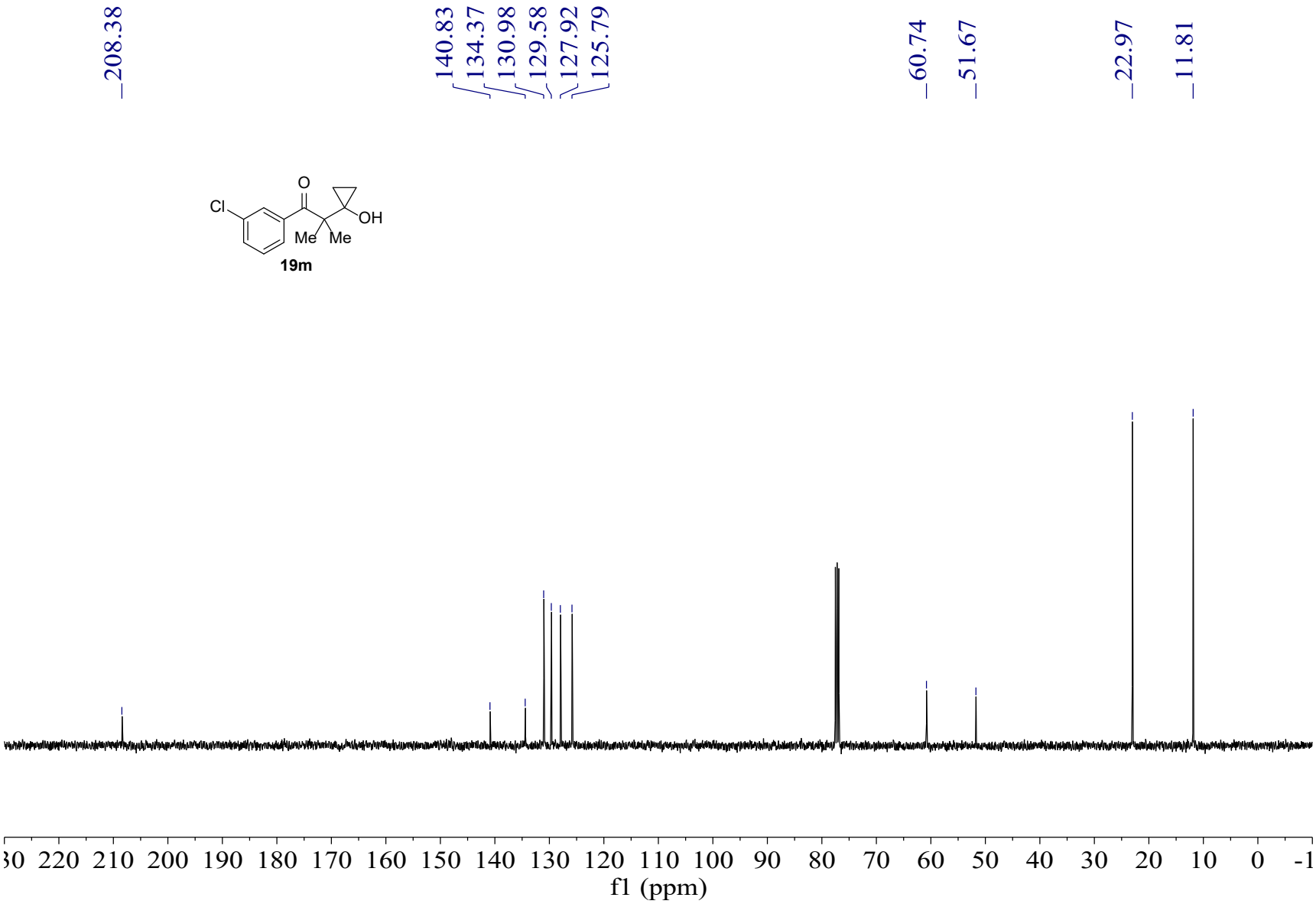
^{13}C NMR spectrum of compound **1l**



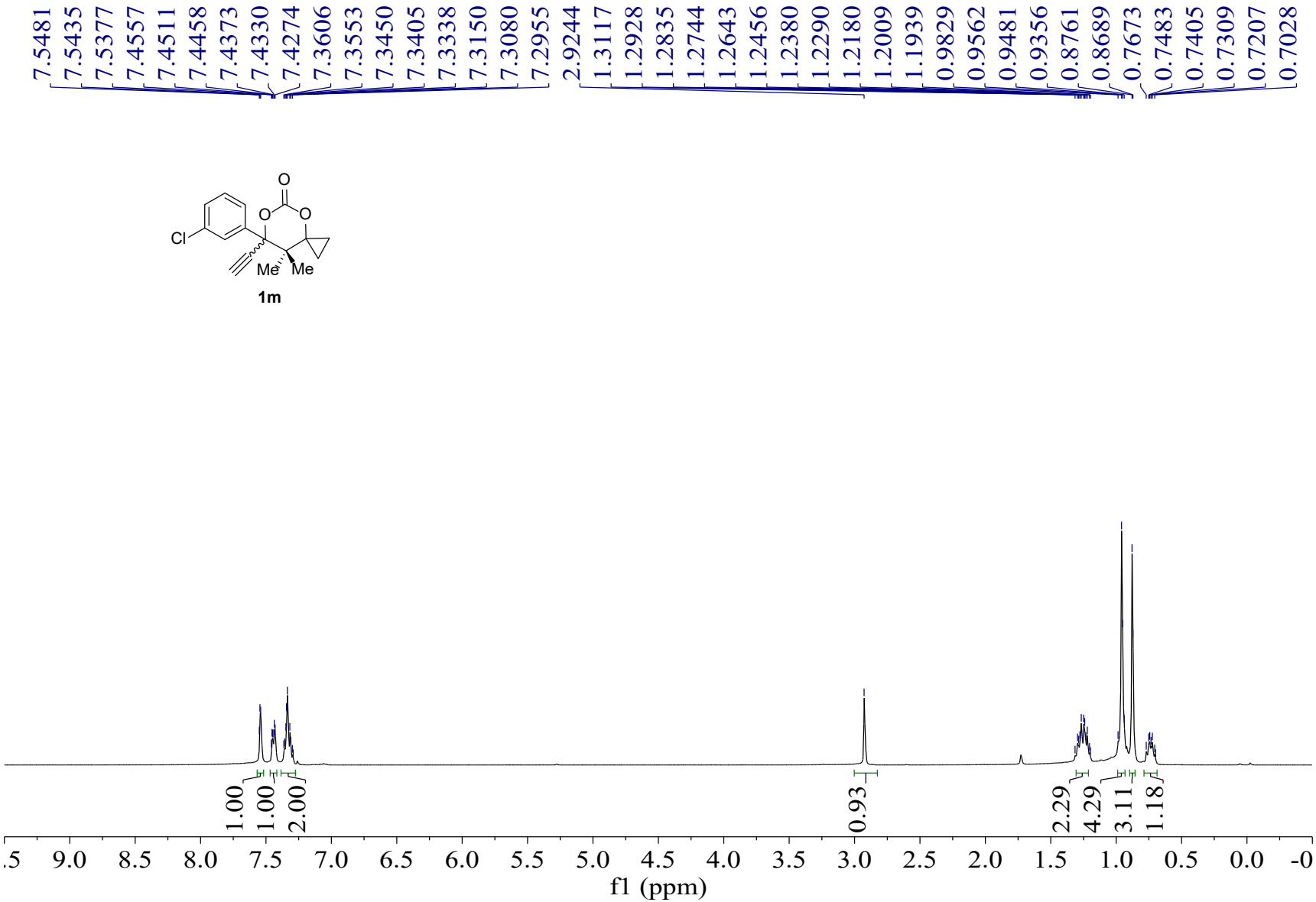
^{19}F NMR spectrum of compound **1l**



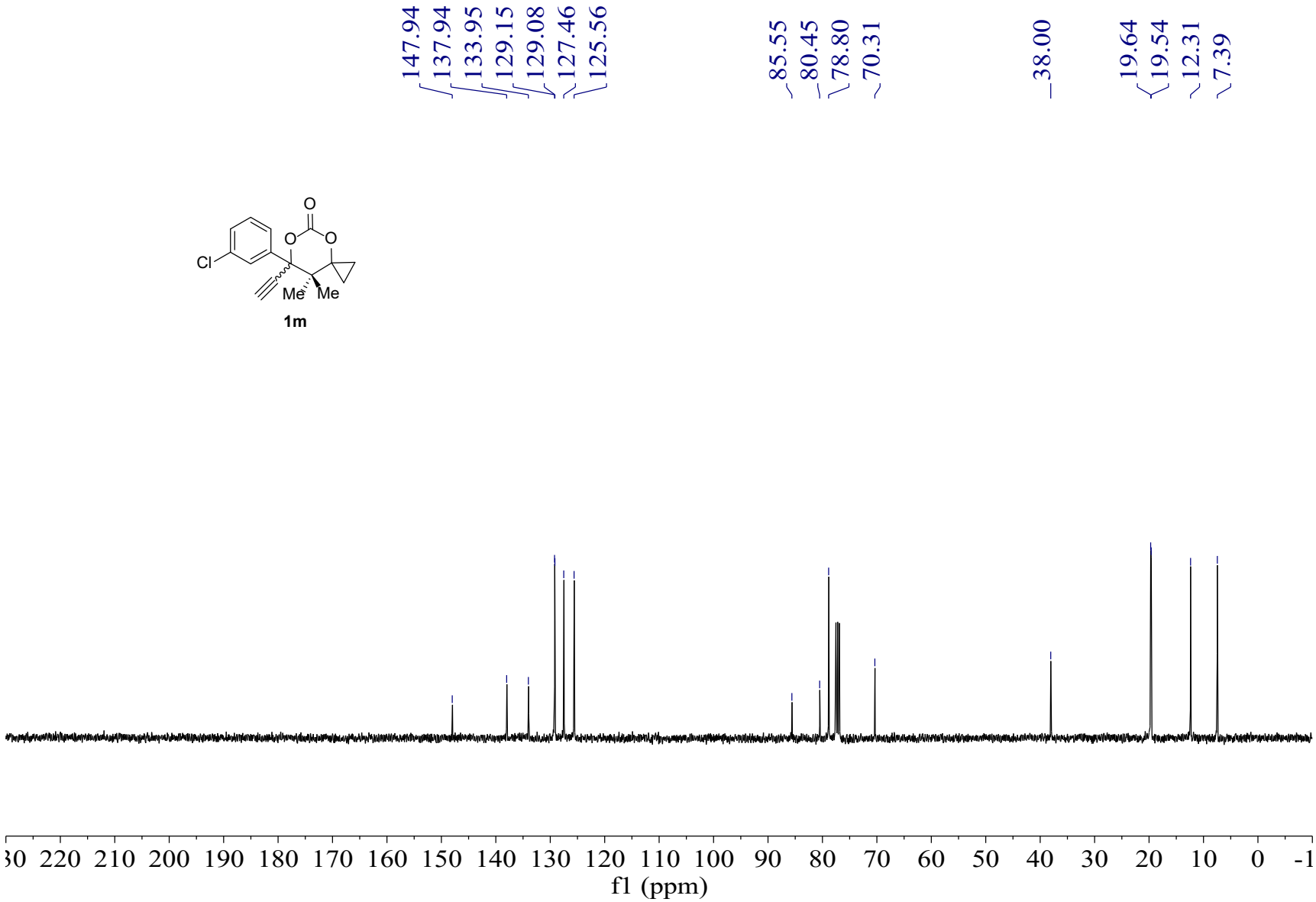
^{1}H NMR spectrum of compound **19m**



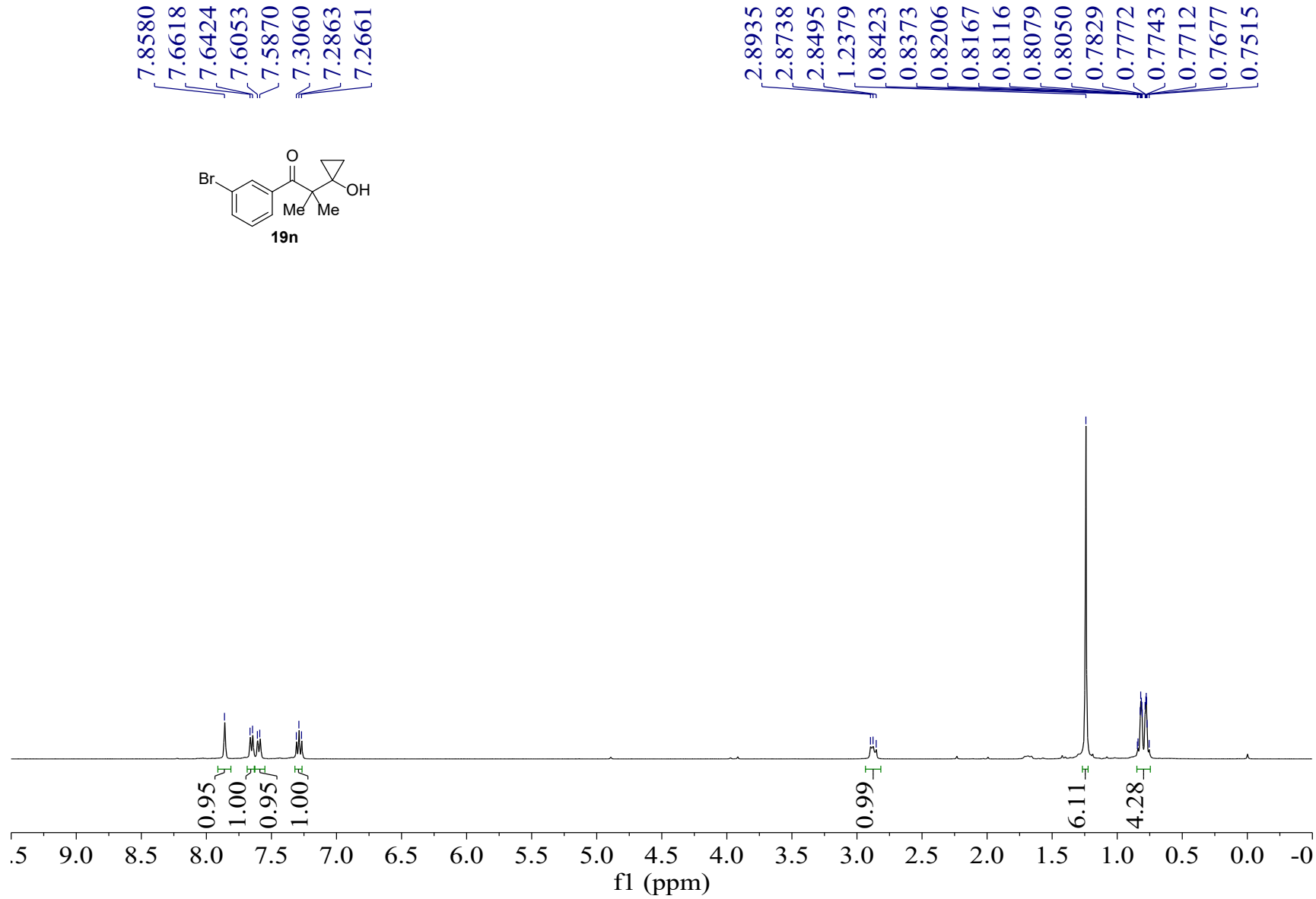
^{13}C NMR spectrum of compound **19m**



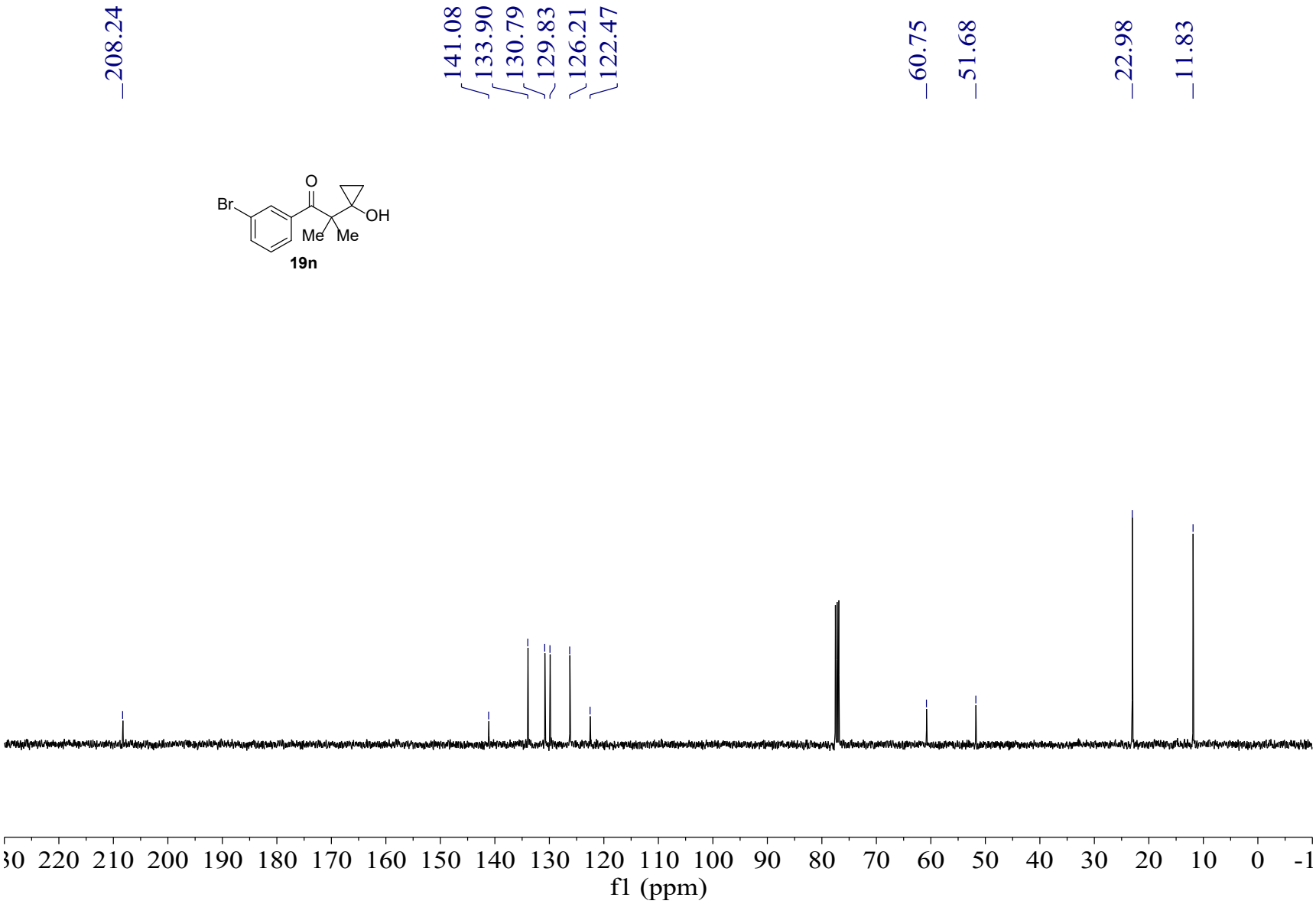
^{1}H NMR spectrum of compound **1m**



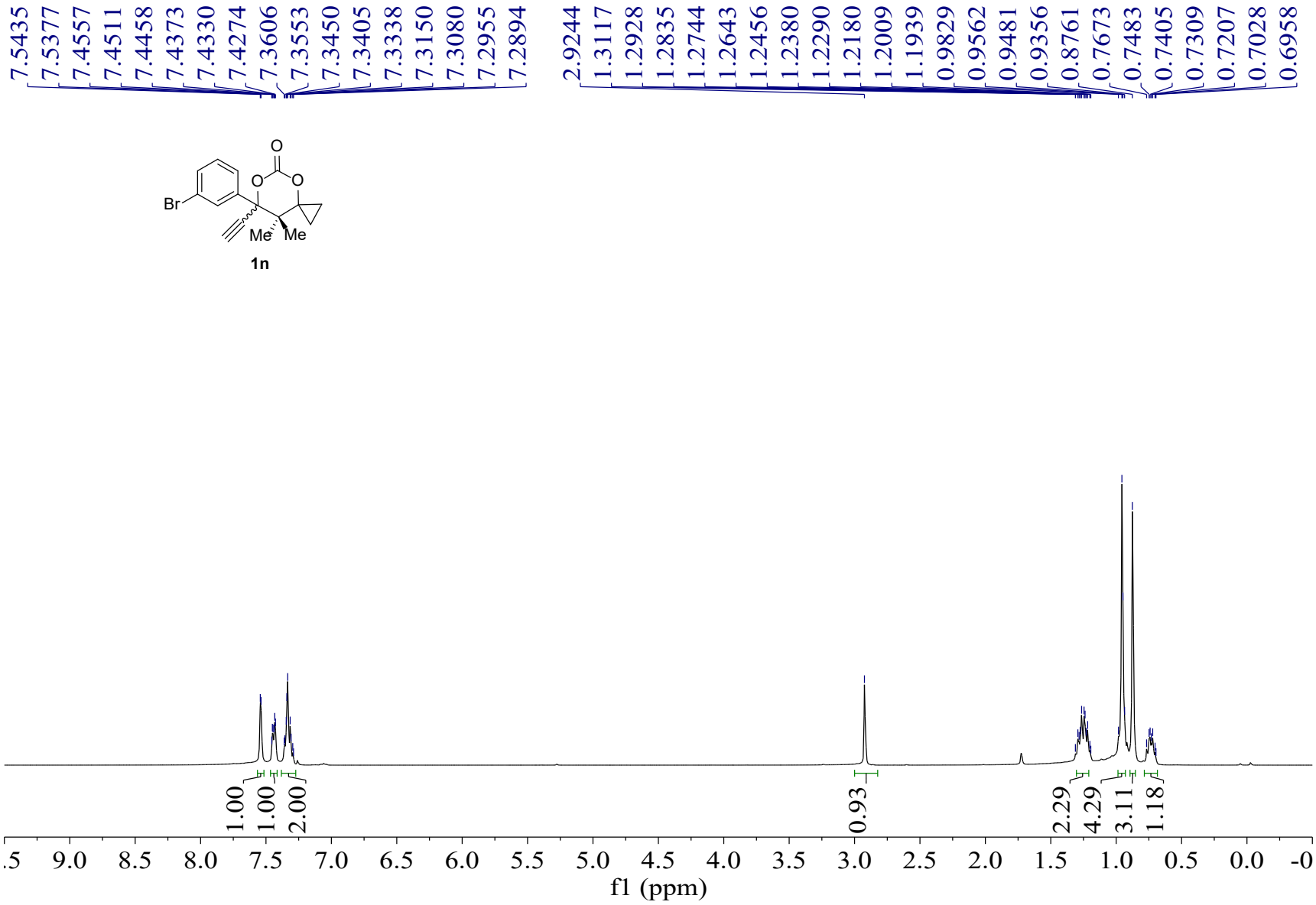
^{13}C NMR spectrum of compound **1m**



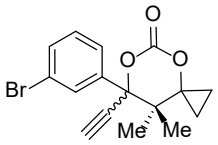
^{1}H NMR spectrum of compound **19n**



^{13}C NMR spectrum of compound **19n**

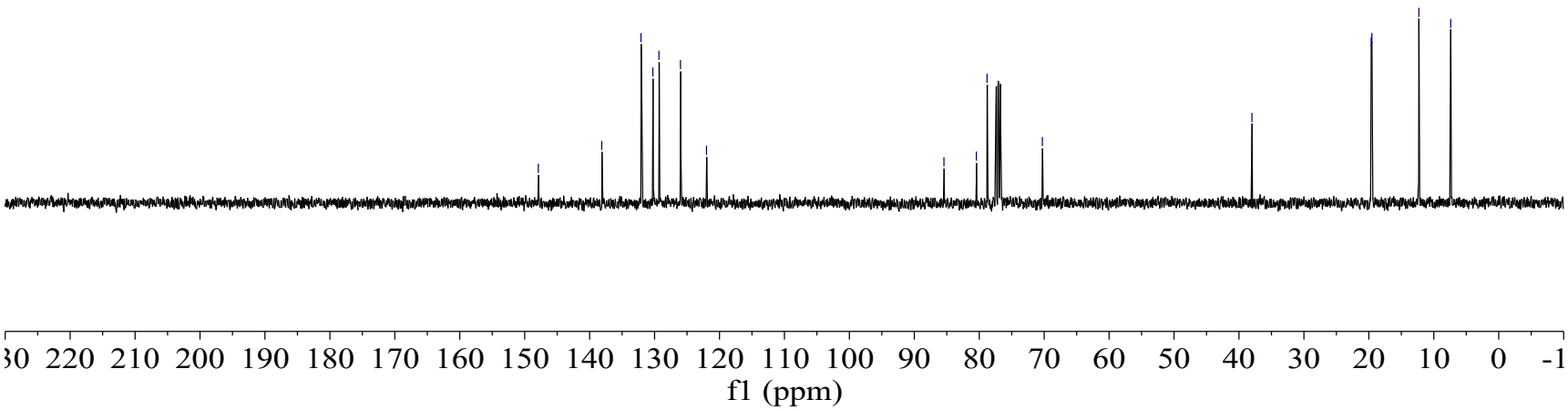


^{1}H NMR spectrum of compound **1n**

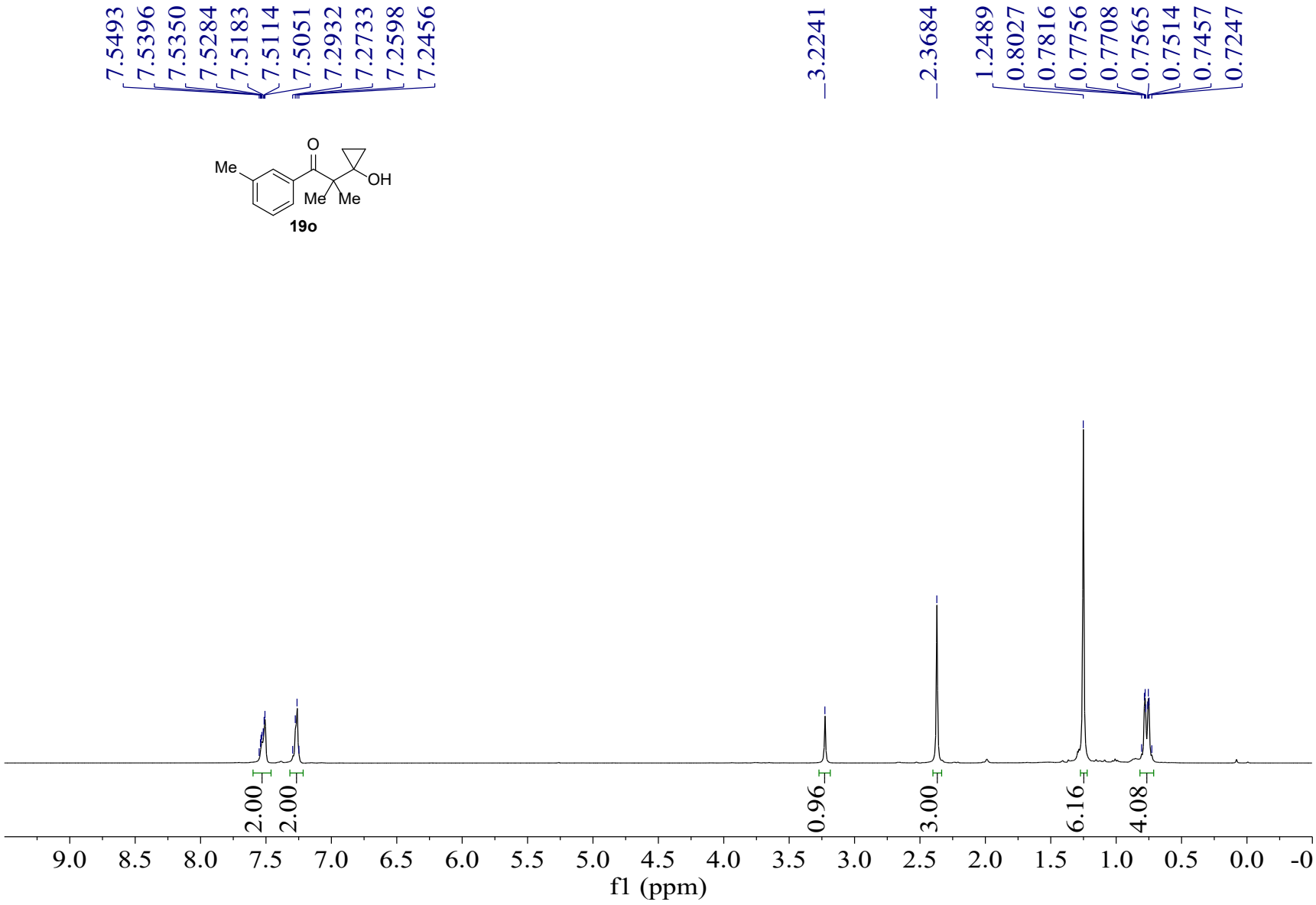


1n

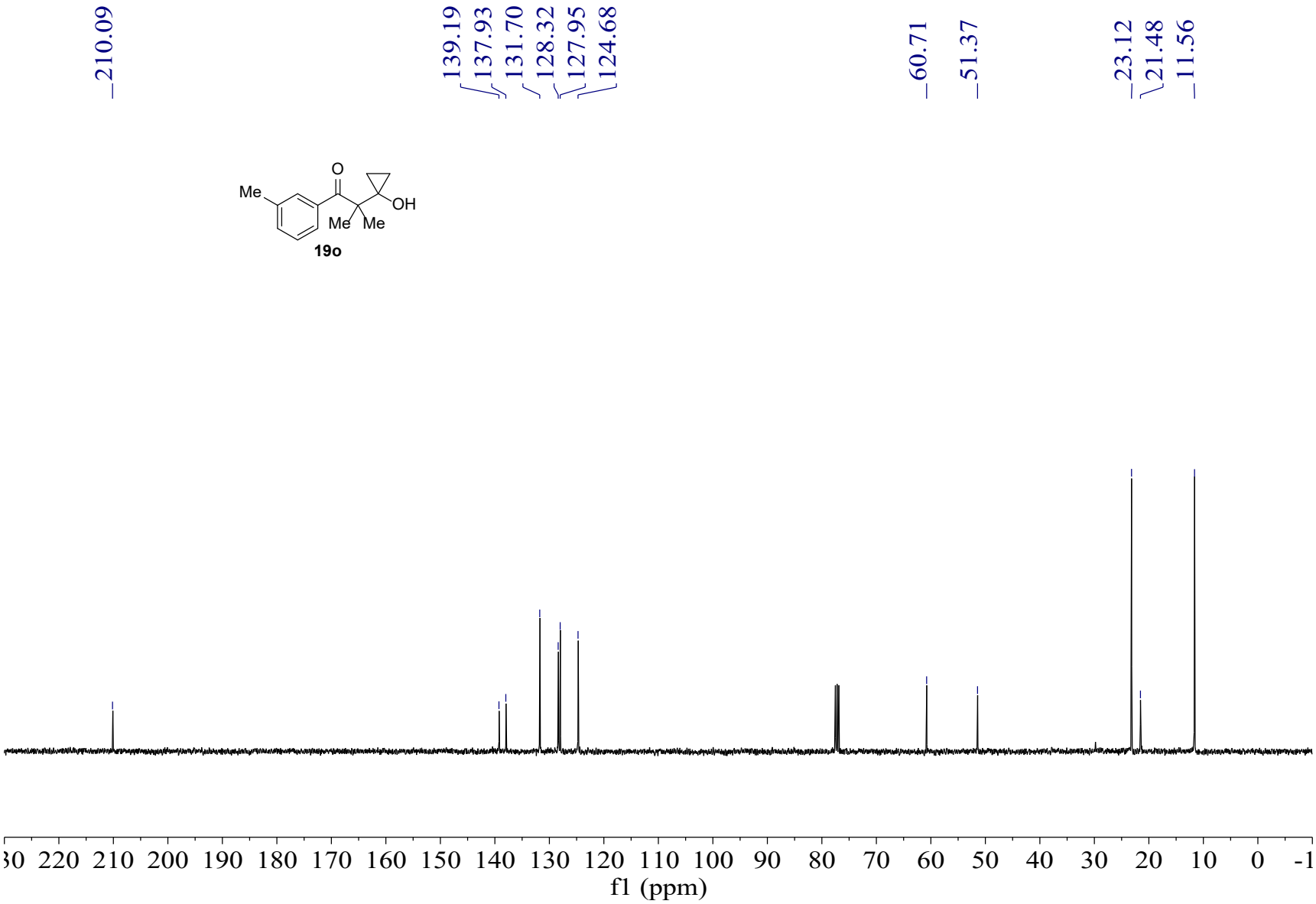
147.84
138.07
132.02
130.20
129.26
125.95
121.94
85.37
80.38
78.73
70.22
37.94
19.58
19.47
12.23
7.33



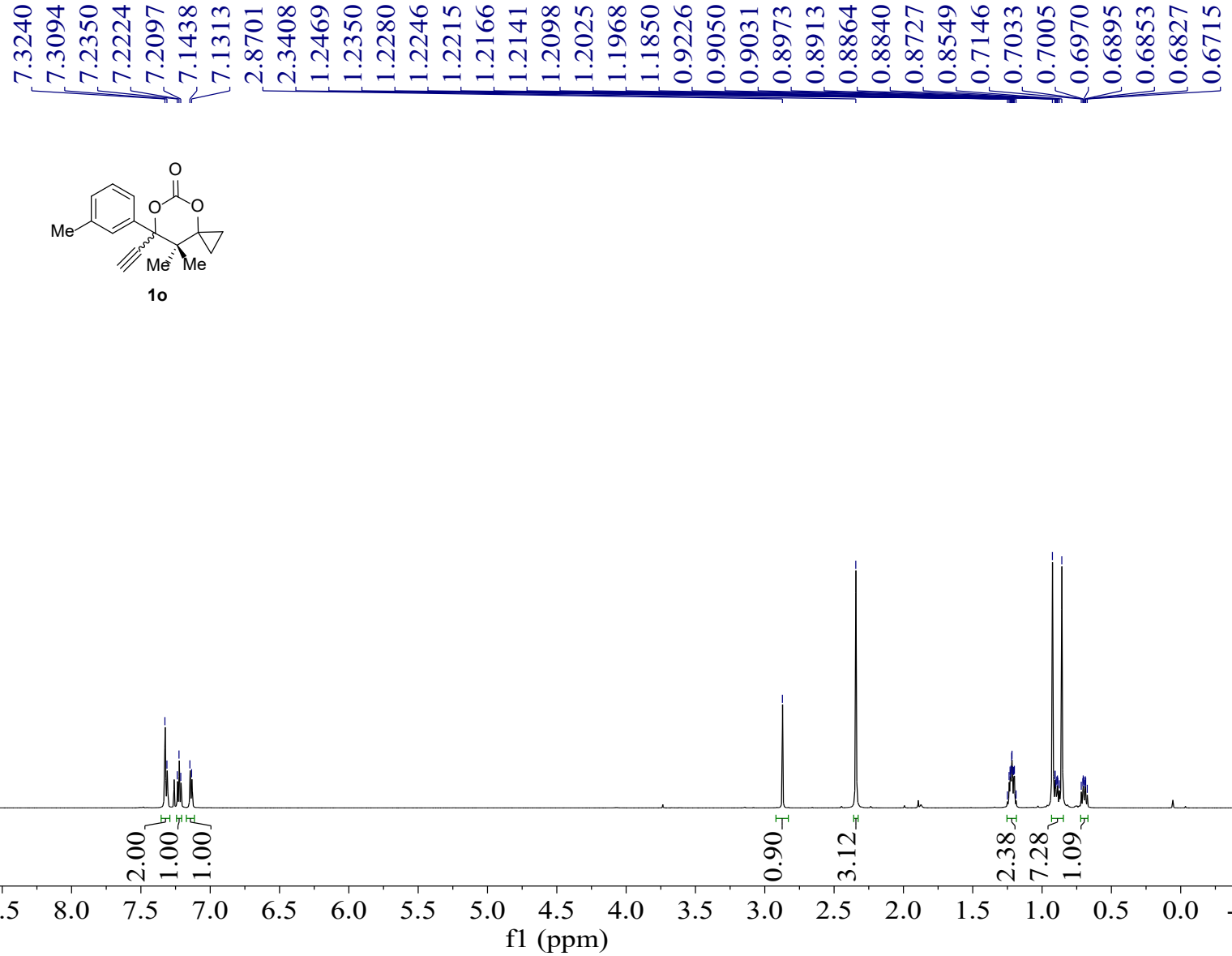
^{13}C NMR spectrum of compound **1n**



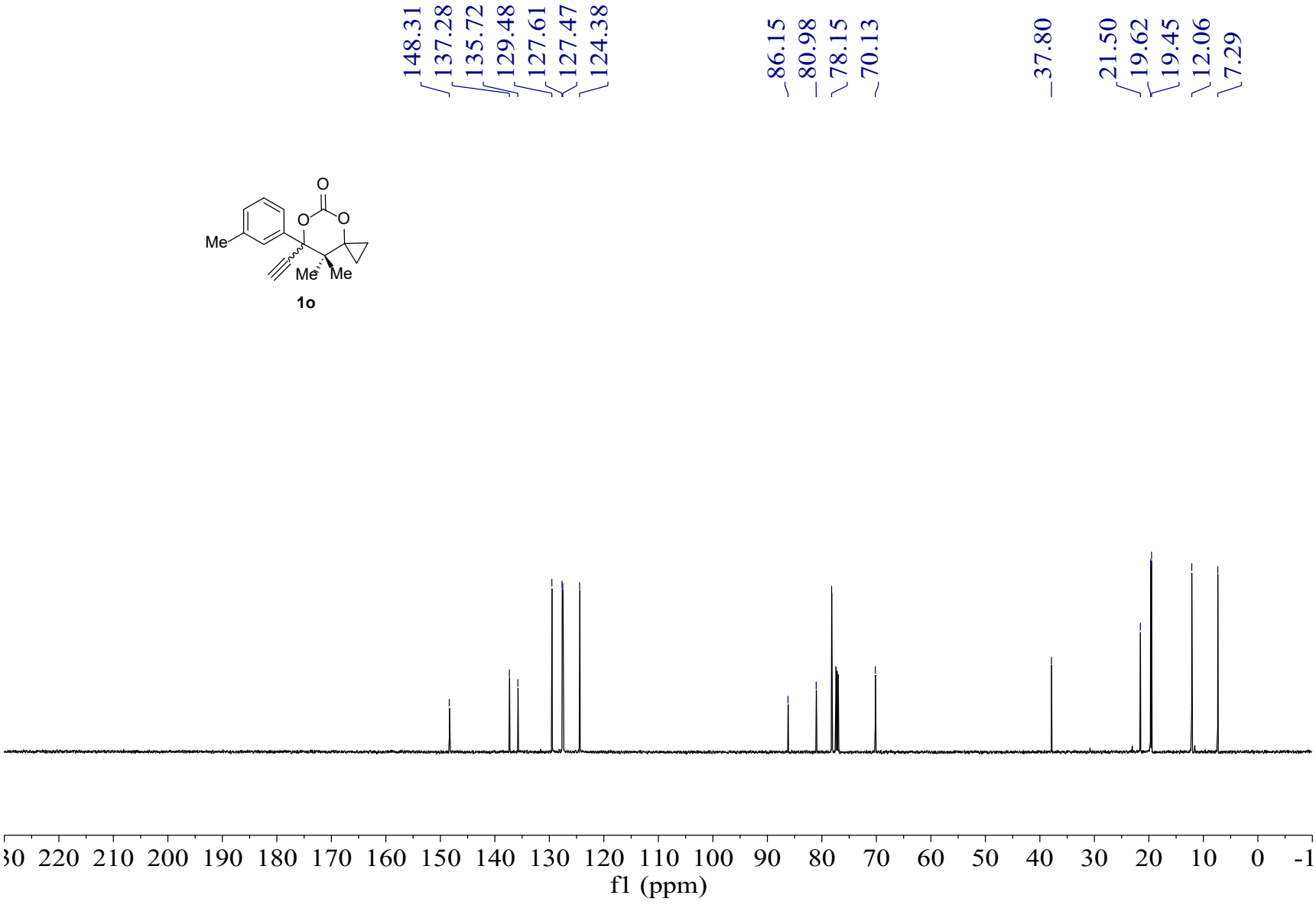
^{1}H NMR spectrum of compound **19o**



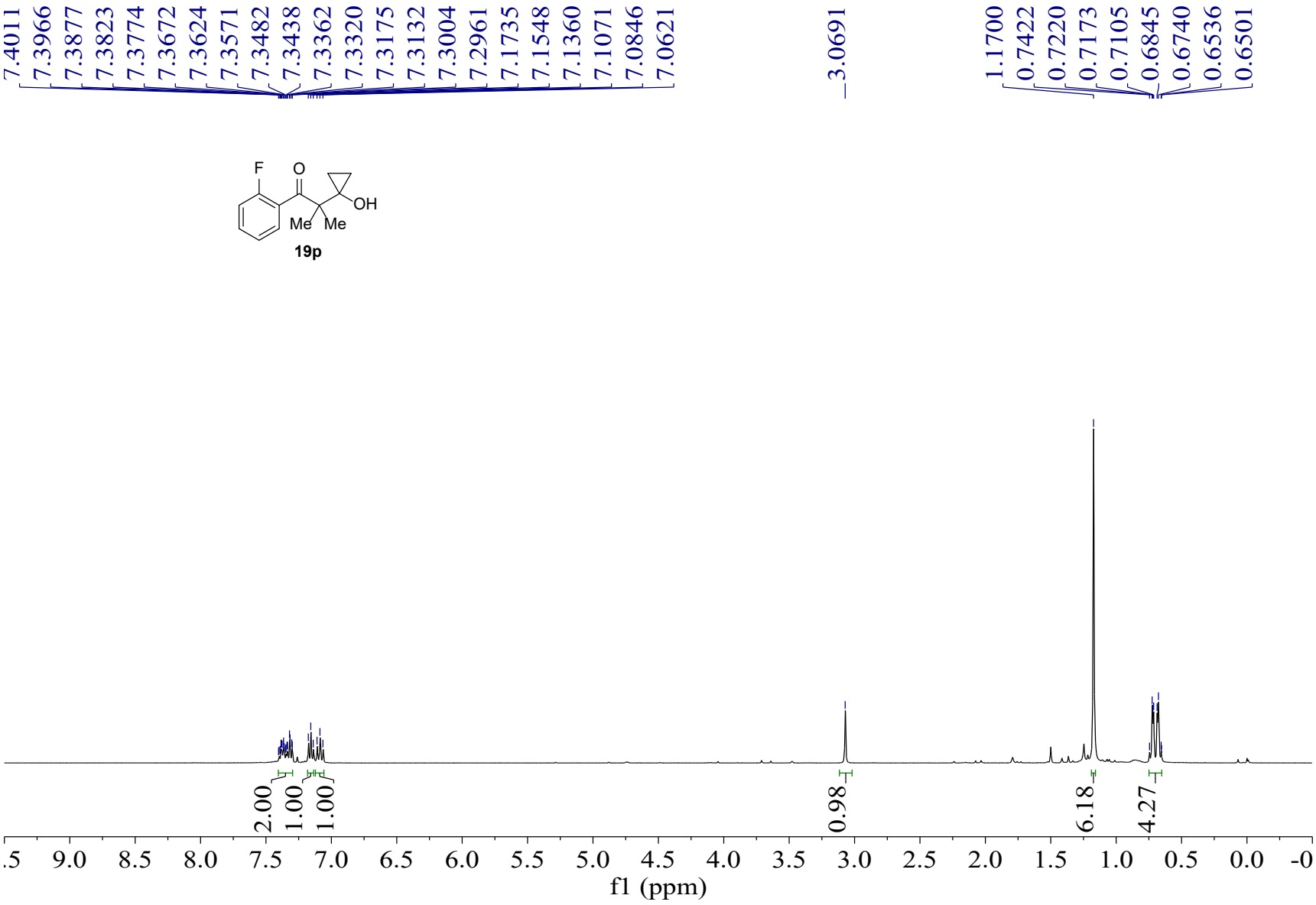
^{13}C NMR spectrum of compound **19o**



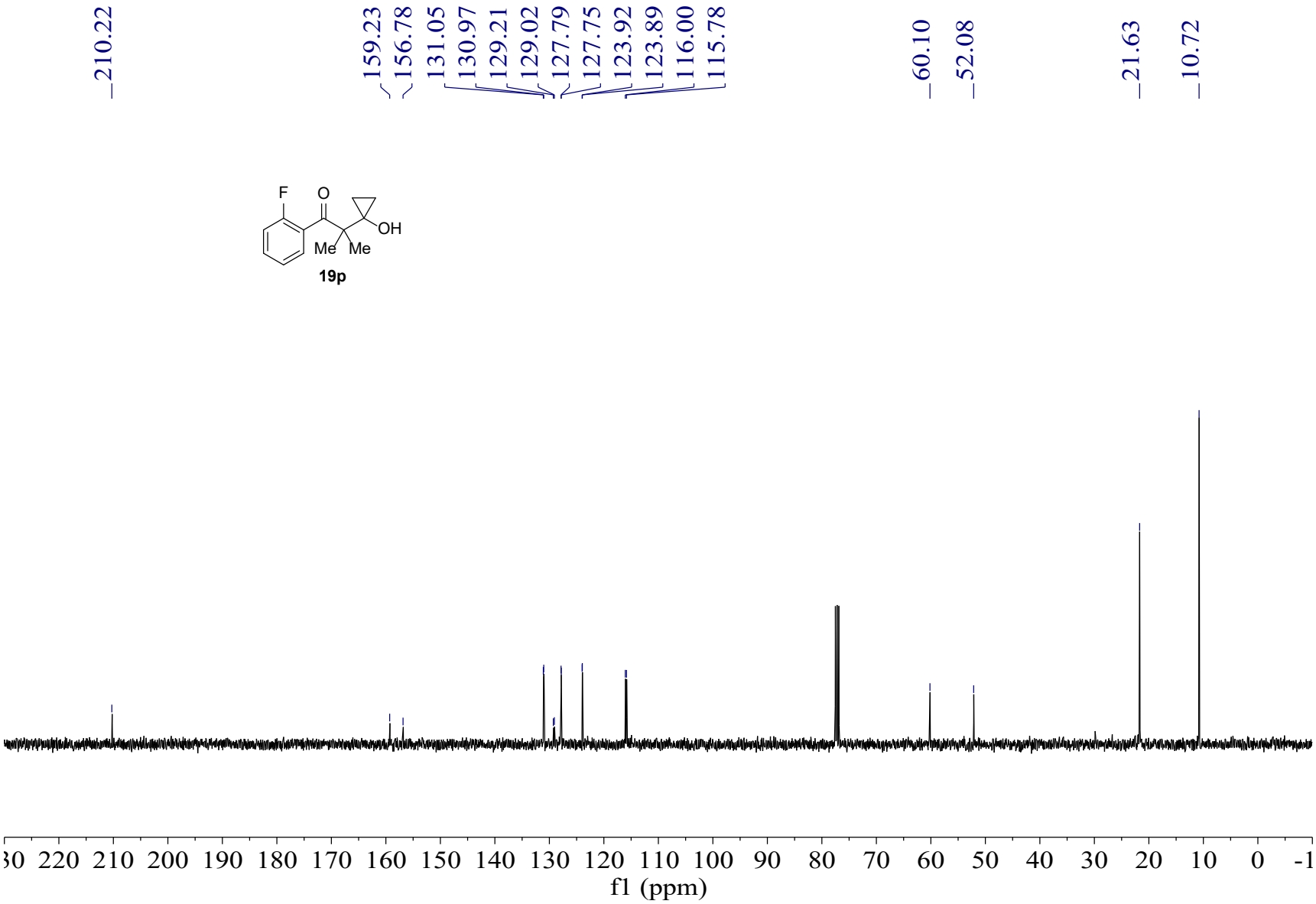
^{1}H NMR spectrum of compound **1o**



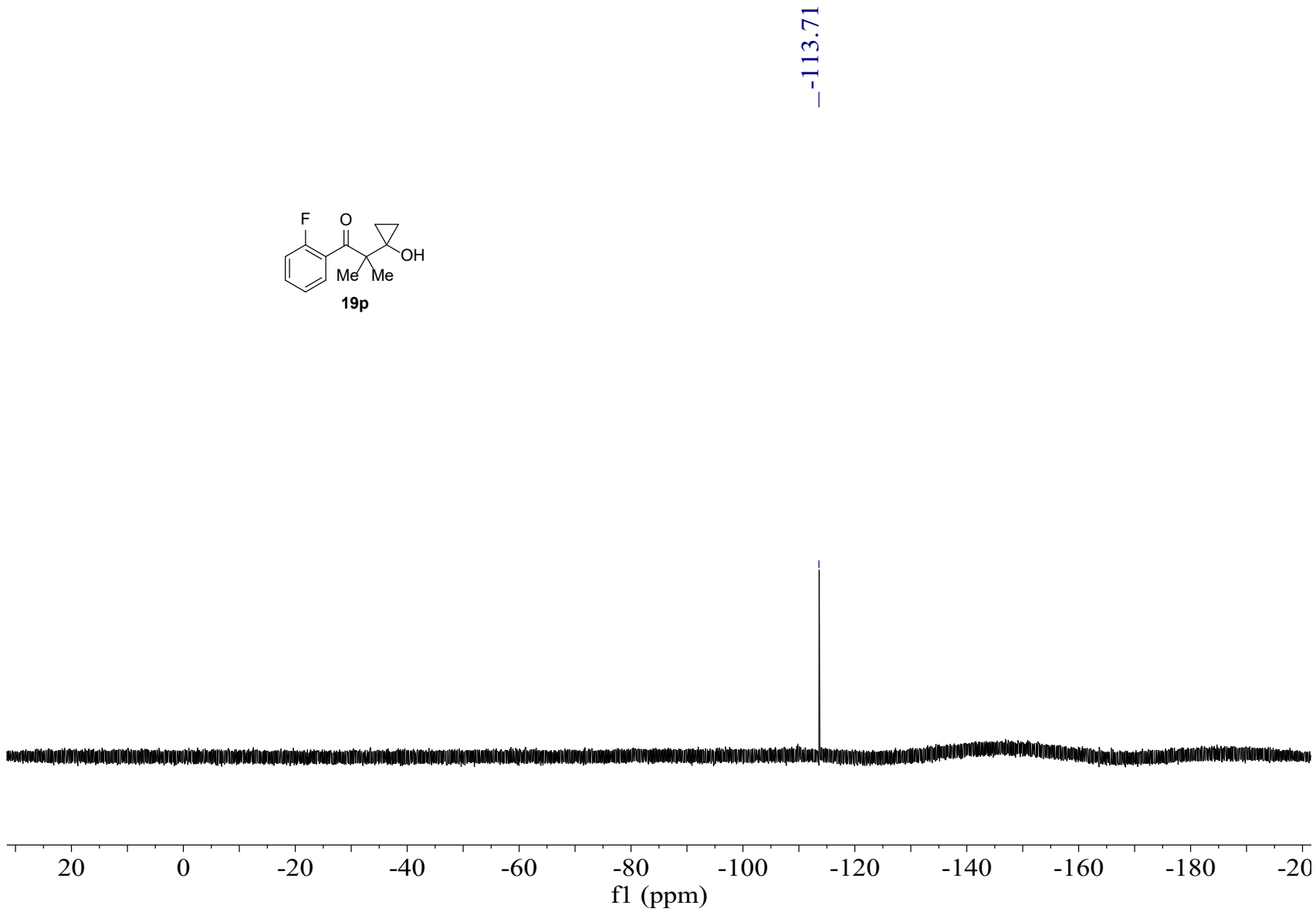
^{13}C NMR spectrum of compound **1o**



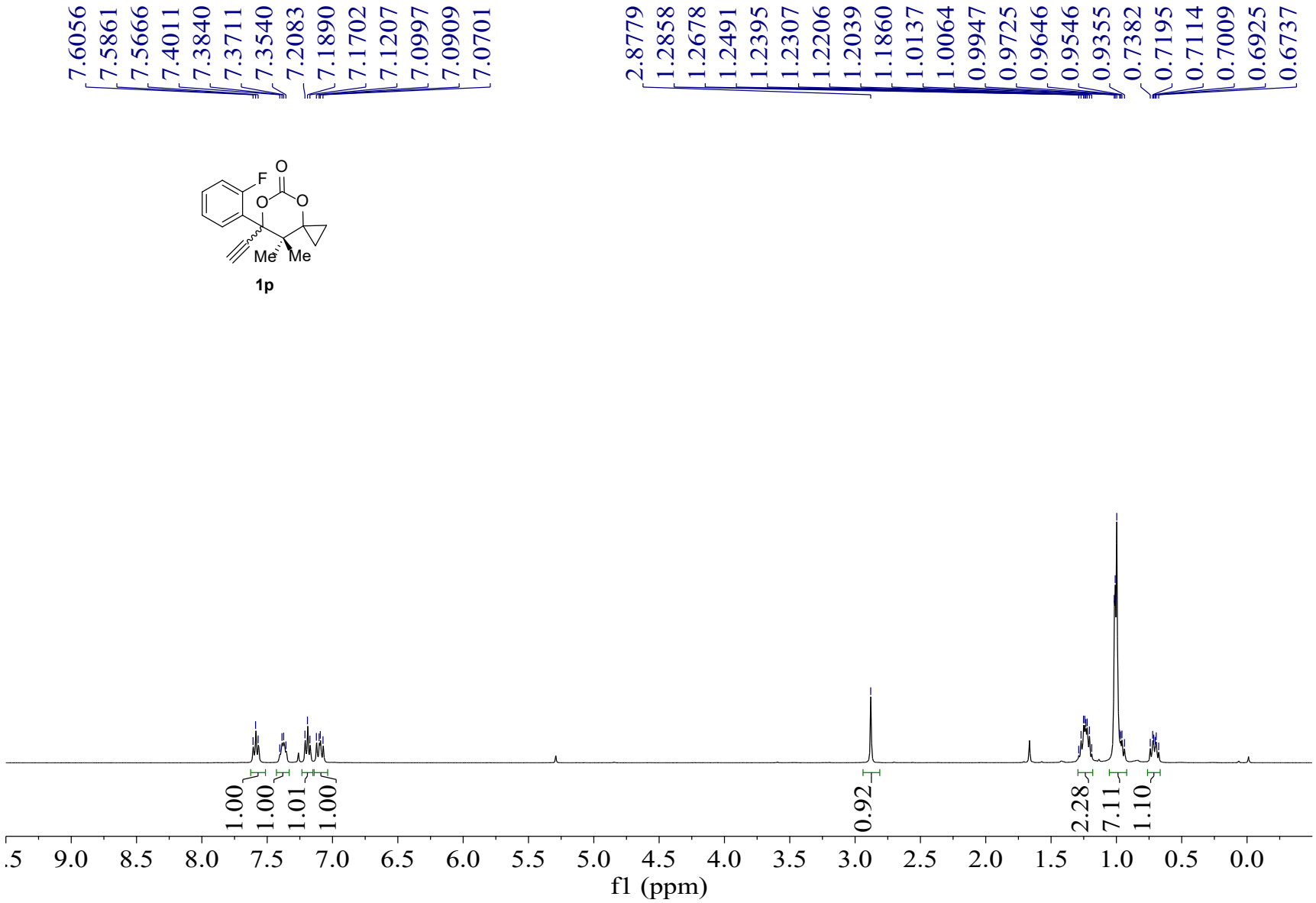
^{1}H NMR spectrum of compound **19p**



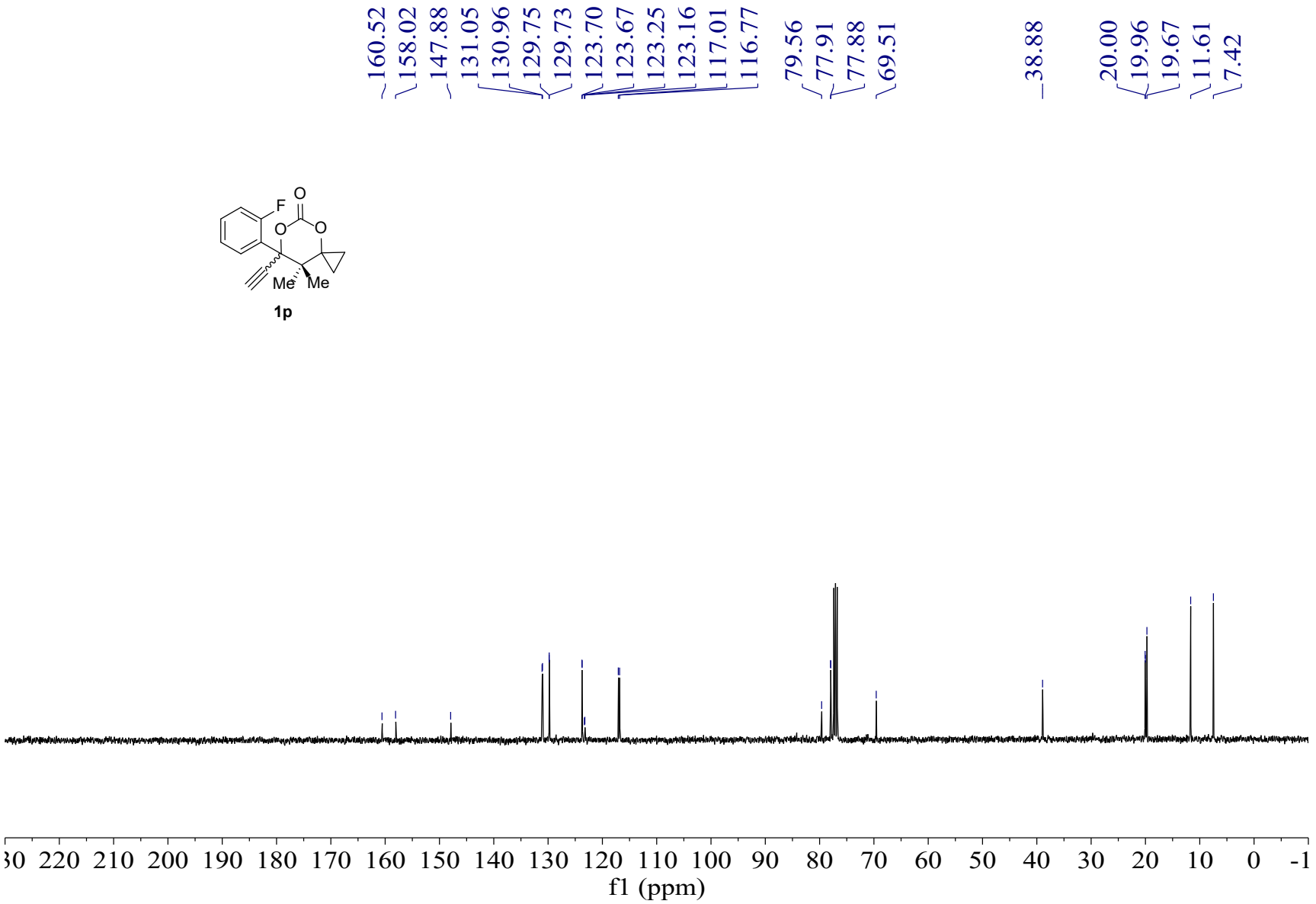
^{13}C NMR spectrum of compound **19p**



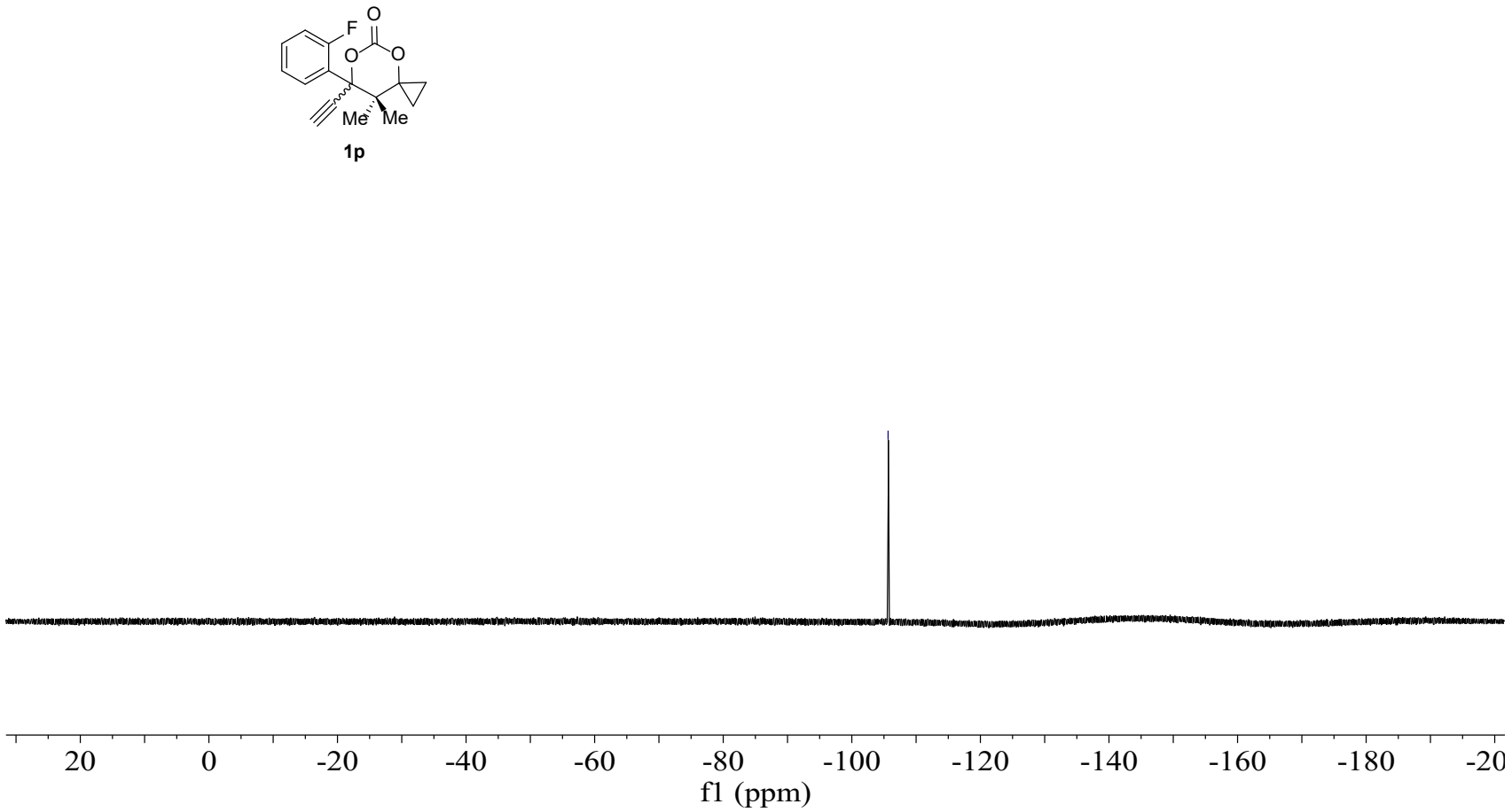
^{19}F NMR spectrum of compound **19p**



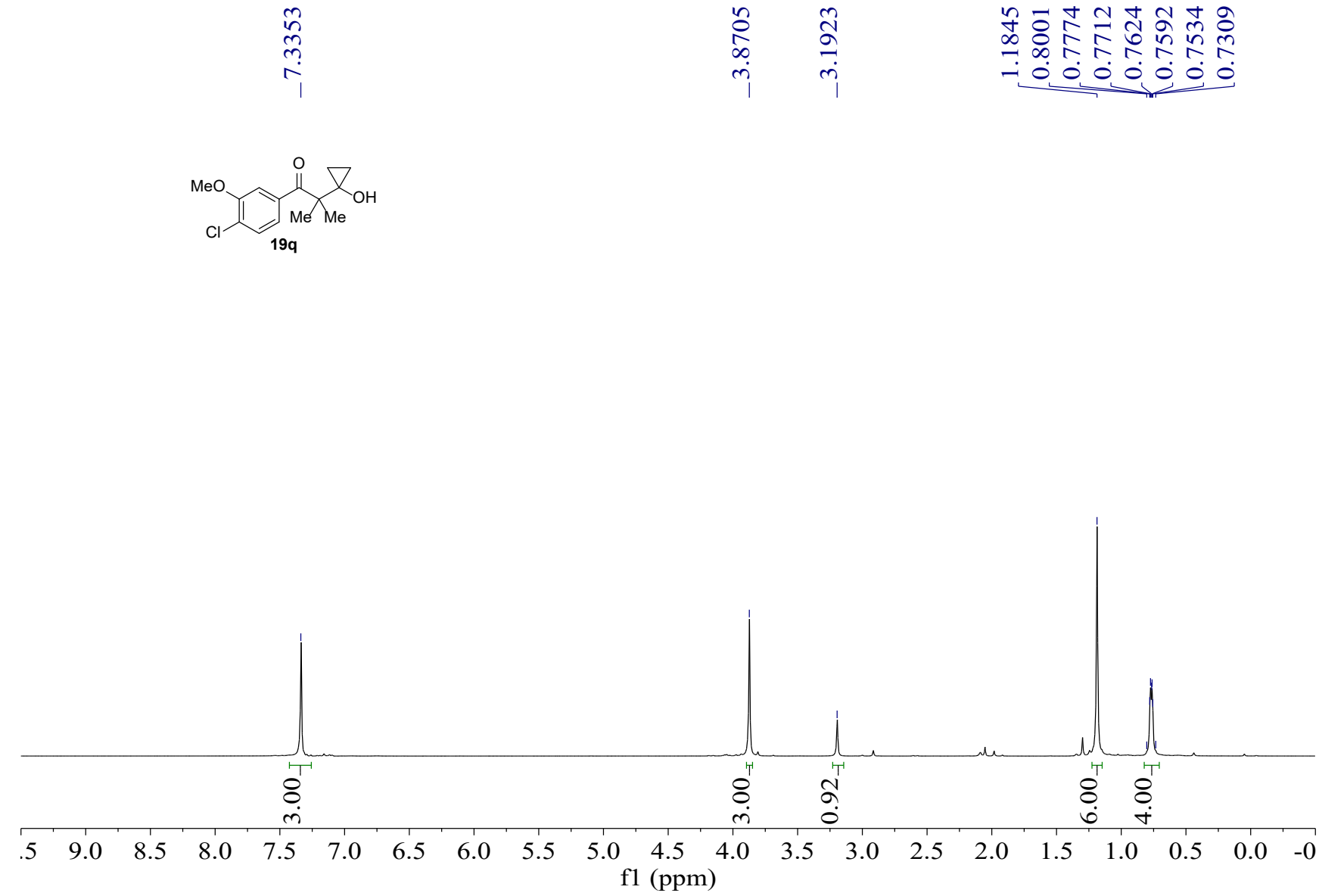
^{1}H NMR spectrum of compound **1p**



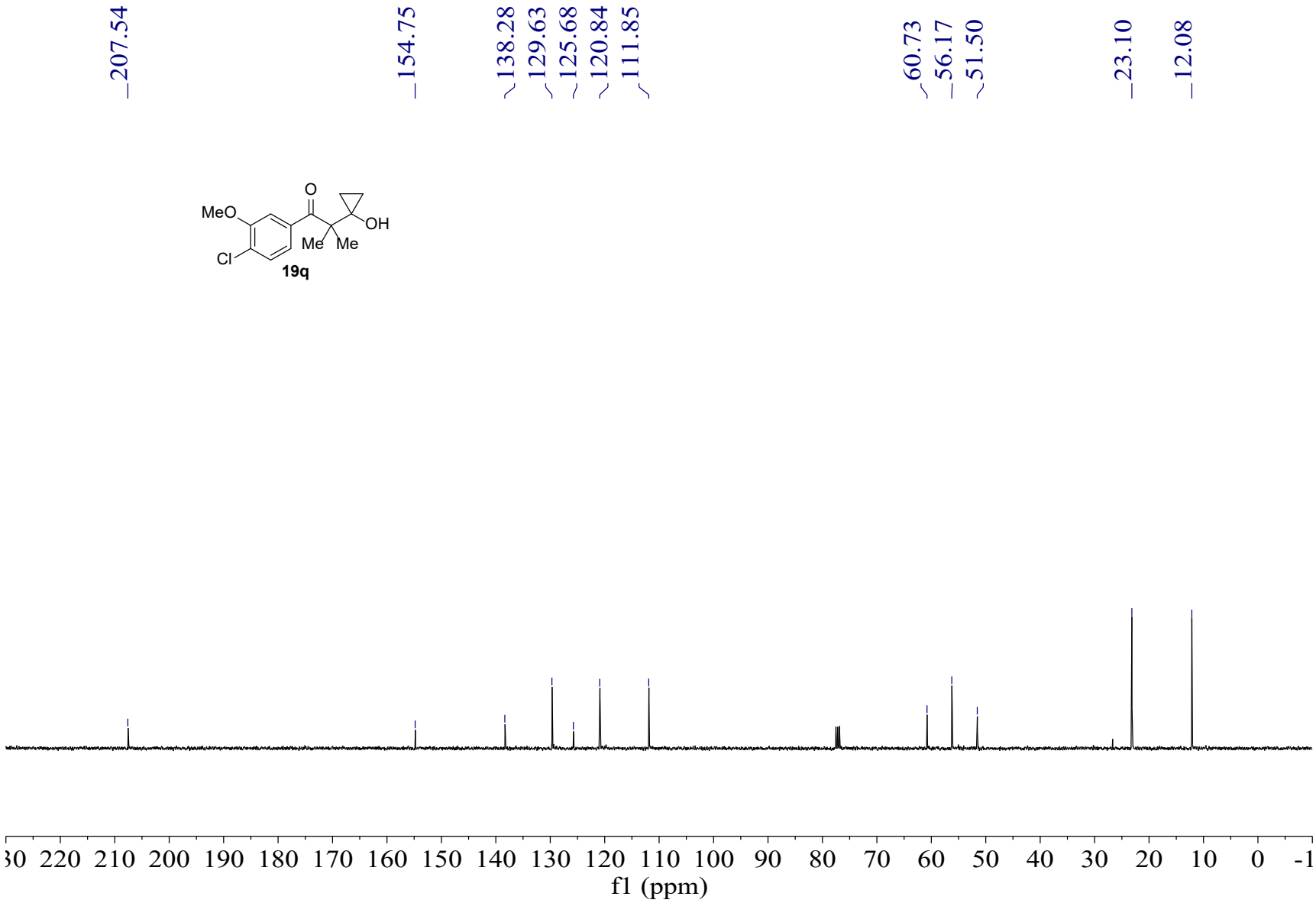
^{13}C NMR spectrum of compound **1p**



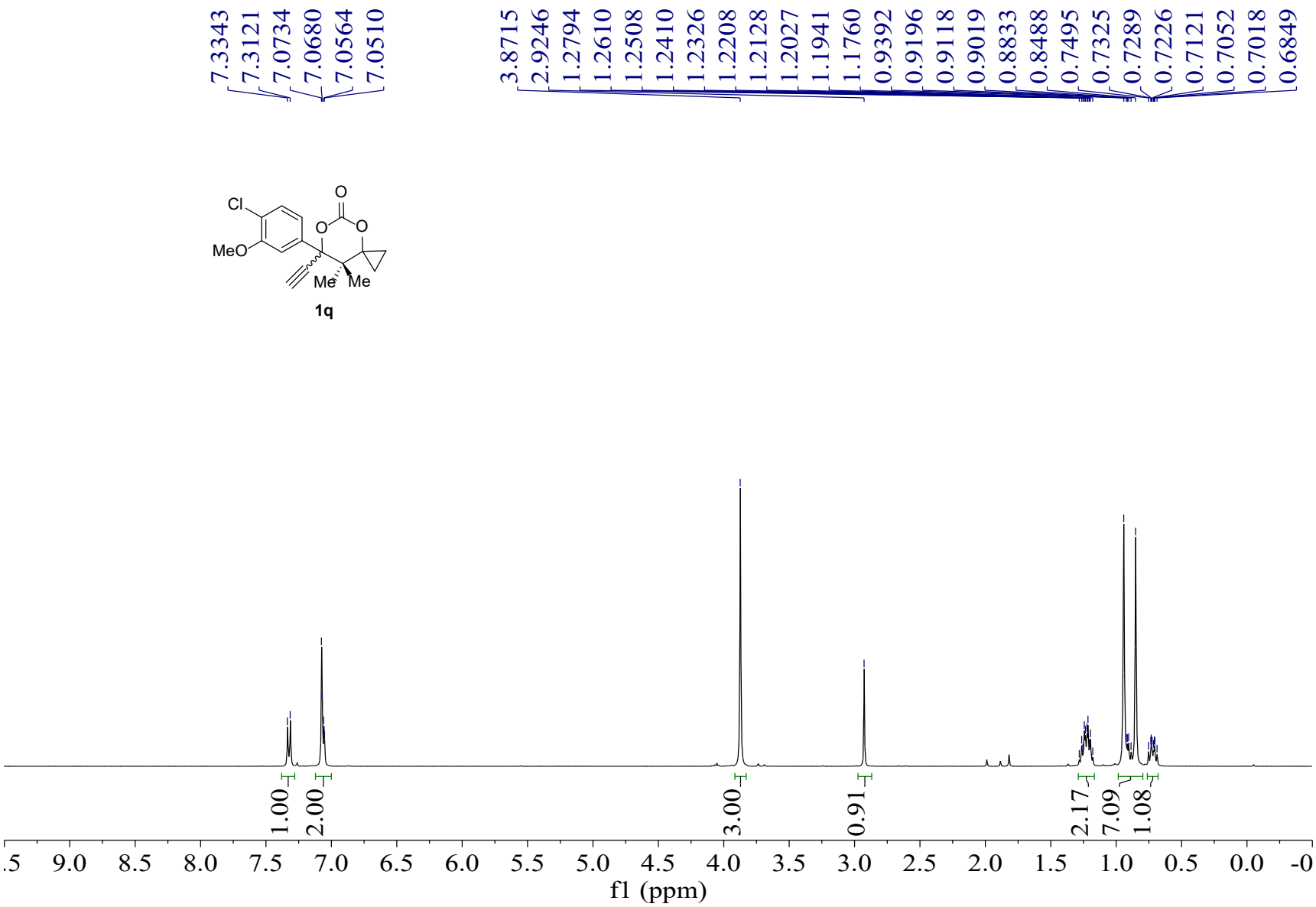
^{19}F NMR spectrum of compound **1p**



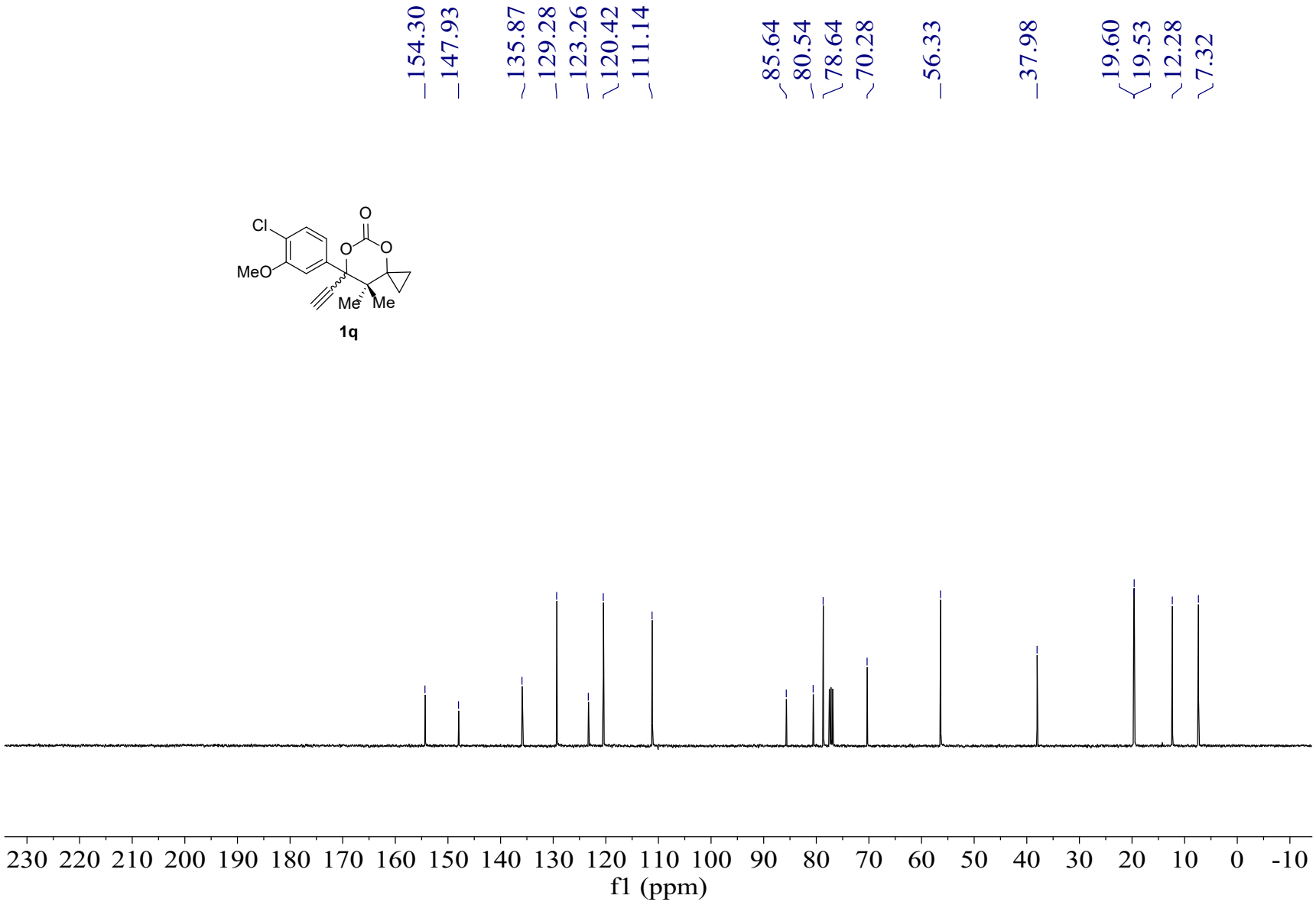
^{1}H NMR spectrum of compound **19q**



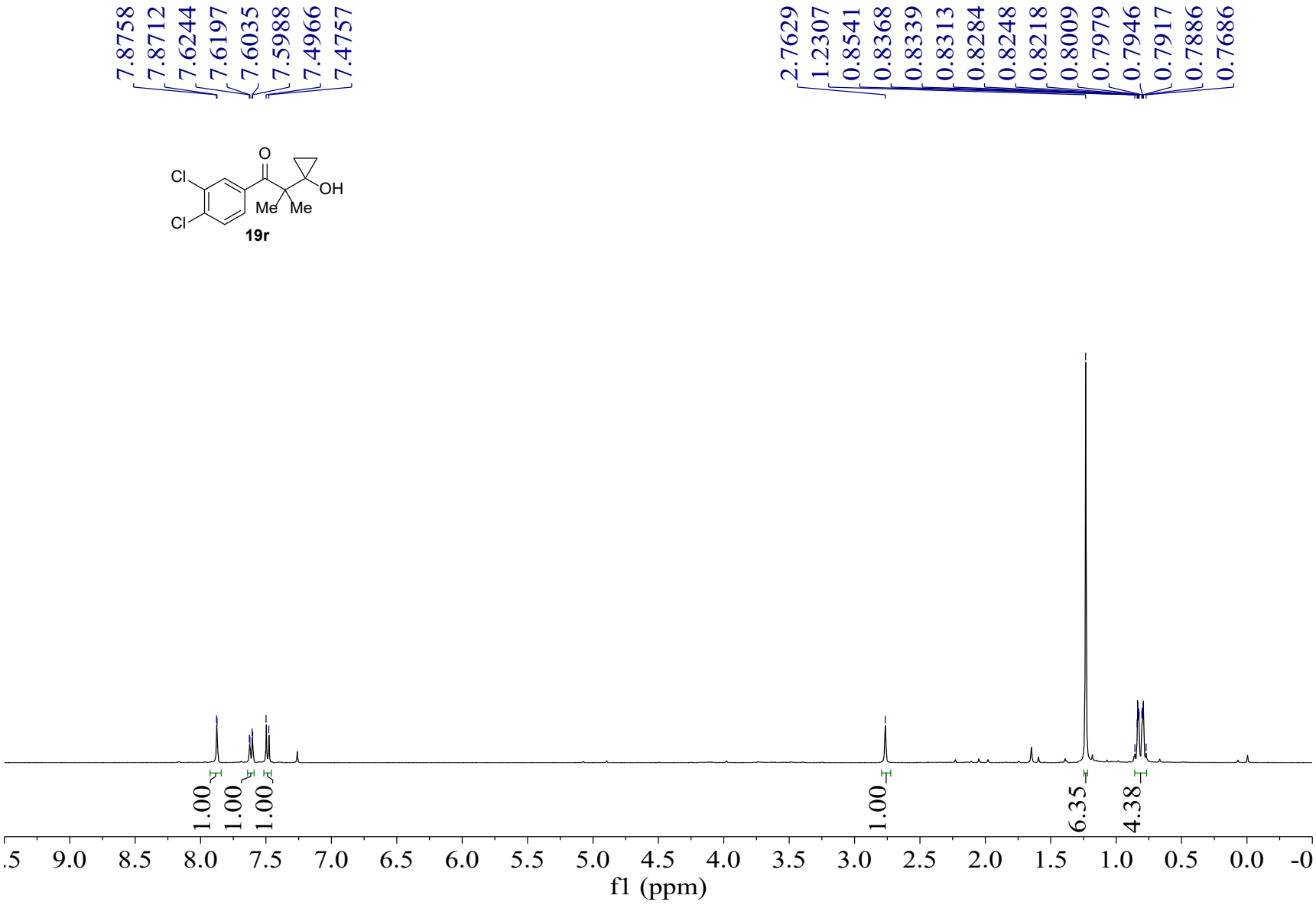
^{13}C NMR spectrum of compound **19q**



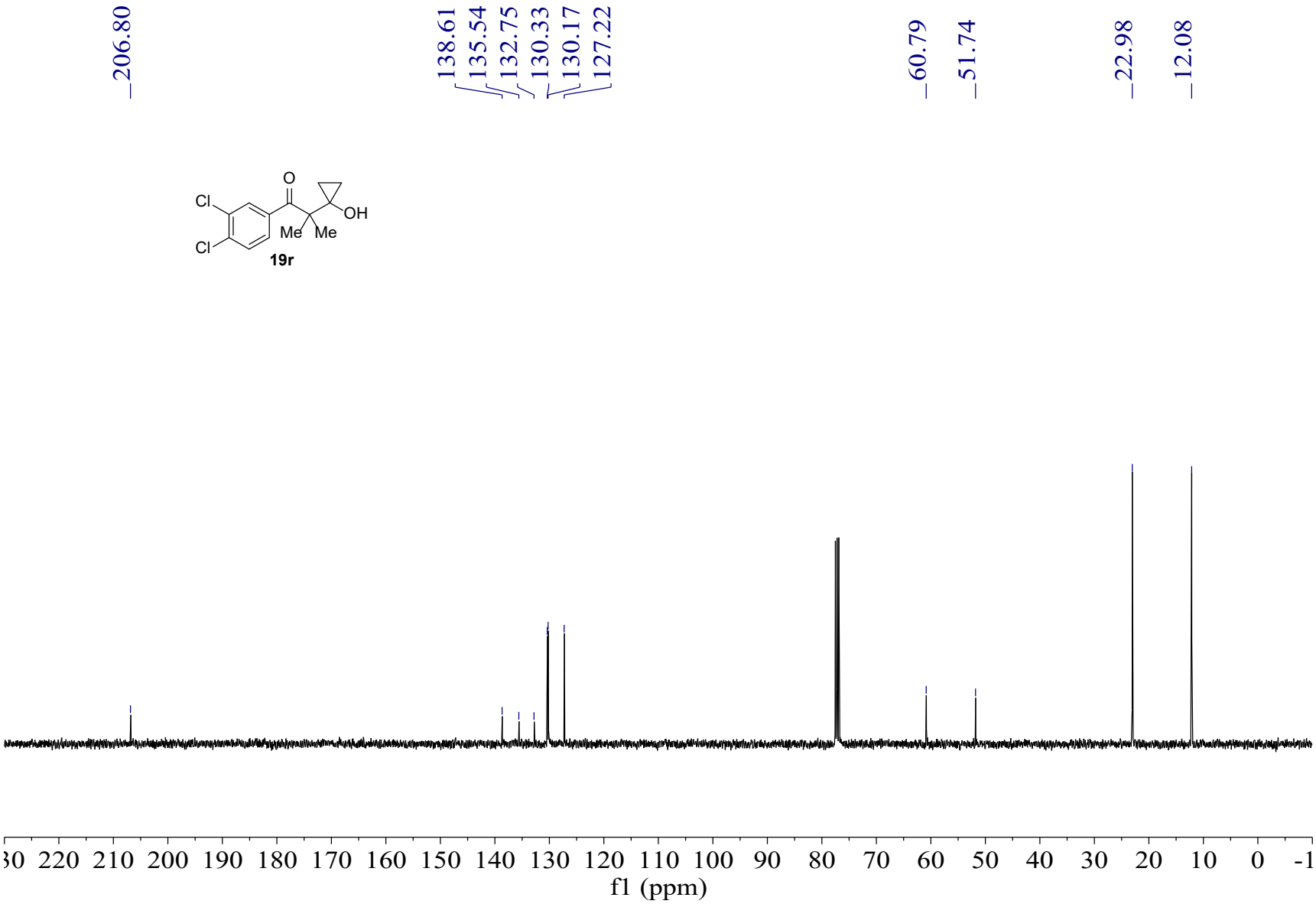
^{1}H NMR spectrum of compound **1q**



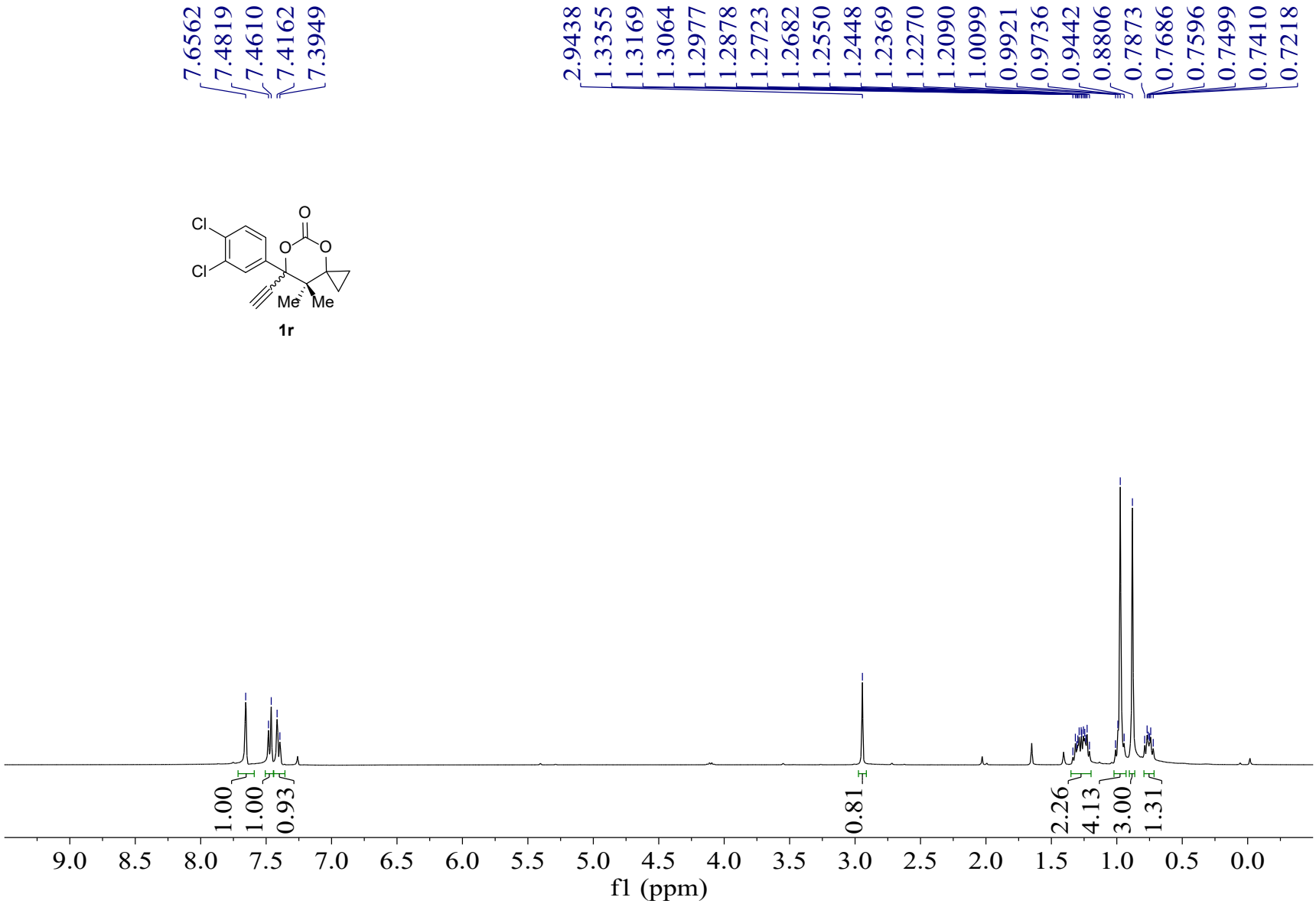
^{13}C NMR spectrum of compound **1q**



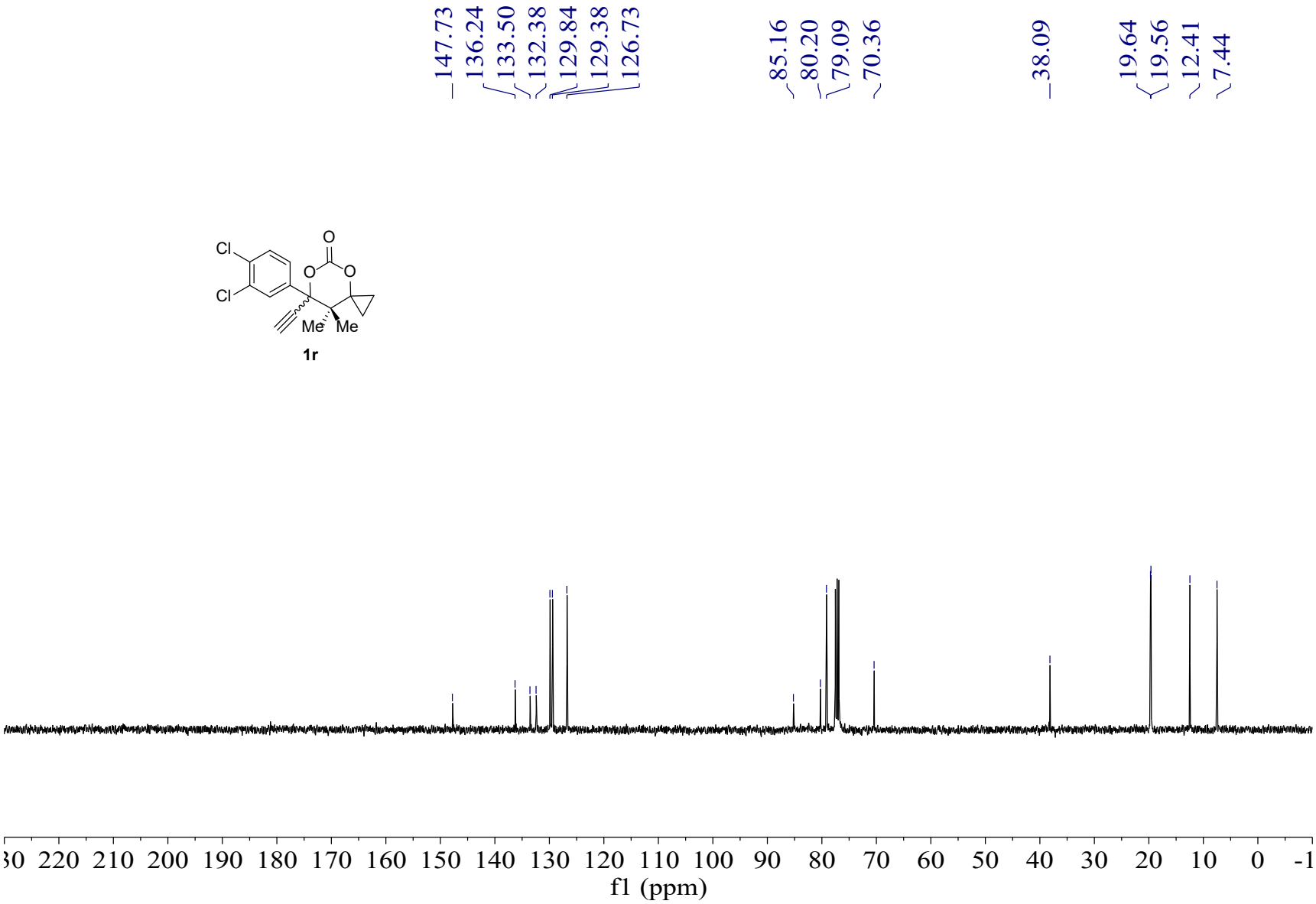
^{1}H NMR spectrum of compound **19r**



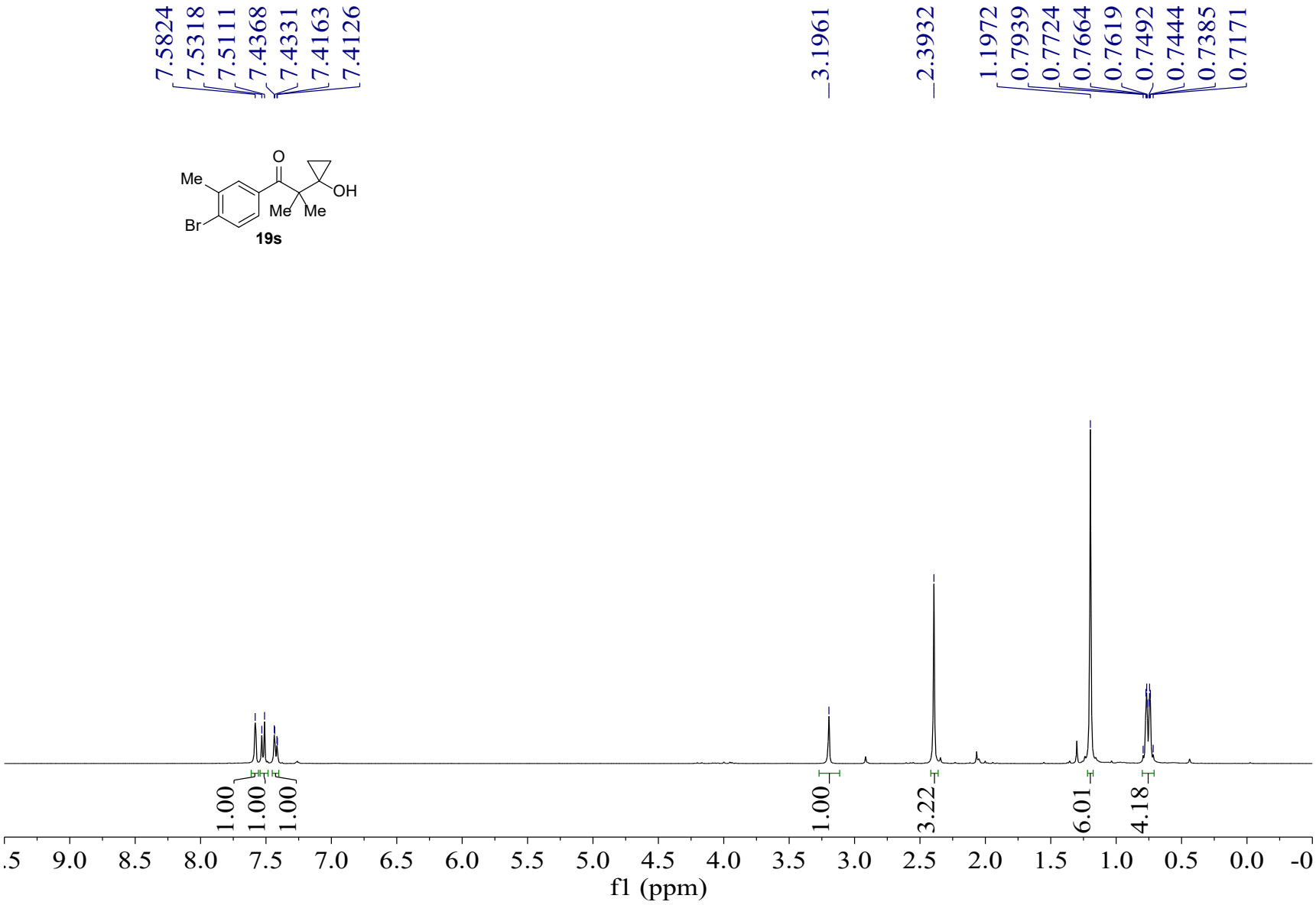
^{13}C NMR spectrum of compound **19r**



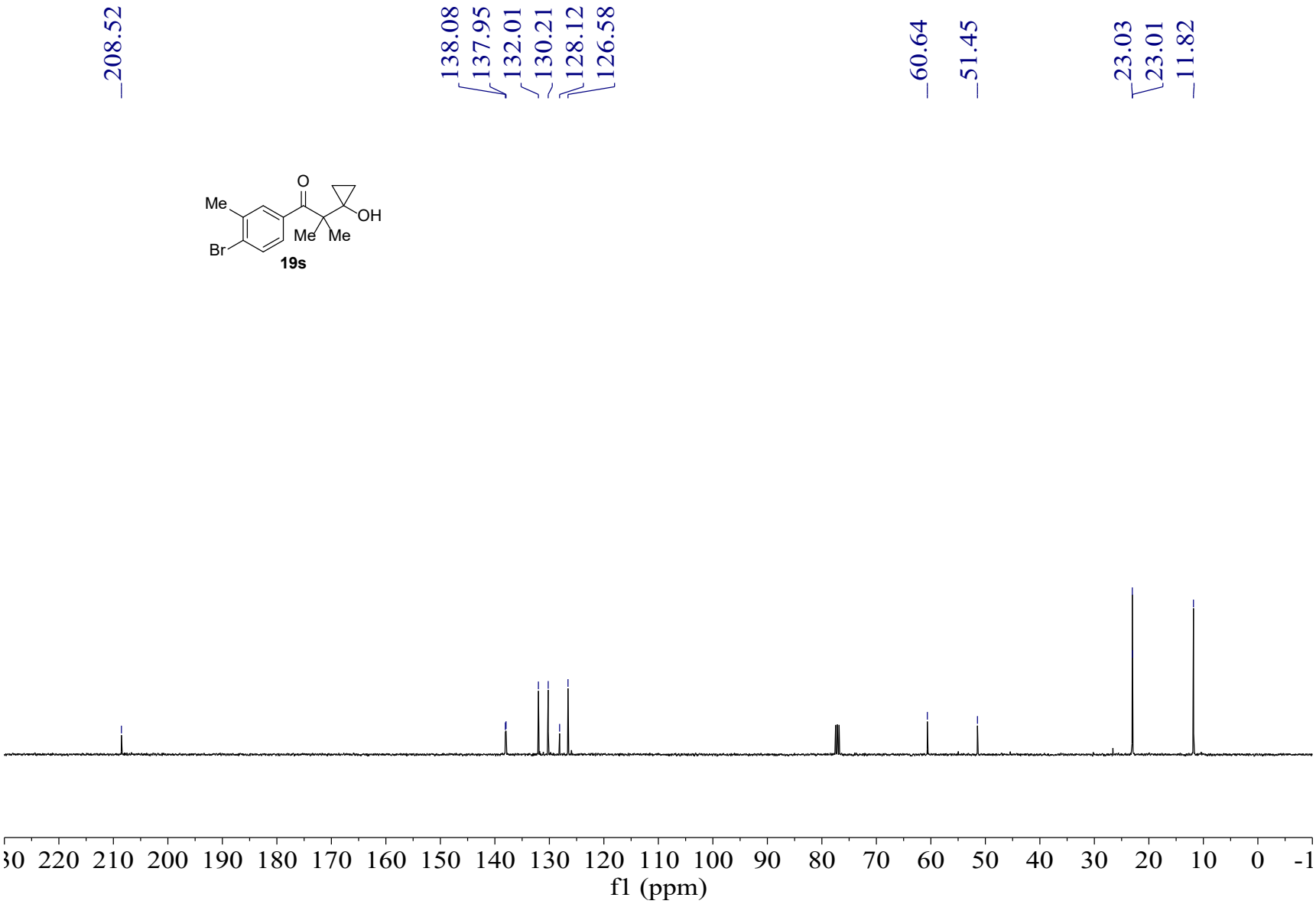
^{1}H NMR spectrum of compound **1r**



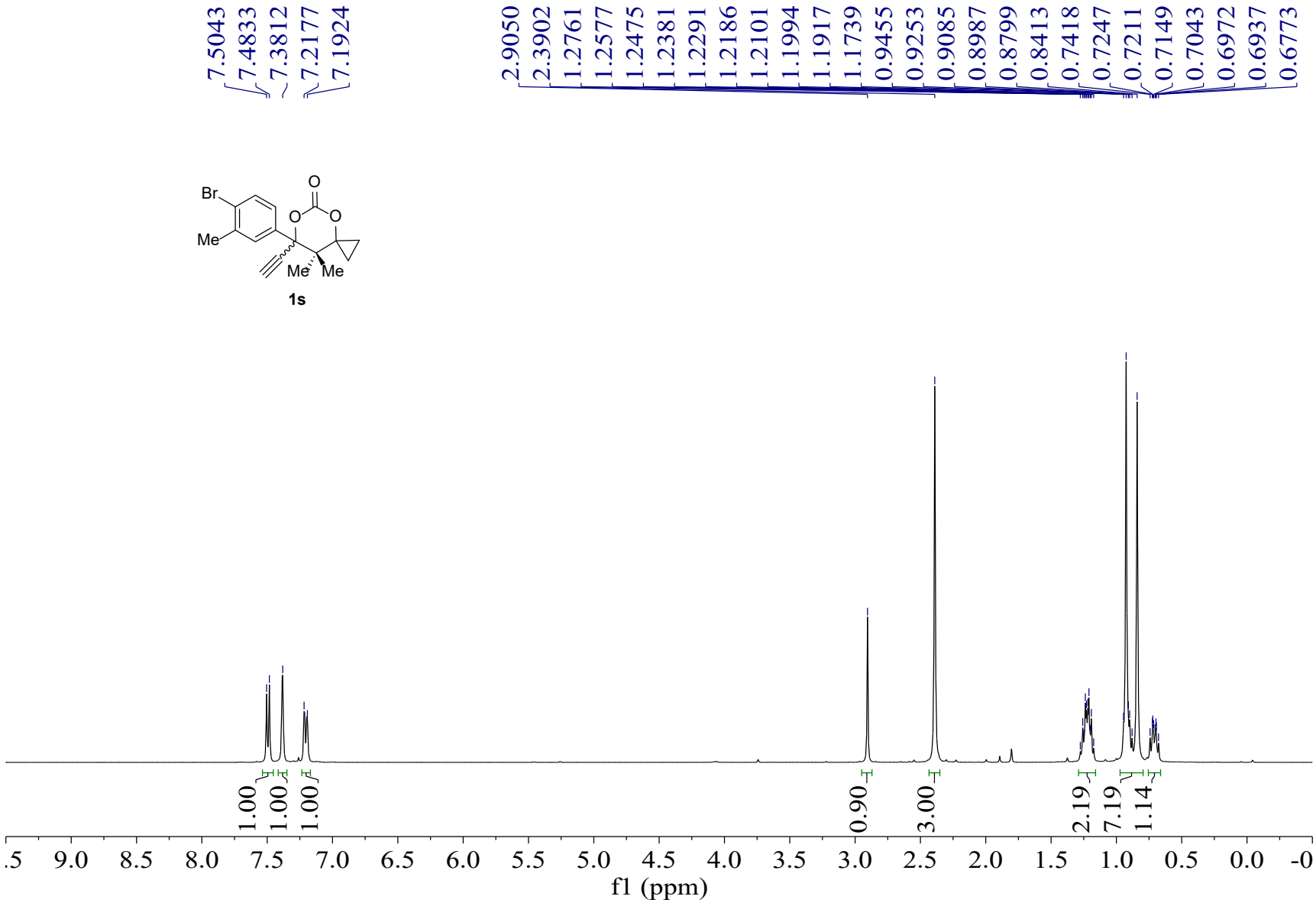
^{13}C NMR spectrum of compound **1r**



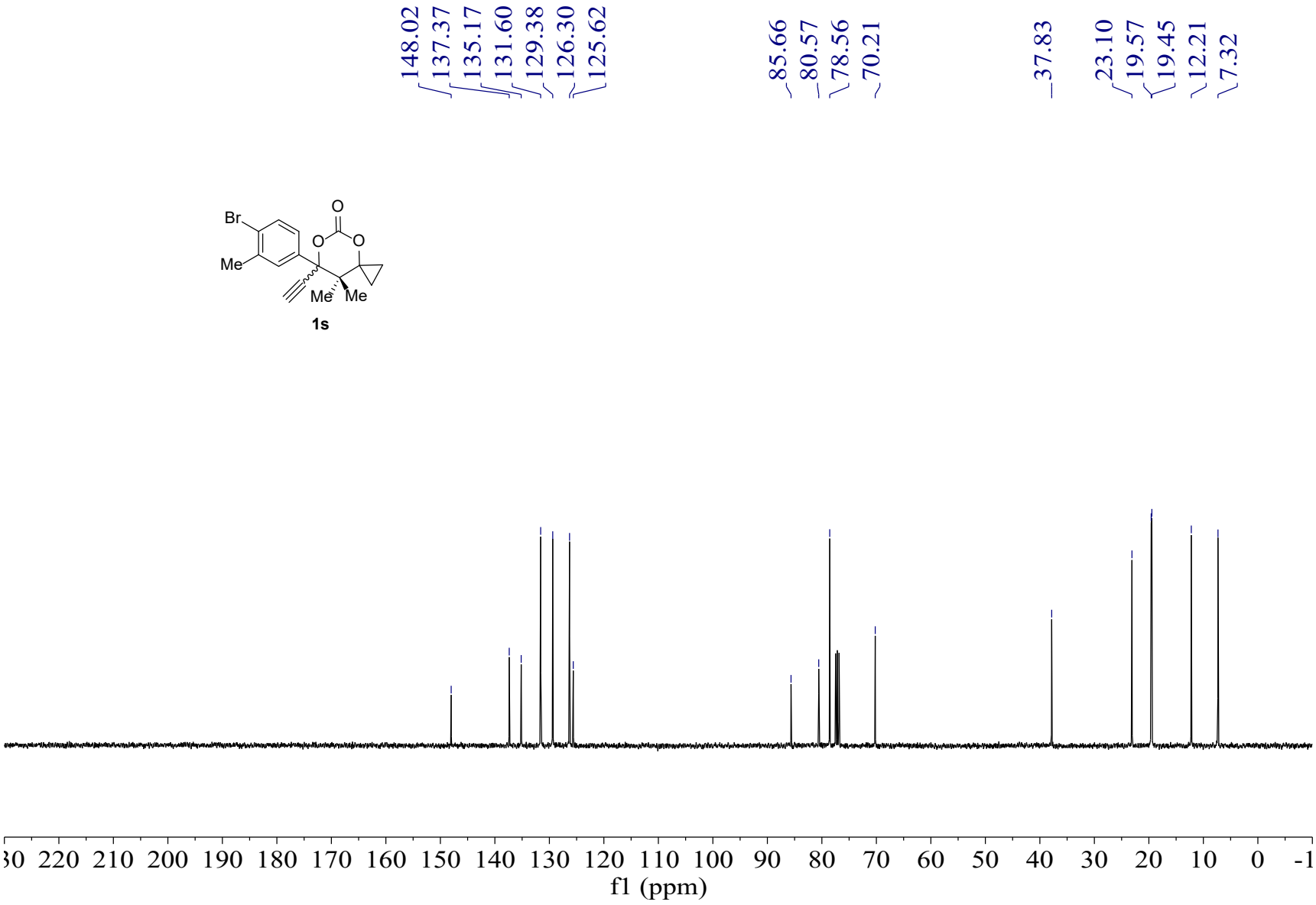
^{1}H NMR spectrum of compound **19s**



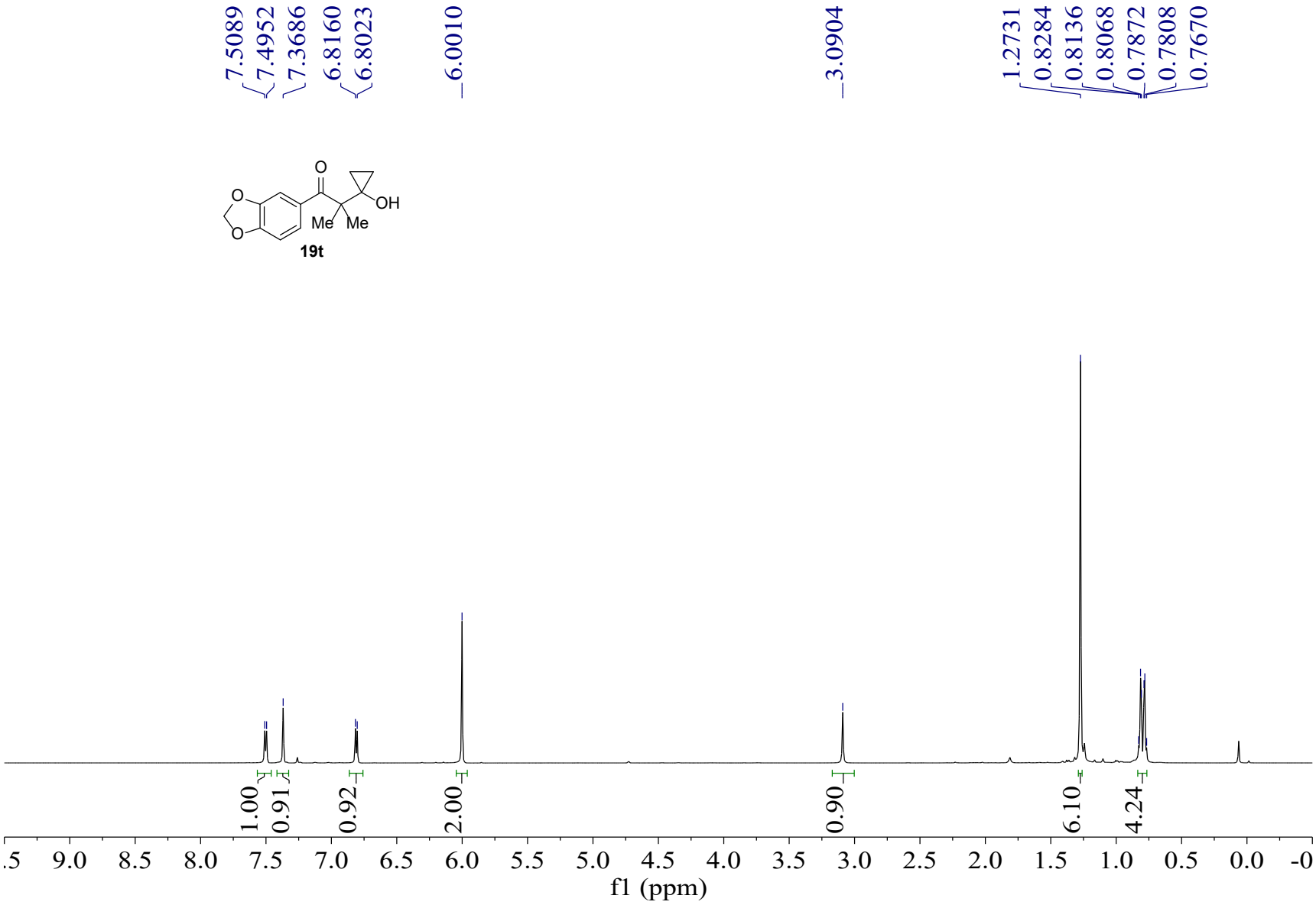
^{13}C NMR spectrum of compound **19s**



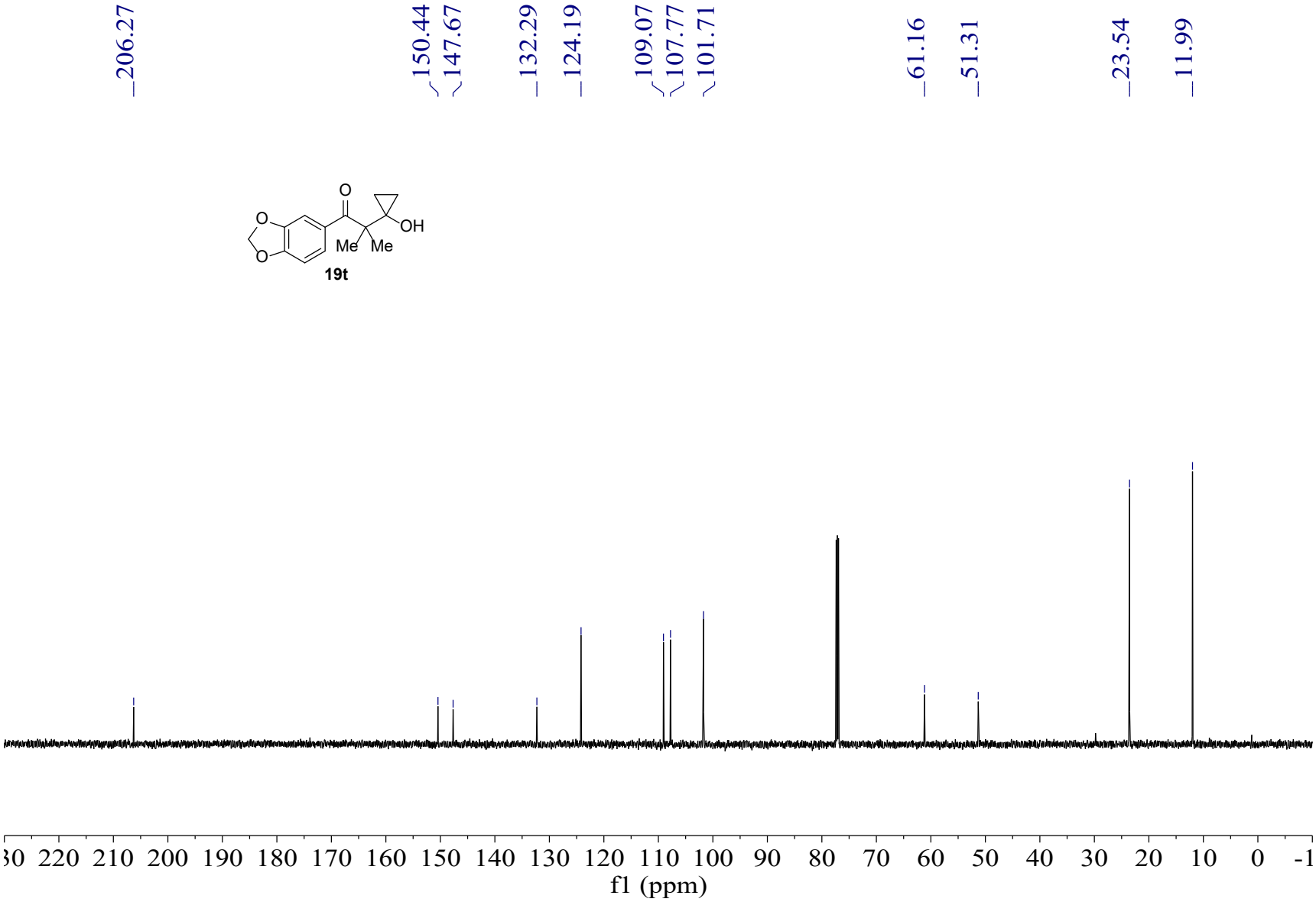
^{1}H NMR spectrum of compound **1s**



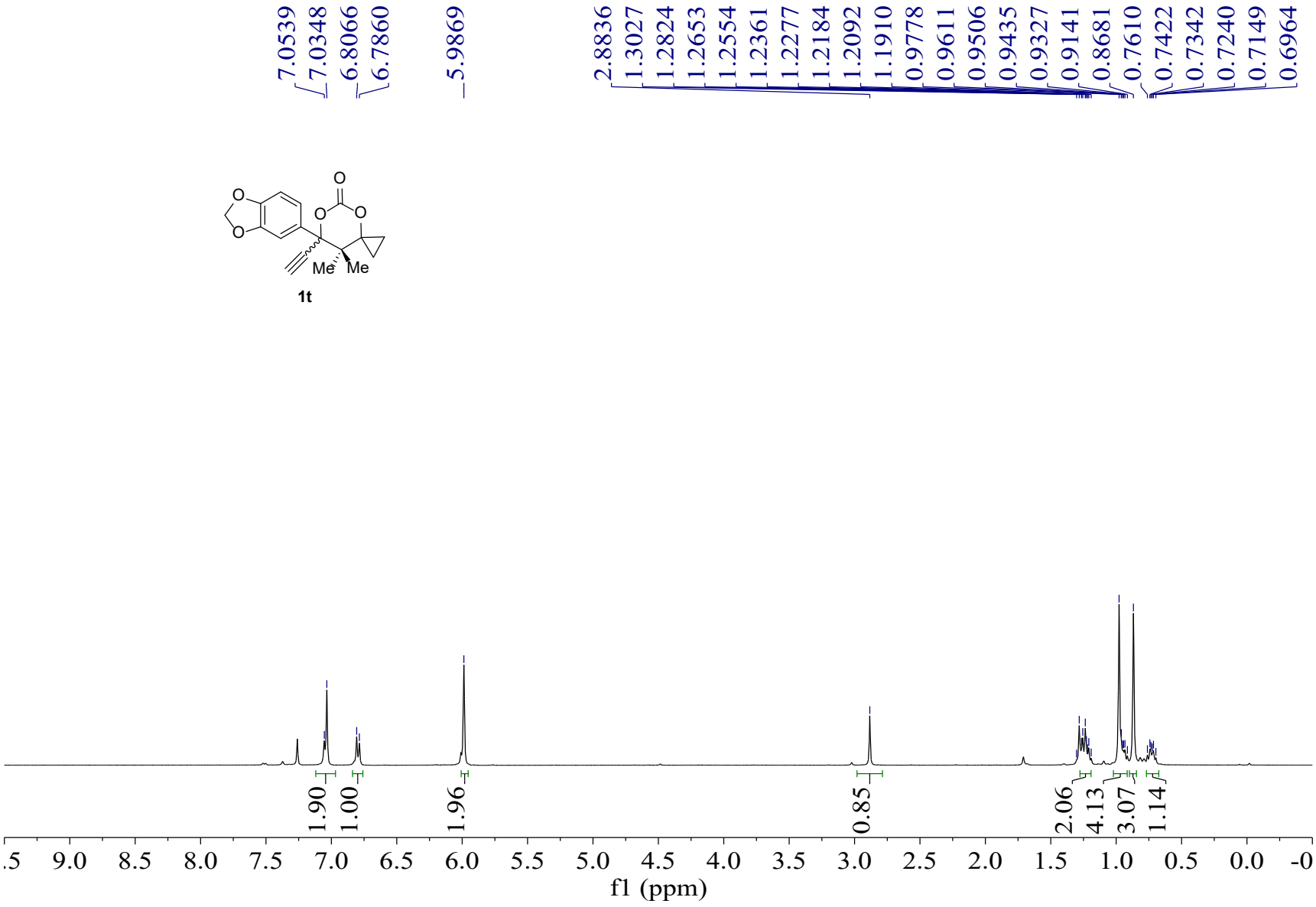
^{13}C NMR spectrum of compound **1s**



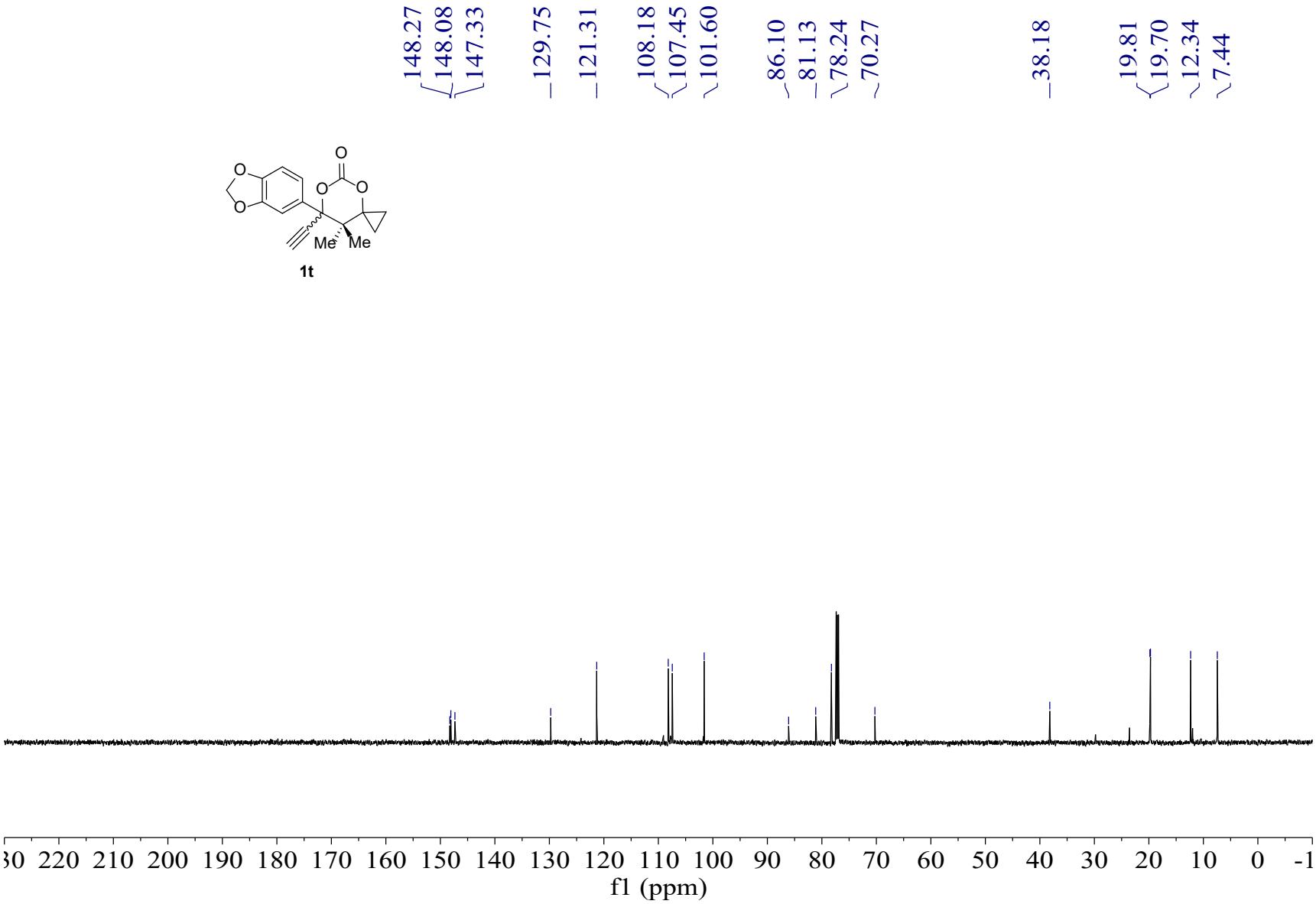
^{1}H NMR spectrum of compound **19t**



^{13}C NMR spectrum of compound **19t**



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



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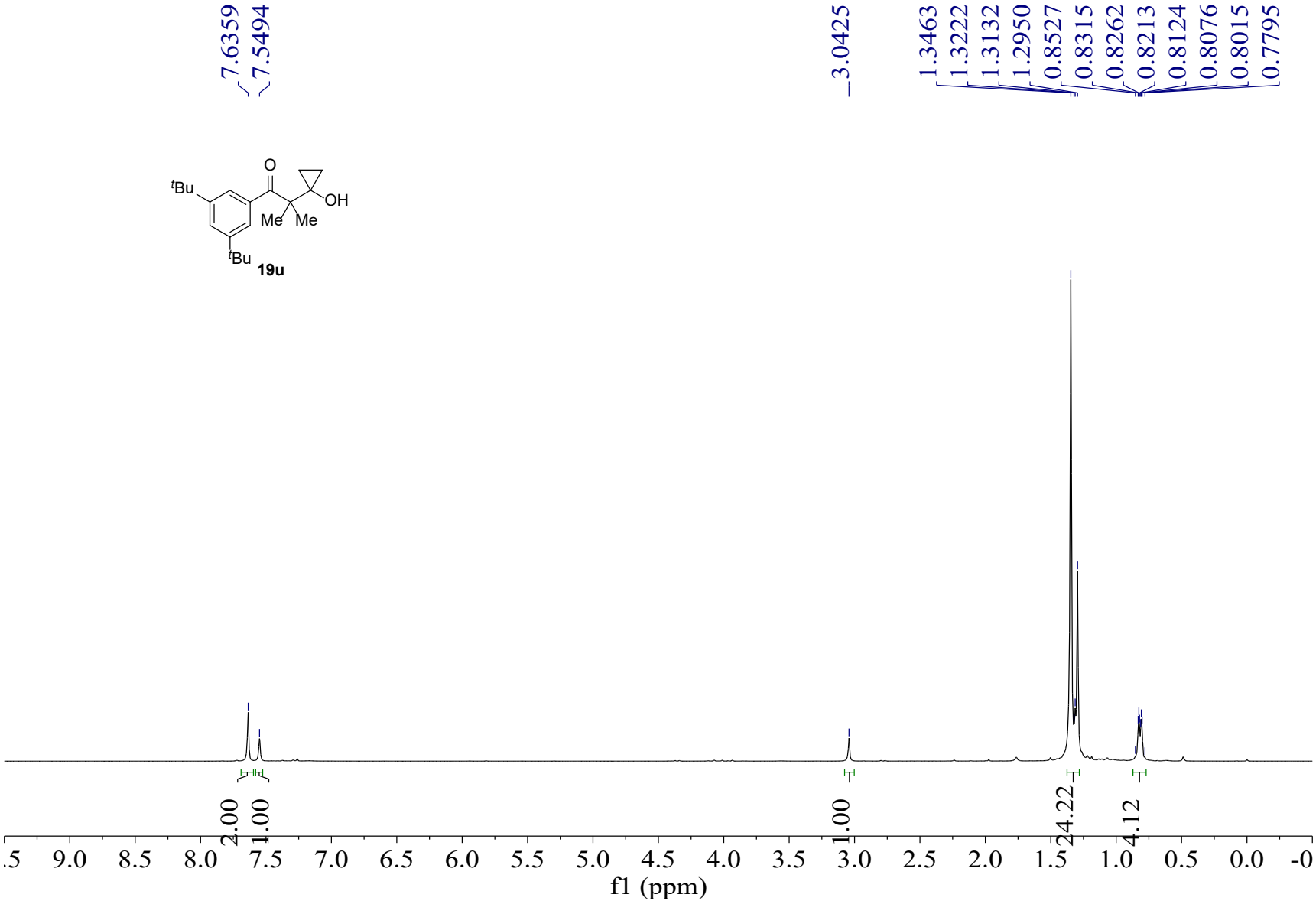
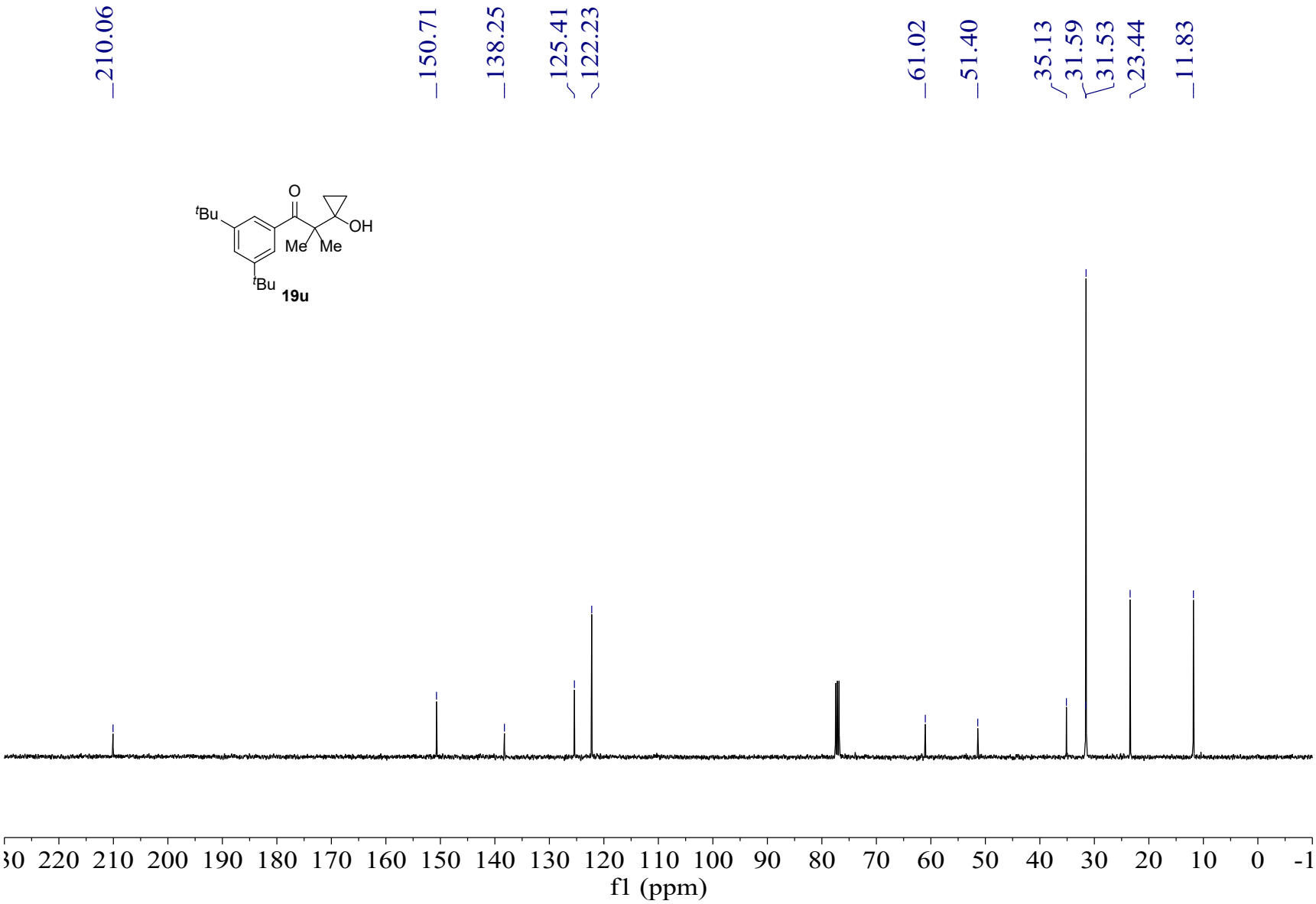
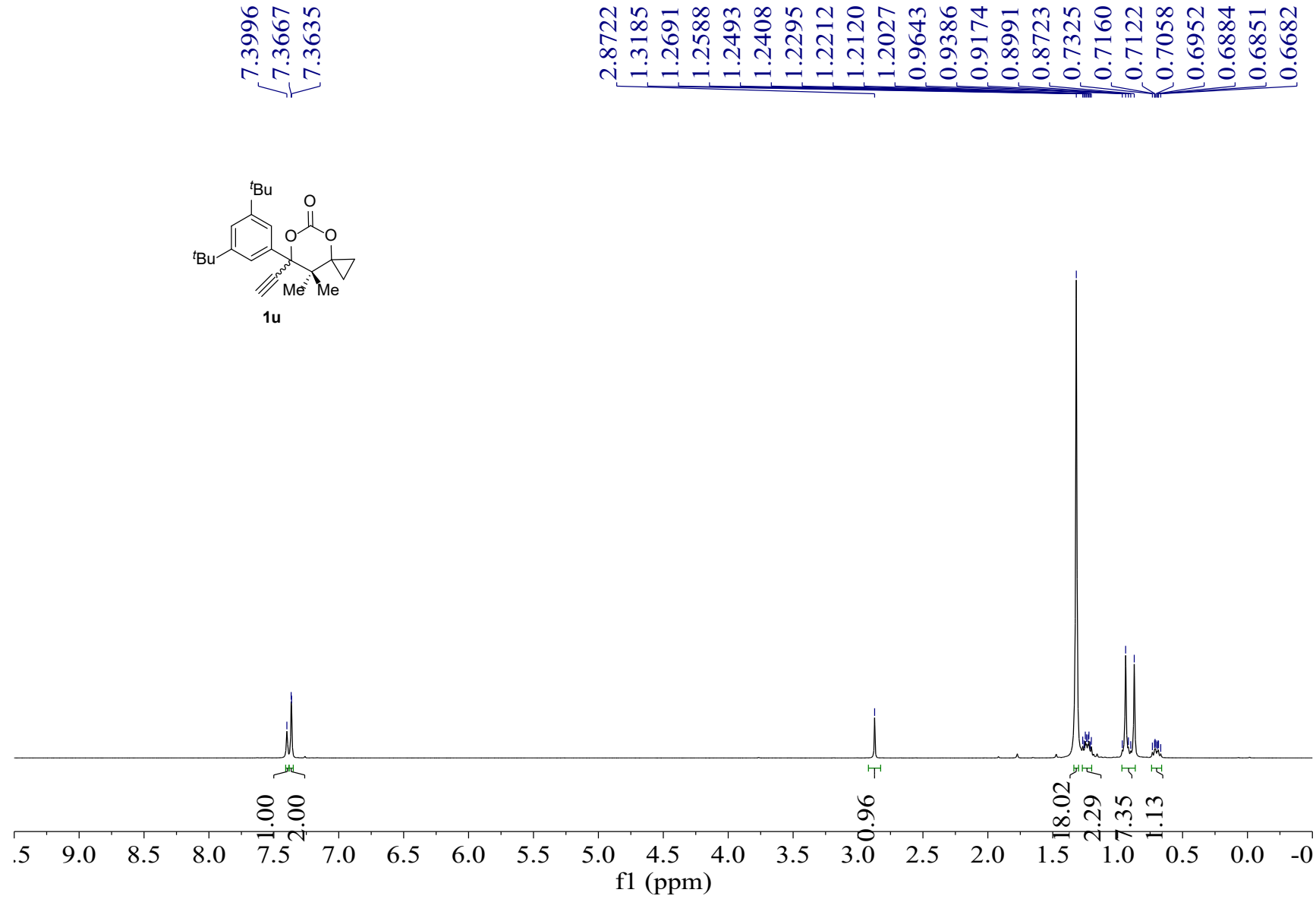


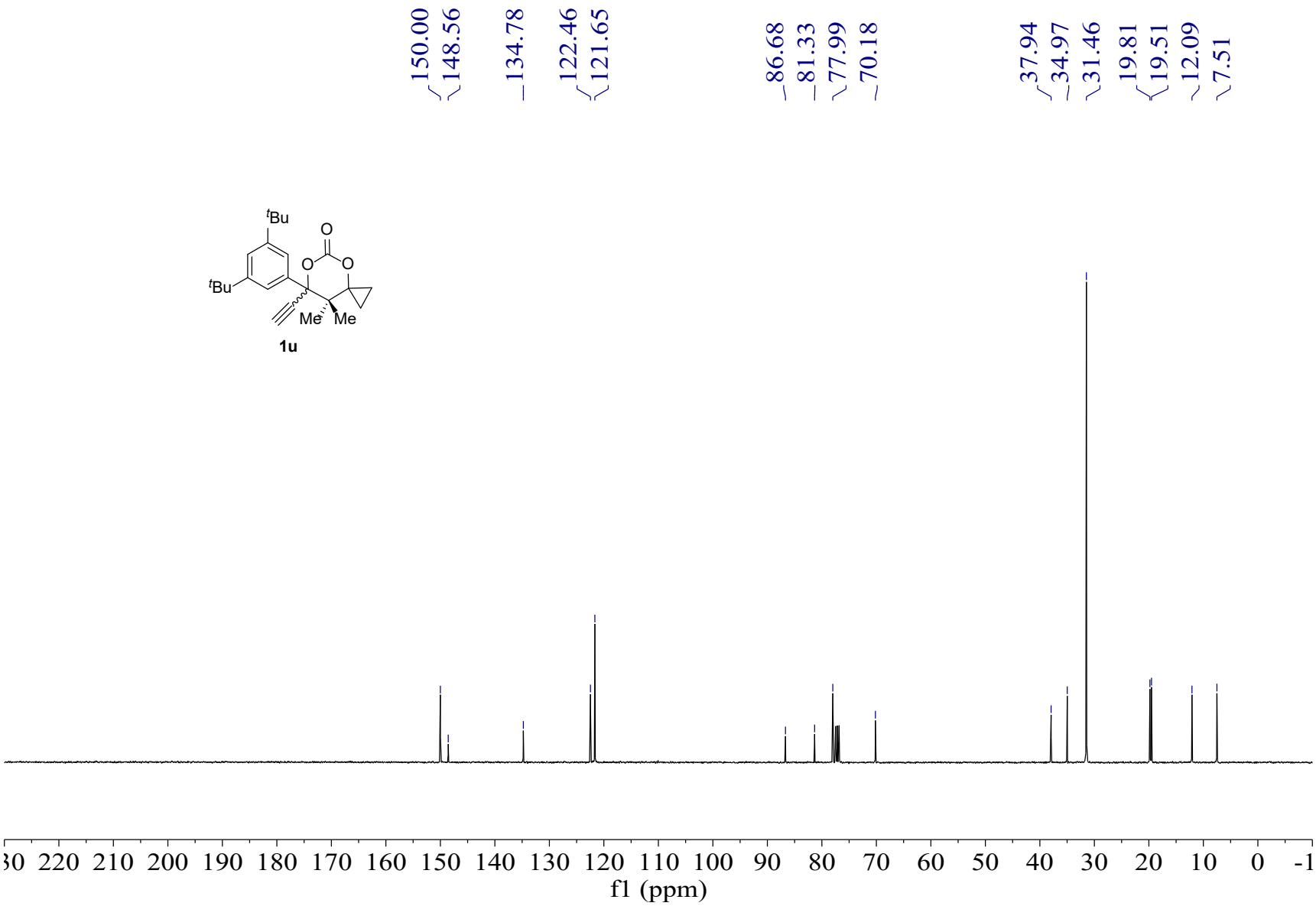
^{1}H NMR spectrum of compound **19u**



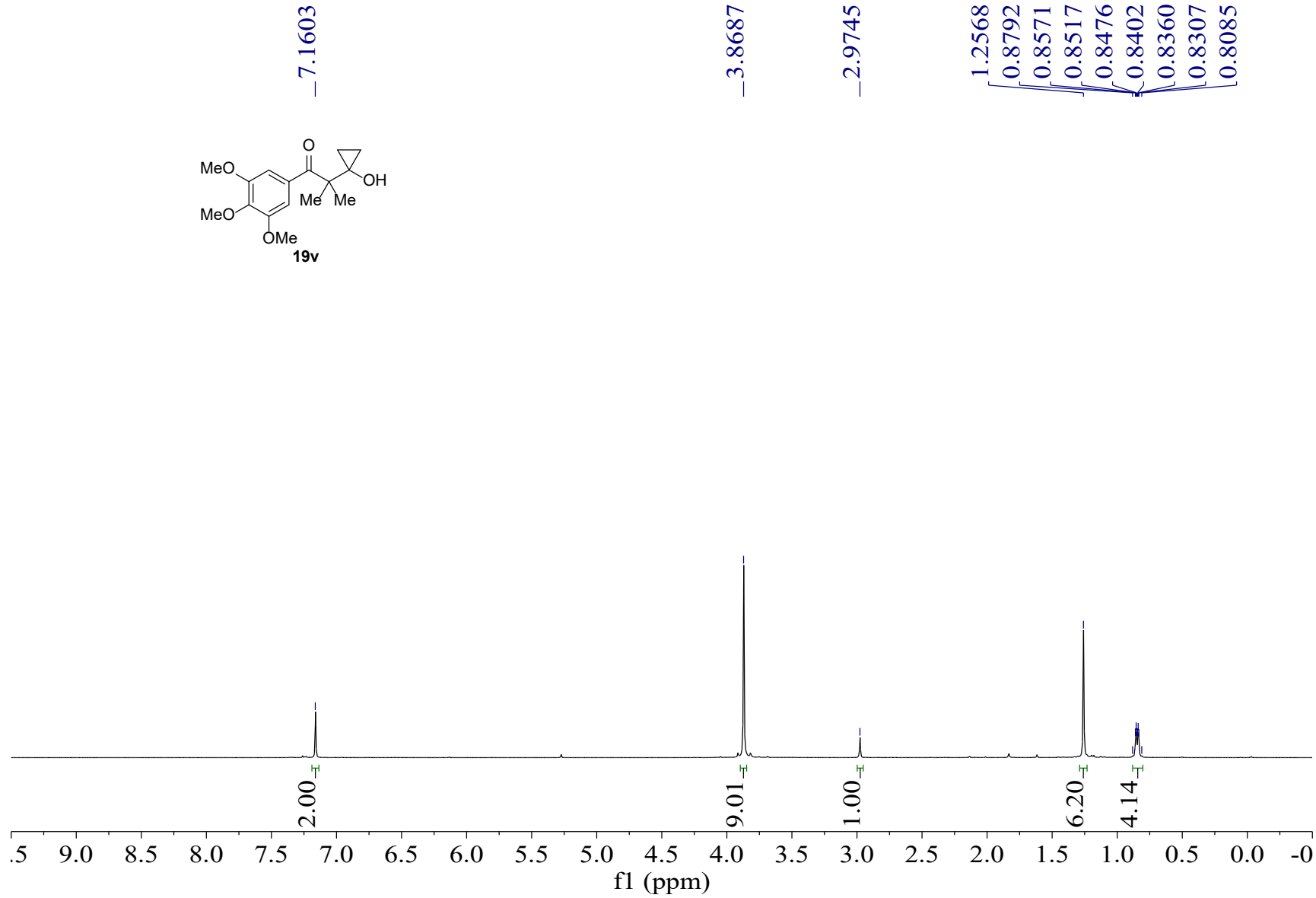
^{13}C NMR spectrum of compound **19u**



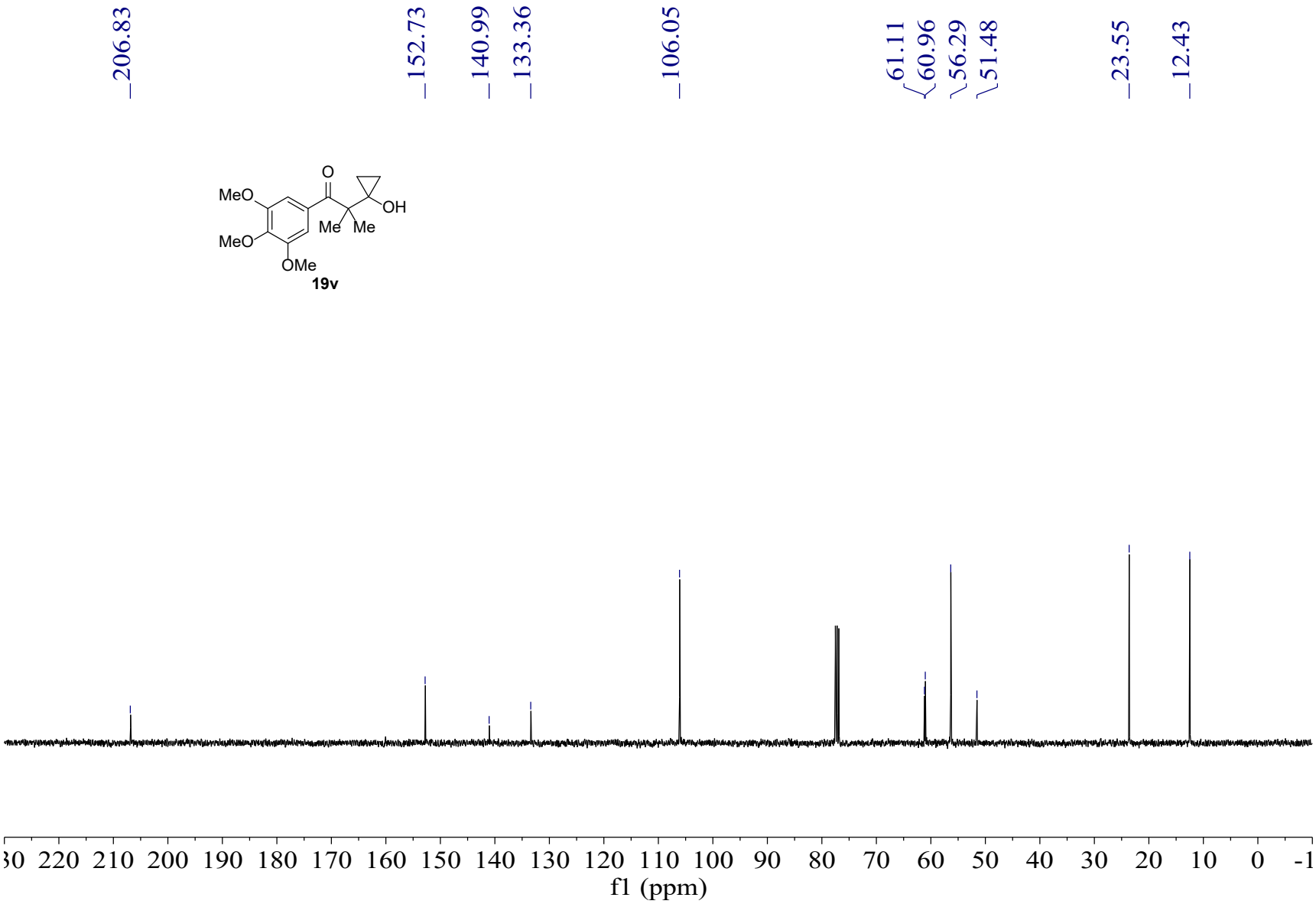
^{1}H NMR spectrum of compound **1u**



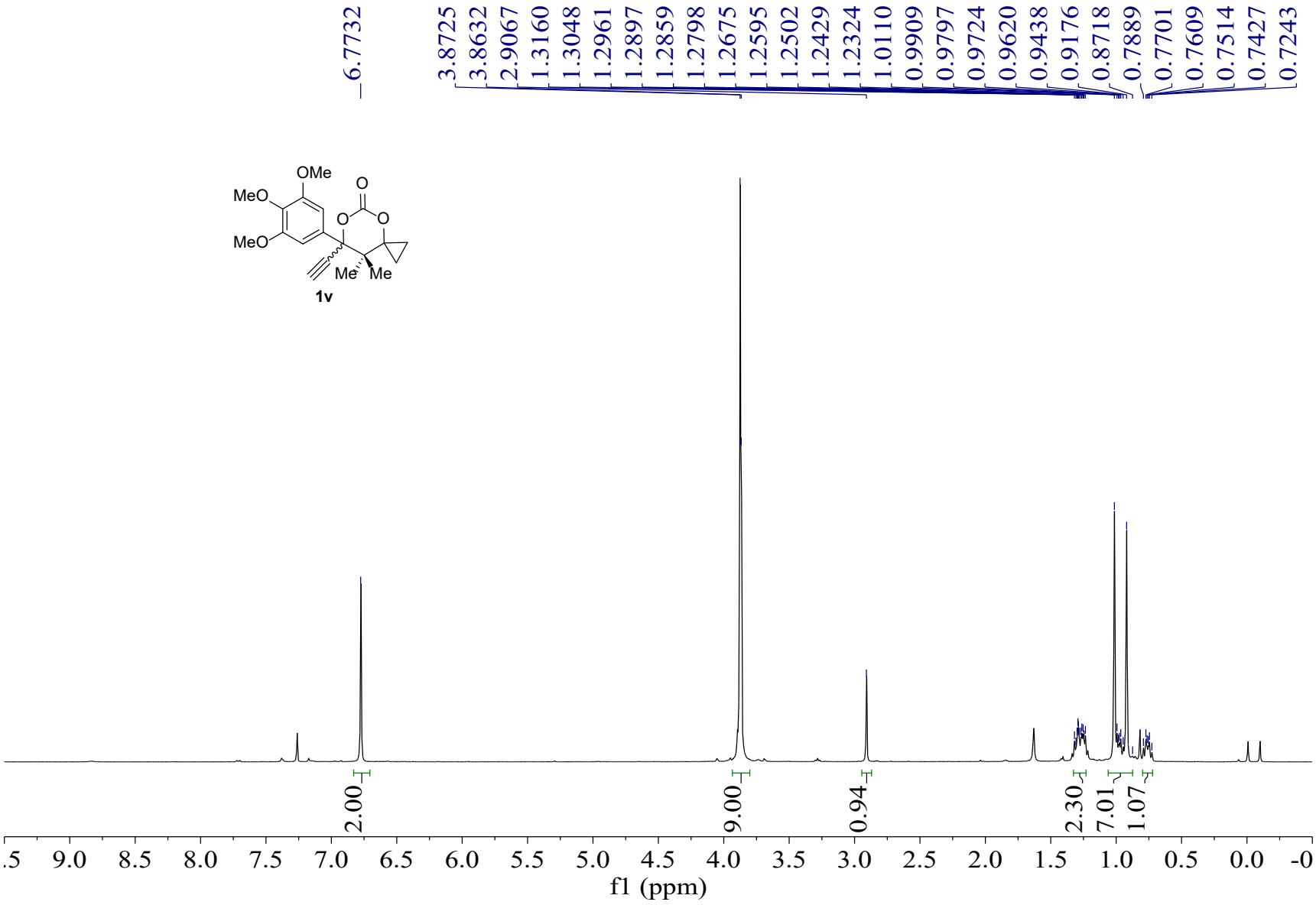
^{13}C NMR spectrum of compound **1u**



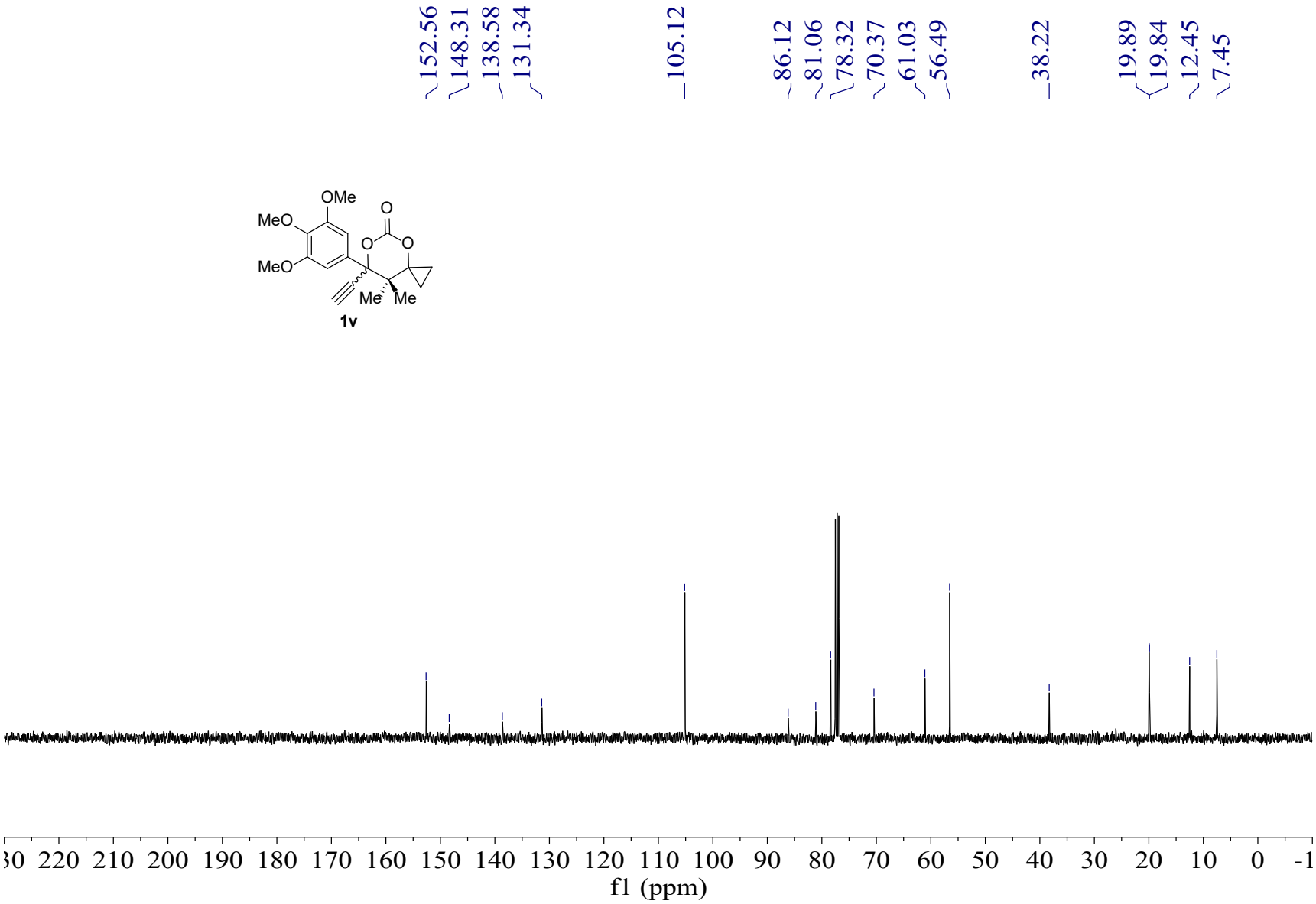
^{1}H NMR spectrum of compound **19v**



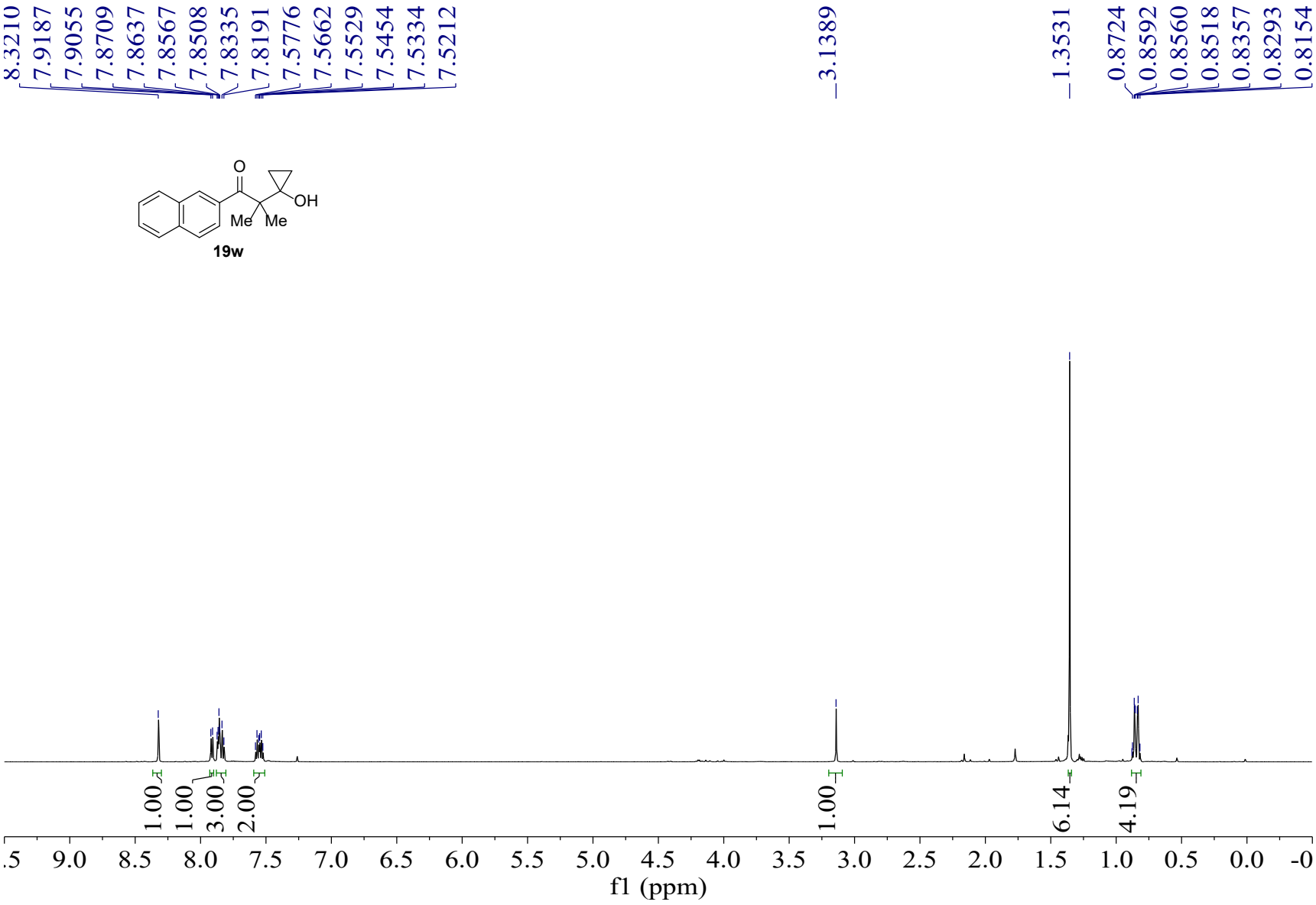
^{13}C NMR spectrum of compound **19v**



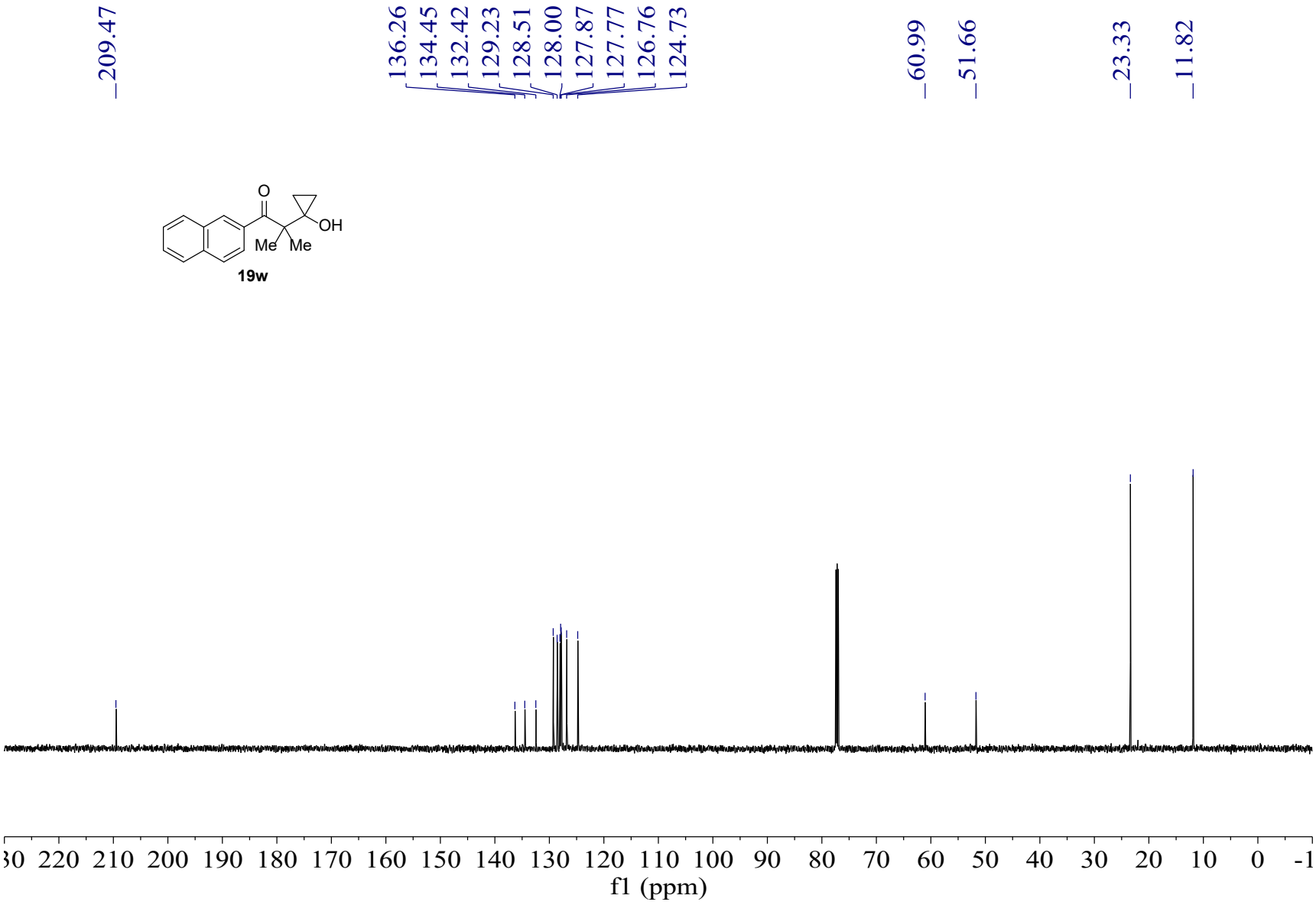
^{1}H NMR spectrum of compound **1v**



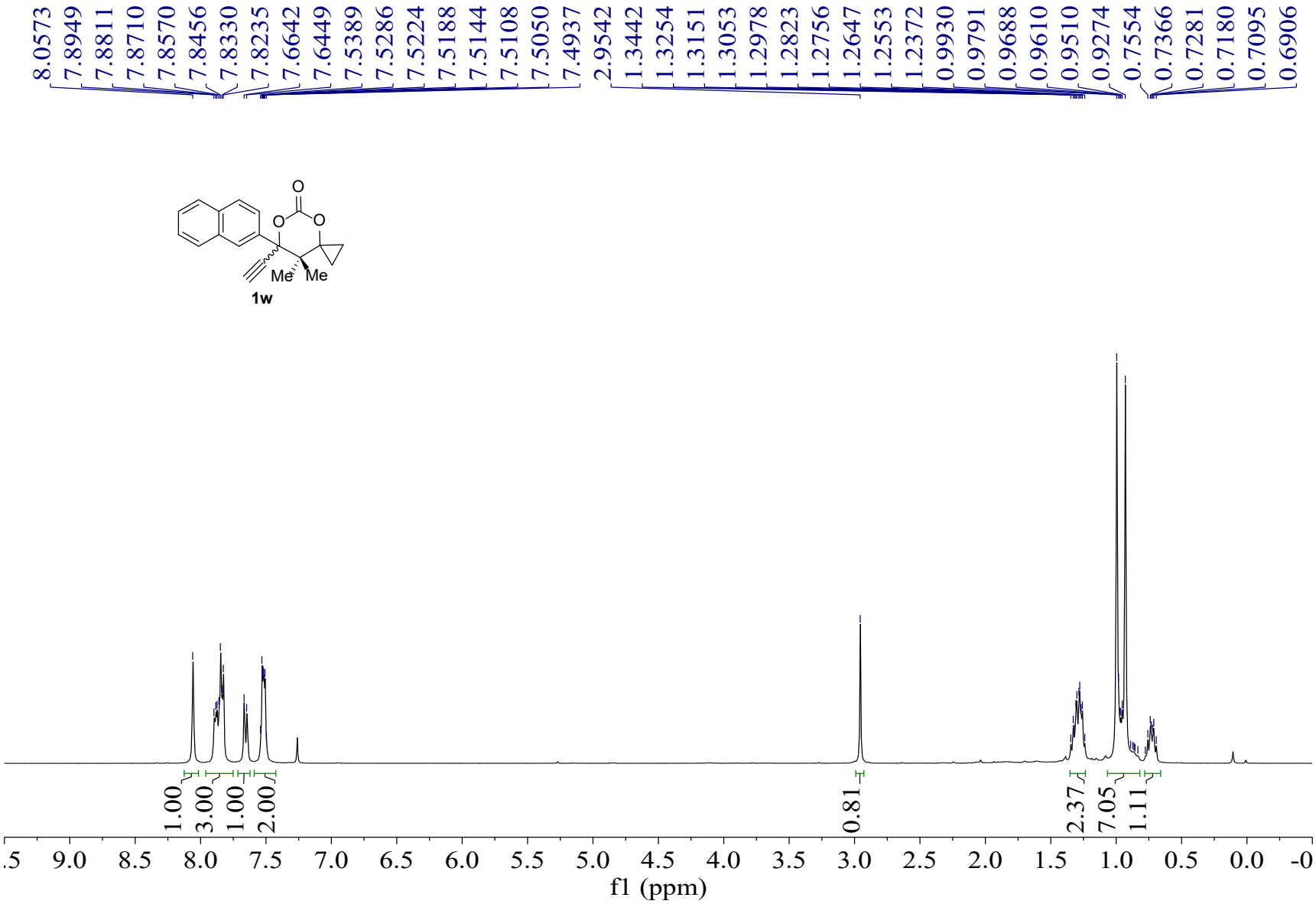
^{13}C NMR spectrum of compound **1v**



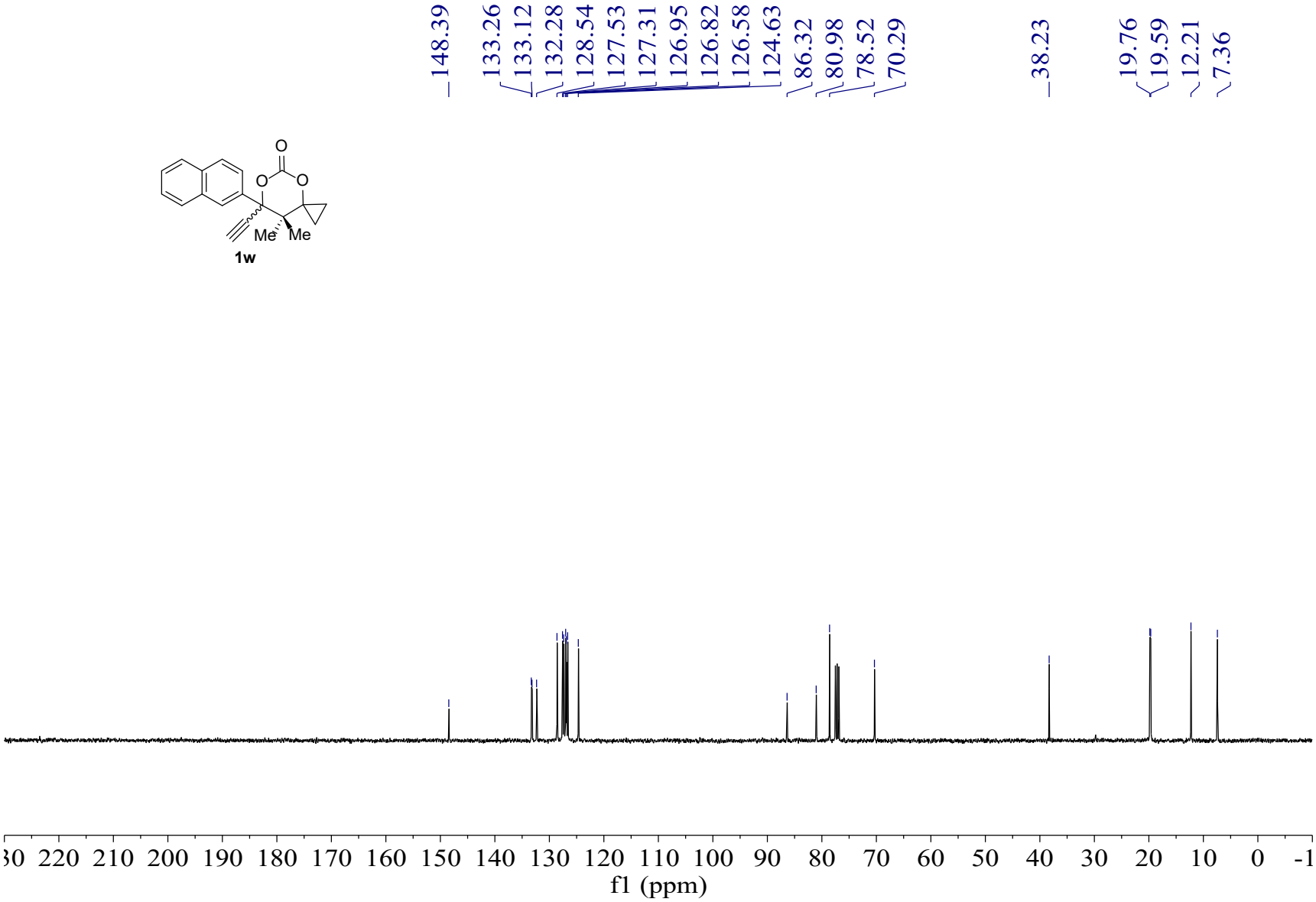
^{1}H NMR spectrum of compound **19w**



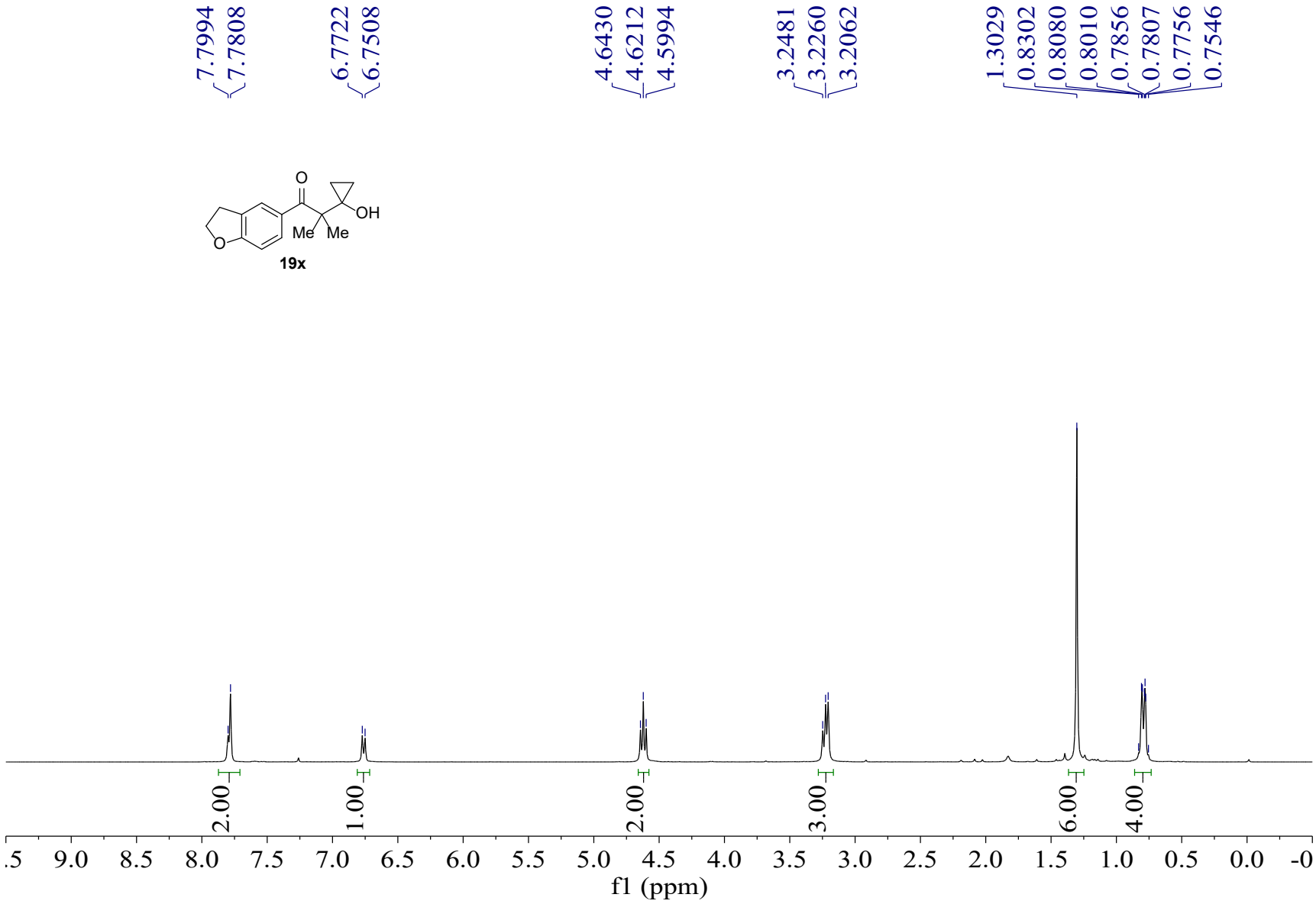
^{13}C NMR spectrum of compound **19w**



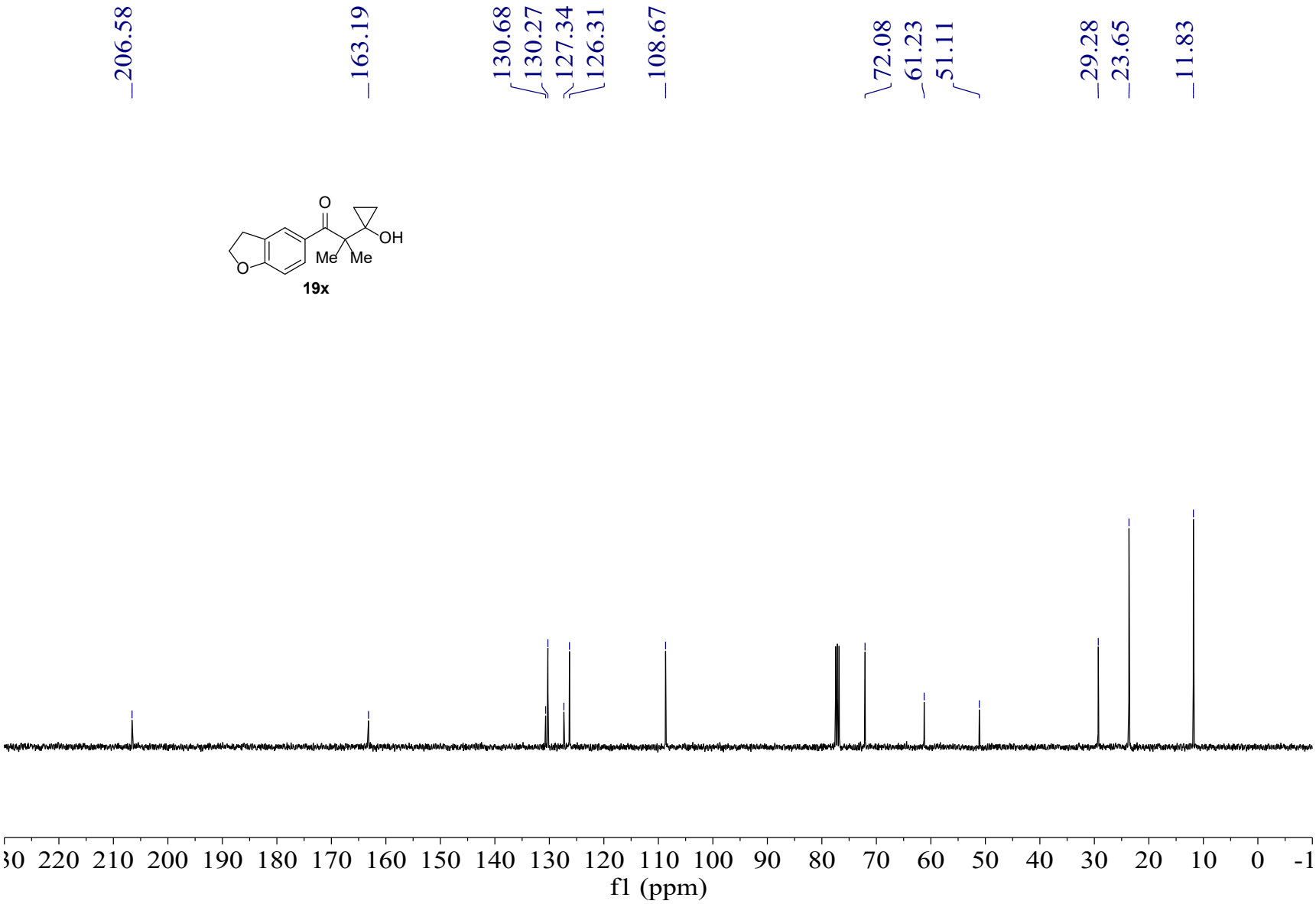
^{1}H NMR spectrum of compound **1w**



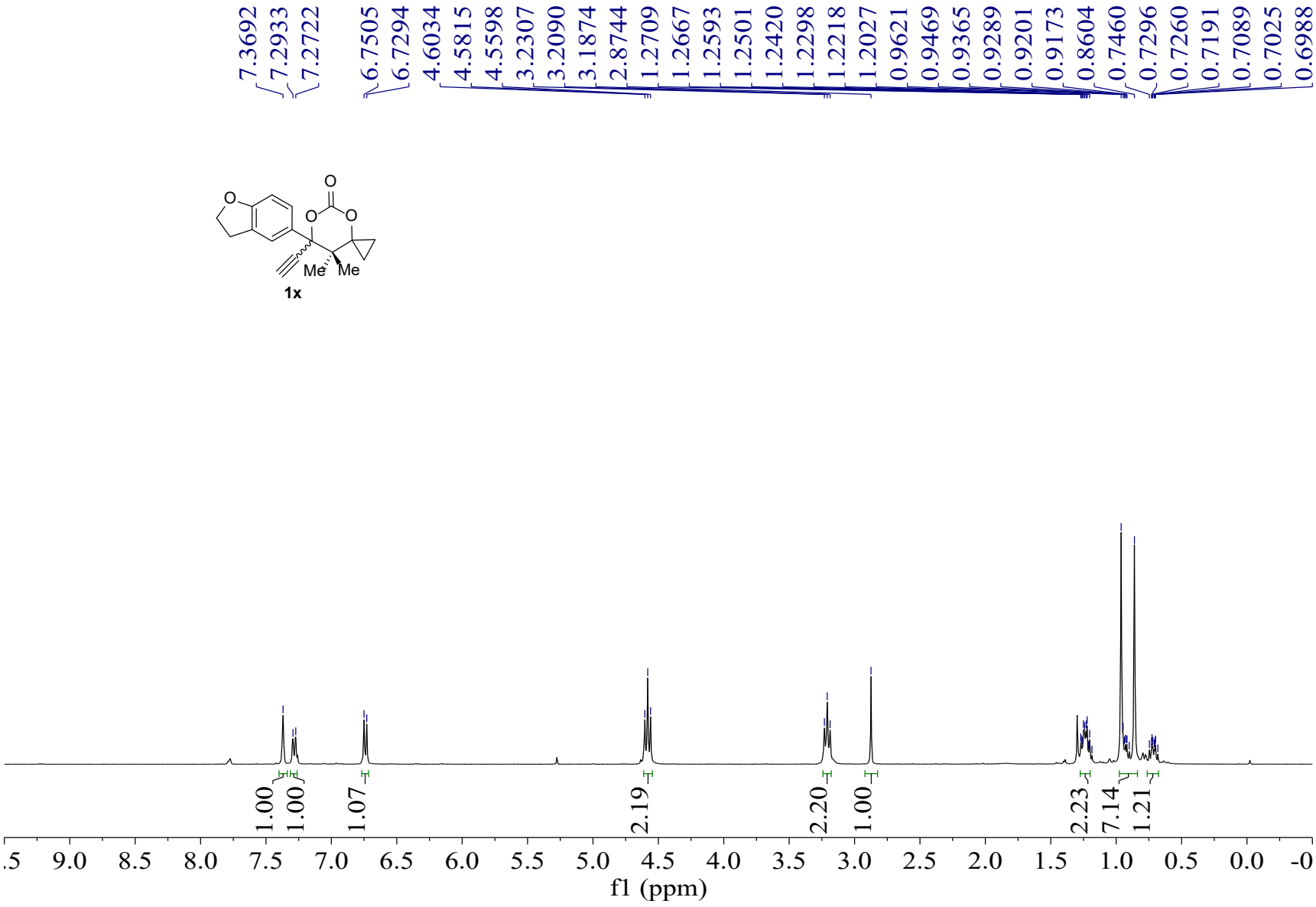
^{13}C NMR spectrum of compound **1w**



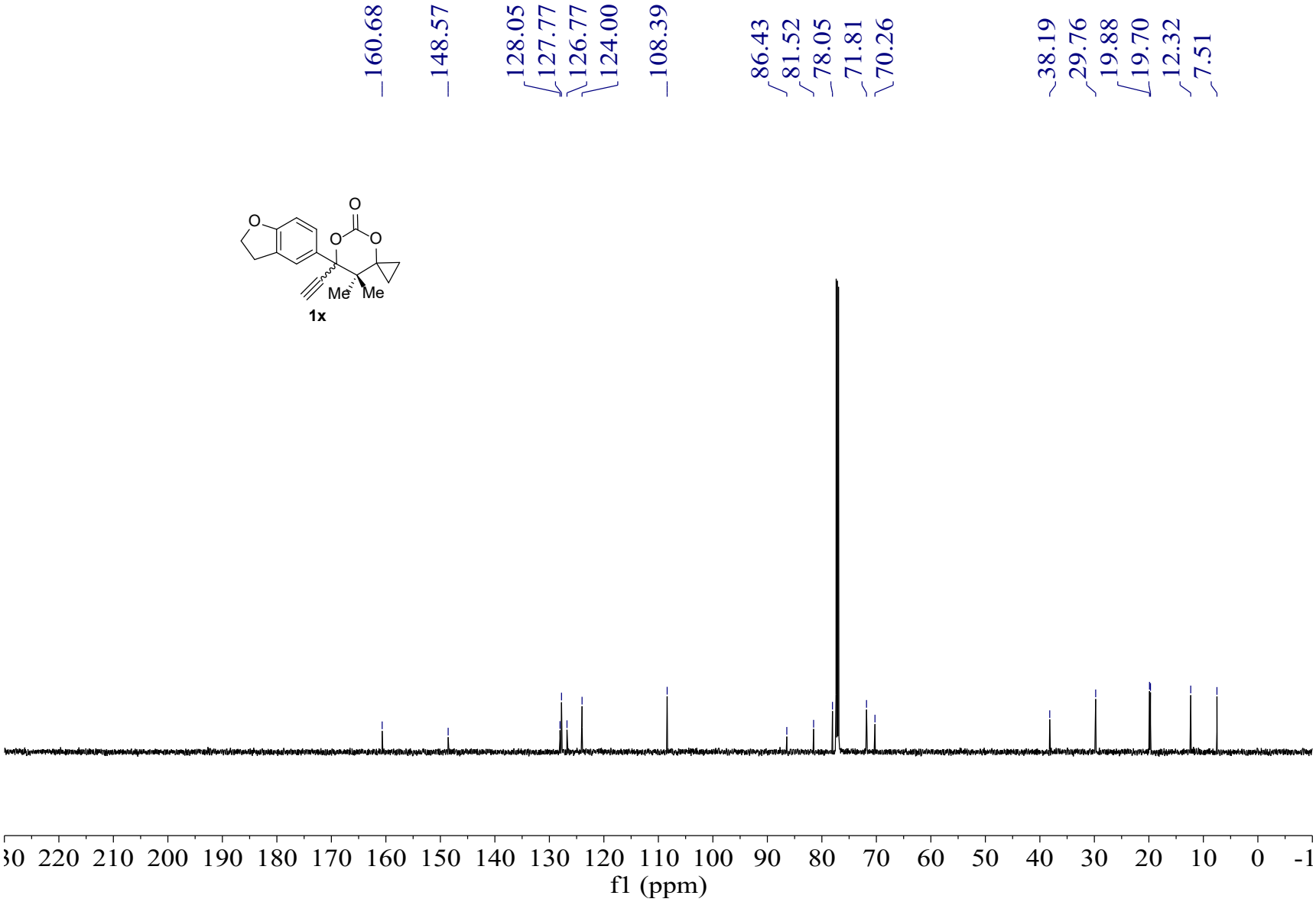
^{1}H NMR spectrum of compound **19x**



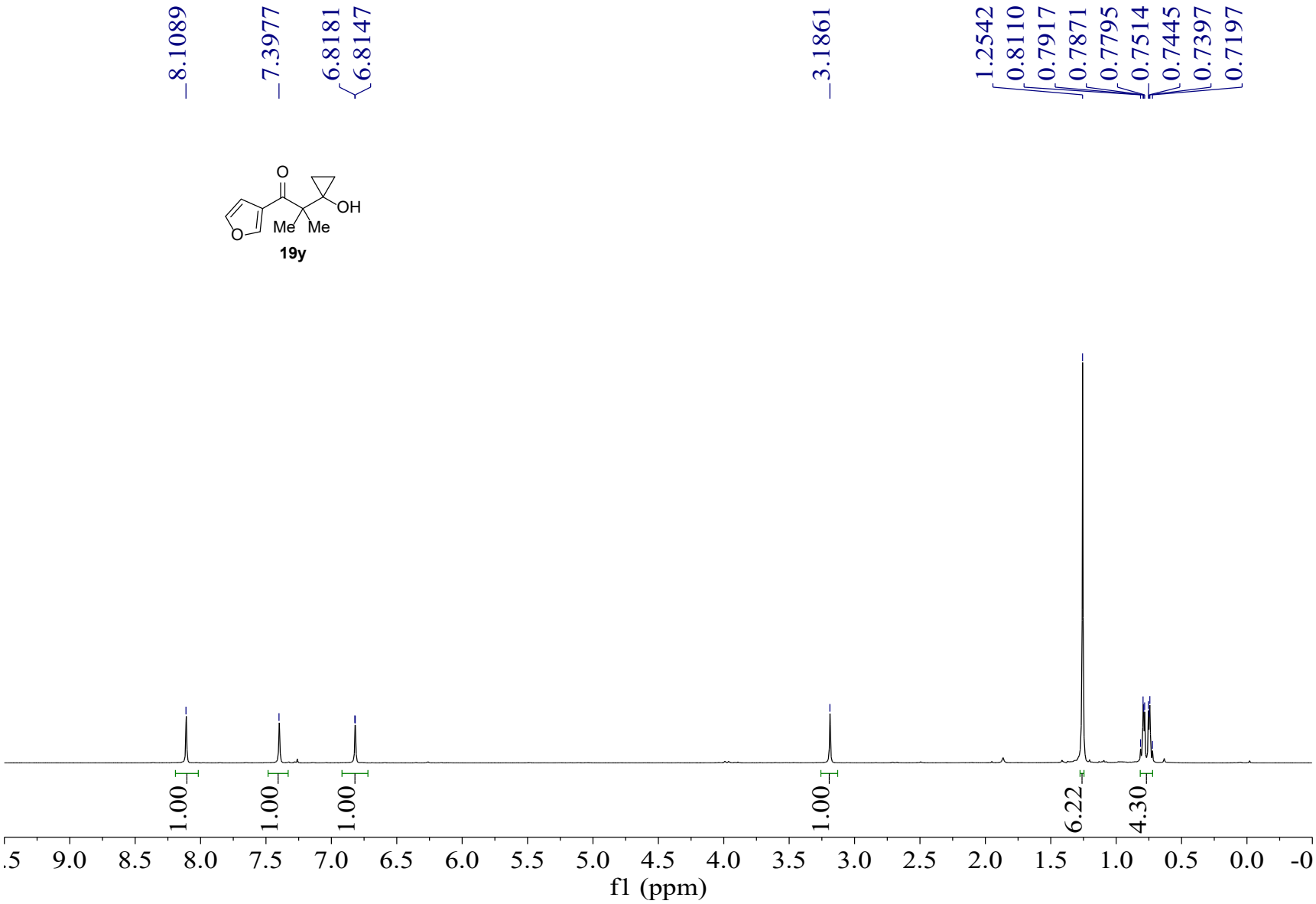
^{13}C NMR spectrum of compound **19x**



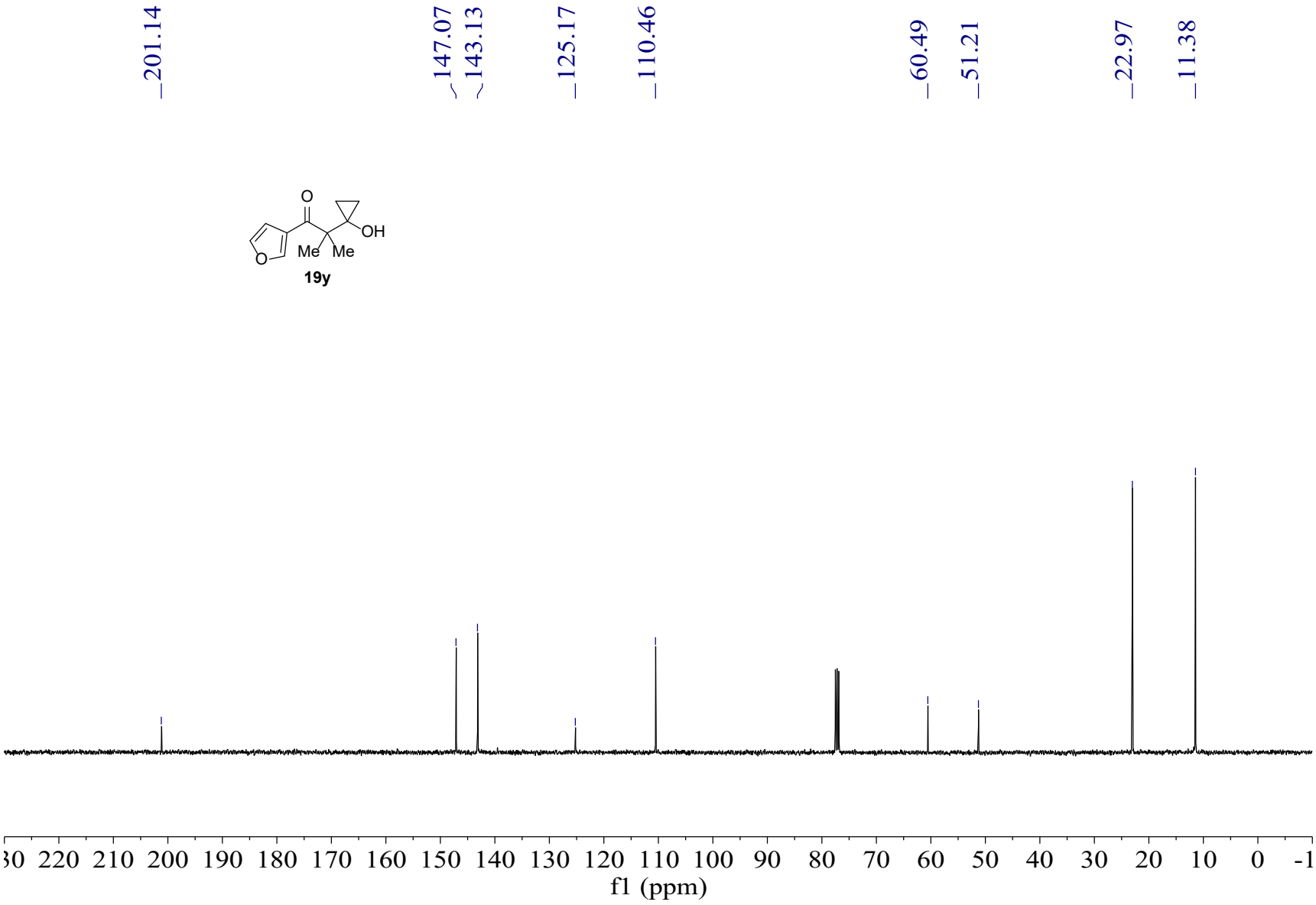
^{1}H NMR spectrum of compound **1x**



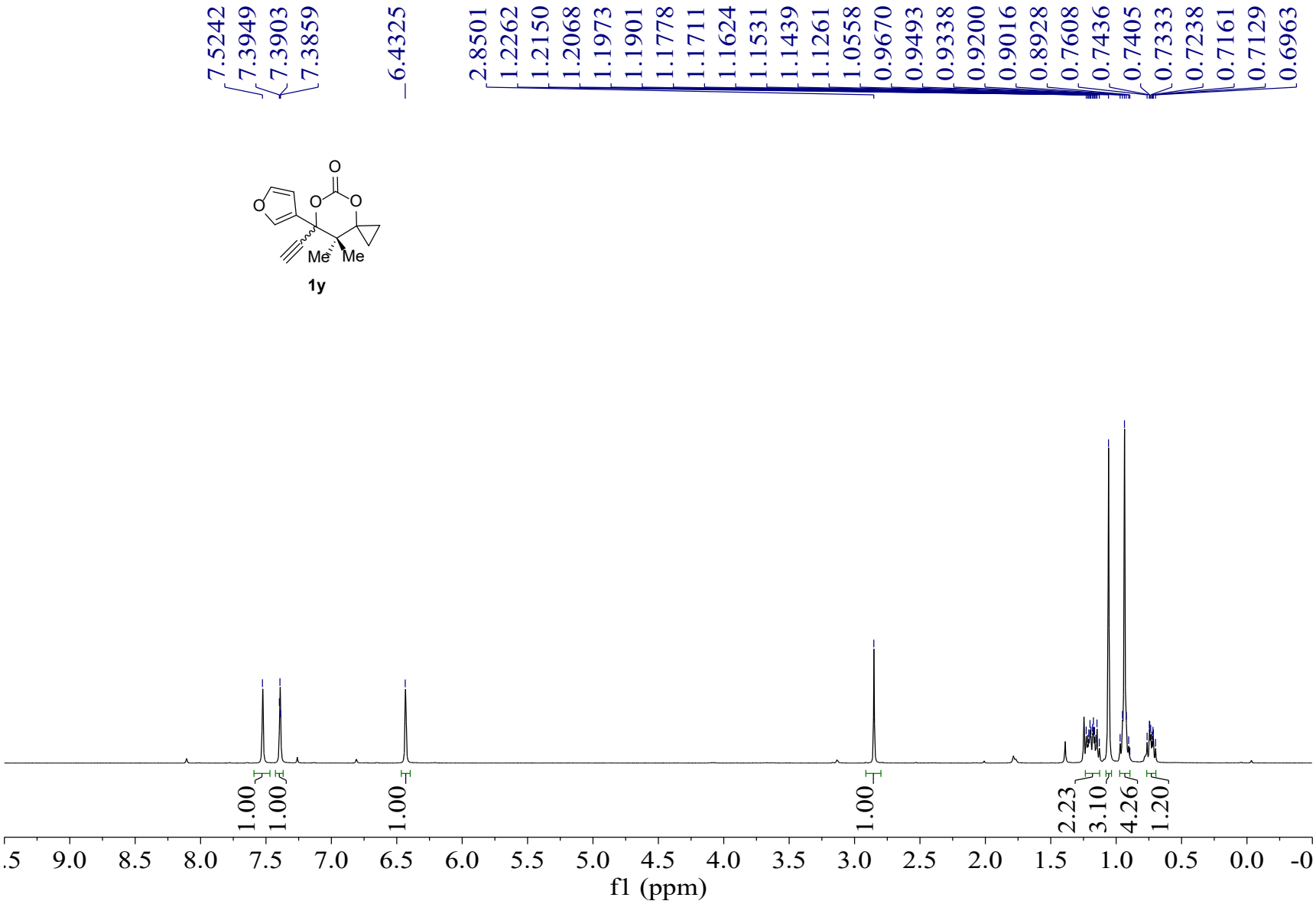
^{13}C NMR spectrum of compound **1x**



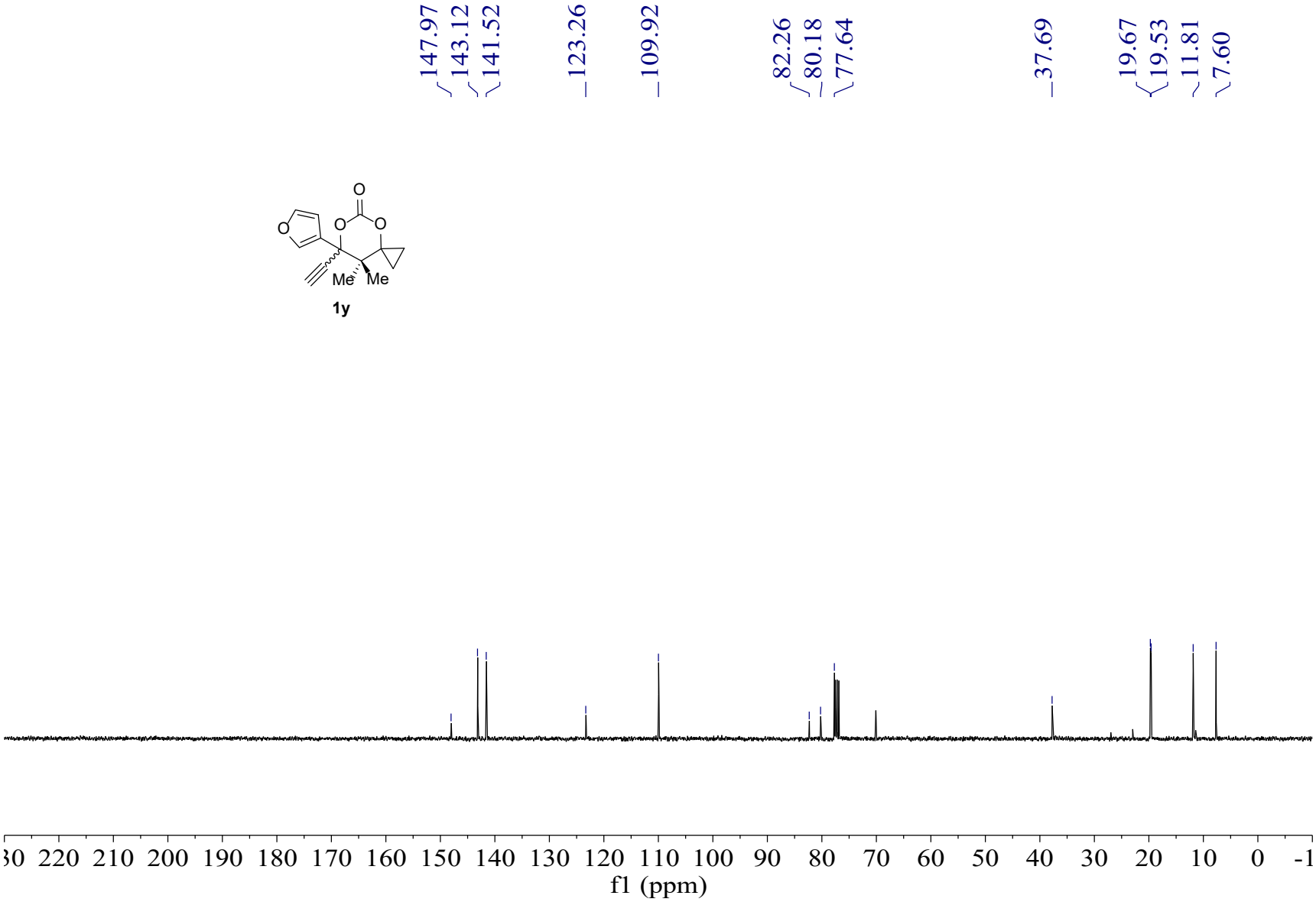
^{1}H NMR spectrum of compound **19y**



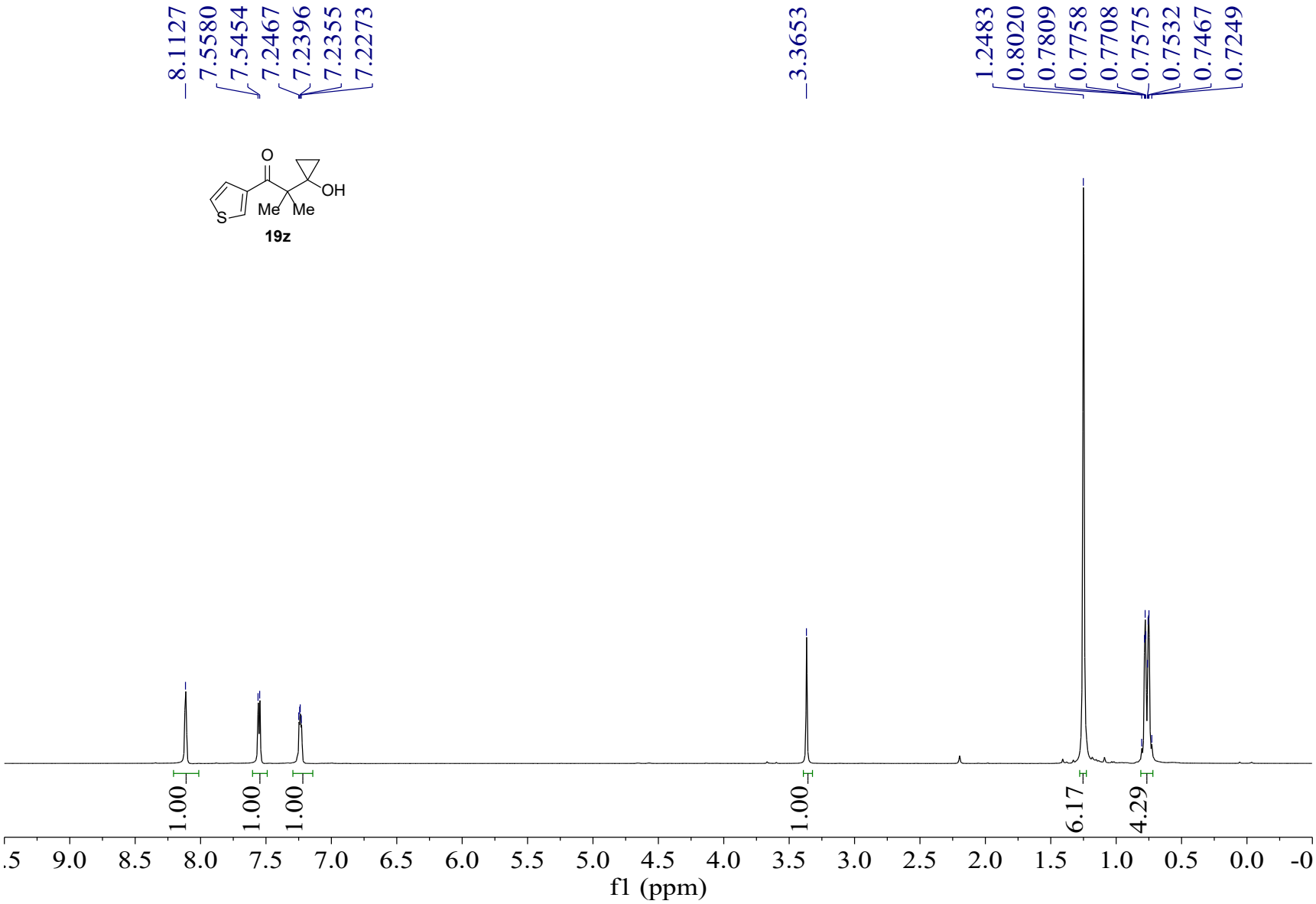
^{13}C NMR spectrum of compound **19y**



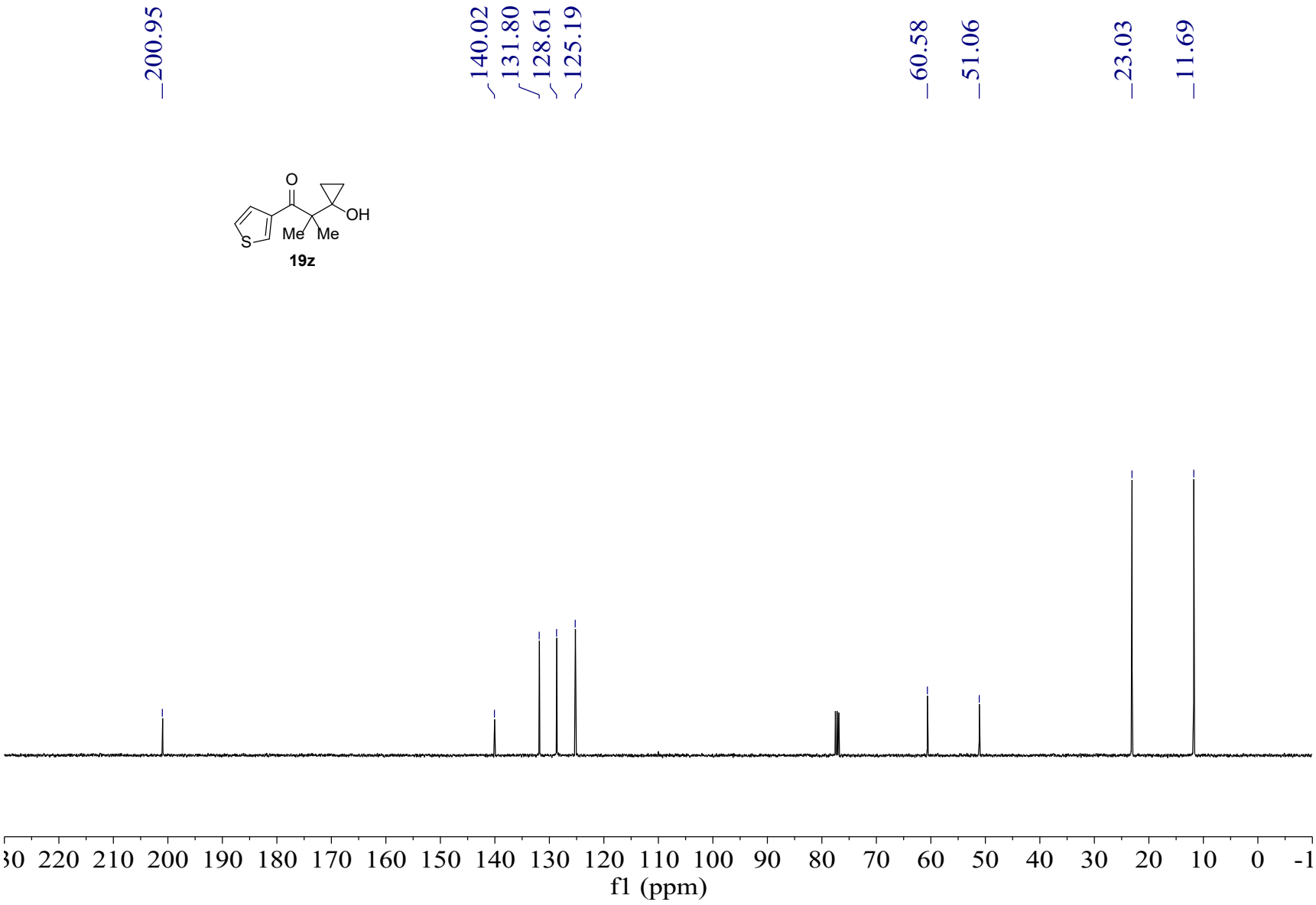
^{1}H NMR spectrum of compound **1y**



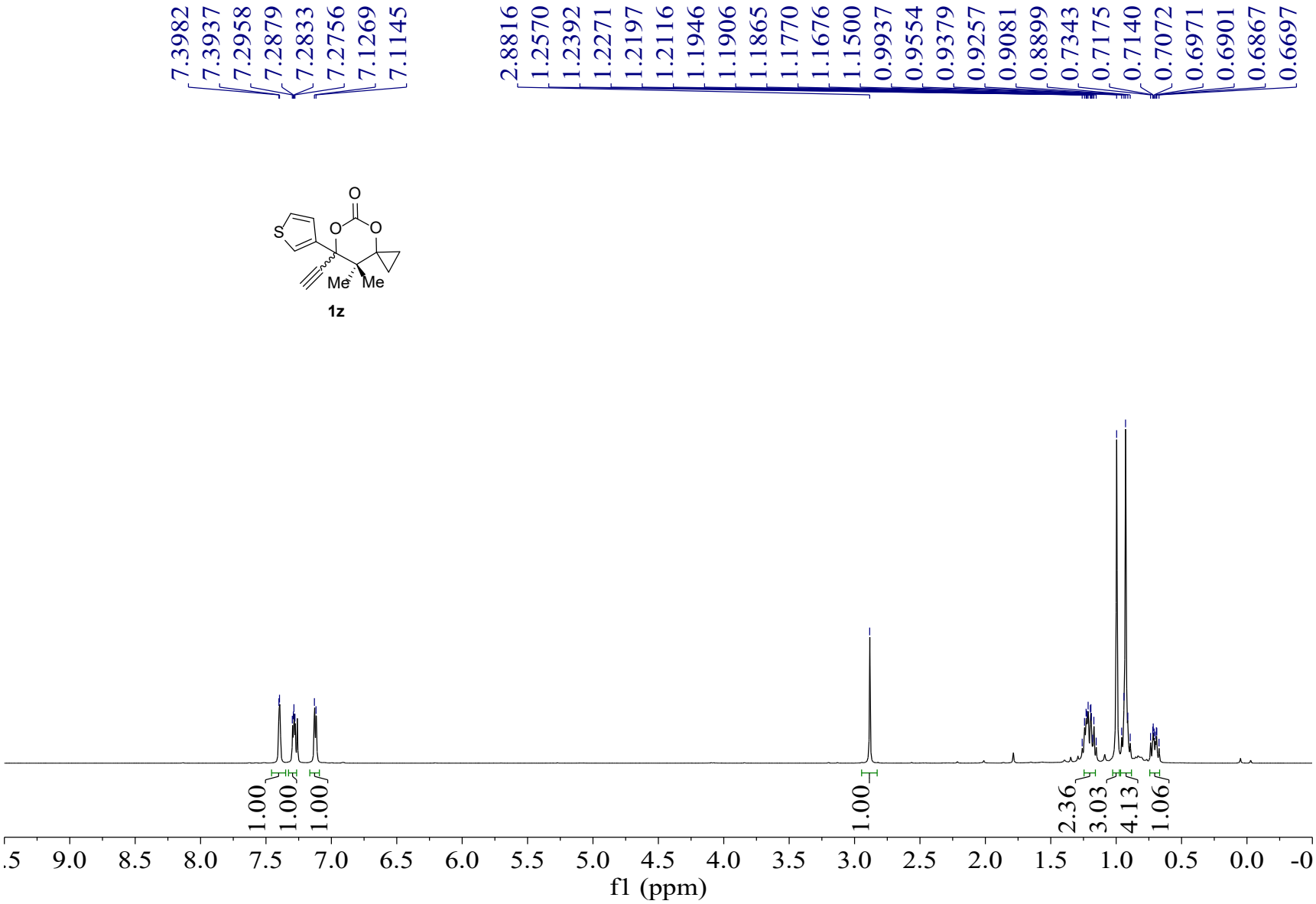
^{13}C NMR spectrum of compound **1y**



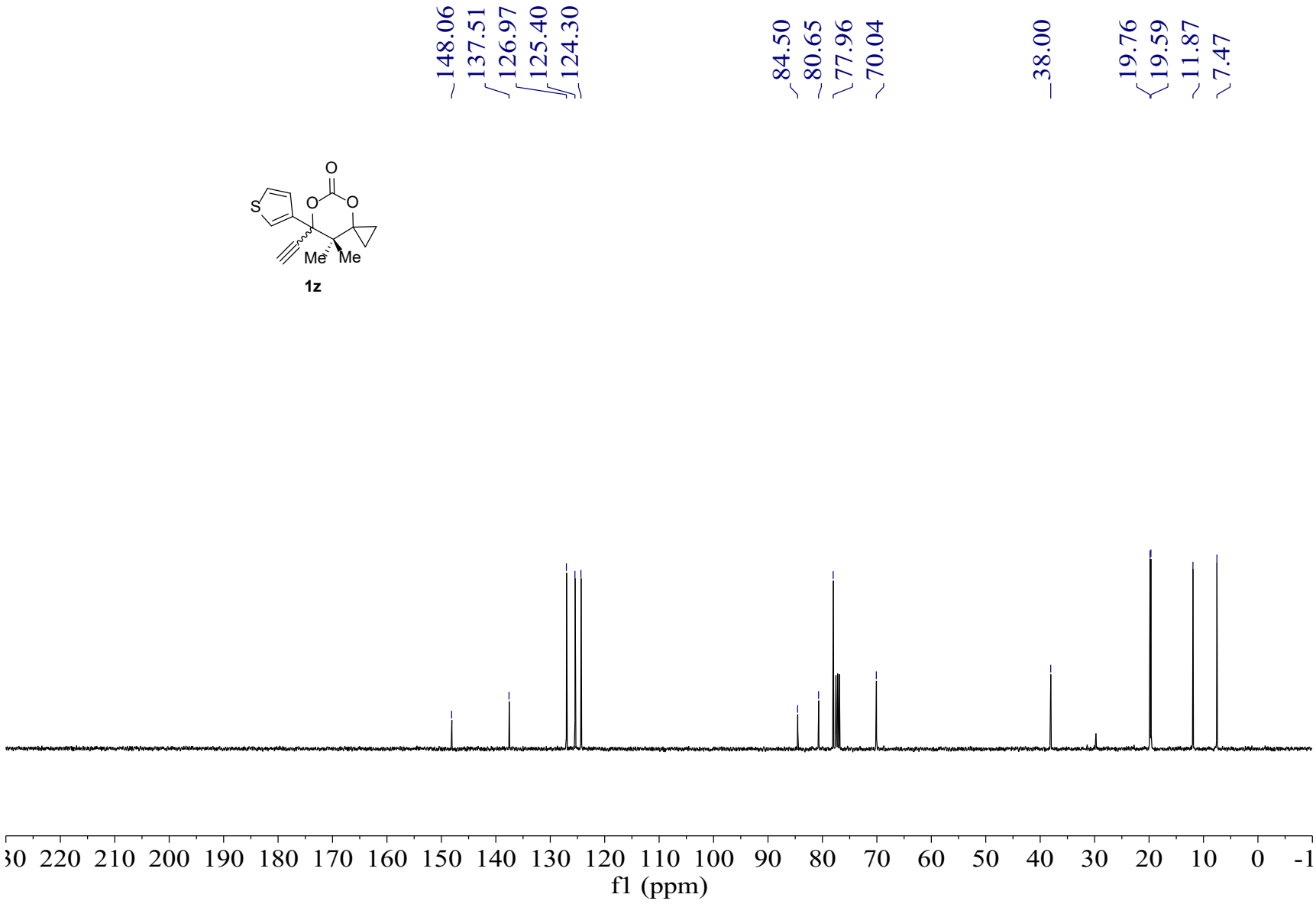
^{1}H NMR spectrum of compound **19z**



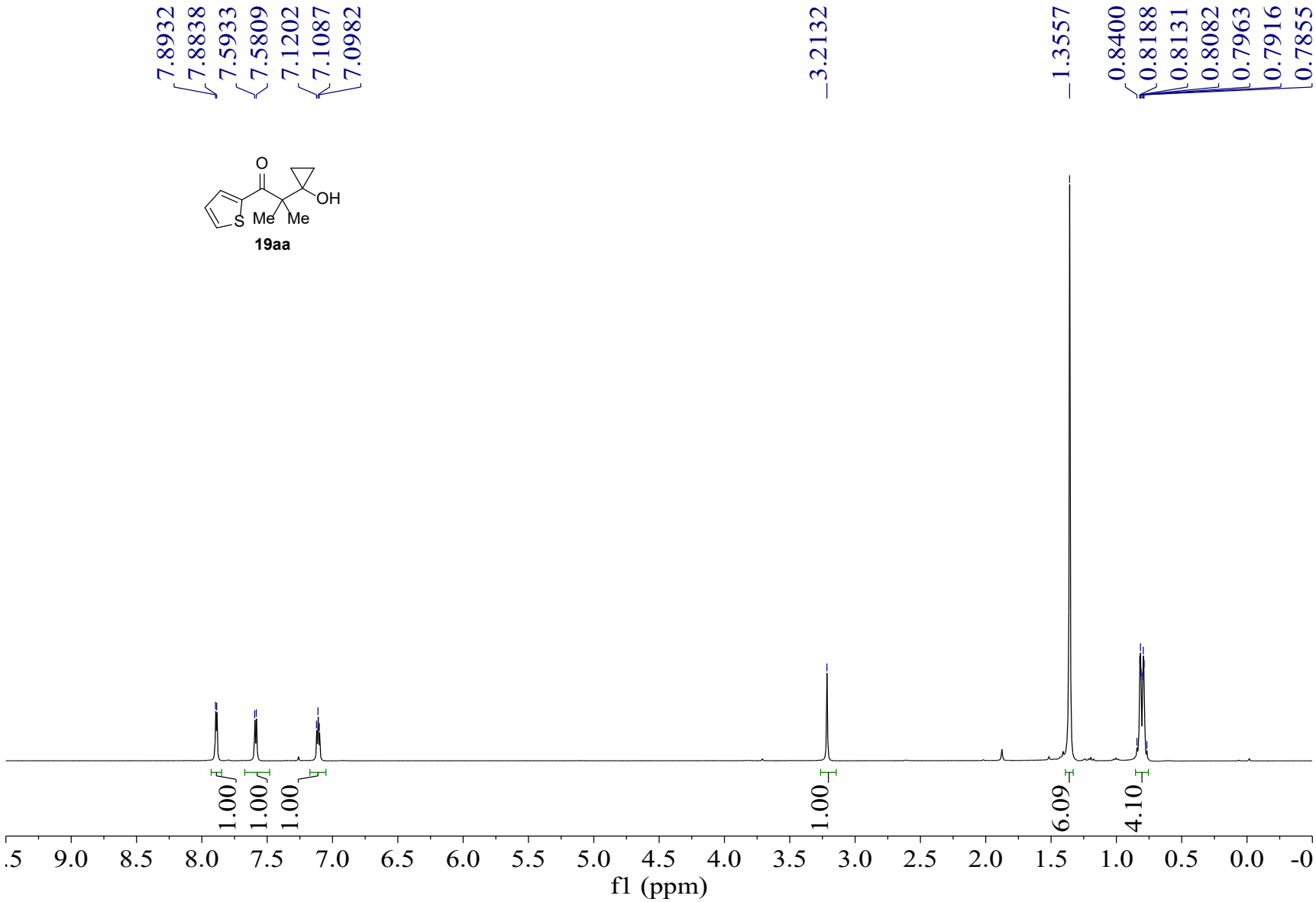
^{13}C NMR spectrum of compound **19z**



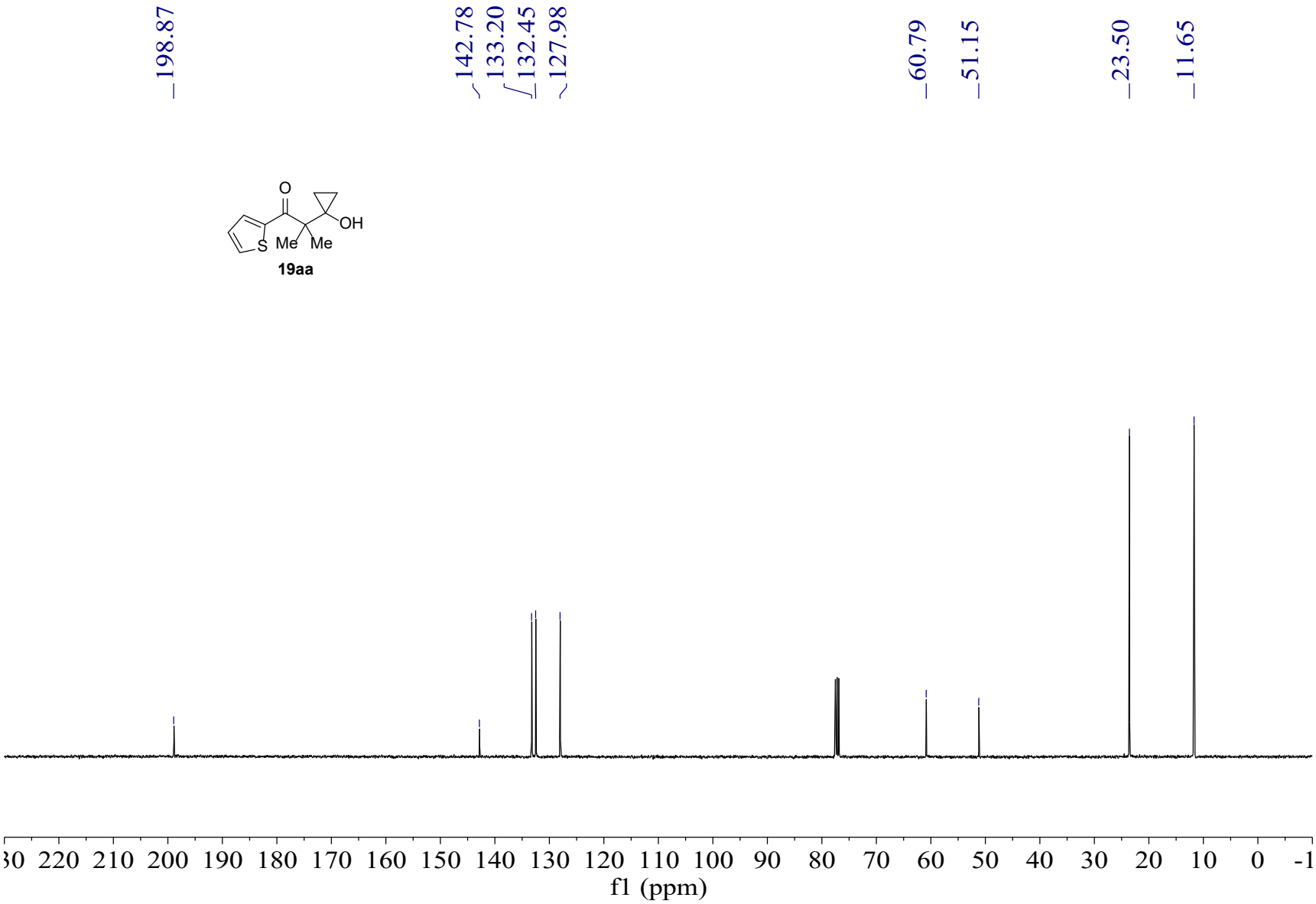
^{1}H NMR spectrum of compound **1z**



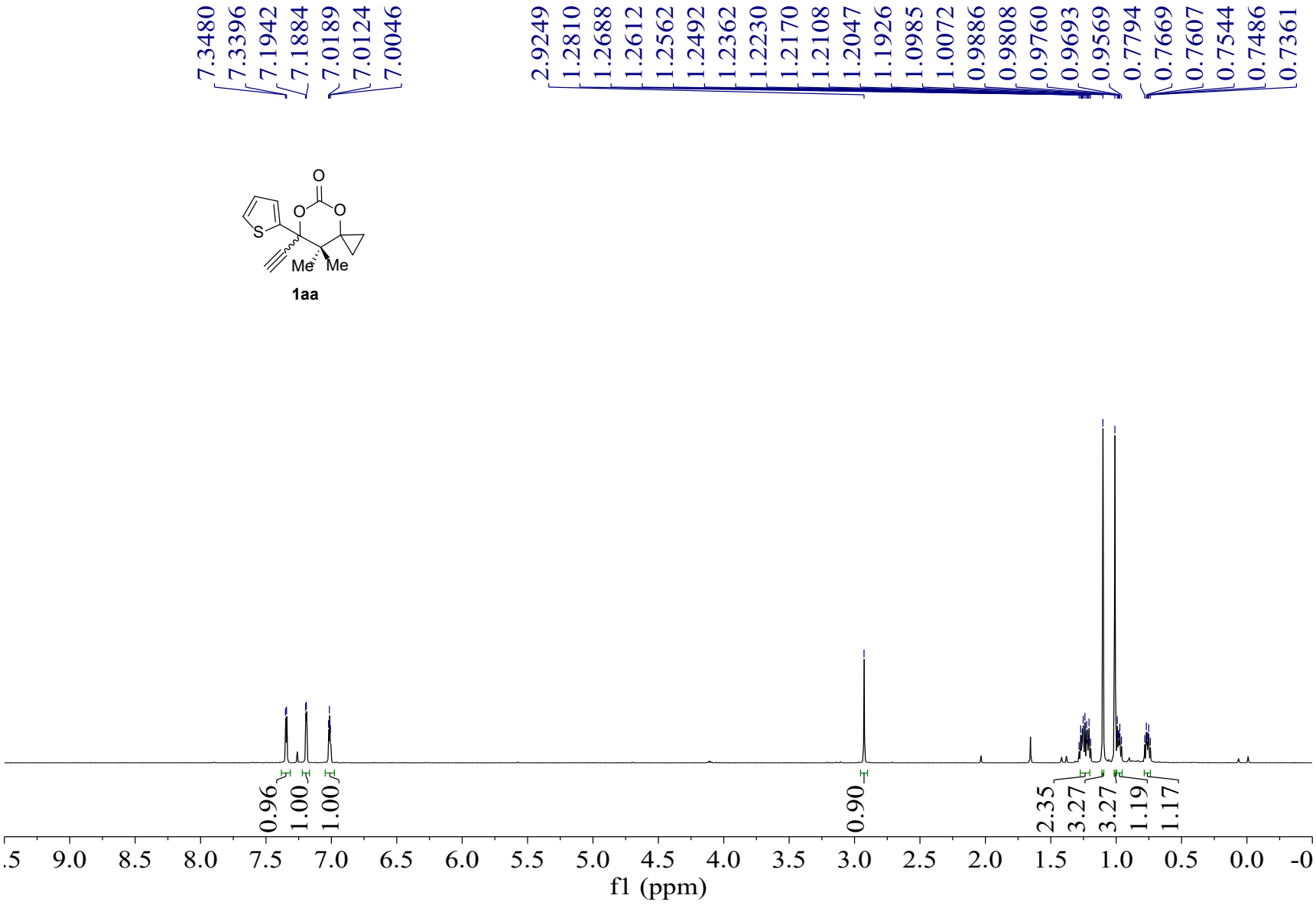
^{13}C NMR spectrum of compound **1z**



^{1}H NMR spectrum of compound **19aa**

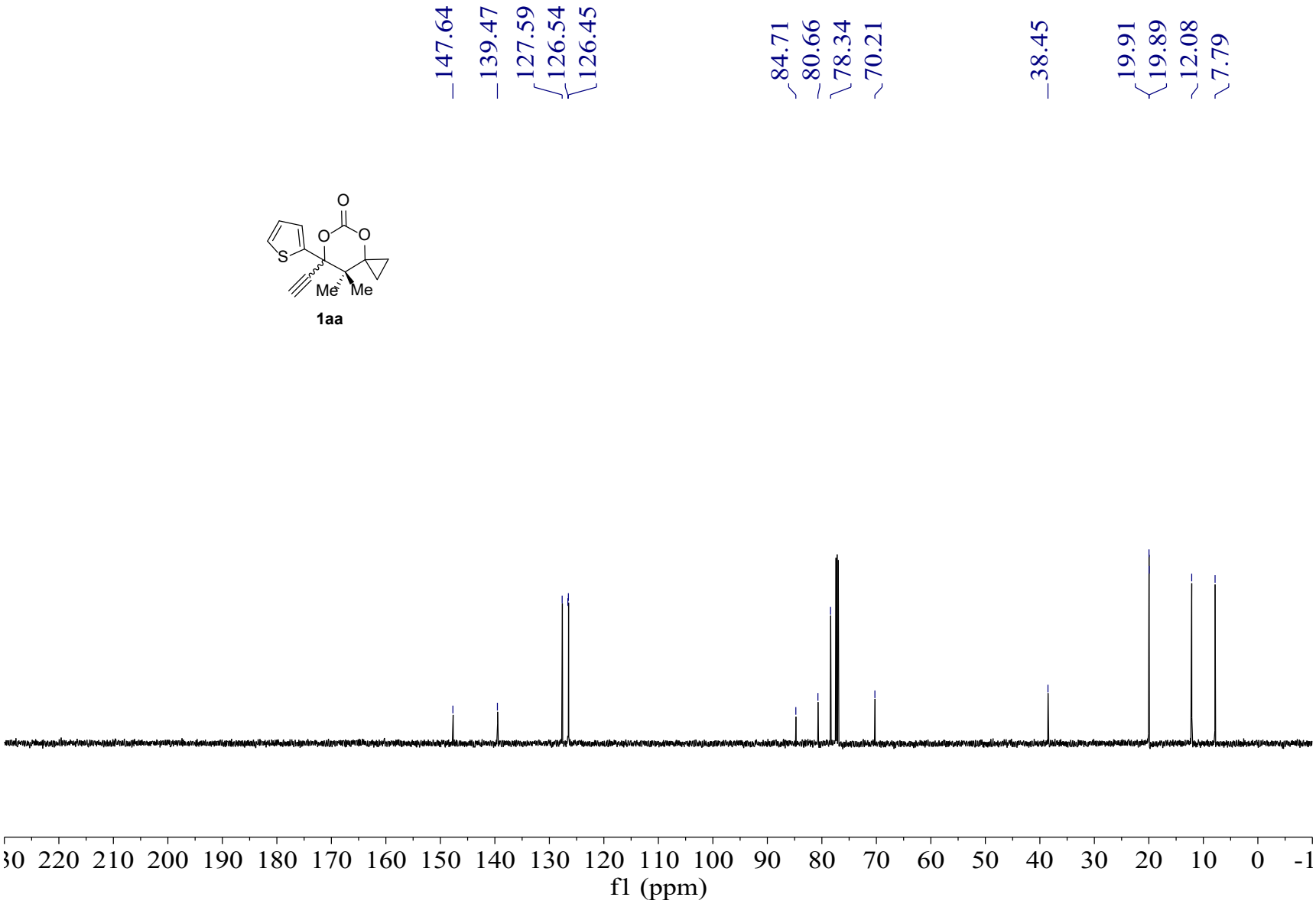


^{13}C NMR spectrum of compound **19aa**

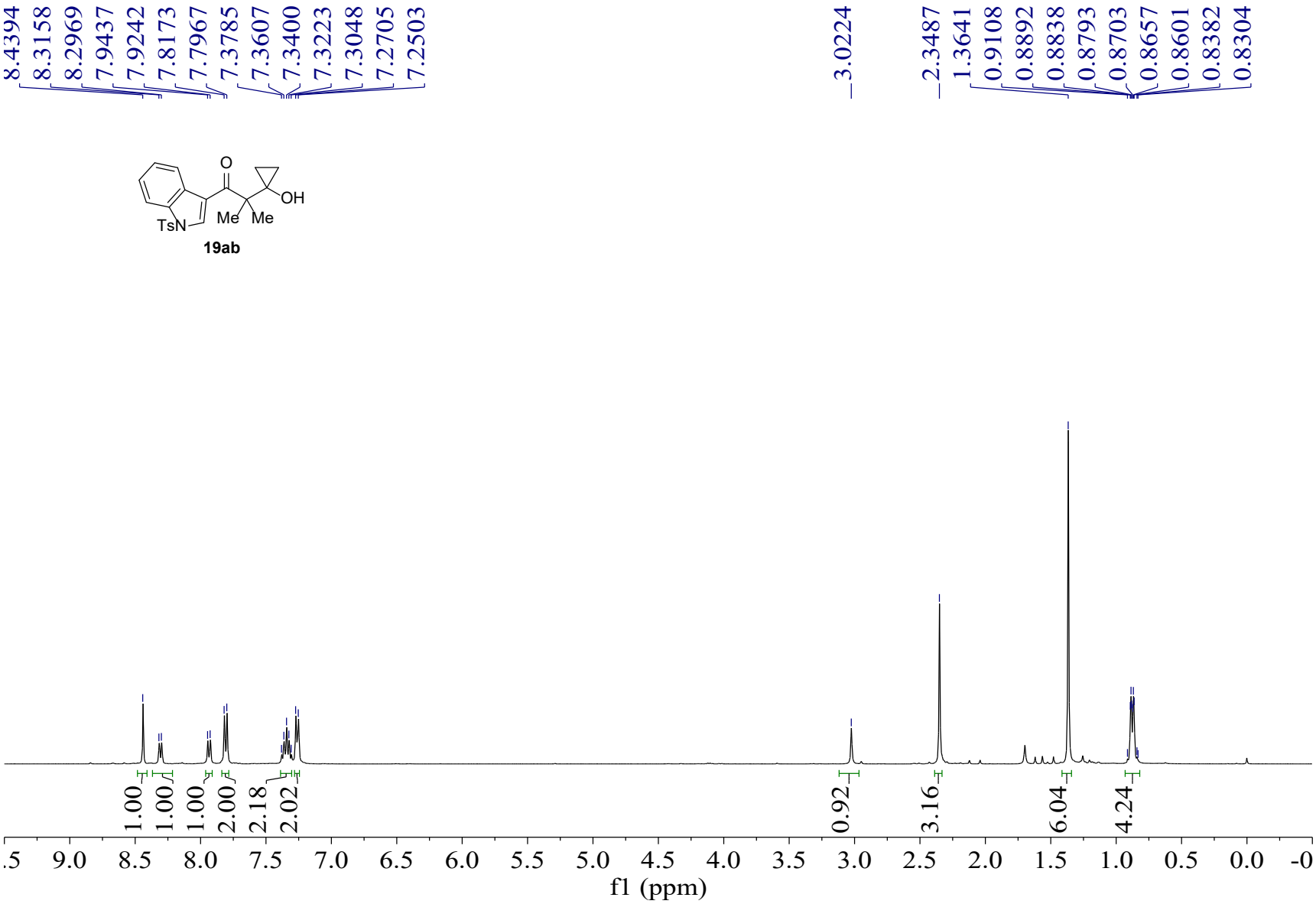


1aa

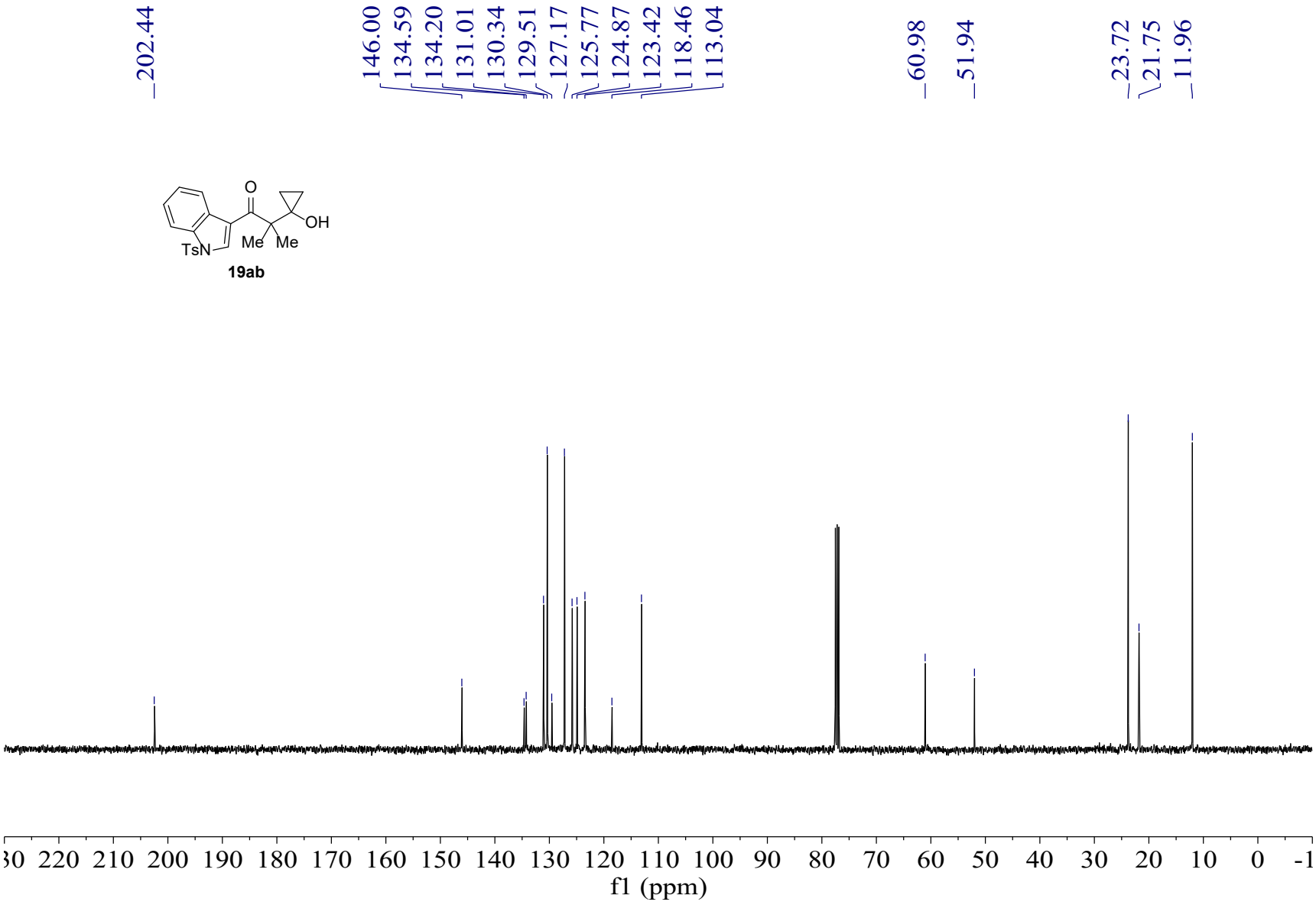
^{1}H NMR spectrum of compound **1aa**



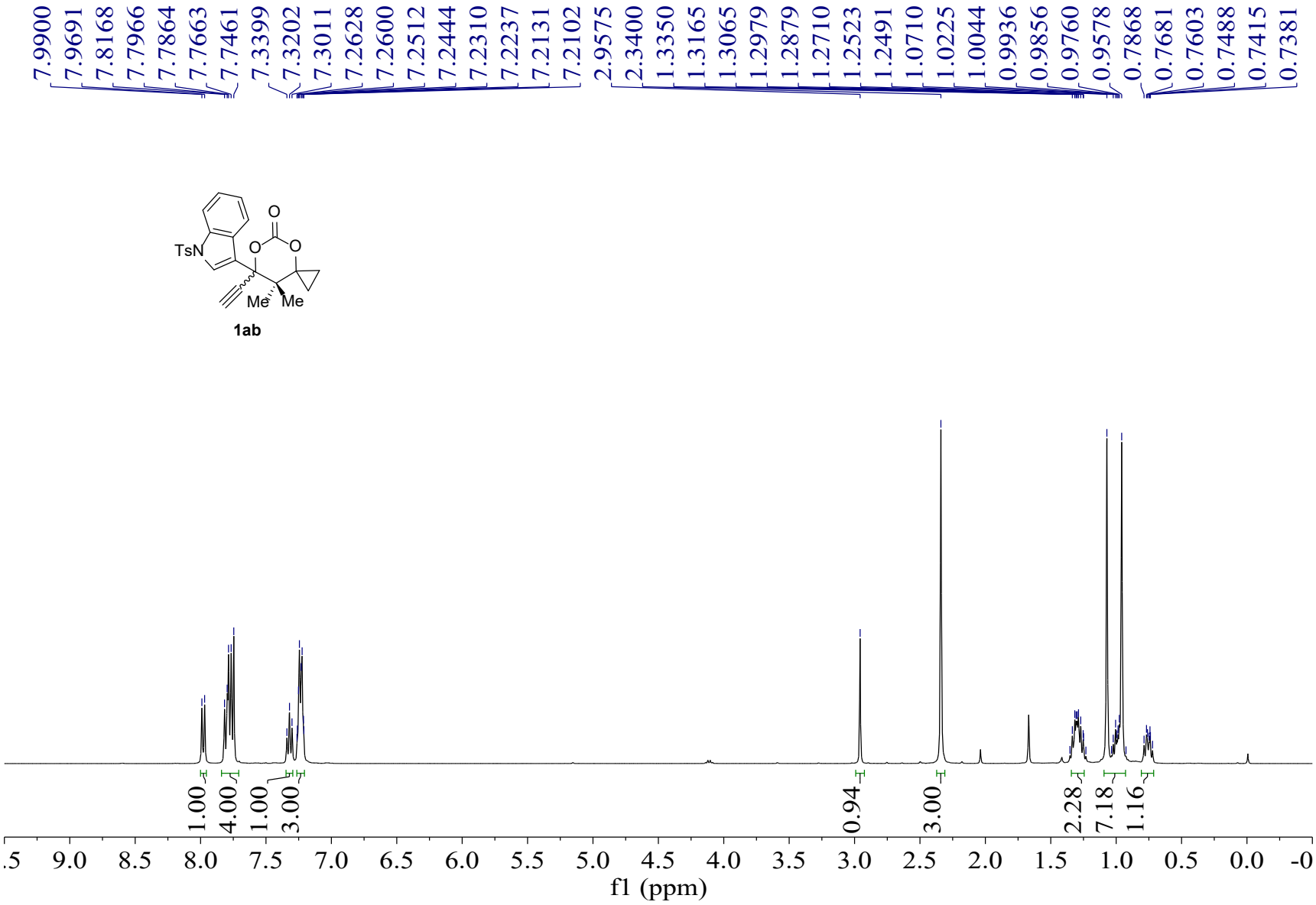
^{13}C NMR spectrum of compound **1aa**



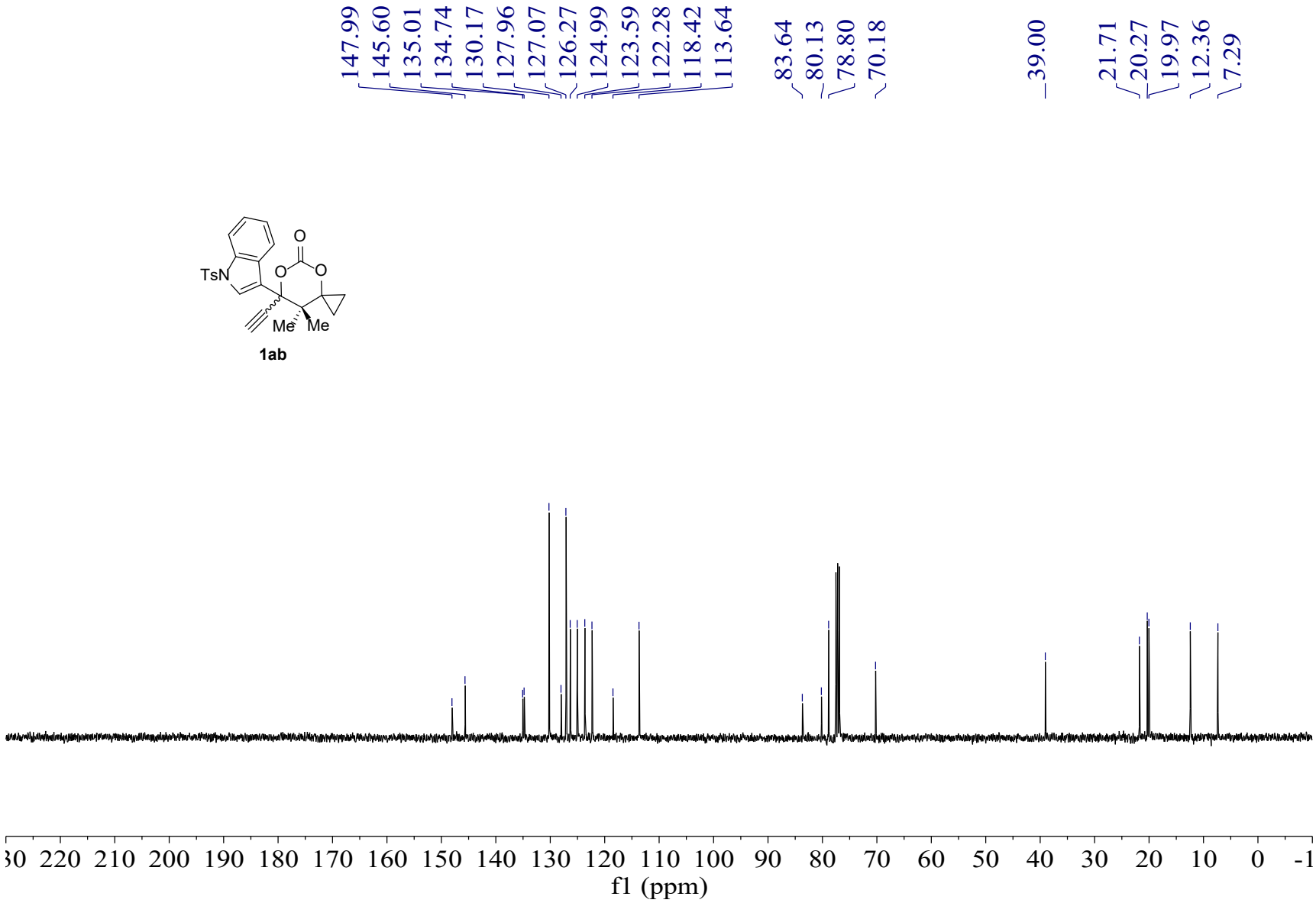
^{1}H NMR spectrum of compound **19ab**



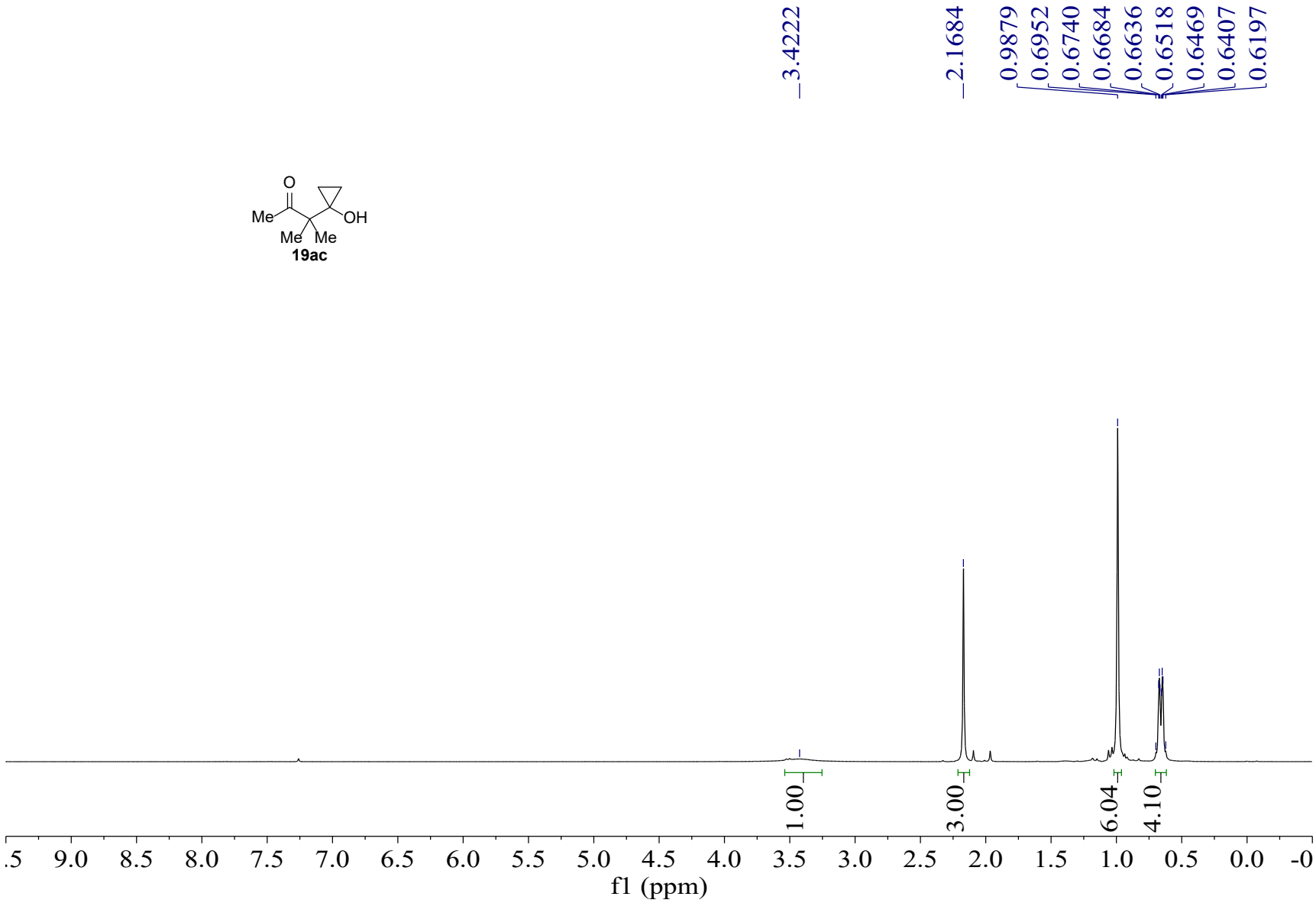
^{13}C NMR spectrum of compound **19ab**



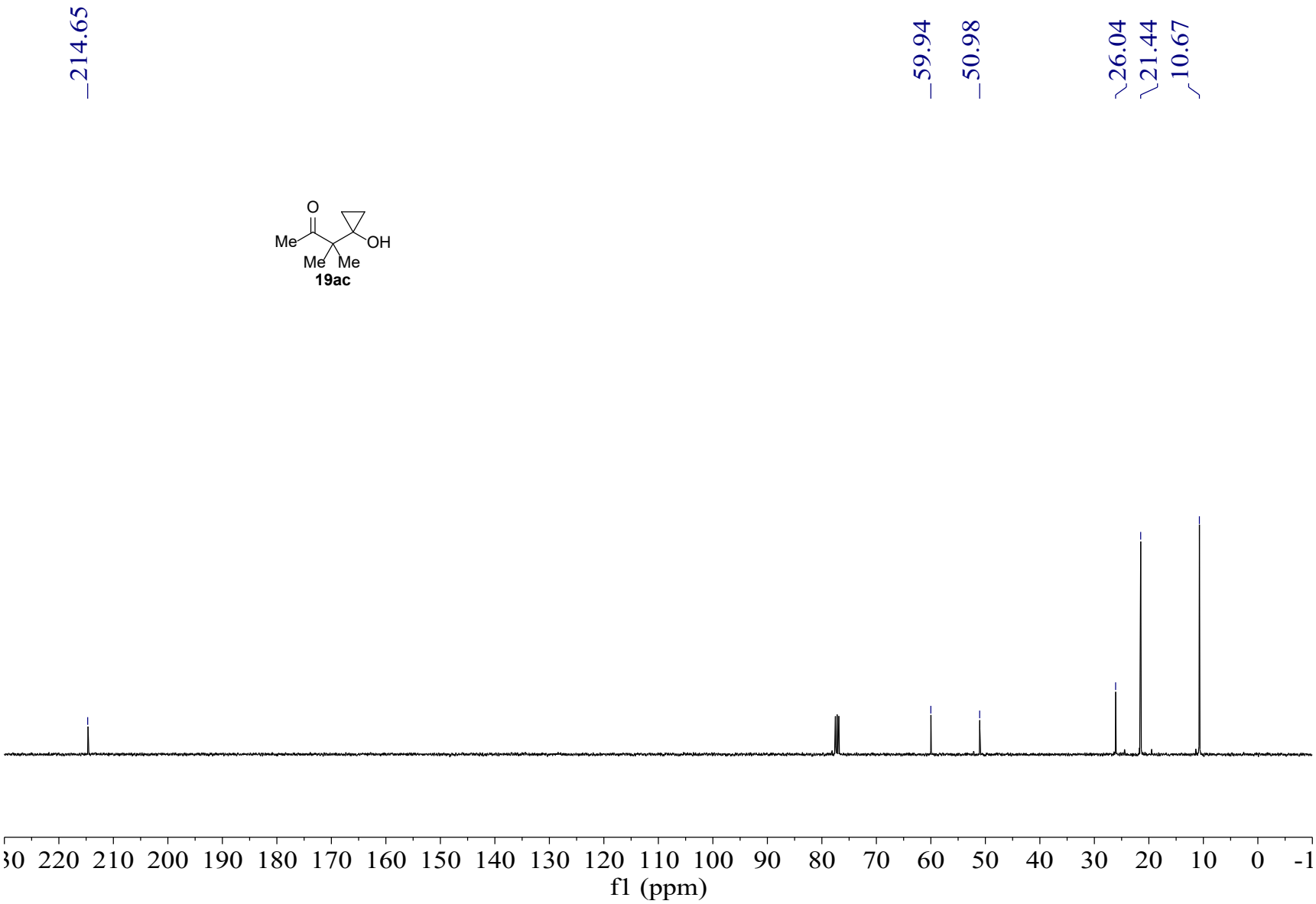
^{1}H NMR spectrum of compound **1ab**



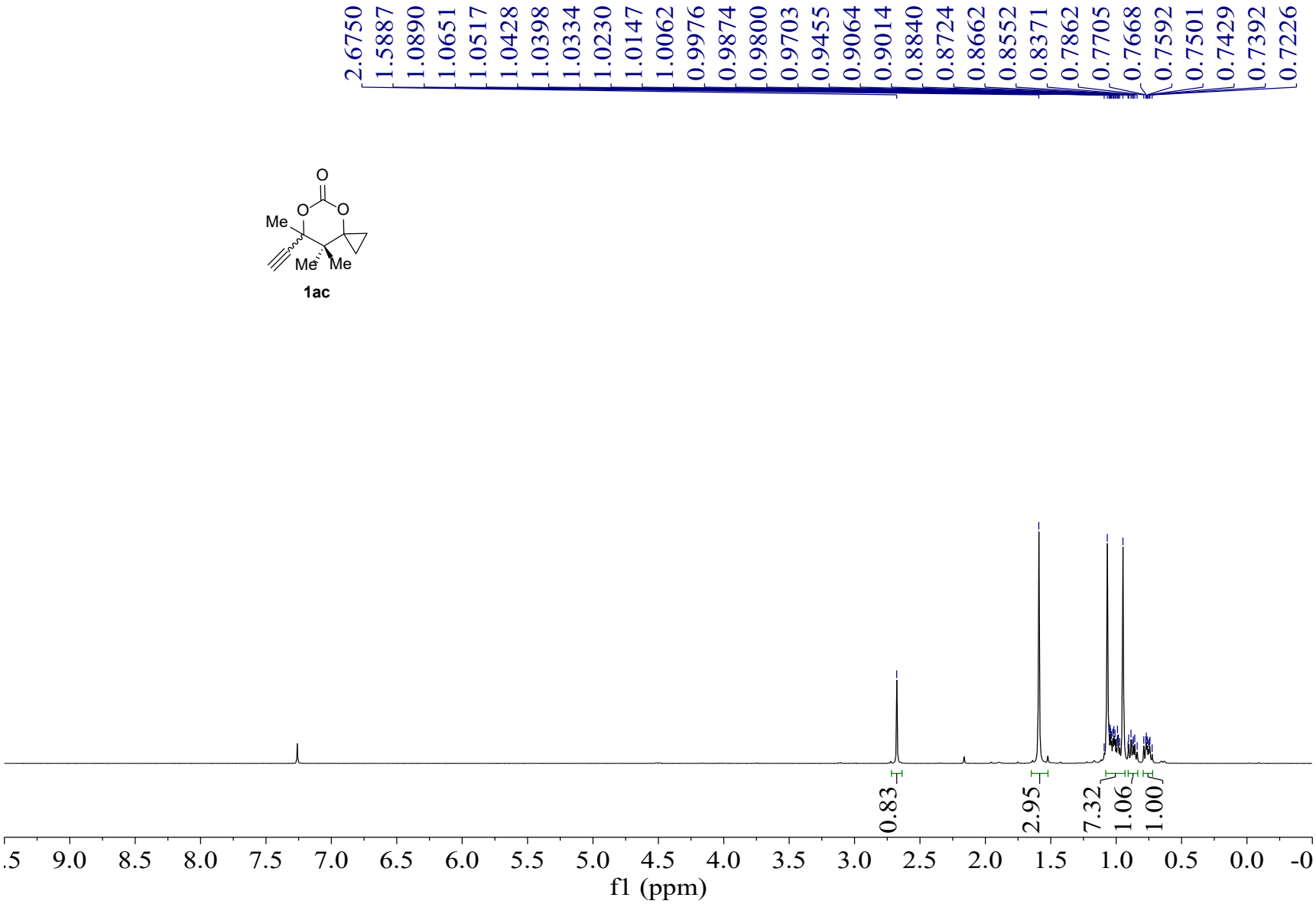
^{13}C NMR spectrum of compound **1ab**



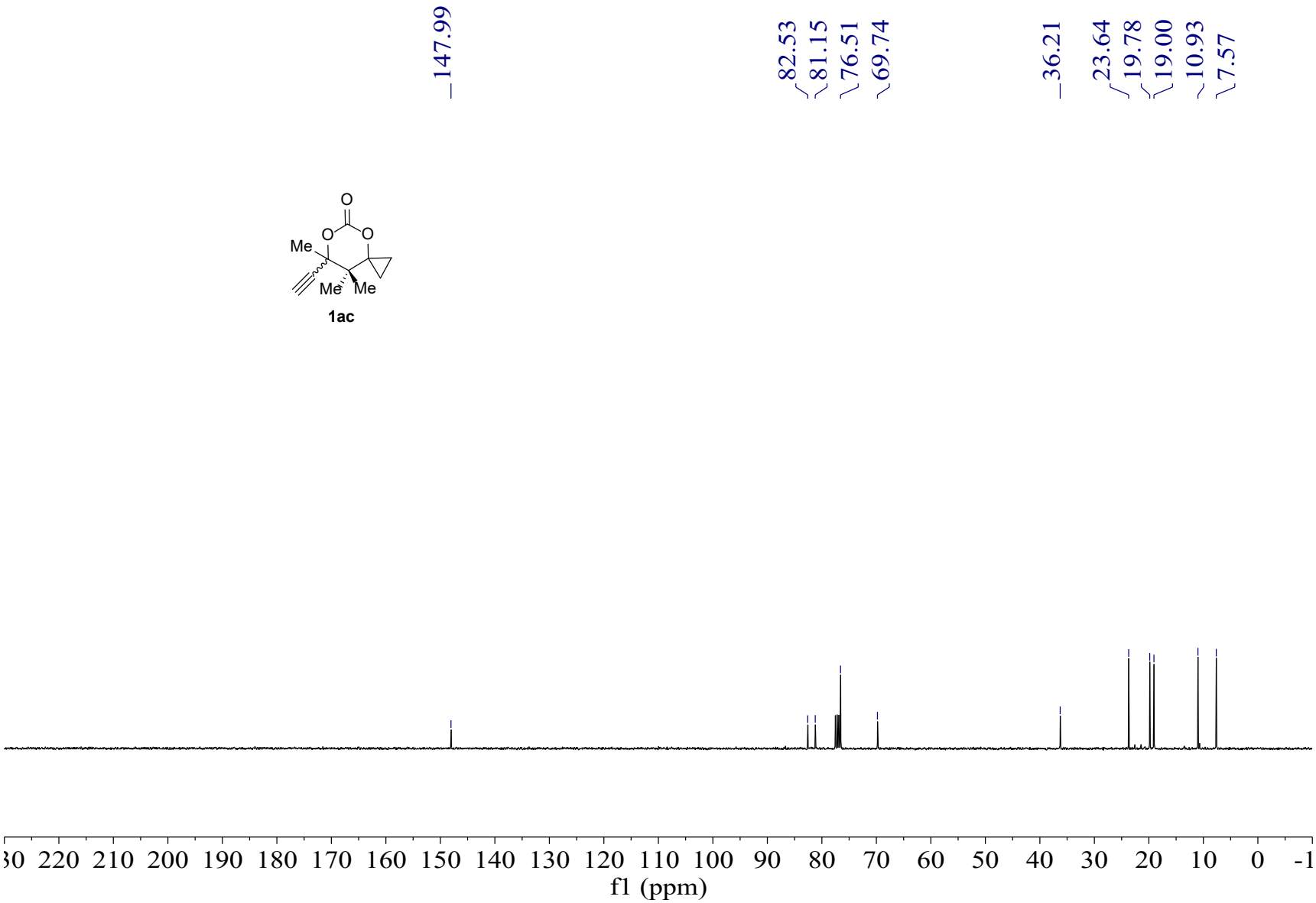
^{1}H NMR spectrum of compound **19ac**



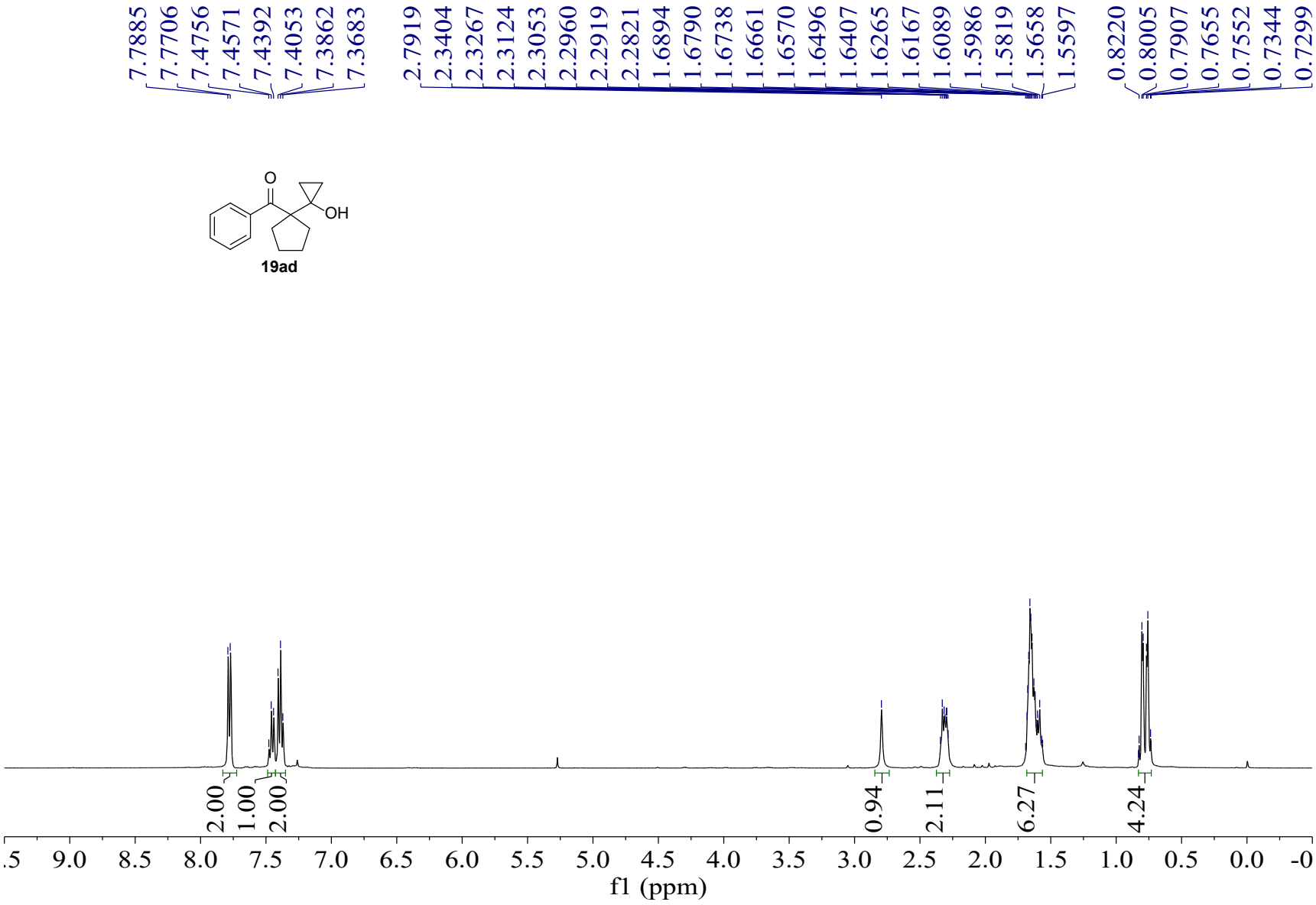
^{13}C NMR spectrum of compound **19ac**



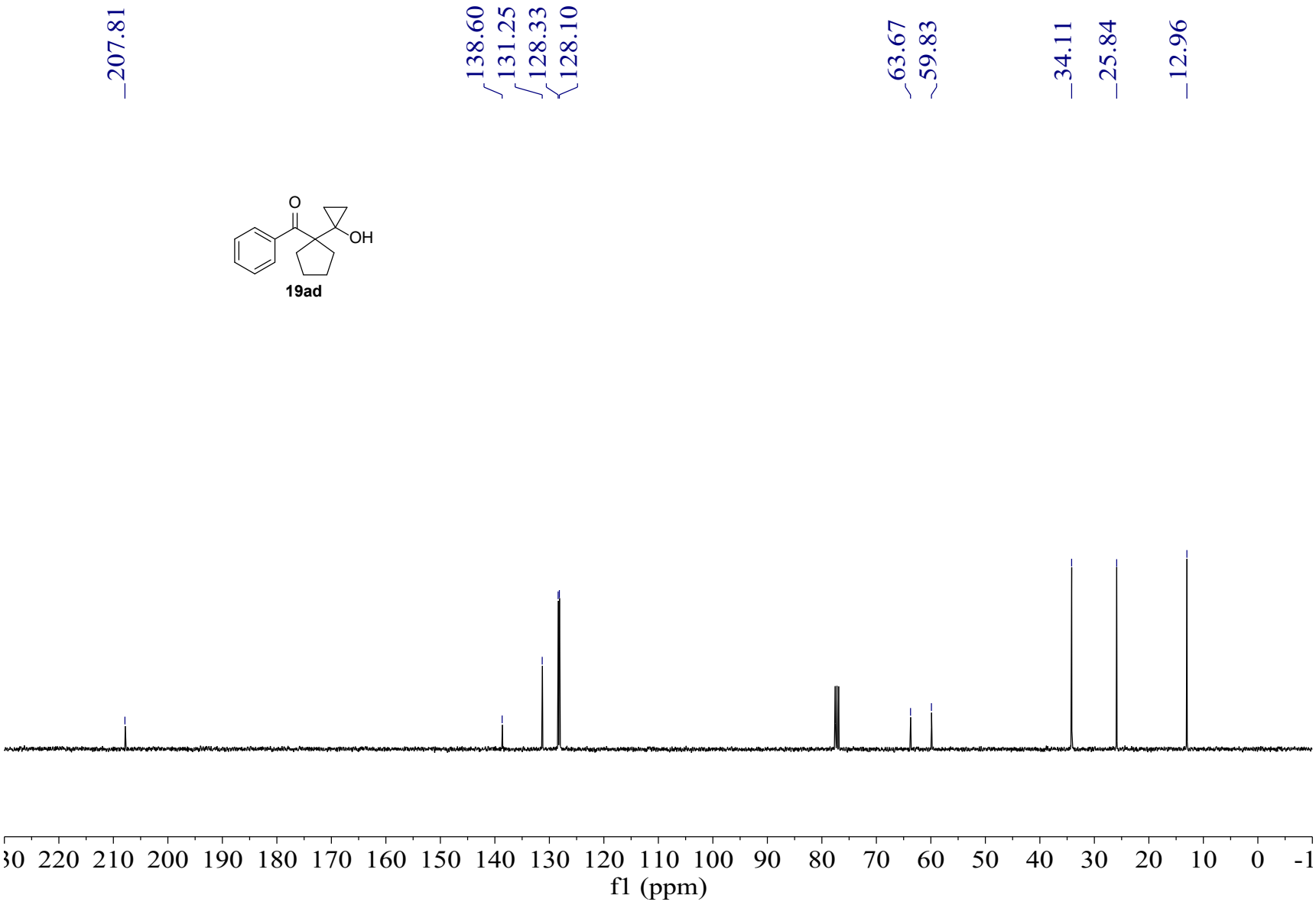
^{1}H NMR spectrum of compound **1ac**



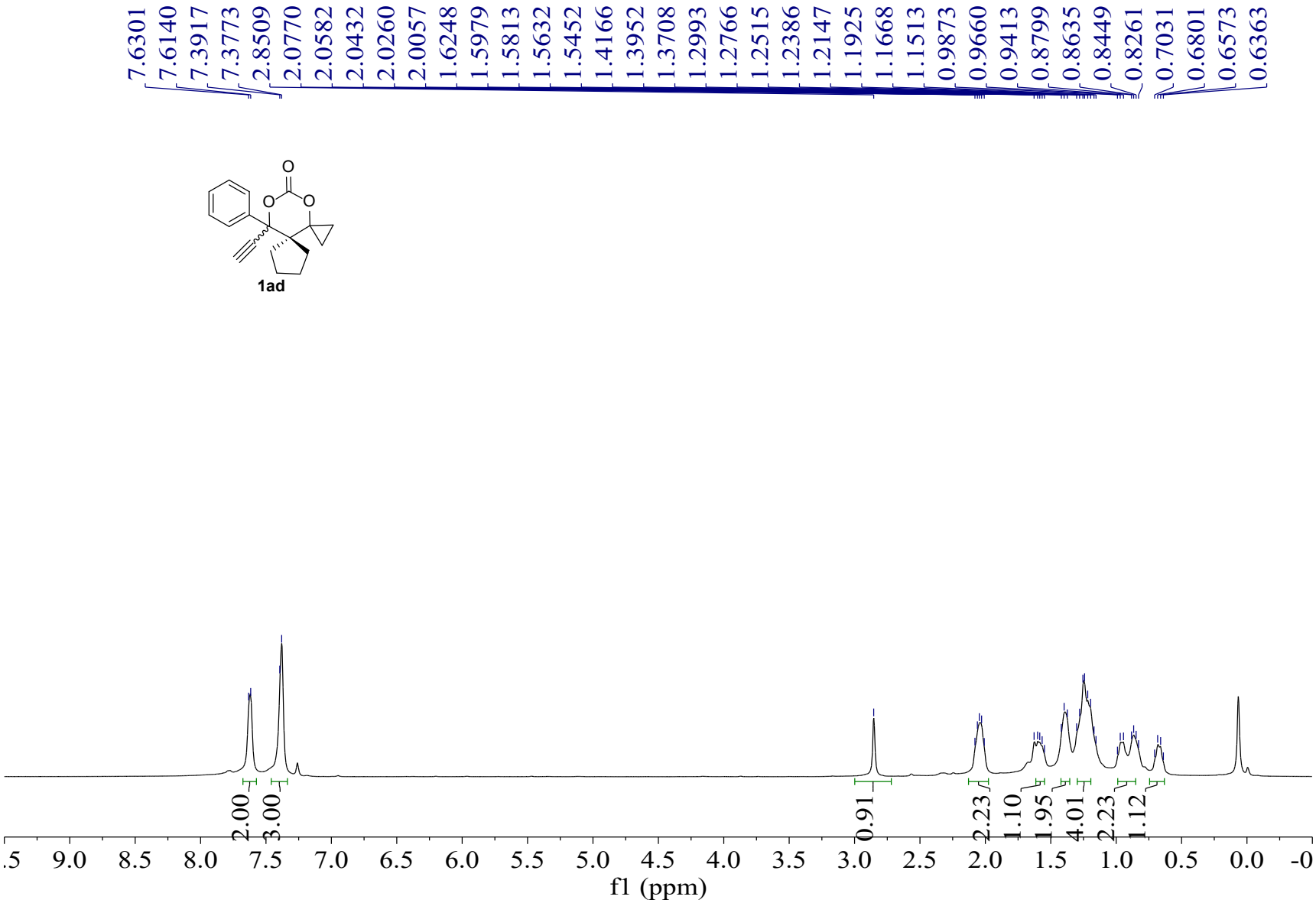
^{13}C NMR spectrum of compound **1ac**



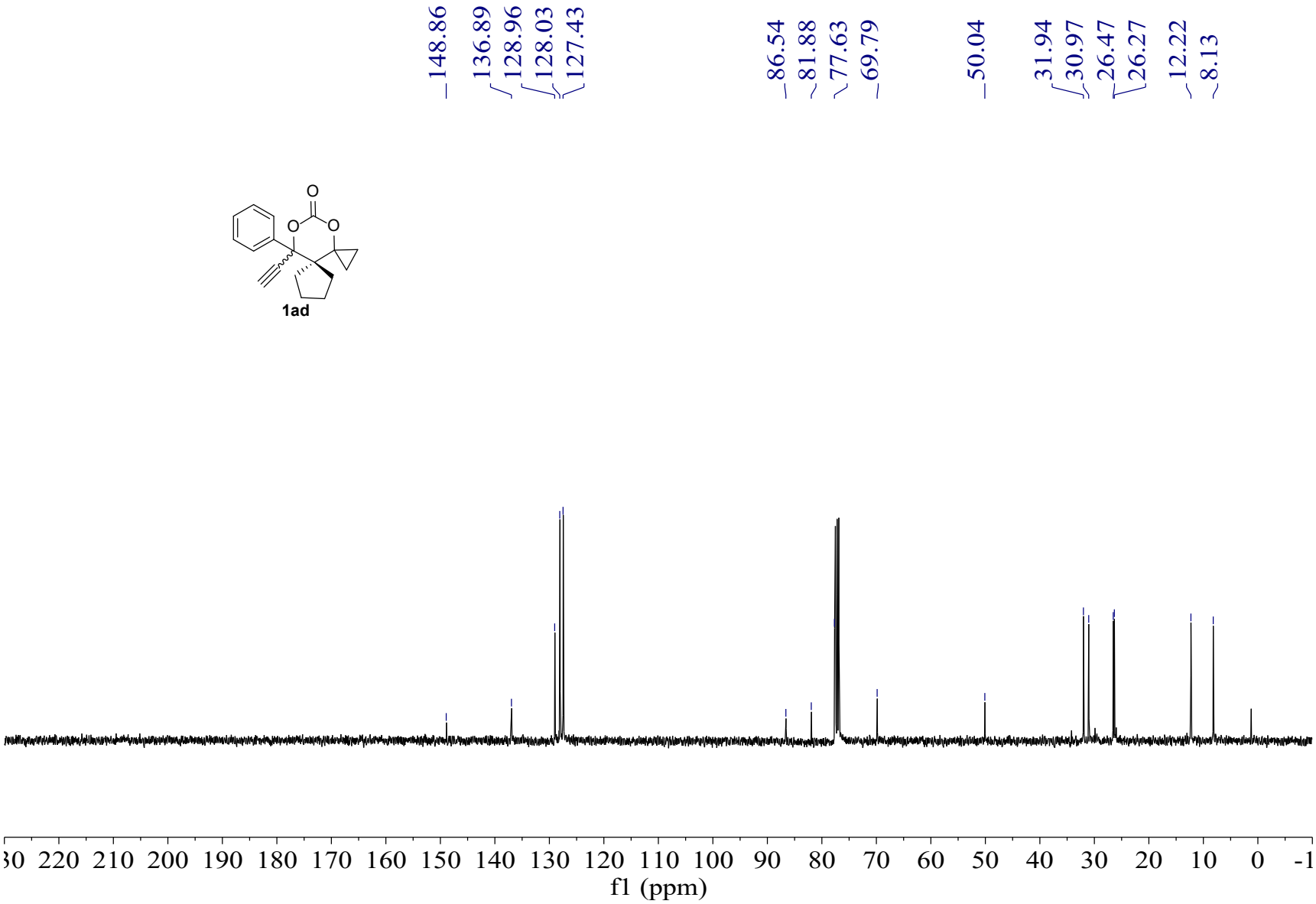
^{1}H NMR spectrum of compound **19ad**



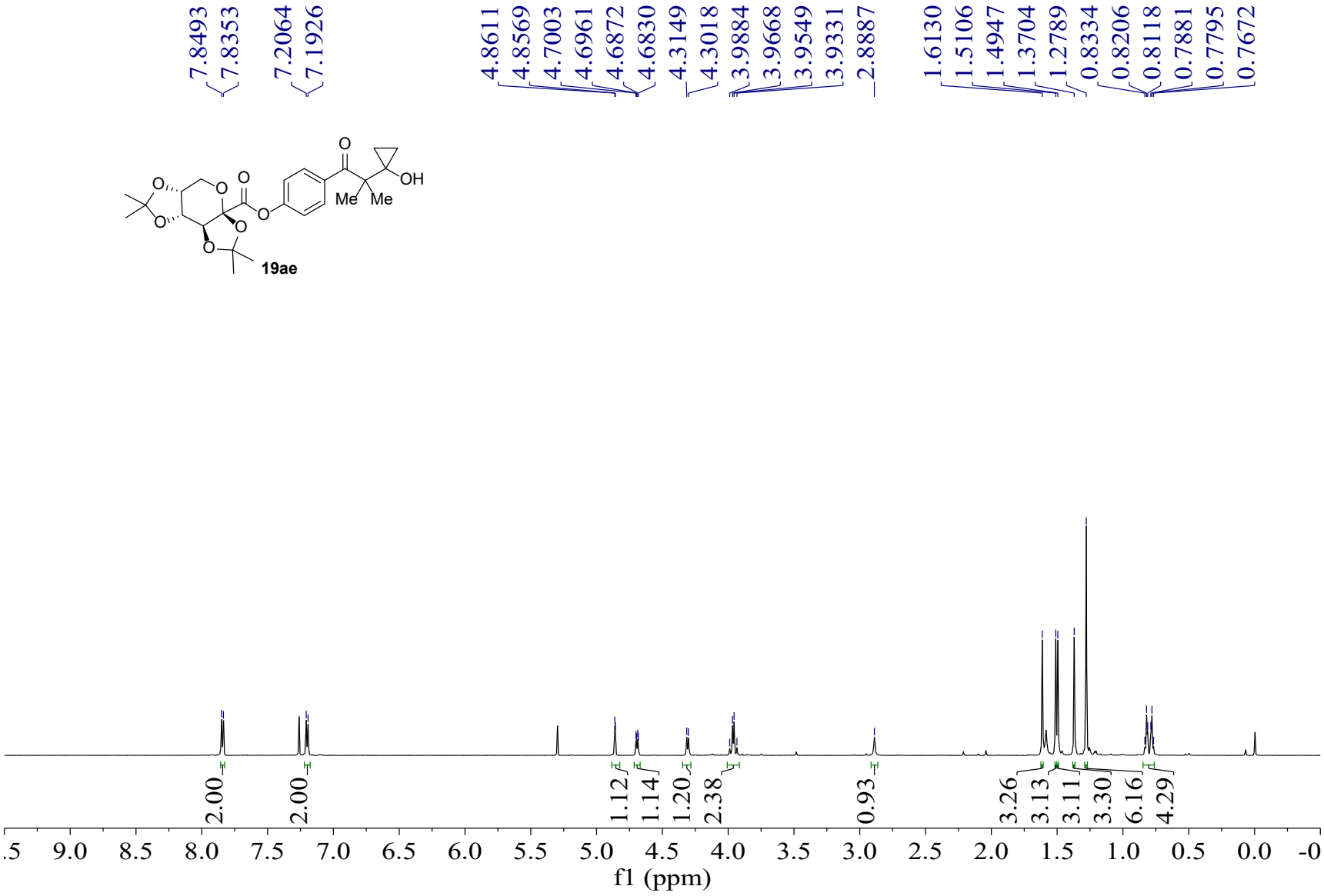
^{13}C NMR spectrum of compound **19ad**



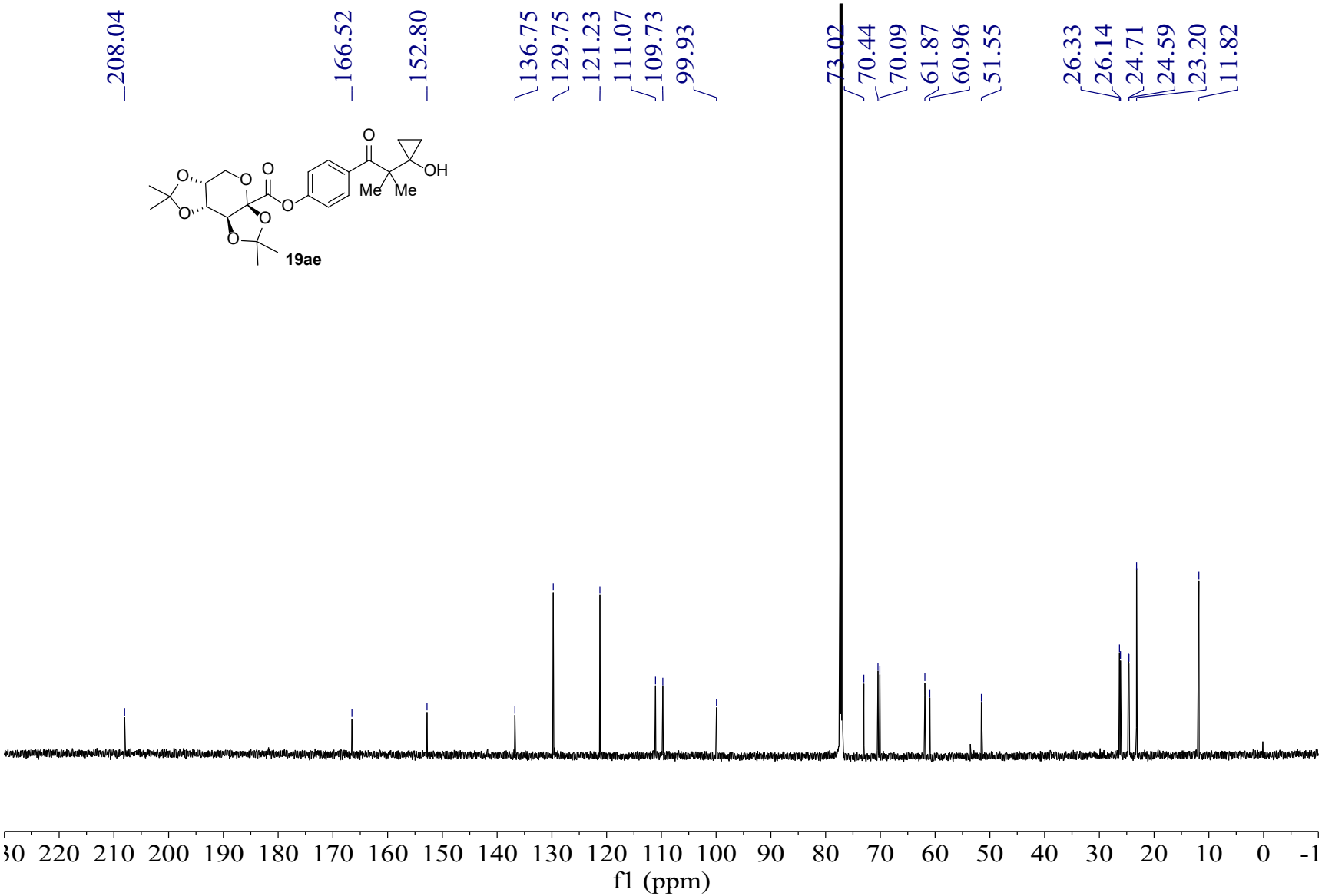
^{1}H NMR spectrum of compound **1ad**



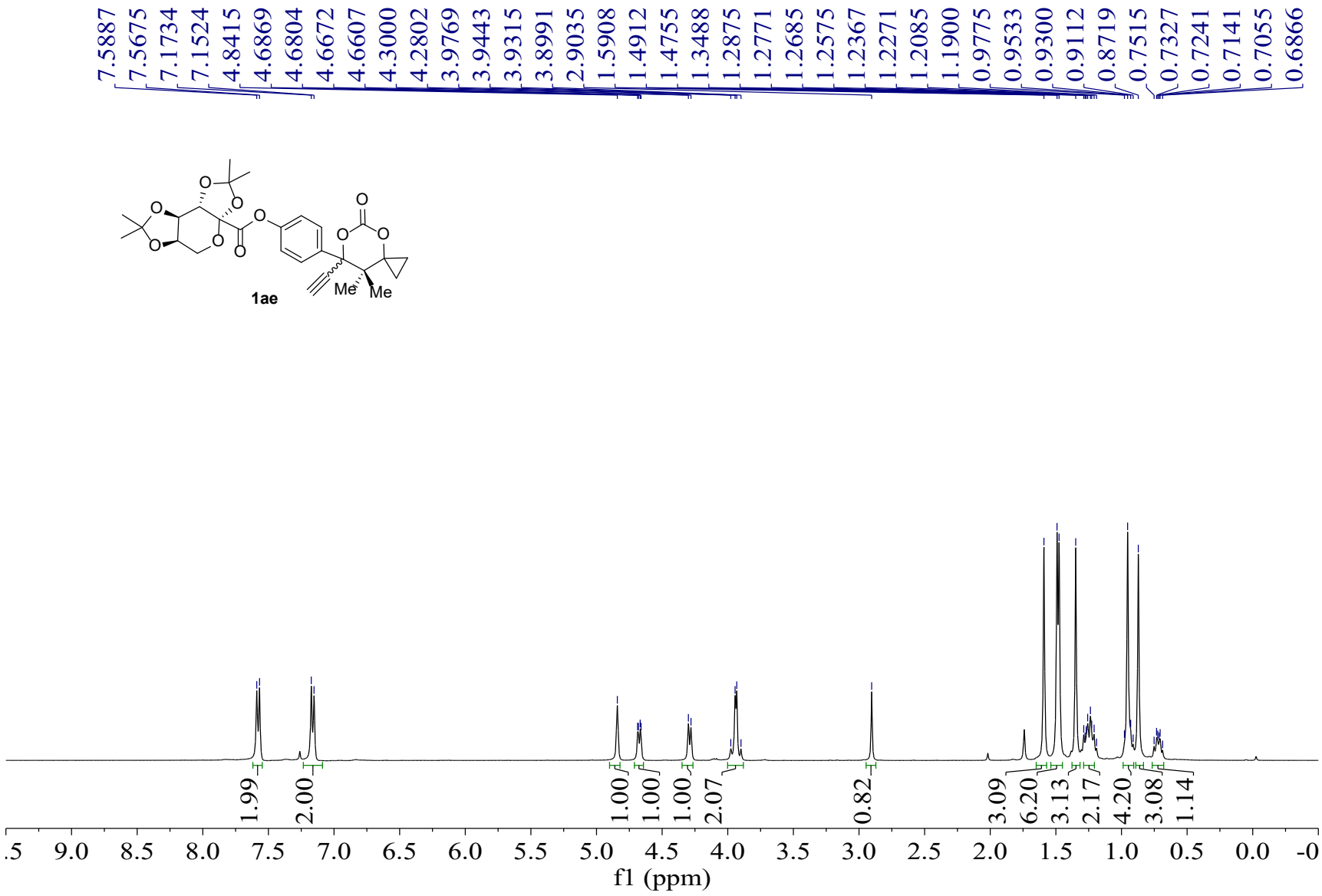
^{13}C NMR spectrum of compound **1ad**



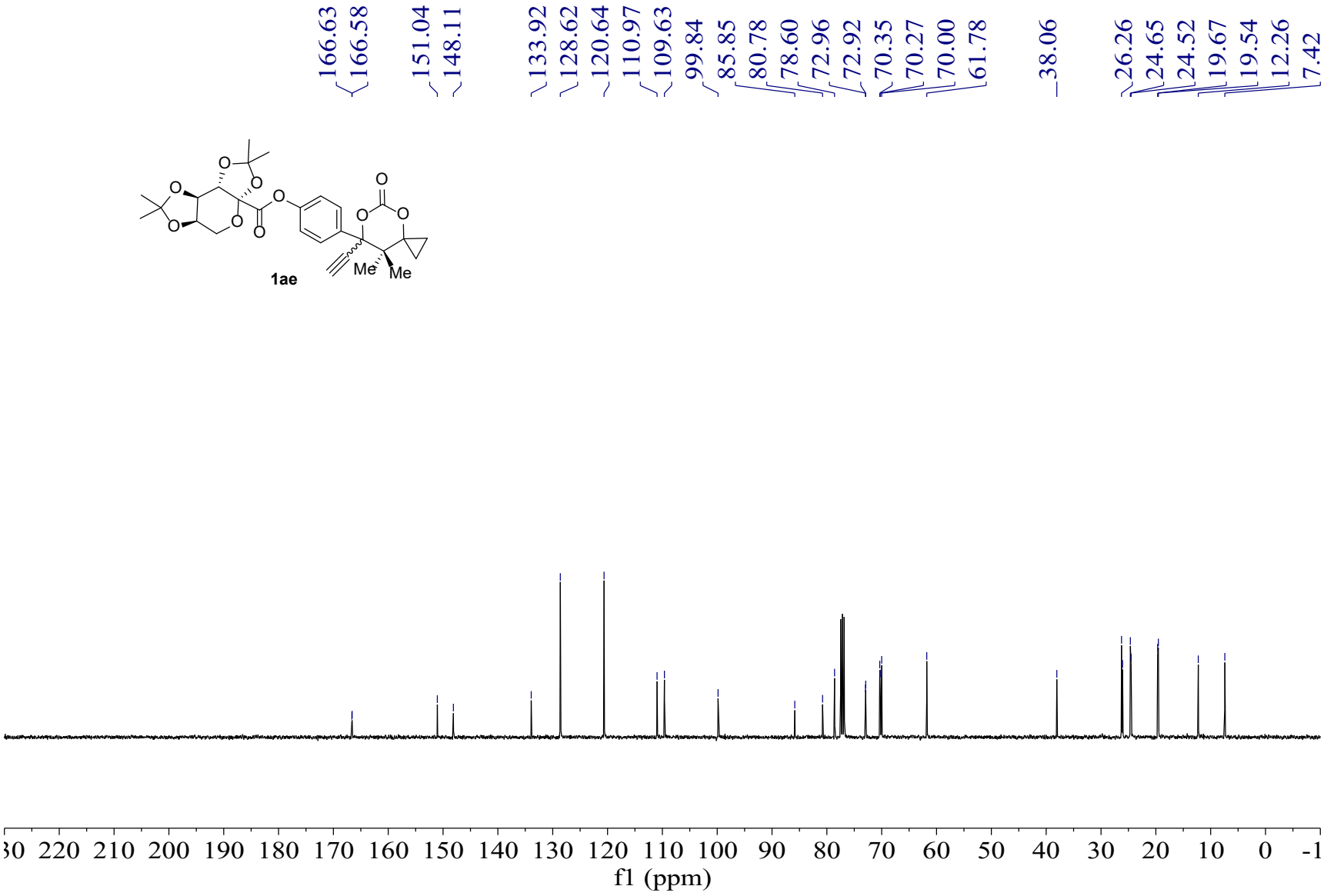
^{1}H NMR spectrum of compound **19ae**



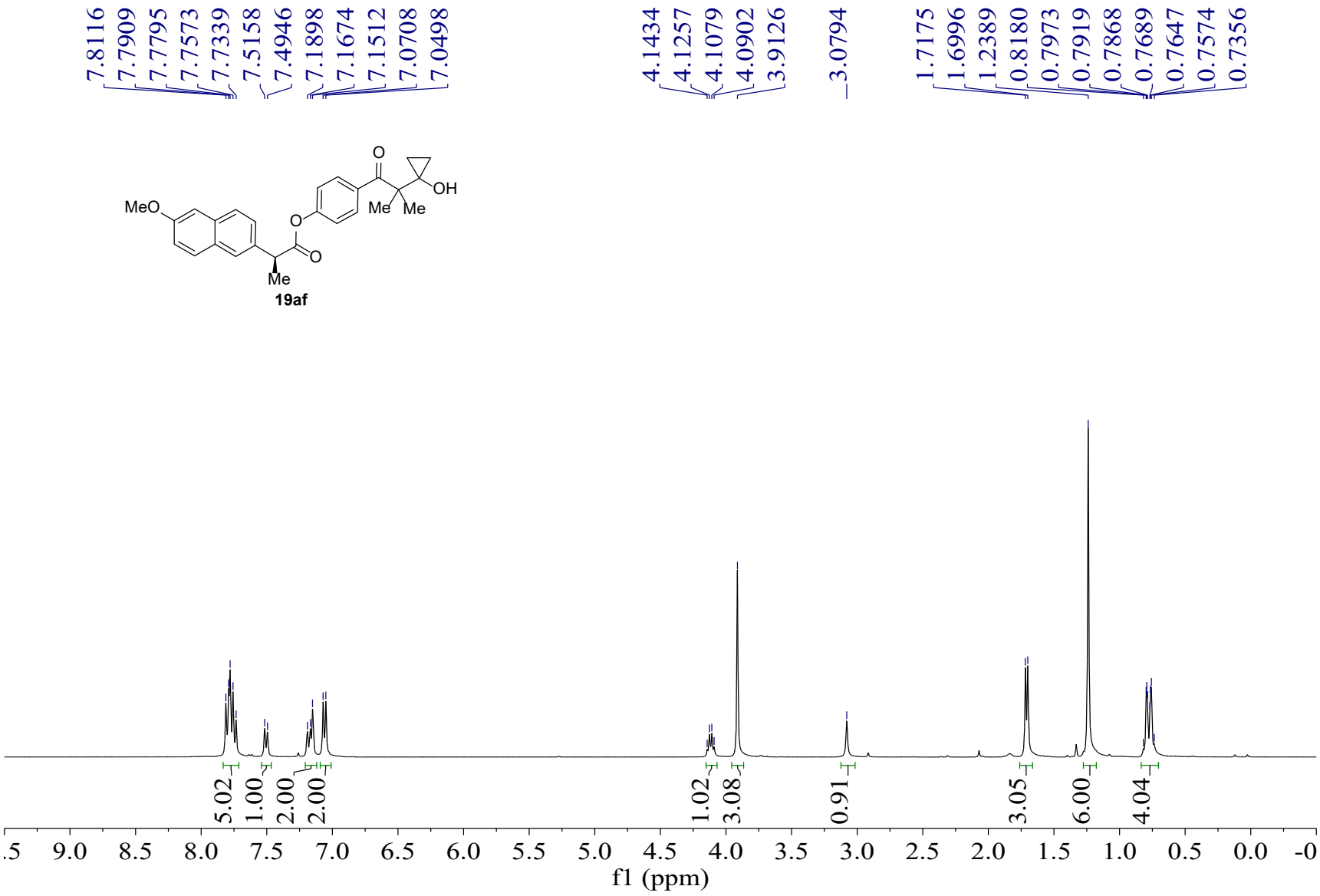
^{13}C NMR spectrum of compound **19ae**



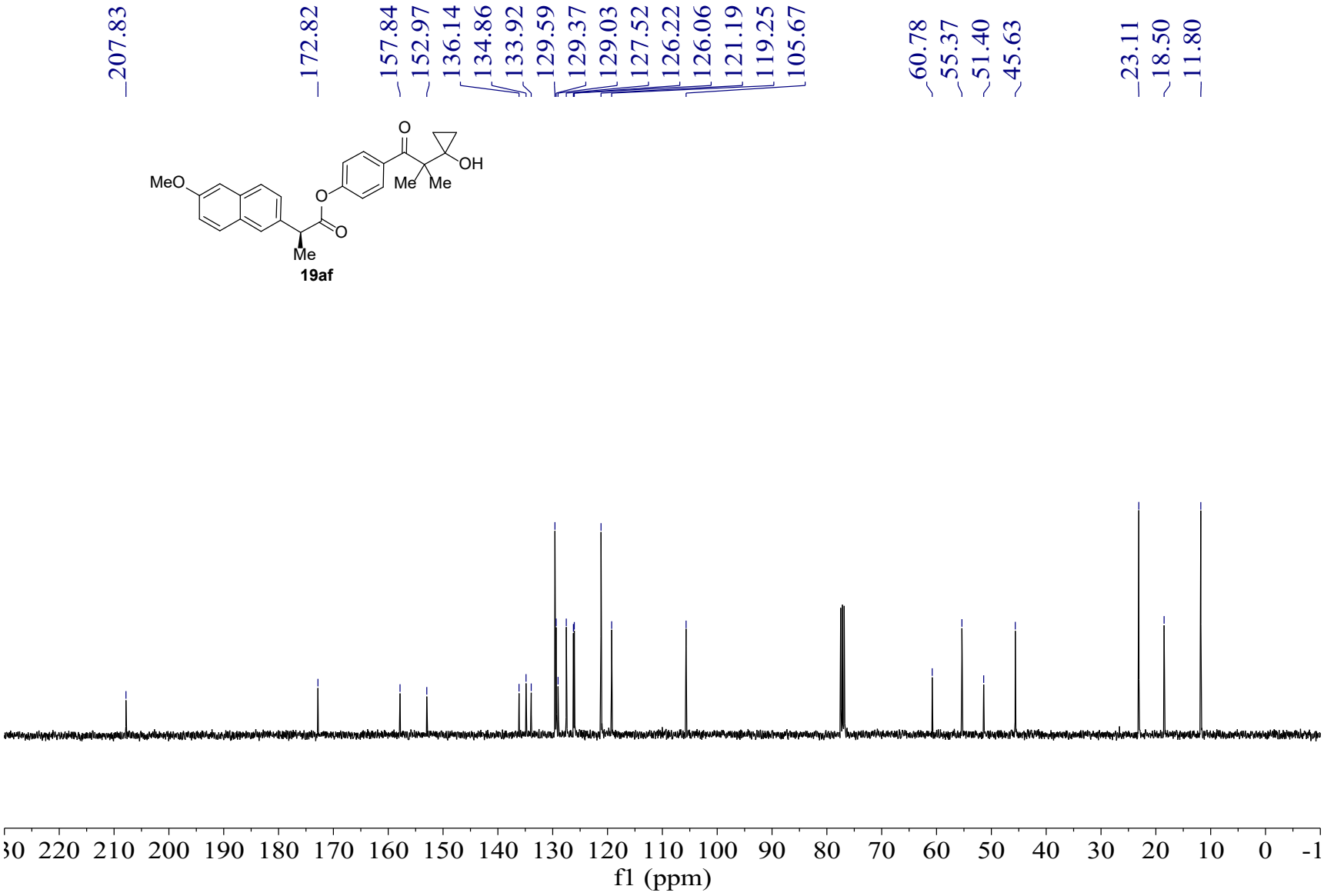
^{1}H NMR spectrum of compound **1ae**



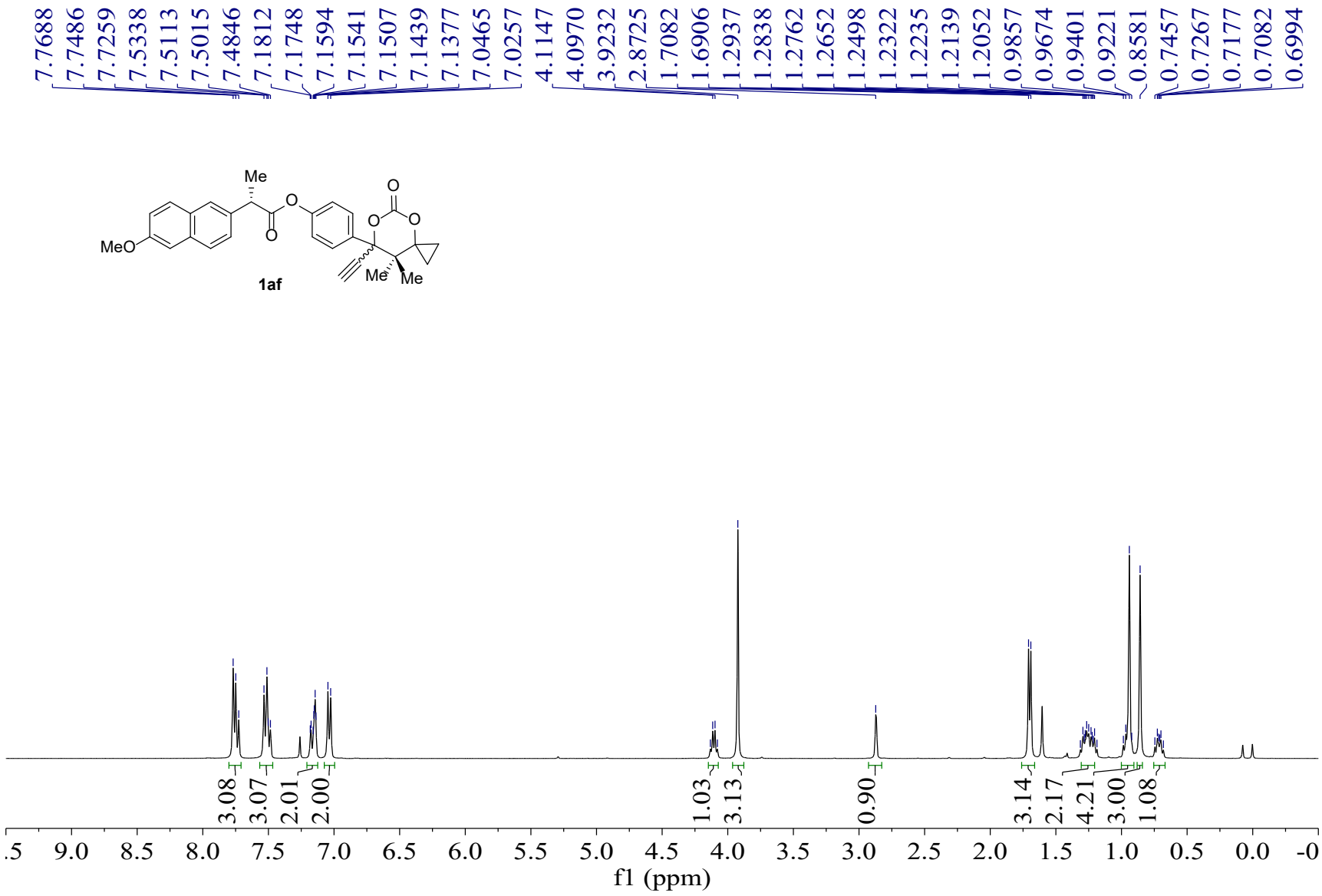
^{13}C NMR spectrum of compound **1ae**



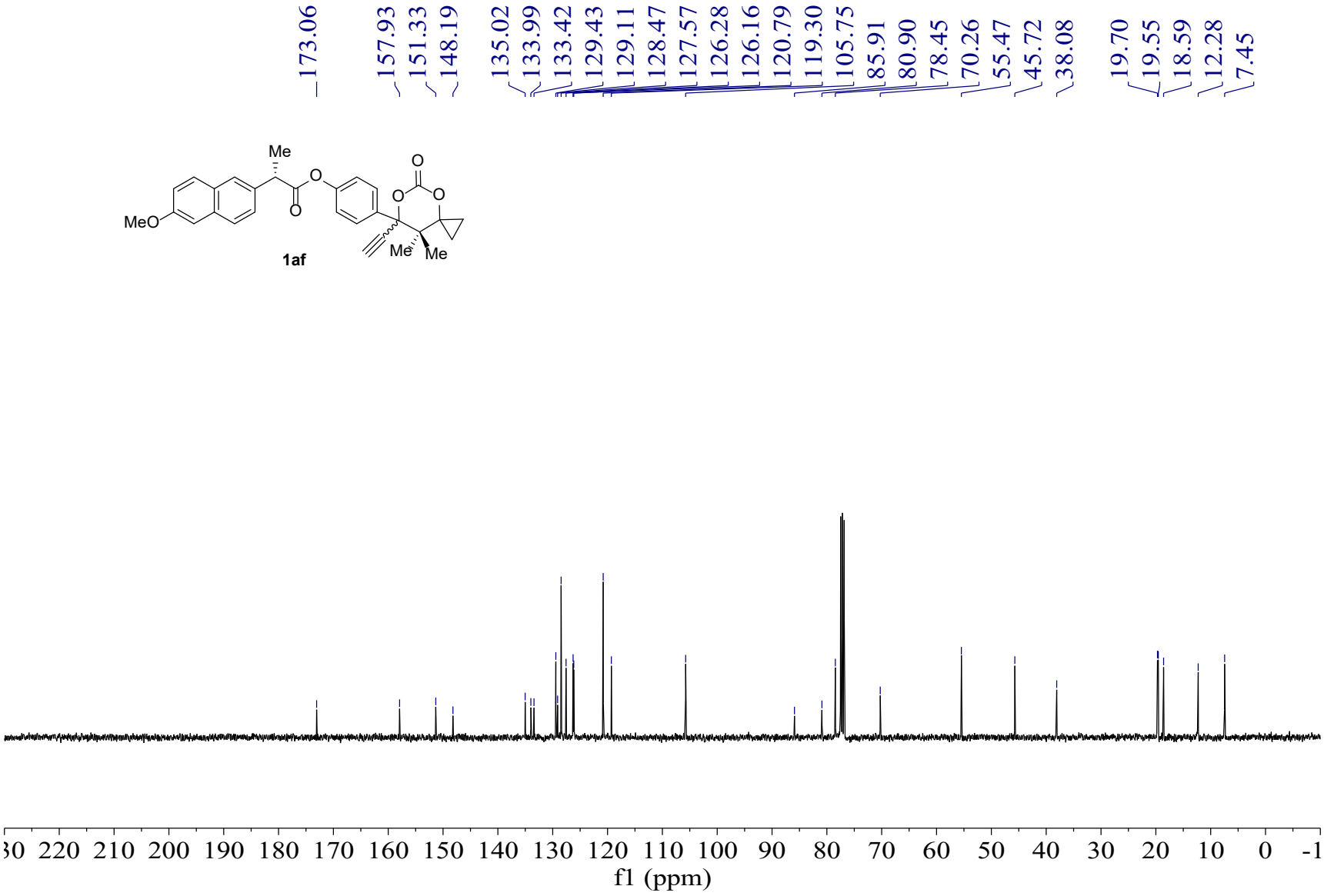
^{1}H NMR spectrum of compound **19af**



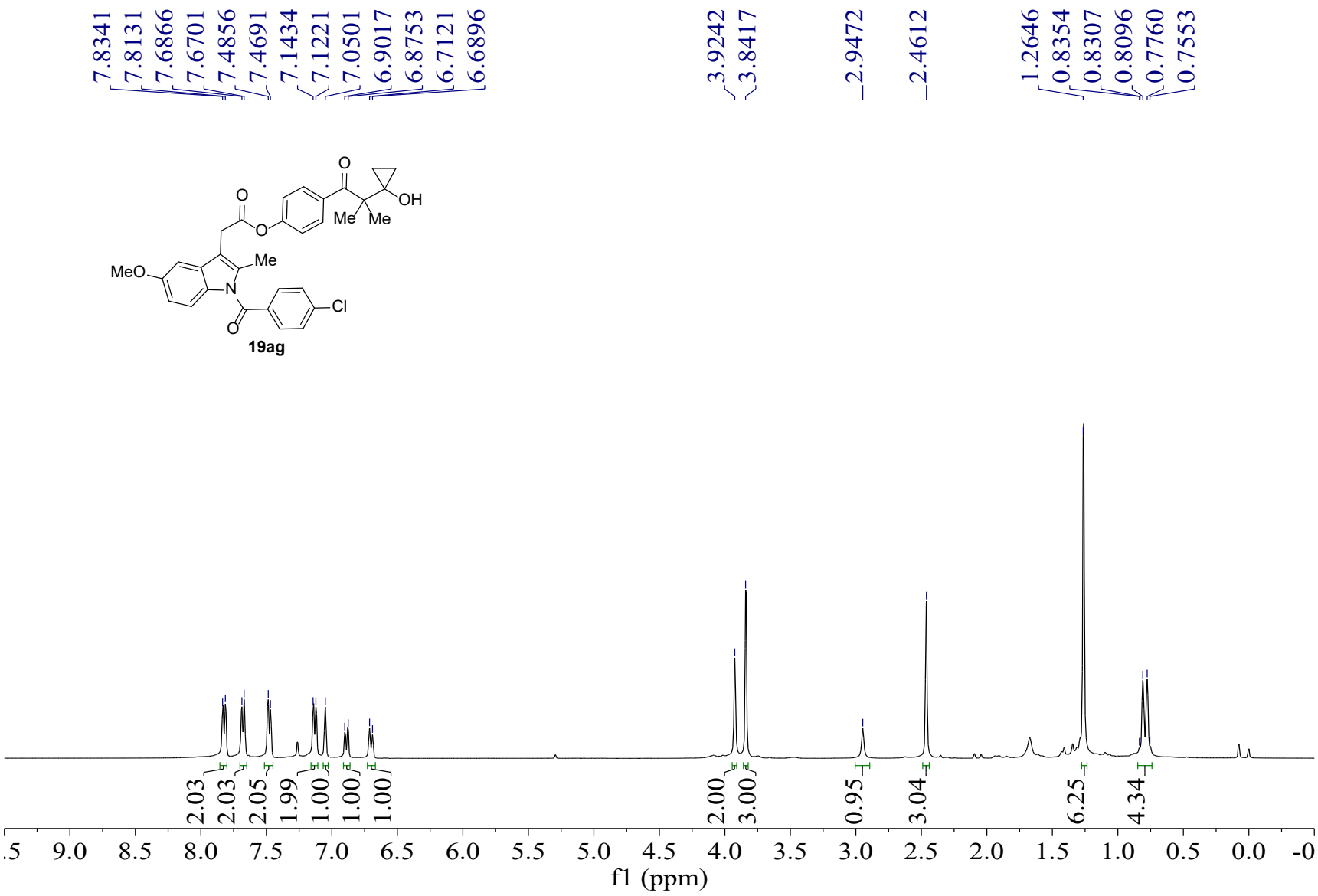
^{13}C NMR spectrum of compound **19af**



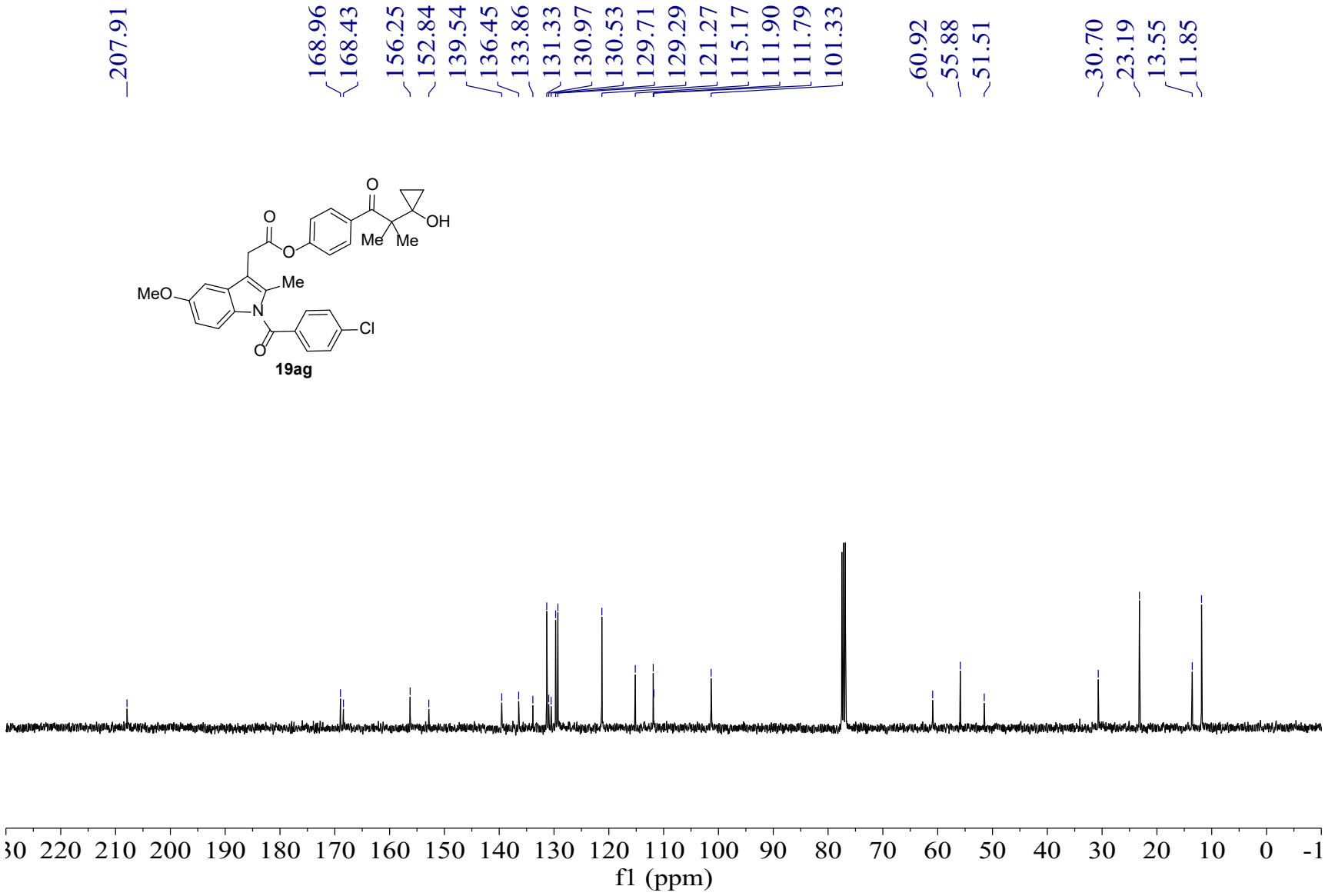
^{1}H NMR spectrum of compound **1af**



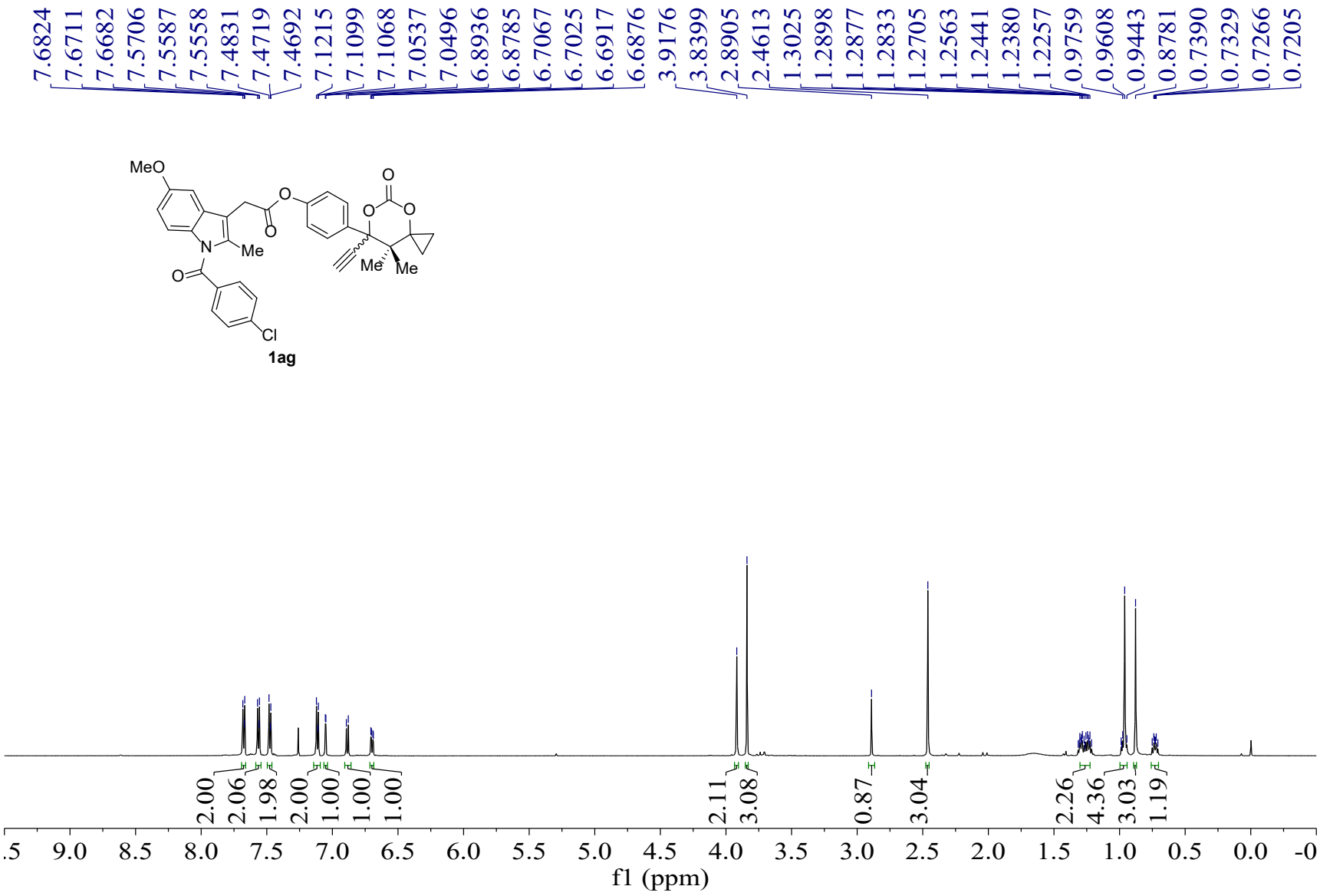
^{13}C NMR spectrum of compound **1af**



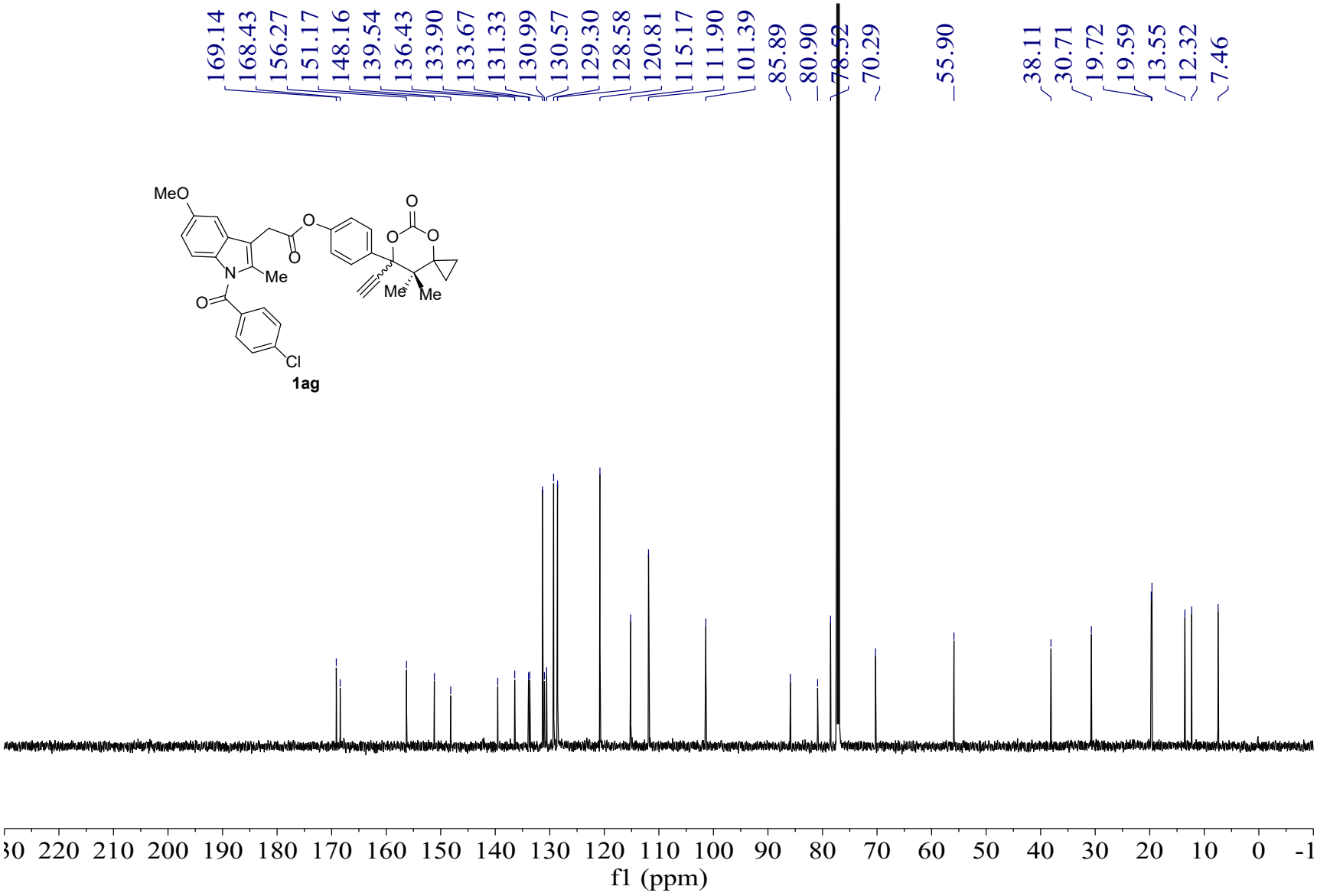
^{1}H NMR spectrum of compound **19ag**



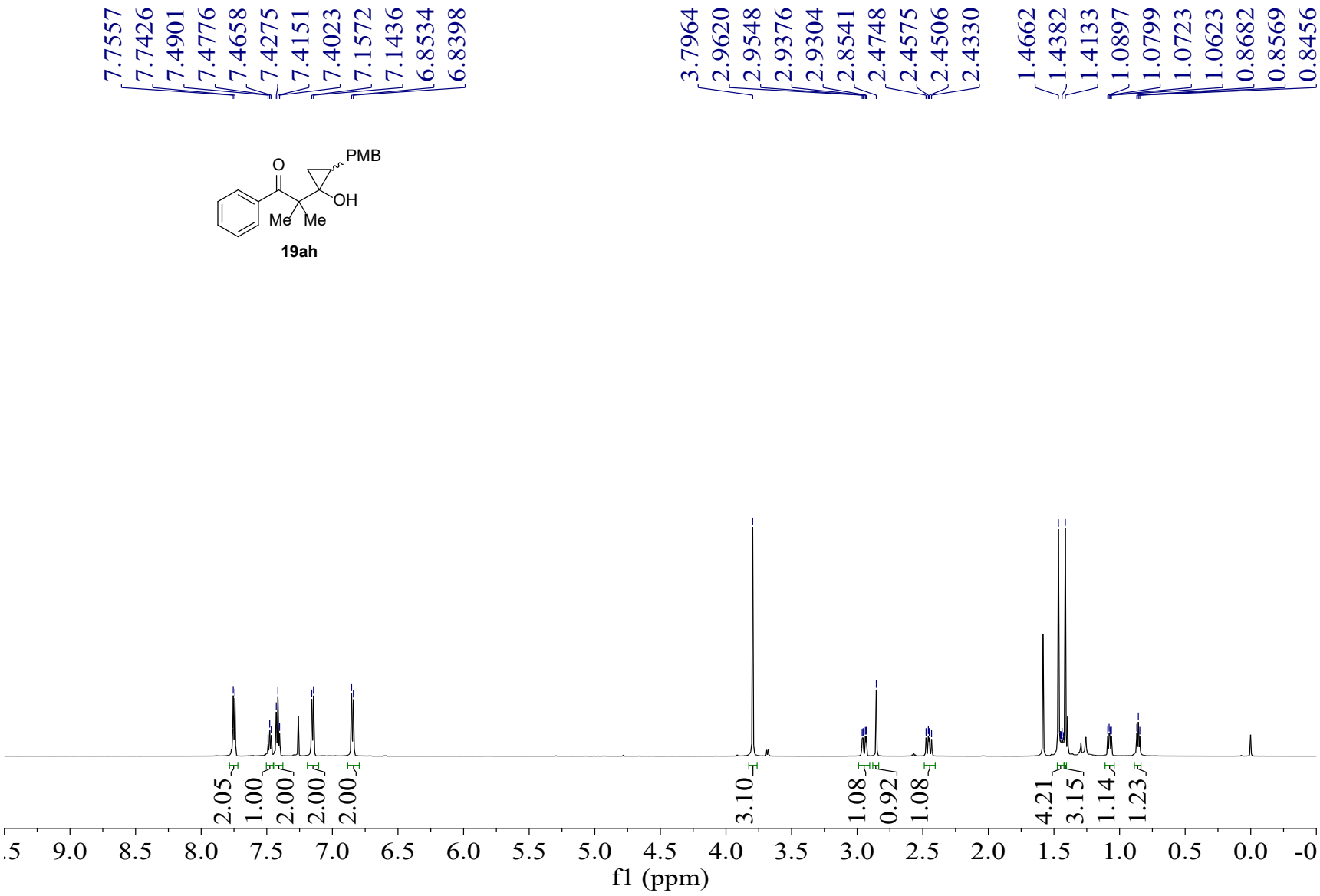
^{13}C NMR spectrum of compound **19ag**



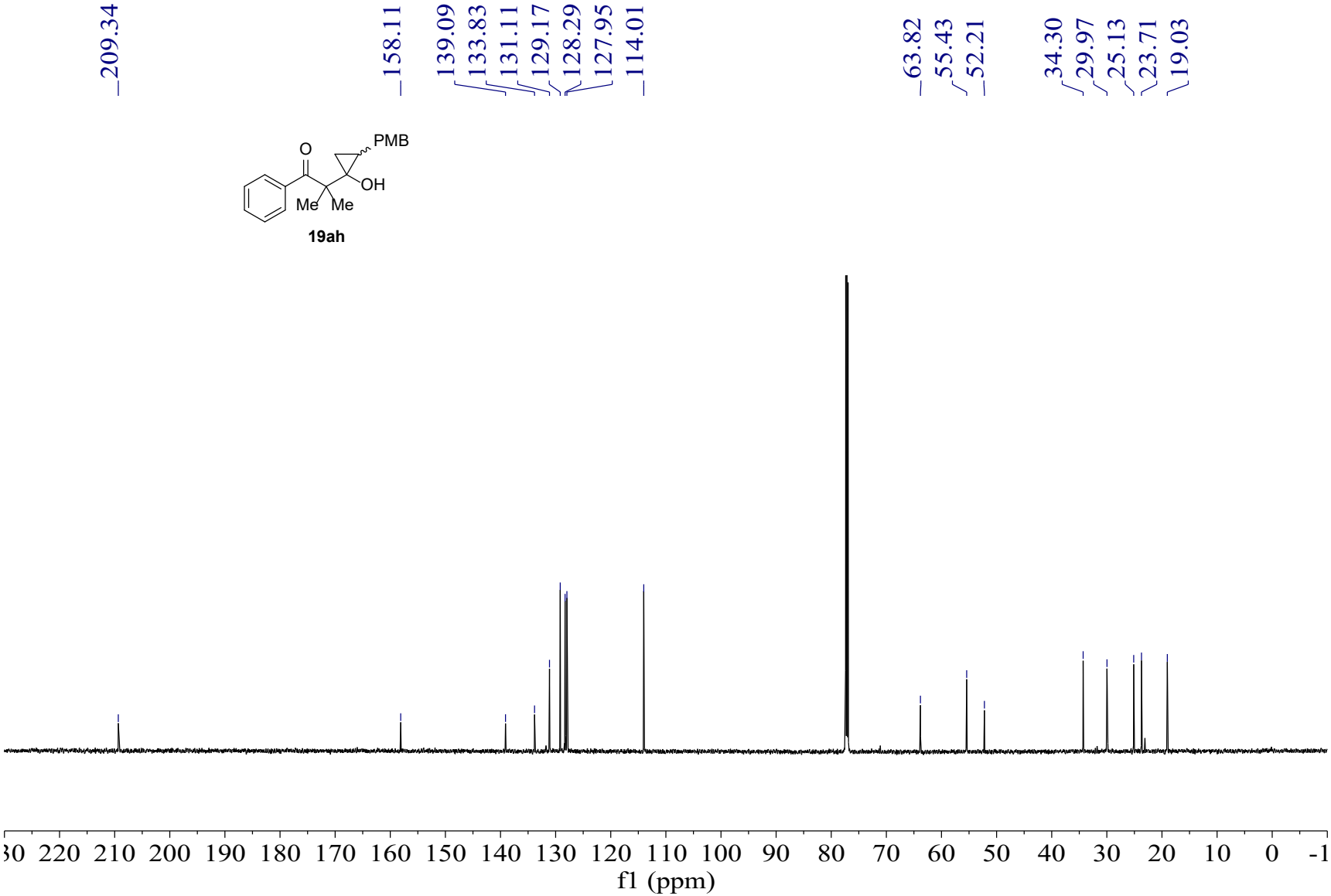
^{1}H NMR spectrum of compound **1ag**



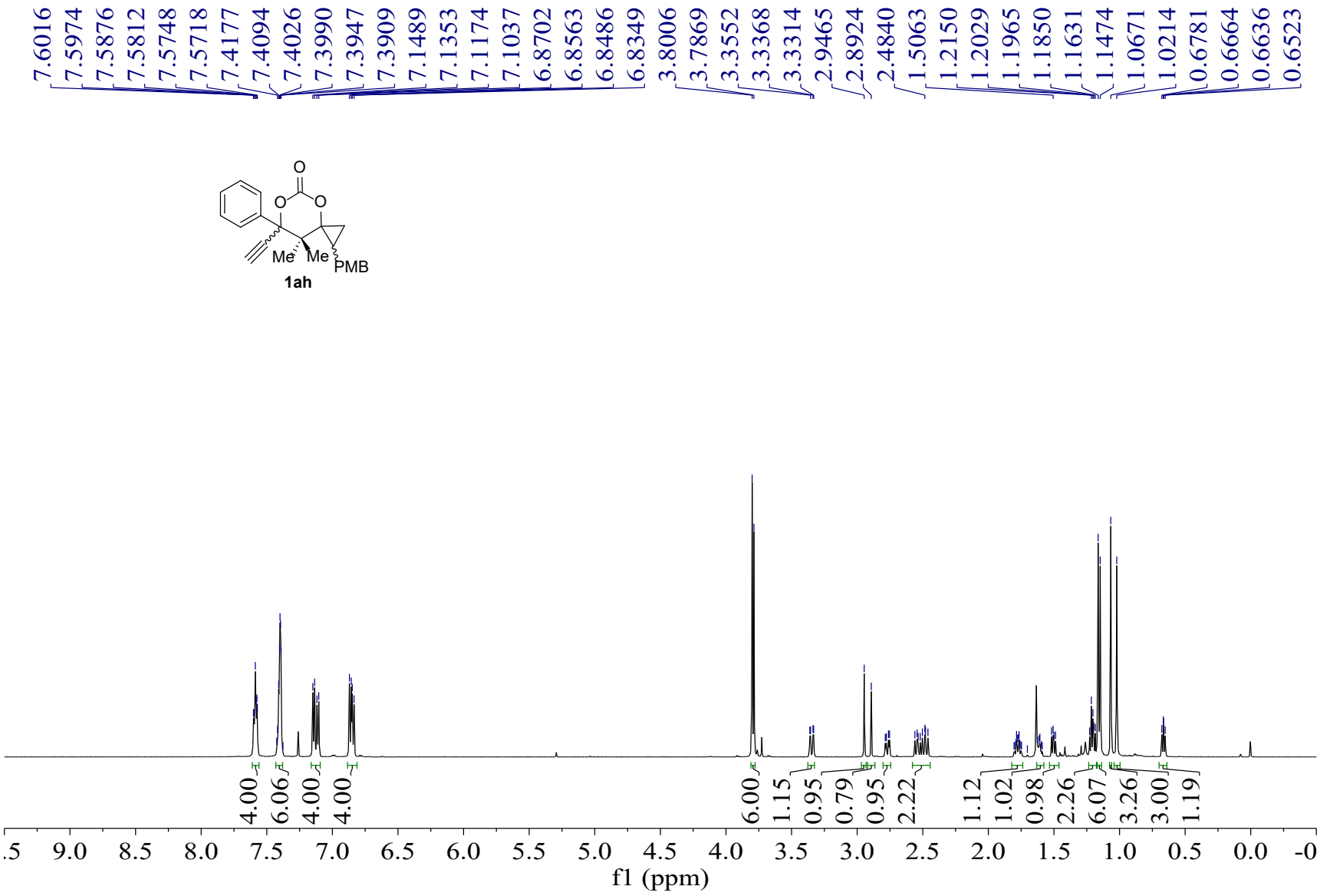
^{13}C NMR spectrum of compound **1ag**



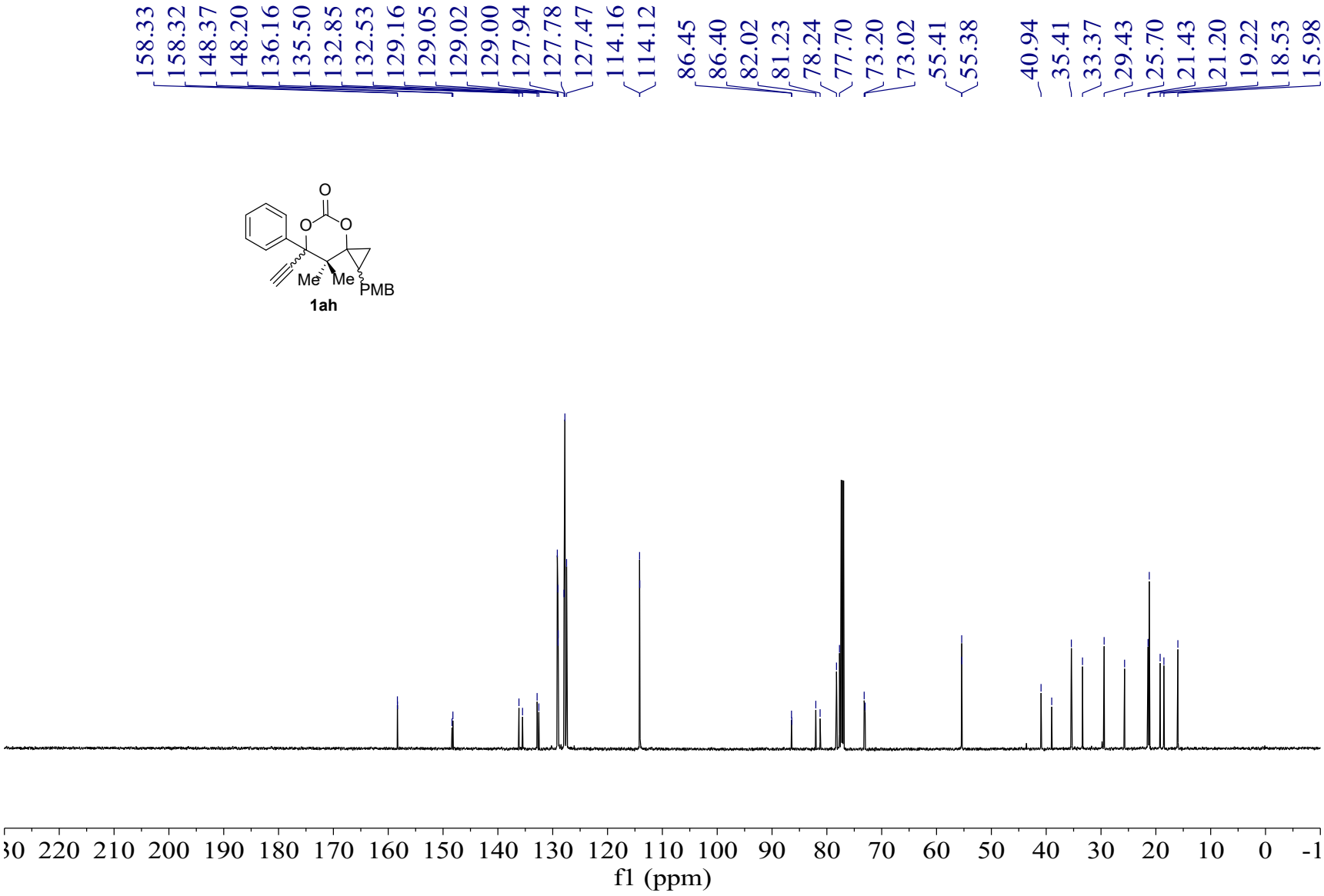
^{1}H NMR spectrum of compound **19ah**



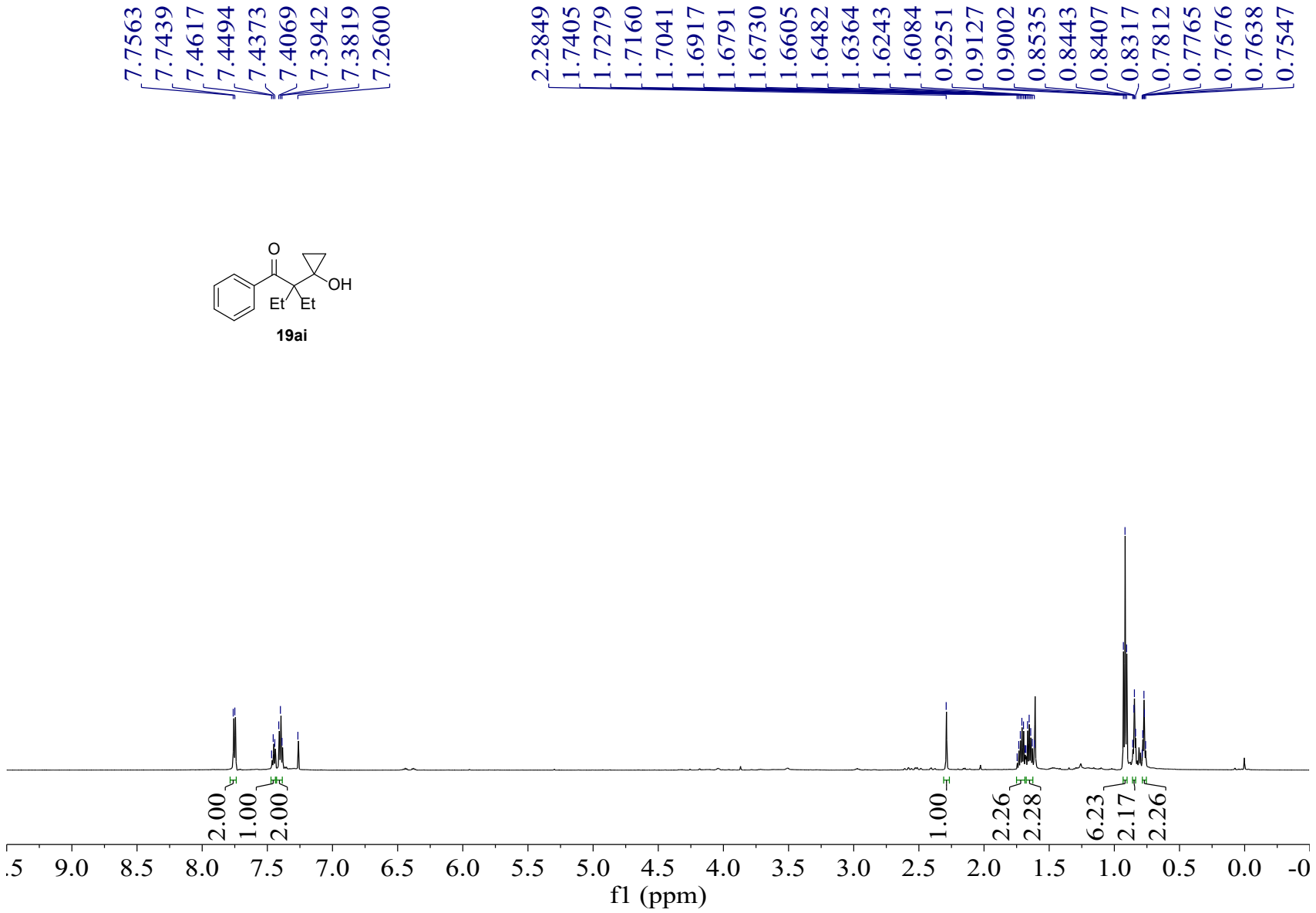
^{13}C NMR spectrum of compound **19ah**



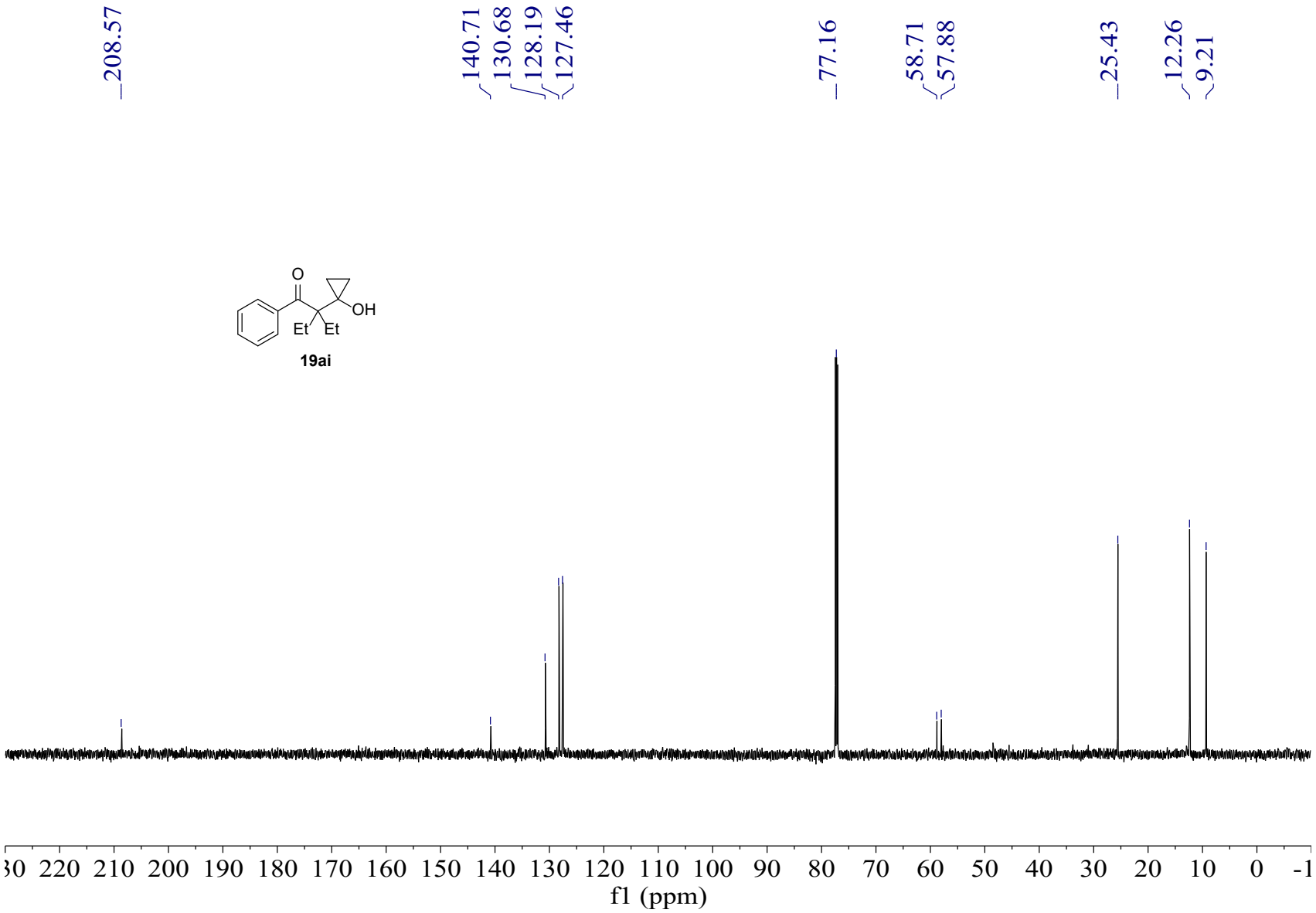
^{1}H NMR spectrum of compound **1ah**



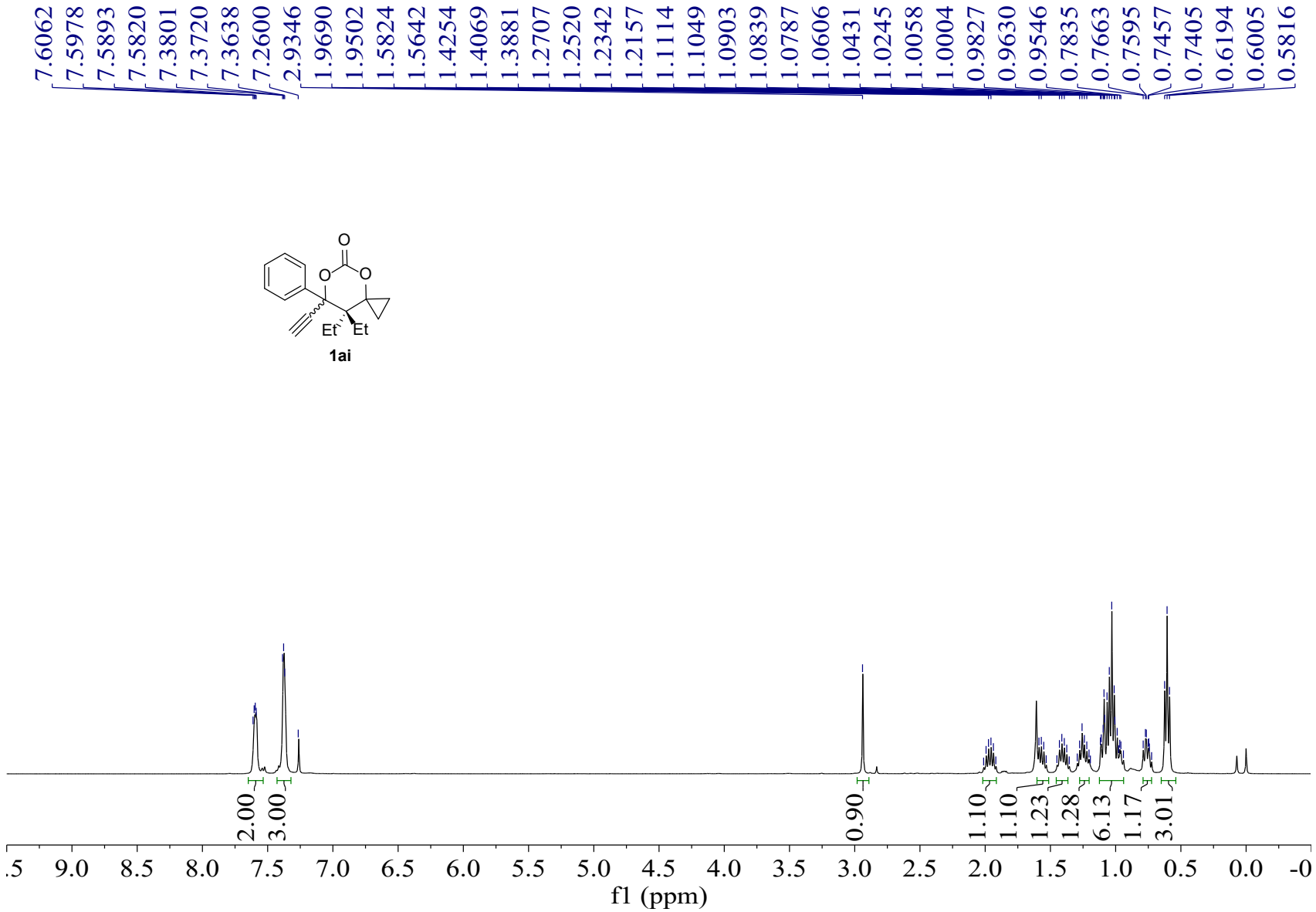
^{13}C NMR spectrum of compound **1ah**



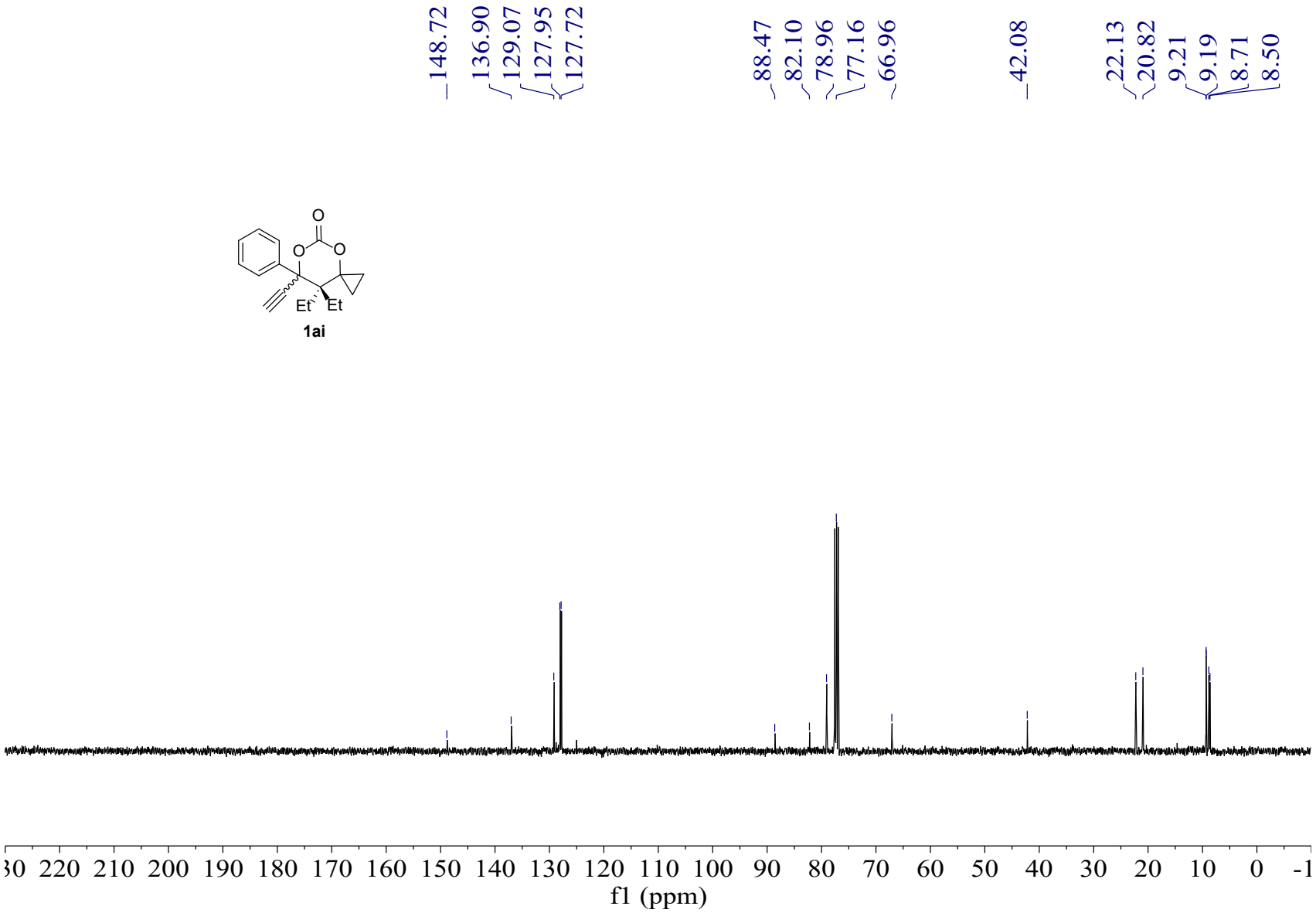
^{1}H NMR spectrum of compound **19ai**



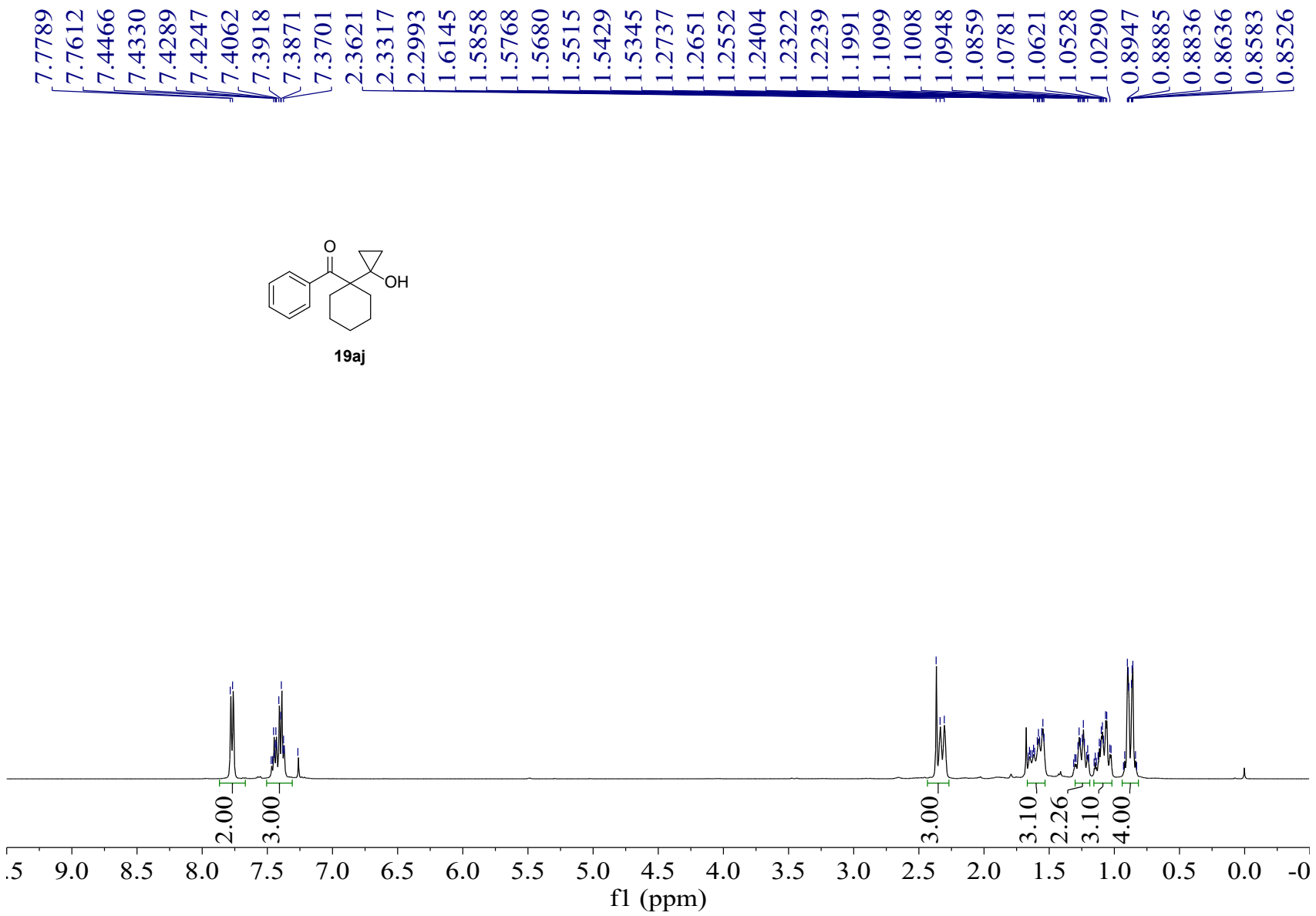
^{13}C NMR spectrum of compound **19ai**



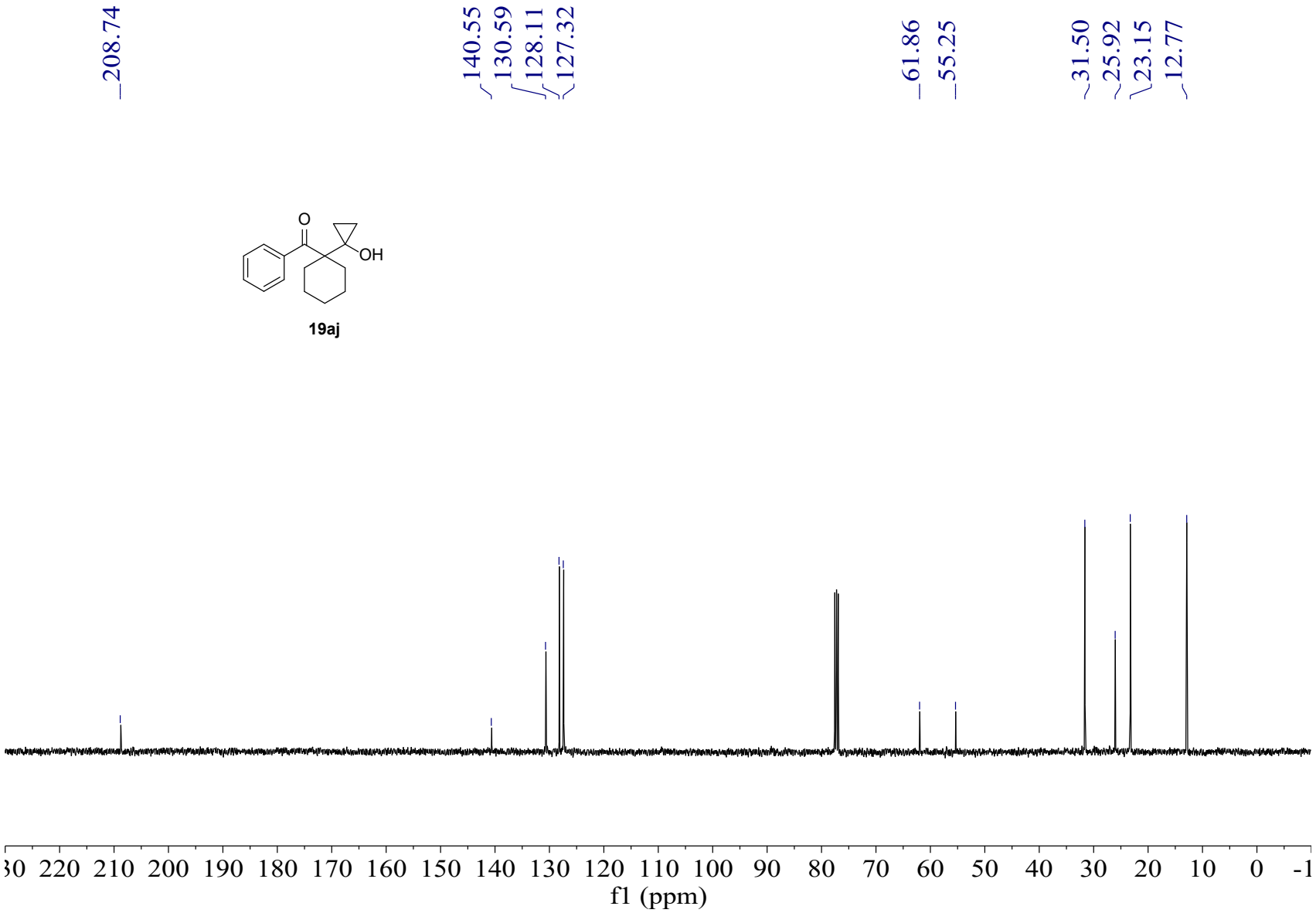
^{1}H NMR spectrum of compound **1ai**



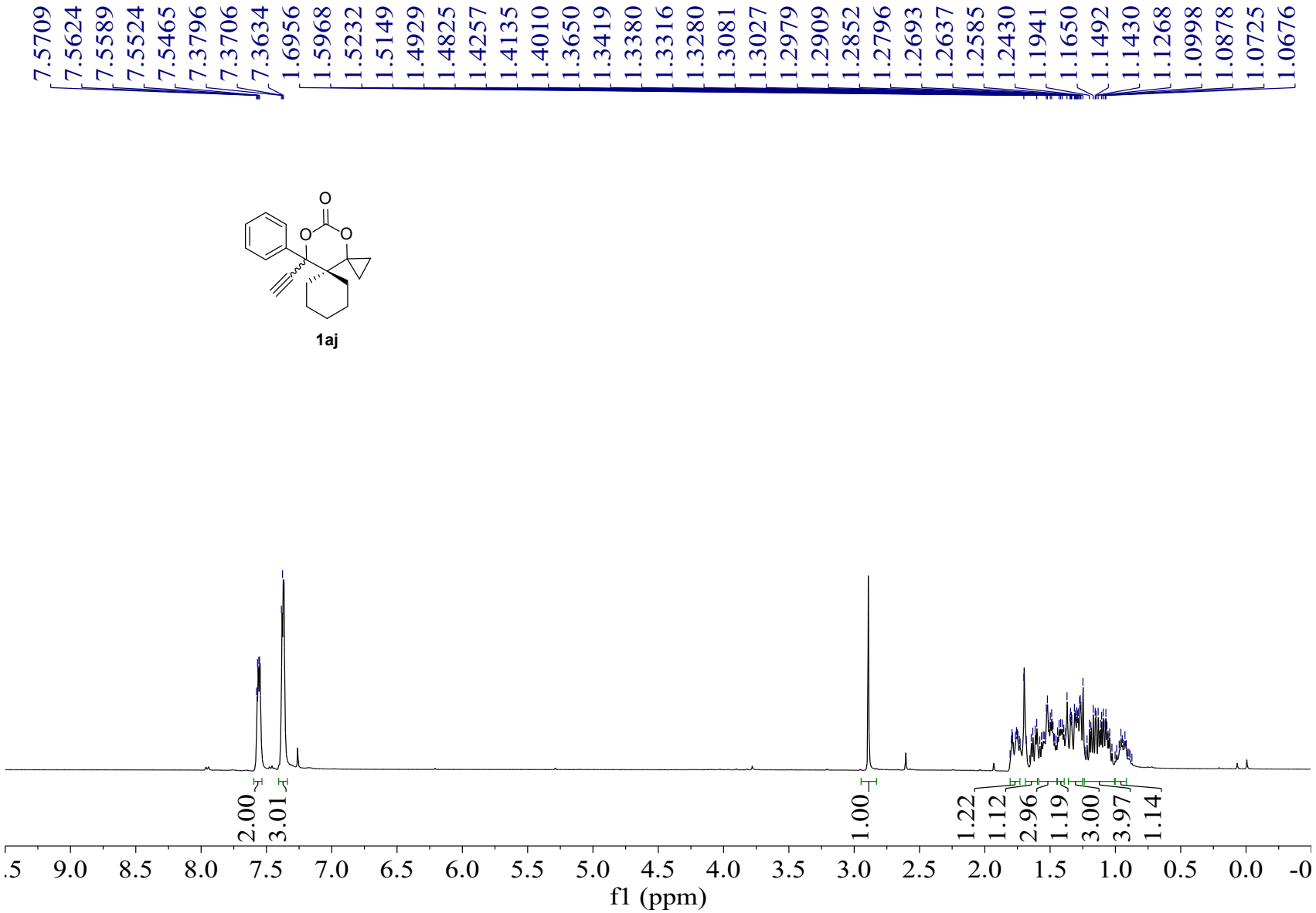
^{13}C NMR spectrum of compound **1ai**



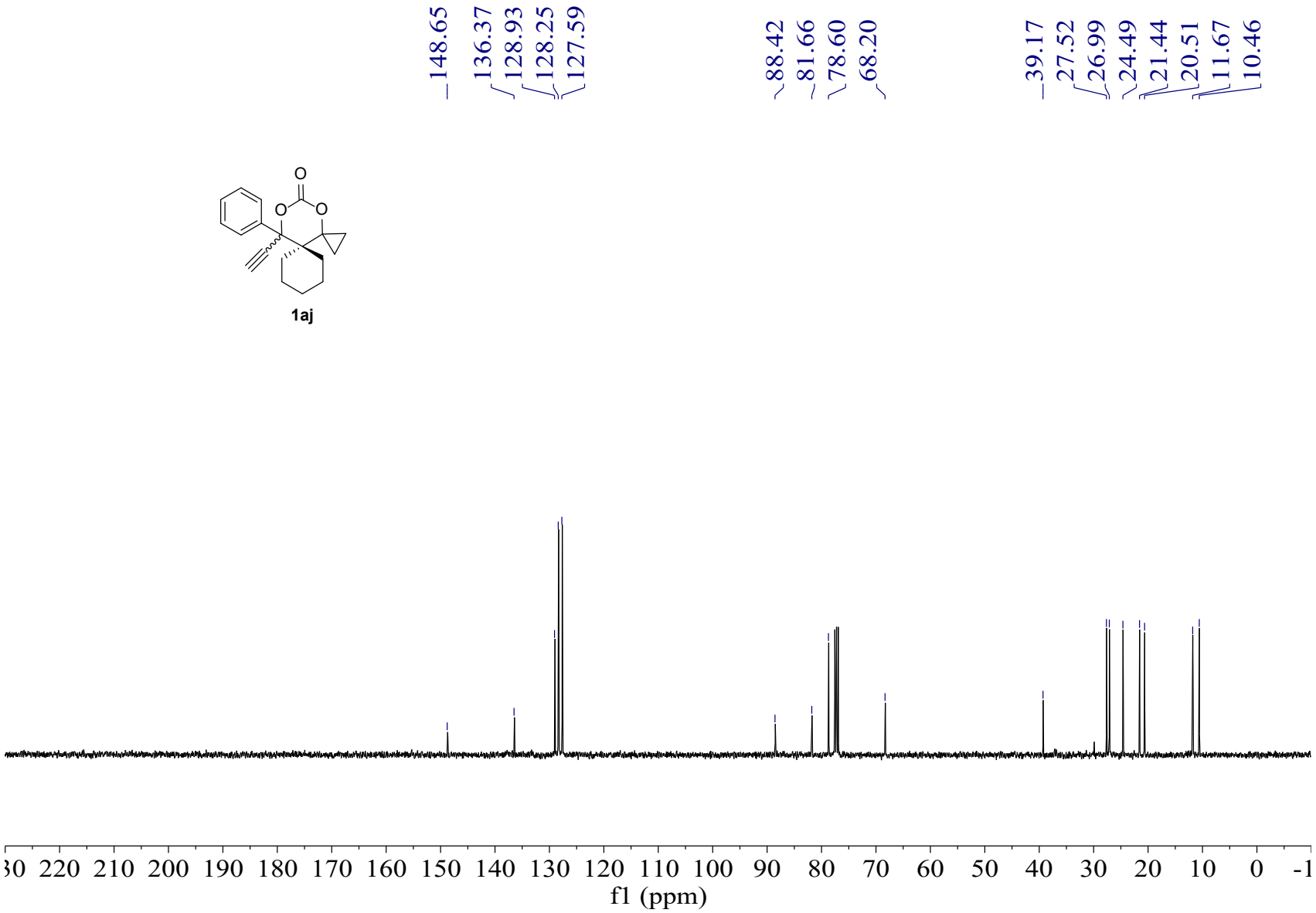
^{1}H NMR spectrum of compound **19aj**



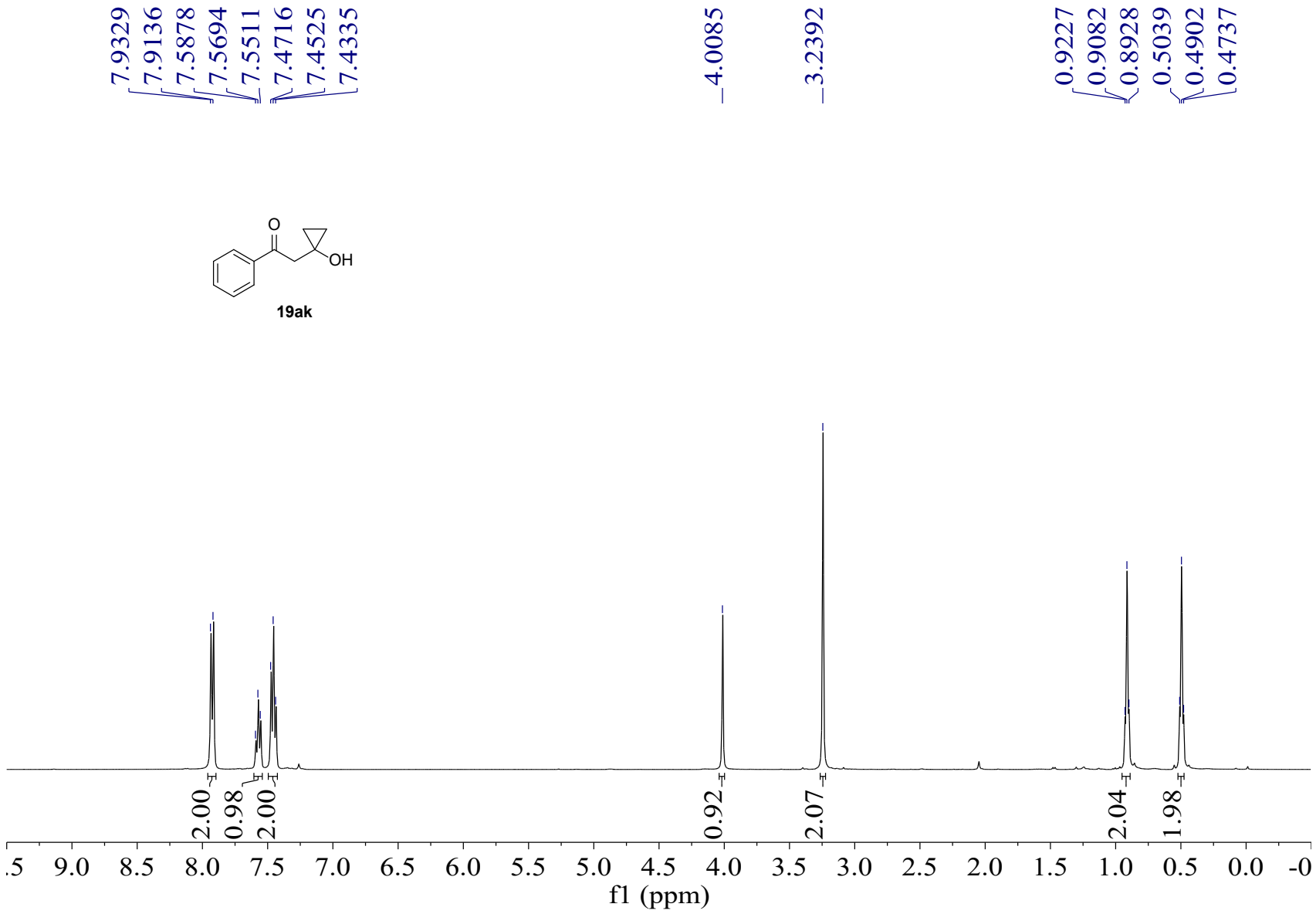
^{13}C NMR spectrum of compound **19aj**



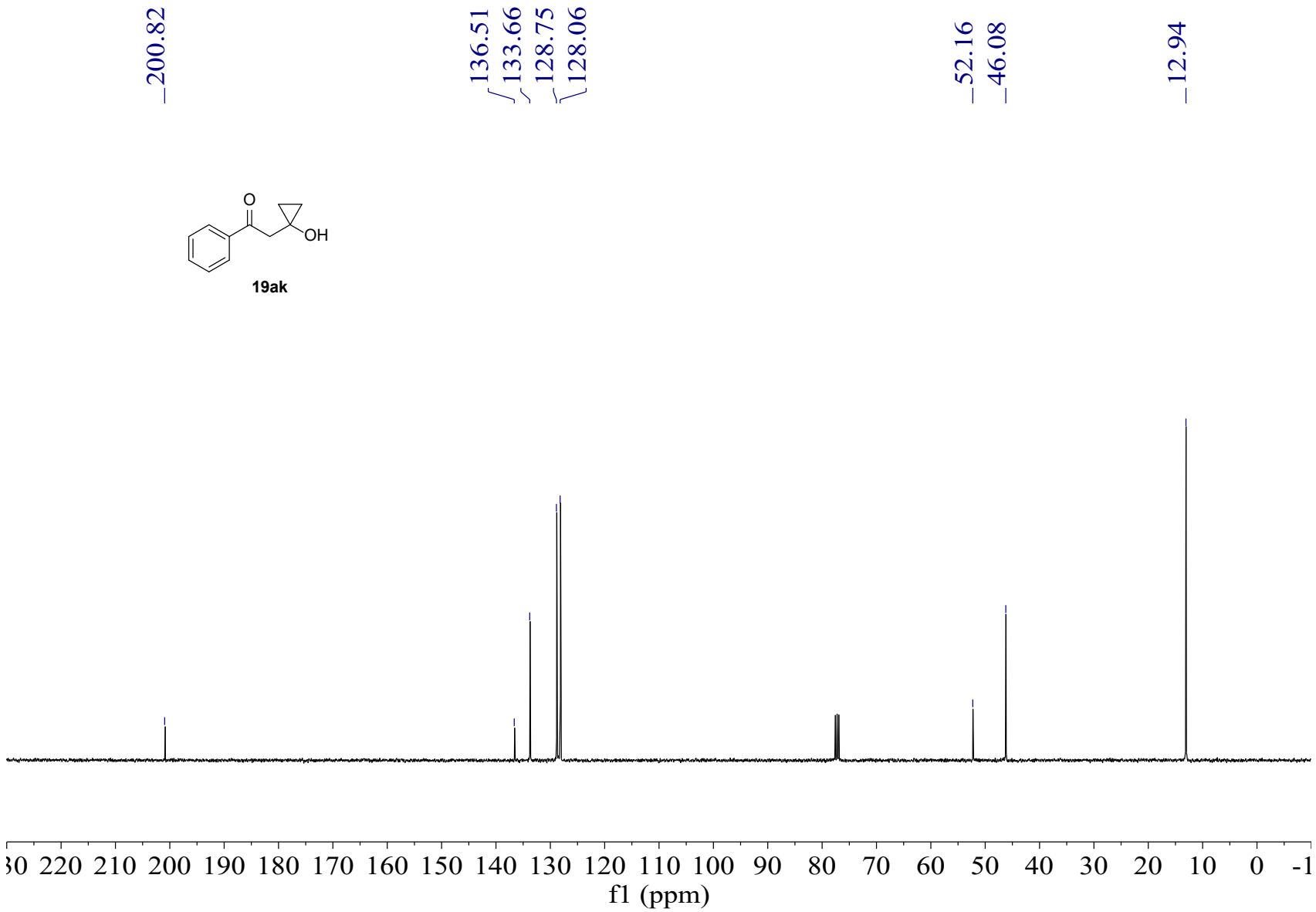
^{1}H NMR spectrum of compound **1aj**



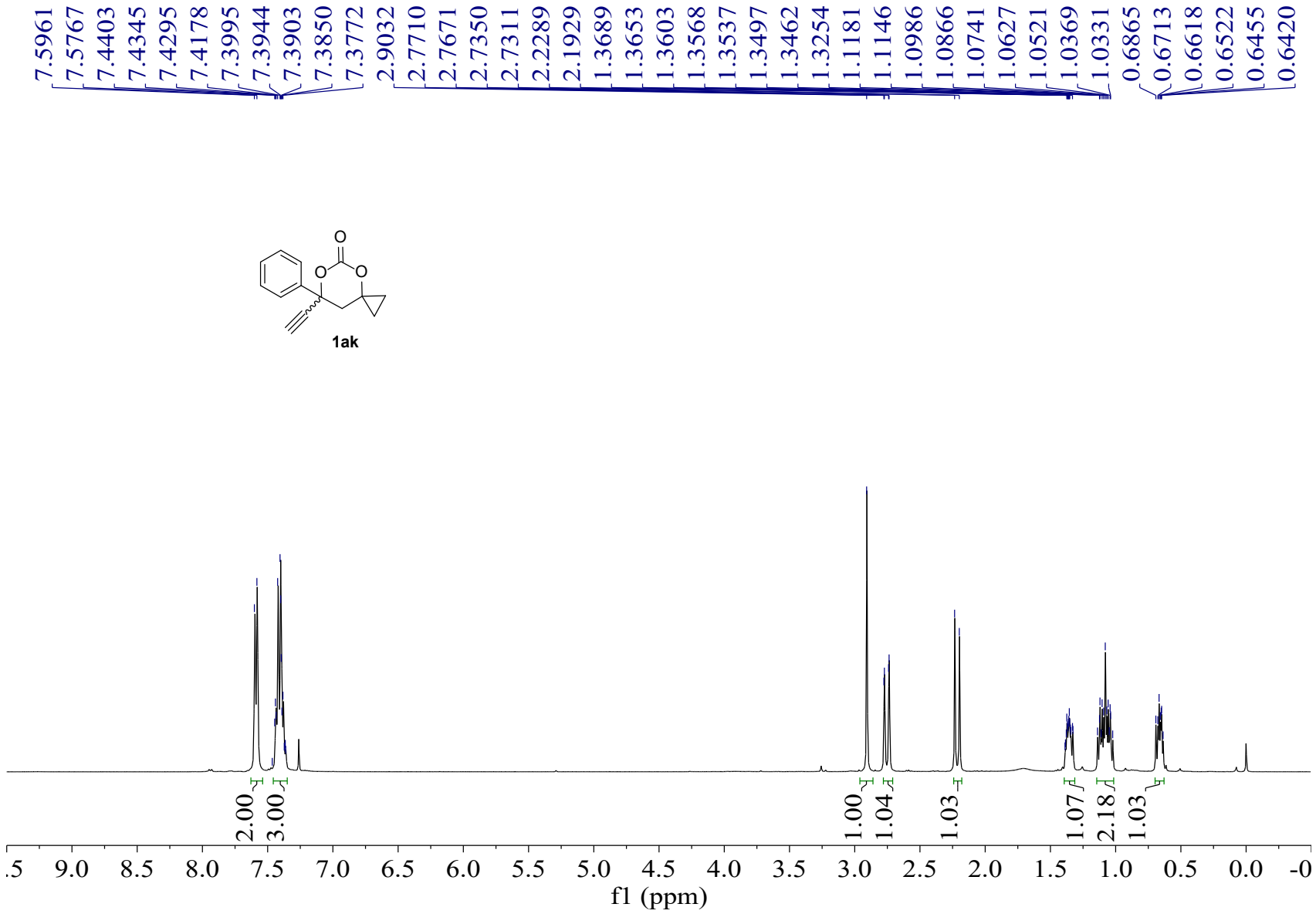
^{13}C NMR spectrum of compound **1aj**



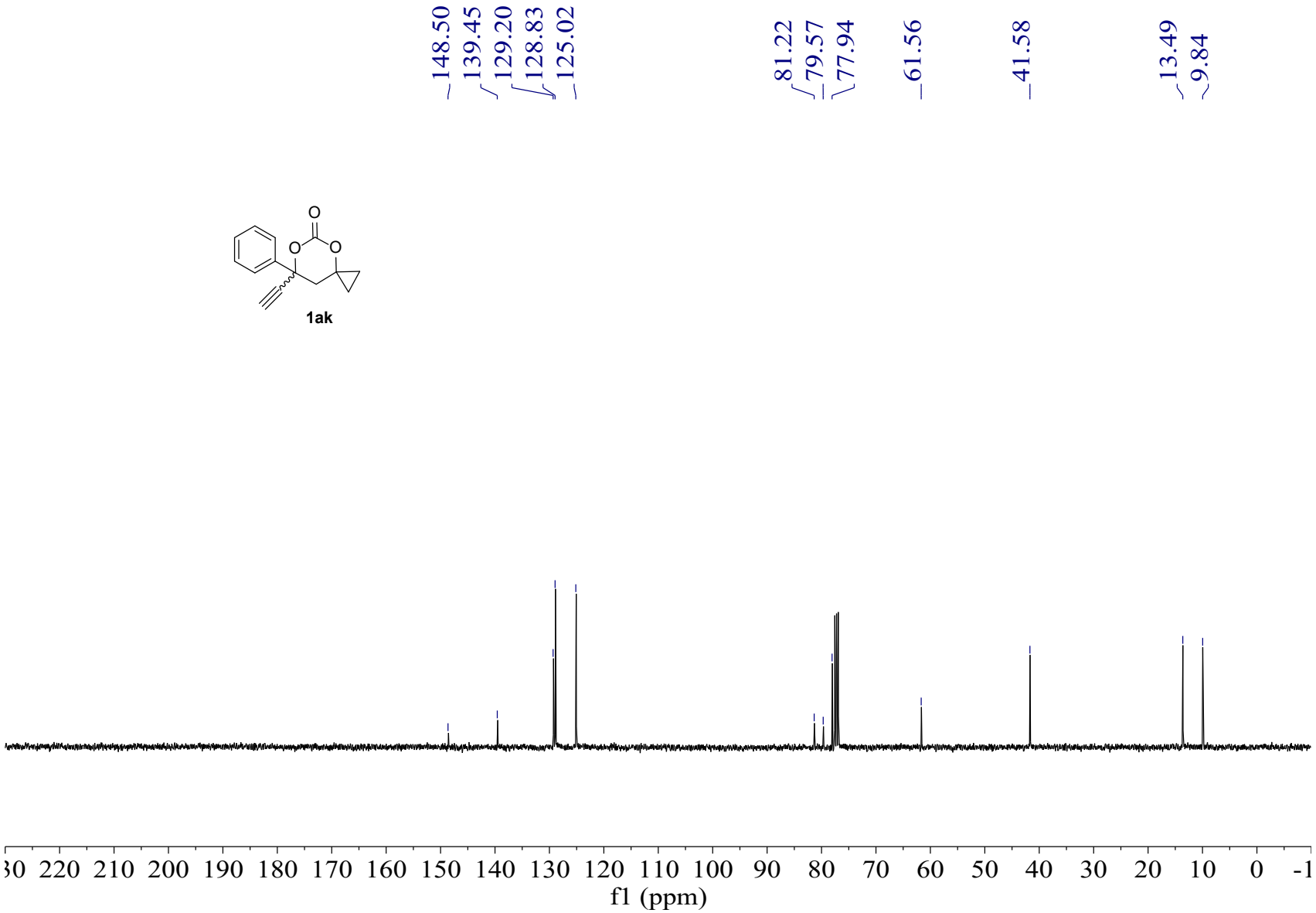
^{1}H NMR spectrum of compound **19ak**



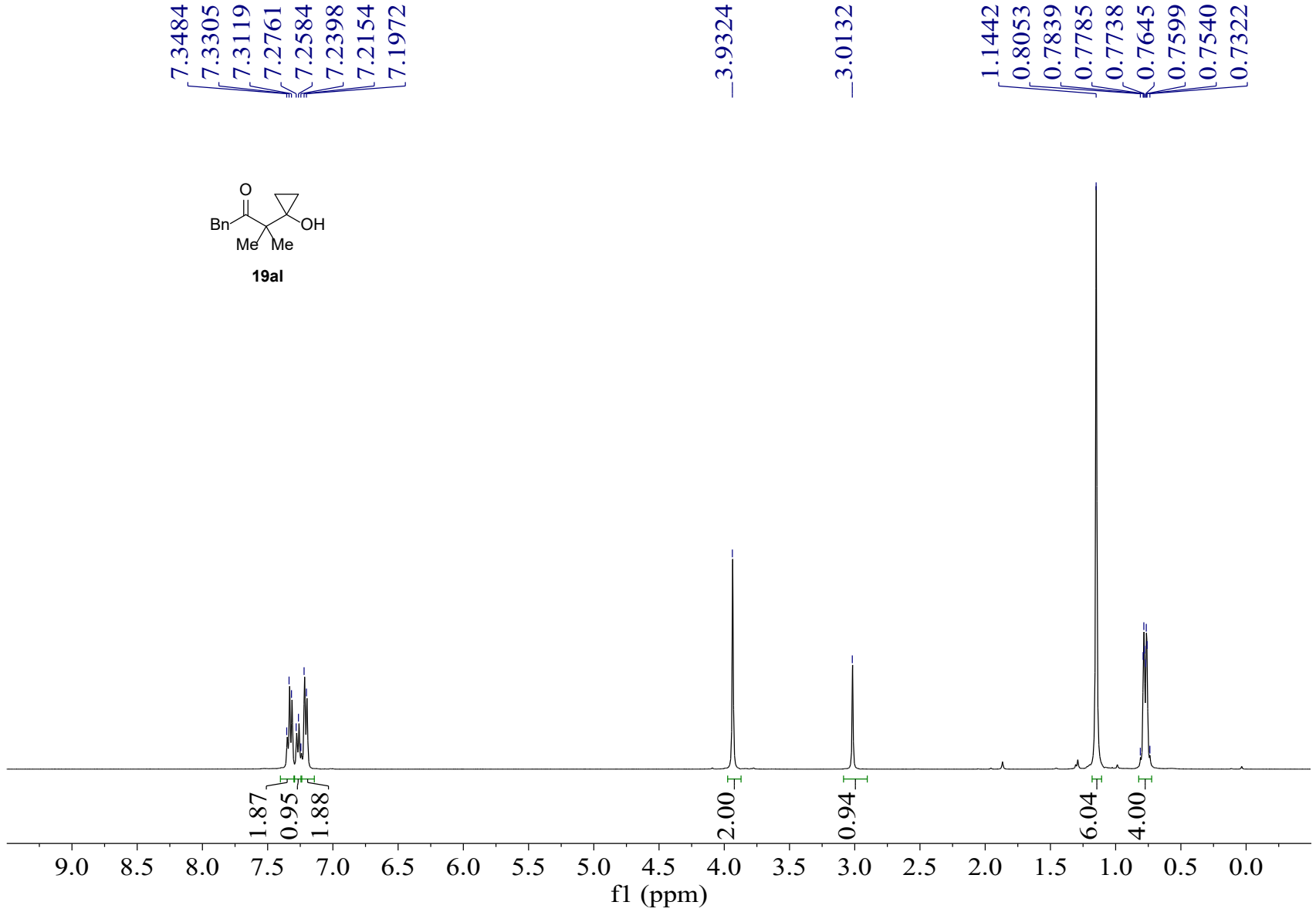
^{13}C NMR spectrum of compound **19ak**



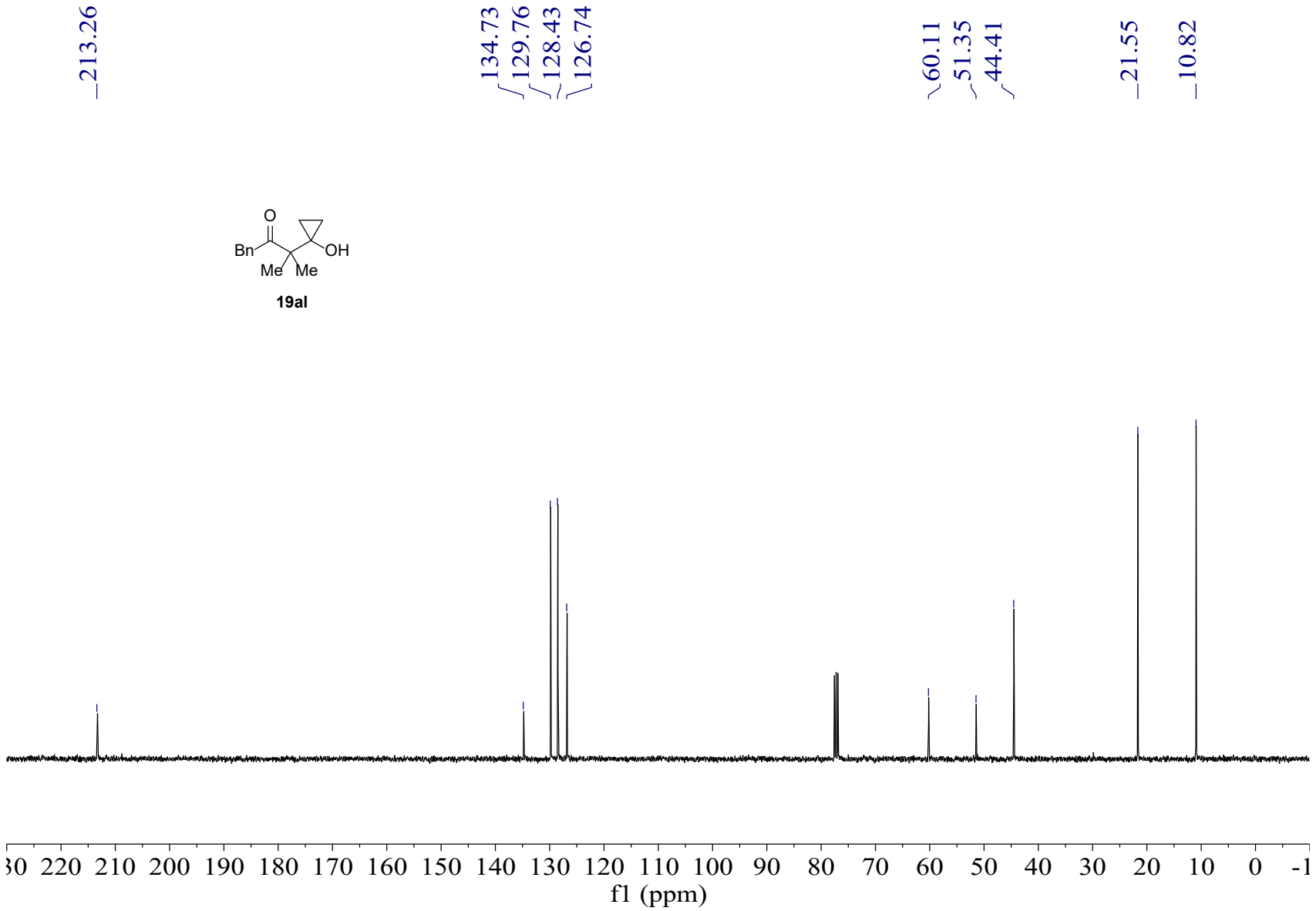
^{1}H NMR spectrum of compound **1ak**



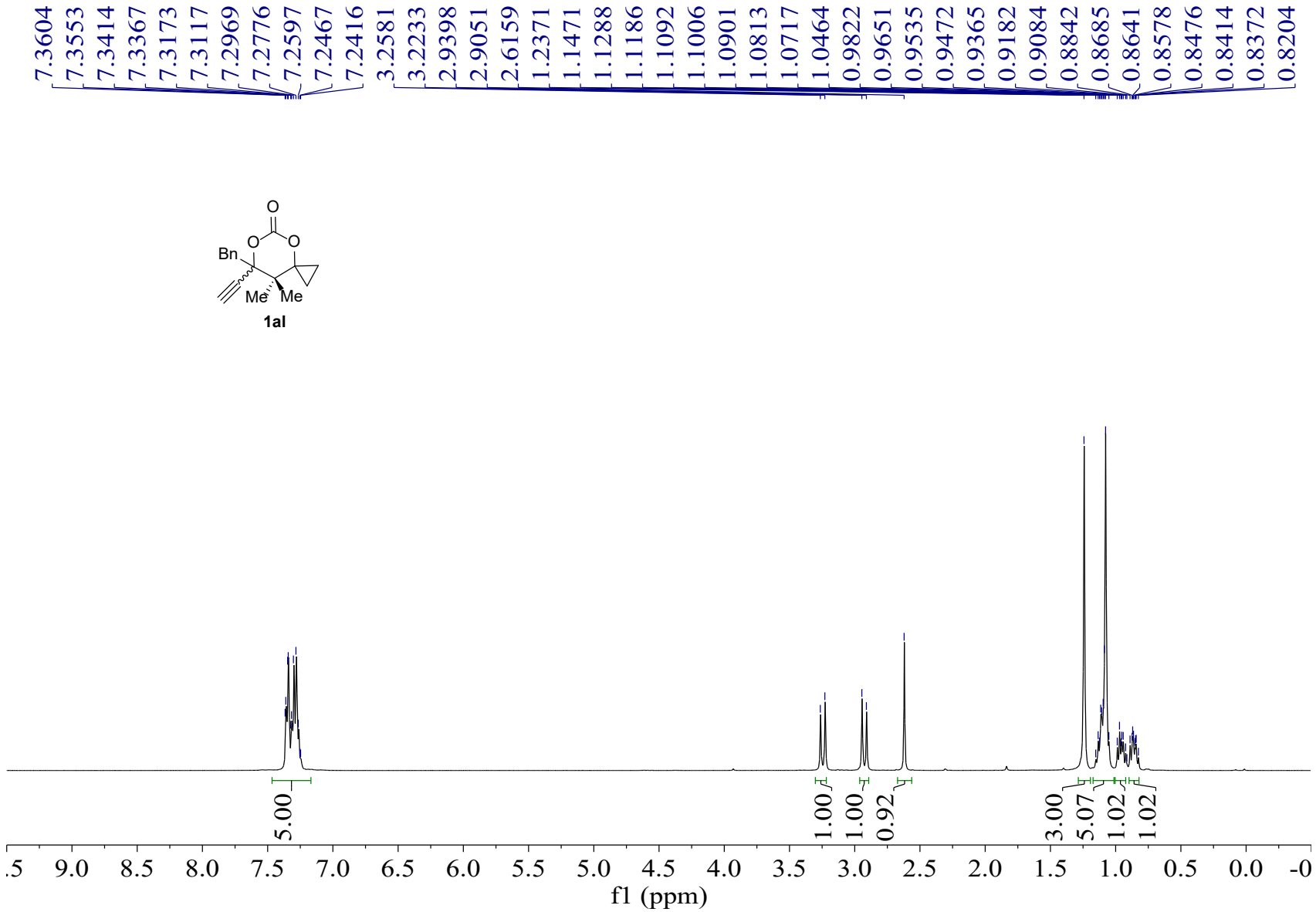
^{13}C NMR spectrum of compound **1ak**



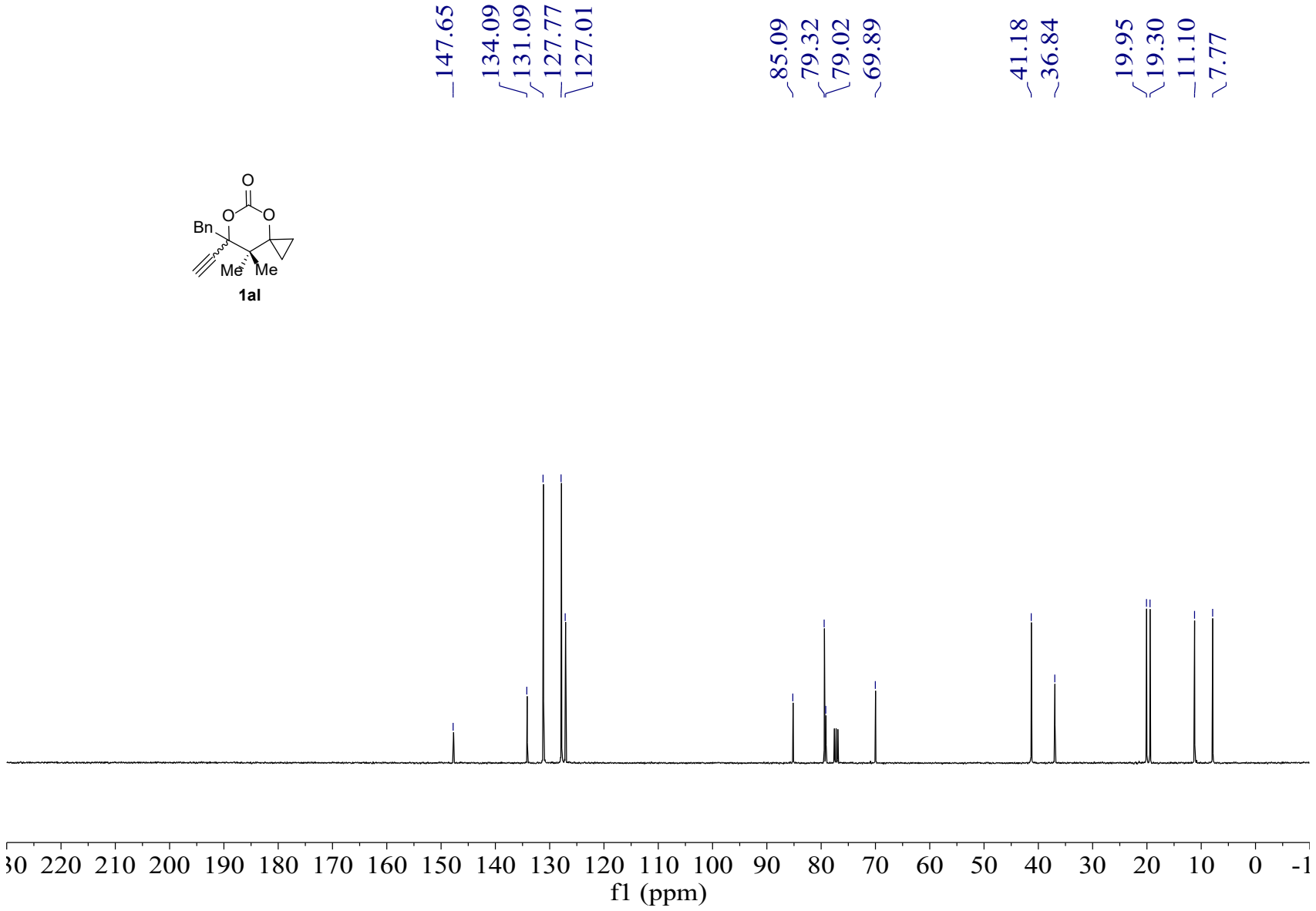
^{1}H NMR spectrum of compound **19al**



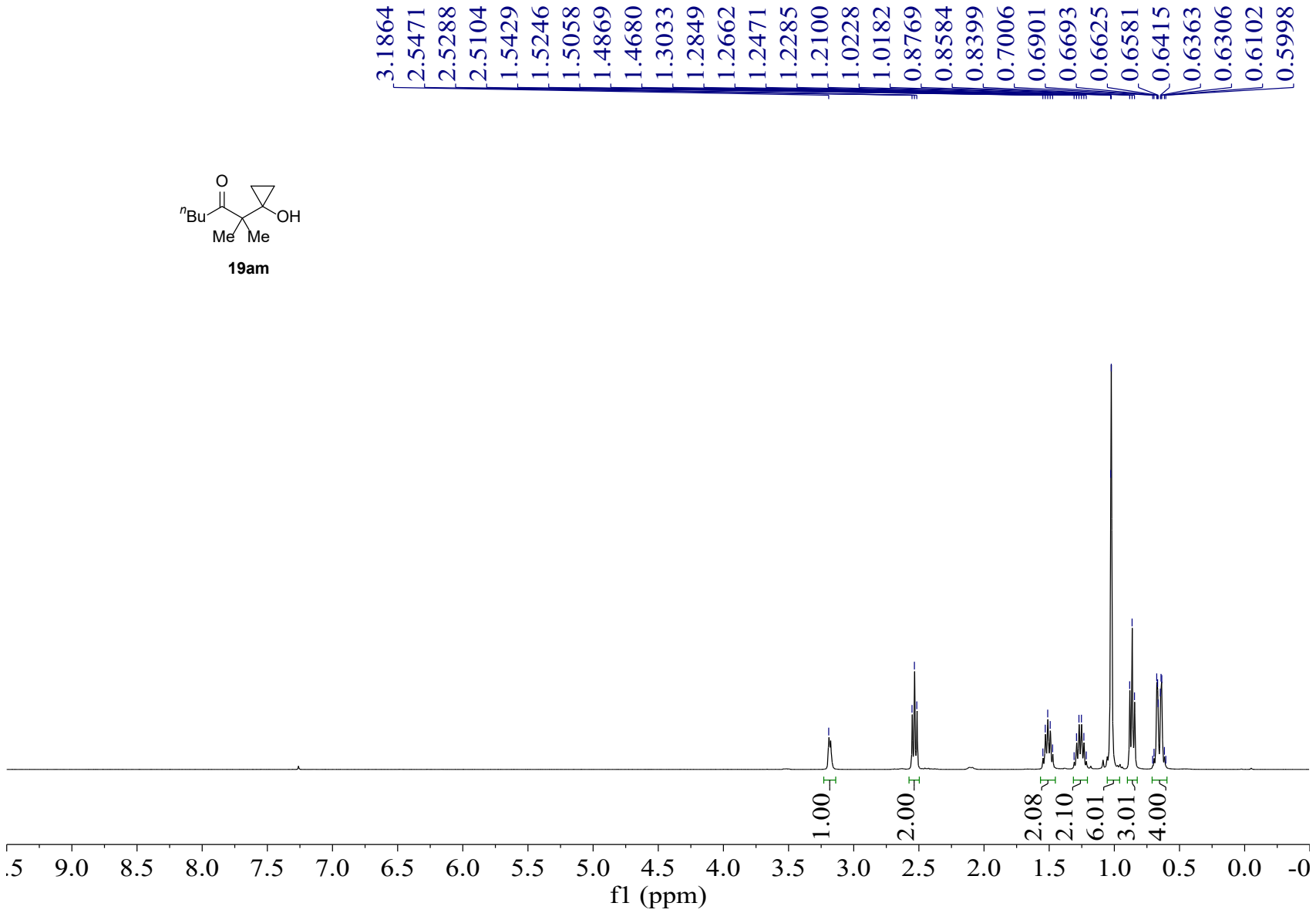
^{13}C NMR spectrum of compound **19al**



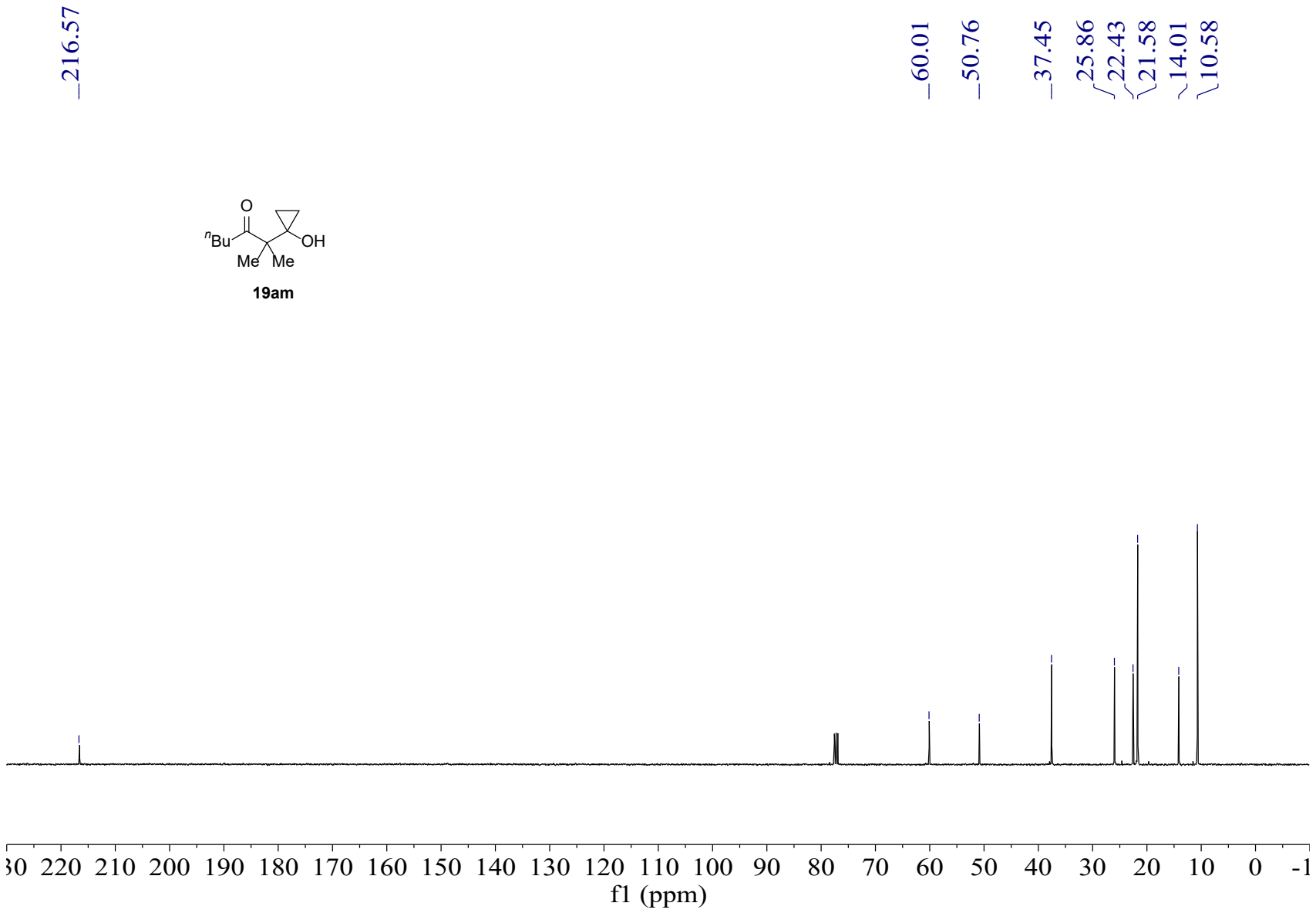
^{1}H NMR spectrum of compound **1al**



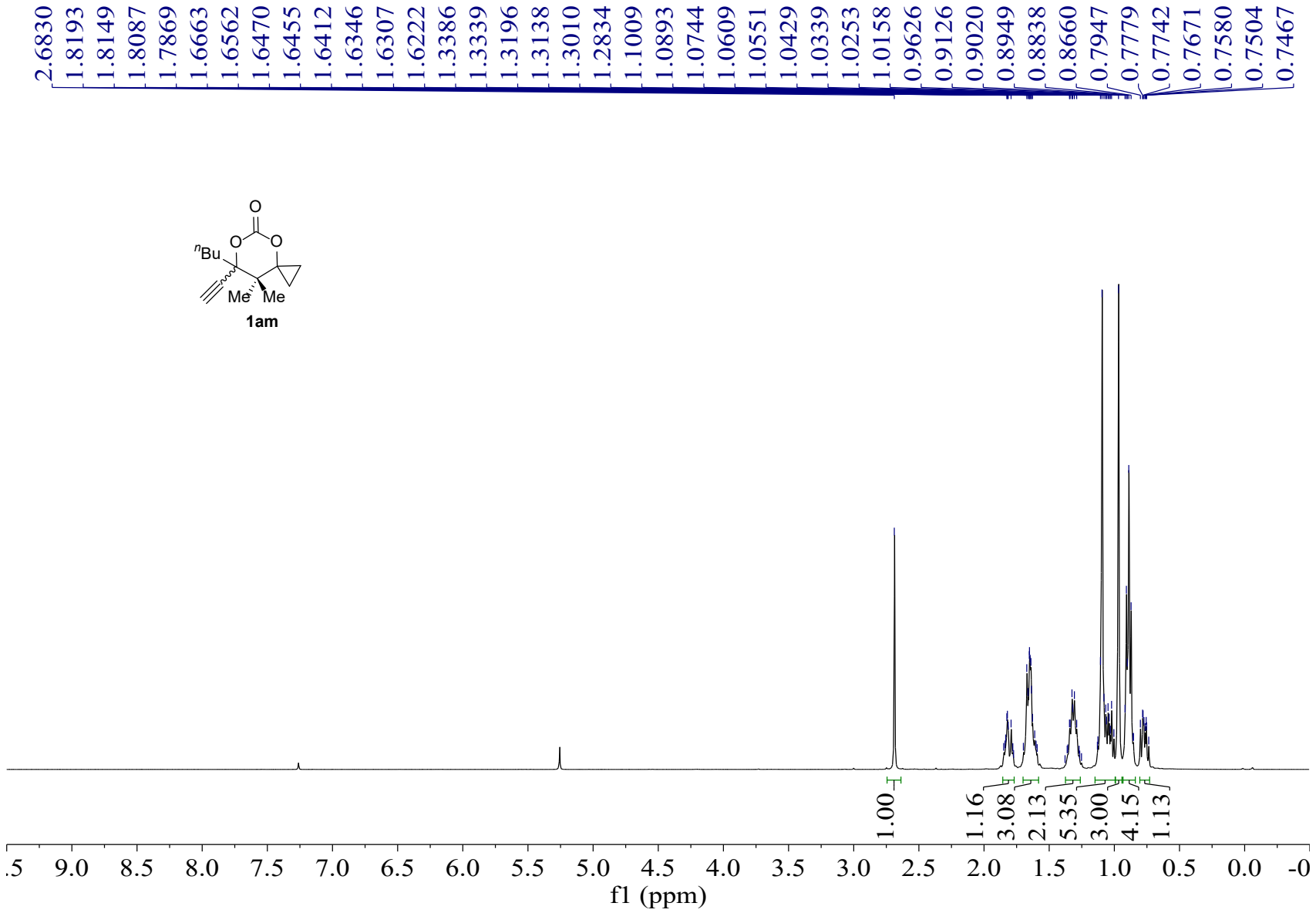
^{13}C NMR spectrum of compound **1al**



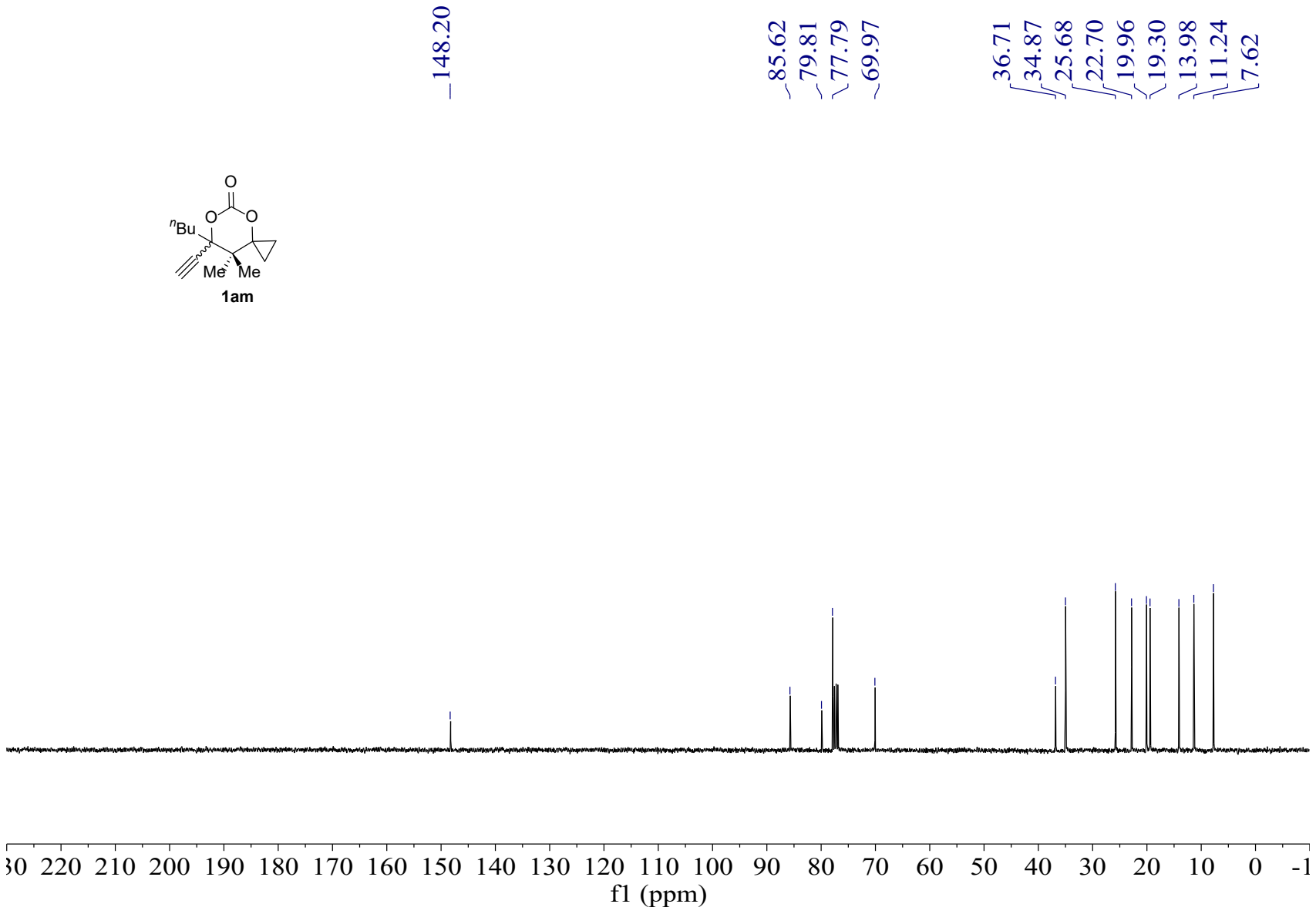
^{1}H NMR spectrum of compound **19am**



^{13}C NMR spectrum of compound **19am**



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



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