Photochemical Nickel-Catalyzed C-H Arylation: Synthetic Scope and Mechanistic Investigations

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Supplementary Material

General Considerations

All reactions were carried out under an inert atmosphere of argon unless otherwise noted. Solvents were purchased extra dry or distilled prior to use. K_2HPO_4 was used as received. The iridium photocatalyst, $Ir[dFCF_3ppy]_2(bpy)•PF_6$, was synthesized from $IrCl_3 \cdot xH_2O$ according to our previously reported procedure.[1] $NiNO_3•6H_2O$ was purchased and used as received from a commercial source. Reactions were irradiated with two standard 26 W compact fluorescent light bulbs. Melting points (°C) are uncorrected. Column chromatography was performed by Combiflash using RediSep Rf Gold Normal-Phase silica columns. ^1H (500 MHz) and ^{13}C (126 MHz) NMR chemical shifts are reported relative to internal TMS. HRMS spectra (ESI-TOF) were collected in CH_2Cl_2 or MeCN.

General Procedure for C-H Arylation

4,4'-Di-*tert*-Butyl-2,2'-bipyridine (4.7 mg, 0.0175 mmol) and $NiNO_3•6H_2O$ (3.2 mg, 0.0175 mmol) were weighed into a 10 mL vial and were placed under argon. Then 1 mL of dry, degassed THF was added, and the mixture was heated at 50 ^oC until a pale green solution was obtained. For coupling reactions in THF, an additional 6 mL of THF was added (0.05 M overall), followed by addition of the aryl bromide (0.35 mmol, 1 equiv) (liquid aryl bromides were added with the solvent). $Ir[dFCF_3ppy]_2(bpy)•PF_6$ (3.5 mg, 2 mol %, 0.02 mmol), 4,4'-dimethoxybenzophenone (21 mg, 25 mol %, 0.0875 mmol), and K_2HPO_4 (122 mg, 2.0 equiv, 0.7 mmol) were added sequentially. For reactions with other solvent-substrates, THF was removed, and 7 mL of distilled solvent (0.05 M), aryl bromide (0.35 mmol, 1 equiv) (liquid aryl bromides were added with the solvent), $Ir[dFCF_3ppy]_2(bpy)•PF_6$ (3.5 mg, 2 mol %, 0.02 mmol), 4,4'-dimethoxybenzophenone (21 mg, 25 mol %, 0.0875 mmol), and K_2HPO_4 (122 mg, 2.0 equiv, 0.7 mmol) were added sequentially. The resulting mixtures was stirred approximately 4 cm away from two 26 W fluorescent light bulbs while a fan was blown across the reaction setup to maintain a temperature of 25 ^oC. Reaction progress was monitored by HPLC, GCMS, or TLC. Upon consumption of aryl bromide, the crude reaction mixture was filtered through a cylindrical plug of Celite and rinsed with CH_2Cl_2 and EtOAc (10-20 mL). The filtrate was concentrated by rotary evaporation, and the residue was purified by column chromatography on silica gel, eluting with EtOAc and hexanes, to obtain products in pure form.

Figure S-1: Initial appearance of reaction (left). Appearance upon completition of reaction (right).

Light Output

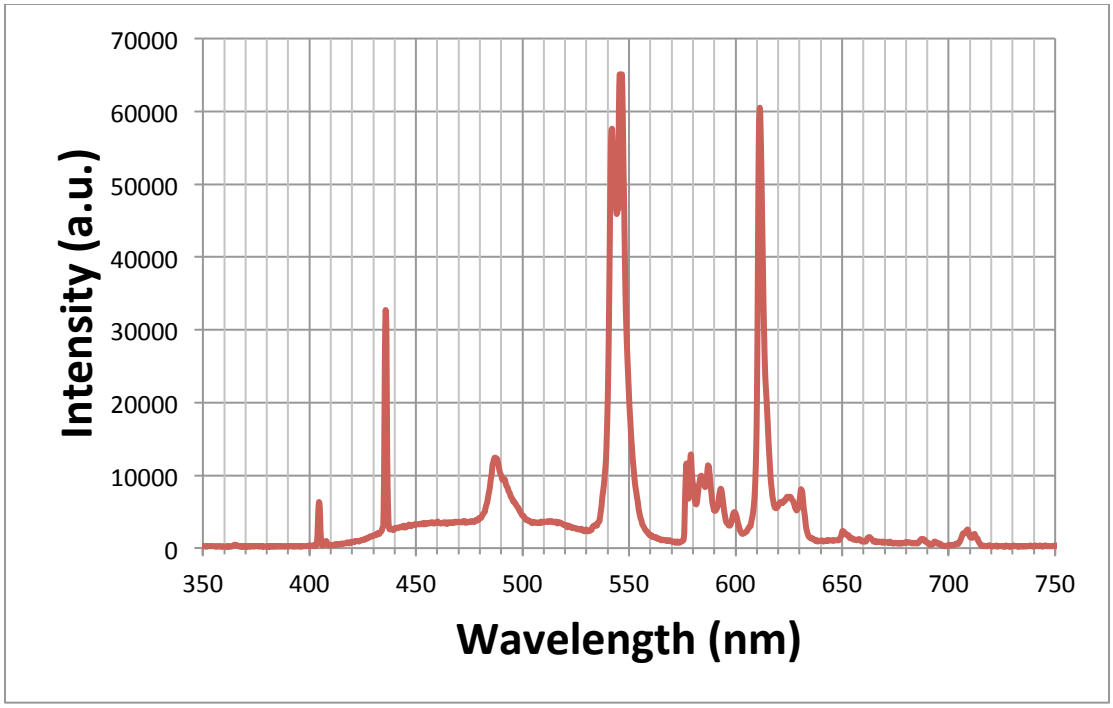
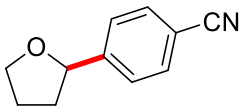
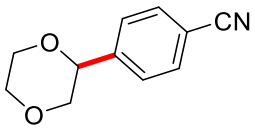


Figure S-2: Emission spectrum of 26 W CFL used for photocatalytic C-H arylation.

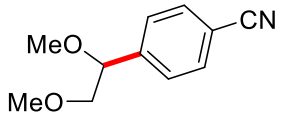
Compound Characterization Data



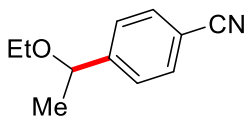
4-(Tetrahydrofuran-2-yl)benzonitrile (2): obtained as a colorless oil (70%, 24 h; 89%, 72 h).
^{1}H NMR ($CDCl_3$, 500 MHz): δ = 7.62 (d, *J* = 7.9 Hz, 2H), 7.43 (d, *J* = 7.7 Hz, 2H), 4.93 (t, *J* = 7.5 Hz, 1H), 4.09 (q, *J* = 8.0 Hz, 1H), 3.96 (q, *J* = 7.2 Hz, 1H), 2.37 (m, 1H), 2.01 (m, 2H), 1.74 (m, 1H).
^{13}C NMR (126 MHz, $CDCl_3$): δ = 149.4, 132.3, 126.3, 119.1, 110.9, 79.9, 69.1, 34.9, 26.1.
Characterization data matched that reported in the literature.[2]



4-(1,4-Dioxan-2-yl)benzonitrile (5): obtained as a white semi-solid (22%, 96 h).
^{1}H NMR ($CDCl_3$, 500 MHz): δ = 7.65 (d, *J* = 8.0 Hz, 2H), 7.47 (d, *J* = 8.0 Hz, 2H), 4.68 (dd, *J* = 10.2, 2.8 Hz, 1H), 3.89, (m, 4H), 3.73 (m, 1H), 3.38 (m, 1H).
^{13}C NMR (126 MHz, $CDCl_3$) δ = 143.6, 132.4, 126.9, 118.8, 112.0, 77.4, 72.2, 67.1, 66.5.
Characterization data matched that reported in the literature.[3]

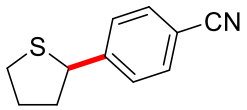


4-(1,2-Dimethoxyethyl)benzonitrile (6): obtained as an oil (91%, 48 h).
^{1}H NMR ($CDCl_3$, 500 MHz): δ = 7.66 (d, *J* = 8.2 Hz, 2H), 7.46 (d, *J* = 8.2 Hz, 2H), 4.42 (dd, *J* = 7.2, 4.0 Hz, 1H), 3.57, (dd, *J* = 10.3, 7.3 Hz, 1H), 3.44 (dd, *J* = 10.4, 4.0 Hz, 1H), 3.37 (s, 3H), 3.31 (s, 3H).
^{13}C NMR (126 MHz, $CDCl_3$) δ = 144.8, 132.5, 127.8, 118.8, 111.9, 82.5, 76.6, 59.5, 57.6.
IR: ν = 2931, 2893, 2827, 2227, 1609, 1587, 1513, 1451, 1352, 1286, 1192, 1169, 1098, 1073, 1034, 869, 838, 584, 569, 549 cm^{-1}.
HRMS: (ESI) m/z calc. for $C_{11}H_{14}NO_2$ (M+H) 192.1025, found 192.1019.

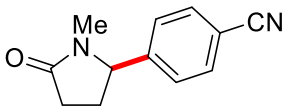


4-(1-Ethoxyethyl)benzonitrile (7): obtained as a colorless oil (56%, 72 h).
^{1}H NMR ($CDCl_3$, 500 MHz): δ = 7.63 (d, *J* = 8.3 Hz, 2H), 7.42 (d, *J* = 8.2 Hz, 2H), 4.44 (q, *J* = 6.5 Hz, 1H), 3.36 (m, 2H), 1.41 (dd, *J* = 6.5, 1.4 Hz, 3H), 1.20 (td, *J* = 7.0, 1.4 Hz, 3H).
^{13}C NMR (126 MHz, $CDCl_3$): δ = 150.1, 132.5, 126.8, 119.1, 111.2, 77.3, 64.6, 24.2, 15.5.
IR: ν = 2977, 2872, 2229, 1609, 1371, 1208, 1100, 1010, 838, 573 cm^{-1}.

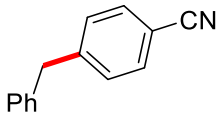
HRMS: (ESI) m/z calc. for $C_{11}H_{14}NO$ (M+H) 176.1075, found 176.1061.



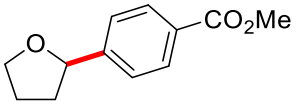
4-(Tetrahydrothiophen-2-yl)benzonitrile (9): obtained as a colorless oil (32%, 72 h).
^{1}H NMR ($CDCl_3$, 500 MHz): δ = 7.59 (d, *J* = 8.3 Hz, 2H), 7.52 (d, *J* = 8.4 Hz, 2H), 4.52 (dd, *J* = 8.5, 6.4 Hz, 1H), 3.16 (m, 1H), 3.03 (m, 1H), 2.42 (m, 1H), 2.26 (m, 1H), 2.02 (m, 1H), 1.90 (m, 1H).
^{13}C NMR (126 MHz, $CDCl_3$) δ = 149.1, 132.4, 128.6, 119.0, 110.9, 52.4, 40.6, 33.8, 31.2.
Characterization data matched that reported in the literature.[4]



4-(1-Methyl-5-oxopyrrolidin-2-yl)benzonitrile (10): isolated as a light brown oil (81%, 96 h); mixture of secondary arylation product (major) with primary *N*-Me arylation isomer (8.3:1).
^{1}H NMR ($CDCl_3$, 500 MHz): δ = 7.72 (d, *J* = 10 Hz, 2H), 7.35 (d, *J* = 10 Hz, 2H), 4.61 (dd, *J* = 5, 5 Hz, 1H), 2.72 (s, 3H), 2.60-2.47 (m, 3H), 1.87-1.83 (m, 1H).
^{13}C NMR (126 MHz, $CDCl_3$): δ 175.5, 146.7, 133.0, 127.1, 118.4, 112.0, 64.1, 29.8, 28.4, 28.2.
Characterization data matched that reported in the literature.[5]

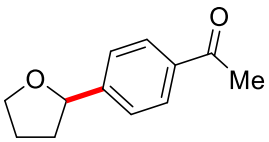


4-Benzylbenzonitrile (11): obtained as a white solid (87%, 72 h), mp = 47-49 °C.
^{1}H NMR ($CDCl_3$, 500 MHz): δ = 7.57 (d, *J* = 8.0 Hz, 2H), 7.30 (m, 5H), 7.17 (d, *J* = 7.4 Hz, 2H), 4.09 (s, 2H).
^{13}C NMR (126 MHz, $CDCl_3$) δ = 146.9, 139.5, 132.5, 129.8, 129.1, 128.9, 126.8, 119.2, 110.2, 42.1.
Characterization data matched that reported in the literature.[1]



Methyl 4-(Tetrahydrofuran-2-yl)benzoate (13): obtained as a colorless oil (75%, 48 h).
^{1}H NMR ($CDCl_3$, 500 MHz): δ = 8.00 (d, *J* = 8.3 Hz, 2H), 7.40 (d, *J* = 8.2 Hz, 2H), 4.94 (t, *J* = 7.2 Hz, 1H), 4.10 (m, 1H), 3.96 (q, *J* = 7.0 Hz, 1H), 3.91 (s, 3H), 2.36 (m, 1H), 2.01 (m, 2H), 1.78 (m, 1H).
^{13}C NMR (126 MHz, $CDCl_3$): δ = 167.2, 149.1, 129.8, 126.3, 125.6, 80.3, 69.0, 52.2, 34.9, 26.1.

Characterization data matched that reported in the literature.[6]

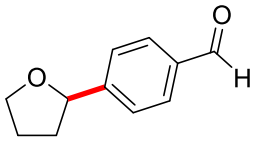


1-(4-(Tetrahydrofuran-2-yl)phenyl)ethan-1-one (14): product obtained with a trace of 4,4'-dimethoxybenzophenone (xx:DMBP = 11.5:1.0 by ^{1}H NMR, 64%, 48 h).

^{1}H NMR ($CDCl_3$, 500 MHz): δ = 7.92 (d, *J* = 8.3 Hz, 2H), 7.42 (d, *J* = 8.4 Hz, 2H), 4.95 (t, *J* = 7.2 Hz, 1H), 4.10 (q, *J* = 6.9 Hz, 1H), 3.96 (q, *J* = 8.0, 1H) 2.59 (s, 3H), 2.37 (m, 1H), 2.01 (m, 2H), 1.77 (m, 1H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 198.0, 149.3, 136.2, 128.6, 125.7, 80.3, 69.0, 34.9, 26.8, 26.1.

Characterization data matched that reported in the literature.[2]



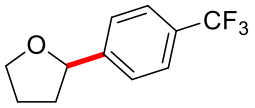
4-(Tetrahydrofuran-2-yl)benzaldehyde (15): using standard conditions, obtained as an inseparable mixture with 4,4'-dimethoxybenzophenone (71%, 48 h); in the absence of DMBP, obtained a clear oil (57%, 72 h) .

^{1}H NMR ($CDCl_3$, 500 MHz): δ = 10.00 (s, 1H), 7.85 (d, *J* = 8.3 Hz, 2 H), 7.50 (d, *J* = 7.9 Hz, 2H), 4.97 (t, *J* = 7.2 Hz, 1H), 4.12 (q, 1H), 3.98 (q, 1H), 2.39 (m, 1H), 2.02 (m, 2H), 1.78 (m, 1H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 192.2, 151.0, 135.6, 130.0, 126.2, 80.3, 69.1, 34.9, 26.1

IR: 2975, 2874, 1699, 1603, 1577, 1509, 1418, 1305, 1285, 1209, 1167, 1114, 1061, 1028, 927, 829, 771 cm^{-1}.

MS: (ESI) m/z calc. for $C_{11}H_{12}O_2$ (M^+) 176.0837, found 176.0827.



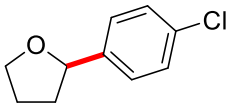
2-(4-(Trifluoromethyl)phenyl)tetrahydrofuran (16): using standard conditions, obtained a clear oil (72% NMR yield, 63% isolated yield, 72 h); in the absence of DMBP, obtained a clear oil (59%, 72 h).

^{1}H NMR ($CDCl_3$, 500 MHz): δ = 7.58 (d, *J* = 8.1 Hz, 2H), 7.44 (d, *J* = 8.0 Hz, 2H), 4.95 (t, *J* = 7.2 Hz, 1H), 4.11 (dt, *J* = 8.4, 6.8 Hz, 1H), 3.96 (dt, *J* = 8.3, 7.0 Hz, 1H), 2.37 (dq, *J* = 13.2, 6.7 Hz, 1H), 2.01 (m, 2H), 1.77 (dq, *J* = 12.3, 7.8 Hz, 1H).

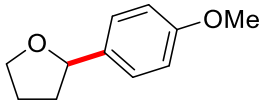
^{13}C NMR (126 MHz, $CDCl_3$): δ = 147.9, 129.6, 125.9, 125.4 (q, *J* = 3.9 Hz), 123.3, 80.1, 69.0, 34.9, 26.1.

^{19}F NMR ($CDCl_3$, 470.8 MHz): δ = -62.4.

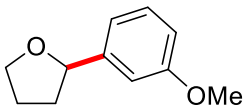
Characterization data matched that reported in the literature.[3]



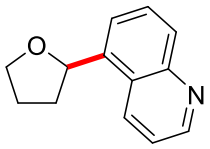
2-(4-Chlorophenyl)tetrahydrofuran (17): using standard conditions, obtained a clear oil (52%, 72 h); in the absence of DMBP, obtained a clear oil (48%, 72 h).
^{1}H NMR ($CDCl_3$, 500 MHz): δ = 7.34 – 7.22 (m, 4H), 4.86 (t, *J* = 7.2 Hz, 1H), 4.08 (dt, *J* = 8.4, 6.8 Hz, 1H), 3.93 (dt, *J* = 8.3, 6.9 Hz, 1H), 2.32 (m, 1H), 2.00 (m, 2H), 1.75 (m, 1H).
^{13}C NMR (126 MHz, $CDCl_3$): δ = 142.2, 132.9, 128.5, 127.1, 80.1, 68.9, 34.8, 26.1.
Characterization data matched that reported in the literature.[3]



2-(4-Methoxyphenyl)tetrahydrofuran (18): obtained as a colorless oil (76%, 72 h).
^{1}H NMR ($CDCl_3$, 500 MHz): δ = 7.26 (d, *J* = 8.6 Hz, 2H), 6.87 (d, *J* = 8.7 Hz, 2H), 4.83 (t, *J* = 7.2 Hz, 1H), 4.12 – 4.03 (m, 1H), 3.91 (td, *J* = 8.1, 6.3 Hz, 1H), 3.80 (s, 3H), 2.32 – 2.21 (m, 1H), 2.07 – 1.93 (m, 2H), 1.79 (m, 1H).
^{13}C NMR (126 MHz, $CDCl_3$): δ = 158.9, 135.5, 127.1, 113.8, 80.6, 68.6, 55.4, 34.6, 26.2.
Characterization data matched that reported in the literature.[3]

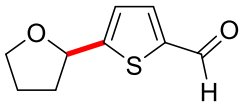


2-(3-Methoxyphenyl)tetrahydrofuran (19): obtained as a colorless oil (62%, 72 h).
^{1}H NMR ($CDCl_3$, 500 MHz): δ = 7.24 (d, *J* = 8.1 Hz, 1H), 6.91 (d, *J* = 5.5 Hz, 2H), 6.79 (dd, *J* = 8.1, 2.4 Hz, 1H), 4.88 (t, *J* = 7.1 Hz, 1H), 4.09 (q, *J* = 7.1 Hz, 1H), 3.93 (q, *J* = 8.0 Hz, 1H), 3.81 (s, 3H), 2.37 – 2.27 (m, 1H), 2.06 – 1.94 (m, 2H), 1.86 – 1.75 (m, 1H).
^{13}C NMR (126 MHz, $CDCl_3$): δ = 159.8, 145.4, 129.4, 118.1, 112.7, 111.2, 80.6, 68.8, 55.4, 34.7, 26.1.
Characterization data matched that reported in the literature.[7]

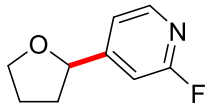


5-(Tetrahydrofuran-2-yl)quinoline (20): obtained as a pale yellow oil (54%, 48 h).
^{1}H NMR ($CDCl_3$, 500 MHz): δ = 8.92 (d, *J* = 3.8 Hz, 1H), 8.37 (d, *J* = 8.5 Hz, 1H), 8.02 (d, *J* = 9.2 Hz, 1H), 7.68 (d, *J* = 7.2 Hz, 2H), 7.41 (dd, *J* = 8.5, 4.1 Hz, 1H), 5.56 (t, *J* = 7.1 Hz, 1H), 4.22 (q, *J* = 7.8, 1H), 4.03 (q, *J* = 7.5 Hz, 1H), 2.51 (m, 1H), 2.08 (m, 2H), 1.92 (m, 1H).
^{13}C NMR (126 MHz, $CDCl_3$): δ = 150.0, 148.7, 139.7, 132.2, 129.2, 129.0, 125.8, 122.8, 120.8, 77.8, 68.9, 33.9, 26.1.

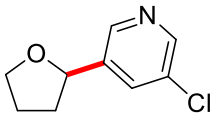
IR: ν = 3063, 2974, 2869, 1611, 1595, 1573, 1500, 1469, 1372, 1317, 1150, 1072, 1048, 1007, 928, 843, 827, 802, 748, 558 cm^{-1}.
HRMS: (ESI) m/z calc. for $C_{14}H_{14}NO$ (M+H) 200.1075, found 200.1039.



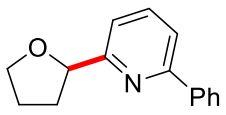
5-(Tetrahydrofuran-2-yl)thiophene-2-carbaldehyde (21): obtained as a pale yellow oil (43%, 48 h).
^{1}H NMR ($CDCl_3$, 500 MHz): δ = 9.85 (s, 1H), 7.64 (d, *J* = 3.8 Hz, 1H), 7.03 (d, *J* = 3.6 Hz, 1H), 5.18 (t, *J* = 6.6 Hz, 1H), 4.08 (m, 1H), 3.93 (m, 1H), 2.39 (m, 1H), 2.11 – 1.87 (m, 3H).
^{13}C NMR (126 MHz, $CDCl_3$): δ = 183.1, 159.4, 142.3, 136.8, 124.3, 77.4, 69.0, 35.0, 26.0.
IR: ν = 2926, 1710, 1666, 1528, 1461, 1228, 1202, 1057, 923, 815, 753, 670 cm^{-1}.
HRMS: (ESI) m/z calc. for $C_9H_{10}O_2S$ (M^+) 182.0402, found 182.0398.



2-Fluoro-4-(tetrahydrofuran-2-yl)pyridine (22): obtained as a colorless oil (86%, 72 h).
^{1}H NMR ($CDCl_3$, 500 MHz): δ = 8.14 (d, *J* = 5.2 Hz, 1H), 7.10 (d, *J* = 5.1 Hz, 1H), 6.91 (s, 1H), 4.92 (t, *J* = 7.2 Hz, 1H), 4.08 (q, *J* = 7.3 Hz, 1H), 3.96 (q, *J* = 7.5 Hz, 1H), 2.40 (m, 1H), 1.99 (m, 2H), 1.81 (m, 1H).
^{13}C NMR (126 MHz, $CDCl_3$): δ = 147.7, 147.6, 118.4, 106.3, 106.0, 78.9, 69.2, 34.4, 25.9
^{19}F NMR ($CDCl_3$, 470.8 MHz): δ = -68.2.
IR: ν = 2979, 2874, 1614, 1568, 1481, 1405, 1293, 1274, 1067, 877, 842 cm^{-1}.
HRMS: (ESI) m/z calc. for $C_9H_{11}FNO$ (M+H) 168.0825, found 168.0822.



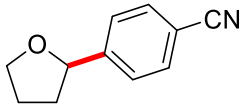
3-Chloro-5-(tetrahydrofuran-2-yl)pyridine (23): obtained as a colorless oil (62%, 72 h).
^{1}H NMR ($CDCl_3$, 500 MHz): δ = 8.45 (d, *J* = 2.4 Hz, 1H), 8.42 (d, *J* = 1.8 Hz, 1H), 7.67 (s, 1H), 4.90 (t, *J* = 7.2 Hz, 1H), 4.08 (m, 1H), 3.94 (m, 1H), 2.38 (m, 1H), 2.02 (m, 2H), 1.78 (m, 1H).
^{13}C NMR (126 MHz, $CDCl_3$): δ = 147.6, 145.5, 140.6, 133.2, 132.1, 77.8, 69.0, 34.7, 26.1.
IR: ν = 2977, 2872, 1582, 1559, 1440, 1421, 1360, 1298, 1233, 1102, 1063, 1022, 925, 880, 704 cm^{-1}.
HRMS: (ESI) m/z calc. for $C_9H_{11}ClNO$ (M+H) 184.0524, found 184.0523.

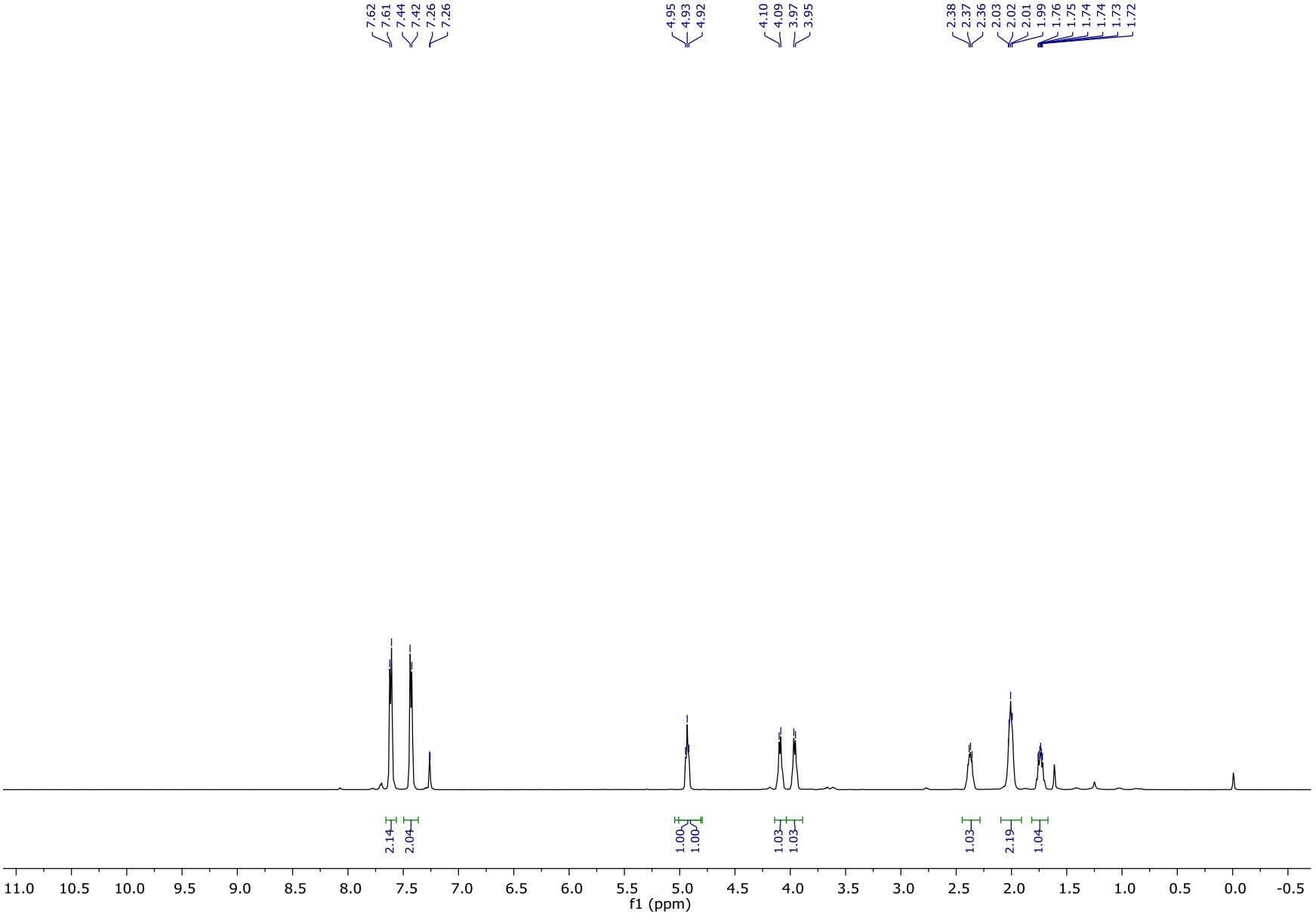


2-Phenyl-6-(tetrahydrofuran-2-yl)pyridine (24): obtained as a colorless oil (49%, 72 h).
^{1}H NMR ($CDCl_3$, 500 MHz): δ = 8.01 (d, *J* = 7.3 Hz, 2H), 7.73 (t, *J* = 7.7 Hz, 1H), 7.59 (d, *J* = 7.8 Hz, 1H), 7.47 (t, *J* = 7.5 Hz, 2H), 7.40 (t, *J* = 6.8 Hz, 2H), 5.12 (t, *J* = 6.8 Hz, 1H), 4.14 (q, *J* = 6.9 Hz, 1H), 4.01 (q, *J* = 7.2 Hz, 1H), 2.47 (m, 1H), 2.15 (m, 1H), 2.00 (m, 2H).
^{13}C NMR (126 MHz, $CDCl_3$): δ = 163.1, 156.7, 139.7, 137.3, 128.9, 128.8, 127.1, 118.9, 118.3, 81.7, 69.2, 33.1, 25.9.
IR: ν = 3062, 2976, 2871, 1590, 1571, 1447, 1331, 1156, 1061, 1026, 922, 815, 762, 694, 623 cm^{-1}.
HRMS: (ESI) m/z calc. for $C_{15}H_{16}NO$ (M+H) 226.1232, found 226.1223.

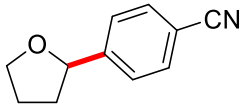
Spectral Data

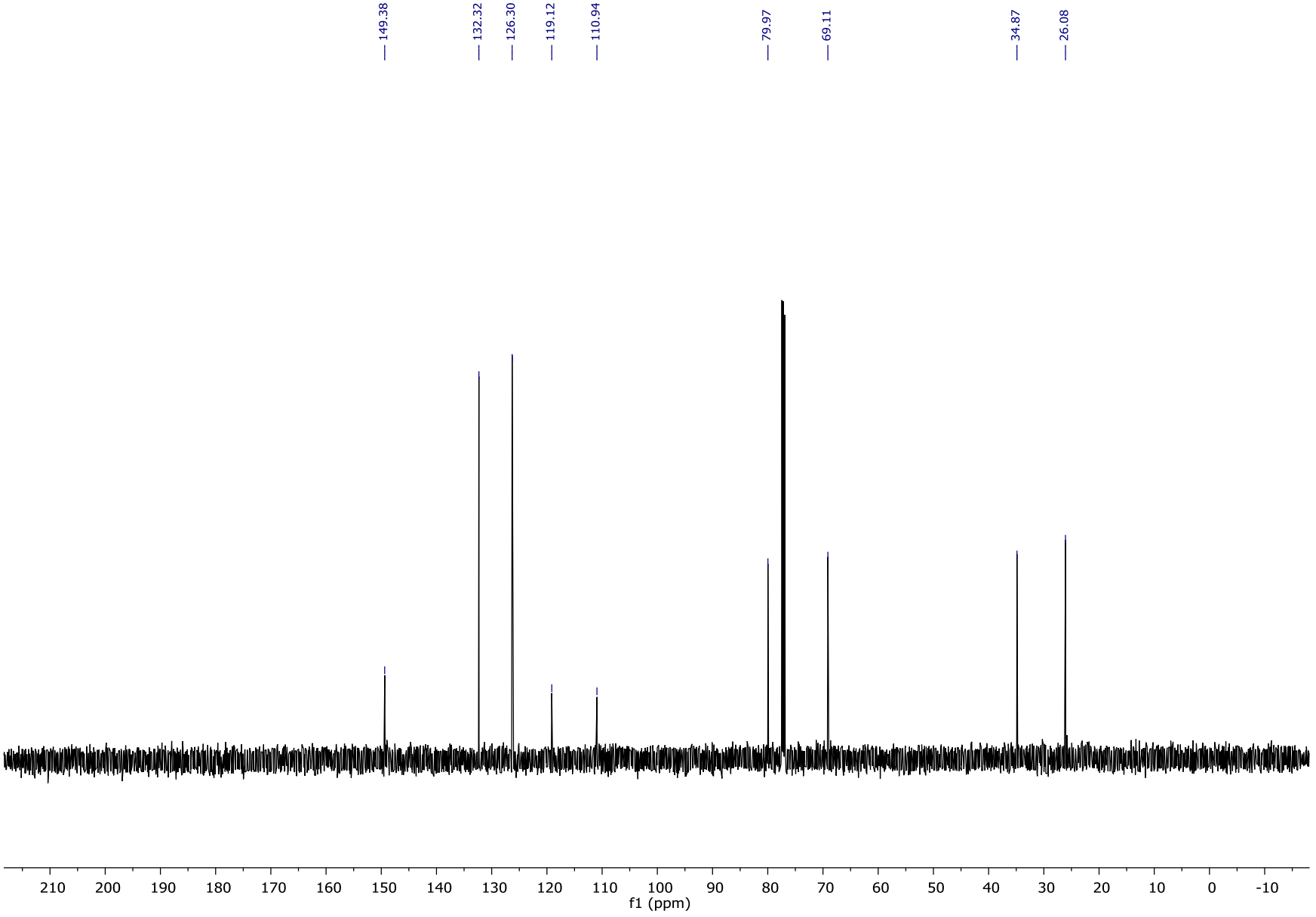
^{1}H NMR Spectrum of 4-(Tetrahydrofuran-2-yl)benzonitrile (2)



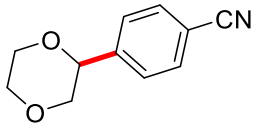


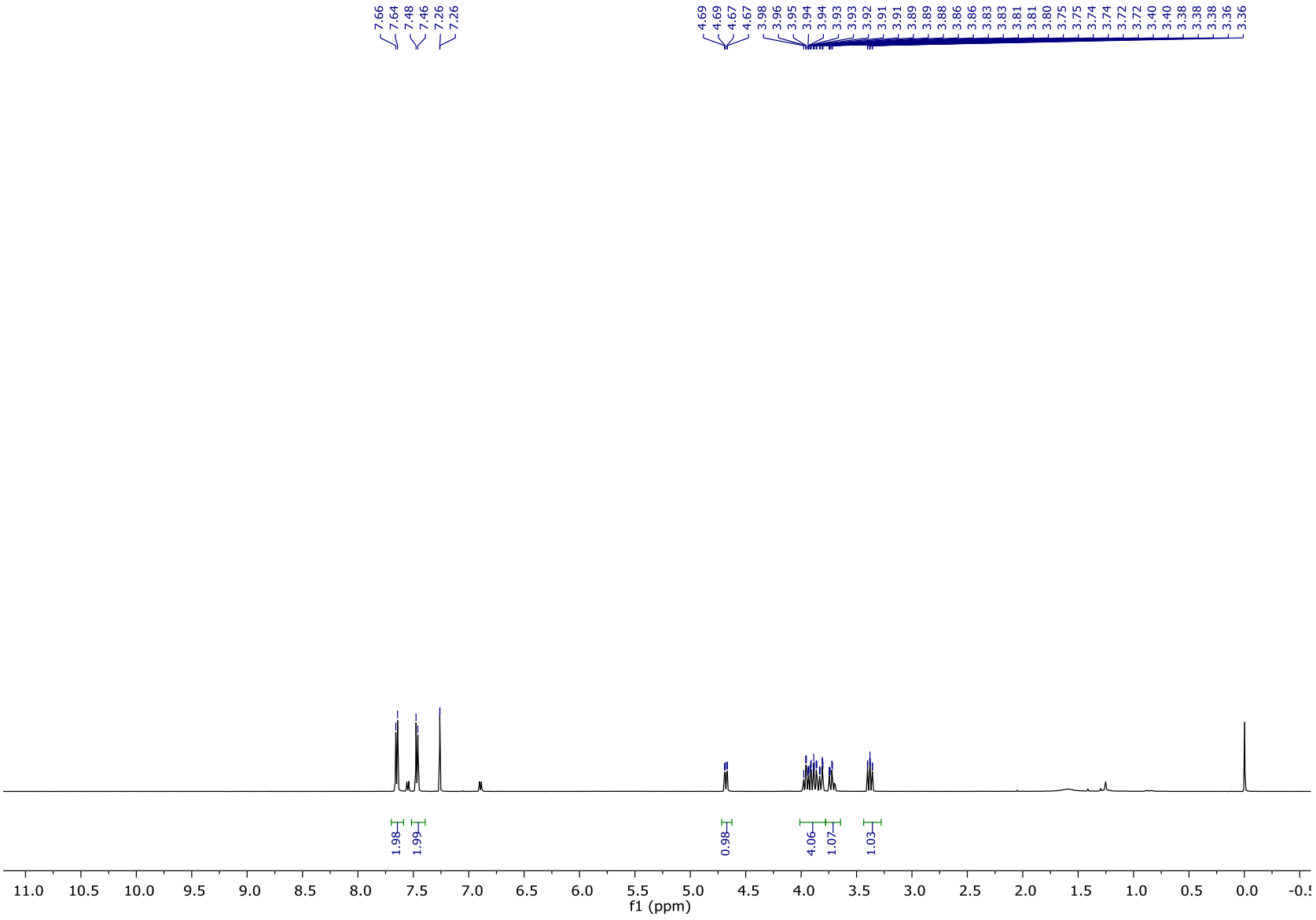
^{13}C NMR Spectrum of 4-(Tetrahydrofuran-2-yl)benzonitrile (2)



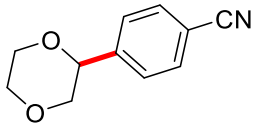


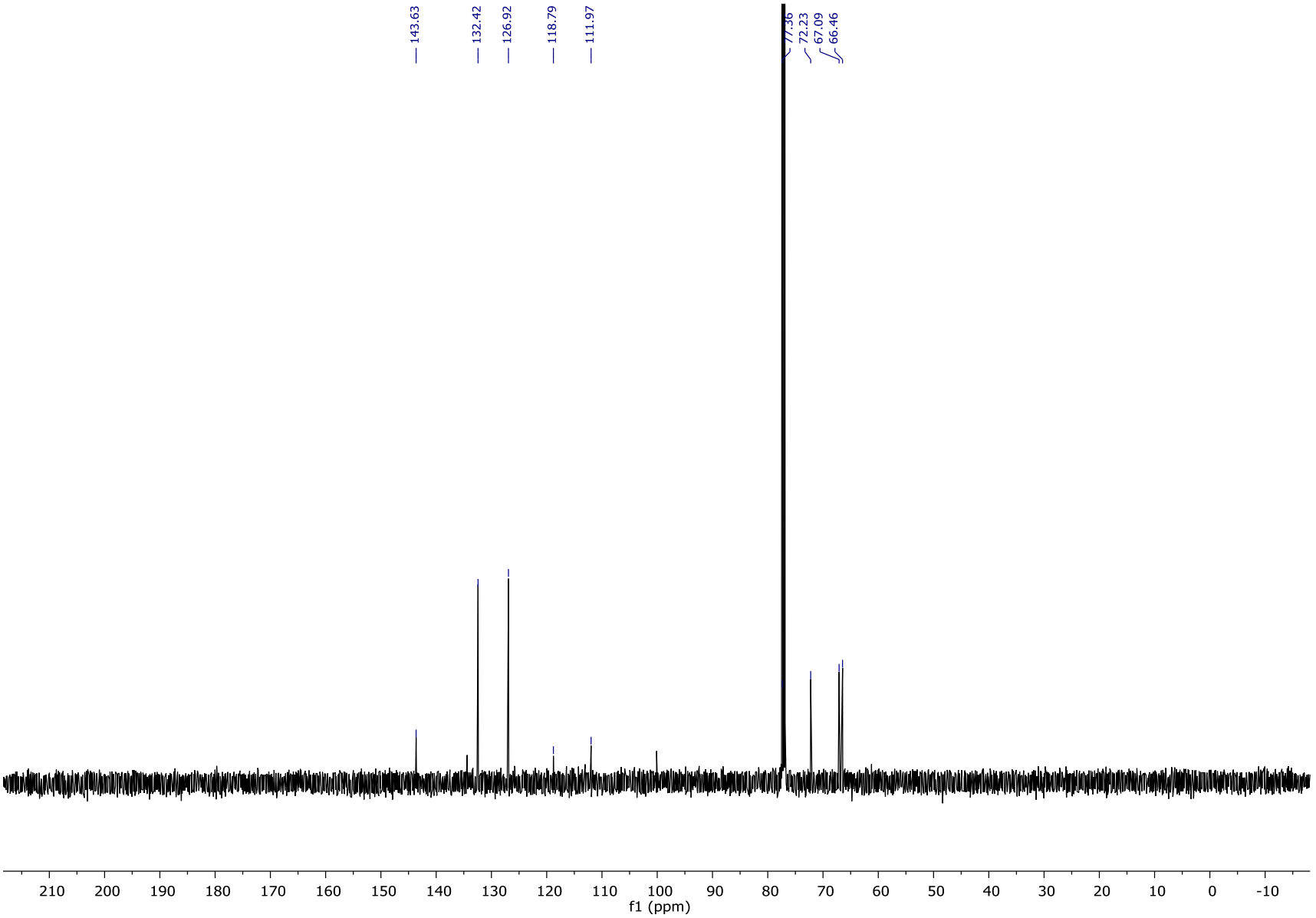
^{1}H NMR Spectrum of 4-(1,4-Dioxan-2-yl)benzonitrile (5)



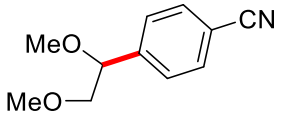


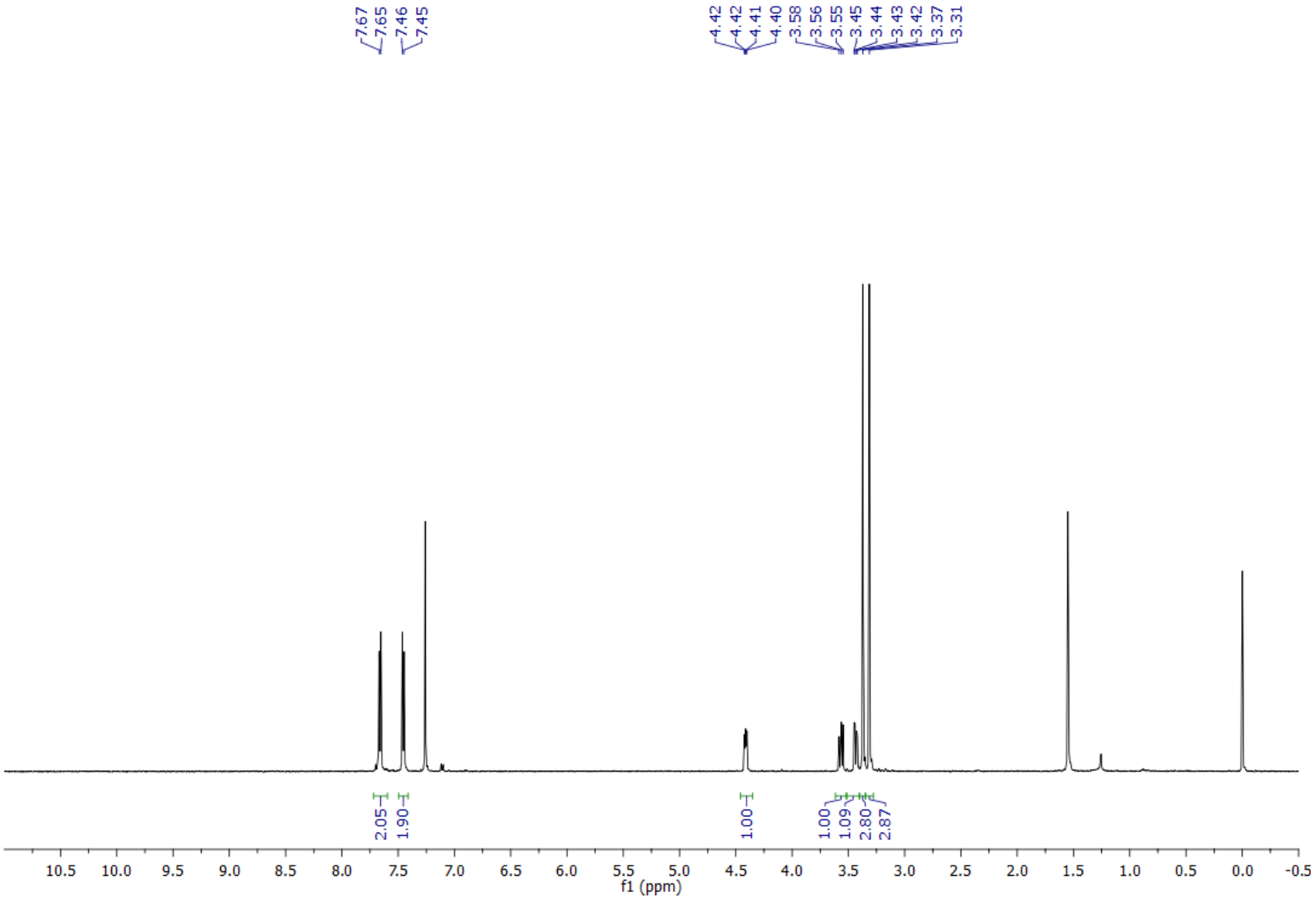
^{13}C NMR Spectrum of 4-(1,4-Dioxan-2-yl)benzonitrile (5)



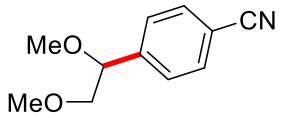


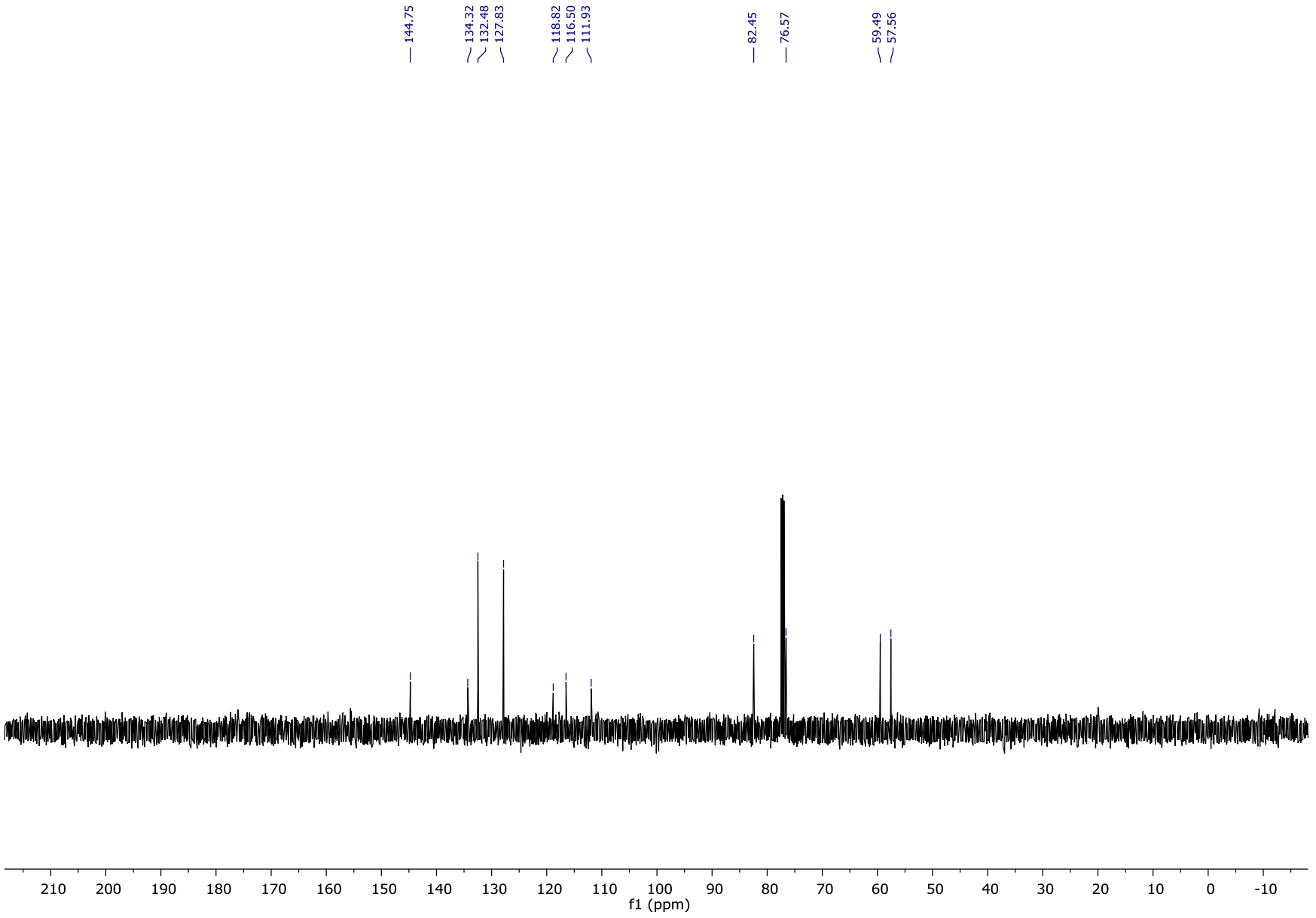
^{1}H NMR Spectrum of 4-(1,2-Dimethoxyethyl)benzonitrile (6)



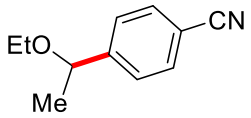


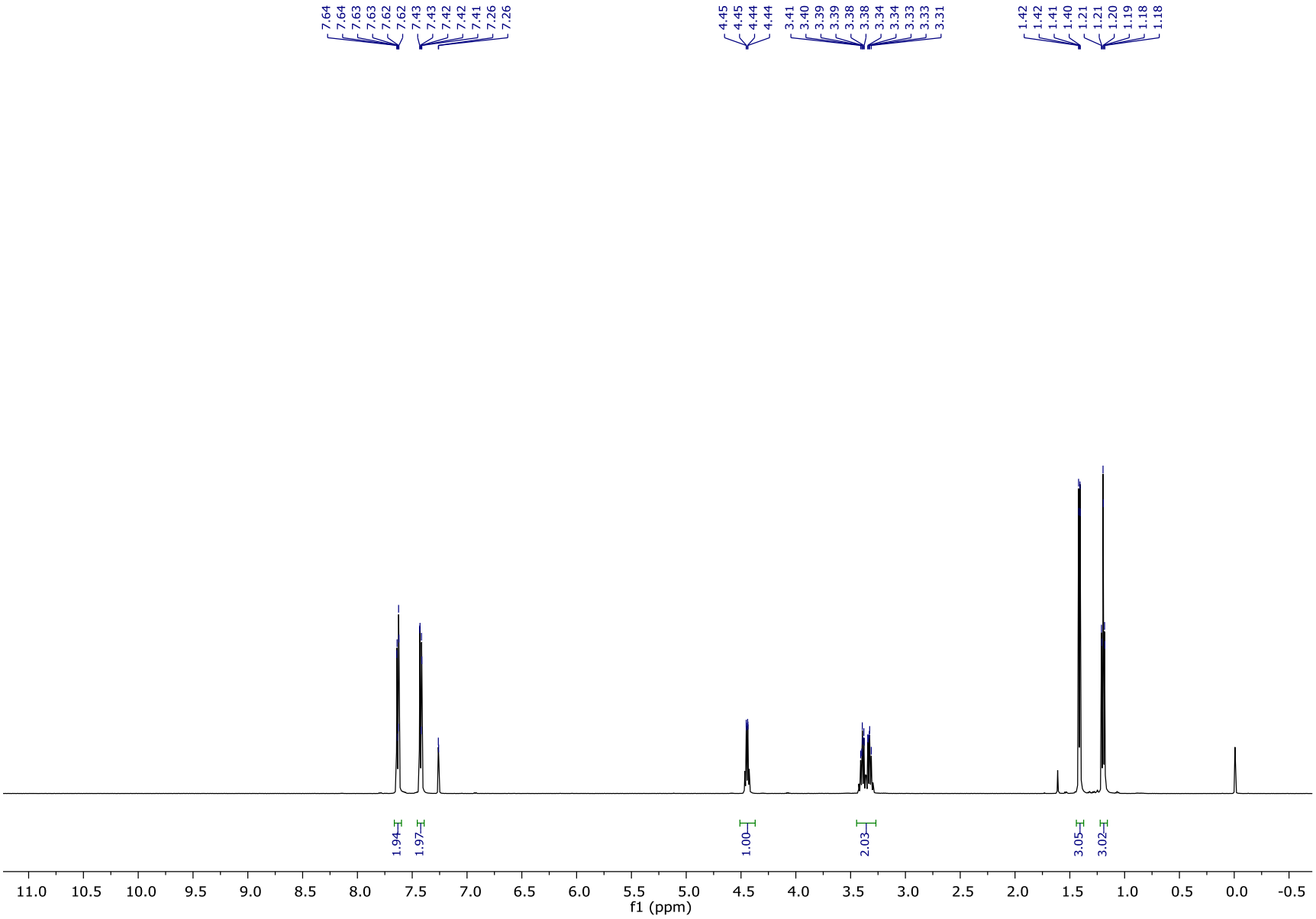
^{13}C NMR Spectrum of 4-(1,2-Dimethoxyethyl)benzonitrile (6)



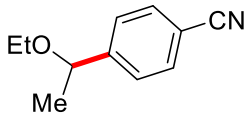


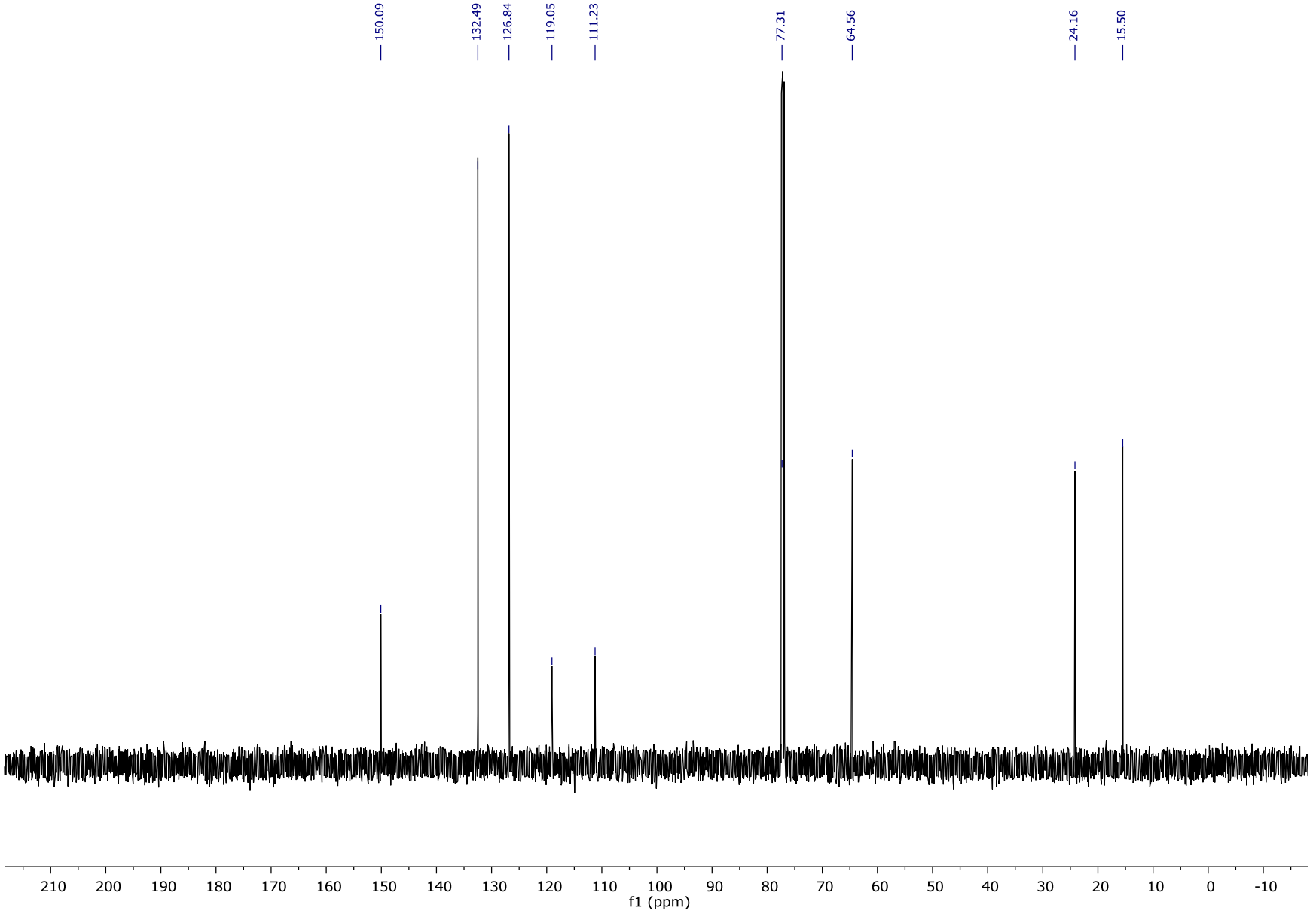
^{1}H NMR Spectrum of 4-(1-Ethoxyethyl)benzonitrile (7)



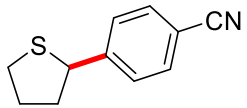


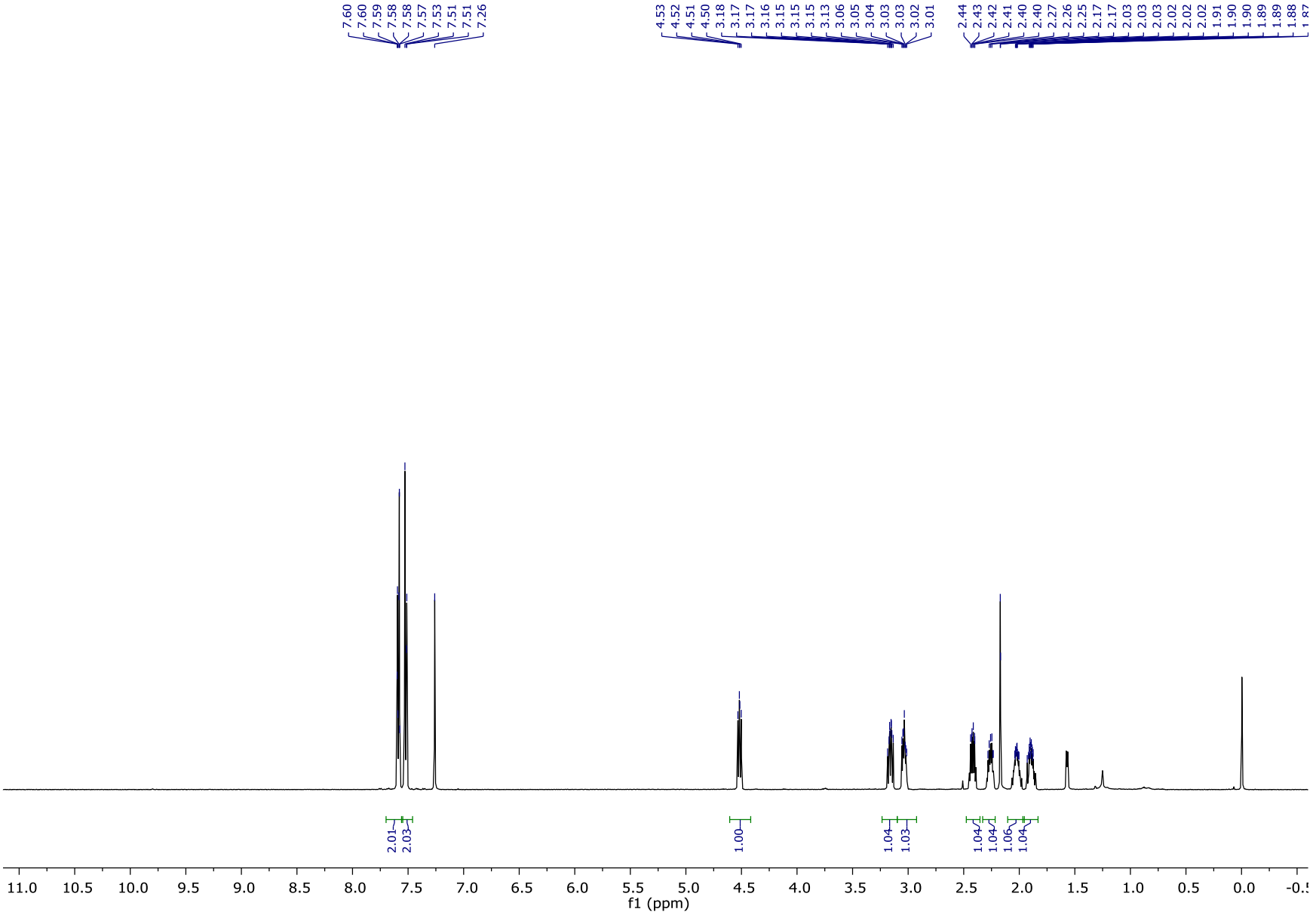
^{13}C NMR Spectrum of 4-(1-Ethoxyethyl)benzonitrile (7)



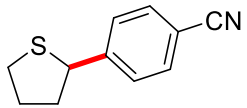


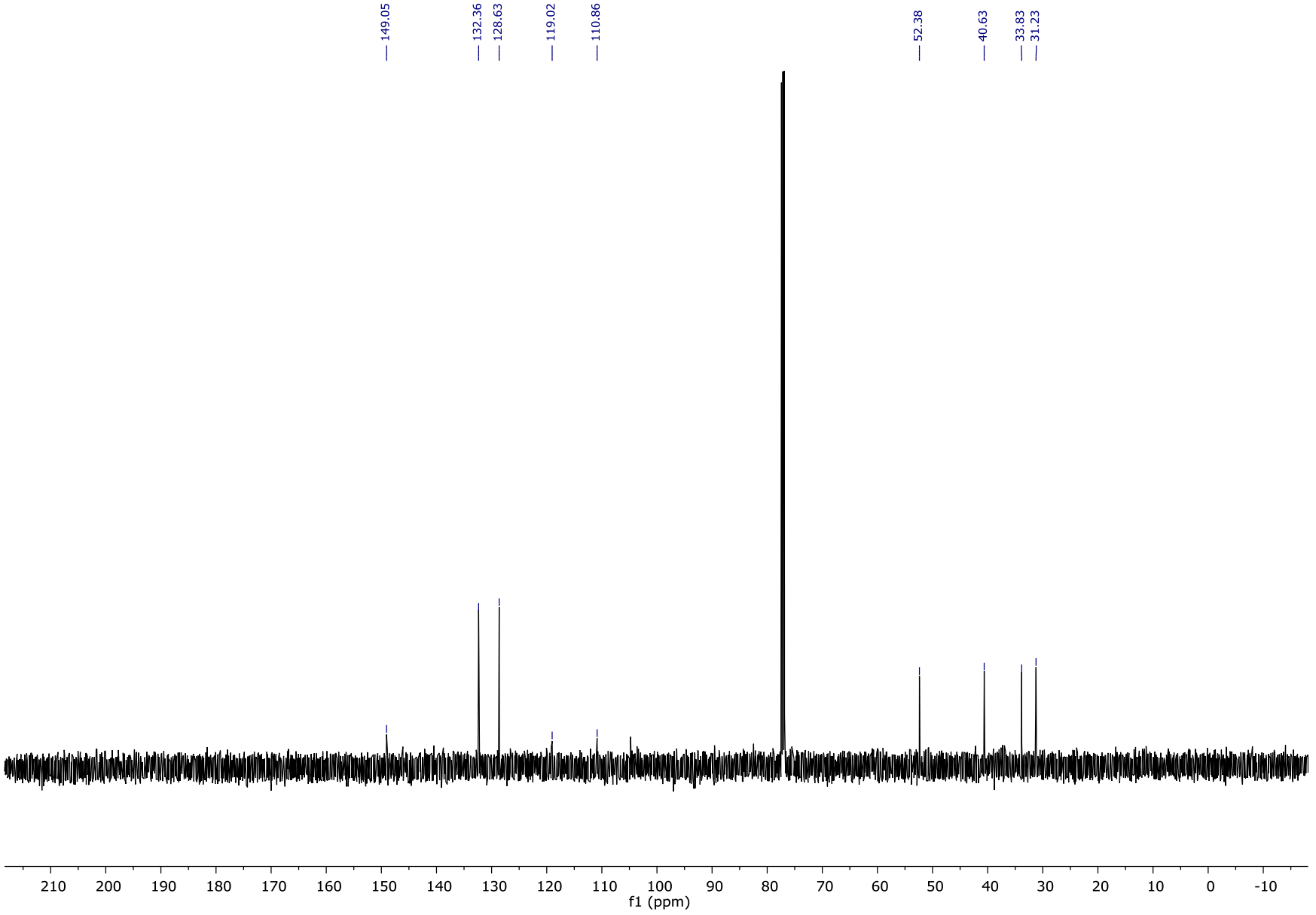
^{1}H NMR Spectrum of 4-(Tetrahydrothiophen-2-yl)benzonitrile (9)



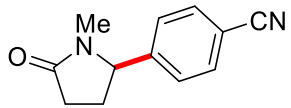


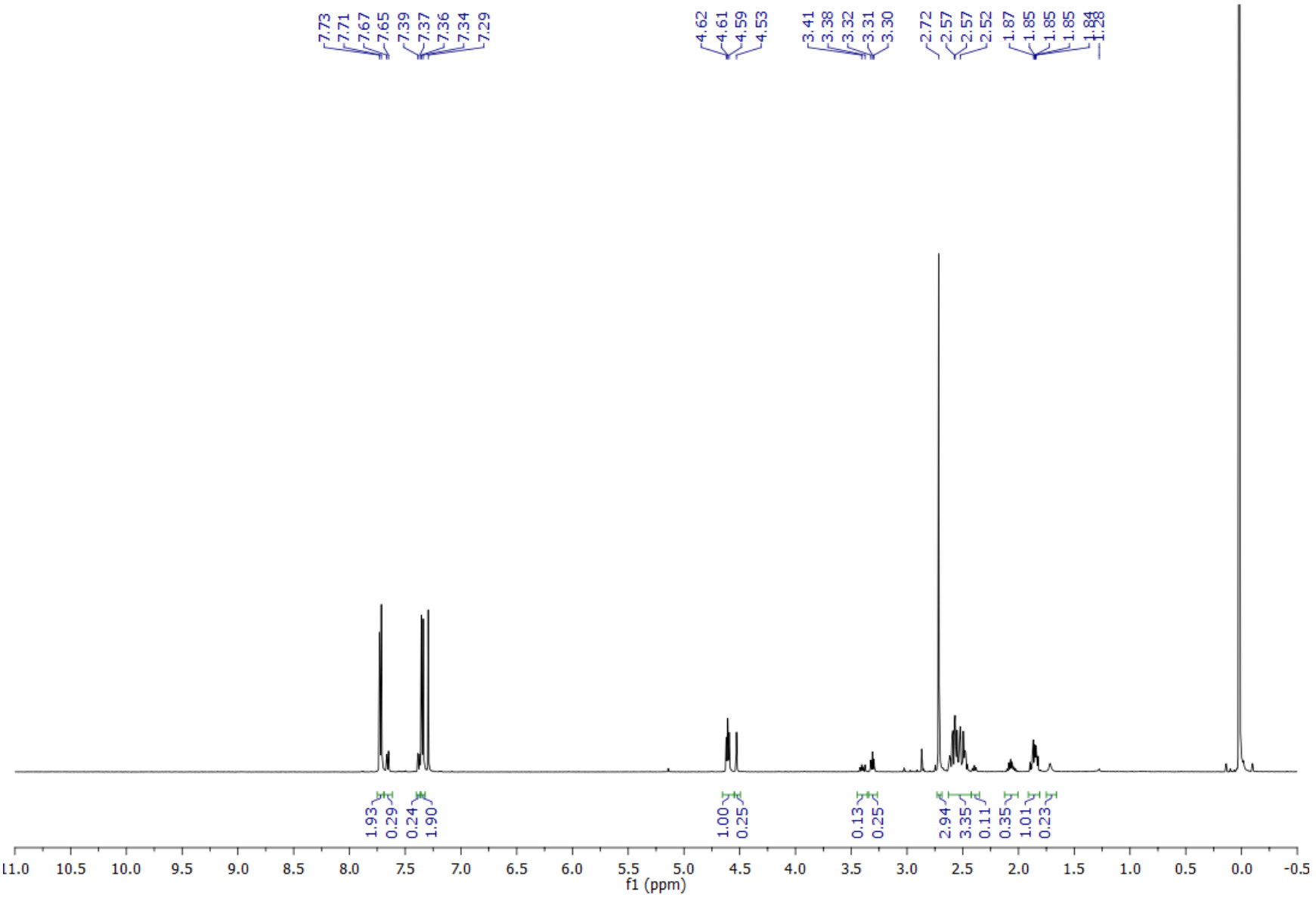
^{13}C NMR Spectrum of 4-(Tetrahydrothiophen-2-yl)benzonitrile (9)



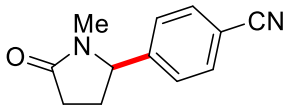


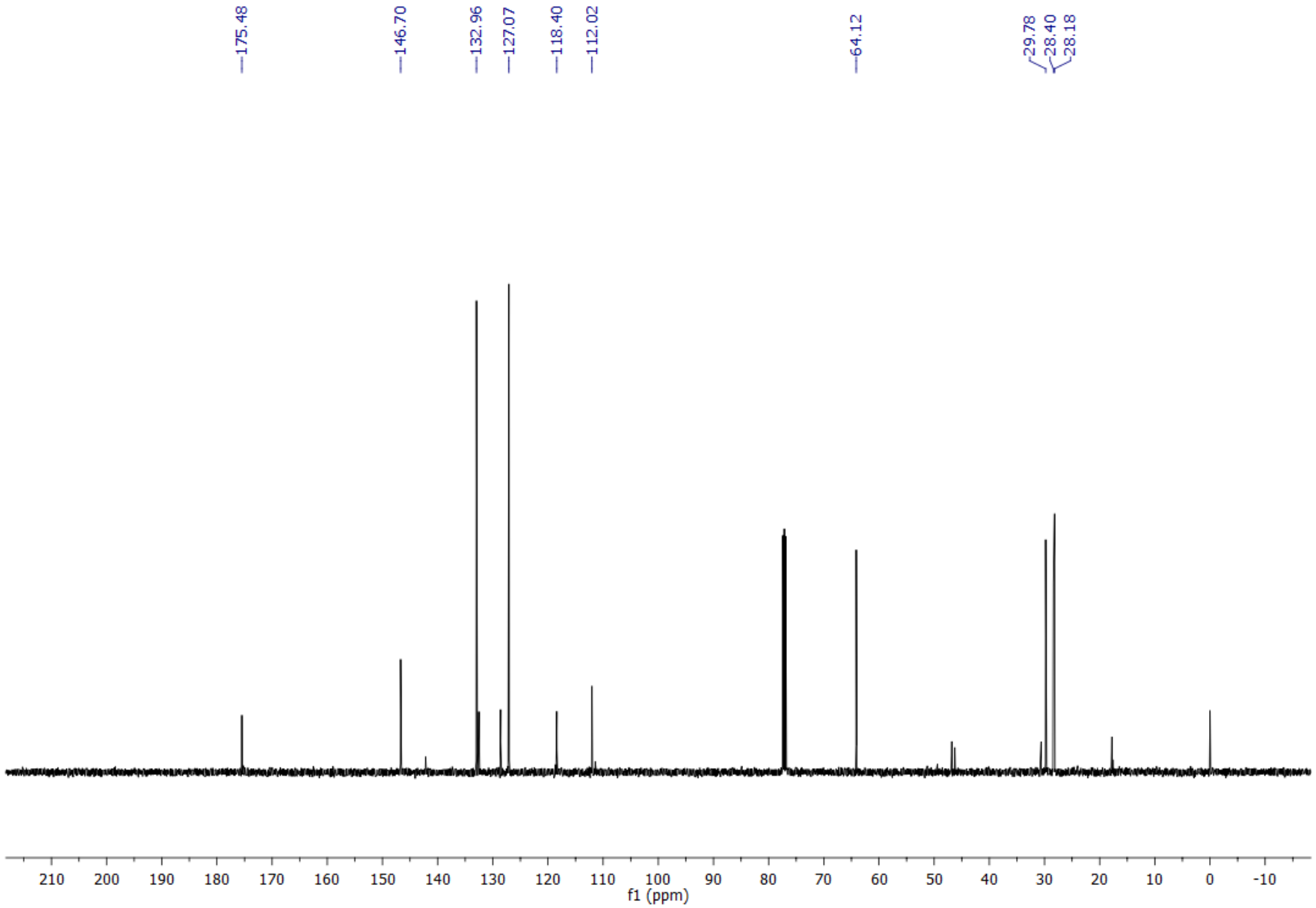
^{1}H NMR Spectrum of 4-(1-Methyl-5-oxopyrrolidin-2-yl)benzonitrile (10)



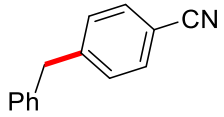


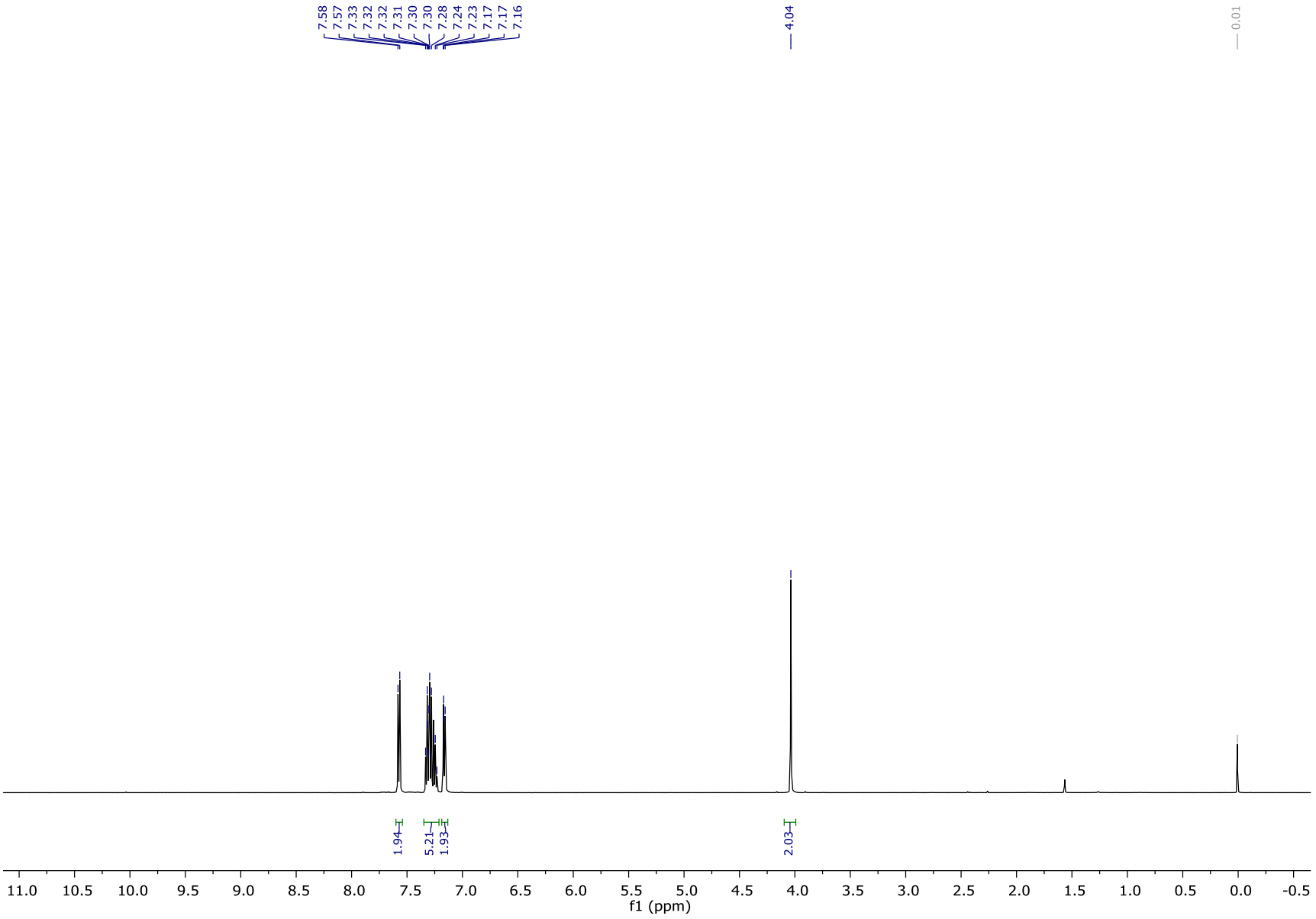
^{13}C NMR Spectrum of 4-(1-Methyl-5-oxopyrrolidin-2-yl)benzonitrile (10)



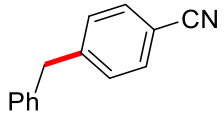


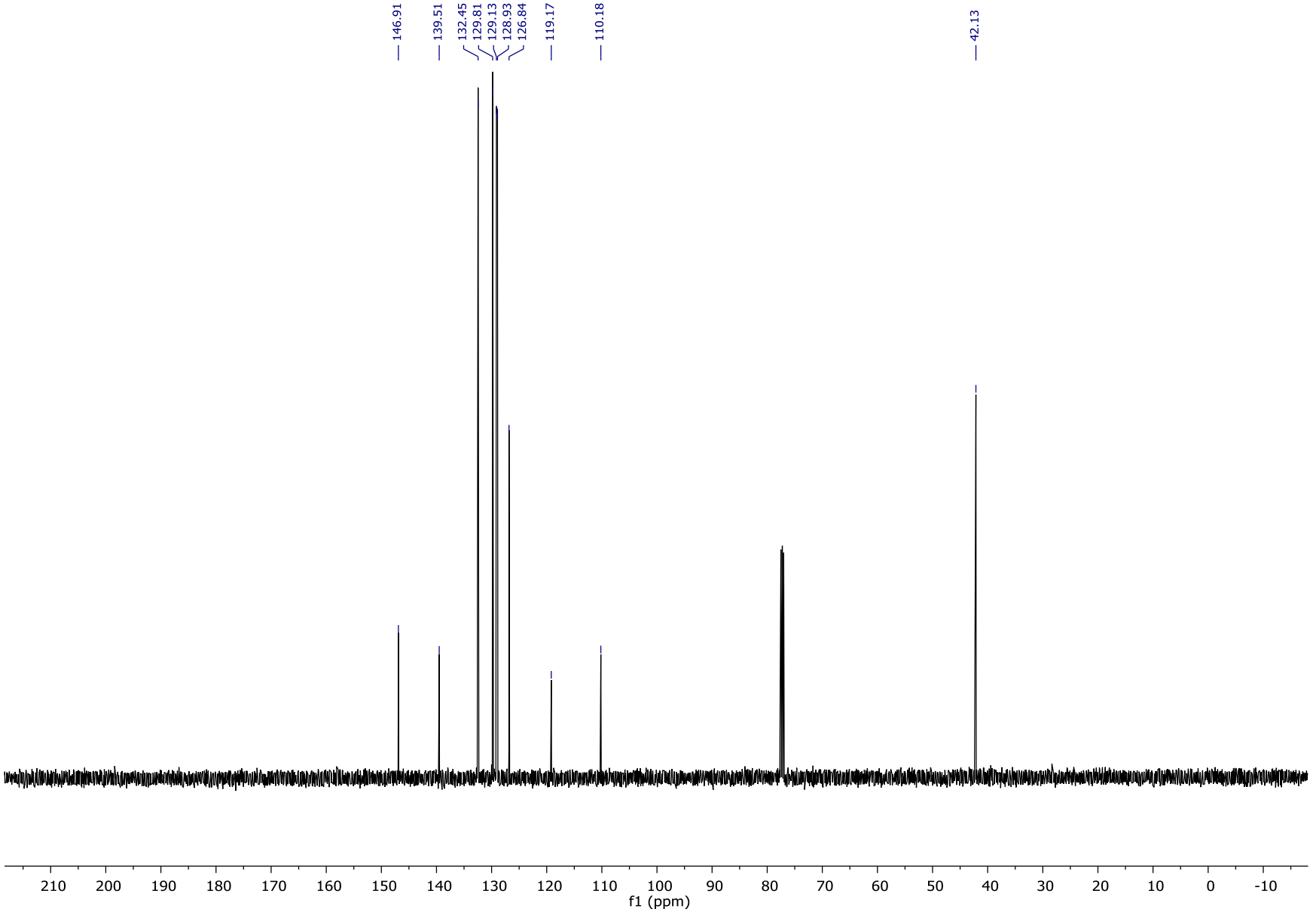
^{1}H NMR Spectrum of 4-Benzylbenzonitrile (11)



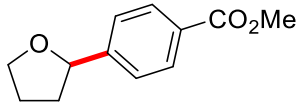


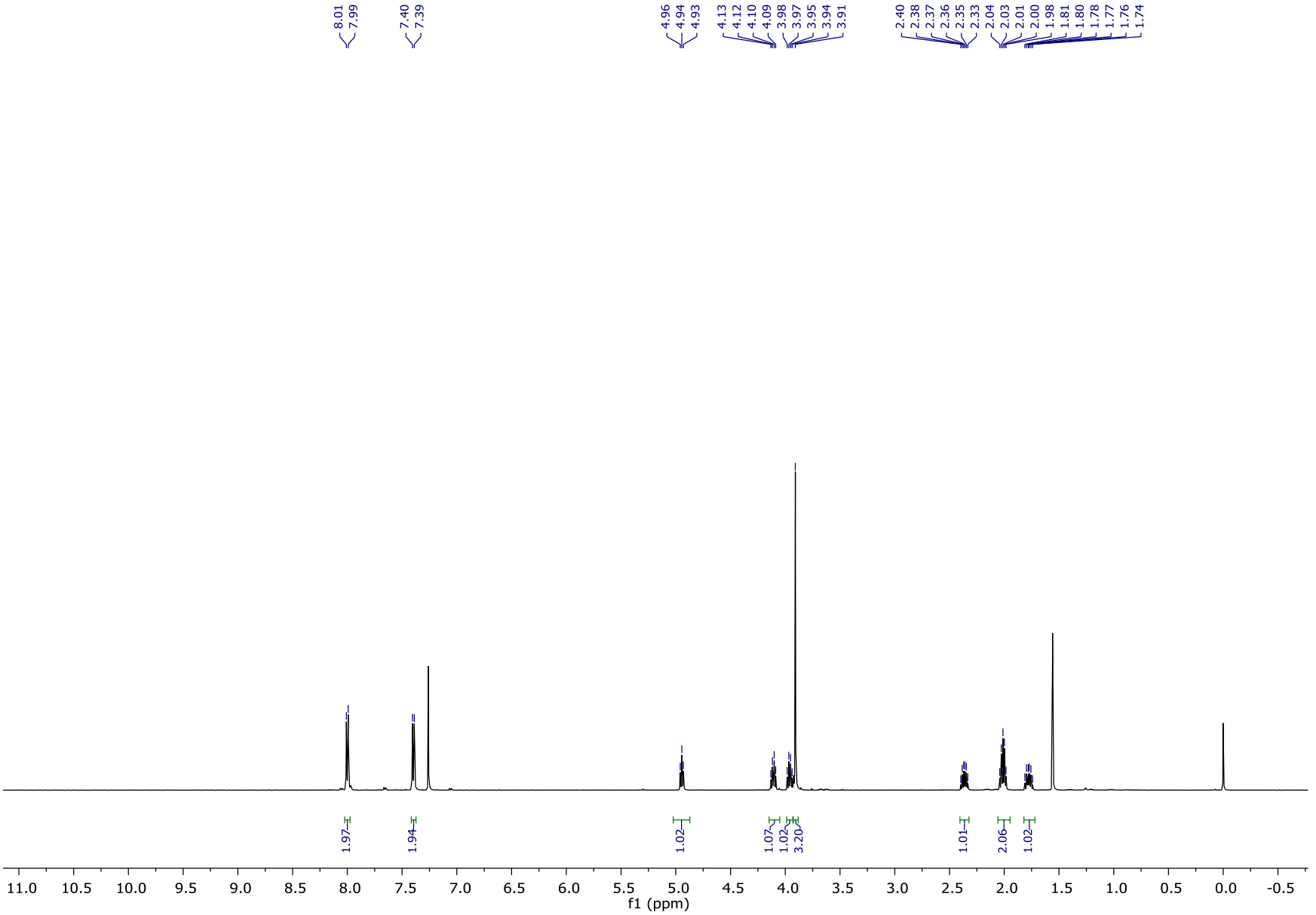
^{13}C NMR Spectrum of 4-Benzylbenzonitrile (11)



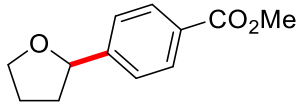


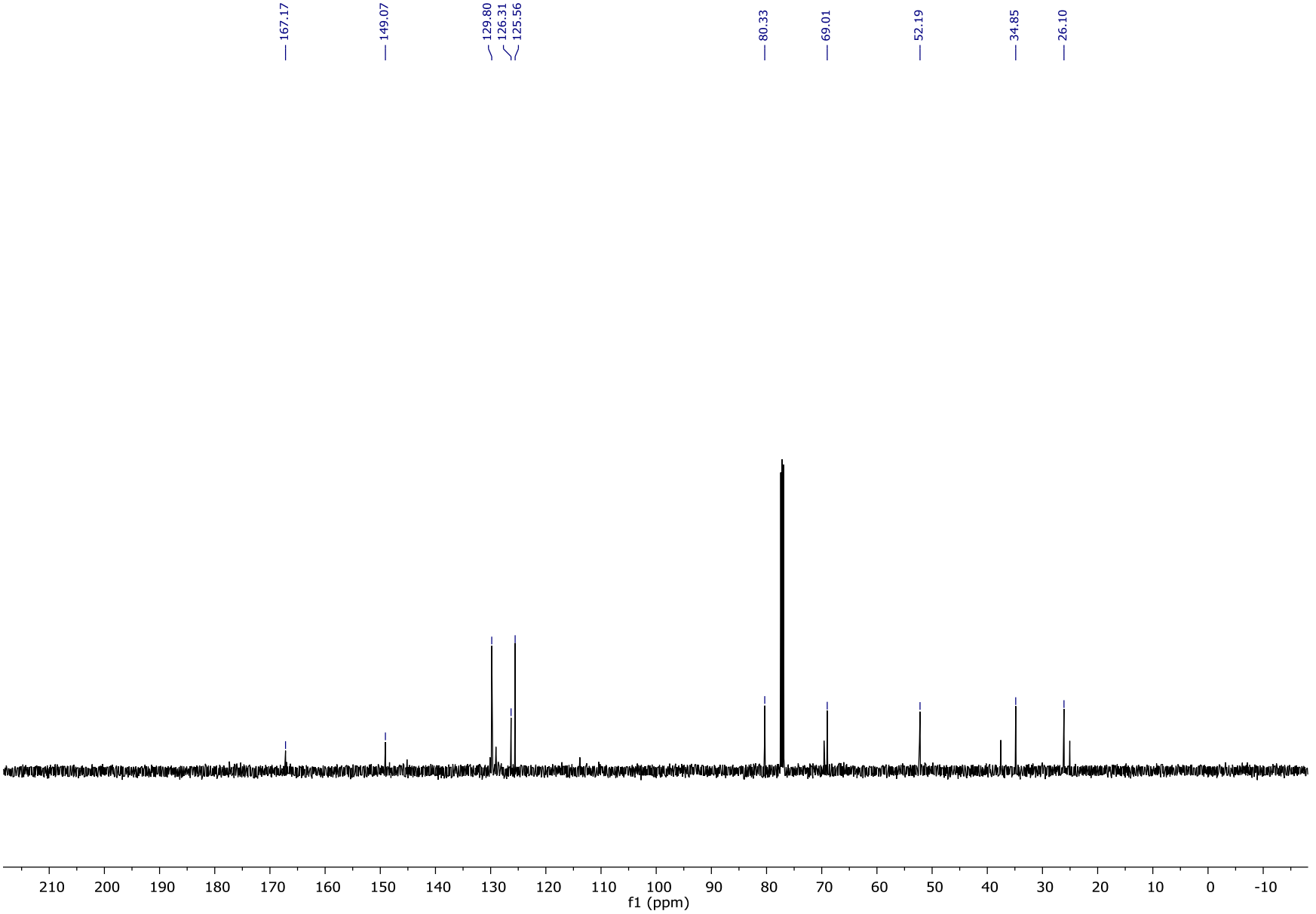
^{1}H NMR Spectrum of Methyl 4-(Tetrahydrofuran-2-yl)benzoate (13)



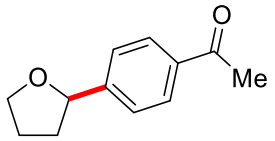


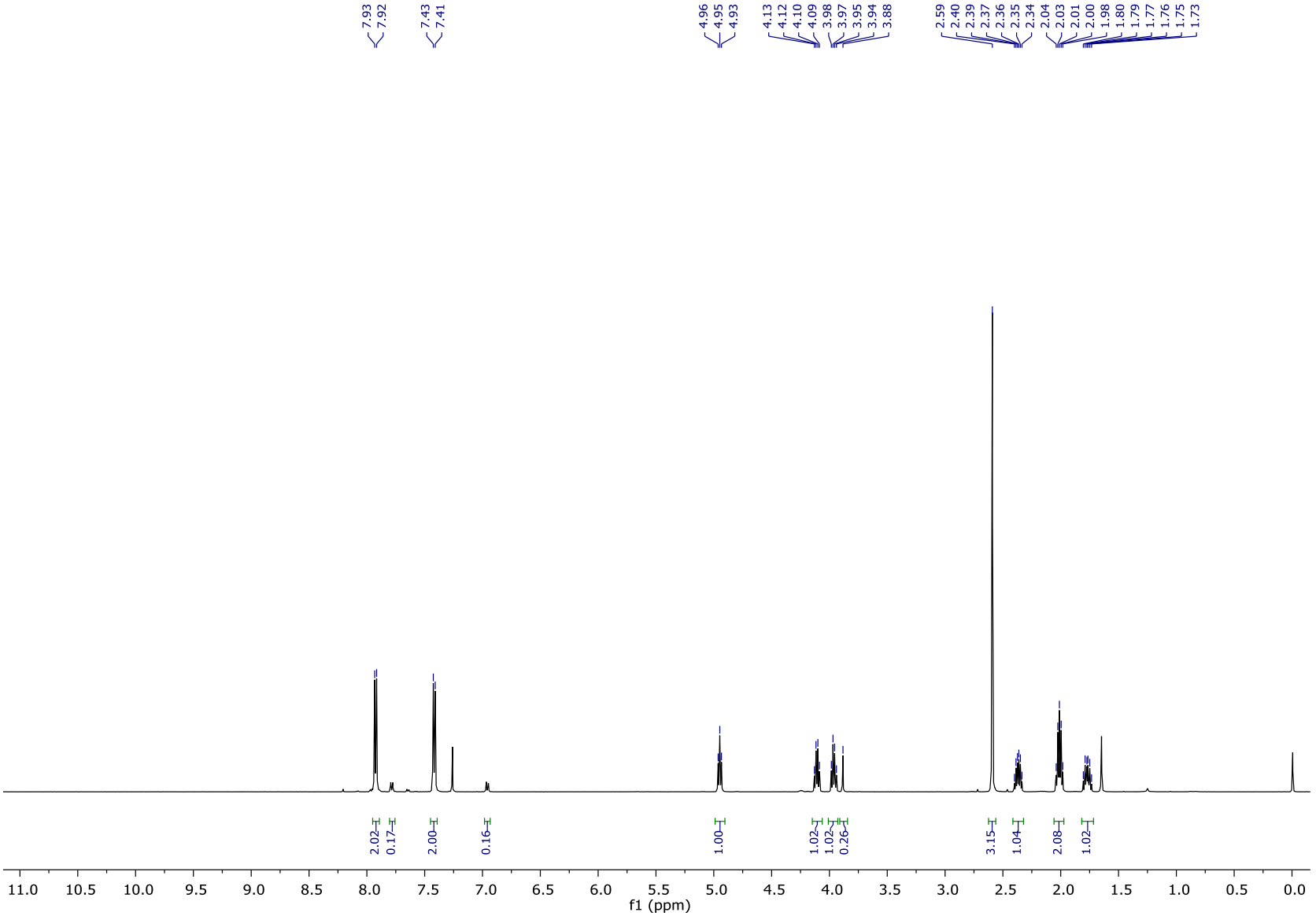
^{13}C NMR Spectrum of Methyl 4-(Tetrahydrofuran-2-yl)benzoate (13)



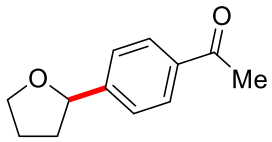


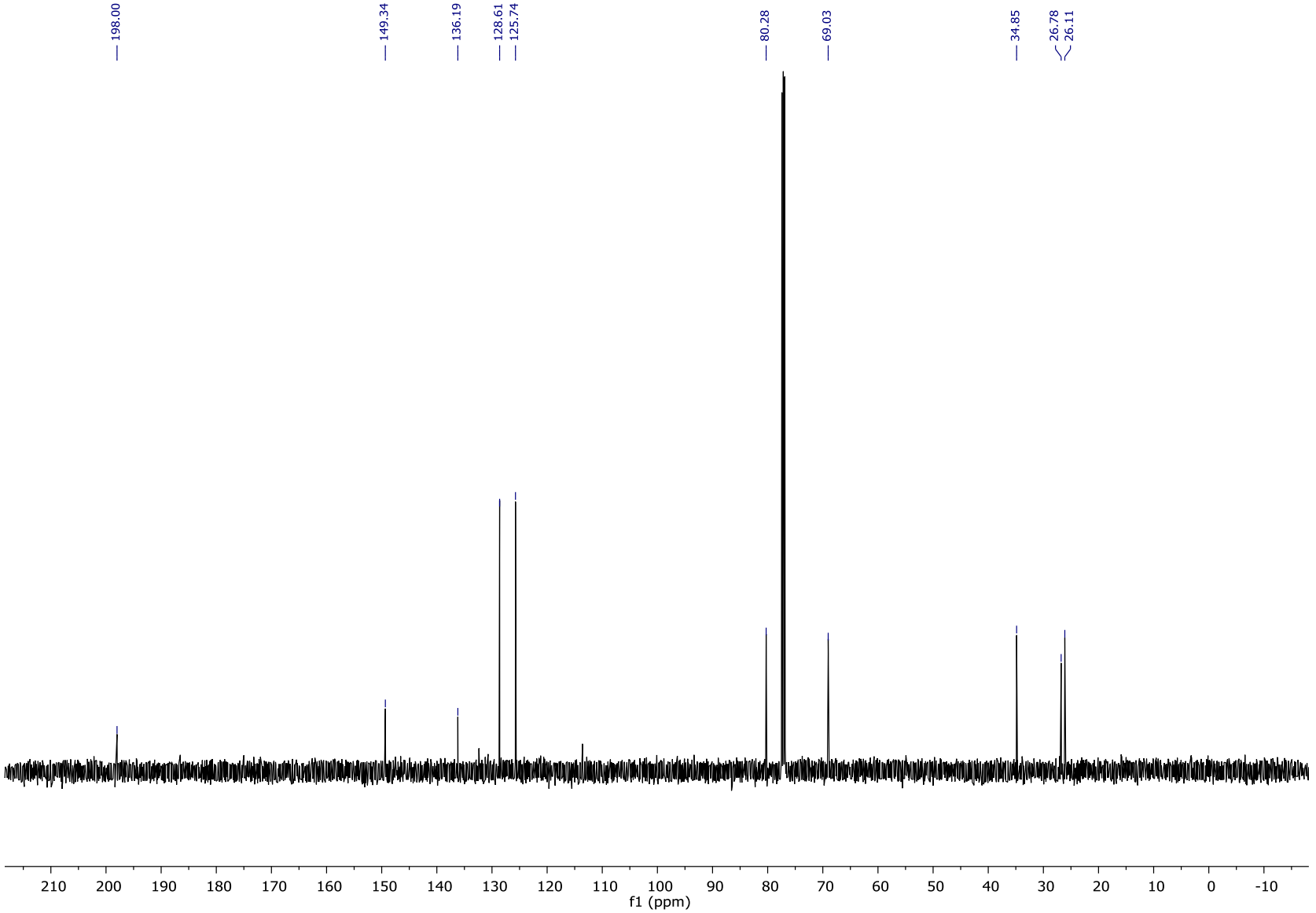
^{1}H NMR Spectrum of 1-(4-(Tetrahydrofuran-2-yl)phenyl)ethan-1-one (14)



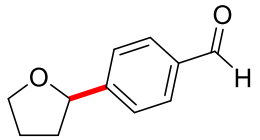


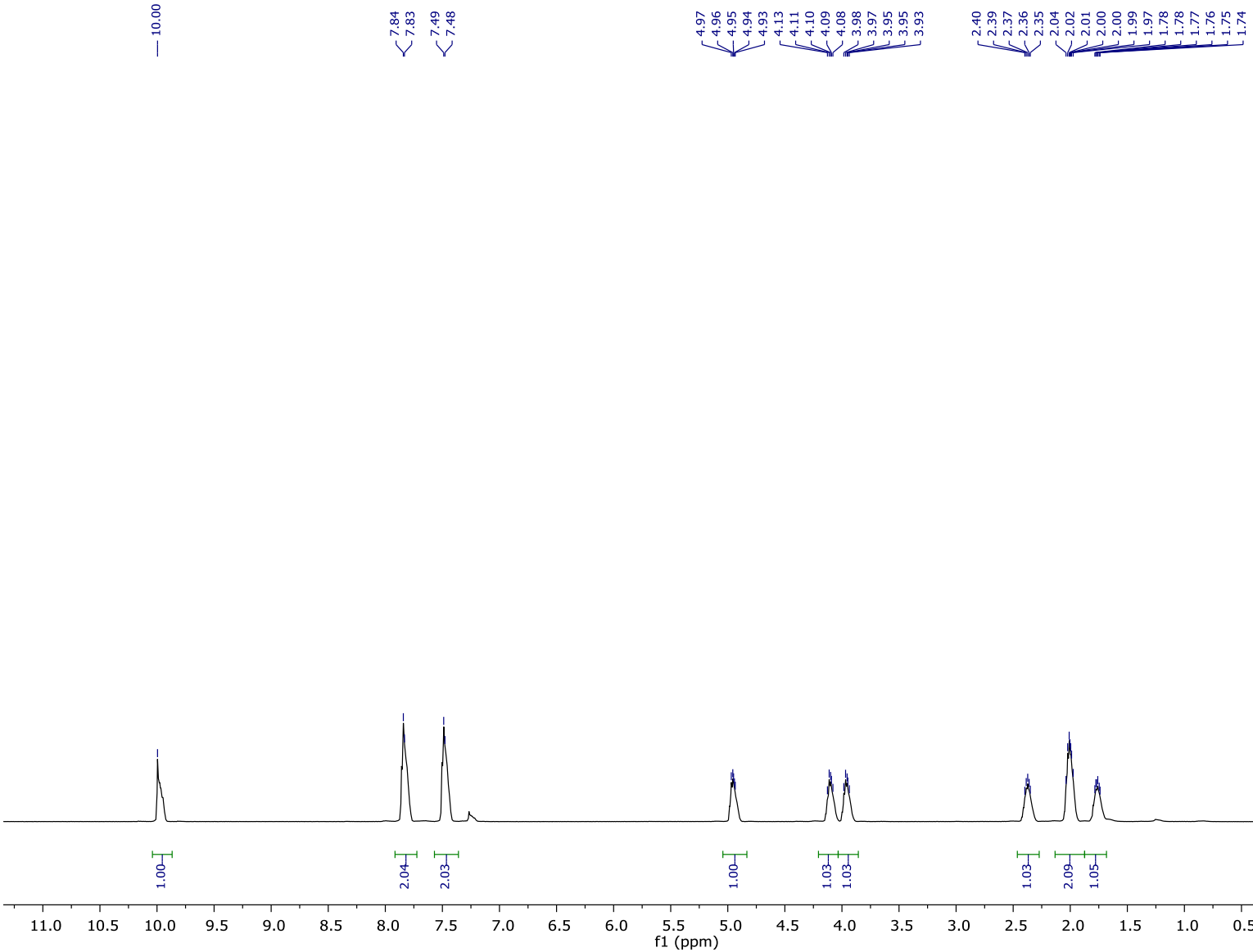
^{13}C NMR Spectrum of 1-(4-(Tetrahydrofuran-2-yl)phenyl)ethan-1-one (14)



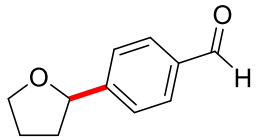


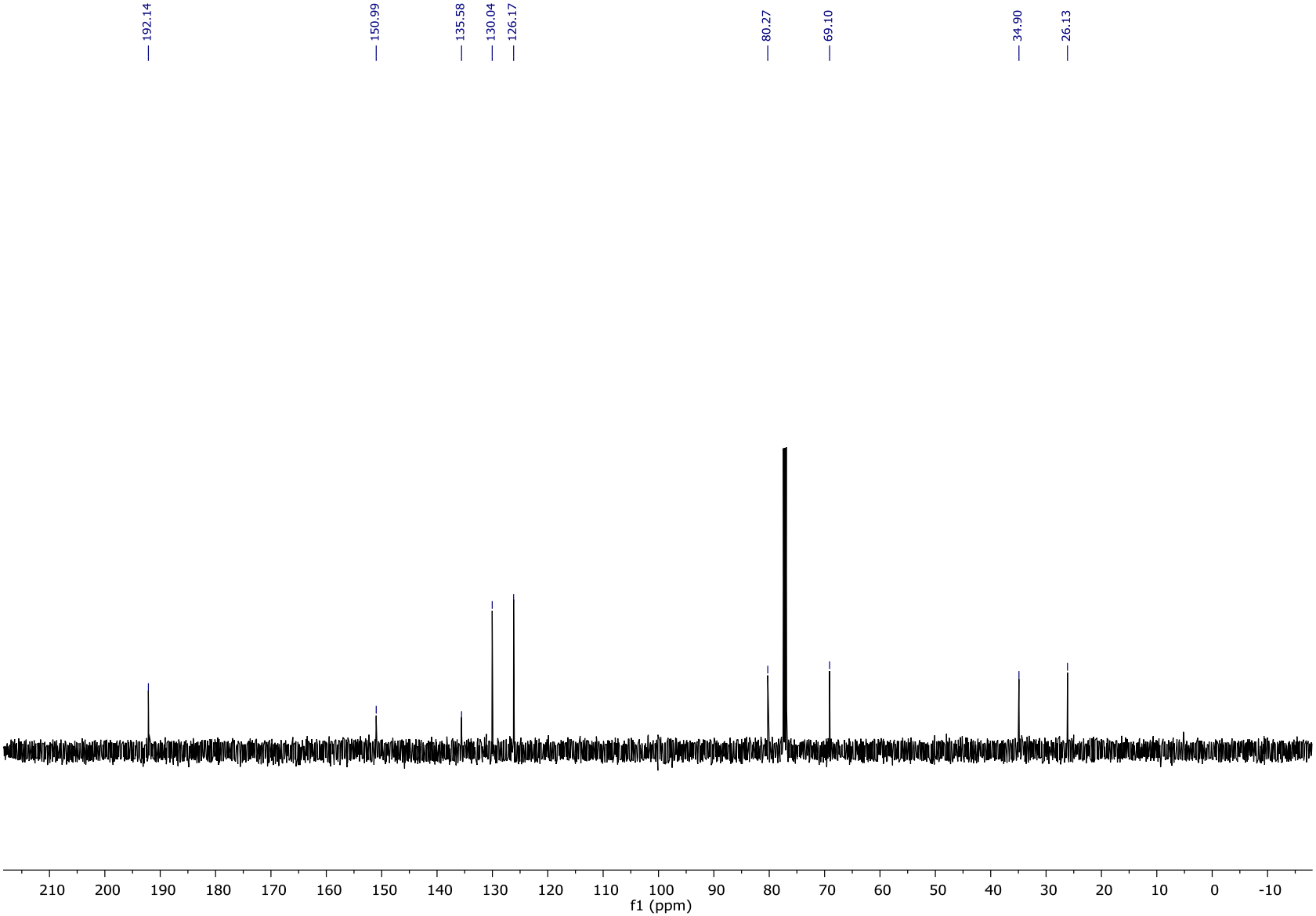
^{1}H NMR Spectrum of 4-(Tetrahydrofuran-2-yl)benzaldehyde (15)



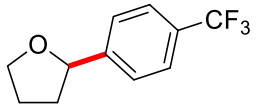


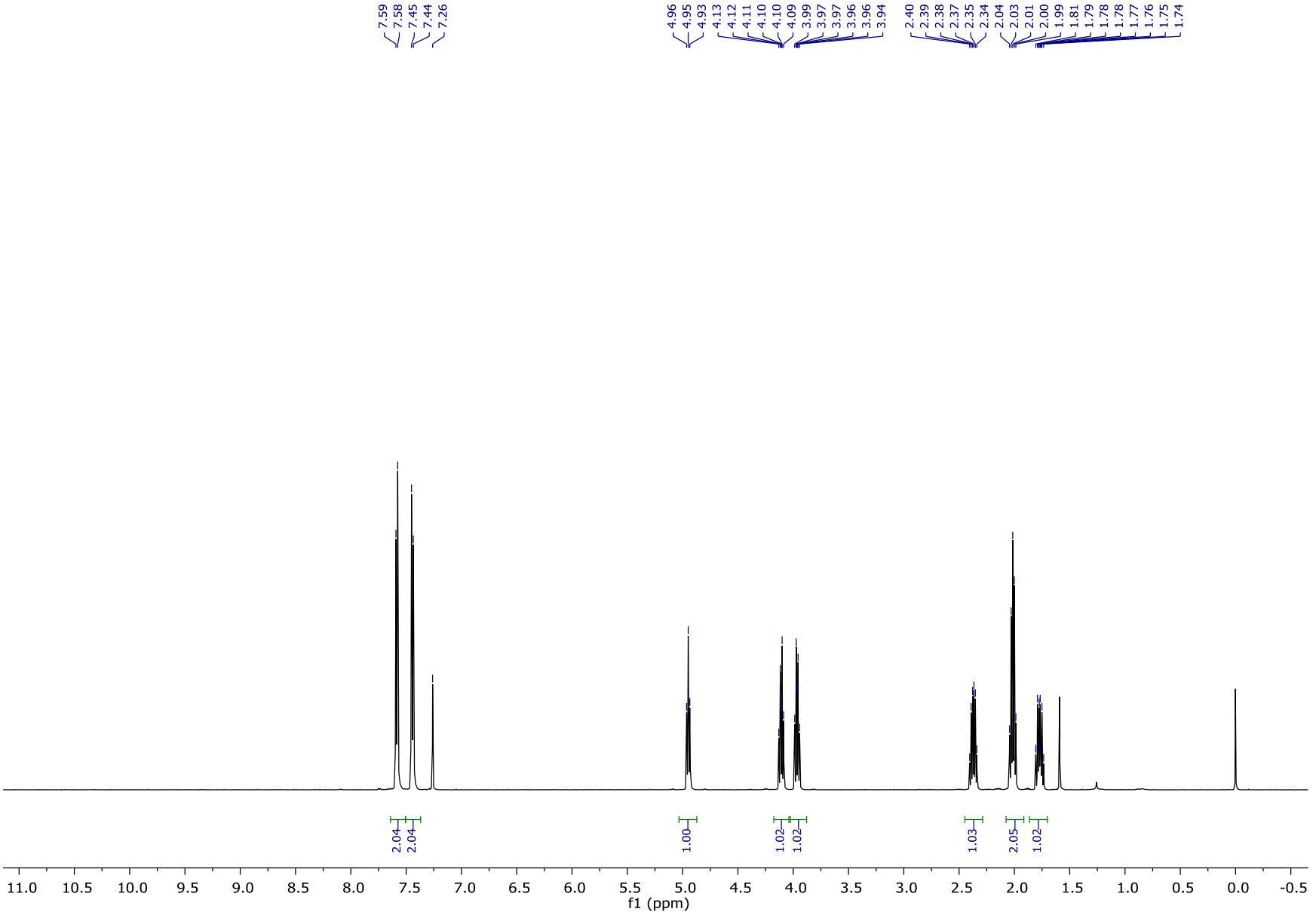
^{13}C NMR Spectrum of 4-(Tetrahydrofuran-2-yl)benzaldehyde (15)



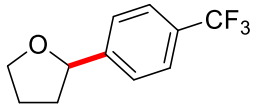


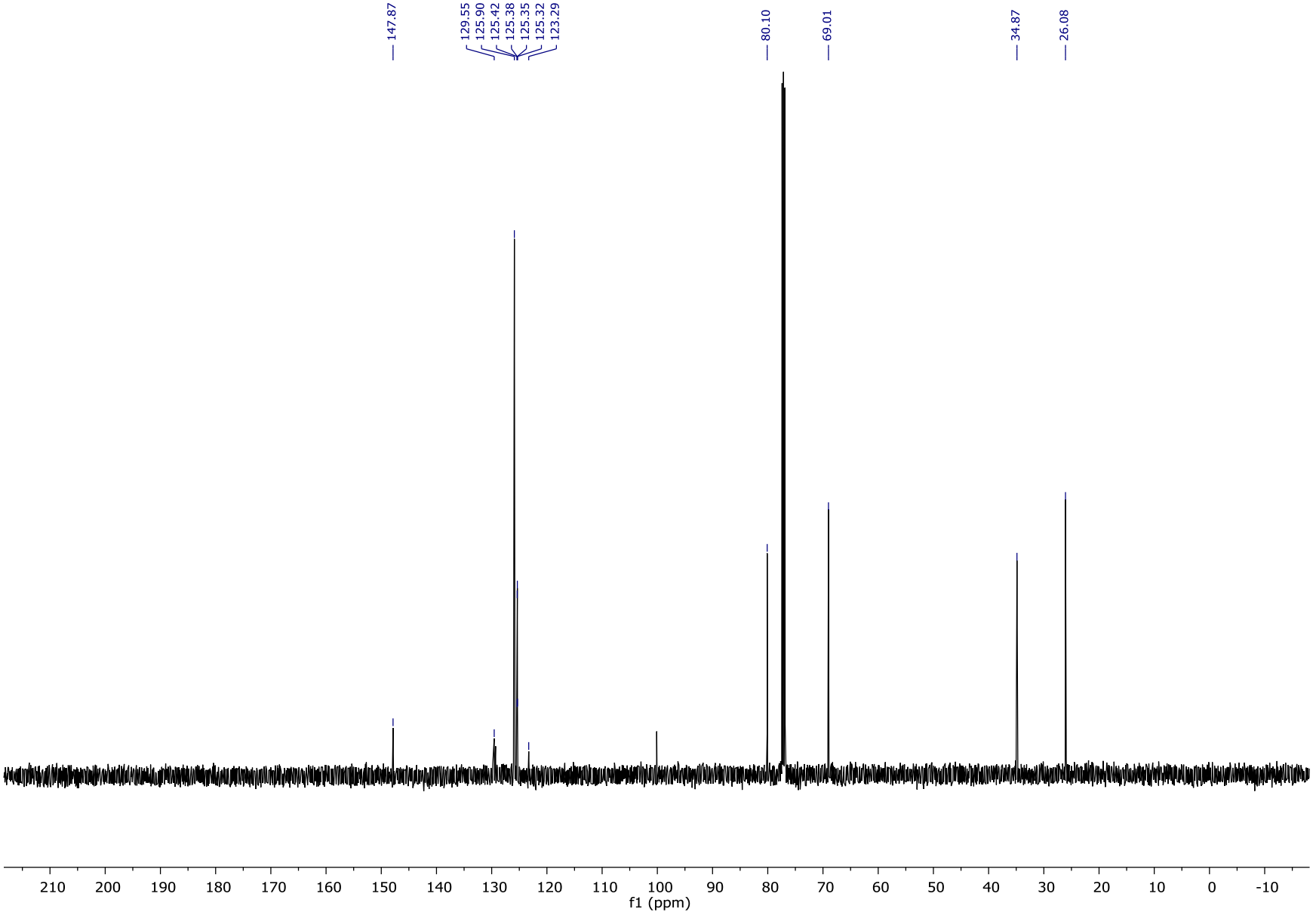
^{1}H NMR Spectrum of 2-(4-(trifluoromethyl)phenyl)tetrahydrofuran (16)



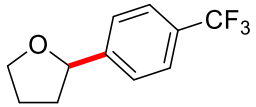


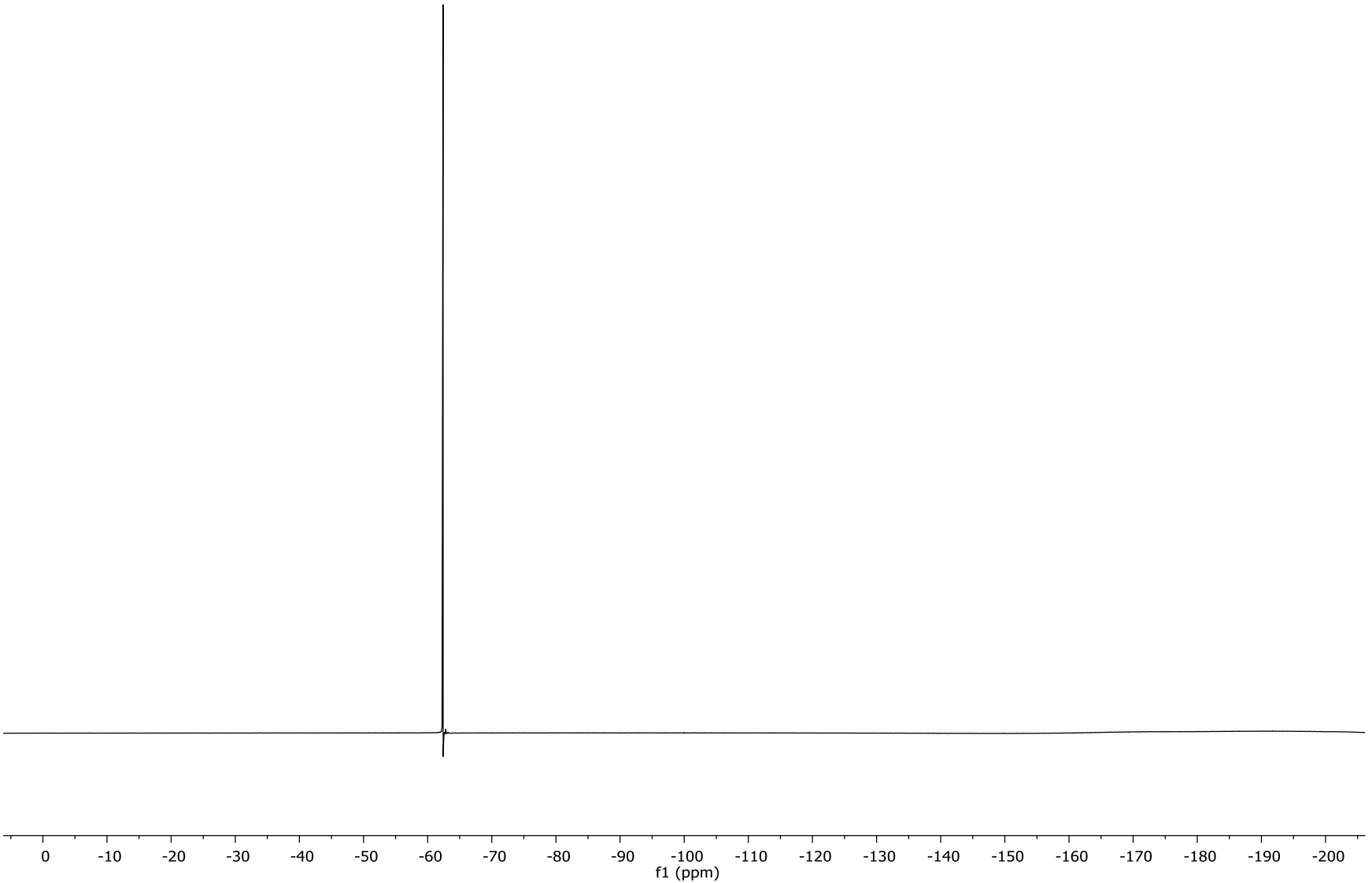
^{13}C NMR Spectrum of 2-(4-(trifluoromethyl)phenyl)tetrahydrofuran (16)



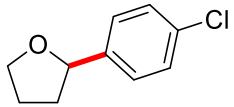


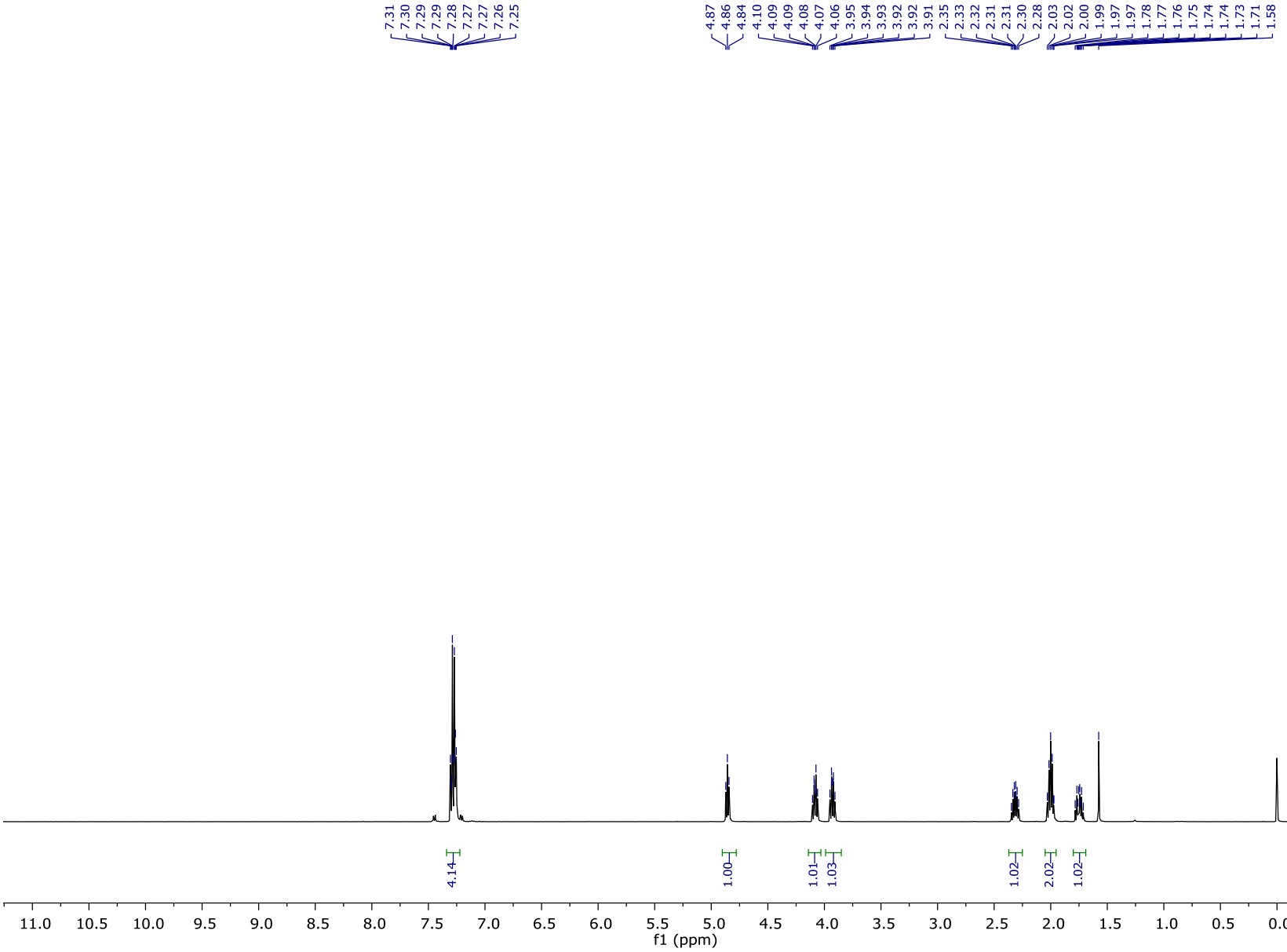
^{19}F NMR Spectrum of 2-(4-(trifluoromethyl)phenyl)tetrahydrofuran (16)



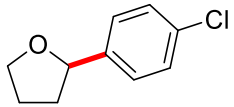


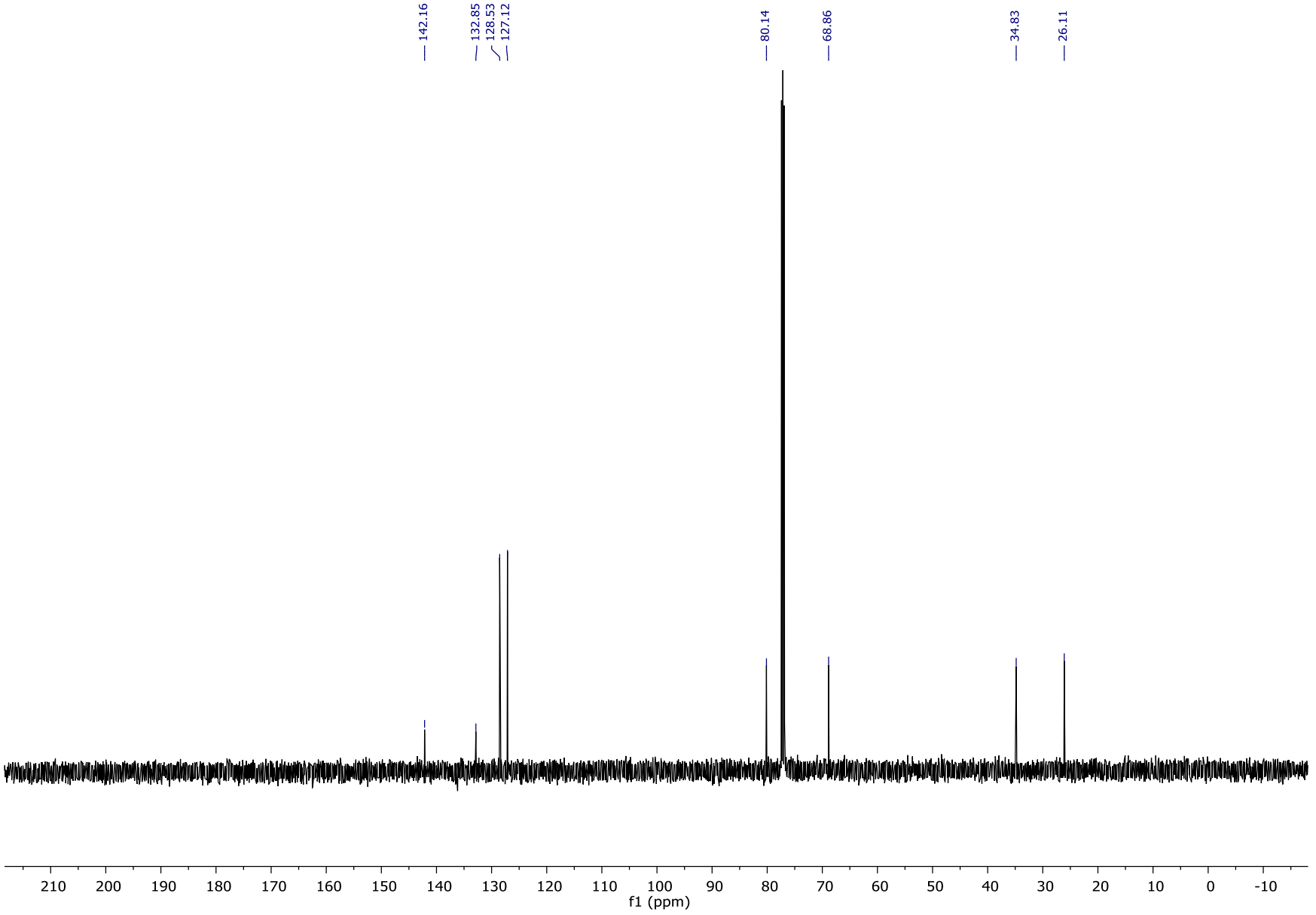
^{1}H NMR Spectrum of 2-(4-Chlorophenyl)tetrahydrofuran (17)



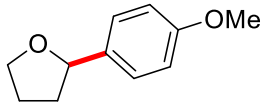


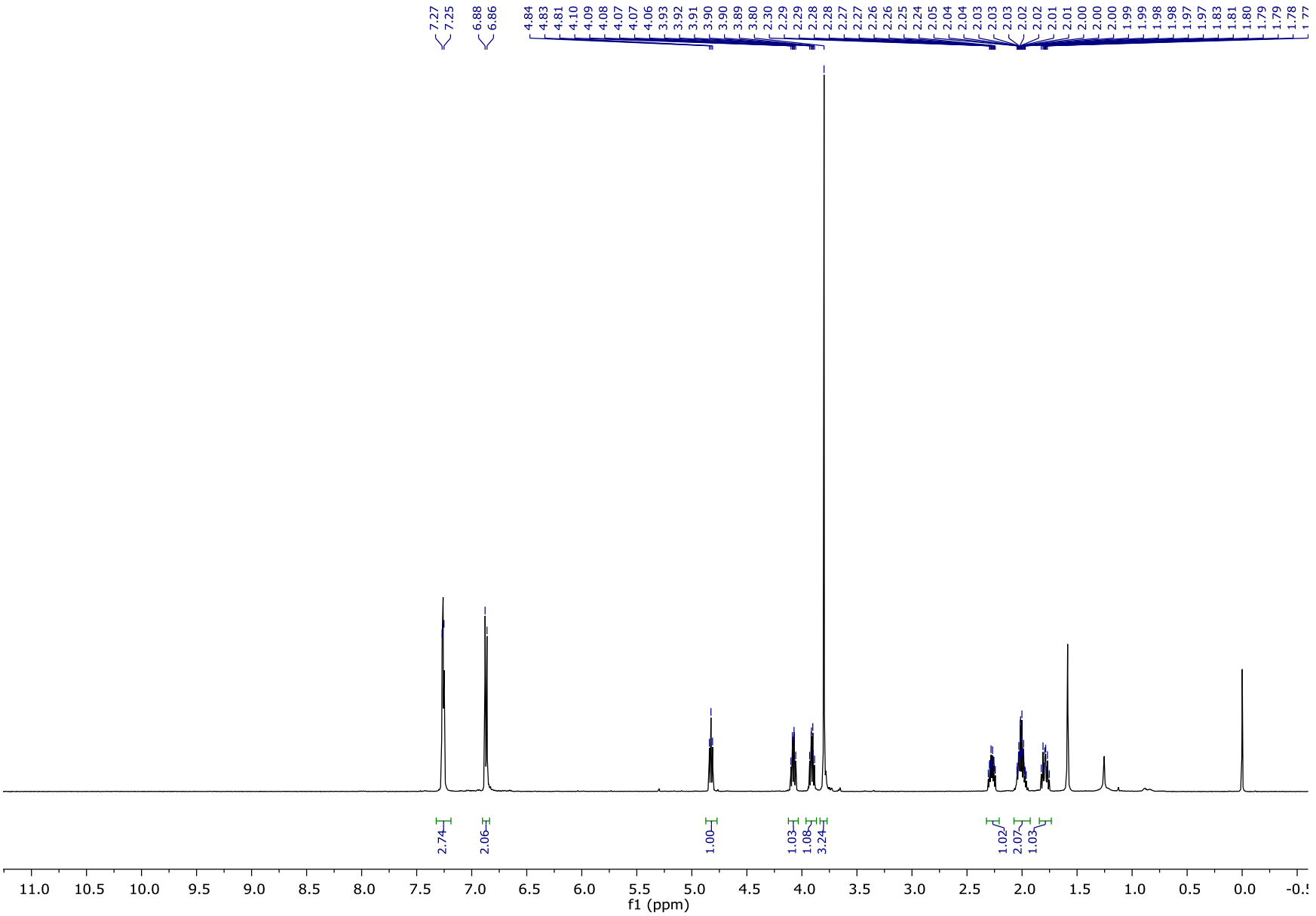
^{13}C NMR Spectrum of 2-(4-Chlorophenyl)tetrahydrofuran (17)



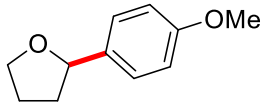


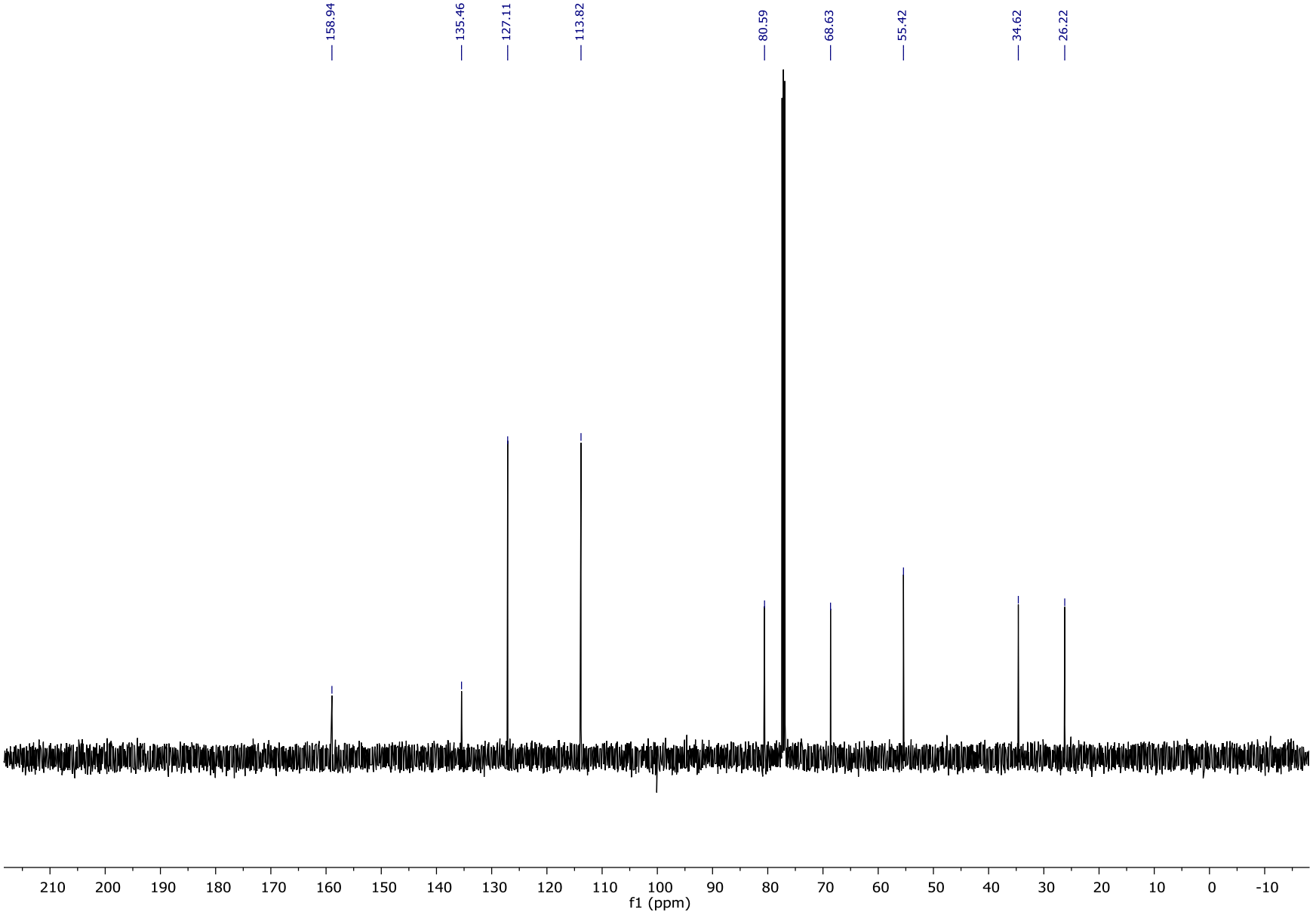
^{1}H NMR Spectrum of 2-(4-Methoxyphenyl)tetrahydrofuran (18)



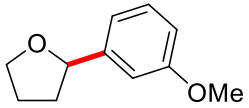


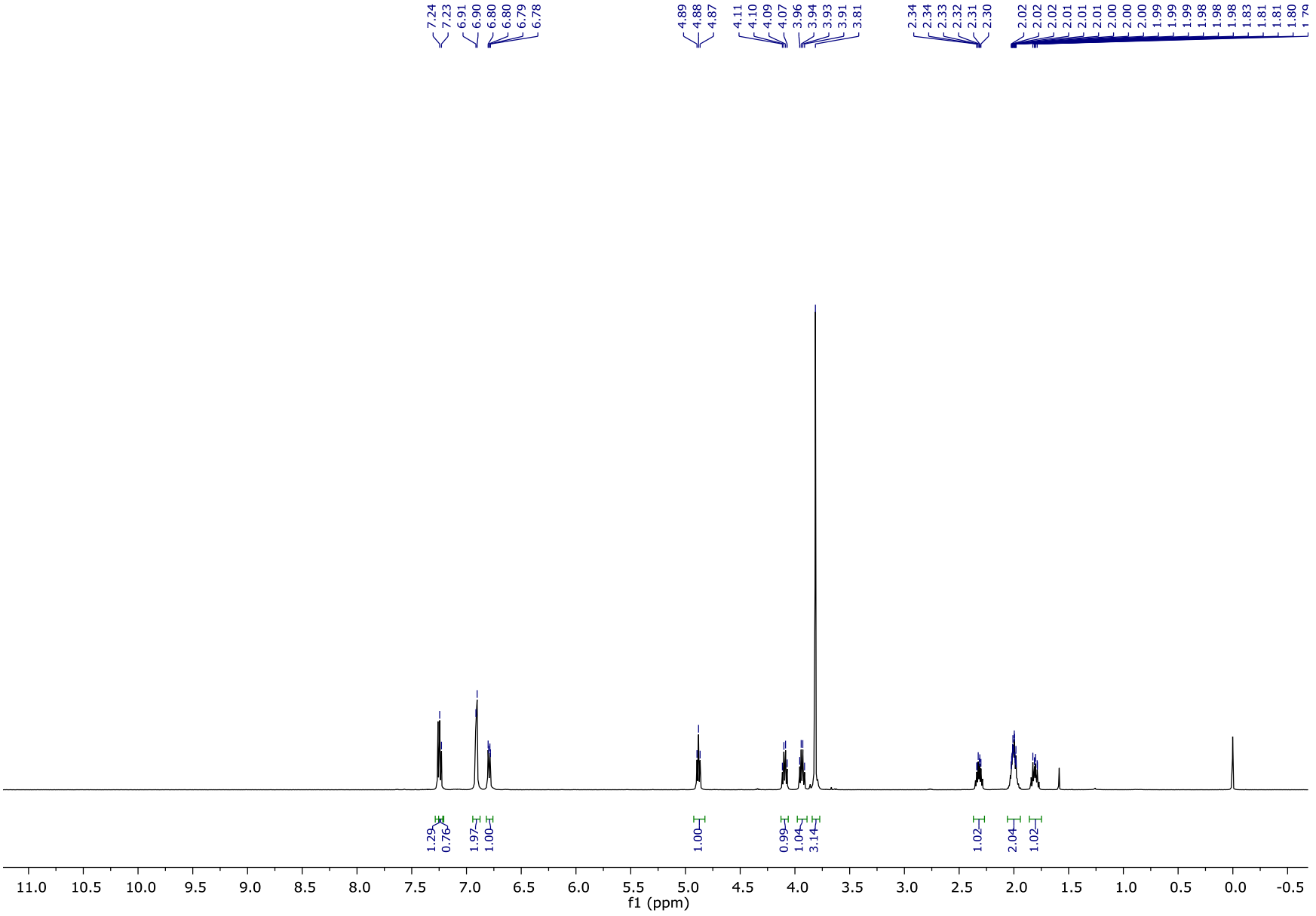
^{13}C NMR Spectrum of 2-(4-Methoxyphenyl)tetrahydrofuran (18)



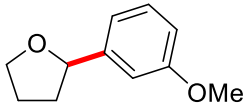


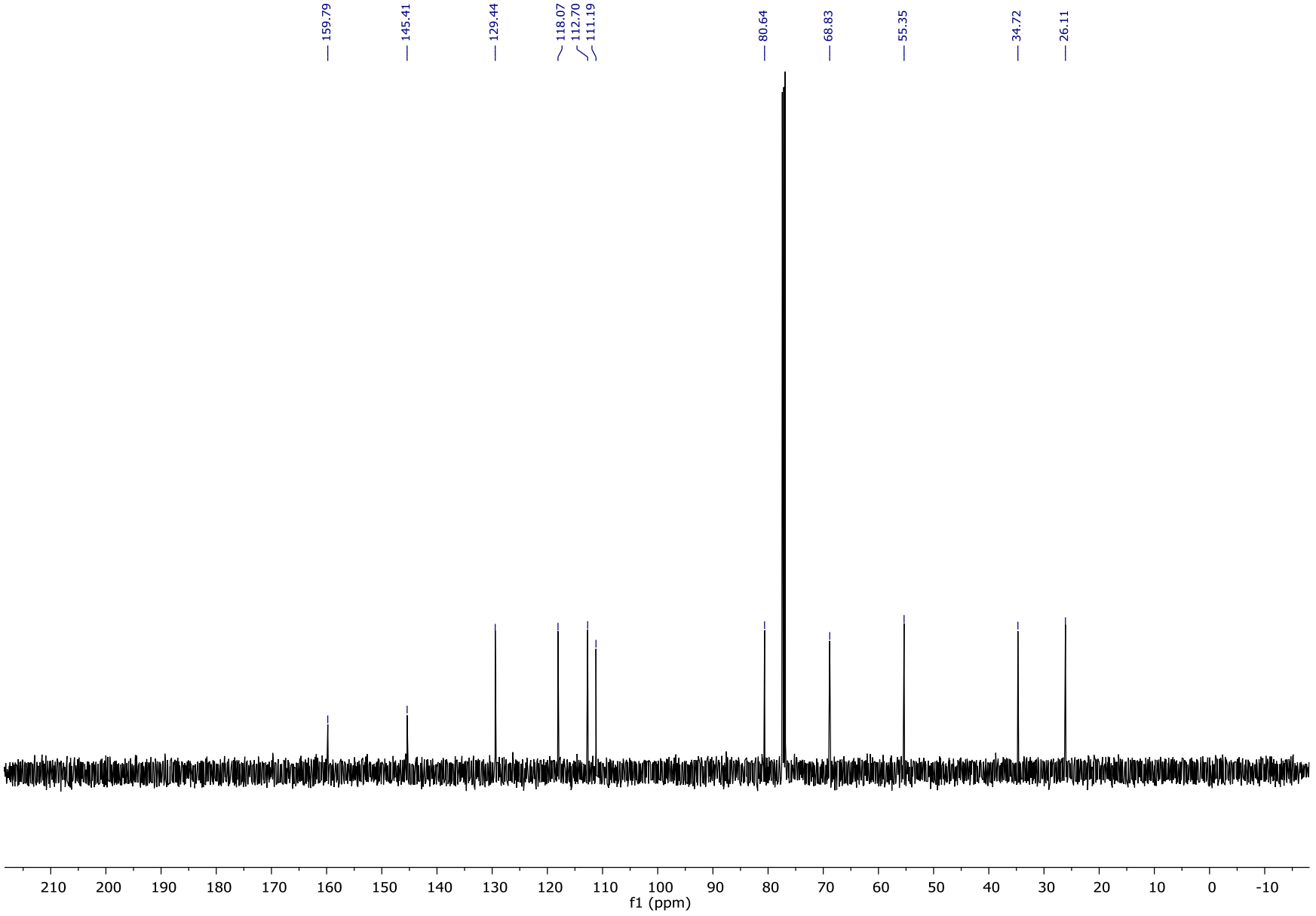
^{1}H NMR Spectrum of 2-(3-Methoxyphenyl)tetrahydrofuran (19)



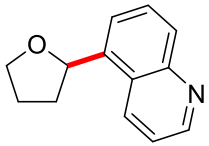


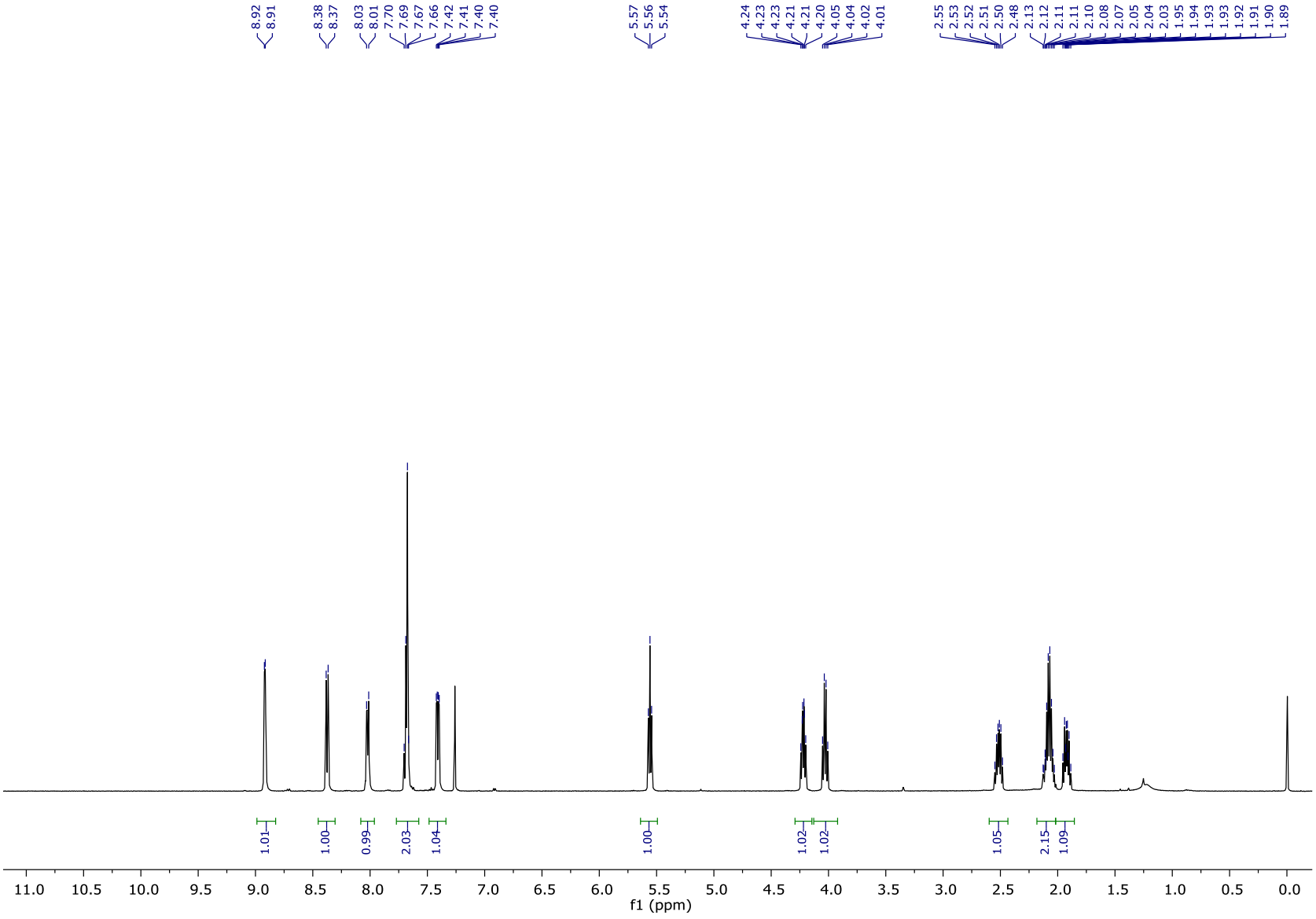
^{13}C NMR Spectrum of 2-(3-Methoxyphenyl)tetrahydrofuran (19)



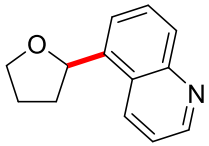


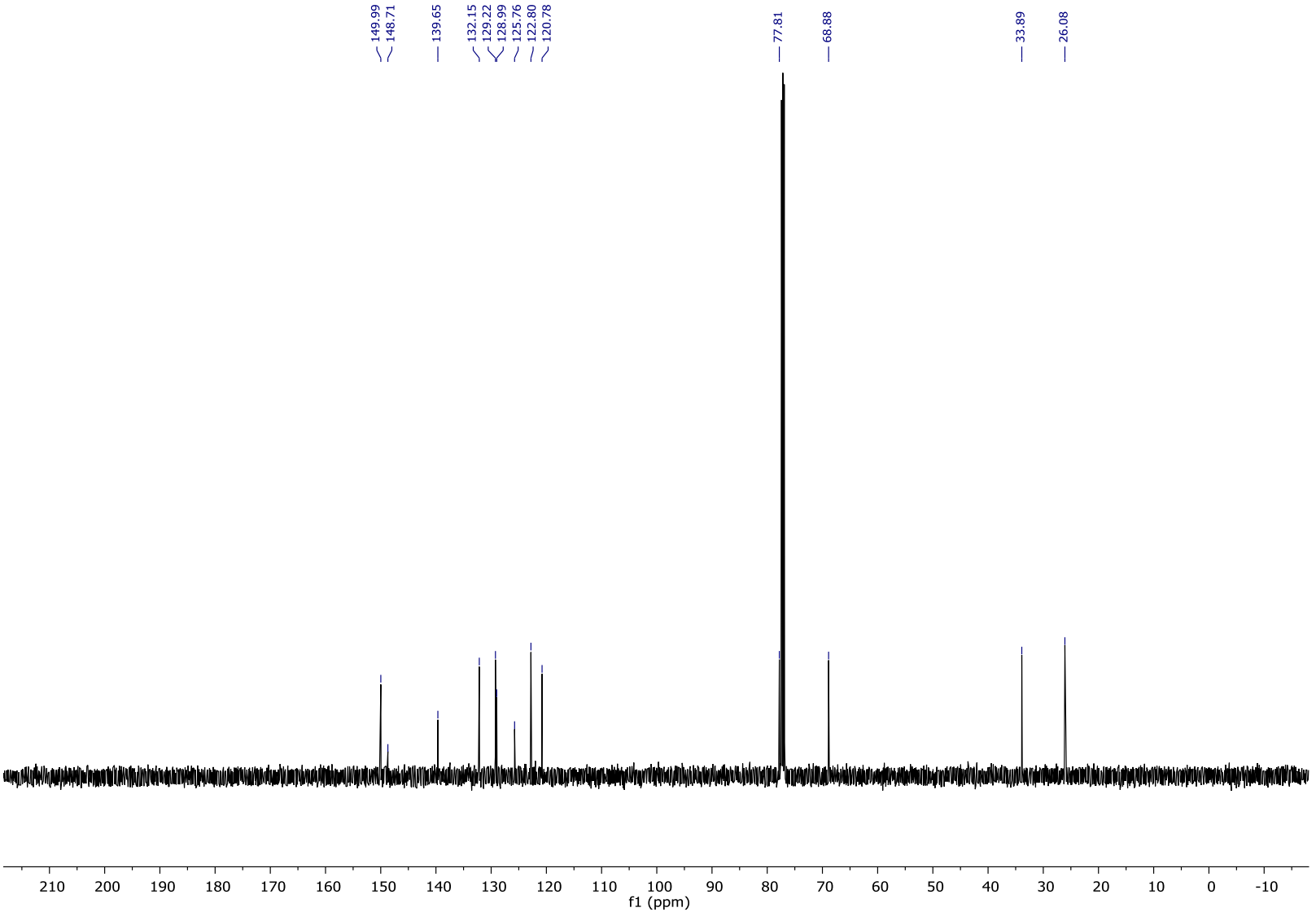
^{1}H NMR Spectrum of 5-(Tetrahydrofuran-2-yl)quinoline (20)



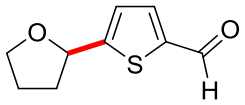


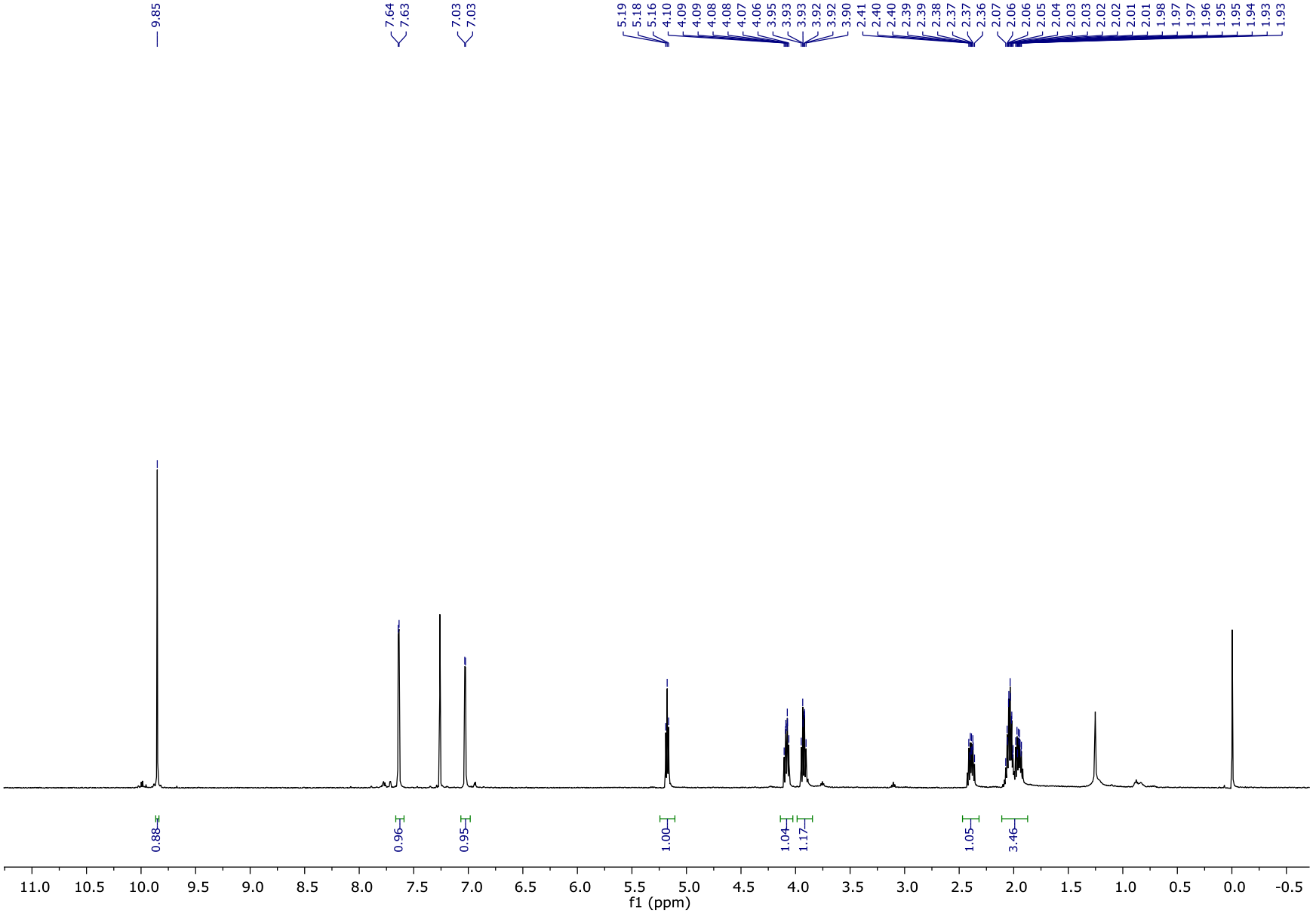
^{13}C NMR Spectrum of 5-(Tetrahydrofuran-2-yl)quinoline (20)



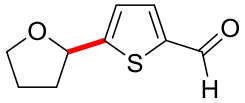


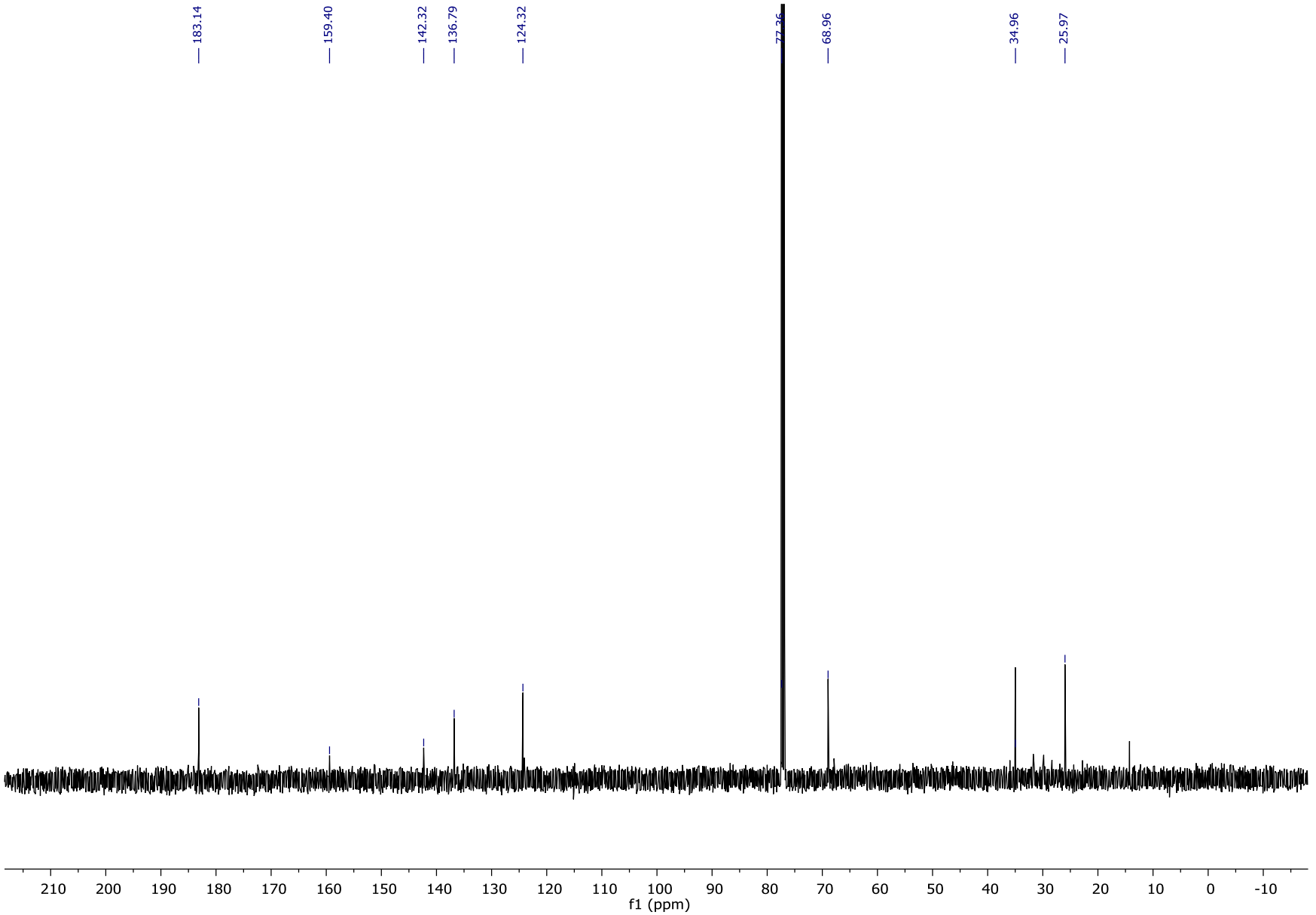
^{1}H NMR Spectrum of 5-(Tetrahydrofuran-2-yl)thiophene-2-carbaldehyde (21)



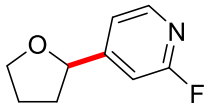


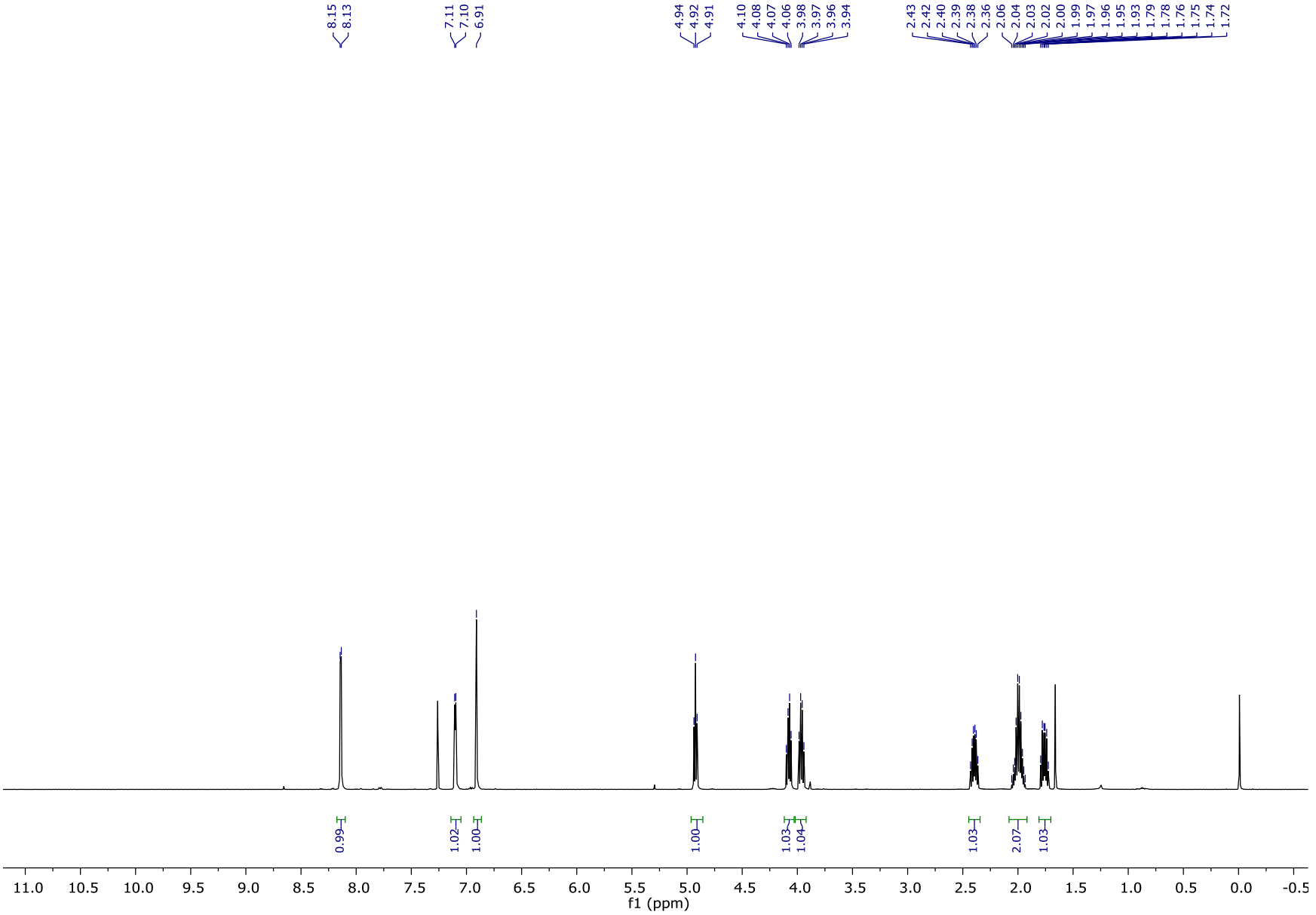
^{13}C NMR Spectrum of 5-(Tetrahydrofuran-2-yl)thiophene-2-carbaldehyde (21)



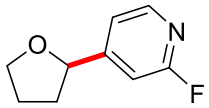


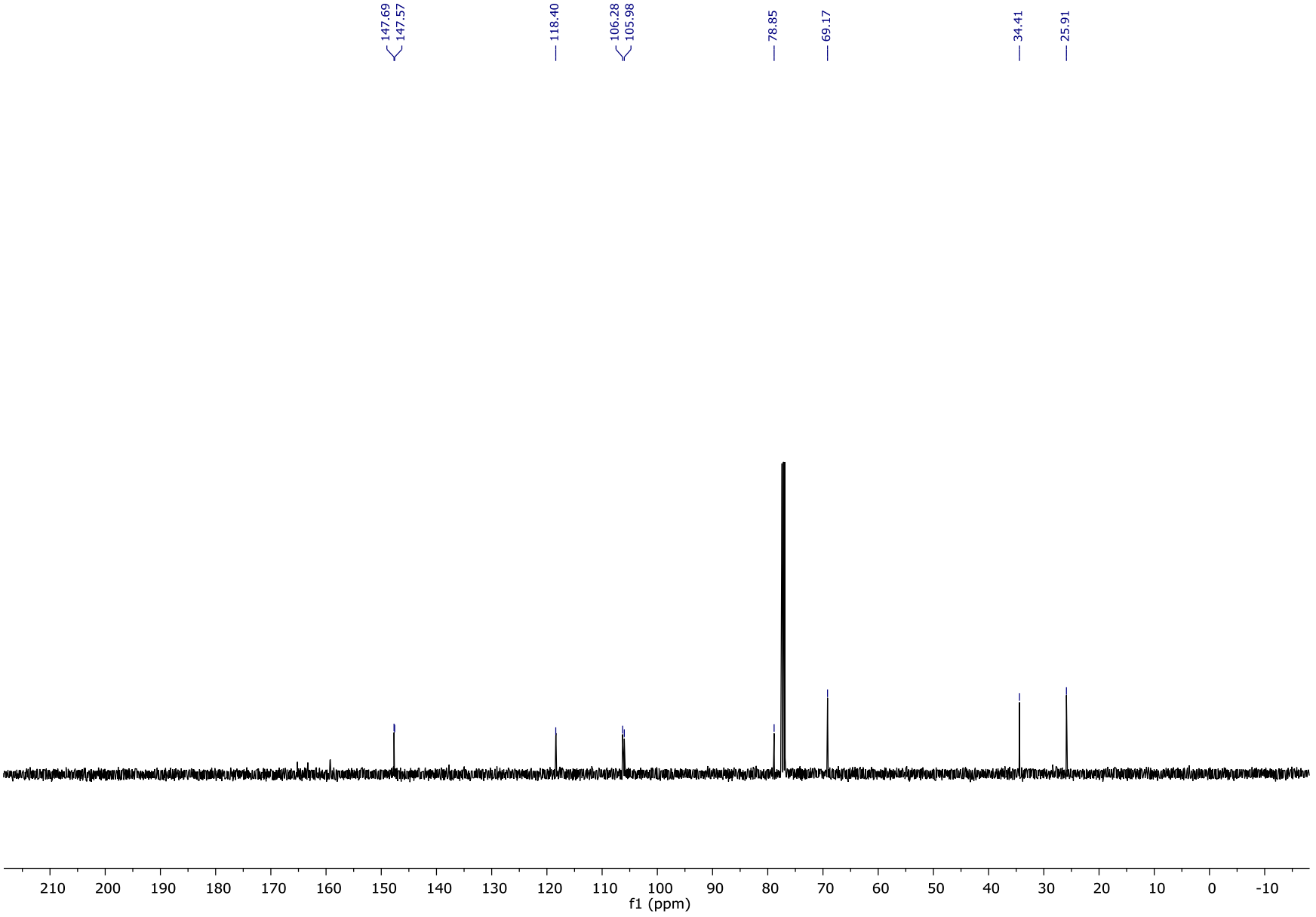
^{1}H NMR Spectrum of 2-Fluoro-4-(tetrahydrofuran-2-yl)pyridine (22)



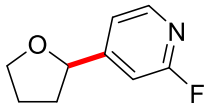


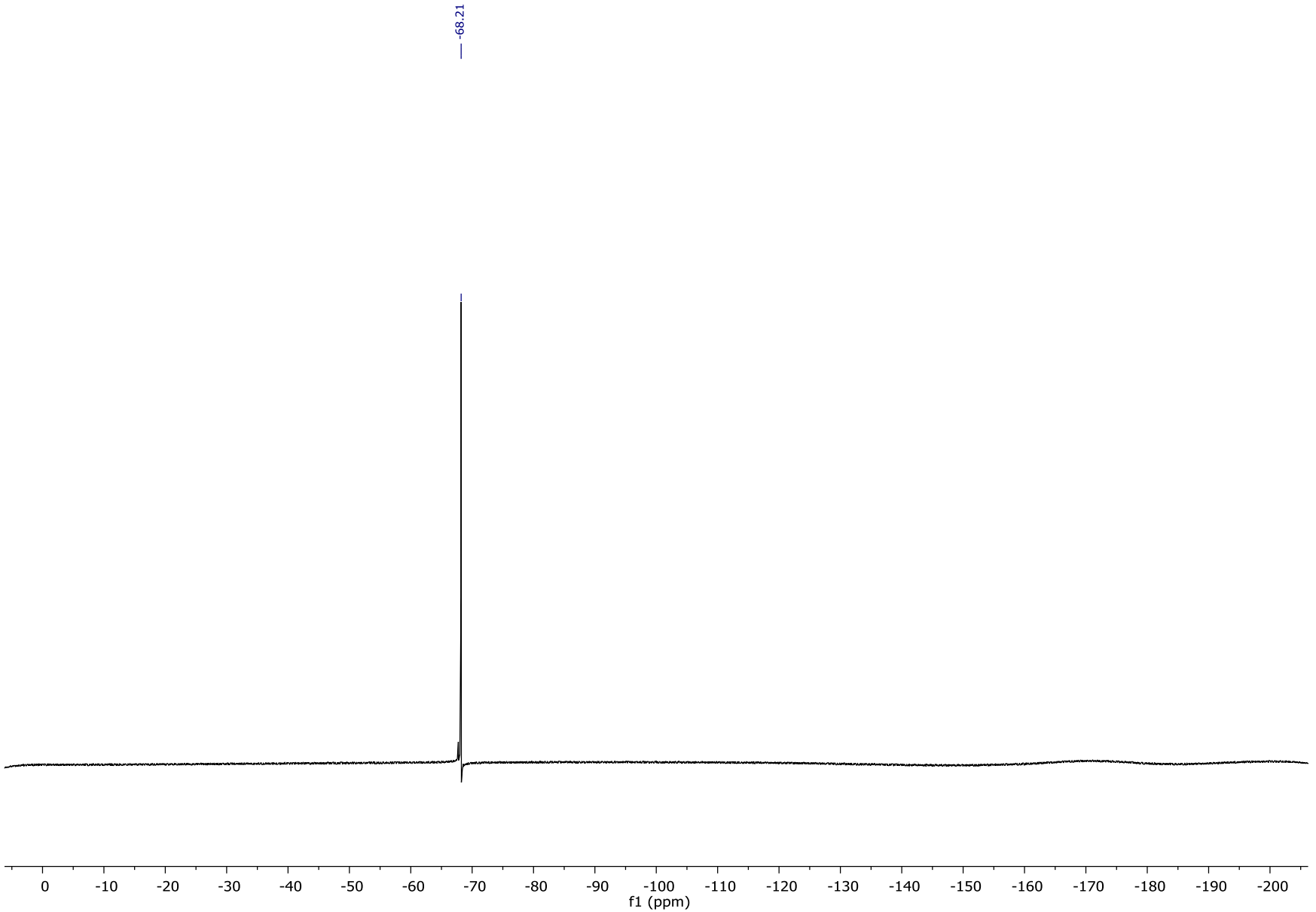
^{13}C NMR Spectrum of 2-Fluoro-4-(tetrahydrofuran-2-yl)pyridine (22)



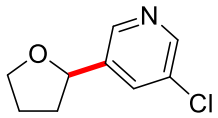


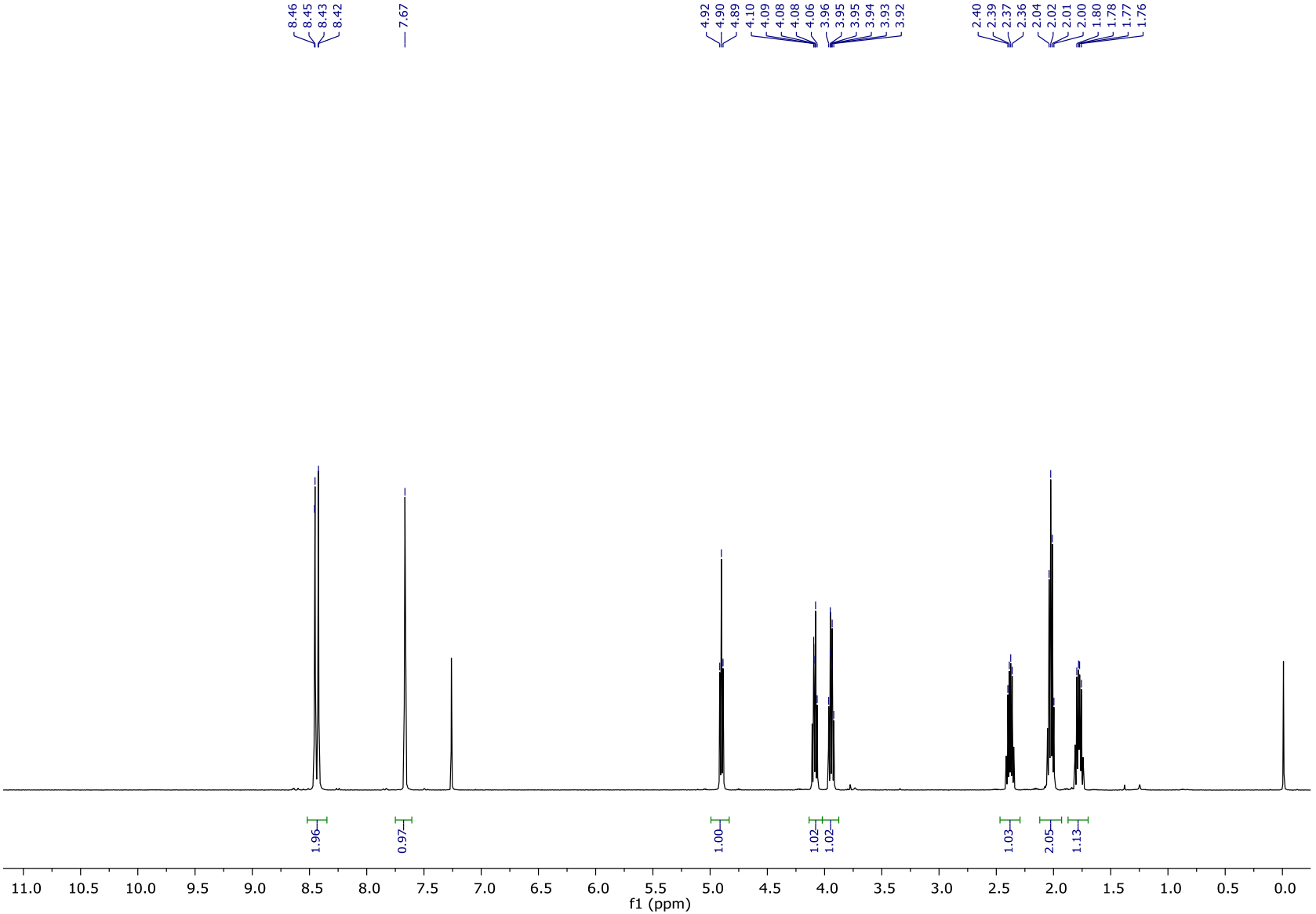
^{19}F NMR Spectrum of 2-Fluoro-4-(tetrahydrofuran-2-yl)pyridine (22)



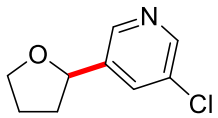


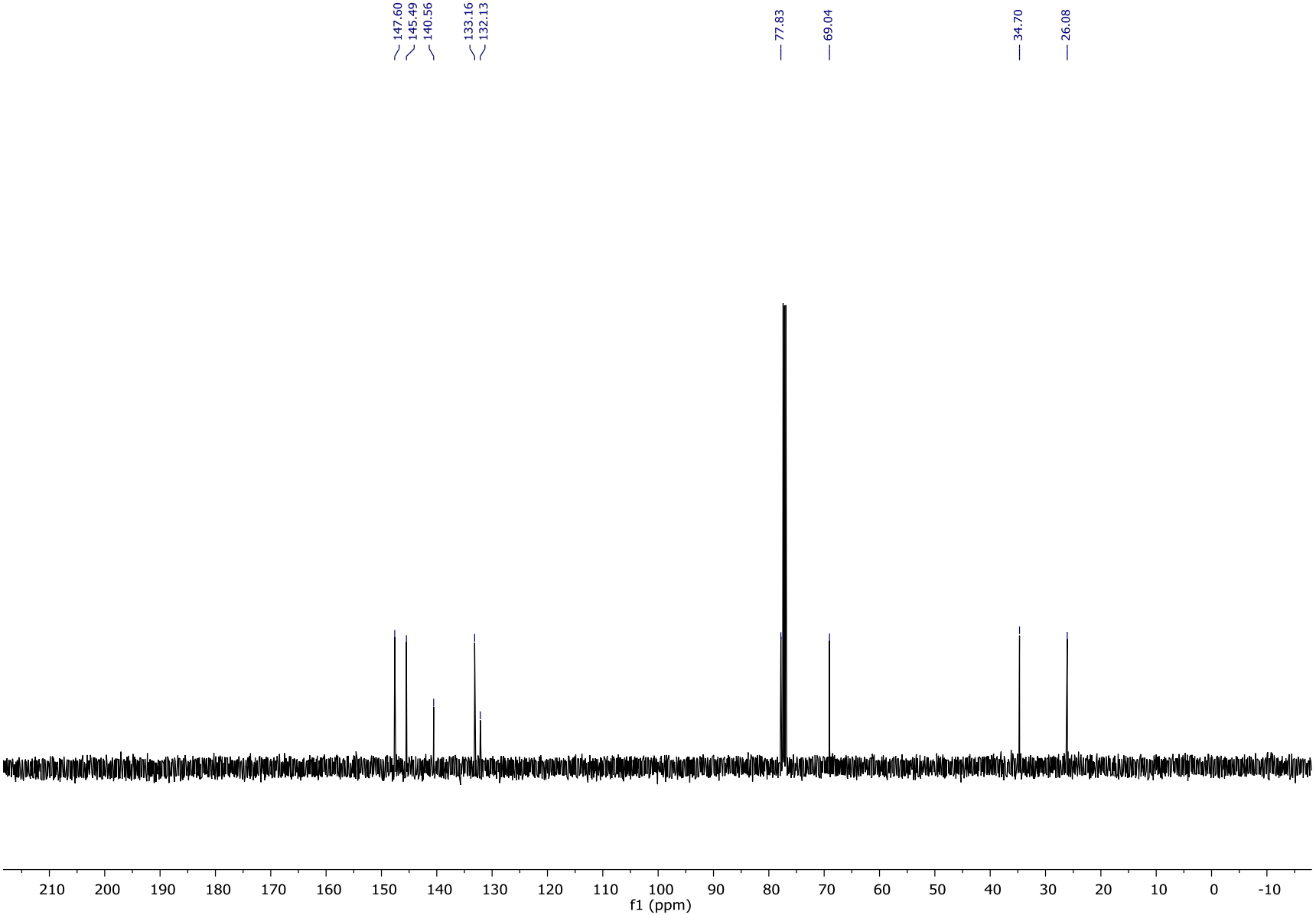
^{1}H NMR Spectrum of 3-Chloro-5(tetrahydrofuran-2-yl)pyridine (23)



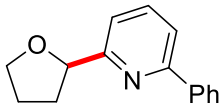


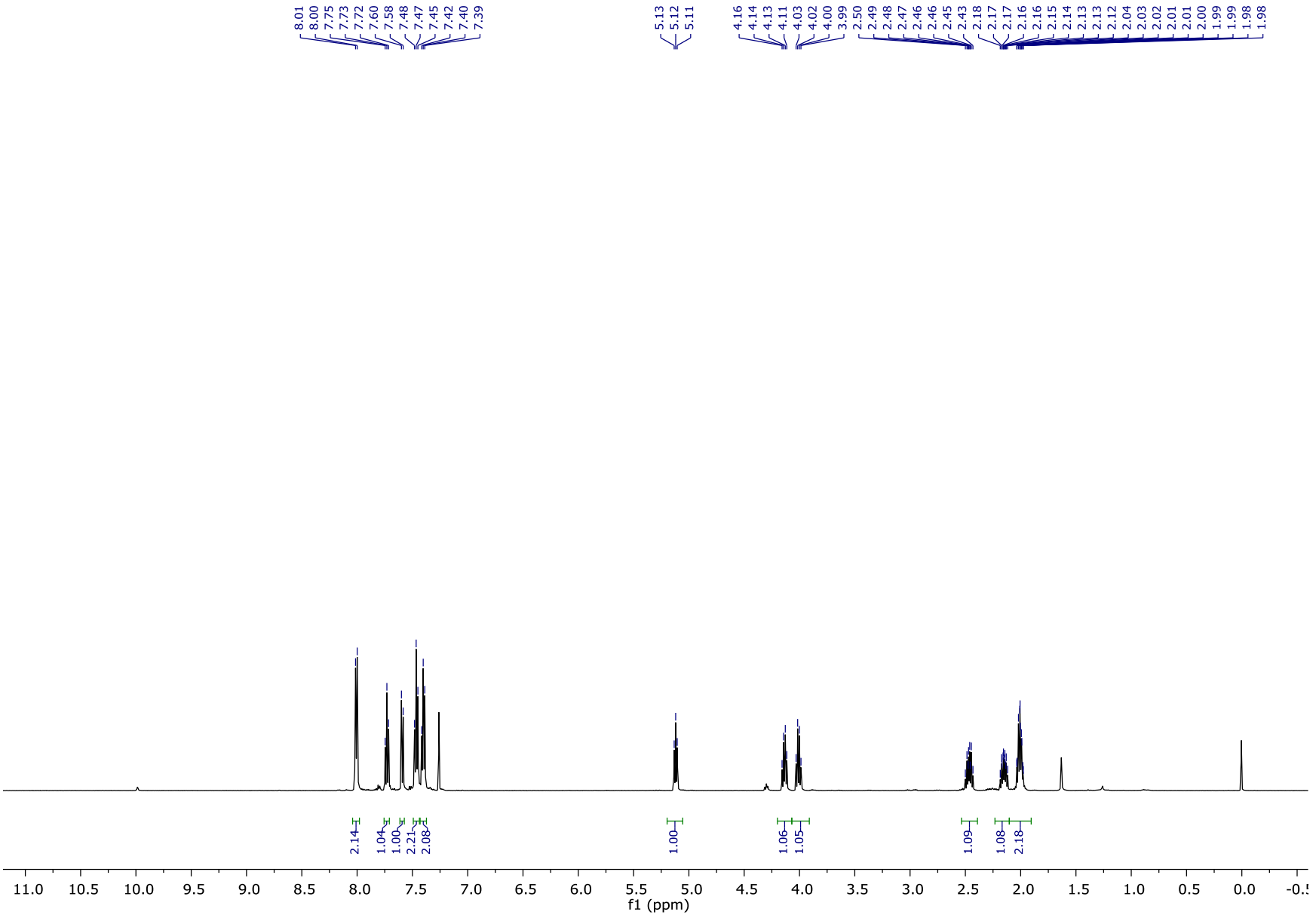
^{13}C NMR Spectrum of 3-Chloro-5(tetrahydrofuran-2-yl)pyridine (23)



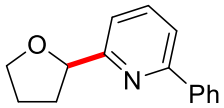


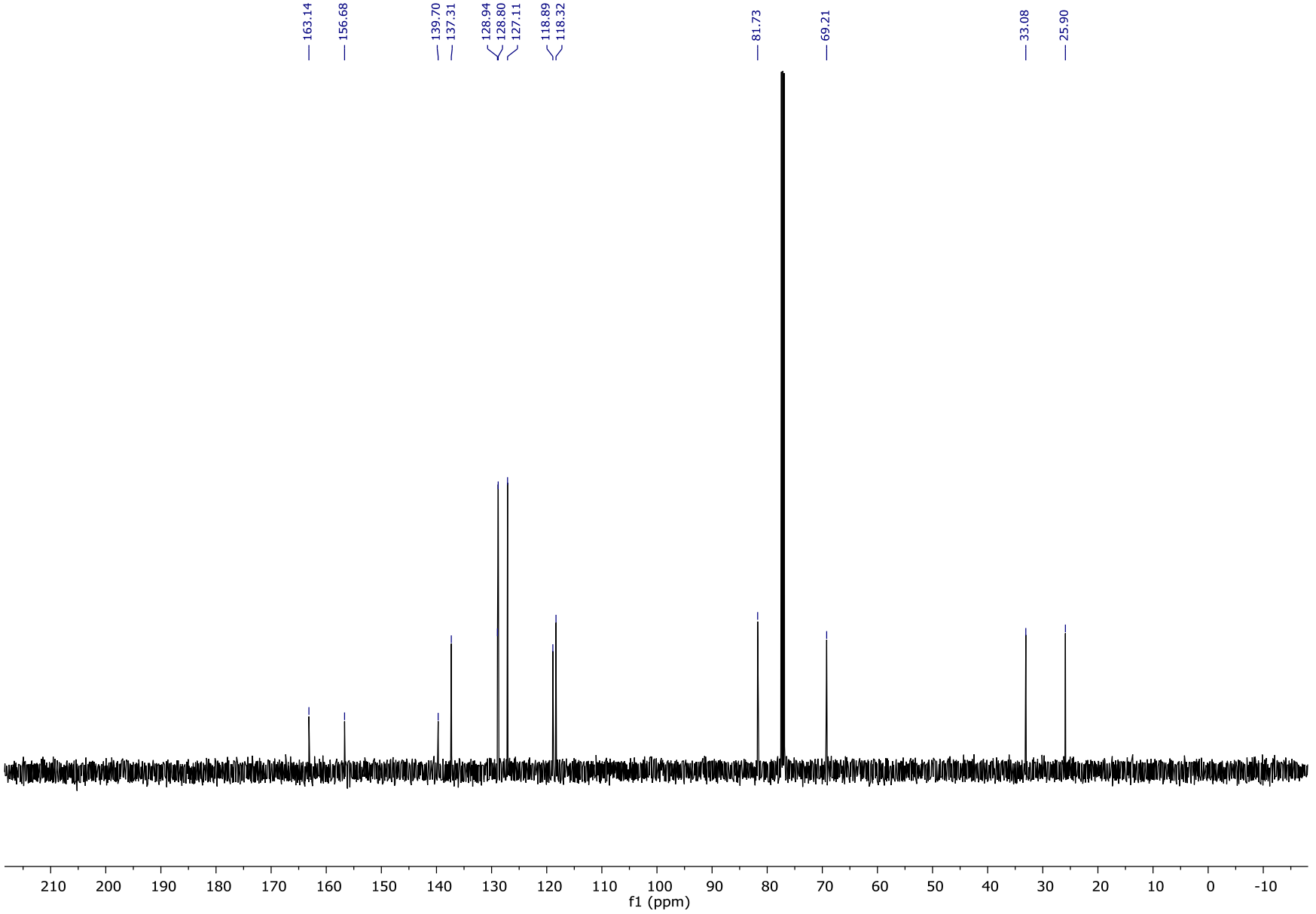
^{1}H NMR Spectrum of 2-Phenyl-6-(tetrahydrofuran-2-yl)pyridine (24)





^{13}C NMR Spectrum of 2-Phenyl-6-(tetrahydrofuran-2-yl)pyridine (24)





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