Supplementary Information for

Nickel-Catalyzed Deaminative Sonogashira Coupling of Alkylpyridinium Salts Enabled by a New NN_2 Pincer Ligand

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Contents

General information

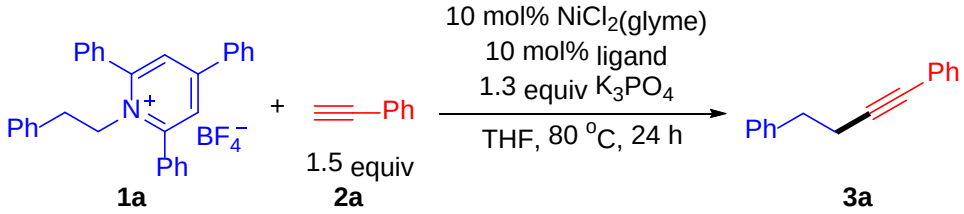
Unless otherwise noted, commercially available reagents were used as received without further purification and all reactions were carried out using standard Schlenk technique or a dry box technique under a nitrogen atmosphere. Tetrahydrofuran (THF), dimethyl sulfoxide (DMSO) and acetonitrile (CH_3CN) were dried using Eminex Solvent Purifier (EX-SPS5-800). Anhydrous *N*, *N*-dimethylformamide (DMF) and 1-methyl-2-pyrrolidinone (NMP) were purchased from J&K Chemical Company. $NiCl_2{\cdot}6H_2O$, $Ni(OAc)_2{\cdot}4H_2O$ and $Ni(acac)_2$ were purchased from J&K Chemical Company. NiI_2 was purchased from Alfa Aesar. $NiCl_2$(glyme) and $NiBr_2$(glyme) were purchased from Sigma-Aldrich. Anhydrous K_3PO_4 was purchased from Acros. Flash column chromatography was performed on silica gel (200-300 mesh). ^1H and ^{13}C NMR spectra were recorded on Bruker 400 MHz and 600 MHz spectrometers at room temperature in $CDCl_3$, DMSO-d_6 or CD_3OD (containing 0.03% TMS) solutions. ^1H NMR spectra was recorded with tetramethylsilane (0.00 ppm) or solvent residual peak ($CDCl_3$: 7.26 ppm; DMSO-d_6: 2.50 ppm; CD_3OD: 3.31 ppm) as internal reference; ^{13}C NMR spectra was recorded with $CDCl_3$ (77.00 ppm) or DMSO-d_6 (39.52 ppm) as internal reference. Data are represented as follows: chemical shift, multiplicity (br = broad, s = singlet, d = doublet, t = triplet, q = quartet, dd = doublet of doublets, m = multiplet), coupling constants (Hz) and integration. High-resolution mass spectra were obtained by using Bruker UHR-ES-TOF MS, Waters Premier GC-TOF MS, JEOL-AccuTOF-GCv4G-GCT MS or Thermo Scientific Q Exactive HF Orbitrap-FTMS. The IR spectra were measured on a PerkinElmer Spectrum 400 FT-IR/FT-FIR spectrometer. Single crystal X-ray diffraction data was collected at 293(2) K for **Int-1** on a SuperNova diffractometer. 2,4,6-Triphenylpyrylium tetrafluoroborate[1] was prepared according to literature procedures.

General procedure for optimization studies

In a nitrogen-filled glovebox, nickel catalyst (0.03 mmol), ligand (0.03 mmol), base (0.39 mmol), phenethylpyridinium salt **1a** (0.3 mmol, 150.0 mg) and solvent (1.5 mL) were successively added to an oven-dried sealable Schlenk tube (10.0 mL) followed by addition of phenylacetylene (0.45 mmol, 46.0 mg) via microliter syringe. Then the tube

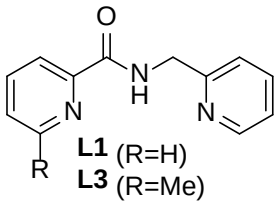
was securely sealed and taken outside the glovebox. And it was immersed into an oil bath preheated at 80 °C. After stirring for 24 h, the reaction mixture was cooled to room temperature and filtered through a short pad of silica gel. Then the filter cake was washed with dichloromethane. The resulting solution was concentrated under vacuum and the residue was dissolved in $CDCl_3$. The NMR yields were obtained by ^1H NMR analysis of the crude mixture using 1,3,5-trimethoxybenzene (0.3 mmol, 50.5 mg) as an internal standard.

Table S1. Effect of ligand

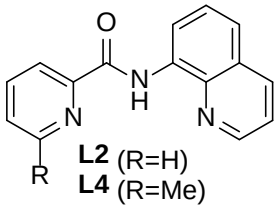


1a + 1.5 equiv **2a** → **3a**

entry	ligand	yield (%)[b]
1	bipy	4
2	phen	6
3	pybox	4
4	terpy	9
5	ttbtpy	53
6	**L1**	87
7	**L2**	40
8	**L3**	83
9	**L4**	**96**



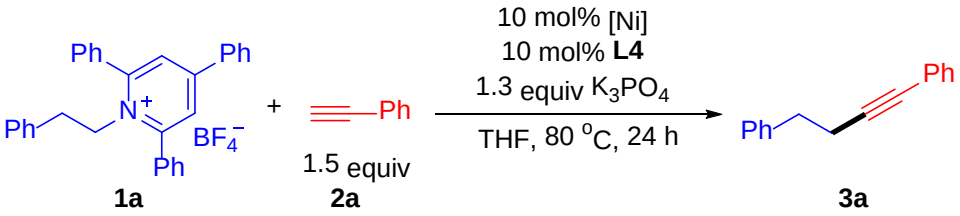
L1 (R=H)
L3 (R=Me)



L2 (R=H)
L4 (R=Me)

[a]Conditions: **1a** (0.3 mmol), **2a** (0.45 mmol), $NiCl_2$(glyme) (10 mol%), ligand (10 mol%), K_3PO_4 (1.3 equiv), THF (1.5 mL), 80 °C. [b]Yields determined by ^1H NMR using 1,3,5-trimethoxybenzene as an internal standard.

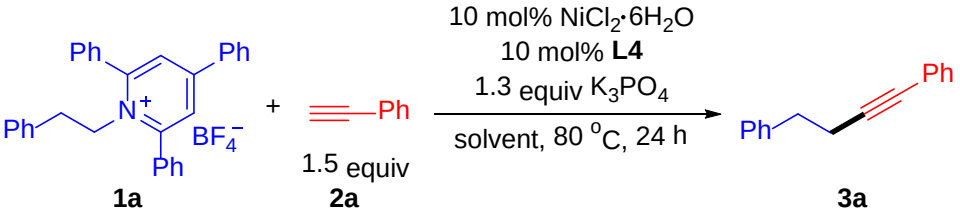
Table S2. Effect of nickel source



entry	[Ni]	yield (%)[b]
1	$NiCl_2$(glyme)	96
2	$NiBr_2$(glyme)	92
3	NiI_2	95
4	$Ni(acac)_2$	7
5	$Ni(OAc)_2 \cdot 4H_2O$	49
6	**$NiCl_2 \cdot 6H_2O$**	**99 (97)[c]**

[a]Conditions: **1a** (0.3 mmol), **2a** (0.45 mmol), [Ni] (10 mol%), **L4** (10 mol%), K_3PO_4 (1.3 equiv), THF (1.5 mL), 80 °C. [b]Yields determined by ^1H NMR using 1,3,5-trimethoxybenzene as an internal standard. [c]Isolated yield.

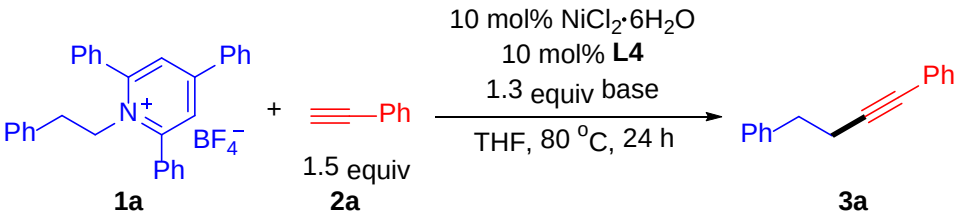
Table S3. Effect of solvent



entry	solvent	yield (%)[b]
1	**THF**	**99 (97)[c]**
2	CH_3CN	67
3	DMF	90
4	DMSO	85
5	NMP	88

[a]Conditions: **1a** (0.3 mmol), **2a** (0.45 mmol), $NiCl_2 \cdot 6H_2O$ (10 mol%), **L4** (10 mol%), K_3PO_4 (1.3 equiv), solvent (1.5 mL), 80 °C. [b]Yields determined by ^1H NMR using 1,3,5-trimethoxybenzene as an internal standard. [c]Isolated yield.

Table S4. Effect of base

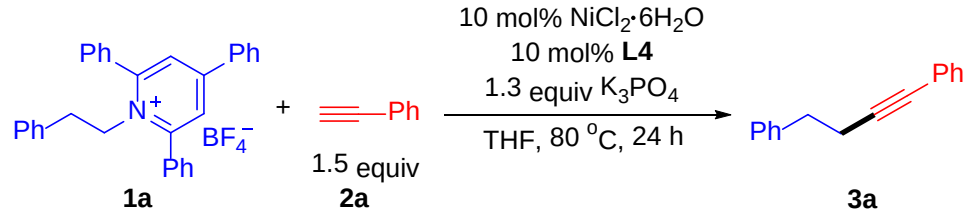


1a **2a** **3a**

entry	base	yield (%)[b]
1	**K_3PO_4**	**99 (97)[c]**
2	Na_3PO_4	38
3	K_2CO_3	95
4	Cs_2CO_3	65
5	Na_2CO_3	11
6	DBU	3
7	Et_3N	0

[a]Conditions: **1a** (0.3 mmol), **2a** (0.45 mmol), $NiCl_2·6H_2O$ (10 mol%), **L4** (10 mol%), base (1.3 equiv), THF (1.5 mL), 80 °C. [b]Yields determined by ^1H NMR using 1,3,5-trimethoxybenzene as an internal standard. [c]Isolated yield.

Table S5. Effect of catalyst loading, reaction temperature and blank experiment

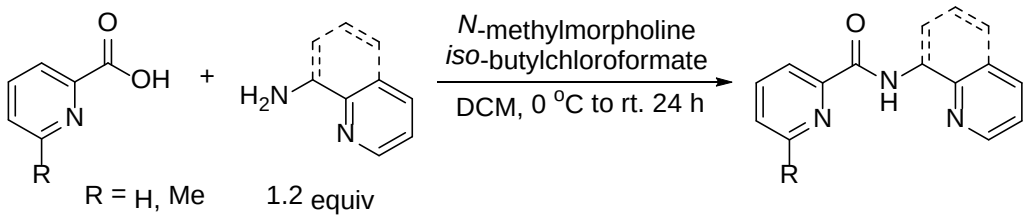


1a **2a** **3a**

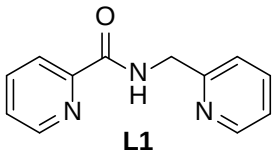
entry	$NiCl_2·6H_2O$ (mol%)	**L4** (mol%)	K_3PO_4 (mol%)	yield (%)[b]
1	5	5	130	91
2[c]	10	10	130	68
3	-	10	130	0
4	10	-	130	0
5	10	10	-	0

[a]Conditions: **1a** (0.3 mmol), **2a** (0.45 mmol), $NiCl_2·6H_2O$ (10 mol%), **L4** (10 mol%), K_3PO_4 (1.3 equiv), THF (1.5 mL), 80 °C. [b]Yields determined by ^1H NMR using 1,3,5-trimethoxybenzene as an internal standard. [c]60 °C.

General procedure A: synthesis of amide-type NN_2 pincer ligand

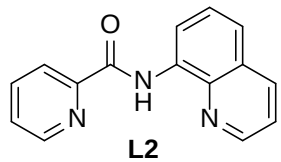


To an oven-dried round-bottomed flask was added carboxylic acid under nitrogen. Then dichloromethane (0.2 M) was added via syringe, followed by addition of *N*-methylmorpholine (1.5 equiv). When the reaction mixture was cooled to 0 °C, *iso*-butylchloroformate (1.2 equiv) was added, and the mixture was stirred at the same temperature for 30 min. Then amine (1.2 equiv) dissolved in dichloromethane was added and it was allowed to warm to room temperature. After stirring for 24 h, the reaction mixture was quenched with water and extracted with dichloromethane. The combined organic extracts were washed with water and brine, and dried over anhydrous Na_2SO_4. The solvent was concentrated under vacuum and the residue was purified by column chromatography on silica gel which was pretreated with triethylamine before loading the sample.



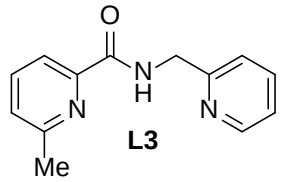
L1

***N*-(Pyridin-2-ylmethyl)picolinamide (L1).** 10.0 mmol scale, according to **general procedure A**, the title product was obtained in 80% yield (1.70 g) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.81 (d, *J* = 5.6 Hz, 2H), 7.20 (dd, *J* = 4.8, 7.0 Hz, 1H), 7.35 (d, *J* = 8.0 Hz, 1H), 7.42-7.45 (m, 1H), 7.67 (td, *J* = 1.6, 7.6 Hz, 1H), 7.86 (td, *J* = 1.6, 7.6 Hz, 1H), 8.23 (d, *J* = 8.0 Hz, 1H), 8.59-8.61 (m, 2H), 8.94 (br, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 44.74, 121.88, 122.26, 122.29, 126.17, 136.73, 137.26, 148.26, 149.36, 149.89, 156.98, 164.50. IR (neat): 3274, 3057, 2919, 1669, 1589, 1568, 1523, 1462, 1434, 1413, 1355, 1303, 1288, 1254, 1239, 1216, 1172, 1151, 1089, 1058, 1049, 1037, 1004, 995, 957, 911, 891, 822, 764, 747, 725, 683, 620, 603, 523, 464, 426, 410 cm^{-1}. HRMS (ESI) calcd. for $C_{12}H_{12}N_3O$ $[M+H]^+$: 214.0975, found 214.0975.



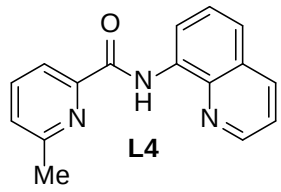
L2

***N*-(Quinolin-8-yl)picolinamide (L2).** 10.0 mmol scale, according to **general procedure A**, the title product was obtained in 70% yield (1.75 g) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.41-7.46 (m, 2H), 7.51-7.60 (m, 2H), 7.88 (t, *J* = 7.6 Hz, 1H), 8.12 (d, *J* = 8.0 Hz, 1H), 8.34 (d, *J* = 8.0 Hz, 1H), 8.74 (d, *J* = 4.4 Hz, 1H), 8.92 (d, *J* = 2.8 Hz, 1H), 9.01 (d, *J* = 7.6 Hz, 1H), 12.26 (br, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 116.63, 121.48, 121.90, 122.27, 126.17, 127.12, 127.98, 134.31, 136.05, 137.30, 139.16, 148.39, 148.56, 150.35, 162.55. IR (neat): 3290, 3052, 1684, 1589, 1569, 1521, 1485, 1464, 1434, 1425, 1387, 1324, 1284, 1241, 1208, 1177, 1131, 1087, 1052, 1042, 1000, 988, 976, 902, 827, 811, 797, 780, 765, 753, 736, 685, 640, 622, 598, 524, 423 cm^{-1}. HRMS (ESI) calcd. for $C_{15}H_{12}N_3O$ $[M+H]^+$: 250.0975, found 250.0976.



L3

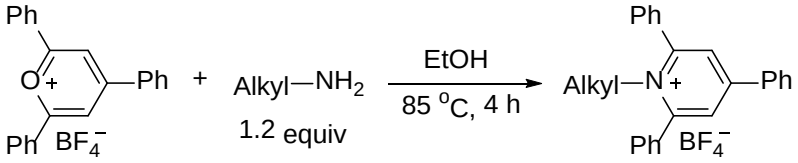
6-Methyl-*N*-(pyridin-2-ylmethyl)picolinamide (L3). 10.0 mmol scale, according to **general procedure A**, the title product was obtained in 74% yield (1.68 g) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.59 (s, 3H), 4.80 (d, *J* = 6.0 Hz, 2H), 7.20 (dd, *J* = 5.2, 7.2 Hz, 1H), 7.28 (d, *J* = 8.0 Hz, 1H), 7.37 (d, *J* = 7.6 Hz, 1H), 7.67 (td, *J* = 1.6, 7.6 Hz, 1H), 7.73 (t, *J* = 8.0 Hz, 1H), 8.03 (d, *J* = 7.6 Hz, 1H), 8.60 (d, *J* = 4.4 Hz, 1H), 8.92 (br, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 24.26, 44.82, 119.34, 122.01, 122.29, 125.91, 136.79, 137.39, 149.14, 149.31, 157.30, 157.38, 164.75. IR (neat): 3278, 3051, 2981, 2932, 1659, 1591, 1567, 1520, 1474, 1448, 1426, 1378, 1358, 1321, 1306, 1259, 1219, 1177, 1151, 1098, 1081, 1052, 1037, 1008, 995, 967, 908, 825, 786, 771, 743, 704, 663, 633, 609, 565, 527, 509, 427, 419, 403 cm^{-1}. HRMS (ESI) calcd. for $C_{13}H_{14}N_3O$ $[M+H]^+$: 228.1131, found 228.1132.



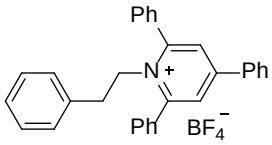
L4

6-Methyl-*N*-(quinolin-8-yl)picolinamide (L4). 10.0 mmol scale, according to **general procedure A**, the title product was obtained in 68% yield (1.80 g) as a white solid. ^{1}H NMR (600 MHz, $CDCl_3$): δ 2.71 (s, 3H), 7.30 (d, *J* = 7.8 Hz, 1H), 7.43 (dd, *J* = 4.2, 8.4 Hz, 1H), 7.51 (d, *J* = 8.4 Hz, 1H), 7.57 (t, *J* = 8.4 Hz, 1H), 7.75 (t, *J* = 7.8 Hz, 1H), 8.13 (t, *J* = 7.8 Hz, 2H), 8.92 (d, *J* = 4.2 Hz, 1H), 9.00 (d, *J* = 7.2 Hz, 1H), 12.29 (br, 1H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 24.41, 116.68, 119.39, 121.47, 121.82, 125.97, 127.17, 128.01, 134.50, 136.04, 137.44, 139.32, 148.57, 149.73, 157.44, 162.88. IR (neat): 3278, 3067, 1676, 1591, 1577, 1523, 1486, 1466, 1448, 1425, 1372, 1324, 1260, 1239, 1201, 1175, 1157, 1143, 1085, 1055, 992, 930, 885, 844, 822, 806, 787, 753, 705, 665, 637, 602, 553, 514, 482, 432, 421 cm^{-1}. HRMS (ESI) calcd. for $C_{16}H_{14}N_3O$ $[M+H]^+$: 264.1131, found 264.1131.

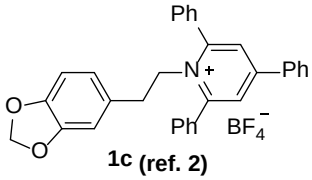
Synthesis of alkylpyridinium salts



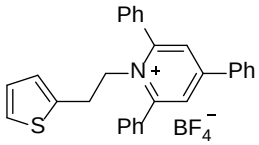
According to previous reported procedures, to a round-bottomed flask were added 2,4,6-triphenylpyrylium tetrafluoroborate (1.0 equiv), EtOH (1.0 M) and primary amine (1.2 equiv). Then the flask was fitted with a reflux condenser and immersed into an oil bath preheated at 85 °C. After stirring for 4 h, the reaction mixture was cooled to room temperature. If product precipitation occurred, the solid was filtered, washed with EtOH and Et_2O, and dried under high vacuum. If product precipitation did not ocurr, then Et_2O was added to the reaction mixture and the solution was vigorously stirred for 1 h to induce trituration. The resulting solid was filtered and washed with Et_2O. If the pyridinium salt still did not precipitate, the reaction mixture was concentrated under vacuum and purified by column chromatography (acetone/dichloromethane).



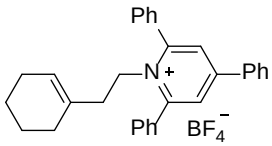
1a (ref. 2)



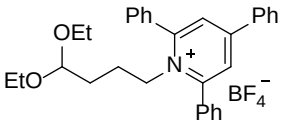
1c (ref. 2)



1f (ref. 3)



1i (ref. 3)



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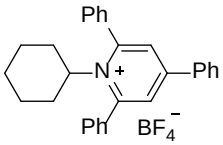

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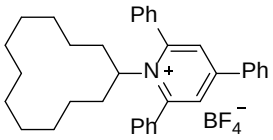
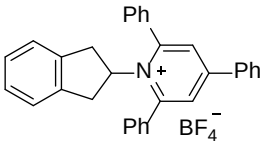


1q (ref. 4)



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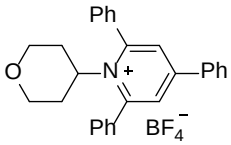

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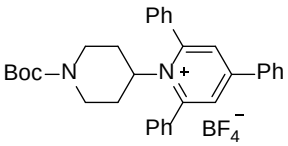

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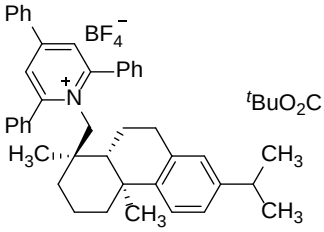

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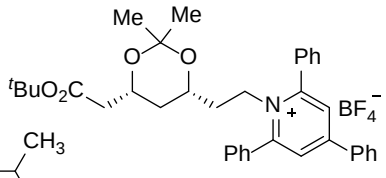

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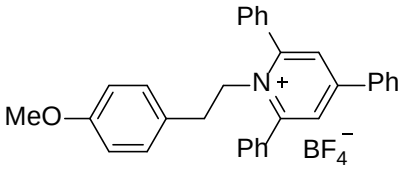
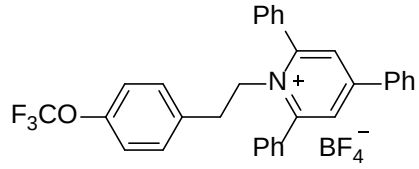


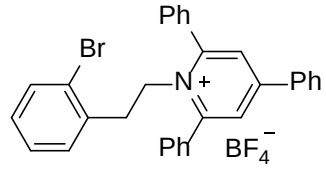
1b

1-(4-Methoxyphenethyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate (1b). 5.0 mmol scale, the title product was obtained in 83% yield (2.20 g) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.61-2.65 (m, 2H), 3.69 (s, 3H), 4.57-4.62 (m, 2H), 6.20 (d, *J* = 8.4 Hz, 2H), 6.57-6.59 (m, 2H), 7.49-7.65 (m, 9H), 7.76-7.80 (m, 6H), 7.88 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 34.64, 55.12, 55.88, 114.04, 126.56, 127.13, 128.06, 129.04, 129.11, 129.19, 129.51, 130.93, 131.89, 132.72, 133.95, 155.73, 156.31, 158.59. IR (neat): 3063, 1624, 1583, 1561, 1514, 1494, 1459, 1446, 1417, 1353, 1334, 1305, 1284, 1252, 1179, 1156, 1080, 1046, 1035, 997, 937, 898, 869, 825, 797, 767, 743, 726, 700, 650, 635, 610, 596, 554, 519, 504, 453, 429 cm^{-1}. HRMS (ESI) calcd. for $C_{32}H_{28}NO$ [M-BF_4]$^{+}$: 442.2165, found 442.2165.



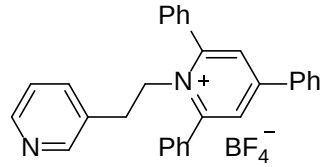
1d

2,4,6-Triphenyl-1-(4-(trifluoromethoxy)phenethyl)pyridin-1-ium tetrafluoroborate (1d). 3.0 mmol scale, the title product was obtained in 94% yield (1.65 g) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.69-2.74 (m, 2H), 4.58-4.62 (m, 2H), 6.28-6.31 (m, 2H), 6.89 (d, *J* = 8.0 Hz, 2H), 7.46-7.50 (m, 2H), 7.53-7.57 (m, 1H), 7.58-7.66 (m, 6H), 7.72-7.74 (m, 2H), 7.78-7.81 (m, 4H), 7.85 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 34.60, 55.36, 120.20 (q, *J* = 255.7 Hz), 121.11, 126.61, 128.06, 129.03, 129.18, 129.45, 129.52, 130.95, 131.86, 132.66, 133.99, 134.23, 148.05 (q, *J* = 2.2 Hz), 155.87, 156.21. IR (neat): 3066, 1625, 1601, 1583, 1566, 1510, 1496, 1460, 1446, 1417, 1330, 1254, 1224, 1198, 1163, 1051, 920, 892, 871, 851, 800, 764, 704, 696, 672, 649, 613, 593, 533, 521, 499, 445 cm^{-1}. HRMS (ESI) calcd. for $C_{32}H_{25}F_3NO$ $[M\text{-}BF_4]^+$: 496.1883, found 496.1881.



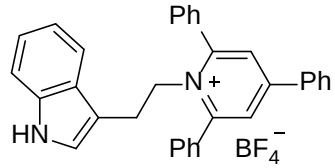
1e

1-(2-Bromophenethyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate (1e). 3.0 mmol scale, the title product was obtained in 85% yield (1.47 g) as a white solid. ^{1}H NMR (600 MHz, $CDCl_3$): δ 2.82 (t, *J* = 7.8 Hz, 2H), 4.78 (t, *J* = 7.8 Hz, 2H), 6.15 (dd, *J* = 1.8, 7.2 Hz, 1H), 6.94-6.98 (m, 2H), 7.26-7.28 (m, 1H), 7.48 (t, *J* = 7.2 Hz, 2H), 7.54 (t, *J* = 7.2 Hz, 1H), 7.57-7.60 (m, 6H), 7.74 (d, *J* = 7.8 Hz, 2H), 7.78-7.80 (m, 4H), 7.84 (s, 2H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 35.52, 53.77, 124.05, 126.78, 127.85, 128.12, 128.99, 129.31, 129.44, 129.60, 130.30, 130.92, 132.02, 132.75, 132.80, 133.97, 135.16, 155.96, 156.61. IR (neat): 3068, 1622, 1601, 1567, 1512, 1495, 1462, 1446, 1417, 1355, 1329, 1286, 1247, 1183, 1163, 1049, 1026, 894, 852, 827, 780, 760, 697, 660, 613, 597, 578, 518, 495, 453 cm^{-1}. HRMS (ESI) calcd. for $C_{31}H_{25}BrN$ $[M\text{-}BF_4]^+$: 490.1165, found 490.1167.



1g

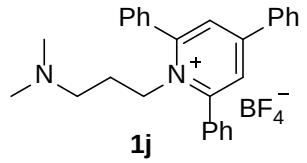
2,4,6-Triphenyl-1-(2-(pyridin-3-yl)ethyl)pyridin-1-ium tetrafluoroborate (1g). 3.0 mmol scale, the title product was obtained in 67% yield (1.0 g) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.71 (t, *J* = 8.0 Hz, 2H), 4.50 (t, *J* = 8.0 Hz, 2H), 6.55 (d, *J* = 7.6 Hz, 1H), 6.93-6.96 (m, 1H), 7.38 (t, *J* = 7.2 Hz, 2H), 7.46-7.64 (m, 10H), 7.73 (s, 2H), 7.80 (d, *J* = 7.2 Hz, 4H), 8.28 (d, *J* = 4.4 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 32.36, 54.93, 123.42, 126.52, 127.97, 128.89, 129.11, 129.35, 130.95, 131.03, 131.78, 132.50, 133.88, 135.58, 148.30, 149.11, 155.81, 156.03. IR (neat): 3070, 1623, 1600, 1567, 1494, 1481, 1461, 1445, 1419, 1354, 1327, 1285, 1255, 1239, 1182, 1165, 1049, 1035, 913, 894, 805, 782, 764, 738, 698, 637, 621, 595, 578, 516, 496, 411 cm^{-1}. HRMS (ESI) calcd. for $C_{30}H_{25}N_2$ $[M\text{-}BF_4]^+$: 413.2012, found 413.2015.



1h

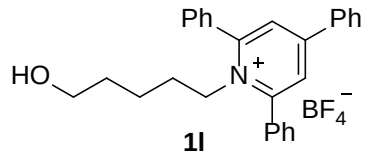
1-(2-(1*H*-Indol-3-yl)ethyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate (1h). 2.0 mmol scale, the title product was obtained in 81% yield (0.87 g) as a light-yellow solid. ^{1}H NMR (600 MHz, DMSO-d_6): δ 2.78 (t, *J* = 8.4 Hz, 2H), 4.58 (t, *J* = 7.8 Hz, 2H), 6.32 (d, *J* = 7.8 Hz, 1H), 6.53 (d, *J* = 1.8 Hz, 1H), 6.71 (t, *J* = 7.8 Hz, 1H), 7.00 (t, *J* = 7.8 Hz, 1H), 7.27 (d, *J* = 7.8 Hz, 1H), 7.63 (t, *J* = 7.8 Hz, 2H), 7.66-7.70 (m, 5H), 7.73 (t, *J* = 7.2 Hz, 2H), 7.80 (d, *J* = 7.8 Hz, 4H), 8.27 (d, *J* = 7.8 Hz, 2H), 8.48 (s, 2H), 10.82 (s, 1H). ^{13}C NMR (151 MHz, DMSO-d_6): δ 25.12, 55.33, 107.96, 111.53, 117.00, 118.55, 121.25, 123.03, 126.04, 126.28, 128.72, 129.06, 129.30, 129.60, 130.86, 132.40, 133.06, 133.21, 136.02, 154.24, 156.07. IR (neat): 3364, 3050, 1623, 1600, 1566, 1494, 1458, 1446, 1418, 1352, 1331, 1287, 1240, 1183, 1160, 1078, 1064, 1006, 937, 893, 861, 818, 799, 767, 739, 724, 700, 660, 645, 626, 595, 559, 517, 497, 466, 424, 408 cm^{-1}. HRMS (ESI) calcd. for

$C_{33}H_{27}N_2$ $[M\text{-}BF_4]^+$: 451.2169, found 451.2170.



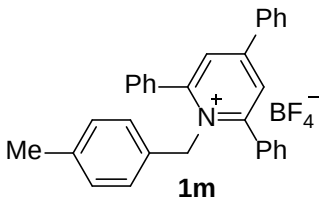
1j

1-(3-(Dimethylamino)propyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate (1j). 3.0 mmol scale, the title product was obtained in 67% yield (0.97 g) as a white solid. ^{1}H NMR (600 MHz, $CDCl_3$): δ 1.60-1.62 (m, 2H), 1.68-1.71 (m, 8H), 4.43 (t, *J* = 8.4 Hz, 2H), 7.45 (t, *J* = 7.2 Hz, 2H), 7.51 (t, *J* = 7.2 Hz, 1H), 7.58 (br, 6H), 7.70 (d, *J* = 7.2 Hz, 2H), 7.79 (br, 6H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 27.42, 44.54, 53.57, 55.85, 126.72, 128.07, 128.98, 129.20, 129.52, 130.84, 131.82, 132.75, 134.07, 155.66, 156.28. IR (neat): 3070, 2945, 2820, 2777, 1625, 1602, 1583, 1568, 1496, 1460, 1447, 1418, 1373, 1359, 1326, 1281, 1250, 1182, 1165, 1035, 960, 893, 851, 833, 816, 794, 778, 762, 725, 696, 646, 611, 596, 548, 521, 495, 456, 430 cm^{-1}. HRMS (ESI) calcd. for $C_{28}H_{29}N_2$ $[M\text{-}BF_4]^+$: 393.2325, found 393.2327.



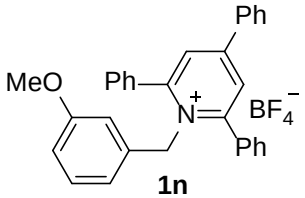
1l

1-(5-Hydroxypentyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate (1l). 3.0 mmol scale, the title product was obtained in 67% yield (0.96 g) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.77-0.84 (m, 2H), 0.97-1.04 (m, 2H), 1.42-1.49 (m, 2H), 1.87 (t, *J* = 5.2 Hz, 1H), 3.24 (q, *J* = 5.6 Hz, 2H), 4.39 (t, *J* = 8.0 Hz, 2H), 7.47 (t, *J* = 7.6 Hz, 2H), 7.53 (t, *J* = 7.2 Hz, 1H), 7.57-7.58 (m, 6H), 7.71 (d, *J* = 7.6 Hz, 2H), 7.76-7.77 (m, 4H), 7.81 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 22.24, 29.18, 30.64, 54.71, 61.46, 126.61, 128.05, 128.96, 129.26, 129.62, 131.00, 132.01, 132.65, 133.91, 155.58, 156.44. IR (neat): 3588, 3071, 2927, 2860, 1624, 1601, 1567, 1496, 1460, 1446, 1418, 1357, 1326, 1283, 1241, 1165, 1049, 893, 852, 763, 697, 609, 596, 521, 496, 408 cm^{-1}. HRMS (ESI) calcd. for $C_{28}H_{28}NO$ $[M\text{-}BF_4]^+$: 394.2165, found 394.2167.



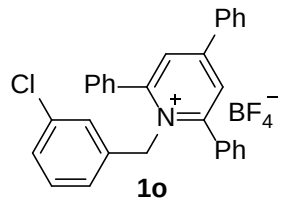
1m

1-(4-Methylbenzyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate (1m). 5.0 mmol scale, the title product was obtained in 83% yield (2.08 g) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.25 (s, 3H), 5.73 (s, 2H), 6.35 (d, *J* = 8.4 Hz, 2H), 6.91 (d, *J* = 8.0 Hz, 2H), 7.45-7.51 (m, 6H), 7.53-7.60 (m, 3H), 7.64-7.66 (m, 4H), 7.82-7.84 (m, 2H), 7.96 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.64, 57.76, 125.84, 126.16, 127.83, 128.77, 129.13, 129.39, 130.41, 130.59, 131.98, 132.47, 133.29, 137.84, 155.77, 157.02 *(1 aromatic carbon signal is not observed due to signal overlap)*. IR (neat): 3062, 1619, 1600, 1563, 1517, 1495, 1446, 1416, 1345, 1284, 1187, 1163, 1032, 999, 932, 890, 856, 784, 763, 750, 698, 611, 595, 549, 520, 507, 482 cm^{-1}. HRMS (ESI) calcd. for $C_{31}H_{26}N$ $[M\text{-}BF_4]^+$: 412.2060, found 412.2058.



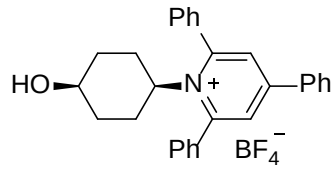
1n

1-(3-Methoxybenzyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate (1n). 3.0 mmol scale, the title product was obtained in 85% yield (1.32 g) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 3.59 (s, 3H), 5.71 (s, 2H), 5.93 (s, 1H), 6.05 (d, *J* = 7.6 Hz, 1H), 6.67 (d, *J* = 8.0 Hz, 1H), 7.03 (t, *J* = 8.0 Hz, 1H), 7.43-7.56 (m, 9H), 7.65 (d, *J* = 7.2 Hz, 4H), 7.76 (d, *J* = 7.2 Hz, 2H), 7.88 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 55.09, 58.02, 111.98, 113.62, 118.21, 126.34, 128.04, 128.99, 129.03, 129.67, 129.91, 130.83, 132.30, 132.59, 133.50, 135.27, 156.15, 157.38, 159.57. IR (neat): 3063, 1620, 1600, 1563, 1493, 1461, 1416, 1367, 1340, 1281, 1264, 1159, 1030, 997, 890, 851, 762, 698, 612, 597, 557, 519, 491, 444 cm^{-1}. HRMS (ESI) calcd. for $C_{31}H_{26}NO$ $[M\text{-}BF_4]^+$: 428.2009, found 428.2005.



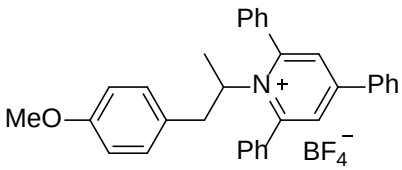
1o

1-(3-Chlorobenzyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate (1o). 3.0 mmol scale, the title product was obtained in 66% yield (1.03 g) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 5.72 (s, 2H), 6.31 (s, 1H), 6.45 (d, *J* = 6.4 Hz, 1H), 7.06-7.10 (m, 2H), 7.44-7.56 (m, 9H), 7.65 (d, *J* = 7.2 Hz, 4H), 7.76 (d, *J* = 7.6 Hz, 2H), 7.89 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 57.46, 124.55, 126.50, 126.60, 128.12, 128.41, 129.00, 129.19, 129.71, 130.28, 131.04, 132.39, 132.49, 133.52, 134.43, 135.59, 156.47, 157.32. IR (neat): 3063, 1618, 1599, 1578, 1560, 1495, 1477, 1459, 1435, 1413, 1347, 1263, 1184, 1156, 1046, 998, 949, 888, 850, 782, 767, 754, 703, 684, 612, 589, 521, 507, 436 cm^{-1}. HRMS (ESI) calcd. for $C_{30}H_{23}ClN$ $[M\text{-}BF_4]^+$: 432.1514, found 432.1512.



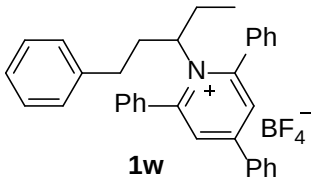
1u

***cis*-1-(4-Hydroxycyclohexyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate (1u).** 3.0 mmol scale, the title product was obtained in 65% yield (0.96 g) as a white solid. ^{1}H NMR (600 MHz, $CDCl_3$): δ 0.92 (t, *J* = 13.2 Hz, 2H), 1.60 (d, *J* = 13.8 Hz, 2H), 1.83 (t, *J* = 12.0 Hz, 3H), 1.99 (q, *J* = 12.6 Hz, 2H), 3.64 (s, 1H), 4.62 (t, *J* = 12.0 Hz, 1H), 7.44 (t, *J* = 7.2 Hz, 2H), 7.51 (t, *J* = 7.2 Hz, 1H), 7.55-7.58 (m, 6H), 7.70-7.71 (m, 6H), 7.77 (s, 2H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 26.89, 32.69, 62.94, 71.47, 127.92, 128.15, 128.82, 129.09, 129.52, 130.81, 131.88, 133.78, 133.82, 154.81, 157.17. IR (neat): 3395, 3064, 2927, 1621, 1601, 1565, 1495, 1446, 1415, 1357, 1288, 1242, 1224, 1186, 1141, 1052, 970, 936, 909, 893, 778, 763, 749, 699, 643, 621, 600, 536, 520, 494, 428 cm^{-1}. HRMS (ESI) calcd. for $C_{29}H_{28}NO$ $[M\text{-}BF_4]^+$: 406.2165, found 406.2169.



1v

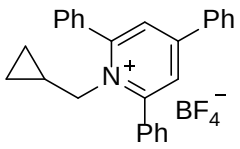
1-(1-(4-Methoxyphenyl)propan-2-yl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate (1v). 3.0 mmol scale, the title product was obtained in 55% yield (0.90 g) as a light-yellow solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.29 (d, *J* = 6.8 Hz, 3H), 2.51 (dd, *J* = 9.6, 13.6 Hz, 1H), 3.25 (dd, *J* = 5.2, 13.6 Hz, 1H), 3.69 (s, 3H), 5.04-5.09 (m, 1H), 6.50 (d, *J* = 8.4 Hz, 2H), 6.61 (d, *J* = 8.8 Hz, 2H), 7.39 (t, *J* = 7.2 Hz, 2H), 7.48 (t, *J* = 7.2 Hz, 1H), 7.53-7.61 (m, 7H), 7.66 (d, *J* = 7.6 Hz, 3H), 7.70 (s, 2H), 7.76 (br, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.81, 41.90, 55.12, 68.27, 113.96, 128.11, 128.14, 128.70, 129.42, 129.55, 130.82, 131.78, 133.78, 133.84, 154.93, 157.12, 158.60 *(2 aromatic carbon signal is not observed due to signal overlap).* IR (neat): 3061, 1618, 1562, 1512, 1494, 1445, 1412, 1354, 1303, 1249, 1181, 1027, 889, 818, 761, 704, 639, 615, 598, 555, 519 cm^{-1}. HRMS (ESI) calcd. for $C_{33}H_{30}NO$ $[M\text{-}BF_4]^+$: 456.2322, found 456.2322.



1w

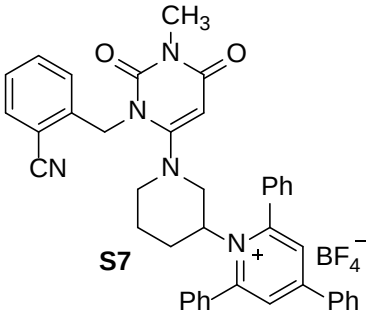
2,4,6-Triphenyl-1-(1-phenylpentan-3-yl)pyridin-1-ium tetrafluoroborate (1w). 3.0 mmol scale, the title product was obtained in 64% yield (1.03 g) as a white solid. ^{1}H NMR (600 MHz, $CDCl_3$): δ 0.65 (t, *J* = 7.8 Hz, 3H), 1.54-1.59 (m, 1H), 1.79-1.82 (m, 1H), 1.97-2.02 (m, 1H), 2.24-2.31 (m, 3H), 4.66 (t, *J* = 6.6 Hz, 1H), 6.93 (d, *J* = 7.2 Hz, 2H), 7.14-7.20 (m, 3H), 7.42 (t, *J* = 7.8 Hz, 2H), 7.49-7.57 (m, 8H), 7.66-7.81 (m, 7H). ^{13}C NMR (151 MHz, $CDCl_3$): 11.14, 28.66, 32.52, 35.42, 72.72, 126.39, 126.61, 127.93, 128.23, 128.60, 129.50, 129.93, 130.89, 132.00, 133.61, 139.03, 155.10, 156.66, 158.23 *(1 aromatic carbon signal is not observed due to signal overlap).* IR (neat): 3061, 2933, 1618, 1599, 1561, 1494, 1446, 1411, 1352, 1283, 1240, 1184, 1162, 1050, 999, 892, 762, 698, 620, 579, 519, 493, 406 cm^{-1}. HRMS (ESI) calcd. for $C_{34}H_{32}N$ $[M\text{-}BF_4]^+$: 454.2529, found

454.2530.



1x

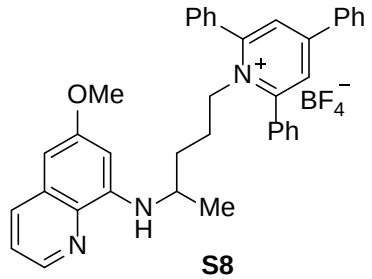
1-(Cyclopropylmethyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate (1x). 3.0 mmol scale, the title product was obtained in 77% yield (1.04 g) as a white solid. ^{1}H NMR (600 MHz, $CDCl_3$): δ -0.35 (s, 2H), 0.29 (d, *J* = 6.6 Hz, 2H), 0.67 (t, *J* = 6.0 Hz, 1H), 4.53 (d, *J* = 6.6 Hz, 2H), 7.52-7.59 (m, 3H), 7.61 (br, 6H), 7.79 (d, *J* = 7.2 Hz, 2H), 7.83-7.84 (m, 4H), 7.90 (s, 2H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 4.83, 10.41, 58.97, 126.41, 127.88, 129.11, 129.24, 129.50, 130.86, 131.94, 133.02, 133.58, 155.34, 156.58. IR (neat): 3062, 1619, 1600, 1563, 1496, 1460, 1446, 1414, 1325, 1284, 1186, 1152, 1047, 998, 932, 889, 854, 835, 766, 735, 700, 596, 531, 520, 490 cm^{-1}. HRMS (ESI) calcd. for $C_{27}H_{24}N$ $[M\text{-}BF_4]^+$: 362.1903, found 362.1900.



S7

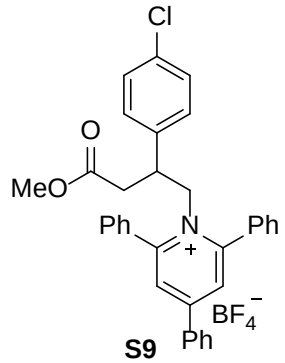
1-(1-(3-(2-Cyanobenzyl)-1-methyl-2,6-dioxo-1,2,3,6-tetrahydropyrimidin-4-yl)piperidin-3-yl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate (S7). 5.0 mmol scale, the title product was obtained in 57% yield (2.05 g) as a white solid. ^{1}H NMR (600 MHz, $CDCl_3$): δ 1.16-1.18 (m, 1H), 1.58 (d, *J* = 11.4 Hz, 1H), 1.82 (br, 1H), 2.01 (br, 2H), 2.36 (d, *J* = 11.4 Hz, 1H), 2.84-2.91 (m, 4H), 3.65 (d, *J* = 10.2 Hz, 1H), 4.72 (br, 1H), 4.81 (d, *J* = 15.0 Hz, 1H), 4.88 (t, *J* = 11.4 Hz, 1H), 4.97 (s, 1H), 7.11 (d, *J* = 7.2 Hz, 1H), 7.29 (s, 1H), 7.34-7.42 (m, 8H), 7.46-7.55 (m, 3H), 7.69-7.70 (m, 6H), 7.78 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 24.56, 27.31, 31.50, 46.12, 50.54, 55.13, 66.42, 90.17, 110.51, 116.84, 127.95, 128.33, 128.49, 129.29, 130.02, 130.77, 131.71, 132.83, 132.92, 133.48, 133.83,

139.90, 151.26, 155.22, 156.36, 157.88, 162.45 *(2 aromatic carbon signal is not observed due to signal overlap)*. IR (neat): 3064, 2224, 1702, 1649, 1618, 1599, 1562, 1493, 1442, 1353, 1283, 1218, 1051, 1030, 947, 891, 854, 809, 764, 702, 603, 551, 520, 480, 414 cm^{-1}. HRMS (ESI) calcd. for $C_{41}H_{36}N_5O_2$ $[M\text{-}BF_4]^+$: 630.2864, found 630.2870.



S8

1-(4-((6-Methoxyquinolin-8-yl)amino)pentyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate (S8). 3.0 mmol scale, the title product was obtained in 56% yield (1.07 g) as a light-yellow solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.96-1.08 (m, 5H), 1.56-1.59 (m, 2H), 3.18 (br, 1H), 3.83 (s, 3H), 4.41 (t, *J* = 8.0 Hz, 2H), 5.63 (d, *J* = 8.0 Hz, 1H), 5.95 (s, 1H), 6.33 (s, 1H), 7.29-7.32 (m, 1H), 7.38-7.49 (m, 9H), 7.62 (d, *J* = 7.6 Hz, 2H), 7.71 (br, 6H), 7.92 (d, *J* = 8.0 Hz, 1H), 8.50 (d, *J* = 3.2 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 19.93, 25.98, 32.45, 46.35, 54.48, 55.05, 91.86, 96.57, 121.78, 126.27, 127.83, 128.68, 128.98, 129.40, 129.65, 130.72, 131.82, 132.39, 133.64, 134.65, 134.93, 144.01, 144.09, 155.31, 156.21, 159.09. IR (neat): 2929, 1619, 1565, 1518, 1496, 1456, 1421, 1387, 1348, 1220, 1160, 1047, 889, 825, 787, 763, 701, 636, 596, 520, 483 cm^{-1}. HRMS (ESI) calcd. for $C_{38}H_{36}N_3O$ $[M\text{-}BF_4]^+$: 550.2853, found 550.2855.

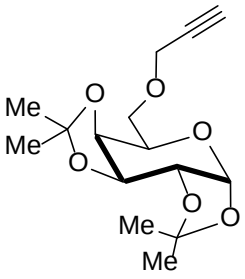


S9

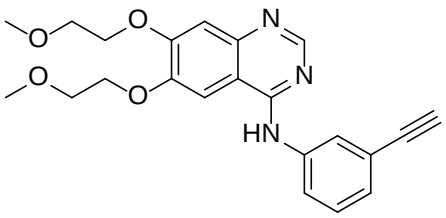
1-(2-(4-Chlorophenyl)-4-methoxy-4-oxobutyl)-2,4,6-triphenylpyridin-1-ium

tetrafluoroborate (S9). 3.0 mmol scale, the title product was obtained in 70% yield (1.27 g) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.07 (dd, *J* = 6.4, 16.0 Hz, 1H), 2.23 (dd, *J* = 8.0, 16.4 Hz, 1H), 3.12-3.19 (m, 1H), 3.38 (s, 3H), 4.93 (dd, *J* = 8.4, 14.8 Hz, 1H), 5.05 (dd, *J* = 6.4, 14.4 Hz, 1H), 6.35 (d, *J* = 8.4 Hz, 2H), 7.02 (d, *J* = 8.4 Hz, 2H), 7.47-7.60 (m, 10H), 7.72-7.94 (m, 7H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 36.99, 40.83, 51.82, 59.07, 126.48, 128.04, 128.32, 129.12, 129.50, 129.75, 131.23, 132.43, 132.72, 133.38, 133.67, 136.44, 155.99, 157.29, 170.22 *(1 aromatic carbon signal is not observed due to signal overlap)*. IR (neat): 3062, 1732, 1617, 1598, 1558, 1493, 1445, 1413, 1351, 1281, 1187, 1156, 1051, 999, 939, 887, 861, 832, 822, 785, 773, 746, 705, 653, 611, 598, 558, 520 cm^{-1}. HRMS (ESI) calcd. for $C_{34}H_{29}ClNO_2$ $[M\text{-}BF_4]^+$: 518.1881, found 518.1881.

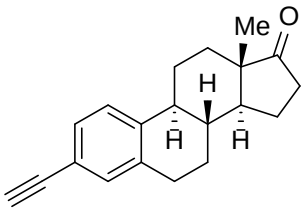
Synthesis of terminal alkynes



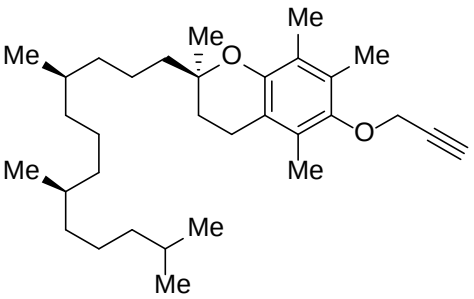
S10 (ref. 5)



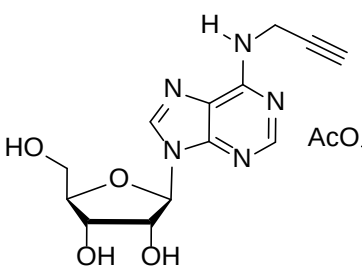
S11 (ref. 6)



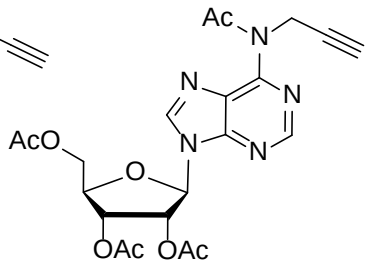
S13 (ref. 7)



S14 (ref. 7)



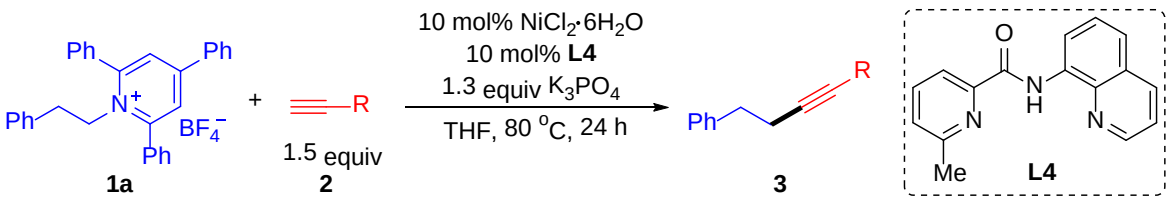
S19 (ref. 8)



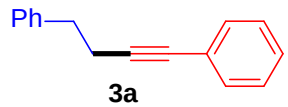
S20 (ref. 8)

Nickel-catalyzed deaminative Sonogashira coupling of alkylpyridinium salts

General procedure B: Sonogashira coupling of 1a with alkynes

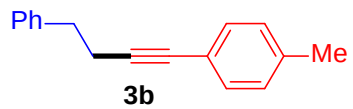


In a nitrogen-filled glovebox, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), phenethylpyridinium salt **1a** (0.3 mmol, 150.0 mg) and tetrahydrofuran (1.5 mL) were successively added to an oven-dried sealable Schlenk tube (10.0 mL) followed by addition of terminal alkyne (0.45 mmol) via microliter syringe *(If terminal alkyne is a solid, it was added before the solvent).* Then the tube was securely sealed and taken outside the glovebox. And it was immersed into an oil bath preheated at 80 ^oC. After stirring for 24 h, the reaction mixture was cooled to room temperature and filtered through a short pad of silica gel. Then the filter cake was washed with dichloromethane or ethyl acetate. The resulting solution was concentrated under vacuum and the residue was purified by column chromatography on silica gel.



3a

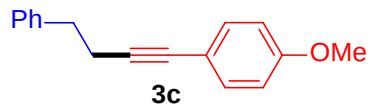
But-1-yne-1,4-diyldibenzene (3a). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), phenethylpyridinium salt **1a** (0.3 mmol, 150.0 mg), phenylacetylene (0.45 mmol, 46.0 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 100:1 to 50:1, gradient) afforded the title product in 97% yield (60.1 mg) as a colorless oil. ^1H NMR (400 MHz, $CDCl_3$): δ 2.68 (t, J = 7.6 Hz, 2H), 2.91 (t, J = 7.6 Hz, 2H), 7.19-7.32 (m, 8H), 7.35-7.38 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.64, 35.14, 81.30, 89.47, 123.83, 126.27, 127.58, 128.16, 128.35, 128.51, 131.50, 141.67. IR (neat): 3062, 3028, 2927, 1599, 1490, 1454, 1442, 1341, 1071, 1030, 913, 754, 715, 691, 580, 530, 497 cm^{-1}. HRMS (EI) calcd. for $C_{16}H_{14}$ $[M]^+$: 206.1090, found 206.1088.



3b

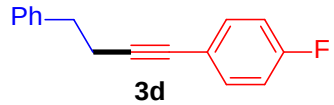
1-Methyl-4-(4-phenylbut-1-yn-1-yl)benzene (3b). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg),

phenethylpyridinium salt **1a** (0.3 mmol, 150.0 mg), 1-ethynyl-4-methylbenzene (0.45 mmol, 52.3 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^{o}C for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 50:1) afforded the title product in 95% yield (62.8 mg) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.23 (s, 3H), 2.59 (t, *J* = 7.6 Hz, 2H), 2.82 (t, *J* = 7.6 Hz, 2H), 6.98 (d, *J* = 8.0, 2H), 7.11-7.23 (m, 7H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.35, 21.67, 35.23, 81.31, 88.66, 120.74, 126.25, 128.33, 128.51, 128.93, 131.37, 137.55, 140.74. IR (neat): 3027, 2922, 1603, 1509, 1496, 1454, 1428, 1341, 1278, 1180, 1106, 1077, 1031, 815, 747, 697, 575, 529, 497 cm^{-1}. HRMS (EI) calcd. for $C_{17}H_{16}$ $[M]^{+}$: 220.1247, found 220.1249.



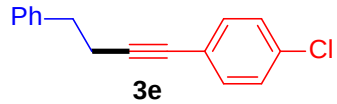
3c

1-Methoxy-4-(4-phenylbut-1-yn-1-yl)benzene (3c). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), phenethylpyridinium salt **1a** (0.3 mmol, 150.0 mg), 1-ethynyl-4-methoxybenzene (0.45 mmol, 59.5 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^{o}C for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 20:1) afforded the title product in 92% yield (65.4 mg) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.58 (t, *J* = 7.6 Hz, 2H), 2.82 (t, *J* = 7.6 Hz, 2H), 3.68 (s, 3H), 6.71 (d, *J* = 8.4 Hz, 2H), 7.12-7.23 (m, 7H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.64, 35.26, 55.16, 80.99, 87.83, 113.77, 115.95, 126.22, 128.31, 128.49, 132.80, 140.76, 159.05. IR (neat): 3021, 2934, 2838, 1889, 1605, 1566, 1508, 1454, 1440, 1303, 1287, 1246, 1180, 1172, 1106, 1078, 1027, 911, 830, 816, 796, 763, 734, 701, 665, 641, 582, 534, 498, 478, 420 cm^{-1}. HRMS (ESI) calcd. for $C_{17}H_{17}O$ $[M+H]^{+}$: 237.1274, found 237.1270.



3d

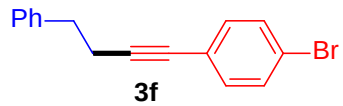
1-Fluoro-4-(4-phenylbut-1-yn-1-yl)benzene (3d). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), phenethylpyridinium salt **1a** (0.3 mmol, 150.0 mg), 1-ethynyl-4-fluorobenzene (0.45 mmol, 54.1 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 50:1) afforded the title product in 97% yield (65.0 mg) as a colorless oil. ^1H NMR (400 MHz, $CDCl_3$): δ 2.66 (t, *J* = 7.6 Hz, 2H), 2.90 (t, *J* = 7.6 Hz, 2H), 6.92-6.97 (m, 2H), 7.20-7.34 (m, 7H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.55, 35.09, 80.25, 89.09 (d, *J* = 1.4 Hz), 115.37 (d, *J* = 21.7 Hz), 119.87 (d, *J* = 2.9 Hz), 126.32, 128.36, 128.49, 133.27 (d, *J* = 8.0 Hz), 140.60, 162.08 (d, *J* = 246.3 Hz). IR (neat): 3028, 2928, 1602, 1505, 1454, 1429, 1342, 1219, 1155, 1092, 1078, 1030, 1014, 834, 810, 748, 698, 661, 632, 576, 530, 498 cm^{-1}. HRMS (ESI) calcd. for $C_{16}H_{14}F$ $[M+H]^+$: 225.1074, found 225.1071.



3e

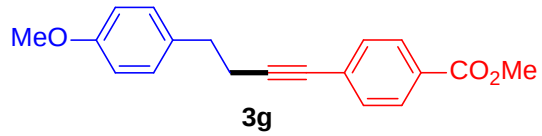
1-Chloro-4-(4-phenylbut-1-yn-1-yl)benzene (3e). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), phenethylpyridinium salt **1a** (0.3 mmol, 150.0 mg), 1-chloro-4-ethynylbenzene (0.45 mmol, 61.5 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 50:1) afforded the title product in 93% yield (67.0 mg) as a light-yellow oil. ^1H NMR (400 MHz, $CDCl_3$): δ 2.67 (t, *J* = 7.6 Hz, 2H), 2.90 (t, *J* = 7.6 Hz, 2H), 7.20-7.32 (m, 9H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.61, 35.01, 80.28, 90.54, 122.32, 126.34, 128.38, 128.48, 132.72, 133.53, 140.52 *(1 aromatic carbon signal is not observed due to signal overlap)*. IR (neat): 3026, 2954, 1601, 1488, 1450, 1423, 1396,

1271, 1089, 1076, 1030, 1012, 827, 756, 740, 697, 638, 614, 527, 505, 442 cm^{-1}. HRMS (EI) calcd. for $C_{16}H_{13}Cl$ $[M]^+$: 240.0700, found 240.0702.



3f

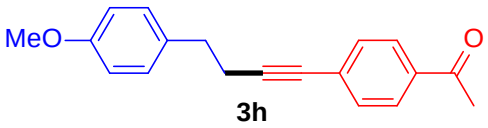
1-Bromo-4-(4-phenylbut-1-yn-1-yl)benzene (3f). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), phenethylpyridinium salt **1a** (0.3 mmol, 150.0 mg), 1-bromo-4-ethynylbenzene (0.45 mmol, 81.5 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 50:1) afforded the title product in 94% yield (80.1 mg) as a light-yellow oil. ^1H NMR (400 MHz, $CDCl_3$): δ 2.66 (t, J = 7.6 Hz, 2H), 2.90 (t, J = 7.6 Hz, 2H), 7.19-7.32 (m, 7H), 7.38 (d, J = 8.4 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.64, 34.97, 80.34, 90.77, 121.70, 122.78, 126.34, 128.37, 128.47, 131.40, 132.96, 140.50. IR (neat): 3022, 2946, 1599, 1487, 1447, 1423, 1394, 1272, 1070, 1028, 1010, 976, 820, 756, 733, 701, 605, 522, 499, 432, 416 cm^{-1}. HRMS (EI) calcd. for $C_{16}H_{13}Br$ $[M]^+$: 284.0195, found 284.0198.



3g

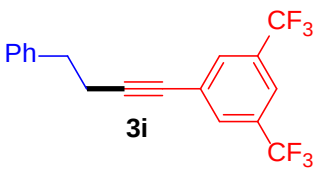
Methyl 4-(4-(4-methoxyphenyl)but-1-yn-1-yl)benzoate (3g). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), *p*-methoxyphenethylpyridinium salt **1b** (0.3 mmol, 158.8 mg), methyl 4-ethynylbenzoate (0.45 mmol, 72.1 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with ethyl acetate. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate = 30:1) afforded the title product in 96% yield (85.1 mg) as a white solid. ^1H NMR (400 MHz, $CDCl_3$): δ 2.67 (t, J = 7.6 Hz, 2H),

2.86 (t, *J* = 7.6 Hz, 2H), 3.78 (s, 3H), 3.89 (s, 3H), 6.84-6.86 (m, 2H), 7.17 (d, *J* = 8.4 Hz, 2H), 7.41 (d, *J* = 8.4 Hz, 2H), 7.93-7.95 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.96, 34.00, 52.05, 55.15, 80.76, 93.05, 113.74, 128.63, 128.87, 129.32, 129.38, 131.37, 132.51, 158.13, 166.53. IR (neat): 3003, 2949, 2835, 2217 , 1716, 1605, 1584, 1557, 1511, 1463, 1443, 1433, 1405, 1307, 1271, 1244, 1177, 1106, 1096, 1033, 1018, 958, 860, 829, 816, 769, 726, 696, 640, 580, 525, 464, 434 cm^{-1}. HRMS (ESI) calcd. for $C_{19}H_{18}NaO_3$ $[M+Na]^+$: 317.1148, found 317.1141.



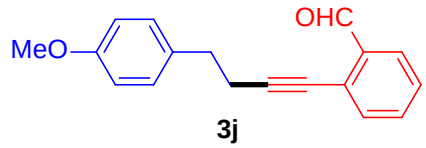
3h

1-(4-(4-(4-Methoxyphenyl)but-1-yn-1-yl)phenyl)ethan-1-one (3h). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), *p*-methoxyphenethylpyridinium salt **1b** (0.3 mmol, 158.8 mg), 1-(4-ethynylphenyl)ethan-1-one (0.45 mmol, 64.9 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^{o}C for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with ethyl acetate. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate = 10:1) afforded the title product in 97% yield (80.7 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.56 (s, 3H), 2.67 (t, *J* = 7.6 Hz, 2H), 2.86 (t, *J* = 7.6 Hz, 2H), 3.78 (s, 3H), 6.85 (d, *J* = 8.4 Hz, 2H), 7.18 (d, *J* = 8.4 Hz, 2H), 7.43 (d, *J* = 8.0 Hz, 2H), 7.85 (d, *J* = 8.4 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.96, 26.44, 33.96, 55.13, 80.76, 93.45, 113.72, 128.07, 128.80, 129.37, 131.53, 132.46, 135.66, 158.12, 197.22. IR (neat): 2922, 1679, 1611, 1598, 1555, 1511, 1447, 1425, 1401, 1357, 1302, 1286, 1259, 1242, 1175, 1108, 1074, 1030, 957, 833, 816, 775, 746, 631, 593, 568, 530, 469, 421 cm^{-1}. RMS (ESI) calcd. for $C_{19}H_{18}NaO_2$ $[M+Na]^+$: 301.1199, found 301.1199.



3i

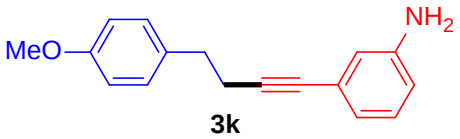
1-(4-Phenylbut-1-yn-1-yl)-3,5-bis(trifluoromethyl)benzene (3i). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), phenethylpyridinium salt **1a** (0.3 mmol, 150.0 mg), 1-ethynyl-3,5-bis(trifluoromethyl)benzene (0.45 mmol, 107.2 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 100:1) afforded the title product in 95% yield (97.1 mg) as a light-yellow oil. ^1H NMR (400 MHz, $CDCl_3$): δ 2.72 (t, *J* = 7.6 Hz, 2H), 2.93 (t, *J* = 7.6 Hz, 2H), 7.22-7.34 (m, 5H), 7.74-7.76 (m, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.54, 34.71, 78.90, 93.61, 120.99 (q, *J* = 3.6 Hz), 123.02 (q, *J* = 270.9 Hz), 126.17, 126.56, 128.48, 128.50, 131.45 (q, *J* = 2.9 Hz), 131.76 (q, *J* = 33.2 Hz), 140.19. IR (neat): 3031, 2231, 1614, 1497, 1456, 1383, 1275, 1234, 1172, 1128, 1106, 1078, 1030, 1001, 896, 847, 747, 716, 698, 683, 582, 505, 427 cm^{-1}. HRMS (EI) calcd. for $C_{18}H_{12}F_6$ $[M]^+$: 342.0838, found 342.0841.



3j

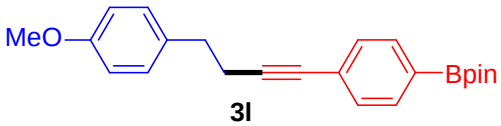
2-(4-(4-Methoxyphenyl)but-1-yn-1-yl)benzaldehyde (3j). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), *p*-methoxyphenethylpyridinium salt **1b** (0.3 mmol, 158.8 mg), 2-ethynylbenzaldehyde (0.45 mmol, 58.6 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with ethyl acetate. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate = 30:1) afforded the title product in 89% yield (70.9 mg) as a light-yellow oil. ^1H NMR (400 MHz, $CDCl_3$): δ 2.74 (t, *J* = 7.6 Hz, 2H), 2.88 (t, *J* = 7.6 Hz, 2H), 3.79 (s, 3H), 6.84-6.88 (m, 2H), 7.16-1.19 (m, 2H), 7.33-7.37 (m, 1H), 7.44-7.50 (m, 2H), 7.85-7.87 (m, 1H), 10.36 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.96, 33.80, 55.17, 77.07, 97.12, 113.82, 126.78, 127.57, 127.88, 129.34, 132.24, 133.17, 133.55, 135.95, 158.22, 192.03. IR (neat): 2932, 2835, 2746, 2229, 1692, 1611, 1594, 1566, 1511, 1476,

1450, 1388, 1340, 1300, 1273, 1242, 1191, 1177, 1159, 1107, 1034, 879, 821, 760, 698, 637, 575, 555, 539, 520, 443 cm^{-1}. HRMS (ESI) calcd. for $C_{18}H_{16}NaO_2$ $[M+Na]^+$: 287.1043, found 287.1042.



3k

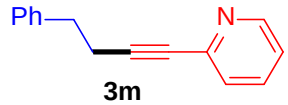
3-(4-(4-Methoxyphenyl)but-1-yn-1-yl)aniline (3k). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), *p*-methoxyphenethylpyridinium salt **1b** (0.3 mmol, 158.8 mg), 3-ethynylaniline (0.45 mmol, 52.7 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with ethyl acetate. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate: dichloromethane = 10:1:3) afforded the title product in 88% yield (66.6 mg) as a yellow oil. ^1H NMR (400 MHz, $CDCl_3$): δ 2.62 (t, *J* = 7.6 Hz, 2H), 2.83 (t, *J* = 7.6 Hz, 2H), 3.53 (br, 2H), 3.76 (s, 3H), 6.56 (dd, *J* = 1.6, 8.0 Hz, 1H), 6.67 (s, 1H), 6.78 (d, *J* = 8.0 Hz, 1H), 6.83-6.85 (m, 2H), 7.04 (t, *J* = 8.0 Hz, 1H), 7.16-7.21 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.85, 34.21, 55.14, 81.38, 88.95, 113.68, 114.64, 117.78, 121.85, 124.45, 129.05, 129.40, 132.82, 146.12, 158.01. IR (neat): 3432, 3350, 3226, 2927, 2840, 1627, 1611, 1595, 1580, 1510, 1484, 1441, 1318, 1301, 1241, 1205, 1178, 1162, 1107, 1021, 1000, 877, 822, 812, 784, 751, 690, 638, 560, 515, 463, 435, 410 cm^{-1}. HRMS (ESI) calcd. for $C_{17}H_{18}NO$ $[M+H]^+$: 252.1383, found 252.1384.



3l

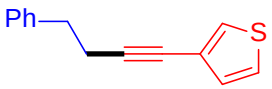
2-(4-(4-(4-Methoxyphenyl)but-1-yn-1-yl)phenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (3l). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), *p*-methoxyphenethylpyridinium salt **1b** (0.3 mmol, 158.8 mg), 2-(4-ethynylphenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (0.45

mmol, 102.6 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 °C for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with ethyl acetate. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate = 100:1 to 50:1, gradient) afforded the title product in 80% yield (86.8 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.32 (s, 12H), 2.65 (t, *J* = 7.6 Hz, 2H), 2.85 (t, *J* = 7.6 Hz, 2H), 3.77 (s, 3H), 6.84 (d, *J* = 8.4 Hz, 2H), 7.17 (d, *J* = 8.4 Hz, 2H), 7.37 (d, *J* = 7.6 Hz, 2H), 7.72 (d, *J* = 8.0 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 22.00, 24.80, 34.20, 55.15, 81.46, 83.80, 91.13, 113.73, 126.61, 129.42, 130.68, 132.72, 134.46, 158.10 *(the signal for the aromatic carbon attached to boron is not observed due to quadrupolar relaxation)*. IR (neat): 2977, 2930, 1607, 1513, 1455, 1441, 1397, 1356, 1320, 1301, 1274, 1241, 1215, 1180, 1139, 1087, 1034, 1019, 961, 856, 837, 825, 764, 740, 702, 669, 655, 575, 536, 518, 451, 434, 407 cm^{-1}. HRMS (ESI) calcd. for $C_{23}H_{27}BNaO_3$ $[M+Na]^+$: 385.1945, found 385.1945.



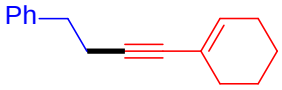
3m

2-(4-Phenylbut-1-yn-1-yl)pyridine (3m). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), phenethylpyridinium salt **1a** (0.3 mmol, 150.0 mg), 2-ethynylpyridine (0.45 mmol, 46.4 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 °C for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with ethyl acetate. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate = 10:1) afforded the title product in 89% yield (55.2 mg) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.72 (t, *J* = 7.6 Hz, 2H), 2.95 (t, *J* = 7.6 Hz, 2H), 7.14-7.17 (m, 1H), 7.20-7.33 (m, 6H), 7.57 (td, *J* = 1.6, 7.6 Hz, 1H), 8.53 (d, *J* = 4.4 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.43, 34.65, 80.85, 89.98, 122.26, 126.26, 126.69, 128.33, 135.92, 140.35, 143.65, 149.71 *(1 aromatic carbon signal is not observed due to signal overlap)*. IR (neat): 3061, 3027, 2928, 2229, 1582, 1561, 1496, 1463, 1427, 1341, 1272, 1149, 1091, 1077, 1049, 1030, 984, 777, 739, 698, 629, 582, 537, 501 cm^{-1}. HRMS (ESI) calcd. for $C_{15}H_{14}N$ $[M+H]^+$: 208.1121, found 208.1127.



3n

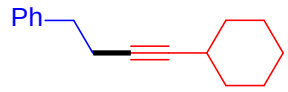
3-(4-Phenylbut-1-yn-1-yl)thiophene (3n). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), phenethylpyridinium salt **1a** (0.3 mmol, 150.0 mg), 3-ethynylthiophene (0.45 mmol, 48.7 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 100:1) afforded the title product in 90% yield (57.5 mg) as a colorless oil. ^1H NMR (400 MHz, $CDCl_3$): δ 2.66 (t, *J* = 7.6 Hz, 2H), 2.90 (t, *J* = 7.6 Hz, 2H), 7.03 (dd, *J* = 1.2, 4.8 Hz, 1H), 7.18-7.26 (m, 4H), 7.28-7.32 (m, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.60, 35.11, 76.32, 88.97, 122.75, 124.97, 126.28, 127.66, 128.35, 128.47, 129.90, 140.63. IR (neat): 3107, 3027, 2927, 1604, 1520, 1495, 1453, 1428, 1356, 1338, 1180, 1077, 1030, 860, 844, 778, 746, 697, 626, 580, 514, 492 cm^{-1}. HRMS (ESI) calcd. for $C_{14}H_{13}S$ $[M+H]^+$: 213.0732, found 213.0732.



3o

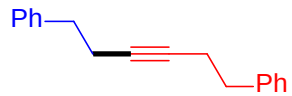
(4-(Cyclohex-1-en-1-yl)but-3-yn-1-yl)benzene (3o). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), phenethylpyridinium salt **1a** (0.3 mmol, 150.0 mg), 1-ethynylcyclohex-1-ene (0.45 mmol, 47.8 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 100:1) afforded the title product in 92% yield (58.3 mg) as a colorless oil. ^1H NMR (400 MHz, $CDCl_3$): δ 1.54-1.64 (m, 4H), 2.05-2.07 (m, 4H), 2.56 (t, *J* = 7.6 Hz, 2H), 2.83 (t, *J* = 7.6 Hz, 2H), 6.00 (s, 1H), 7.18-7.22 (m, 3H), 7.26-7.30 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.54, 22.34, 25.50, 29.43, 35.39,

82.98, 86.48, 120.86, 126.14, 128.26, 128.44, 133.37, 140.81 *(1 aliphatic carbon signal is not observed due to signal overlap)*. IR (neat): 3027, 2928, 2859, 1673, 1496, 1453, 1435, 1343, 1136, 1077, 1030, 918, 841, 800, 748, 697, 585, 497 cm^{-1}. HRMS (EI) calcd. for $C_{16}H_{18}$ $[M]^+$: 210.1403, found 210.1410.



3p

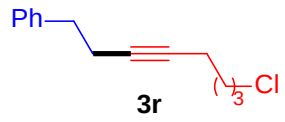
(4-Cyclohexylbut-3-yn-1-yl)benzene (3p). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), phenethylpyridinium salt **1a** (0.3 mmol, 150.0 mg), ethynylcyclohexane (0.45 mmol, 48.7 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 100:1) afforded the title product in 83% yield (52.6 mg) as a colorless oil. ^1H NMR (400 MHz, $CDCl_3$): δ 1.21-1.30 (m, 3H), 1.34-1.41 (m, 2H), 1.48-1.53 (m, 1H), 1.63-1.70 (m, 2H), 1.73-1.76 (m ,2H), 2.29-2.33 (m, 1H), 2.44 (td, *J* = 2.0, 7.6 Hz, 2H), 2.79 (t, *J* = 7.6 Hz, 2H), 7.17-7.22 (m, 3H), 7.26-7.29 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.04, 24.89, 25.92, 29.11, 33.04, 35.71, 79.27, 85.40, 126.08, 128.22, 128.51, 141.05. IR (neat): 3028, 2927, 2853, 1605, 1496, 1449, 1341, 1299, 1077, 1030, 889, 749, 698, 492 cm^{-1}. HRMS (EI) calcd. for $C_{16}H_{20}$ $[M]^+$: 212.1560, found 212.1556.



3q

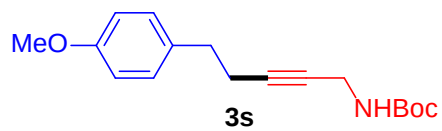
1,6-Diphenylhex-3-yne (3q). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), phenethylpyridinium salt **1a** (0.3 mmol, 150.0 mg), but-3-yn-1-ylbenzene (0.45 mmol, 58.6 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short

pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 100:1 to 10:1, gradient) afforded the title product in 88% yield (62.0 mg) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.42 (t, *J* = 7.6 Hz, 4H), 2.77 (t, *J* = 7.6 Hz, 4H), 7.16-7.20 (m, 6H), 7.27 (t, *J* = 7.2 Hz, 4H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.92, 35.43, 80.20, 126.12, 128.26, 128.41, 140.91. IR (neat): 3062, 3027, 2927, 2860, 1604, 1495, 1454, 1431, 1342, 1077, 1031, 747, 696, 567, 500 cm^{-1}. HRMS (EI) calcd. for $C_{18}H_{18}$ [M]$^{+}$: 234.1403, found 234.1401.



3r

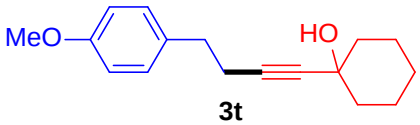
(8-Chlorooct-3-yn-1-yl)benzene (3r). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), phenethylpyridinium salt **1a** (0.3 mmol, 150.0 mg), 6-chlorohex-1-yne (0.45 mmol, 52.5 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^{o}C for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 100:3) afforded the title product in 78% yield (51.7 mg) as a colorless oil. ^{1}H NMR (600 MHz, $CDCl_3$): δ 1.57-1.61 (m, 2H), 1.79-1.84 (m, 2H), 2.17 (t, *J* = 6.6 Hz, 2H), 2.44 (t, *J* = 7.2 Hz, 2H), 2.79 (t, *J* = 7.2 Hz, 2H), 3.51 (t, *J* = 6.6 Hz, 2H), 7.18-7.23 (m, 3H), 7.27-7.29 (m, 2H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 17.94, 20.85, 26.04, 31.42, 35.42, 44.59, 80.01, 80.11, 126.13, 128.25, 128.41, 140.85. IR (neat): 3028, 2930, 2862, 1604, 1496, 1453, 1433, 1339, 1301, 1275, 1077, 1030, 748, 698, 650, 578, 507 cm^{-1}. HRMS (EI) calcd. for $C_{14}H_{17}Cl$ [M]$^{+}$: 220.1013, found 220.1009.



3s

***tert*-Butyl (5-(4-methoxyphenyl)pent-2-yn-1-yl)carbamate (3s).** 0.3 mmol scale,

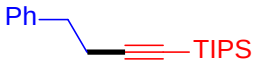
$NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), *p*-methoxyphenethylpyridinium salt **1b** (0.3 mmol, 158.8 mg), *tert*-butyl prop-2-yn-1-ylcarbamate (0.45 mmol, 69.8 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^{o}C for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with ethyl acetate. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate = 20:1) afforded the title product in 90% yield (78.4 mg) as a yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.50 (s, 9H), 2.39-2.42 (m, 2H), 2.73 (t, *J* = 7.6 Hz, 2H), 3.78 (s, 3H), 3.87 (s, 2H), 4.70 (br, 1H), 6.83 (d, *J* = 8.4 Hz, 2H), 7.11 (d, *J* = 8.4 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.05, 28.28, 30.69, 34.05, 55.12, 76.77, 79.62, 82.84, 113.68, 129.29, 132.66, 155.24, 158.03. IR (neat): 3357, 2989, 2943, 1675, 1612, 1509, 1459, 1446, 1389, 1363, 1303, 1266, 1243, 1181, 1165, 1108, 1050, 1029, 963, 873, 851, 820, 805, 782, 765, 753, 714, 607, 561, 544, 520, 464, 433 cm^{-1}. HRMS (ESI) calcd. for $C_{17}H_{23}NNaO_3$ $[M+Na]^+$: 312.1570, found 312.1570.



3t

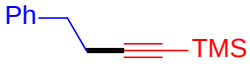
1-(4-(4-Methoxyphenyl)but-1-yn-1-yl)cyclohexan-1-ol (3t). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), *p*-methoxyphenethylpyridinium salt **1b** (0.3 mmol, 158.8 mg), 1-ethynylcyclohexan-1-ol (0.45 mmol, 55.9 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^{o}C for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with ethyl acetate. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate = 15:1) afforded the title product in 88% yield (68.1 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.17-1.26 (m, 1H), 1.40-1.55 (m, 5H), 1.60-1.65 (m, 2H), 1.81-1.85 (m, 2H), 2.08 (br, 1H), 2.46 (t, *J* = 7.6 Hz, 2H), 2.76 (t, *J* = 7.6 Hz, 2H), 3.77 (s, 3H), 6.81-6.84 (m, 2H), 7.13 (d, *J* = 8.8 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.06, 23.26, 25.15, 34.22, 40.10, 55.17, 68.64, 83.86, 84.67, 113.65, 129.36, 132.77, 158.01. IR (neat): 3404, 2931, 2856, 1612, 1585, 1512, 1445, 1340, 1300, 1243,

1177, 1132, 1108, 1057, 1034, 962, 904, 867, 821, 755, 700, 549, 519, 431 cm^{-1}. HRMS (ESI) calcd. for $C_{17}H_{22}NaO_2$ $[M+Na]^+$: 281.1512, found 281.1511.



3u

Triisopropyl(4-phenylbut-1-yn-1-yl)silane (3u). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), phenethylpyridinium salt **1a** (0.3 mmol, 150.0 mg), ethynyltriisopropylsilane (0.45 mmol, 82.1 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 100:1) afforded the title product in 87% yield (75.2 mg) as a colorless oil. ^1H NMR (400 MHz, $CDCl_3$): δ 0.96-1.07 (m, 21H), 2.54 (t, *J* = 7.6 Hz, 2H), 2.83 (t, *J* = 7.6 Hz, 2H), 7.16-7.29 (m, 5H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 11.27, 18.58, 22.04, 35.27, 80.97, 108.13, 126.17, 128.28, 128.51, 140.65. IR (neat): 3029, 2942, 2864, 2172, 1605, 1497, 1463, 1383, 1366, 1337, 1242, 1076, 1042, 995, 919, 883, 746, 697, 675, 660, 640, 620, 577, 530, 512, 457, 419 cm^{-1}. HRMS (EI) calcd. for $C_{19}H_{30}Si$ $[M]^+$: 286.2111, found 286.2109.

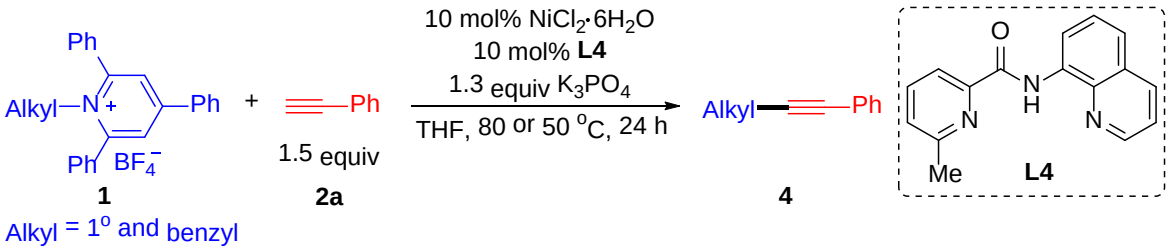


3v

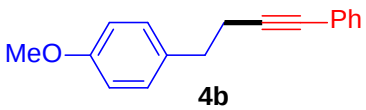
Trimethyl(4-phenylbut-1-yn-1-yl)silane (3v). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), phenethylpyridinium salt **1a** (0.3 mmol, 150.0 mg), ethynyltrimethylsilane (0.45 mmol, 44.2 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 100:1) afforded the title product in 75% yield (45.4

mg) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.10 (s, 9H), 2.45 (t, *J* = 7.6 Hz, 2H), 2.79 (t, *J* = 7.6 Hz, 2H), 7.16-7.19 (m, 3H), 7.22-7.26 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 0.06, 22.17, 35.09, 85.23, 106.64, 126.25, 128.29, 128.51, 140.60. IR (neat): 3852, 3746, 3029, 2958, 2176, 1603, 1497, 1454, 1339, 1250, 1077, 1042, 996, 841, 760, 698, 646, 514, 436, 415 cm^{-1}. HRMS (EI) calcd. for $C_{13}H_{18}Si$ $[M]^+$: 202.1172, found 202.1175.

General procedure C: Sonogashira coupling of primary alkylpyridinium salts



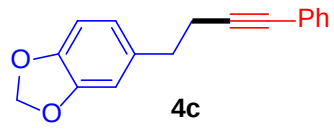
In a nitrogen-filled glovebox, $NiCl_2·6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), primary alkylpyridinium salt (0.3 mmol) and tetrahydrofuran (1.5 mL) were successively added to an oven-dried sealable Schlenk tube (10.0 mL) followed by addition of phenylacetylene (0.45 mmol, 46.0 mg) via microliter syringe. Then the tube was securely sealed and taken outside the glovebox. And it was immersed into an oil bath preheated at 80 or 50 °C. After stirring for 24 h, the reaction mixture was cooled to room temperature and filtered through a short pad of silica gel. Then the filter cake was washed with dichloromethane or ethyl acetate. The resulting solution was concentrated under vacuum and the residue was purified by column chromatography on silica gel.



4b

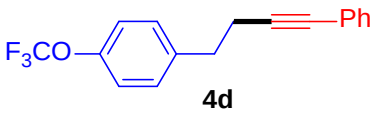
1-Methoxy-4-(4-phenylbut-3-yn-1-yl)benzene (4b). 0.3 mmol scale, $NiCl_2·6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), *p*-methoxyphenethylpyridinium salt **1b** (0.3 mmol, 158.8 mg), phenylacetylene (0.45 mmol, 46.0 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 °C for 24 h. Then the reaction

mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 20:1) afforded the title product in 93% yield (66.0 mg) as a light-yellow solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.64 (t, *J* = 7.6 Hz, 2H), 2.85 (t, *J* = 7.6 Hz, 2H), 3.76 (s, 3H), 6.84 (d, *J* = 8.4 Hz, 2H), 7.17 (d, *J* = 8.4 Hz, 2H), 7.24-7.28 (m, 3H), 7.36-7.38 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.91, 34.25, 55.17, 81.25, 89.60, 113.73, 123.84, 127.55, 128.14, 129.43, 131.47, 132.80, 158.09. IR (neat): 3045, 3017, 2924, 2857, 2835, 1885, 1612, 1586, 1511, 1489, 1462, 1441, 1424, 1320, 1301, 1241, 1178, 1155, 1107, 1071, 1035, 1004, 917, 829, 815, 757, 714, 691, 637, 566, 535, 518, 489, 412 cm^{-1}. HRMS (ESI) calcd. for $C_{17}H_{17}O$ $[M+H]^+$: 237.1274, found 237.1274.



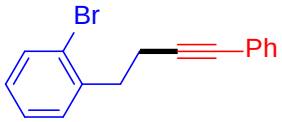
4c

5-(4-Phenylbut-3-yn-1-yl)benzo[*d*][1,3]dioxole (4c). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(2-(benzo[*d*][1,3]dioxol-5-yl)ethyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1c** (0.3 mmol, 163.0 mg), phenylacetylene (0.45 mmol, 46.0 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^{o}C for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether to petroleum ether: dichloromethane = 100:3, gradient) afforded the title product in 91% yield (68.3 mg) as a colorless oil. ^{1}H NMR (600 MHz, $CDCl_3$): δ 2.55 (t, *J* = 7.2 Hz, 2H), 2.74 (t, *J* = 7.2 Hz, 2H), 5.83 (s, 2H), 6.62-6.68 (m, 3H), 7.14-7.18 (m, 3H), 7.28-7.29 (m, 2H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 21.95, 34.87, 81.39, 89.37, 100.78, 108.11, 108.96, 121.36, 123.78, 127.60, 128.17, 131.49, 134.52, 145.97, 147.53. IR (neat): 2900, 1598, 1502, 1488, 1441, 1363, 1337, 1243, 1188, 1122, 1097, 1070, 1038, 935, 890, 856, 806, 780, 754, 725, 690, 634, 603, 549, 525, 473, 421 cm^{-1}. HRMS (ESI) calcd. for $C_{17}H_{15}O_2$ $[M+H]^+$: 251.1067, found 251.1067.



4d

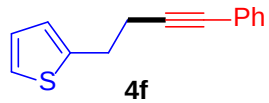
1-(4-Phenylbut-3-yn-1-yl)-4-(trifluoromethoxy)benzene (4d). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 2,4,6-triphenyl-1-(4-(trifluoromethoxy)phenethyl)pyridin-1-ium tetrafluoroborate **1d** (0.3 mmol, 175.0 mg), phenylacetylene (0.45 mmol, 46.0 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 100:1) afforded the title product in 94% yield (81.5 mg) as a white solid. ^1H NMR (400 MHz, $CDCl_3$): δ 2.68 (t, *J* = 7.2 Hz, 2H), 2.90 (t, *J* = 7.2 Hz, 2H), 7.15 (d, *J* = 8.4 Hz, 2H), 7.25-7.28 (m, 5H), 7.34-7.36 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.49, 34.34, 81.71, 88.90, 120.53 (q, *J* = 255.0 Hz), 120.89, 123.65, 127.73, 128.22, 129.85, 131.48, 139.35, 147.78 (q, *J* = 2.1 Hz). IR (neat): 3036, 2937, 2364, 2327, 1594, 1506, 1490, 1444, 1211, 1155, 1105, 1070, 1018, 919, 848, 781, 758, 692, 671, 614, 527, 460 cm^{-1}. HRMS (ESI) calcd. for $C_{17}H_{14}F_3O$ $[M+H]^+$: 291.0991, found 291.0991.



4e

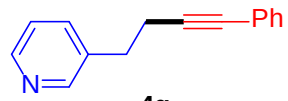
1-Bromo-2-(4-phenylbut-3-yn-1-yl)benzene (4e). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(2-bromophenethyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1e** (0.3 mmol, 173.5 mg), phenylacetylene (0.45 mmol, 46.0 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 100:1) afforded the title product in 90% yield (76.7 mg) as a colorless oil. ^1H NMR (600 MHz, $CDCl_3$): δ 2.72 (t, *J* = 7.2 Hz, 2H), 3.04 (t, *J* = 7.2 Hz, 2H), 7.07 (t, *J* = 7.2 Hz, 1H), 7.21-7.27 (m, 4H), 7.32 (d, *J* = 7.2 Hz, 1H), 7.36-7.37 (m, 2H), 7.53 (d, *J* = 7.8 Hz, 1H). ^{13}C NMR (151

MHz, $CDCl_3$): δ 19.80, 35.34, 81.51, 88.95, 123.73, 124.36, 127.31, 127.61, 128.08, 128.15, 130.83, 131.49, 132.77, 139.68. IR (neat): 3056, 2936, 1597, 1568, 1489, 1471, 1440, 1340, 1249, 1159, 1116, 1070, 1025, 913, 842, 748, 690, 657, 585, 534, 526, 446 cm^{-1}. HRMS (EI) calcd. for $C_{16}H_{13}Br$ $[M]^+$: 284.0195, found 284.0202.



4f

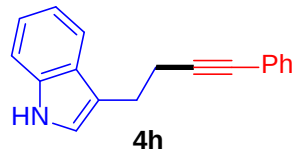
2-(4-Phenylbut-3-yn-1-yl)thiophene (4f). 0.3 mmol scale, $NiCl_2·6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 2,4,6-triphenyl-1-(2-(thiophen-2-yl)ethyl)pyridin-1-ium tetrafluoroborate **1f** (0.3 mmol, 151.6 mg), phenylacetylene (0.45 mmol, 46.0 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 100:1) afforded the title product in 94% yield (60.1 mg) as a colorless oil. ^1H NMR (400 MHz, $CDCl_3$): δ 2.73 (t, *J* = 7.6 Hz, 2H), 3.12 (t, *J* = 7.6 Hz, 2H), 6.89-6.94 (m, 2H), 7.13 (dd, *J* = 1.2, 5.2 Hz, 1H), 7.25-7.29 (m, 3H), 7.37-7.40 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 22.10, 29.40, 81.70, 88.90, 123.55, 123.68, 124.80, 126.69, 127.68, 128.17, 131.51, 143.09. IR (neat): 2925, 1598, 1489, 1440, 1339, 1252, 1070, 1041, 913, 848, 823, 755, 690, 529, 500, 436, 416, 406 cm^{-1}. HRMS (ESI) calcd. for $C_{14}H_{13}S$ $[M+H]^+$: 213.0732, found 213.0730.



4g

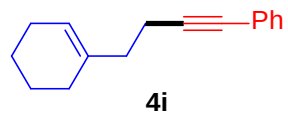
3-(4-Phenylbut-3-yn-1-yl)pyridine (4g). 0.3 mmol scale, $NiCl_2·6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 2,4,6-triphenyl-1-(2-(pyridin-3-yl)ethyl)pyridin-1-ium tetrafluoroborate **1g** (0.3 mmol, 150.1 mg), phenylacetylene (0.45 mmol, 46.0 mg) and *N*, *N*-dimethylformamide (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was extracted with ethyl acetate, washed with water and brine, and dried over anhydrous Na_2SO_4. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate =

5:1) afforded the title product in 92% yield (57.2 mg) as a yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.70 (t, *J* = 7.2 Hz, 2H), 2.90 (t, *J* = 7.2 Hz, 2H), 7.24-7.29 (m, 4H) 7.34-7.36 (m, 2H), 7.60 (d, *J* = 7.6 Hz, 1H), 8.50 (s, 1H), 8.57 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.23, 32.06, 81.95, 88.35, 123.26, 123.40, 127.70, 128.14, 131.40, 135.83, 136.00, 147.69, 149.91. IR (neat): 3030, 2929, 1597, 1575, 1490, 1479, 1442, 1423, 1343, 1191, 1157, 1104, 1070, 1028, 916, 797, 755, 712, 691, 629, 604, 531, 500 cm^{-1}. HRMS (ESI) calcd. for $C_{15}H_{14}N$ $[M+H]^+$: 208.1121, found 208.1126.



4h

3-(4-Phenylbut-3-yn-1-yl)-1*H*-indole (4h). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(2-(1*H*-indol-3-yl)ethyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1h** (0.3 mmol, 161.5 mg), phenylacetylene (0.45 mmol, 46.0 mg) and *N*, *N*-dimethylformamide (1.5 mL) were stirred at 80 ^{o}C for 24 h. Then the reaction mixture was extracted with ethyl acetate, washed with water and brine, and dried over anhydrous Na_2SO_4. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate = 20:1) afforded the title product in 76% yield (56.1 mg) as a yellow oil. ^{1}H NMR (600 MHz, $CDCl_3$): δ 2.76 (t, *J* = 7.2 Hz, 2H), 3.06 (t, *J* = 7.2 Hz, 2H), 7.00 (s, 1H), 7.11 (t, *J* = 7.8 Hz, 1H), 7.18 (t, *J* = 8.4 Hz, 1H), 7.22-7.29 (m, 4H), 7.37 (d, *J* = 6.6 Hz, 2H), 7.63 (d, *J* = 7.8 Hz, 1H), 7.79 (br, 1H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 20.77, 24.81, 81.06, 90.37, 111.09, 115.15, 118.75, 119.25, 121.60, 121.93, 123.91, 127.23, 127.54, 128.17, 131.51, 136.14. IR (neat): 3396, 3048, 2939, 2909, 2847, 1599, 1488, 1456, 1442, 1424, 1354, 1334, 1302, 1245, 1227, 1169, 1091, 1069, 1008, 910, 823, 774, 748, 686, 594, 583, 547, 524, 503, 466, 449, 424 cm^{-1}. HRMS (ESI) calcd. for $C_{18}H_{16}N$ $[M+H]^+$: 246.1277, found 246.1274.



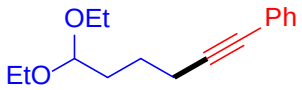
4i

(4-(Cyclohex-1-en-1-yl)but-1-yn-1-yl)benzene (4i). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03

mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(2-(cyclohex-1-en-1-yl)ethyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1i** (0.3 mmol, 151.0 mg), phenylacetylene (0.45 mmol, 46.0 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^{o}C for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether) afforded the title product in 90% yield (56.6 mg) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.53-1.66 (m, 4H), 1.97-2.01 (m, 4H), 2.24 (t, *J* = 7.6 Hz, 2H), 2.48 (t, *J* = 7.6 Hz, 2H), 5.50 (s, 1H), 7.22-7.29 (m, 3H), 7.37-7.39 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 18.41, 22.43, 22.91, 25.21, 28.14, 37.08, 80.77, 90.25, 122.05, 124.07, 127.43, 128.14, 131.49, 136.26. IR (neat): 3054, 2924, 2856, 2834, 1598, 1490, 1441, 1333, 1270, 1133, 1070, 913, 801, 754, 691, 527, 452, 431 cm^{-1}. HRMS (EI) calcd. for $C_{16}H_{18}$ [M]$^{+}$: 210.1403, found 210.1398.

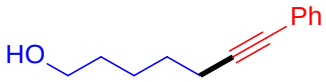
4j

***N*, *N*-Dimethyl-5-phenylpent-4-yn-1-amine (4j).** 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(3-(dimethylamino)propyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1j** (0.3 mmol, 144.1 mg), phenylacetylene (0.45 mmol, 46.0 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^{o}C for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with methanol. Purification of the crude product by column chromatography on silica gel (eluent: dichloromethane: acetone: methanol = 15:1:1) afforded the title product in 80% yield (45.2 mg) as a yellow oil. ^{1}H NMR (600 MHz, $CDCl_3$): δ 1.80 (br, 2H), 2.37 (br, 5H), 2.47 (s, 3H), 2.56 (br, 2H), 7.27 (br, 3H), 7.39 (d, *J* = 5.4 Hz, 2H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 17.20, 26.32, 44.74, 58.22, 80.97, 89.28, 123.74, 127.53, 128.12, 131.46. IR (neat): 3401, 2948, 2677, 1598, 1490, 1466, 1442, 1341, 1070, 1029, 975, 828, 756, 692, 557, 526, 416 cm^{-1}. HRMS (ESI) calcd. for $C_{13}H_{18}N$ [M+H]$^{+}$: 188.1434, found 188.1434.



4k

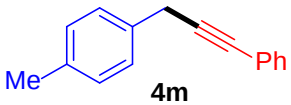
(6,6-Diethoxyhex-1-yn-1-yl)benzene (4k). 0.3 mmol scale, $NiCl_2·6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(4,4-diethoxybutyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1k** (0.3 mmol, 161.8 mg), phenylacetylene (0.45 mmol, 46.0 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate = 100:1) afforded the title product in 83% yield (61.3 mg) as a light-yellow oil. ^1H NMR (400 MHz, $CDCl_3$): δ 1.12-1.21 (m, 6H), 1.56-1.64 (m, 2H), 1.69-1.74 (m, 2H), 2.36 (t, *J* = 7.2 Hz, 2H), 3.39-3.46 (m, 2H), 3.54-3.62 (m, 2H), 4.46 (t, *J* = 6.0 Hz, 1H), 7.18-7.22 (m, 3H), 7.30-7.32 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 15.28, 19.20, 23.96, 32.71, 60.94, 80.86, 89.78, 102.48, 123.91, 127.47, 128.12, 131.47. IR (neat): 2974, 2928, 2875, 1599, 1490, 1442, 1374, 1343, 1128, 1059, 991, 913, 755, 691, 526 cm^{-1}. HRMS (ESI) calcd. for $C_{16}H_{22}NaO_2$ $[M+Na]^+$: 269.1512, found 269.1507.



4l

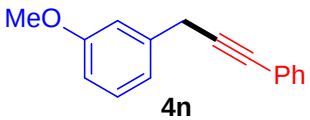
7-Phenylhept-6-yn-1-ol (4l). 0.3 mmol scale, $NiCl_2·6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(5-hydroxypentyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1l** (0.3 mmol, 144.4 mg), phenylacetylene (0.45 mmol, 46.0 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with ethyl acetate. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate = 5:1) afforded the title product in 91% yield (51.3 mg) as a light-yellow oil. ^1H NMR (400 MHz, $CDCl_3$): δ 1.49-1.66 (m, 6H), 1.93 (br, 1H), 2.41 (t, *J* = 6.8 Hz, 2H), 3.64 (t, *J* = 6.4 Hz, 2H), 7.25-7.29 (m, 3H),

7.38-7.39 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 19.27, 24.98, 28.41, 32.14, 62.63, 80.68, 90.02, 123.88, 127.44, 128.11, 131.44. IR (neat): 3324, 2934, 2860, 1598, 1489, 1441, 1331, 1070, 1051, 914, 754, 691, 525, 421 cm^{-1}. HRMS (ESI) calcd. for $C_{13}H_{16}NaO$ $[M+Na]^+$: 211.1093, found 211.1093.



4m

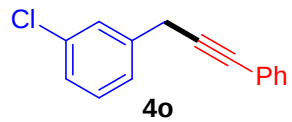
1-Methyl-4-(3-phenylprop-2-yn-1-yl)benzene (4m). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(4-methylbenzyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1m** (0.3 mmol, 150.0 mg), phenylacetylene (0.45 mmol, 46.0 mg) and tetrahydrofuran (1.5 mL) were stirred at 50 °C for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether) afforded the title product in 86% yield (53.5 mg) as a light-yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.24 (s, 3H), 3.69 (s, 2H), 7.05 (d, *J* = 8.0 Hz, 2H), 7.18-7.22 (m, 5H), 7.34-7.36 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.99, 25.29, 82.42, 87.83, 123.74, 127.72, 127.81, 128.18, 129.19, 131.60, 133.68, 136.14. IR (neat): 3024, 2921, 2198, 1690, 1638, 1602, 1513, 1490, 1450, 1416, 1317, 1285, 1210, 1172, 1115, 1070, 1022, 913, 808, 755, 712, 690, 663, 595, 571, 525, 509, 477, 408 cm^{-1}. HRMS (EI) calcd. for $C_{16}H_{14}$ $[M]^+$: 206.1090, found 206.1092.



4n

1-Methoxy-3-(3-phenylprop-2-yn-1-yl)benzene (4n). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(3-methoxybenzyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1n** (0.3 mmol, 154.6 mg), phenylacetylene (0.45 mmol, 46.0 mg) and tetrahydrofuran (1.5 mL) were stirred at 50 °C for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column

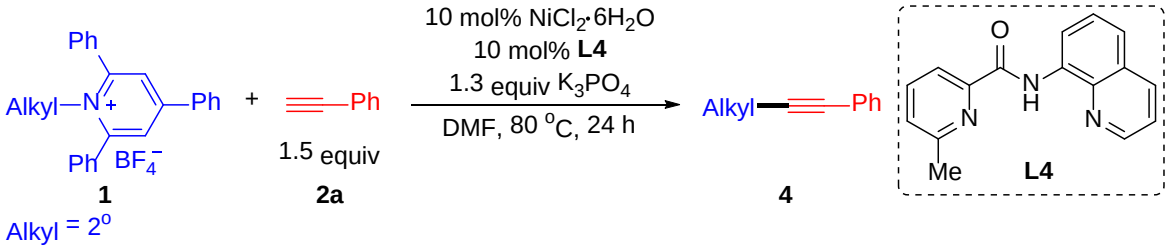
chromatography on silica gel (eluent: petroleum ether) afforded the title product in 86% yield (57.5 mg) as a light-yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 3.80 (s, 5H), 6.78-6.80 (m, 1H), 6.99 (d, *J* = 6.0 Hz, 2H), 7.22-7.29 (m, 4H), 7.43-7.45 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 25.70, 55.15, 82.69, 87.34, 112.03, 113.70, 120.31, 123.63, 127.80, 128.20, 129.48, 131.60, 138.29, 159.80. IR (neat): 2937, 2835, 1694, 1599, 1585, 1489, 1465, 1453, 1435, 1318, 1283, 1258, 1145, 1070, 1047, 996, 916, 877, 776, 756, 740, 714, 690, 548, 527, 512, 480, 444 cm^{-1}. HRMS (ESI) calcd. for $C_{16}H_{15}O$ $[M+H]^+$: 223.1117, found 223.1114.



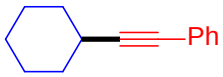
4o

1-Chloro-3-(3-phenylprop-2-yn-1-yl)benzene (4o). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(3-chlorobenzyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1o** (0.3 mmol, 156.0 mg), phenylacetylene (0.45 mmol, 46.0 mg) and tetrahydrofuran (1.5 mL) were stirred at 50 °C for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether) afforded the title product in 91% yield (62.0 mg) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 3.79 (s, 2H), 7.22 (d, *J* = 8.0 Hz, 2H), 7.25-7.32 (m, 4H), 7.41 (s, 1H), 7.44-7.46 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 25.41, 83.15, 86.47, 123.36, 126.13, 126.86, 127.99, 128.12, 128.26, 129.73, 131.64, 134.36, 138.73. IR (neat): 3062, 2200, 1693, 1596, 1574, 1490, 1474, 1443, 1430, 1317, 1286, 1196, 1177, 1094, 1077, 1027, 999, 846, 775, 755, 712, 689, 527, 431, 418 cm^{-1}. HRMS (EI) calcd. for $C_{15}H_{11}Cl$ $[M]^+$: 226.0544, found 226.0542.

General procedure D: Sonogashira coupling of secondary alkylpyridinium salts



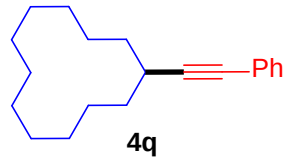
In a nitrogen-filled glovebox, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), secondary alkylpyridinium salt (0.3 mmol) and *N*, *N*-dimethylformamide (1.5 mL) were successively added to an oven-dried sealable Schlenk tube (10.0 mL) followed by addition of phenylacetylene (0.45 mmol, 46.0 mg) via microliter syringe. Then the tube was securely sealed and taken outside the glovebox. And it was immersed into an oil bath preheated at 80 °C. After stirring for 24 h, the reaction mixture was cooled to room temperature and quenched with water. Then it was extracted with ethyl acetate or diethyl ether, washed with water and brine, and dried over anhydrous Na_2SO_4. The resulting solution was concentrated under vacuum and the residue was purified by column chromatography on silica gel.



4p

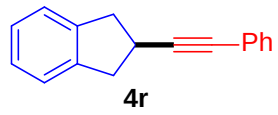
(Cyclohexylethynyl)benzene (4p). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-cyclohexyl-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1p** (0.3 mmol, 143.2 mg), phenylacetylene (0.45 mmol, 46.0 mg) and *N*, *N*-dimethylformamide (1.5 mL) were stirred at 80 °C for 24 h. Then the reaction mixture was extracted with diethyl ether, washed with water and brine, and dried over anhydrous Na_2SO_4. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 100:1) afforded the title product in 92% yield (50.8 mg) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.31-1.40 (m, 3H), 1.49-1.58 (m, 3H), 1.72-1.77 (m, 2H), 1.86-1.89 (m, 2H), 2.55-2.61 (m, 1H), 7.21-7.28 (m, 3H),7.36-7.40 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 24.87, 25.91, 29.63, 32.69, 80.49, 94.41, 124.12, 127.36, 128.11, 131.55. IR (neat): 3423, 2931, 2855, 1703, 1598, 1490, 1444, 1339, 1306, 1161, 1070, 1047, 1027, 933, 913, 889,

847, 818, 754, 690, 639, 585, 559, 535 cm^{-1}. HRMS (EI) calcd. for $C_{14}H_{16}$ $[M]^+$: 184.1247, found 184.1245.



4q

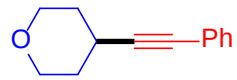
(Phenylethynyl)cyclododecane (4q). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-cyclododecyl-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1q** (0.3 mmol, 168.5 mg), phenylacetylene (0.45 mmol, 46.0 mg) and *N*, *N*-dimethylformamide (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was extracted with ethyl acetate, washed with water and brine, and dried over anhydrous Na_2SO_4. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 100:1) afforded the title product in 86% yield (69.0 mg) as a colorless oil. ^1H NMR (400 MHz, $CDCl_3$): δ 1.36-1.50 (m, 16H), 1.54-1.57 (m, 4H), 1.59-1.73 (m, 2H), 2.65-2.71 (m, 1H), 7.20-7.28 (m, 3H), 7.35-7.39 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 22.19, 23.37, 23.44, 23.80, 23.88, 27.42, 29.89, 80.19, 94.90, 124.20, 127.29, 128.09, 131.55. IR (neat): 2925, 2899, 2847, 2223, 1598, 1489, 1469, 1439, 1334, 1298, 1286, 1250, 1070, 1042, 1026, 964, 952, 910, 754, 722, 707, 690, 663, 558, 549, 523, 496, 478, 408 cm^{-1}. HRMS (EI) calcd. for $C_{20}H_{28}$ $[M]^+$: 268.2186, found 268.2190.



4r

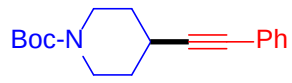
2-(Phenylethynyl)-2,3-dihydro-1*H*-indene (4r). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(2,3-dihydro-1*H*-inden-2-yl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1r** (0.3 mmol, 153.4 mg), phenylacetylene (0.45 mmol, 46.0 mg) and *N*, *N*-dimethylformamide (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was extracted with ethyl acetate, washed with water and brine, and dried over anhydrous Na_2SO_4. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether) afforded

the title product in 90% yield (59.0 mg) as a white solid. ^{1}H NMR (600 MHz, $CDCl_3$): δ 3.11 (dd, *J* = 8.4, 15.3 Hz, 2H), 3.29 (dd, *J* = 8.4, 15.3 Hz, 2H), 3.39-3.43 (m, 1H), 7.15 (d, *J* = 3.6 Hz, 2H), 7.20 (d, *J* = 4.2 Hz, 2H), 7.23-7.26 (m, 3H), 7.40 (d, *J* = 7.8 Hz, 2H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 30.17, 40.29, 80.56, 92.99, 123.71, 124.30, 126.50, 127.63, 128.16, 131.58, 141.96. IR (neat): 3035, 2901, 2844, 1595, 1487, 1473, 1458, 1442, 1346, 1316, 1222, 1203, 1175, 1160, 1095, 1070, 1017, 1000, 931, 912, 859, 787, 752, 739, 689, 663, 603, 540, 532, 499, 478, 416 cm^{-1}. HRMS (EI) calcd. for $C_{17}H_{14}$ $[M]^+$: 218.1090, found 218.1091.



4s

4-(Phenylethynyl)tetrahydro-2*H*-pyran (4s). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 2,4,6-triphenyl-1-(tetrahydro-2*H*-pyran-4-yl)pyridin-1-ium tetrafluoroborate **1s** (0.3 mmol, 143.8 mg), phenylacetylene (0.45 mmol, 46.0 mg) and *N*, *N*-dimethylformamide (1.5 mL) were stirred at 80 ^{o}C for 24 h. Then the reaction mixture was extracted with ethyl acetate, washed with water and brine, and dried over anhydrous Na_2SO_4. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate = 100:1) afforded the title product in 91% yield (50.8 mg) as a light-yellow oil. ^{1}H NMR (600 MHz, $CDCl_3$): δ 1.73-1.78 (m, 2H), 1.89-1.91 (m, 2H), 2.84 (s, 1H), 3.52-3.56 (m, 2H), 3.94-3.95 (m, 2H), 7.27 (br, 3H), 7.40-7.41 (m, 2H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 26.74, 32.24, 66.33, 81.48, 92.13, 123.57, 127.70, 128.17, 131.54. IR (neat): 2949, 2923, 2846, 1598, 1490, 1465, 1442, 1386, 1361, 1315, 1298, 1239, 1207, 1183, 1127, 1103, 1084, 1064, 1034, 1011, 980, 968, 945, 914, 859, 811, 755, 691, 596, 536, 503, 443, 420 cm^{-1}. HRMS (FI) calcd. for $C_{13}H_{14}O$ $[M]^+$: 186.1039, found 186.1038.

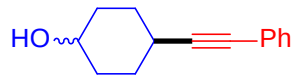


4t

***tert*-Butyl 4-(phenylethynyl)piperidine-1-carboxylate (4t).** 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg),

1-(1-(*tert*-butoxycarbonyl)piperidin-4-yl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1t** (0.3 mmol, 173.5 mg), phenylacetylene (0.45 mmol, 46.0 mg) and *N*, *N*-dimethylformamide (1.5 mL) were stirred at 80 ^{o}C for 24 h. Then the reaction mixture was extracted with ethyl acetate, washed with water and brine, and dried over anhydrous Na_2SO_4. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate = 30:1) afforded the title product in 98% yield (83.5 mg) as a colorless oil. ^{1}H NMR (600 MHz, $CDCl_3$): δ 1.38 (s, 9H), 1.58-1.59 (m, 2H), 1.76 (br, 2H), 2.69-2.72 (m, 1H), 3.14-3.18 (m, 2H), 3.65 (br, 2H), 7.19-7.21 (m, 3H), 7.30-7.32 (m, 2H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 27.47, 28.35, 31.32, 42.12, 79.34, 81.89, 91.69, 123.46, 127.67, 128.12, 131.48, 154.69. IR (neat): 2927, 2857, 1689, 1491, 1443, 1419, 1365, 1322, 1301, 1272, 1230, 1164, 1117, 1070, 1049, 1029, 1001, 988, 960, 936, 913, 864, 755, 691, 532, 461, 412 cm^{-1}. HRMS (ESI) calcd. for $C_{18}H_{23}NNaO_2$ $[M+Na]^+$: 308.1621, found 308.1621.

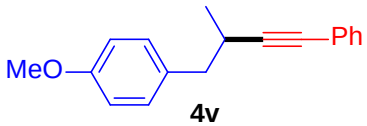
However, when the reaction was conducted using tetrahydrofuran as the solvent (following ***General procedure C****), a dramatic drop in reaction efficiency was observed and* ***4t*** *was obtained in only 74% yield.*



4u

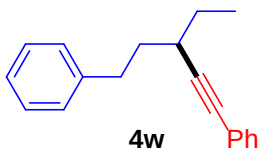
4-(Phenylethynyl)cyclohexan-1-ol (4u). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), *cis*-1-(4-hydroxycyclohexyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1u** (0.3 mmol, 148.0 mg), phenylacetylene (0.45 mmol, 46.0 mg) and *N*, *N*-dimethylformamide (1.5 mL) were stirred at 80 ^{o}C for 24 h. Then the reaction mixture was extracted with ethyl acetate, washed with water and brine, and dried over anhydrous Na_2SO_4. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate = 3:1) afforded a mixture of products (*trans*/*cis* = 2:1) in 94% yield (56.5 mg) as a light-yellow oil. ^{1}H NMR (600 MHz, $CDCl_3$): δ 1.29-1.35 (m, 2H), 1.48-1.54 (m, 2H), 1.62-1.64 (m, 1H), 1.76-1.77 (m, 1.5H), 1.90-1.91 (m, 1H), 1.99-2.07 (m, 6H), 2.45-2.48 (m, 1H, major), 2.78 (s, 0.5H, minor), 3.65-3.68 (m, 1.5H), 7.26 (br, 4.5H), 7.38 (d, *J* = 6.0

Hz, 2H, major), 7.40 (d, *J* = 6.6 Hz, 1H, minor). ^{13}C NMR (151 MHz, $CDCl_3$): δ 27.39 (minor), 28.60 (major), 28.98 (major), 30.37 (minor), 31.59 (major), 34.03 (minor), 68.85 (minor), 69.28 (major), 80.51 (major), 81.62 (minor), 92.86 (minor), 93.20 (major), 123.73 (major), 123.80 (minor), 127.50, 128.09, 131.47. IR (neat): 3264, 3078, 2931, 2859, 1598, 1488, 1443, 1365, 1325, 1282, 1221, 1204, 1175, 1061, 1035, 1004, 995, 968, 944, 918, 900, 866, 842, 756, 691, 664, 591, 558, 545, 527, 509, 494, 459, 438, 420 cm^{-1}. HRMS (ESI) calcd. for $C_{14}H_{17}O$ $[M+H]^+$: 201.1274, found 201.1272.



4v

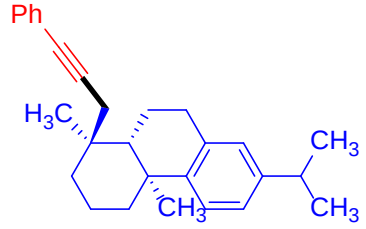
1-Methoxy-4-(2-methyl-4-phenylbut-3-yn-1-yl)benzene (4v). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(1-(4-methoxyphenyl)propan-2-yl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1v** (0.3 mmol, 163.0 mg), phenylacetylene (0.45 mmol, 46.0 mg) and *N*, *N*-dimethylformamide (1.5 mL) were stirred at 80 °C for 24 h. Then the reaction mixture was extracted with ethyl acetate, washed with water and brine, and dried over anhydrous Na_2SO_4. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 20:1) afforded the title product in 84% yield (62.8 mg) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.24 (d, *J* = 6.4 Hz, 2H), 2.69-2.75 (m, 1H), 2.80-2.88 (m, 3H), 3.77 (s, 3H), 6.82-6.86 (m, 2H), 7.16-7.21 (m, 2H), 7.23-7.28 (m, 3H), 7.34-7.37 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.44, 28.75, 42.22, 55.16, 81.51, 94.18, 113.51, 123.91, 127.48, 128.12, 130.25, 131.47, 131.69, 158.11. IR (neat): 2968, 2931, 2834, 2230, 1611, 1584, 1511, 1489, 1455, 1442, 1373, 1336, 1300, 1244, 1177, 1113, 1070, 1034, 914, 835, 807, 754, 691, 621, 575, 537 cm^{-1}. HRMS (ESI) calcd. for $C_{18}H_{19}O$ $[M+H]^+$: 251.1430, found 251.1430.



4w

(3-Ethylpent-1-yne-1,5-diyl)dibenzene (4w). 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 2,4,6-triphenyl-1-(1-phenylpentan-3-yl)pyridin-1-ium tetrafluoroborate **1w** (0.3 mmol, 162.4 mg), phenylacetylene (0.45 mmol, 46.0 mg) and *N*, *N*-dimethylformamide (1.5 mL) were stirred at 80 ^{o}C for 24 h. Then the reaction mixture was extracted with ethyl acetate, washed with water and brine, and dried over anhydrous Na_2SO_4. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 100:1) afforded the title product in 82% yield (61.2 mg) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.06 (t, *J* = 7.6 Hz, 3H), 1.53-1.62 (m, 2H), 1.79-1.86 (m, 2H), 2.45-2.52 (m, 2H), 2.73-2.81 (m, 1H), 2.87-2.94 (m, 1H), 7.16-7.19 (m, 1H), 7.22-7.30 (m, 7H), 7.41-7.44 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 11.81, 28.15, 33.48, 33.77, 36.59, 82.46, 93.04, 124.09, 125.77, 127.48, 128.17, 128.33, 128.51, 131.59, 142.17. IR (neat): 3061, 3026, 2963, 2927, 2859, 1599, 1489, 1454, 1443, 1380, 1347, 1070, 1029, 913, 754, 691, 544, 516, 492, 403 cm^{-1}. HRMS (EI) calcd. for $C_{19}H_{20}$ $[M]^+$: 248.1560, found 248.1559.

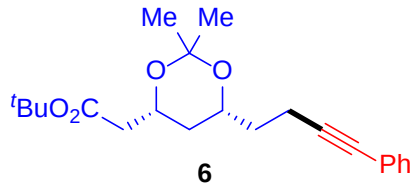
Late-stage modification of natural products and medicinally relevant molecules



5

(1*S*,4a*S*,10a*S*)-7-Isopropyl-1,4a-dimethyl-1-(3-phenylprop-2-yn-1-yl)-1,2,3,4,4a,9,10,10a-octahydrophenanthrene (5). Following **General procedure C**, 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(((1*R*,4a*S*,10a*R*)-7-isopropyl-1,4a-dimethyl-1,2,3,4,4a,9,10,10a-octahydrophenanthren-1-yl)methyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **S5** (0.3 mmol, 199.1 mg), phenylacetylene (0.45 mmol, 46.0 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^{o}C for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and

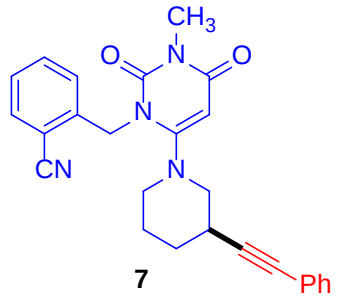
washed with dichloromethane. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 100:3) afforded the title product in 83% yield (92.4 mg) as a white solid. ^{1}H NMR (600 MHz, $CDCl_3$): δ 1.03 (s, 3H), 1.21-1.22 (m, 9H), 1.40-1.47 (m, 1H), 1.54-1.63 (m, 2H), 1.66-1.72 (m, 2H), 1.74-1.79 (m, 2H), 1.83-1.85 (m, 1H), 2.27 (d, *J* = 12.6 Hz, 1H), 2.36 (d, *J* = 16.8 Hz, 1H), 2.43 (d, *J* = 16.8 Hz, 1H), 2.79-2.83 (m, 1H), 2.87-2.90 (m, 2H), 6.88 (s, 1H), 6.98 (d, *J* = 7.8 Hz, 1H), 7.17 (d, *J* = 7.8 Hz, 1H), 7.22-7.23 (m, 3H), 7.35 (d, *J* = 6.0 Hz, 2H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 19.08, 20.50, 23.96, 25.29, 30.63, 33.40, 34.91, 37.11, 37.70, 38.00, 38.48, 47.52, 82.91, 88.11, 123.84, 124.04, 124.43, 126.83, 127.43, 128.12, 131.57, 134.82, 145.40, 147.24 *(1 aliphatic carbon signal is not observed due to signal overlap).* IR (neat): 2982, 2958, 2925, 1597, 1489, 1455, 1442, 1422, 1380, 1362, 1340, 1299, 1176, 1086, 1070, 1026, 985, 974, 914, 889, 822, 754, 691, 627, 526, 432, 416 cm^{-1}. HRMS (EI) calcd. for $C_{28}H_{34}$ $[M]^+$: 370.2655, found 370.2654.



6

***tert*-Butyl 2-((4*R*,6*R*)-2,2-dimethyl-6-(4-phenylbut-3-yn-1-yl)-1,3-dioxan-4-yl)acetate (6).** Following **General procedure C**, 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(2-((4*R*,6*R*)-6-(2-(*tert*-butoxy)-2-oxoethyl)-2,2-dimethyl-1,3-dioxan-4-yl)ethyl)-2,4,6-tri phenylpyridin-1-ium tetrafluoroborate **S6** (0.3 mmol, 195.5 mg), phenylacetylene (0.45 mmol, 46.0 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 °C for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with ethyl acetate. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate = 25:1) afforded the title product in 94% yield (100.8 mg) as a colorless oil. ^{1}H NMR (600 MHz, $CDCl_3$): δ 1.19-1.26 (m, 1H), 1.38 (s, 3H), 1.44 (s, 9H), 1.47 (s, 3H), 1.60 (d, *J* = 12.6 Hz, 1H), 1.69-1.77 (m, 2H), 2.31 (dd, *J* = 5.4, 15.0 Hz, 1H), 2.44 (dd, *J* = 6.6, 15.0 Hz, 1H), 2.47-2.54 (m, 2H), 4.07 (br, 1H), 4.25-4.29 (m, 1H),

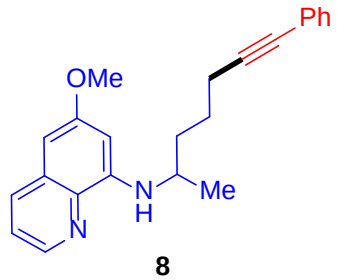
7.26-7.27 (m, 3H), 7.38 (d, J = 6.0 Hz, 2H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 15.06, 19.62, 28.01, 30.01, 34.96, 36.25, 42.63, 66.19, 67.29, 80.48, 80.73, 89.47, 98.72, 123.86, 127.50, 128.14, 131.44, 170.21. IR (neat): 2993, 2977, 2950, 2912, 1717, 1490, 1459, 1442, 1375, 1342, 1317, 1295, 1284, 1262, 1203, 1191, 1167, 1144, 1121, 1087, 1069, 1040, 1030, 988, 968, 953, 927, 912, 869, 838, 777, 752, 690, 655, 525, 502, 479, 422 cm^{-1}. HRMS (ESI) calcd. for $C_{22}H_{30}NaO_4$ $[M+Na]^+$: 381.2036, found 381.2034.



7

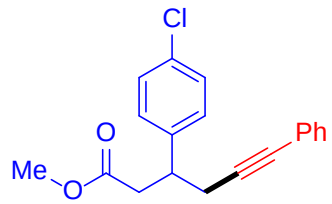
2-((3-Methyl-2,4-dioxo-6-(3-(phenylethynyl)piperidin-1-yl)-3,4-dihydropyrimidin-1(2*H*)-yl)methyl)benzonitrile (7). Following **General procedure D**, 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(1-(3-(2-cyanobenzyl)-1-methyl-2,6-dioxo-1,2,3,6-tetrahydropyrimidin-4-yl)piperidin-3-yl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **S7** (0.3 mmol, 215.3 mg), phenylacetylene (0.45 mmol, 46.0 mg) and *N*, *N*-dimethylformamide (1.5 mL) were stirred at 80 ^{o}C for 24 h. Then the reaction mixture was extracted with ethyl acetate, washed with water and brine, and dried over anhydrous Na_2SO_4. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate: dichloromethane = 3:1:3) afforded the title product in 94% yield (120.1 mg) as a light-yellow solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.65-1.68 (m, 2H), 1.96-2.03 (m, 2H), 2.87-2.94 (m, 4H), 3.10-3.13 (m, 1H), 3.28 (s, 3H), 5.28 (d, J = 16.0 Hz, 1H), 5.41-5.44 (m, 2H), 7.15 (d, J = 8.0 Hz, 1H), 7.18-7.26 (m, 5H), 7.29-7.32 (m, 1H), 7.50 (t, J = 7.6 Hz, 1H), 7.58 (d, J = 7.6 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 23.10, 27.71, 28.48, 29.80, 46.06, 51.76, 55.80, 82.48, 89.24, 90.20, 110.84, 116.94, 122.65, 126.61, 127.65, 127.81, 128.00, 131.32, 132.89, 132.93, 140.52, 152.31, 159.52, 162.92. IR (neat): 2943, 2855,

2224, 1702, 1651, 1608, 1489, 1434, 1376, 1312, 1284, 1223, 1164, 1104, 1028, 1008, 947, 918, 862, 806, 756, 692, 659, 625, 607, 587, 559, 536, 519, 432 cm^{-1}. HRMS (ESI) calcd. for $C_{26}H_{25}N_4O_2$ $[M+H]^+$: 425.1972, found 425.1972.



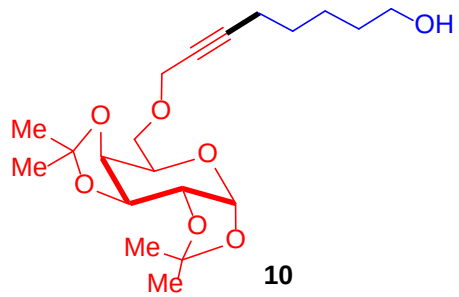
8

6-Methoxy-*N*-(7-phenylhept-6-yn-2-yl)quinolin-8-amine (8). Following **General procedure C**, 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(4-((6-methoxyquinolin-8-yl)amino)pentyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **S8** (0.3 mmol, 191.3 mg), phenylacetylene (0.45 mmol, 46.0 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with ethyl acetate. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate = 25:1) afforded the title product in 75% yield (77.7 mg) as a yellow oil. ^1H NMR (400 MHz, $CDCl_3$): δ 1.32 (d, *J* = 6.4 Hz, 3H), 1.70-1.82 (m, 3H), 1.83-1.90 (m, 1H), 2.43 (t, *J* = 6.4 Hz, 2H), 3.66 (br, 1H), 3.84 (s, 3H), 6.06 (br, 1H), 6.30-6.32 (m, 2H), 7.21-7.28 (m, 4H), 7.36-7.39 (m, 2H), 7.88 (dd, *J* = 1.6, 8.2 Hz, 1H), 8.51 (dd, *J* = 1.6, 4.0 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 19.36, 20.46, 25.35, 35.85, 47.65, 55.07, 80.92, 89.85, 91.50, 96.63, 121.74, 123.88, 127.43, 128.08, 129.84, 131.50, 134.70, 135.30, 144.19, 144.95, 159.40. IR (neat): 3385, 2935, 2862, 1614, 1595, 1576, 1517, 1489, 1455, 1422, 1386, 1335, 1261, 1217, 1196, 1160, 1070, 1050, 1030, 968, 900, 819, 790, 755, 691, 624, 525, 463 cm^{-1}. HRMS (ESI) calcd. for $C_{23}H_{25}N_2O$ $[M+H]^+$: 345.1961, found 345.1961.



9

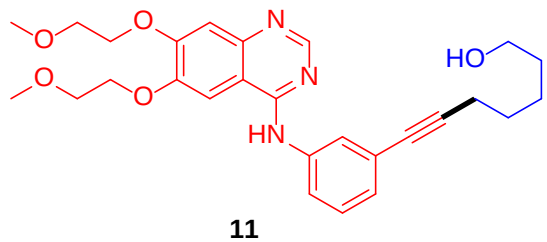
Methyl 3-(4-chlorophenyl)-6-phenylhex-5-ynoate (9). Following **General procedure D**, 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(2-(4-chlorophenyl)-4-methoxy-4-oxobutyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **S9** (0.3 mmol, 181.8 mg), phenylacetylene (0.45 mmol, 46.0 mg) and *N*, *N*-dimethylformamide (1.5 mL) were stirred at 80 ^{o}C for 24 h. Then the reaction mixture was extracted with ethyl acetate, washed with water and brine, and dried over anhydrous Na_2SO_4. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate = 100:1) afforded the title product in 70% yield (65.9 mg) as a light-yellow oil. ^{1}H NMR (600 MHz, $CDCl_3$): δ 2.67-2.76 (m, 3H), 2.96 (dd, *J* = 6.6, 15.6 Hz, 1H), 3.42-3.46 (m, 1H), 3.59 (s, 3H), 7.22 (d, *J* = 8.4 Hz, 2H), 7.26-7.29 (m, 5H), 7.33-7.34 (m, 2H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 26.67, 39.03, 40.21, 51.61, 82.97, 86.88, 123.33, 127.83, 128.19, 128.57, 128.67, 131.46, 132.62, 141.18, 172.17. IR (neat): 2951, 2913, 1734, 1596, 1489, 1442, 1429, 1367, 1344, 1308, 1287, 1253, 1217, 1200, 1190, 1179, 1157, 1106, 1092, 1070, 1026, 1013, 1000, 974, 956, 919, 890, 827, 792, 756, 731, 692, 667, 544, 527, 489, 441 cm^{-1}. HRMS (ESI) calcd. for $C_{19}H_{17}ClNaO_2$ $[M+Na]^+$: 335.0809, found 335.0803.



10

8-(((3a*R*,5*R*,5a*S*,8a*S*,8b*R*)-2,2,7,7-Tetramethyltetrahydro-5*H*-bis([1,3]dioxolo)[4,5-*b*:4',5'-*d*]pyran-5-yl)methoxy)oct-6-yn-1-ol (10). Following **General procedure C**, 0.3

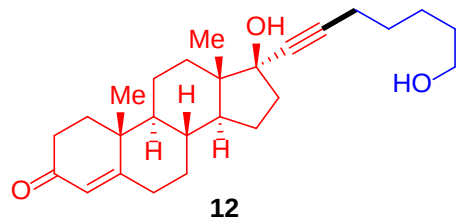
mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(5-hydroxypentyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1l** (0.3 mmol, 144.4 mg), (3a*R*,5*R*,5a*S*,8a*S*,8b*R*)-2,2,7,7-tetramethyl-5-((prop-2-yn-1-yloxy)methyl)tetrahydro-5*H*-bis([1,3]dioxolo)[4,5-*b*:4',5'-*d*]pyran **S10** (0.45 mmol, 134.3 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with ethyl acetate. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate: dichloromethane = 3:1:1) afforded the title product in 89% yield (102.7 mg) as a light-yellow oil. ^1H NMR (600 MHz, $CDCl_3$): δ 1.33 (s, 3H), 1.35 (s, 3H), 1.44-1.49 (m, 5H), 1.52-1.60 (m, 7H), 2.11 (br, 1H), 2.22-2.25 (m, 2H), 3.62-3.66 (m, 3H), 3.73 (dd, *J* = 5.4, 9.9 Hz, 1H), 3.98-4.00 (m, 1H), 4.15-4.23 (m, 2H), 4.27 (dd, *J* = 1.2, 7.8 Hz, 1H), 4.32 (dd, *J* = 2.4, 5.4 Hz, 1H), 4.60 (dd, *J* = 2.4, 7.8 Hz, 1H), 5.54 (d, *J* = 5.4 Hz, 1H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 18.59, 24.35, 24.78, 24.86, 25.83, 25.89, 28.14, 32.05, 58.89, 62.42, 66.57, 68.16, 70.35, 70.52, 71.06, 75.86, 86.89, 96.21, 108.48, 109.18. IR (neat): 3461, 2987, 2935, 1457, 1372, 1308, 1255, 1210, 1168, 1097, 1066, 1000, 917, 889, 864, 824, 804, 771, 693, 651, 512, 422 cm^{-1}. HRMS (ESI) calcd. for $C_{20}H_{32}NaO_7$ $[M+Na]^+$: 407.2040, found 407.2042.



11

7-(3-((6,7-Bis(2-methoxyethoxy)quinazolin-4-yl)amino)phenyl)hept-6-yn-1-ol (11). Following **General procedure C**, 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(5-hydroxypentyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1l** (0.3 mmol, 144.4 mg), *N*-(3-ethynylphenyl)-6,7-bis(2-methoxyethoxy)quinazolin-4-amine **S11** (0.45 mmol, 177.0 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction

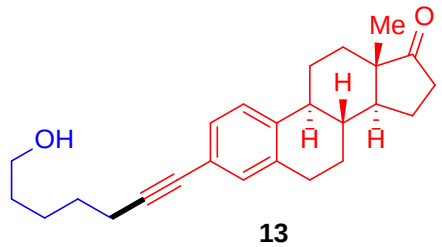
mixture was filtered through a short pad of silica gel and washed with acetone. Purification of the crude product by column chromatography on silica gel (eluent: dichloromethane: acetone = 3:1) afforded the title product in 87% yield (124.7 mg) as a light-yellow solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.38-1.48 (m, 6H), 2.26 (t, *J* = 6.4 Hz, 2H), 3.25 (s, 6H), 3.54 (t, *J* = 6.4 Hz, 3H), 3.60 (br, 4H), 3.95 (br, 2H), 4.09 (br, 2H), 7.00 (d, *J* = 8.0 Hz, 1H), 7.07-7.14 (m, 2H), 7.33 (s, 1H), 7.57 (d, *J* = 8.0 Hz, 1H), 7.64 (s, 1H), 8.44 (s, 1H), 8.53 (br, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 19.18, 25.02, 28.25, 32.10, 58.98, 59.01, 62.30, 68.09, 68.63, 70.20, 70.63, 80.42, 90.23, 102.77, 107.76, 109.15, 121.50, 124.41, 124.95, 127.10, 128.56, 138.65, 146.61, 148.49, 153.13, 154.19, 156.60. IR (neat): 3311, 2928, 2858, 1621, 1578, 1529, 1509, 1480, 1430, 1391, 1354, 1286, 1251, 1213, 1124, 1095, 1070, 1030, 931, 897, 859, 785, 686, 658, 588, 546, 513, 501, 482, 462, 450, 430, 421, 408 cm^{-1}. HRMS (ESI) calcd. for $C_{27}H_{34}N_3O_5$ $[M+H]^+$: 480.2493, found 480.2493.



12

(8*R*,9*S*,10*R*,13*S*,14*S*,17*S*)-17-Hydroxy-17-(7-hydroxyhept-1-yn-1-yl)-10,13-dimethyl-1,2,6,7,8,9,10,11,12,13,14,15,16,17-tetradecahydro-3*H*-cyclopenta[*a*]phenanthren-3-one (12). Following **General procedure C**, 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(5-hydroxypentyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1l** (0.3 mmol, 144.4 mg), (8*R*,9*S*,10*R*,13*S*,14*S*,17*R*)-17-ethynyl-17-hydroxy-10,13-dimethyl-1,2,6,7,8,9,10,11,12,13,14,15,16,17-tetradecahydro-3*H*-cyclopenta[*a*]phenanthren-3-one **S12** (0.45 mmol, 140.6 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 °C for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with ethyl acetate. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate: dichloromethane = 1:1:1) afforded the title product in 89% yield (106.6 mg) as a light-yellow solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.80 (s, 3H), 0.85-0.92 (m, 1H),

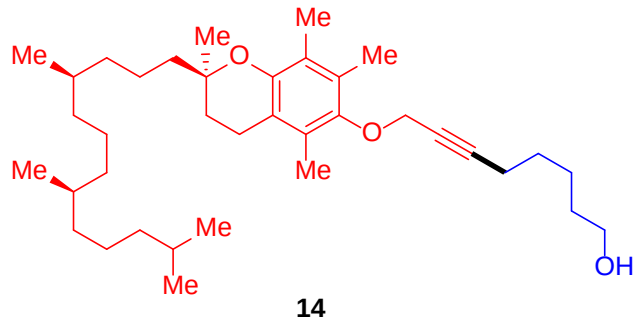
0.96-1.03 (m, 1H), 1.13 (s, 3H), 1.22-1.29 (m, 1H), 1.32-1.70 (m, 14H), 1.78 (d, *J* = 12.0 Hz, 1H), 1.87-1.99 (m, 2H), 2.10-2.40 (m, 7H), 2.61 (s, 2H), 3.54 (t, *J* = 6.0 Hz, 2H), 5.67 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 12.65, 17.22, 18.50, 20.56, 22.84, 24.78, 28.21, 31.36, 31.81, 32.36, 32.63, 33.69, 35.43, 36.01, 38.46, 38.78, 46.48, 49.63, 53.34, 62.21, 79.36, 83.65, 85.76, 123.52, 171.66, 199.74. IR (neat): 3386, 2934, 2858, 1658, 1614, 1449, 1434, 1379, 1357, 1330, 1273, 1232, 1188, 1128, 1067, 1052, 1023, 954, 867, 698, 676, 571, 514, 462, 437, 413 cm^{-1}. HRMS (ESI) calcd. for $C_{26}H_{39}O_3$ $[M+H]^+$: 399.2894, found 399.2894.



13

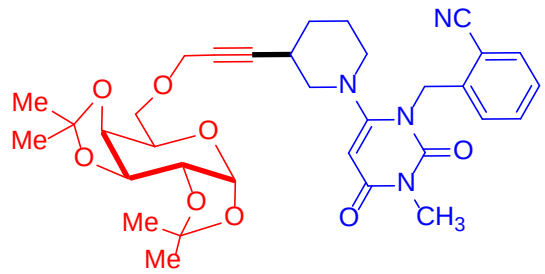
(8*R*,9*S*,13*S*,14*S*)-3-(7-Hydroxyhept-1-yn-1-yl)-13-methyl-6,7,8,9,11,12,13,14,15,16-decahydro-17*H*-cyclopenta[*a*]phenanthren-17-one (13). Following **General procedure C**, 0.3 mmol scale, $NiCl_2·6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(5-hydroxypentyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1l** (0.3 mmol, 144.4 mg), (8*R*,9*S*,13*S*,14*S*)-3-ethynyl-13-methyl-6,7,8,9,11,12,13,14,15,16-decahydro-17*H*-cyclopenta[*a*]phenanthren-17-one **S13** (0.45 mmol, 125.3 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 °C for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with ethyl acetate. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate: dichloromethane = 5:1:3) afforded the title product in 91% yield (99.5 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.89 (s, 3H), 1.34-1.66 (m, 12H), 1.91-2.17 (m, 5H), 2.21-2.26 (m, 1H), 2.36-2.41 (m, 3H), 2.49 (dd, *J* = 8.8, 18.8 Hz, 1H), 2.85 (dd, *J* = 4.0, 8.8 Hz, 2H), 3.65 (t, *J* = 6.4 Hz, 2H), 7.12-7.19 (m, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 13.68, 19.25, 21.42, 24.95, 25.43, 26.21, 28.45, 28.94, 31.38, 32.14, 35.71, 37.83, 44.19, 47.81, 50.31, 62.58, 80.56, 89.23, 121.16, 125.10, 128.72, 131.84, 136.26, 139.26, 220.86. IR (neat): 3482,

2933, 2858, 1721, 1495, 1466, 1452, 1402, 1261, 1085, 1069, 1045, 1009, 963, 896, 823, 781, 578, 519, 498, 471, 441 cm^{-1}. HRMS (ESI) calcd. for $C_{25}H_{32}NaO_2$ $[M+Na]^+$: 387.2295, found 387.2294.



14

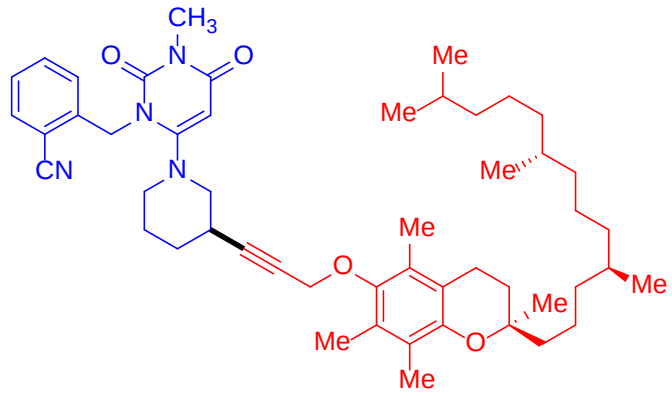
8-(((*R*)-2,5,7,8-Tetramethyl-2-((4*R*,8*R*)-4,8,12-trimethyltridecyl)chroman-6-yl)oxy)oct-6-yn-1-ol (14). Following **General procedure C**, 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(5-hydroxypentyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1l** (0.3 mmol, 144.4 mg), (*R*)-2,5,7,8-tetramethyl-6-(prop-2-yn-1-yloxy)-2-((4*R*,8*R*)-4,8,12-trimethyltridecyl)chroma ne **S14** (0.45 mmol, 211.0 mg) and tetrahydrofuran (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was filtered through a short pad of silica gel and washed with ethyl acetate. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: acetone = 5:1) afforded the title product in 77% yield (128.8 mg) as a colorless oil. ^1H NMR (600 MHz, $CDCl_3$): δ 0.84-0.87 (m, 12H), 1.02-1.09 (m, 3H), 1.10-1.17 (m, 3H), 1.20-1.33 (m, 11H), 1.34-1.40 (m, 3H), 1.43-1.48 (m, 3H), 1.51-1.59 (m, 7H), 1.72-1.76 (m, 1H), 1.78-1.83 (m, 2H), 2.07 (s, 3H), 2.15 (s, 3H), 2.20 (s, 3H), 2.24-2.27 (m, 2H), 2.56 (t, *J* = 6.6 Hz, 2H), 3.62 (t, *J* = 6.6 Hz, 2H), 4.32 (t, *J* = 1.8 Hz, 2H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 11.72, 12.13, 12.99, 18.76, 19.59, 19.68, 20.58, 20.95, 22.56, 22.65, 23.78, 24.37, 24.73, 24.93, 27.90, 28.18, 31.19, 32.16, 32.62, 32.72, 37.22, 37.35, 37.38, 37.40, 39.30, 40.01, 61.08, 62.62, 74.77, 76.14, 86.79, 117.40, 122.76, 126.03, 127.98, 147.85, 147.99. IR (neat): 3364, 2926, 2863, 1458, 1412, 1376, 1365, 1332, 1251, 1157, 1085, 983, 925, 864, 736, 669, 611, 476, 431, 419, 406 cm^{-1}. HRMS (ESI) calcd. for $C_{37}H_{63}O_3$ $[M+H]^+$: 555.4772, found 555.4768.



15

2-((3-Methyl-2,4-dioxo-6-(3-(3-(((3a*R*,5*R*,5a*S*,8a*S*,8b*R*)-2,2,7,7-tetramethyltetrahydro-5*H*-bis([1,3]dioxolo)[4,5-*b*:4',5'-*d*]pyran-5-yl)methoxy)prop-1-yn-1-yl)piperidin-1-yl)-3,4-dihydropyrimidin-1(2*H*)-yl)methyl)benzonitrile (15). Following **General procedure D**, 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(1-(3-(2-cyanobenzyl)-1-methyl-2,6-dioxo-1,2,3,6-tetrahydropyrimidin-4-yl)piperidin-3-yl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **S7** (0.3 mmol, 215.3 mg), (3a*R*,5*R*,5a*S*,8a*S*,8b*R*)-2,2,7,7-tetramethyl-5-((prop-2-yn-1-yloxy)methyl)tetrahydro-5*H*-bis([1,3]dioxolo)[4,5-*b*:4',5'-*d*]pyran **S10** (0.45 mmol, 134.3 mg) and *N*, *N*-dimethylformamide (1.5 mL) were stirred at 80 ^{o}C for 24 h. Then the reaction mixture was extracted with ethyl acetate, washed with water and brine, and dried over anhydrous Na_2SO_4. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate: dichloromethane = 1:1:1) afforded the title product in 92% yield (171.5 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.25 (s, 3H), 1.27 (s, 3H), 1.37 (s, 3H), 1.46 (s, 3H), 1.52 (br, 2H), 1.76 (br, 1H), 1.85 (br, 1H), 2.59 (br, 1H), 2.69 (br, 2H), 2.84 (br, 1H), 2.96 (d, *J* = 10.4 Hz, 1H), 3.21 (s, 3H), 3.45-3.50 (m, 1H), 3.52-3.59 (m, 1H), 3.87 (t, *J* = 5.6 Hz, 1H), 3.96-4.05 (m, 2H), 4.16 (d, *J* = 7.6 Hz, 1H), 4.24 (dd, *J* = 2.4, 4.8 Hz, 1H), 4.52 (dd, *J* = 2.0, 7.6 Hz, 1H), 5.19-5.23 (m, 2H), 5.30 (s, 1H), 5.45 (d, *J* = 4.4 Hz, 1H), 7.09 (d, *J* = 7.6 Hz, 1H), 7.32 (t, *J* = 7.6 Hz, 1H), 7.50 (d, *J* = 7.6 Hz, 1H), 7.61 (d, *J* = 7.6 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 23.13, 24.25, 24.66, 25.75, 25.82, 27.63, 27.92, 29.68, 46.04, 51.68, 55.51, 58.47, 66.40, 68.21, 70.19, 70.37, 70.88, 77.87, 86.20, 90.22, 96.05, 108.28, 108.98, 110.64, 116.84, 126.47, 127.69, 132.88, 132.98, 140.45, 152.30, 159.37, 162.75. IR (neat): 2934, 2224, 1703, 1653, 1610, 1436, 1376, 1310, 1255, 1210, 1167, 1099, 1067, 1002, 955, 917, 889, 863, 806, 765, 730, 694, 650, 630, 607,

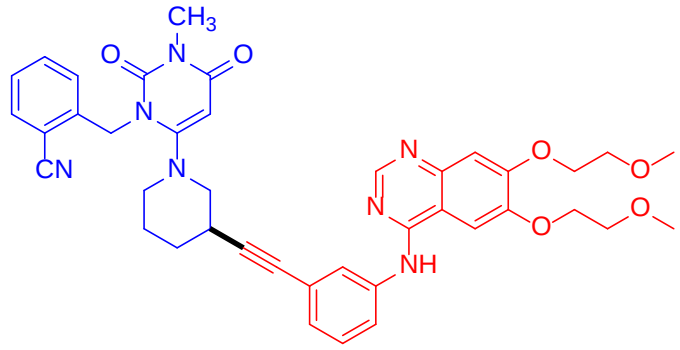
588, 559, 543, 514, 464, 430, 420 cm^{-1}. HRMS (ESI) calcd. for $C_{33}H_{41}N_4O_8$ $[M+H]^+$: 621.2919, found 621.2913.



16

2-((3-Methyl-2,4-dioxo-6-(3-(3-(((*R*)-2,5,7,8-tetramethyl-2-((4*R*,8*R*)-4,8,12-trimethyltridecyl)chroman-6-yl)oxy)prop-1-yn-1-yl)piperidin-1-yl)-3,4-dihydropyrimidin-1(2*H*)-yl)methyl)benzonitrile (16). Following **General procedure D**, 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(1-(3-(2-cyanobenzyl)-1-methyl-2,6-dioxo-1,2,3,6-tetrahydropyrimidin-4-yl)piperidin-3-yl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **S7** (0.3 mmol, 215.3 mg), (*R*)-2,5,7,8-tetramethyl-6-(prop-2-yn-1-yloxy)-2-((4*R*,8*R*)-4,8,12-trimethyltridecyl)chromane **S14** (0.45 mmol, 211.0 mg) and *N*, *N*-dimethylformamide (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was extracted with ethyl acetate, washed with water and brine, and dried over anhydrous Na_2SO_4. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate: dichloromethane = 3:1:1) afforded the title product in 90% yield (212.8 mg) as a white solid. ^1H NMR (400 MHz, $CDCl_3$): δ 0.84-0.87 (m, 12H), 1.03-1.46 (m, 21H), 1.47-1.60 (m, 5H), 1.72-1.84 (m, 3H), 1.90-1.93 (m, 1H), 2.06 (s, 3H), 2.09 (s, 3H), 2.13 (s, 3H), 2.55 (t, *J* = 6.4 Hz, 2H), 2.69-2.90 (m, 4H), 3.02-3.05 (m, 1H), 3.29 (s, 3H), 4.24 (s, 2H), 5.25-5.38 (m, 3H), 7.16 (d, *J* = 7.6 Hz, 1H), 7.33 (t, *J* = 7.6 Hz, 1H), 7.52 (t, *J* = 7.6 Hz, 1H), 7.62 (d, *J* = 7.6 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 11.61, 12.04, 12.89, 19.49, 19.58, 20.45, 20.81, 22.45, 22.55, 23.10, 23.63, 24.22, 24.58, 27.68, 27.76, 28.03, 29.64, 31.06, 32.47, 32.57, 37.07,

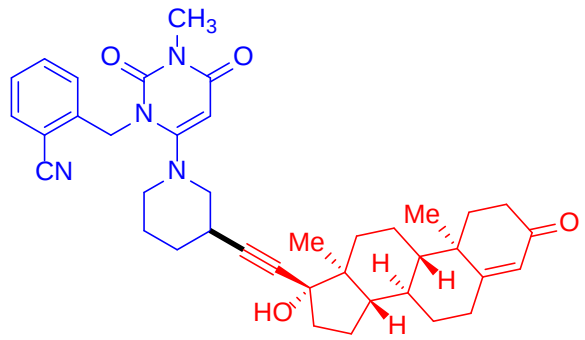
37.20, 37.23, 37.26, 39.16, 39.86, 46.12, 51.71, 55.57, 60.53, 74.63, 78.19, 86.16, 90.29, 110.78, 116.91, 117.25, 122.61, 125.78, 126.65, 127.65, 127.67, 132.88, 132.93, 140.55, 147.61, 147.89, 152.34, 159.46, 162.80. IR (neat): 2925, 2862, 2226, 1705, 1657, 1612, 1436, 1376, 1364, 1327, 1250, 1228, 1164, 1085, 997, 925, 862, 807, 764, 697, 657, 608, 588, 558, 522, 417 cm^{-1}. HRMS (ESI) calcd. for $C_{50}H_{71}N_4O_4$ $[M+H]^+$: 791.5470, found 791.5468.



17

2-((6-(3-((3-((6,7-Bis(2-methoxyethoxy)quinazolin-4-yl)amino)phenyl)ethynyl)piperidin-1-yl)-3-methyl-2,4-dioxo-3,4-dihydropyrimidin-1(2*H*)-yl)methyl)benzonitrile (17). Following **General procedure D**, 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(1-(3-(2-cyanobenzyl)-1-methyl-2,6-dioxo-1,2,3,6-tetrahydropyrimidin-4-yl)piperidin-3-yl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **S7** (0.3 mmol, 215.3 mg), *N*-(3-ethynylphenyl)-6,7-bis(2-methoxyethoxy)quinazolin-4-amine **S11** (0.45 mmol, 177.0 mg) and *N*, *N*-dimethylformamide (1.5 mL) were stirred at 80 ^oC for 24 h. Then the reaction mixture was extracted with ethyl acetate, washed with water and brine, and dried over anhydrous Na_2SO_4. Purification of the crude product by column chromatography on silica gel (eluent: dichloromethane: ethyl acetate: acetone = 1:2:1) afforded the title product in 85% yield (183.3 mg) as a yellow solid. ^1H NMR (400 MHz, $CDCl_3$): δ 1.60 (br, 1H), 1.70-1.95 (m, 3H), 2.89 (br, 3H), 3.02 (br, 2H), 3.27 (s, 3H), 3.39 (s, 3H), 3.42 (s, 3H), 3.79 (dt, *J* = 4.4, 16.0 Hz, 4H), 4.21-4.24 (m, 4H), 5.27 (d, *J* = 16.0 Hz, 1H), 5.37-5.46 (m, 2H), 6.98 (d, *J* = 7.6 Hz, 1H), 7.14 (d, *J* = 8.0 Hz, 1H), 7.20-7.24 (m, 2H), 7.29 (t, *J* = 7.6 Hz, 1H), 7.52 (t, *J* = 7.6 Hz, 1H), 7.57-7.61 (m, 3H), 7.94 (d, *J* = 7.2 Hz, 1H), 8.46 (br, 1H),

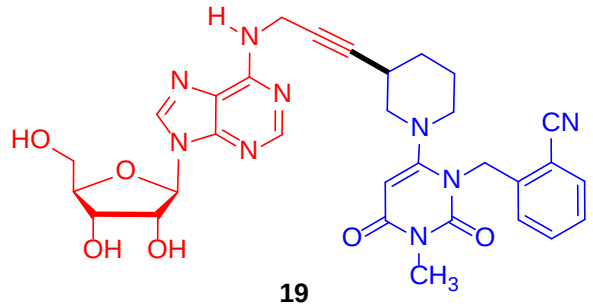
8.63 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 22.26, 27.65, 28.23, 29.29, 46.38, 51.56, 55.36, 58.95, 68.04, 68.48, 70.15, 70.43, 82.48, 89.33, 89.70, 102.28, 108.12, 109.26, 110.16, 117.18, 121.52, 123.05, 124.30, 126.25, 126.34, 127.61, 128.54, 132.91, 133.14, 138.95, 140.47, 146.95, 148.56, 152.20, 153.18, 154.00, 156.28, 159.62, 163.08 *(1 aliphatic carbon signal is not observed due to signal overlap)*. IR (neat): 2927, 2225, 1702, 1650, 1621, 1574, 1531, 1503, 1485, 1427, 1330, 1285, 1210, 1123, 1070, 1029, 926, 859, 786, 765, 687, 658, 587, 557, 520, 415 cm^{-1}. HRMS (ESI) calcd. for $C_{40}H_{42}N_7O_6$ $[M+H]^+$: 716.3191, found 716.3196.



18

2-((6-(3-(((8*R*,9*S*,10*R*,13*S*,14*S*,17*S*)-17-Hydroxy-10,13-dimethyl-3-oxo-2,3,6,7,8,9,10,11,12,13,14,15,16,17-tetradecahydro-1*H*-cyclopenta[*a*]phenanthren-17-yl)ethynyl)piperidin-1-yl)-3-methyl-2,4-dioxo-3,4-dihydropyrimidin-1(2*H*)-yl)methyl)benzonitrile (18). Following **General procedure D**, 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(1-(3-(2-cyanobenzyl)-1-methyl-2,6-dioxo-1,2,3,6-tetrahydropyrimidin-4-yl)piperidin-3-yl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **S7** (0.3 mmol, 215.3 mg), (8*R*,9*S*,10*R*,13*S*,14*S*,17*R*)-17-ethynyl-17-hydroxy-10,13-dimethyl-1,2,6,7,8,9,10,11,12,13,14,15,16,17-tetradecahydro-3*H*-cyclopenta[*a*]phenanthren-3-one **S12** (0.45 mmol, 140.6 mg) and *N*, *N*-dimethylformamide (1.5 mL) were stirred at 80 °C for 24 h. Then the reaction mixture was extracted with ethyl acetate, washed with water and brine, and dried over anhydrous Na_2SO_4. Purification of the crude product by column chromatography on silica gel (eluent: petroleum ether: ethyl acetate: dichloromethane = 1:2:1) afforded a mixture of diastereoisomers (d.r. 3:2) in 90% yield (171.5 mg) as a white solid. ^{1}H NMR

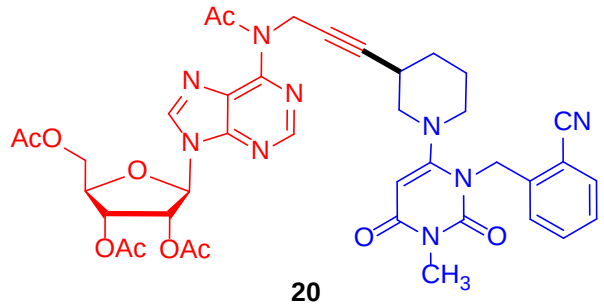
(400 MHz, DMSO-d_6): δ 0.70-0.71 (m, 3H), 0.76-0.87 (m, 2H), 1.05-1.13 (m, 4H), 1.21-1.32 (m, 3H), 1.44-1.54 (m, 7H), 1.63-1.80 (m, 5H), 1.92-1.99 (m, 1H), 2.13-2.24 (m, 2H), 2.34-2.44 (m, 2H), 2.63-2.77 (m, 2H), 2.87 (br, 2H), 2.94-3.03 (m, 1H), 3.06-3.08 (m, 3H), 4.99-5.01 (m, 1H), 5.09 (d, *J* = 6.0 Hz, 0.4H, minor), 5.12 (d, *J* = 6.0 Hz, 0.6H, major), 5.22 (d, *J* = 16.0 Hz, 0.4H, minor), 5.30 (d, *J* = 15.6 Hz, 0.6H, major), 5.36-5.37 (m, 1H), 5.62 (br, 1H), 7.26-7.29 (m, 1H), 7.44 (d, *J* = 7.6 Hz, 1H), 7.61-7.65 (m, 1H), 7.81 (d, *J* = 7.6 Hz, 1H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 12.64, 17.25, 20.55, 22.87, 22.96, 23.17, 27.77, 27.79, 28.01, 30.09, 31.35, 32.51, 32.59, 33.77, 35.52, 36.03, 38.46, 38.47, 38.92, 46.38, 46.55, 46.57, 49.85, 49.88, 51.71, 51.77, 53.37, 53.41, 55.61, 55.69, 79.25, 85.50, 85.57, 85.68, 90.18, 110.52, 110.67, 117.03, 123.72, 123.76, 126.76, 126.81, 127.81, 127.83, 132.88, 132.91, 133.13, 133.15, 140.61, 140.66, 152.48, 152.54, 159.48, 159.51, 162.88, 170.97, 171.05, 199.32, 199.35. IR (neat): 3422, 2941, 2225, 1702, 1650, 1611, 1435, 1377, 1329, 1271, 1229, 1165, 1127, 1105, 1068, 1026, 947, 863, 806, 765, 732, 698, 608, 588, 556, 517, 416 cm^{-1}. HRMS (ESI) calcd. for $C_{39}H_{47}N_4O_4$ $[M+H]^+$: 635.3592, found 635.3592.



19

2-((6-(3-(3-((9-((2*R*,3*R*,4*S*,5*R*)-3,4-Dihydroxy-5-(hydroxymethyl)tetrahydrofuran-2-yl)-9*H*-purin-6-yl)amino)prop-1-yn-1-yl)piperidin-1-yl)-3-methyl-2,4-dioxo-3,4-dihydropyrimidin-1(2*H*)-yl)methyl)benzonitrile (19). Following **General procedure D**, 0.3 mmol scale, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(1-(3-(2-cyanobenzyl)-1-methyl-2,6-dioxo-1,2,3,6-tetrahydropyrimidin-4-yl)piperidin-3-yl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **S7** (0.3 mmol, 215.3 mg), (2*R*,3*S*,4*R*,5*R*)-2-(hydroxymethyl)-5-(6-(prop-2-yn-1-ylamino)-9*H*-purin-9-yl)tetrahydrofu

ran-3,4-diol **S19** (0.45 mmol, 137.4 mg) and *N*, *N*-dimethylformamide (1.5 mL) were stirred at 80 ^{o}C for 24 h. Then the reaction mixture was extracted with dichloromethane, washed with water and brine, and dried over anhydrous Na_2SO_4. Purification of the crude product by column chromatography on silica gel which was pretreated with triethylamine before loading the sample (eluent: dichloromethane: methanol = 15:1) afforded the title product in 51% yield (95.1 mg) as a white solid. ^{1}H NMR (600 MHz, $CDCl_3$): δ 1.51-1.56 (m, 2H), 1.80 (br, 2H), 2.65-2.79 (m, 4H), 2.97 (br, 1H), 3.23 (s, 3H), 3.72-3.73 (m, 1H), 3.90-3.92 (m, 1H), 4.30-4.45 (m, 5H), 4.98 (s, 1H), 5.21-5.31 (m, 4H), 5.86 (s, 1H), 6.71-6.74 (m, 2H), 7.14 (br, 1H), 7.32-7.33 (m, 1H), 7.50-7.51 (m, 1H), 7.60-7.62 (m, 1H), 7.90 (br, 1H), 8.17 (br, 1H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 22.95, 27.91, 28.00, 29.63, 30.35, 46.48, 51.88, 55.46, 63.07, 72.38, 73.78, 78.30, 83.50, 87.58, 90.10, 91.01, 110.56, 117.16, 120.75, 126.72, 127.85, 133.05, 133.22, 140.48, 140.53, 147.51, 152.17, 152.50, 153.99, 159.73, 163.29. IR (neat): 3293, 2925, 2857, 2226, 1700, 1638, 1609, 1512, 1440, 1376, 1334, 1301, 1228, 1178, 1106, 1084, 1035, 1005, 984, 863, 815, 795, 758, 733, 691, 647, 609, 588, 535, 519, 414 cm^{-1}. HRMS (ESI) calcd. for $C_{31}H_{34}N_9O_6$ $[M+H]^+$: 628.2627, found 628.2622.

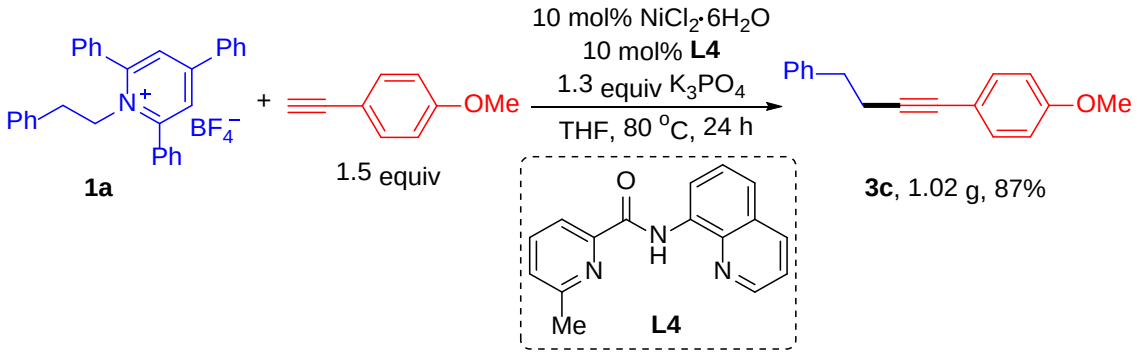


20

(2*R*,3*R*,4*R*,5*R*)-2-(Acetoxymethyl)-5-(6-(*N*-(3-(1-(3-(2-cyanobenzyl)-1-methyl-2,6-dioxo-1,2,3,6-tetrahydropyrimidin-4-yl)piperidin-3-yl)prop-2-yn-1-yl)acetamido)-9*H*-purin-9-yl)tetrahydrofuran-3,4-diyl diacetate (20). Following **General procedure D**, 0.3 mmol scale, $NiCl_2{\cdot}6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(1-(3-(2-cyanobenzyl)-1-methyl-2,6-dioxo-1,2,3,6-tetrahydropyrimidin-4-yl)piperidin-3-yl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **S7** (0.3 mmol, 215.3 mg),

(2*R*,3*R*,4*R*,5*R*)-2-(acetoxymethyl)-5-(6-(*N*-(prop-2-yn-1-yl)acetamido)-9*H*-purin-9-yl)tetra hydrofuran-3,4-diyl diacetate **S20** (0.45 mmol, 213.0 mg) and *N*, *N*-dimethylformamide (1.5 mL) were stirred at 80 ^{o}C for 24 h. Then the reaction mixture was extracted with dichloromethane, washed with water and brine, and dried over anhydrous Na_2SO_4. Purification of the crude product by column chromatography on silica gel (eluent: dichloromethane: ethanol = 100:1) afforded a mixture of diastereoisomers (d.r. 10:1) in 88% yield (210.0 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.34-1.36 (m, 1H), 1.43-1.49 (m, 1H), 1.62 (br, 1H), 1.74 (br, 1H), 2.08-2.17 (m, 9H), 2.30 (s, 3H), 2.46 (br, 1H), 2.65 (br, 2H), 2.86-2.89 (m, 2H), 3.27-3.29 (m, 3H), 4.38-4.51 (m, 3H), 4.88-4.97 (m, 2H), 5.19-5.36 (m, 3H), 5.70-5.71 (m, 1H), 5.97-5.99 (m, 1H), 6.17 (d, *J* = 4.8 Hz, 0.09H, minor), 6.24 (d, *J* = 4.4 Hz, 0.9H, major), 7.12-7.17 (m, 1H), 7.36 (t, *J* = 7.6 Hz, 1H), 7.54 (t, *J* = 7.6 Hz, 1H), 7.65 (d, *J* = 7.6 Hz, 1H), 7.94 (s, 0.09H, minor), 8.26 (s, 0.9H, major), 8.39 (s, 0.09H, minor), 8.80 (s, 0.9H, major). ^{13}C NMR (151 MHz, $CDCl_3$): δ 20.23, 20.31, 20.56, 22.90, 24.02, 27.61, 27.74, 29.52, 36.35, 45.96, 46.15 (minor), 51.60, 51.73 (minor), 55.29, 62.74, 62.89 (minor), 70.18, 70.39 (minor), 72.87, 79.93 (minor), 80.01, 83.31, 86.01 (minor), 86.77, 90.05, 110.52 (minor), 110.80, 116.97, 126.43 (minor), 126.58, 127.07 (minor), 127.09, 127.69, 132.85, 132.97, 138.36 (minor), 140.39, 140.46 (minor), 142.39, 151.91, 152.23, 152.31, 152.35, 159.33, 159.43 (minor), 162.80, 169.25, 169.39, 170.09, 170.36. IR (neat): 2925, 2861, 2226, 1745, 1703, 1655, 1611, 1433, 1364, 1329, 1227, 1164, 1085, 980, 946, 925, 862, 806, 764, 696, 657, 608, 587, 558, 522, 416 cm^{-1}. HRMS (ESI) calcd. for $C_{39}H_{41}N_9NaO_{10}$ $[M+Na]^+$: 818.2869, found 818.2867.

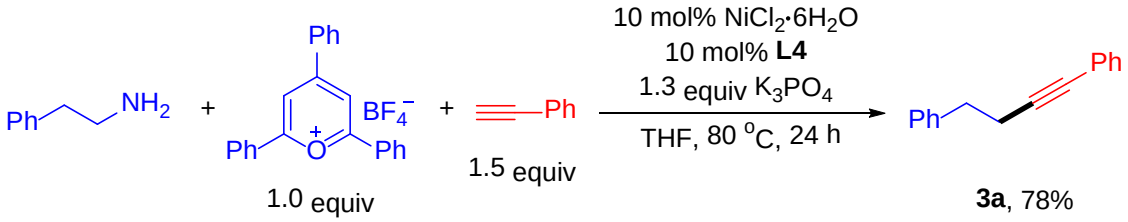
Gram scale study



To an oven-dried sealable Schlenk tube (100.0 mL) were added $NiCl_2·6H_2O$ (0.5

mmol, 118.8 mg), **L4** (0.5 mmol, 131.7 mg), anhydrous K_3PO_4 (6.5 mmol, 1.38 g) and phenethylpyridinium salt **1a** (5.0 mmol, 2.5 g) using standard Schlenk technique under nitrogen atmosphere. Subsequently, tetrahydrofuran (25.0 mL) was added via syringe followed by addition of 4-methoxyphenylacetylene (7.5 mmol, 991.2 mg). Then the Schlenk tube was securely sealed and immersed into an oil bath preheated at 80 ^{o}C. After stirring for 24 h, the reaction mixture was cooled to room temperature and filtered through a short pad of silica gel. Then the filter cake was washed with dichloromethane. The resulting solution was concentrated under vacuum and the residue was purified by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 20:1) to afford **3c** in 87% yield (1.02 g) as a colorless oil.

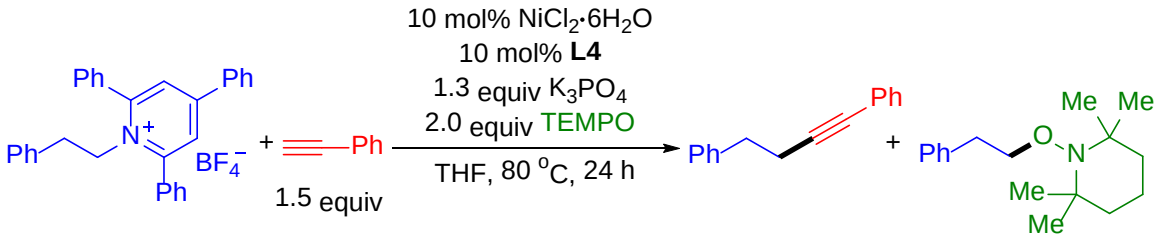
One-pot transformation



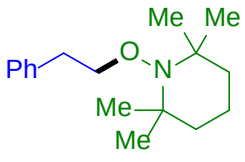
In a nitrogen-filled glovebox, $NiCl_2{\cdot}6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 2,4,6-triphenylpyrylium salt (0.3 mmol, 118.9 mg) and tetrahydrofuran (1.5 mL) were successively added to an oven-dried sealable Schlenk tube (10.0 mL). Subsequently, 2-phenylethylamine (0.3 mmol, 36.4 mg) was added via microliter syringe followed by addition of phenylacetylene (0.45 mmol, 46.0 mg). Then the tube was securely sealed and taken outside the glovebox. And it was immersed into an oil bath preheated at 80 ^{o}C. After stirring for 24 h, the reaction mixture was cooled to room temperature and filtered through a short pad of silica gel. Then the filter cake was washed with dichloromethane. The resulting solution was concentrated under vacuum and the residue was purified by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 100:1) to afford **3a** in 78% yield (48.1 mg) as a colorless oil.

Mechanistic studies:

Radical trap experiment



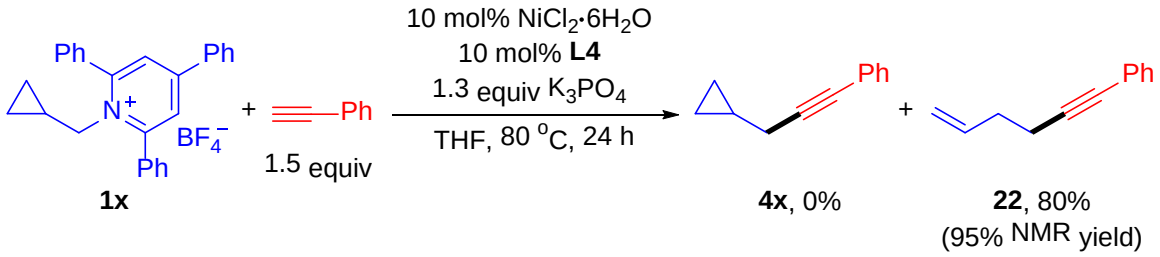
In a nitrogen-filled glovebox, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), phenethylpyridinium salt **1a** (0.3 mmol, 150.0 mg), 2,2,6,6-tetramethylpiperidine-*N*-oxyl (TEMPO, 0.6 mmol, 93.8 mg) and tetrahydrofuran (1.5 mL) were successively added to an oven-dried sealable Schlenk tube (10.0 mL) followed by addition of phenylacetylene (0.45 mmol, 46.0 mg) via microliter syringe. Then the tube was securely sealed and taken outside the glovebox. And it was immersed into an oil bath preheated at 80 °C. After stirring for 24 h, the reaction mixture was cooled to room temperature and filtered through a short pad of silica gel. Then the filter cake was washed with dichloromethane. The resulting solution was concentrated under vacuum and the residue was purified by preparative TLC on silica gel (eluent: petroleum ether: dichloromethane = 100:1) to afford TEMPO-trapped adduct **21** in 16% yield (12.5 mg) as a colorless oil, while the normal cross-coupling product **3a** was obtained in only 3% yield (1.7 mg).



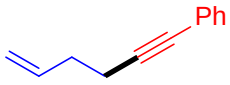
21

2,2,6,6-Tetramethyl-1-phenethoxypiperidine (21). ^{1}H NMR (600 MHz, $CDCl_3$): δ 1.07 (s, 12H), 1.26-1.31 (m, 1H), 1.41-1.42 (m, 4H), 1.53-1.54 (m, 1H), 2.82 (t, *J* = 6.6 Hz, 2H), 3.94 (t, *J* = 6.6 Hz, 2H), 7.18 (t, *J* = 7.2 Hz, 1H), 7.23 (d, *J* = 7.2 Hz, 2H), 7.27 (t, *J* = 7.2 Hz, 2H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 17.11, 20.11, 32.91, 35.37, 39.59, 59.68, 77.46, 125.89, 128.09, 129.10, 139.62. IR (neat): 2975, 2929, 2872, 1496, 1470, 1454, 1373, 1359, 1262, 1246, 1184, 1133, 1083, 1064, 1032, 994, 957, 750, 710, 697, 557, 512 cm^{-1}. HRMS (ESI) calcd. for $C_{17}H_{28}NO$ $[M+H]^+$: 262.2165, found 262.2166.

Radical clock experiment



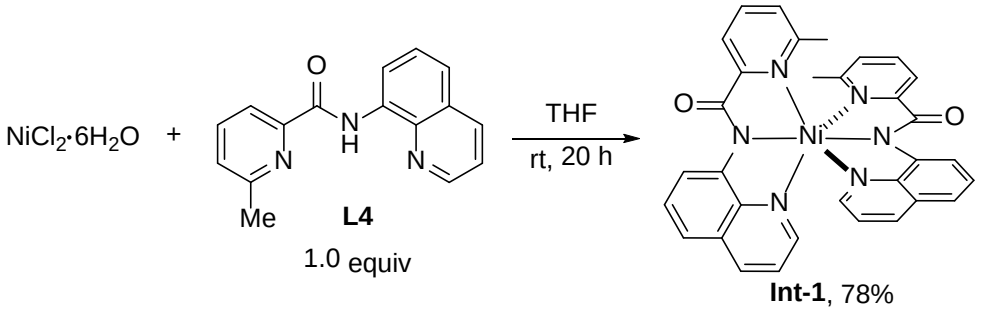
In a nitrogen-filled glovebox, $NiCl_2 \cdot 6H_2O$ (0.03 mmol, 7.1 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), 1-(cyclopropylmethyl)-2,4,6-triphenylpyridin-1-ium tetrafluoroborate **1x** (0.3 mmol, 134.8 mg) and tetrahydrofuran (1.5 mL) were successively added to an oven-dried sealable Schlenk tube (10.0 mL) followed by addition of phenylacetylene (0.45 mmol, 46.0 mg) via microliter syringe. Then the tube was securely sealed and taken outside the glovebox. And it was immersed into an oil bath preheated at 80 °C. After stirring for 24 h, the reaction mixture was cooled to room temperature and filtered through a short pad of silica gel. Then the filter cake was washed with dichloromethane. The resulting solution was concentrated under vacuum and the residue was purified by column chromatography on silica gel (eluent: petroleum ether) to afford the ring-opened product **22** in 80% yield (37.6 mg) as a colorless oil, and no cross-coupling product **4x** was observed. Due to the lower boiling point of product **22**, the NMR yield was determined to be 95% by ^{1}H NMR analysis of the crude mixture using 1,3,5-trimethoxybenzene (0.3 mmol, 50.5 mg) as an internal standard.



22

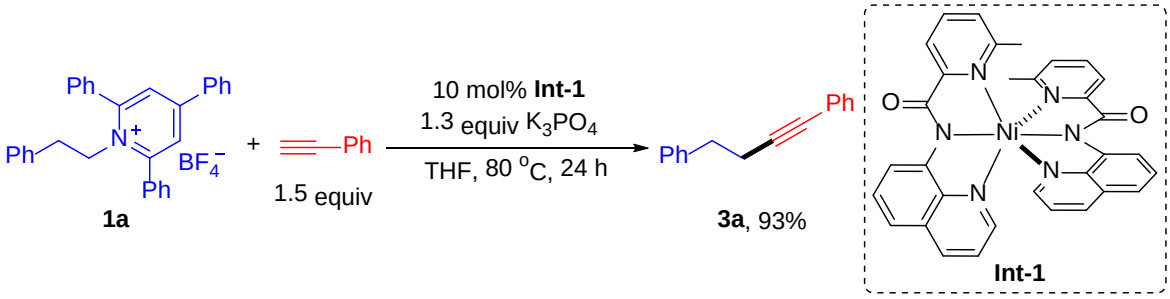
Hex-5-en-1-yn-1-ylbenzene (22). ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.33-2.38 (m, 2H), 2.49 (t, *J* = 7.2 Hz, 2H), 5.06 (d, *J* = 10.0 Hz, 1H), 5.12 (d, *J* = 17.2 Hz, 1H), 5.87-5.97 (m, 1H), 7.23-7.29 (m, 3H), 7.38-7.40 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 19.23, 32.93, 80.99, 89.47, 115.67, 123.88, 127.54, 128.15, 131.54, 136.93. IR (neat): 3080, 2925, 1642, 1599, 1490, 1442, 1333, 995, 914, 755, 691, 537, 451 cm^{-1}. HRMS (EI) calcd. for $C_{12}H_{12}$ $[M]^+$: 156.0934, found 156.0938.

Synthesis of Ni(II) complex Int-1



To an oven-dried round-bottomed flask (25.0 mL) were added $NiCl_2 \cdot 6H_2O$ (0.3 mmol, 71.3 mg), **L4** (0.3 mmol, 79.0 mg) and tetrahydrofuran (15.0 mL). Then the reaction mixture was stirred at room temperature for 20 h, and a light-brown suspension was obtained. Then it was filtrated and washed with tetrahydrofuran, the residue was dried under high vacuum at room temperature to afford **Int-1** in 78% yield (67.9 mg) as a yellow solid. ^{1}H NMR (400 MHz, CD_3OD): δ 2.70 (s, 6H), 7.57 (d, *J* = 7.6 Hz, 2H), 7.79-7.86 (m, 4H), 7.96-8.00 (m, 4H), 8.10 (d, *J* = 7.6 Hz, 2H), 8.50 (d, *J* = 7.6 Hz, 2H), 8.80 (d, *J* = 8.4 Hz, 2H), 9.03 (d, *J* = 4.0 Hz, 2H). IR (neat): 3186, 1638, 1580, 1561, 1500, 1463, 1428, 1409, 1392, 1319, 1300, 1255, 1050, 1008, 952, 821, 759, 704, 679, 617, 562, 500, 449 cm^{-1}. HRMS (ESI) calcd. for $C_{32}H_{25}N_6NiO_2$ $[M+H]^+$: 583.1387, found 583.1387.

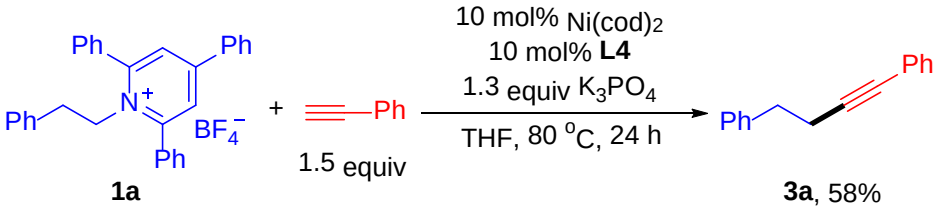
Ni(II) complex Int-1 catalyzed deaminative Sonogashira coupling of 1a



In a nitrogen-filled glovebox, **Int-1** (0.03 mmol, 17.5 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), phenethylpyridinium salt **1a** (0.3 mmol, 150.0 mg) and tetrahydrofuran (1.5 mL) were successively added to an oven-dried sealable Schlenk tube (10.0 mL) followed by addition of phenylacetylene (0.45 mmol, 46.0 mg) via microliter syringe. Then the tube was securely sealed and taken outside the glovebox. And it was immersed into an oil bath preheated at 80 °C. After stirring for 24 h, the reaction mixture was cooled to room

temperature and filtered through a short pad of silica gel. Then the filter cake was washed with dichloromethane. The resulting solution was concentrated under vacuum and the residue was purified by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 100:1) to afford **3a** in 93% yield (57.6 mg) as a colorless oil.

Ni(cod)$_2$ catalyzed deaminative Sonogashira coupling of 1a



In a nitrogen-filled glovebox, Ni(cod)$_2$ (0.03 mmol, 8.3 mg), **L4** (0.03 mmol, 7.9 mg), anhydrous K_3PO_4 (0.39 mmol, 82.8 mg), phenethylpyridinium salt **1a** (0.3 mmol, 150.0 mg) and tetrahydrofuran (1.5 mL) were successively added to an oven-dried sealable Schlenk tube (10.0 mL) followed by addition of phenylacetylene (0.45 mmol, 46.0 mg) via microliter syringe. Then the tube was securely sealed and taken outside the glovebox. And it was immersed into an oil bath preheated at 80 ^{o}C. After stirring for 24 h, the reaction mixture was cooled to room temperature and filtered through a short pad of silica gel. Then the filter cake was washed with dichloromethane. The resulting solution was concentrated under vacuum and the residue was purified by column chromatography on silica gel (eluent: petroleum ether: dichloromethane = 100:1) to afford **3a** in 58% yield (36.1 mg) as a colorless oil. *(Note: in this case, the reaction mixture turned out to be more complicated, and the competitive alkyne cyclotrimerization and/or oligomerization products catalyzed by low-valent nickel species was observed.)*

References:

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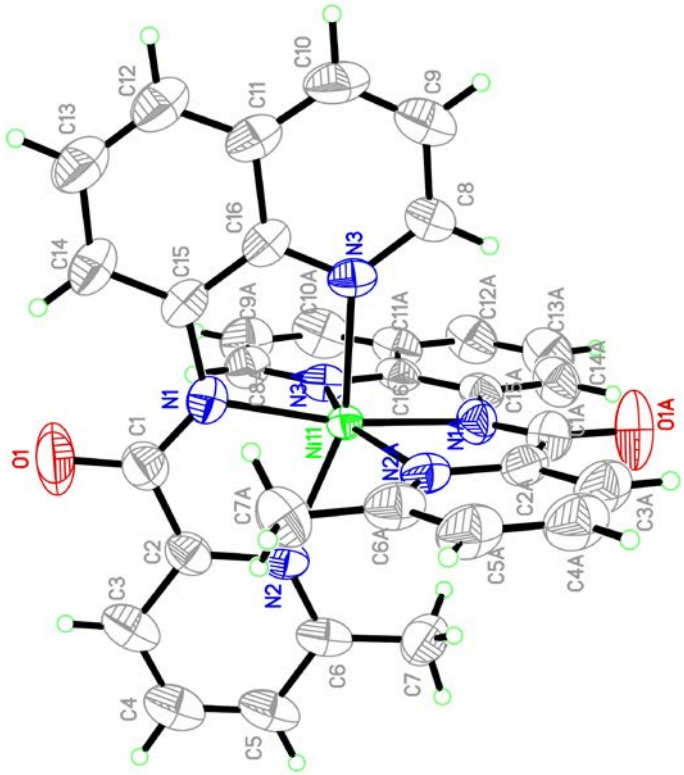
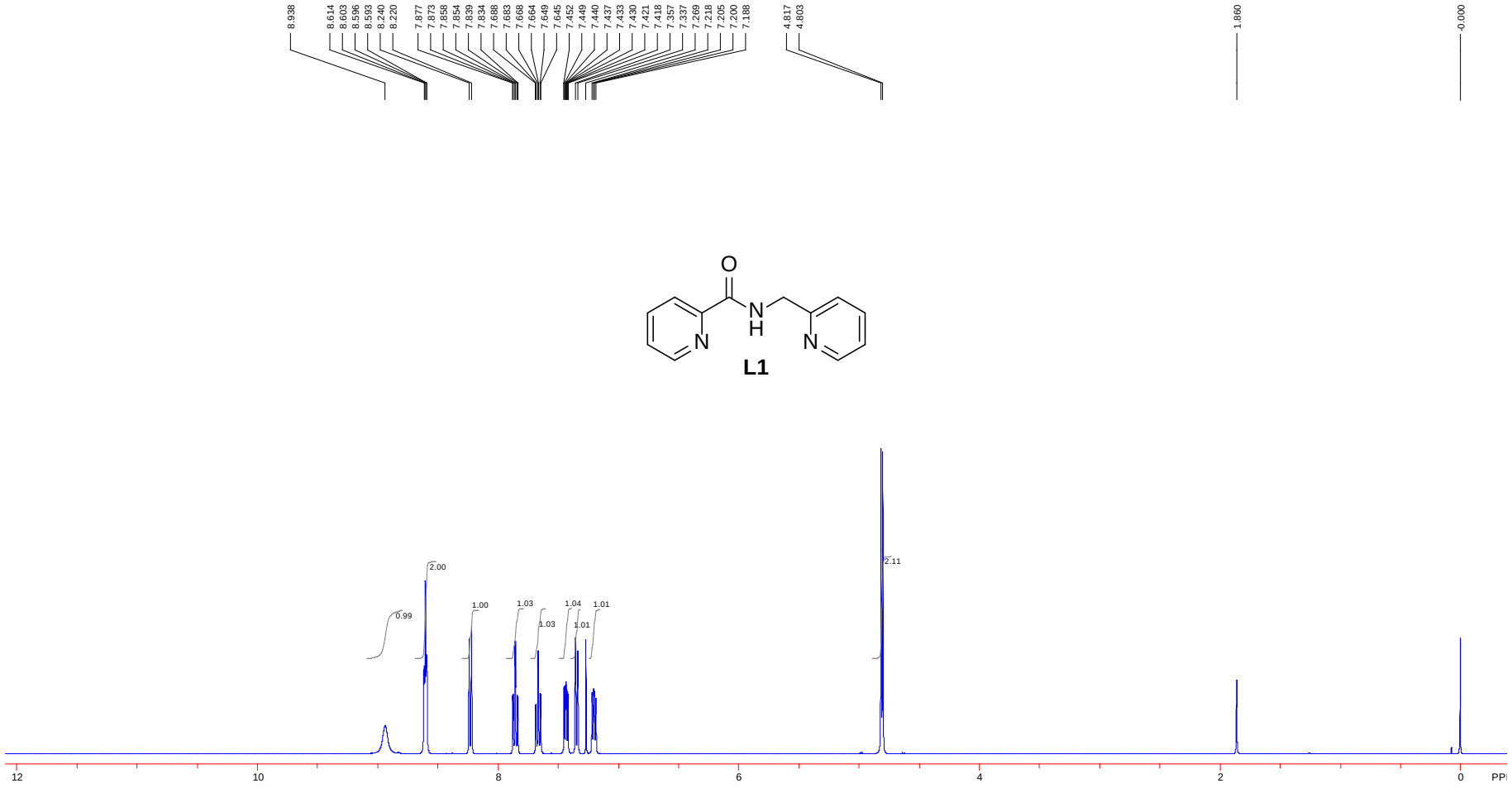


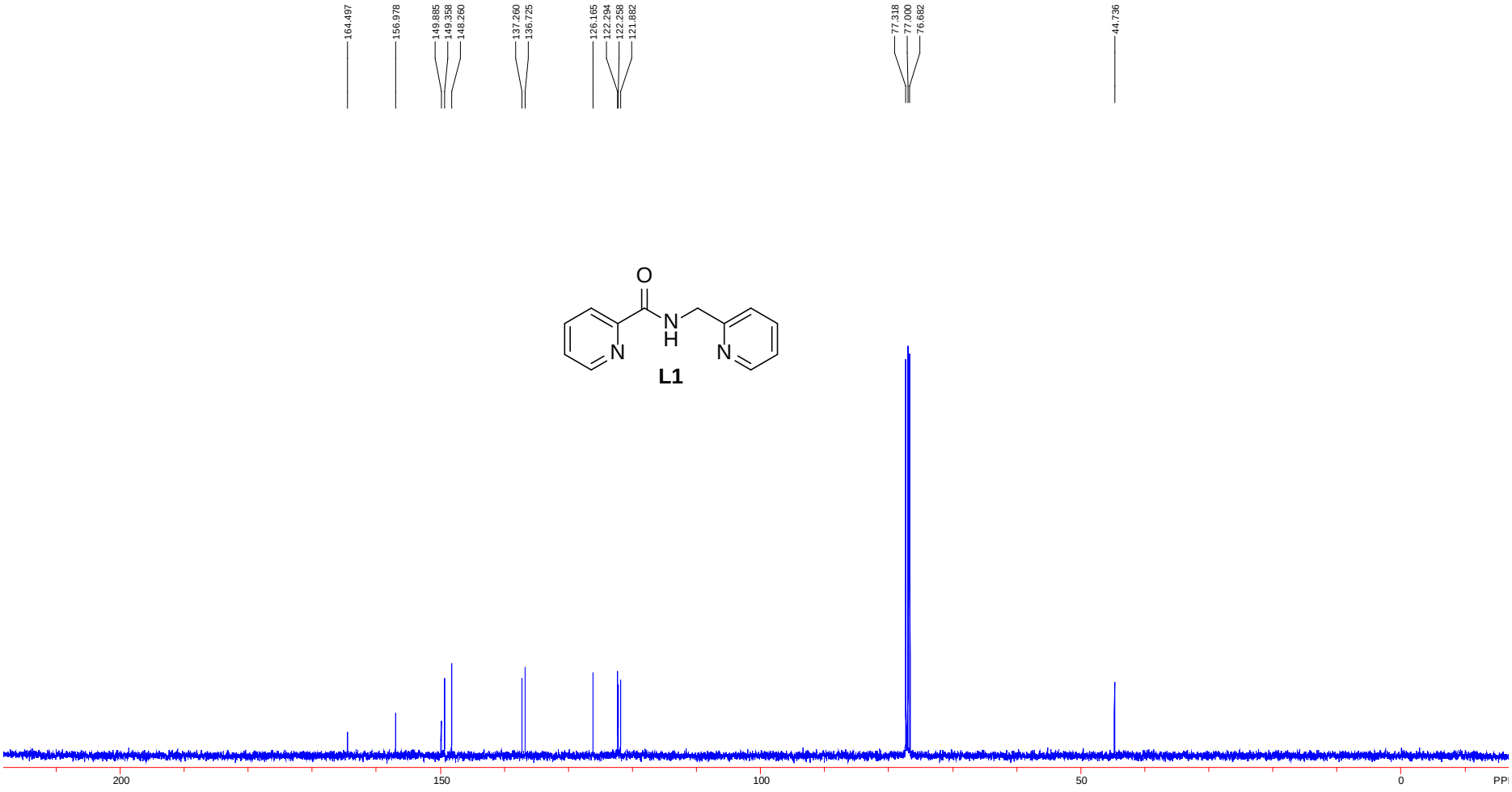
Figure S1. X-ray crystal structure of Ni(II) complex **Int-1**

NMR spectra of all new compounds

^{1}H NMR(400 MHz, $CDCl_3$)



^{13}C NMR(100 MHz, $CDCl_3$)



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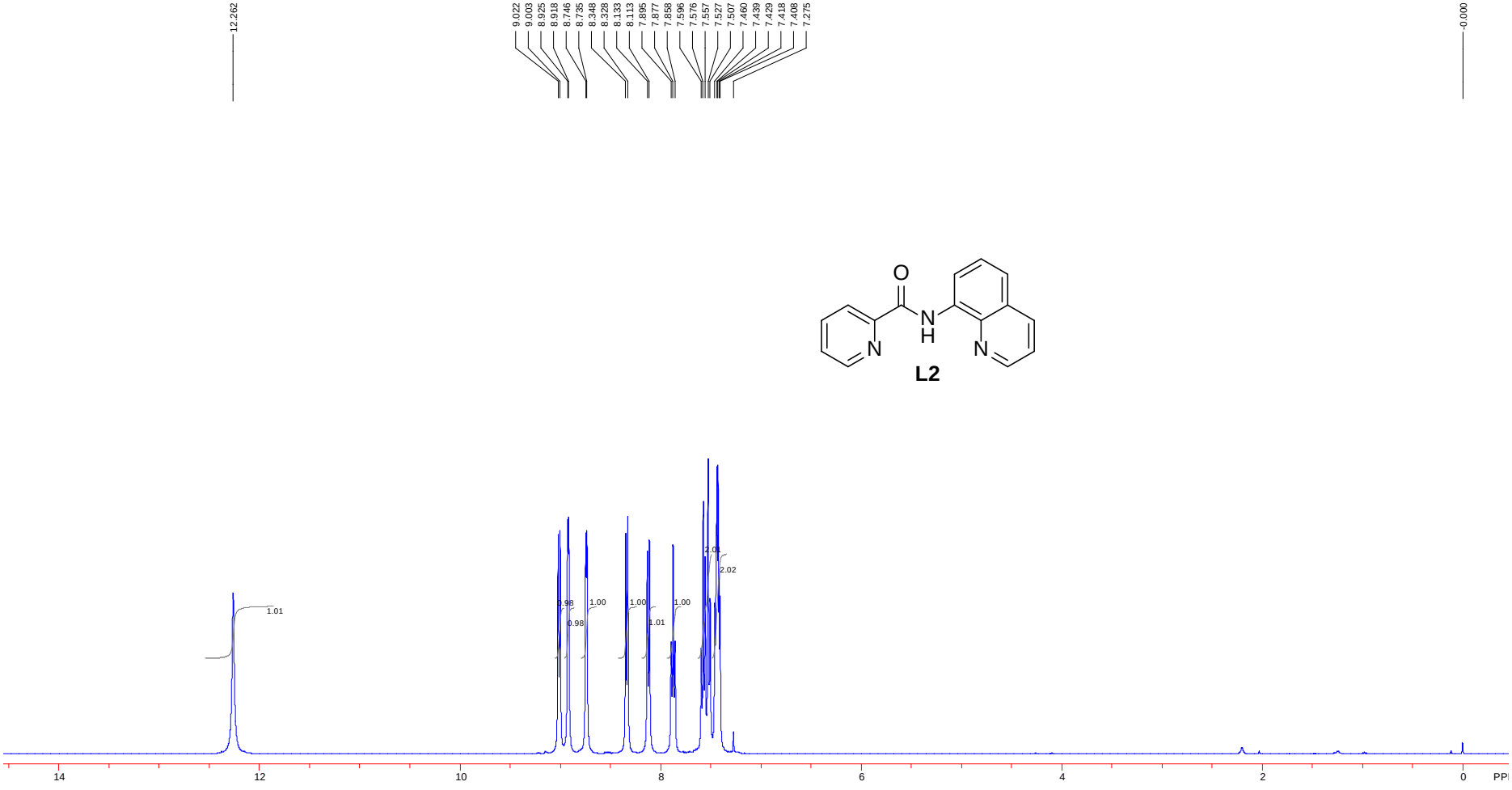

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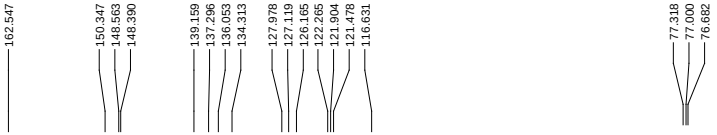
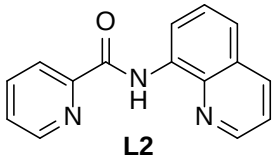
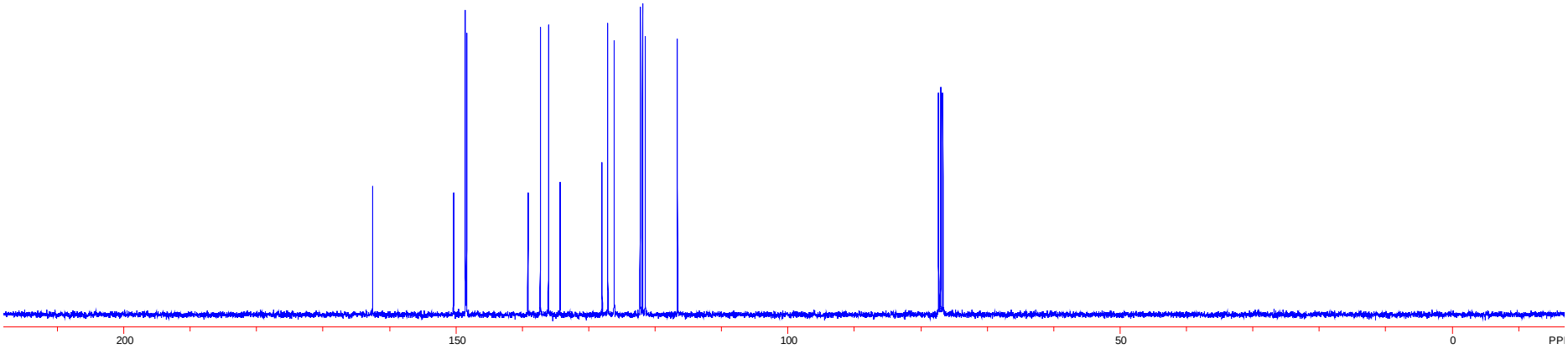




L2



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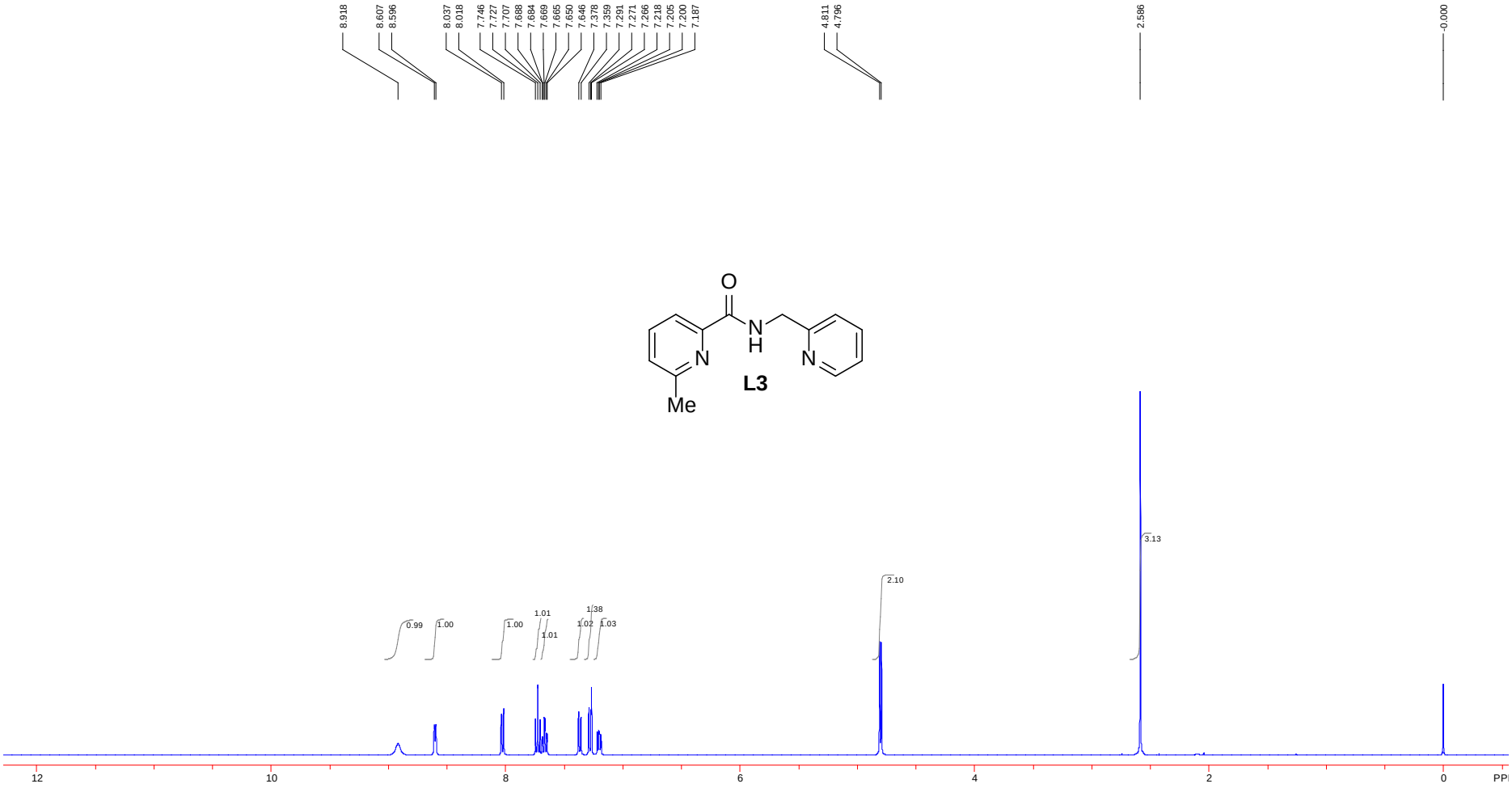

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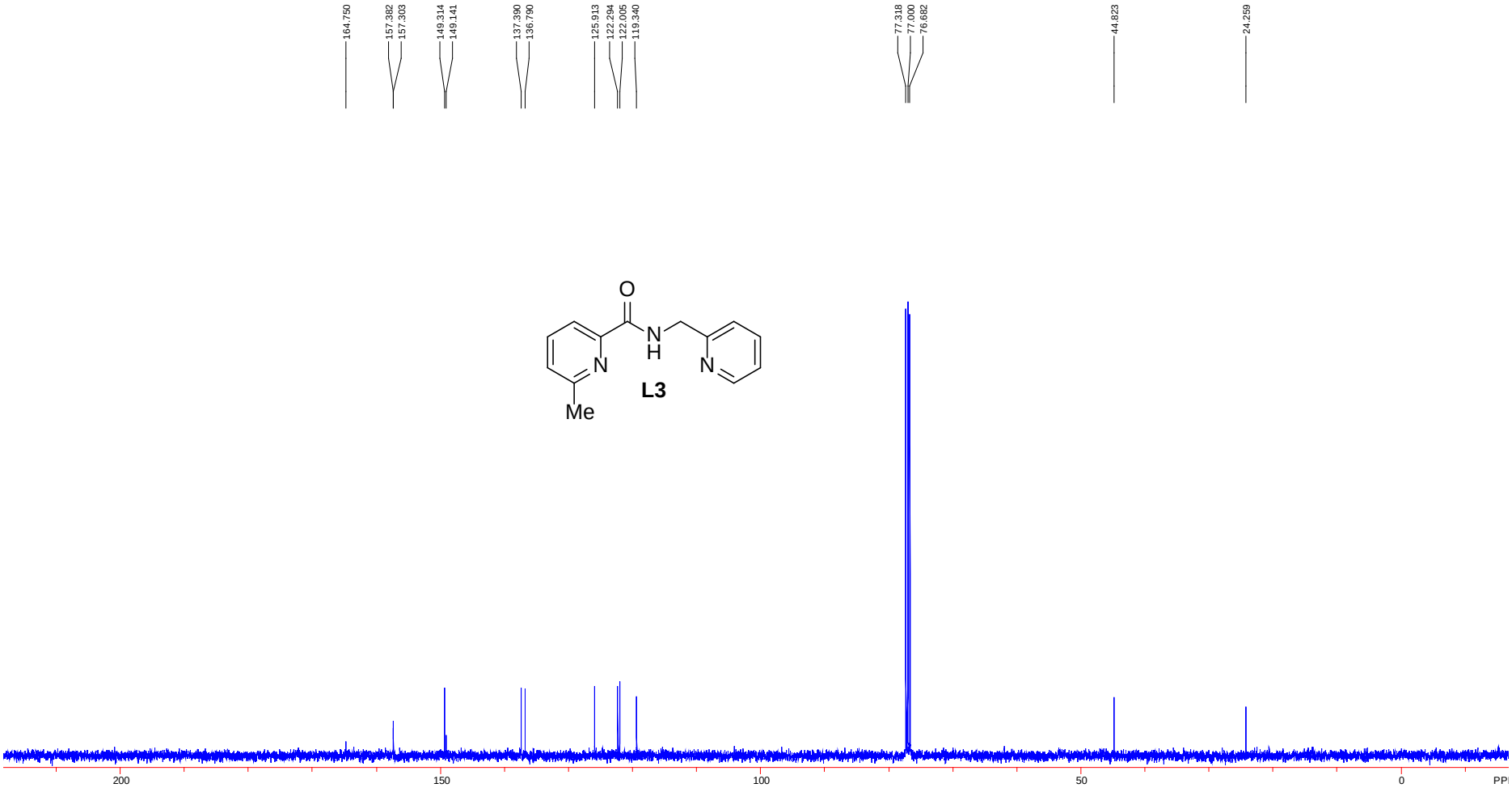
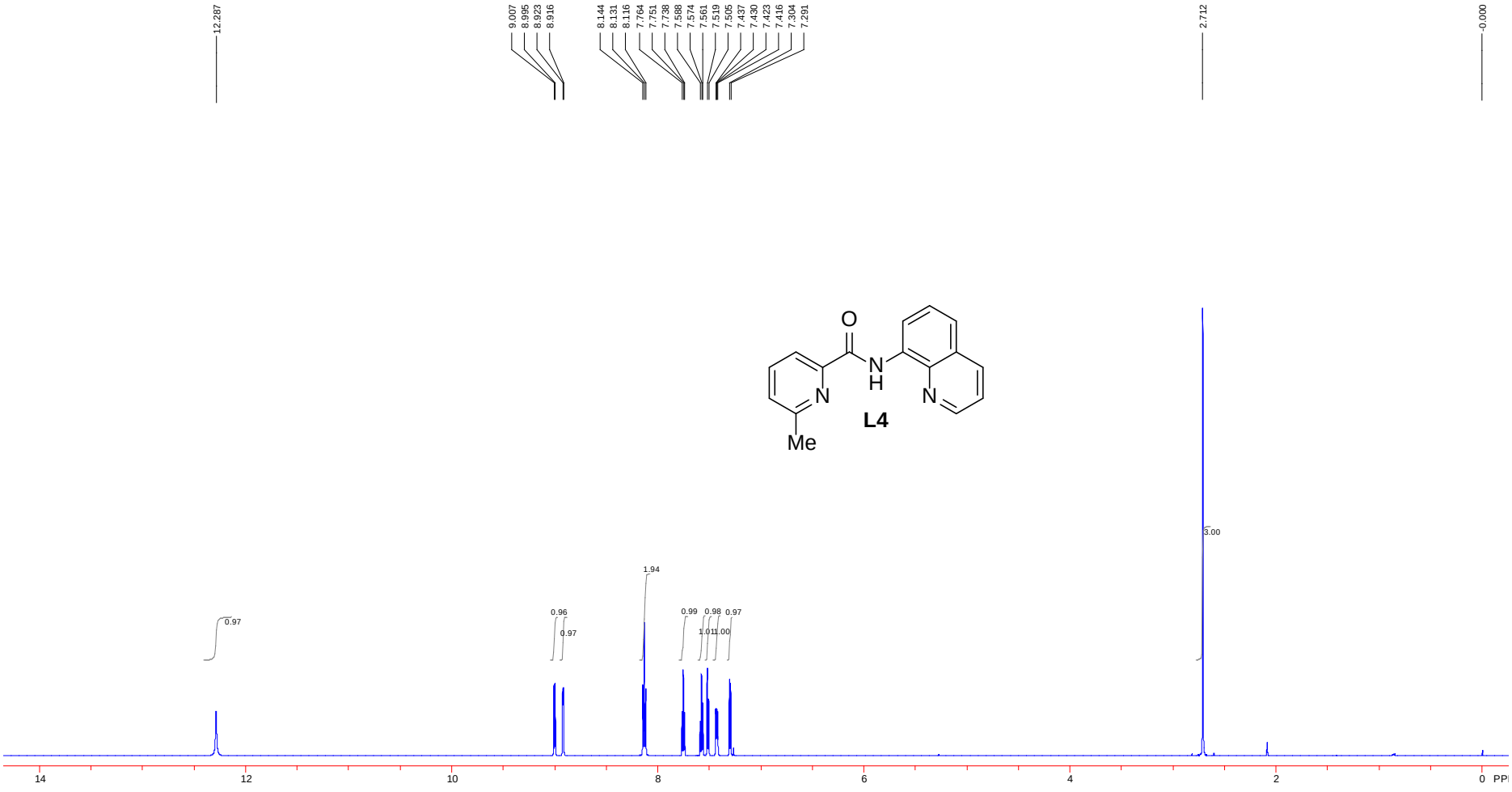
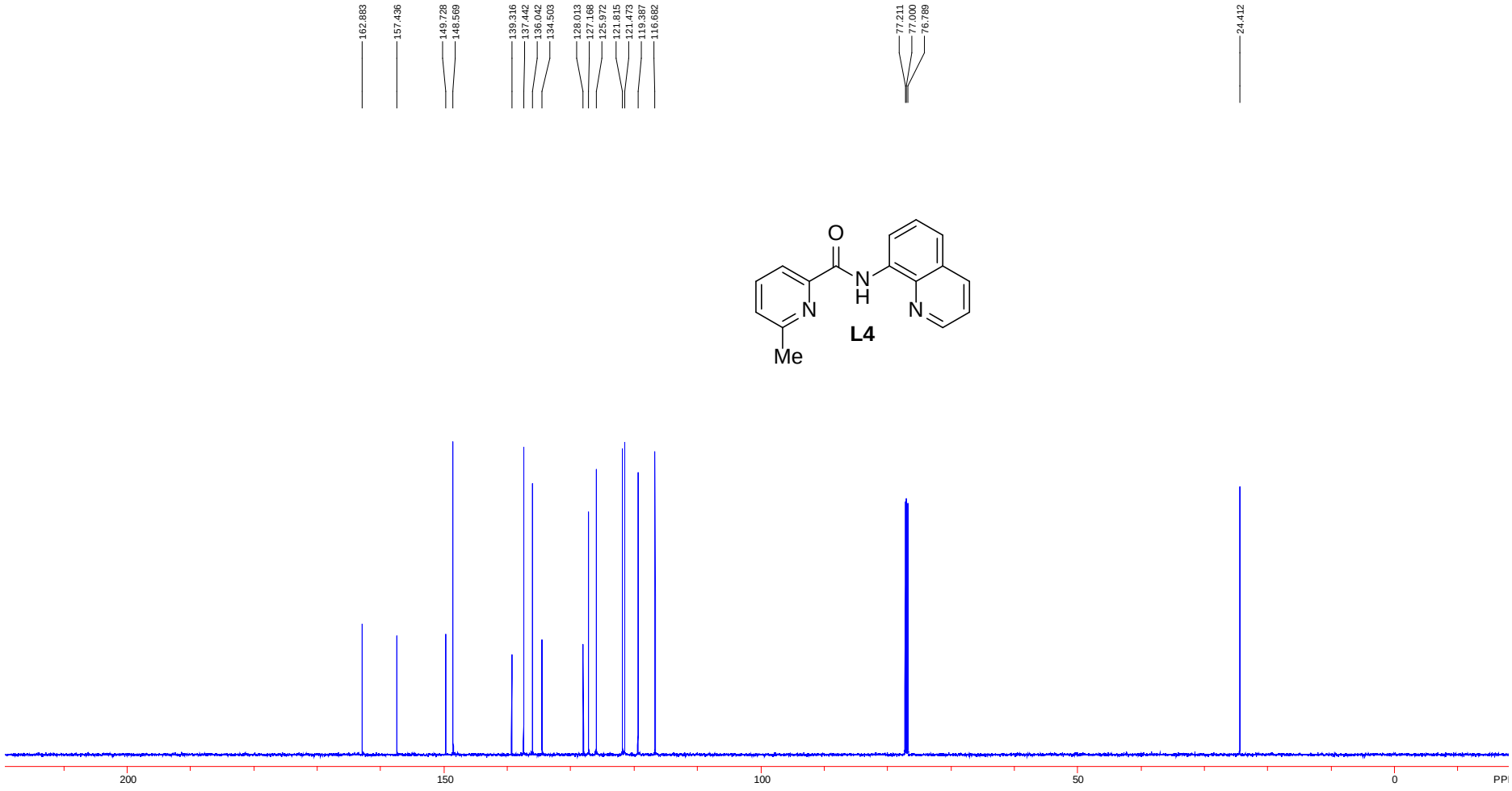


^{1}H NMR(600 MHz, $CDCl_3$)



^{13}C NMR(151 MHz, $CDCl_3$)



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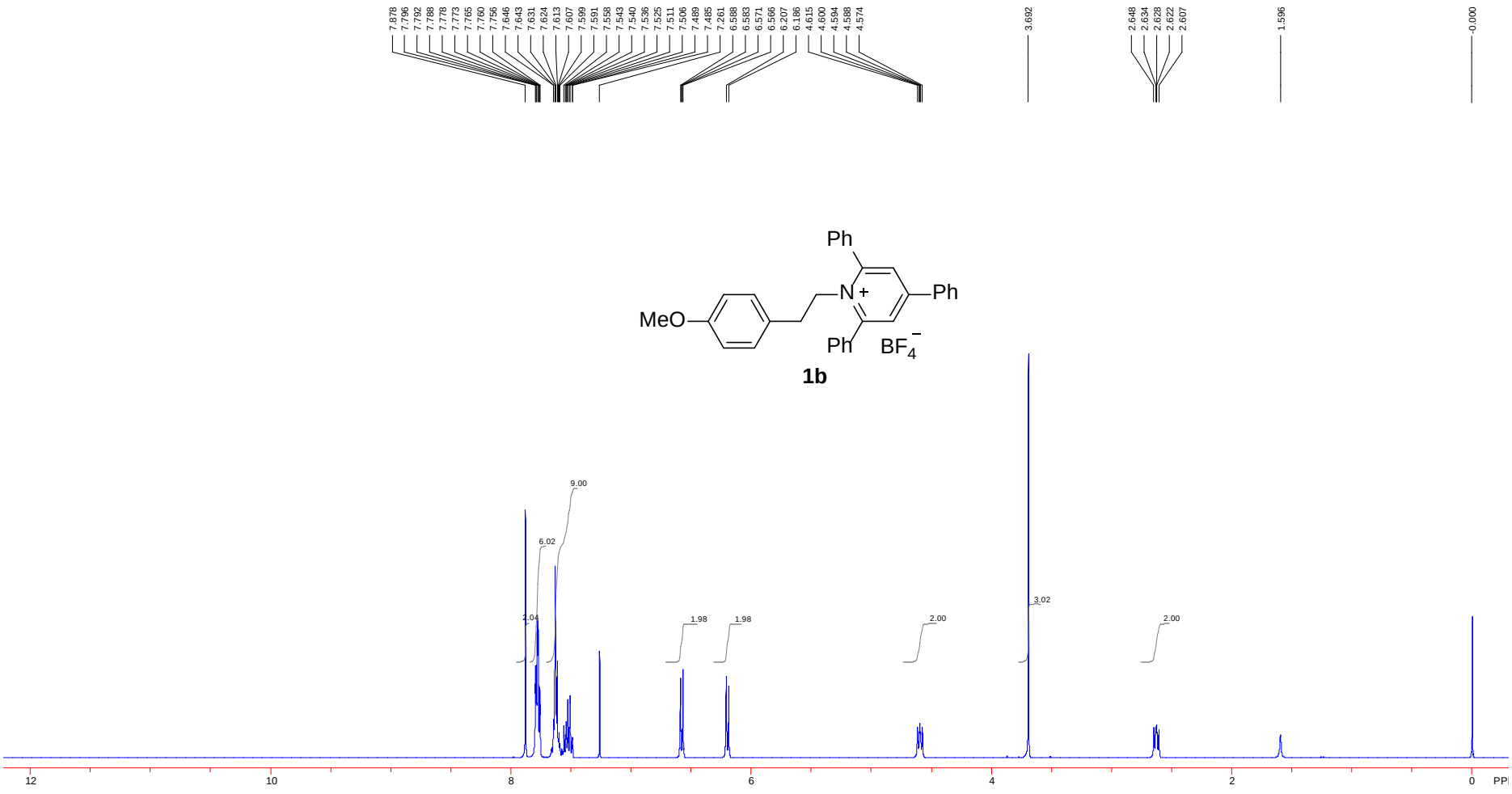
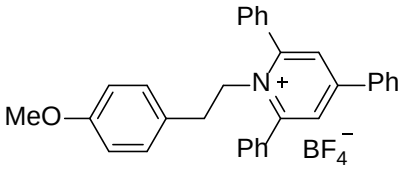


^{13}C NMR(100 MHz, $CDCl_3$)



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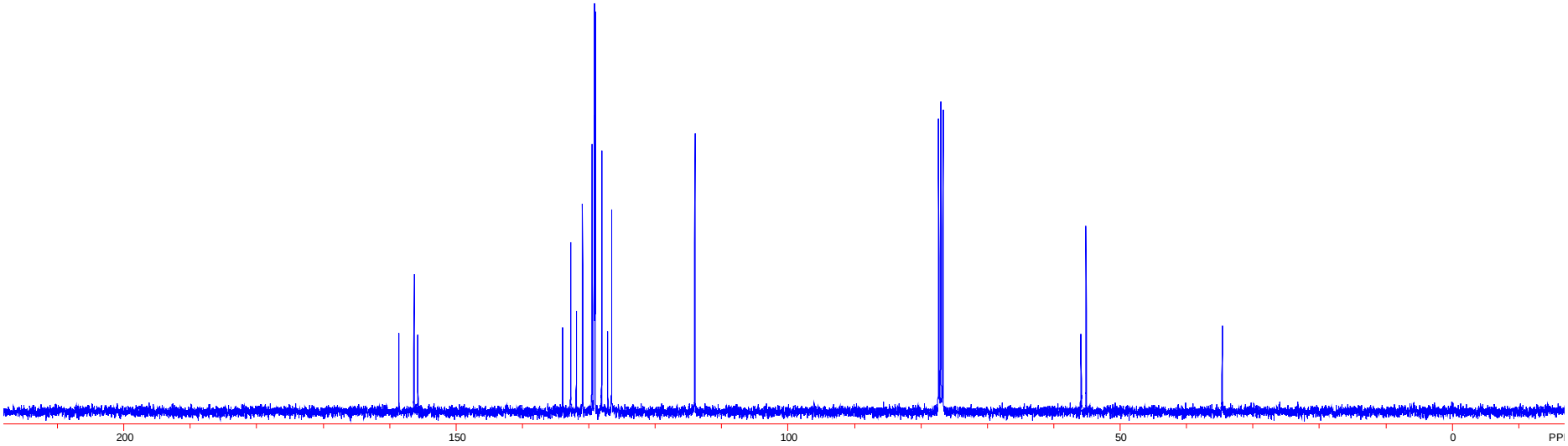
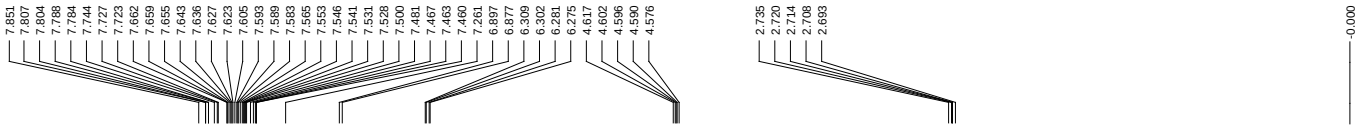
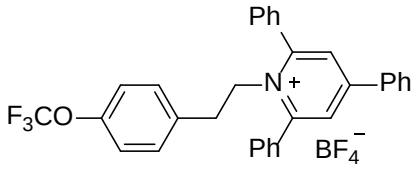


^{1}H NMR(400 MHz, $CDCl_3$)





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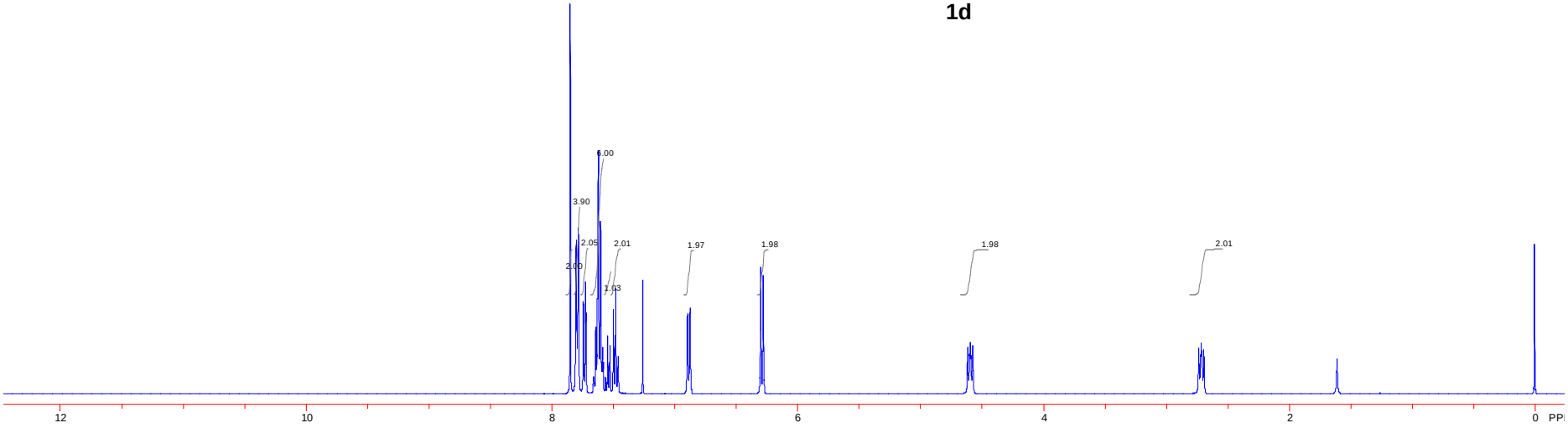
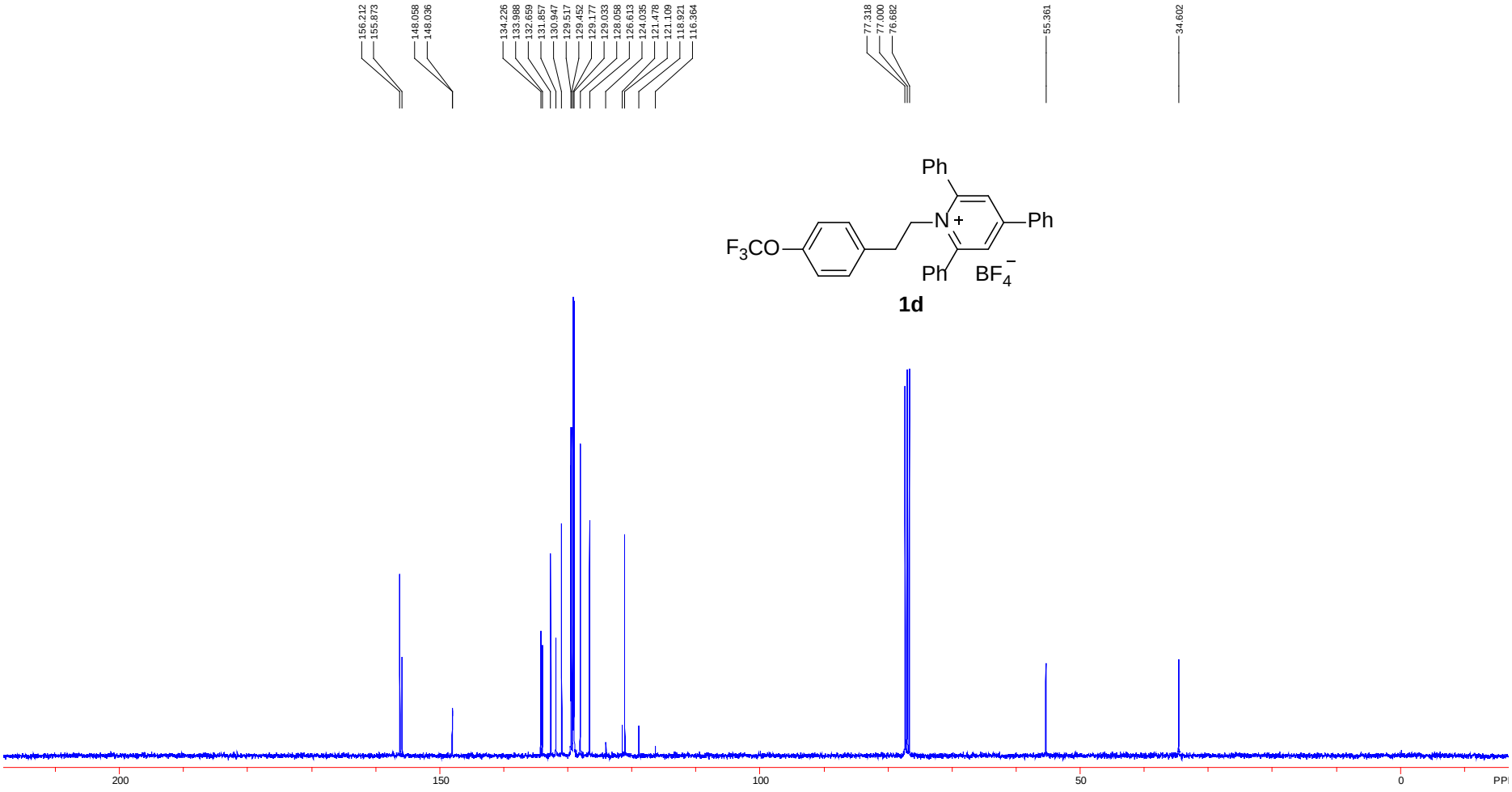
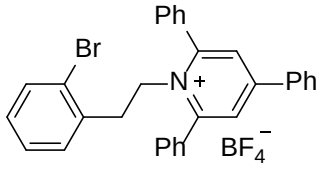


^{13}C NMR(100 MHz, $CDCl_3$)



^{1}H NMR(600 MHz, $CDCl_3$)



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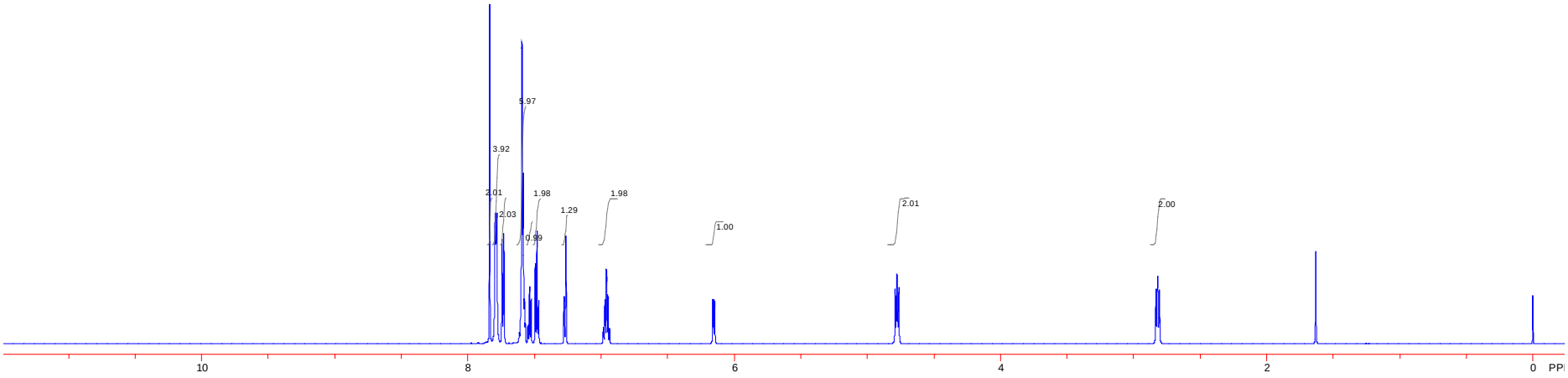
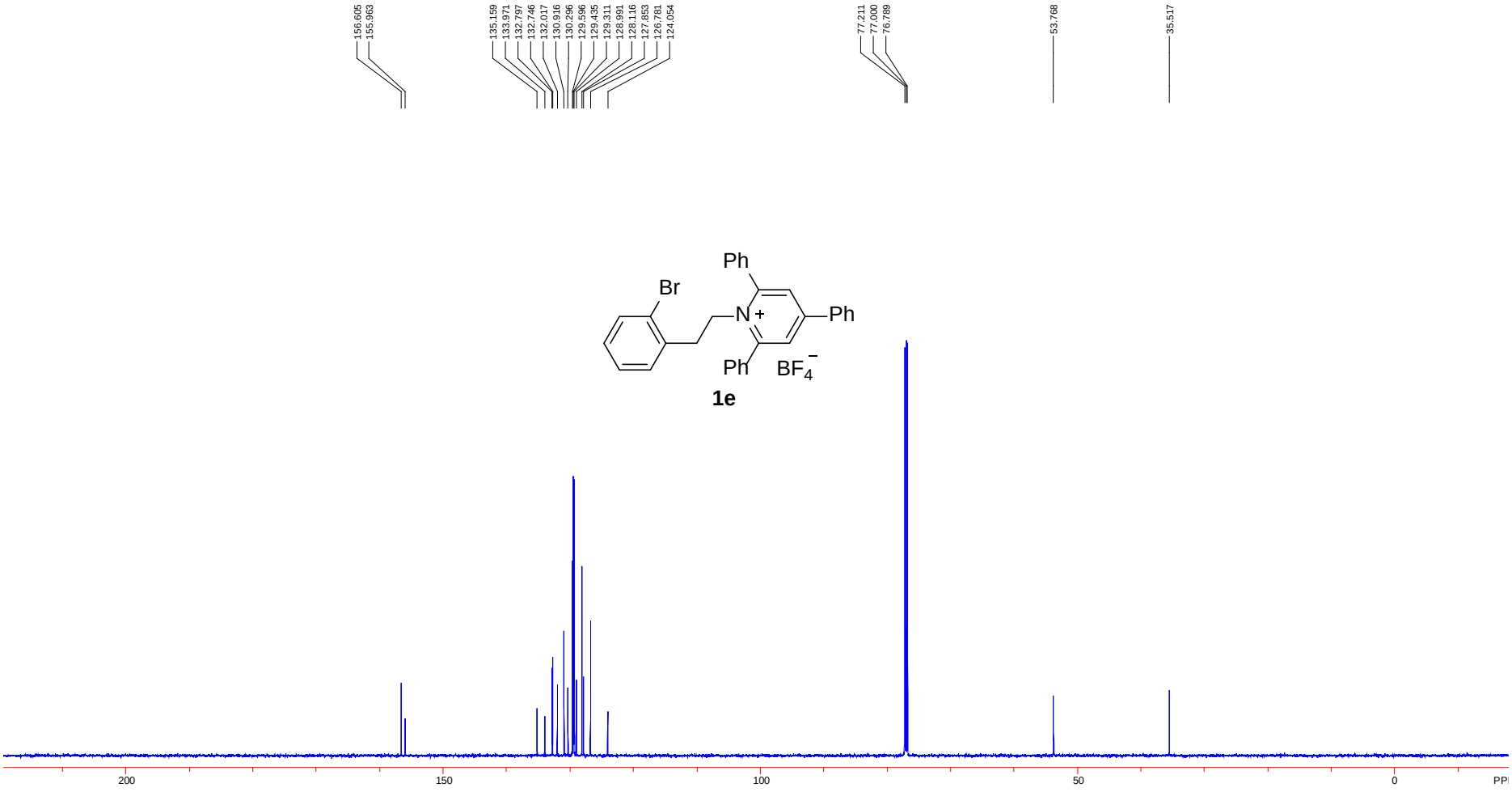


^{13}C NMR(151 MHz, $CDCl_3$)



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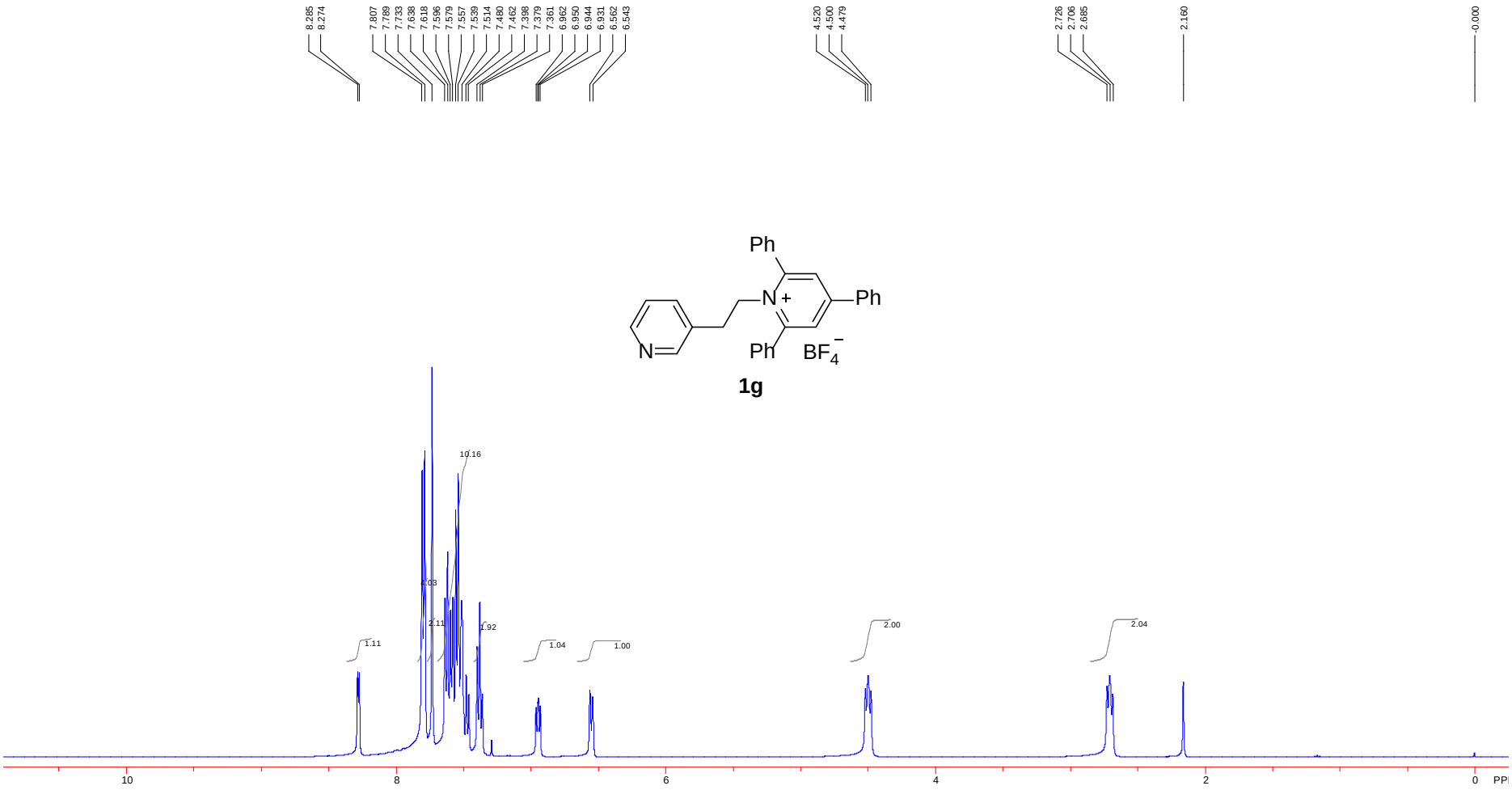

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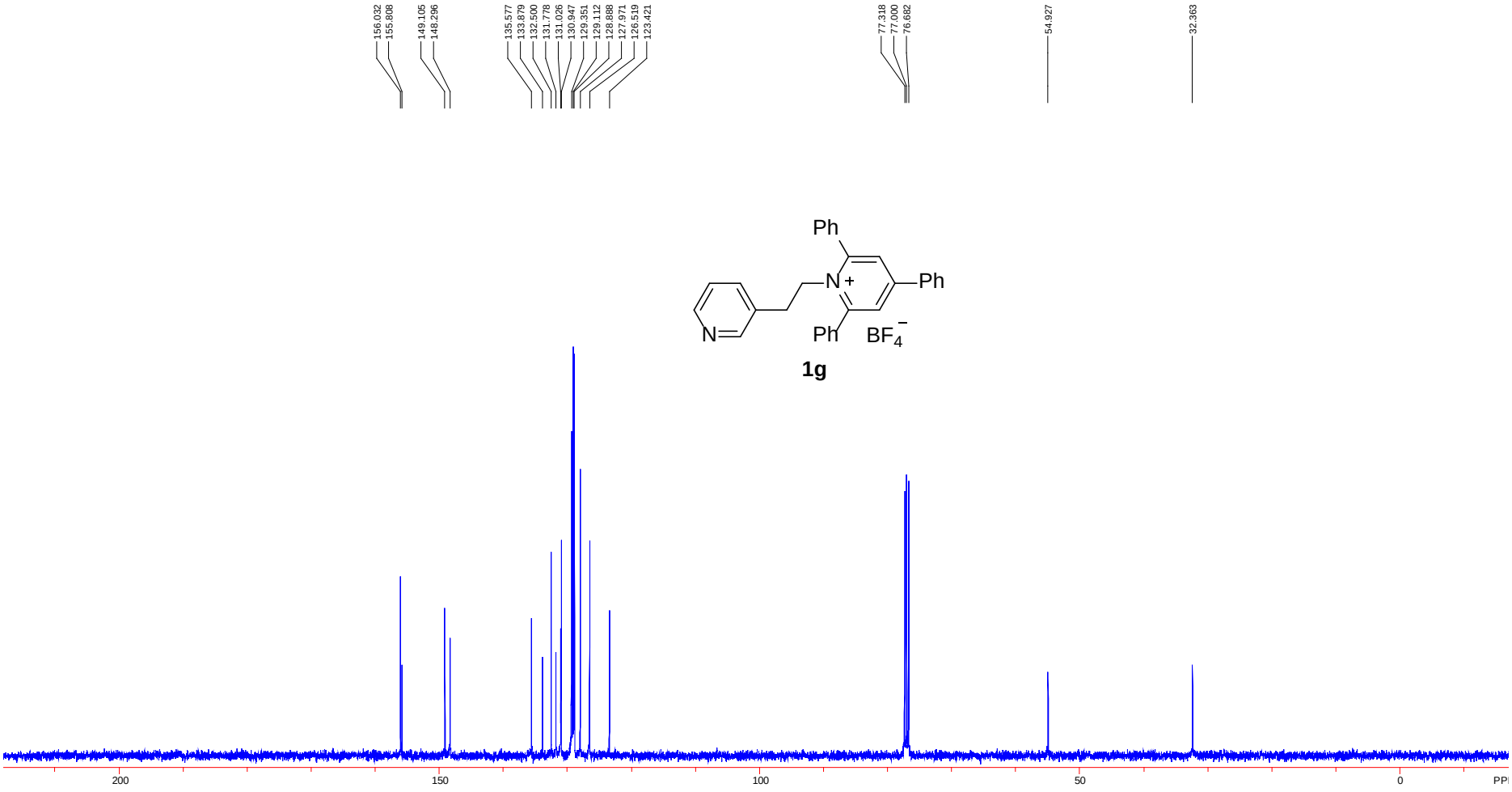

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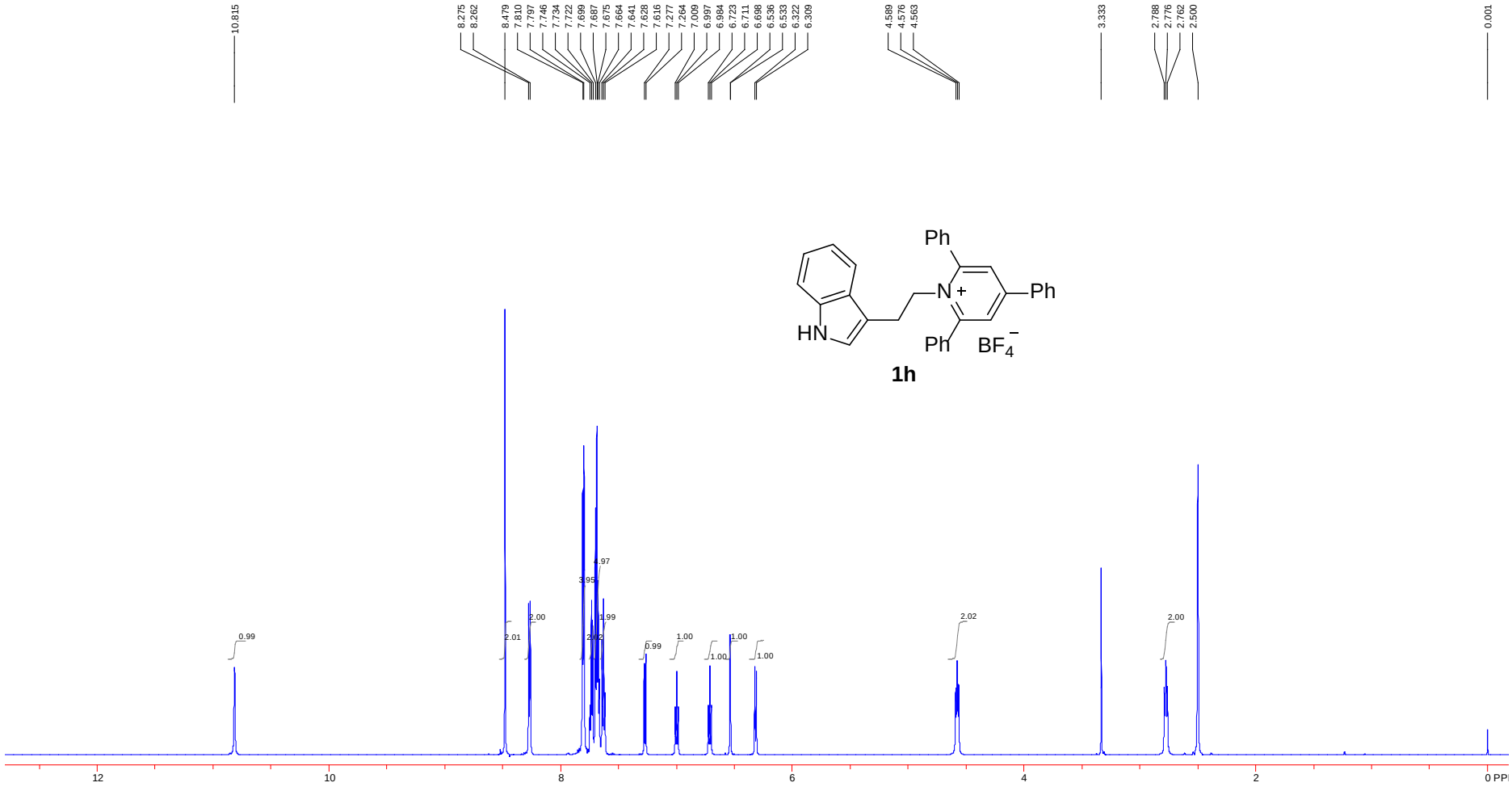
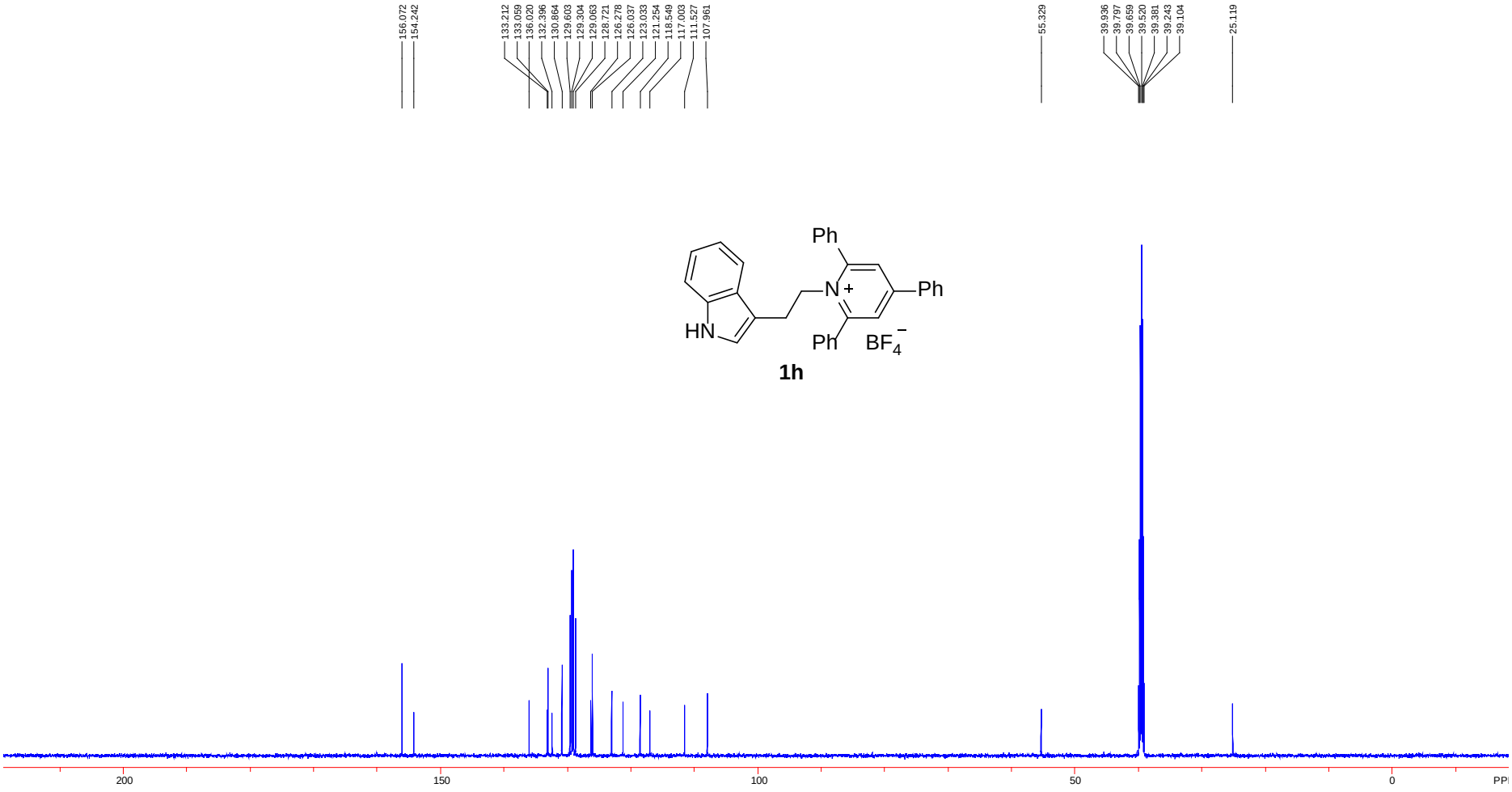


^{13}C NMR (151 MHz, DMSO-d_6)



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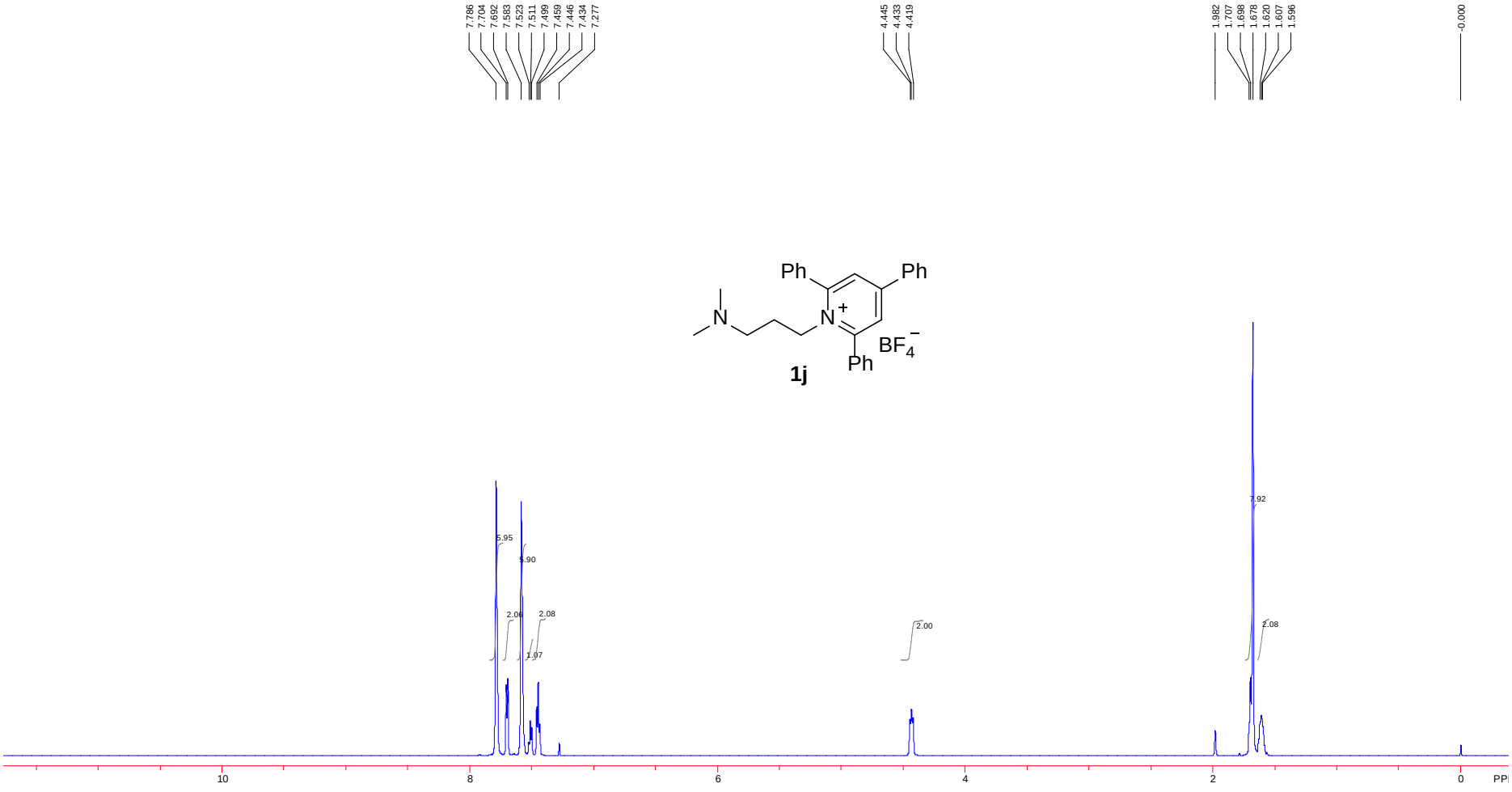

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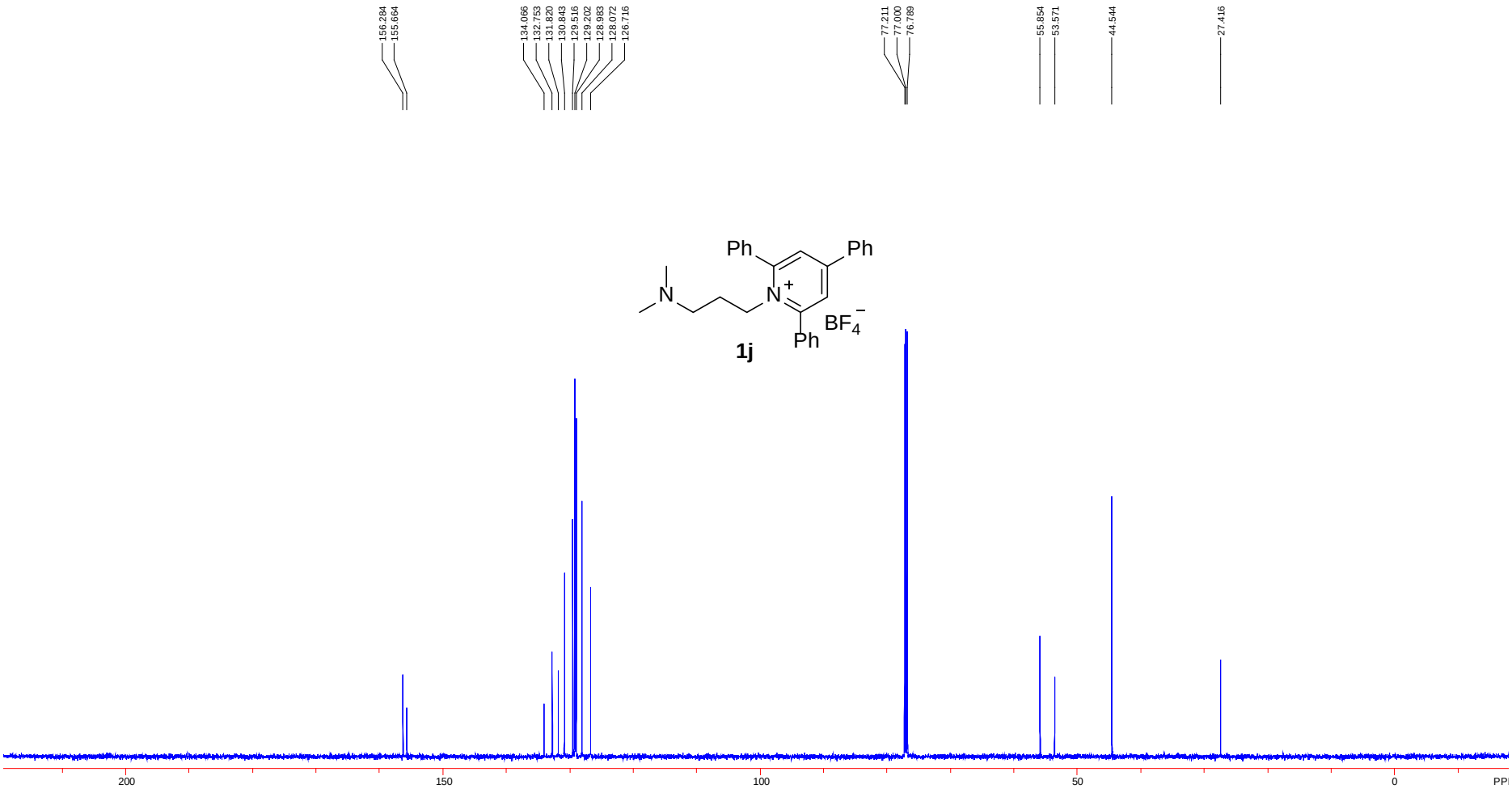
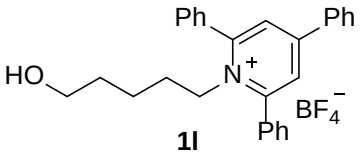


^{1}H NMR(400 MHz, $CDCl_3$)



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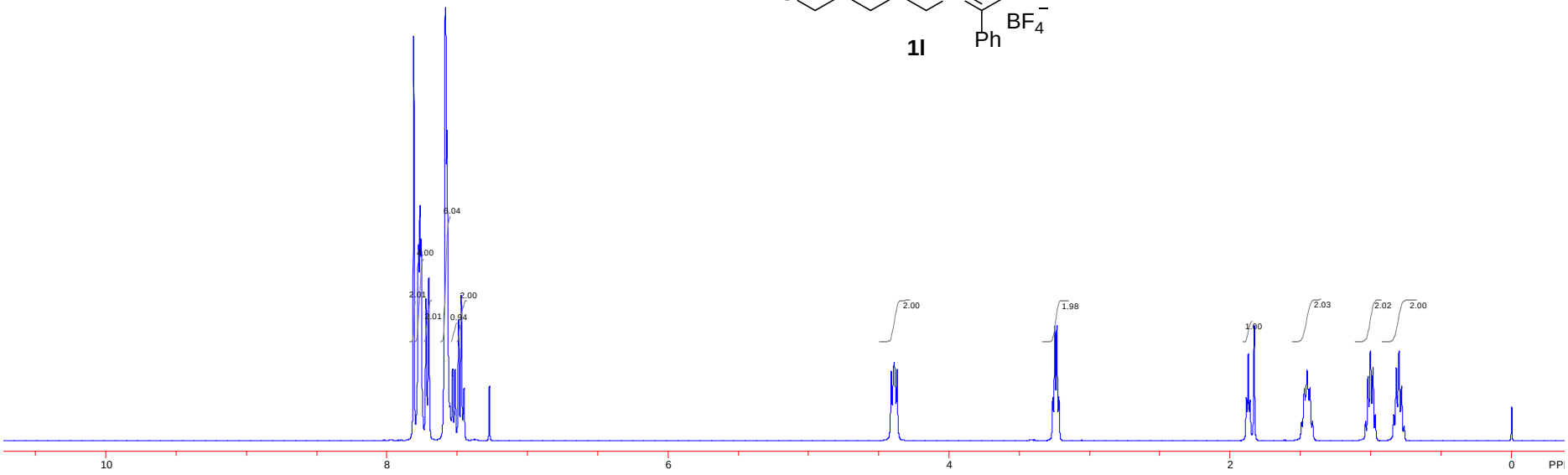

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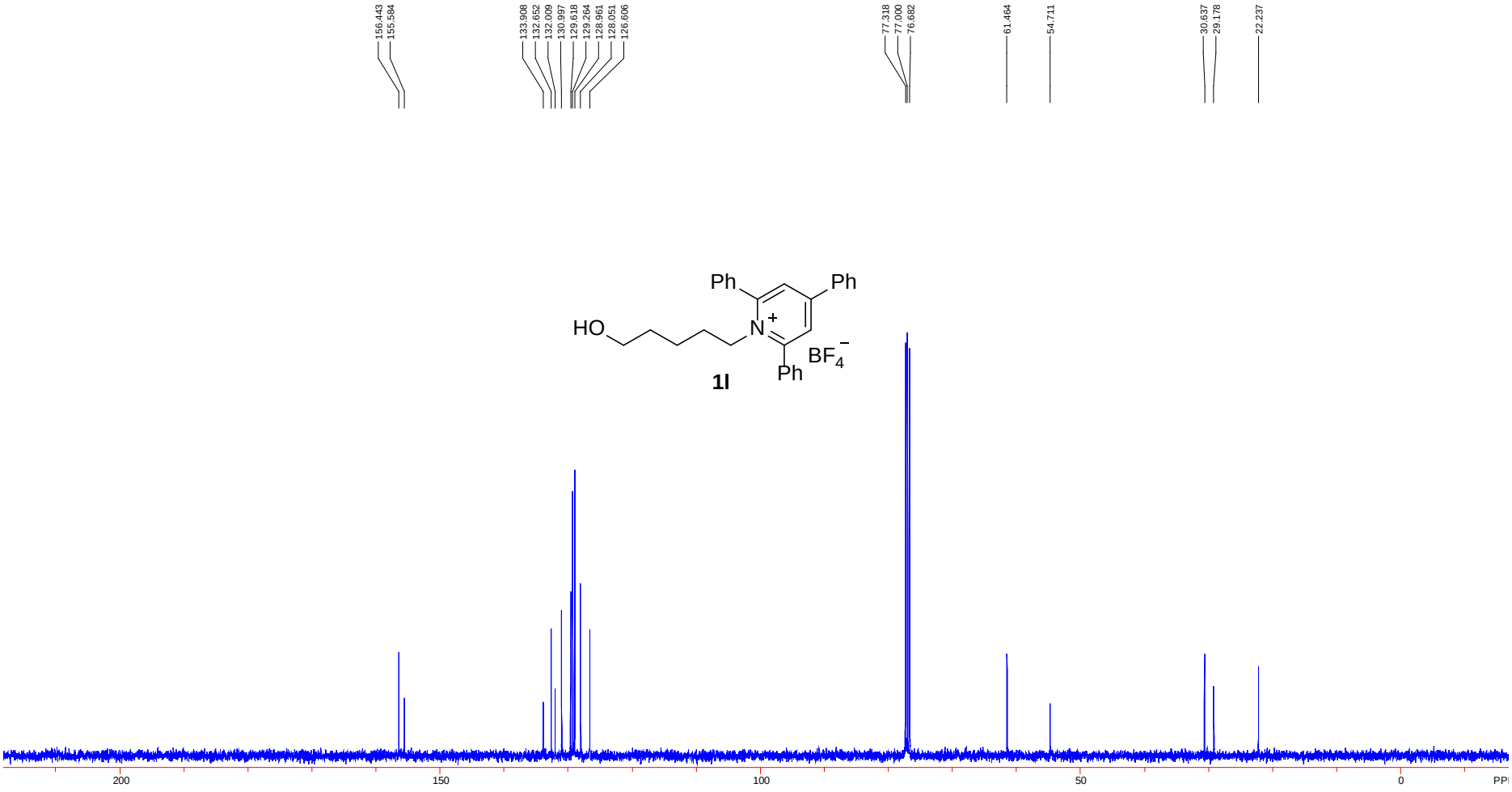

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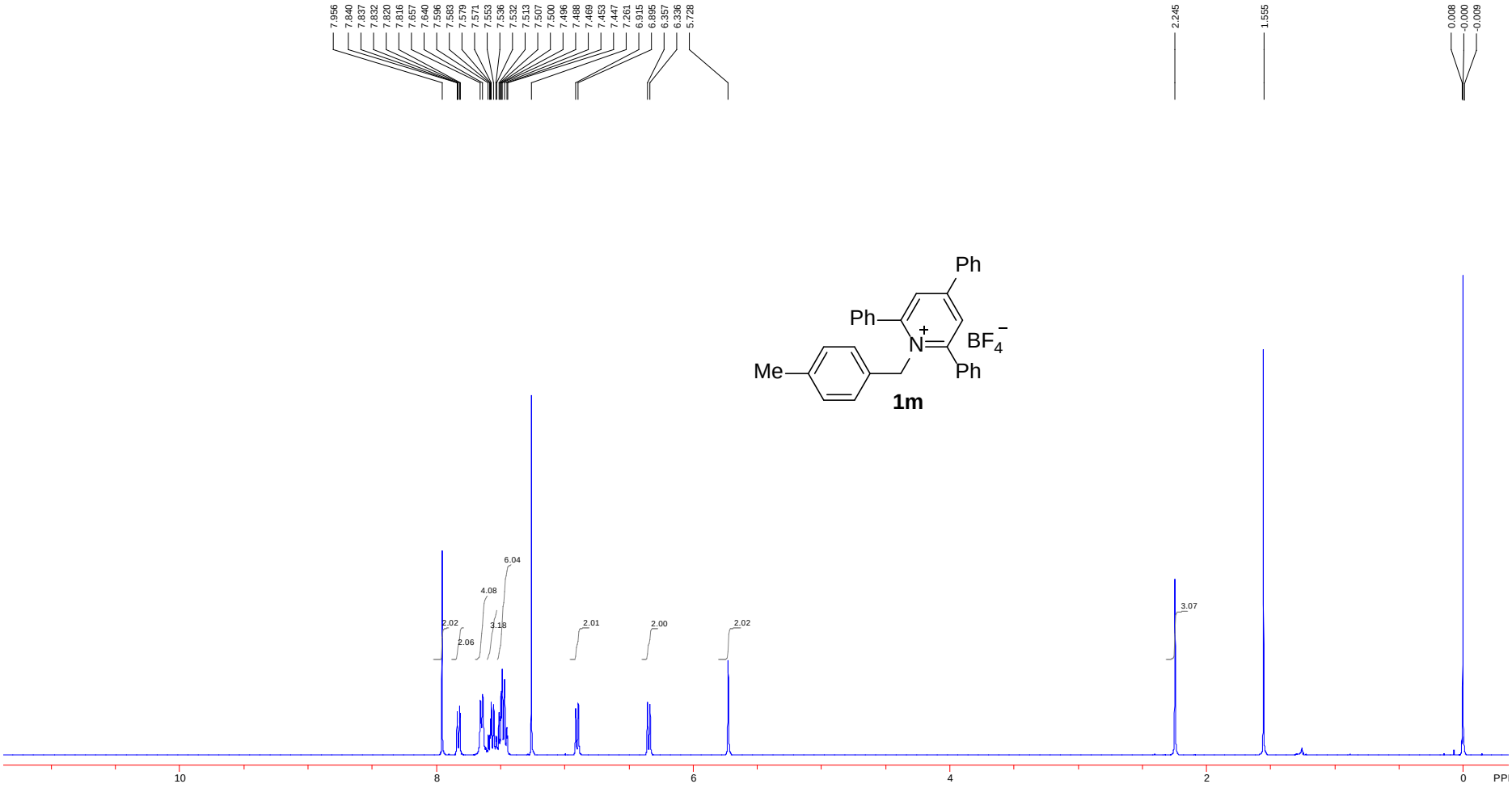

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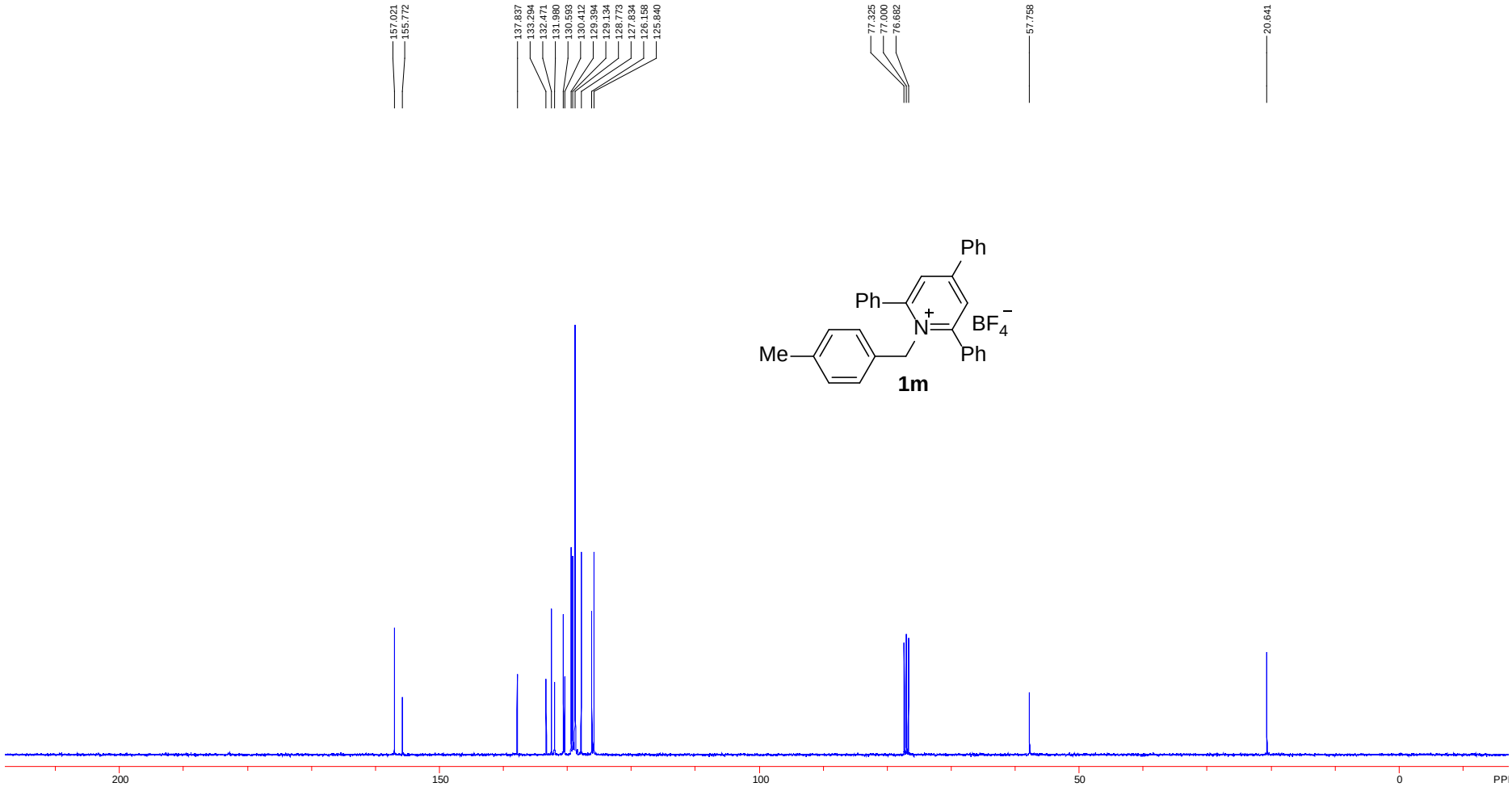

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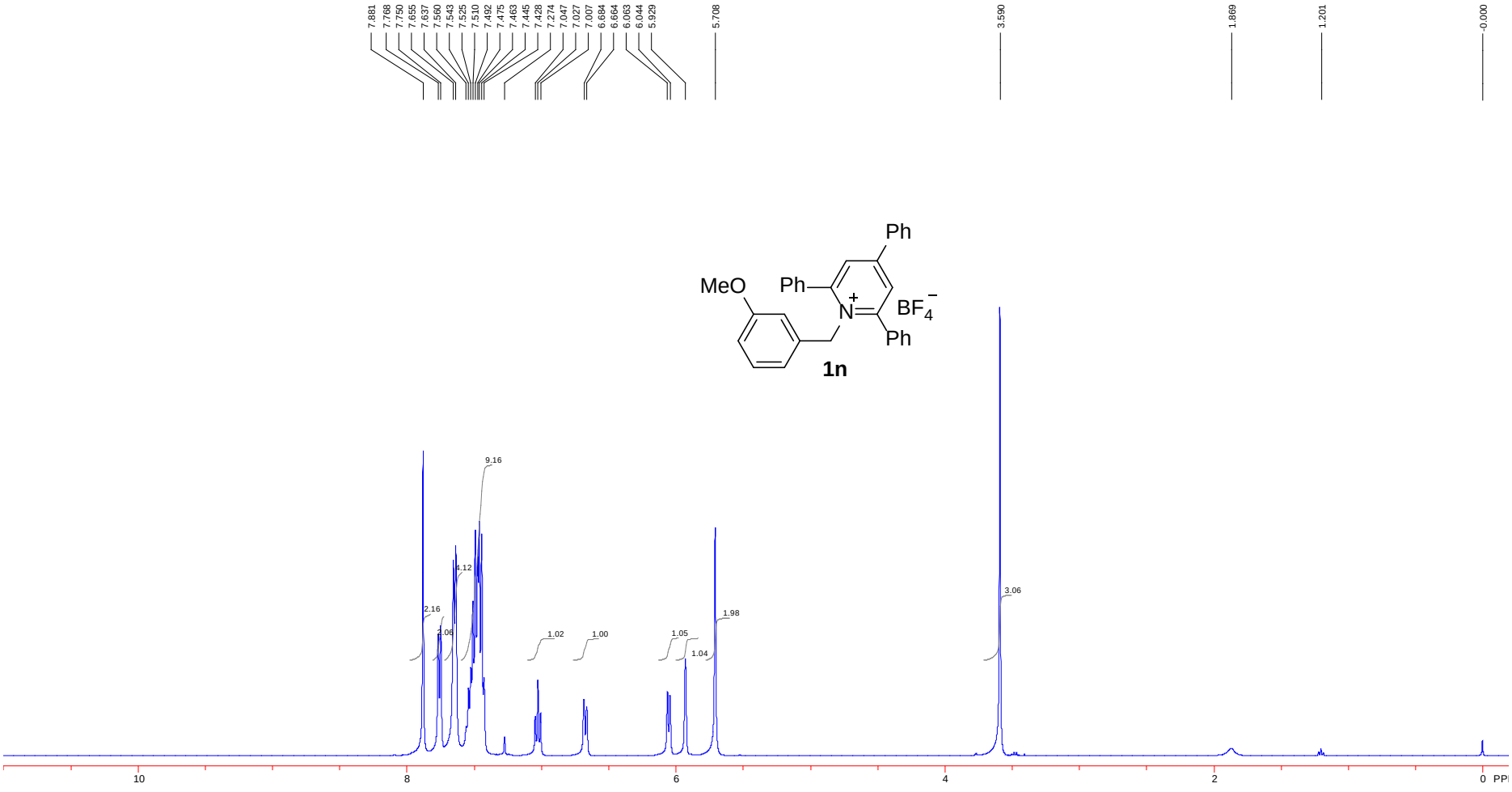

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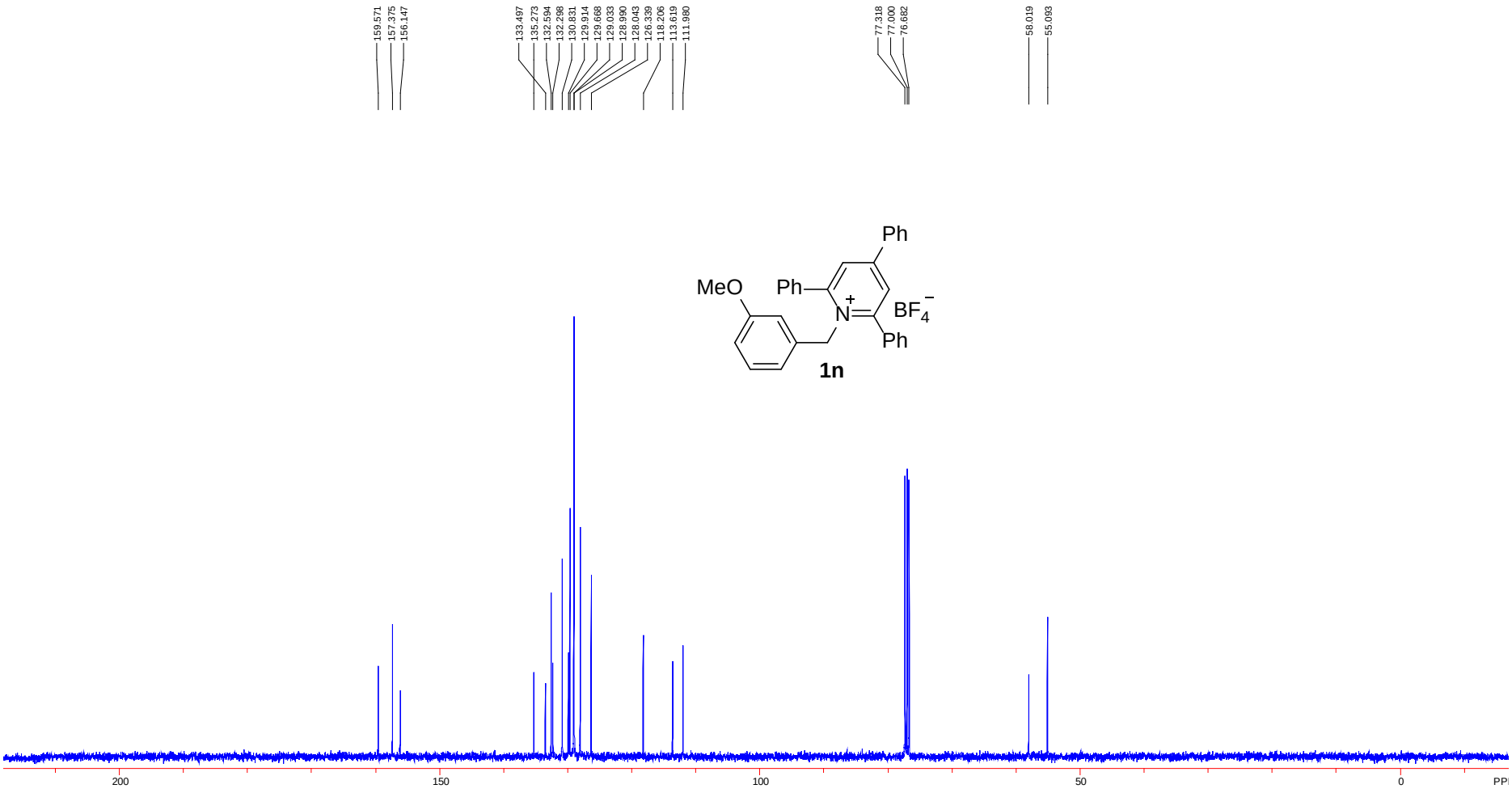

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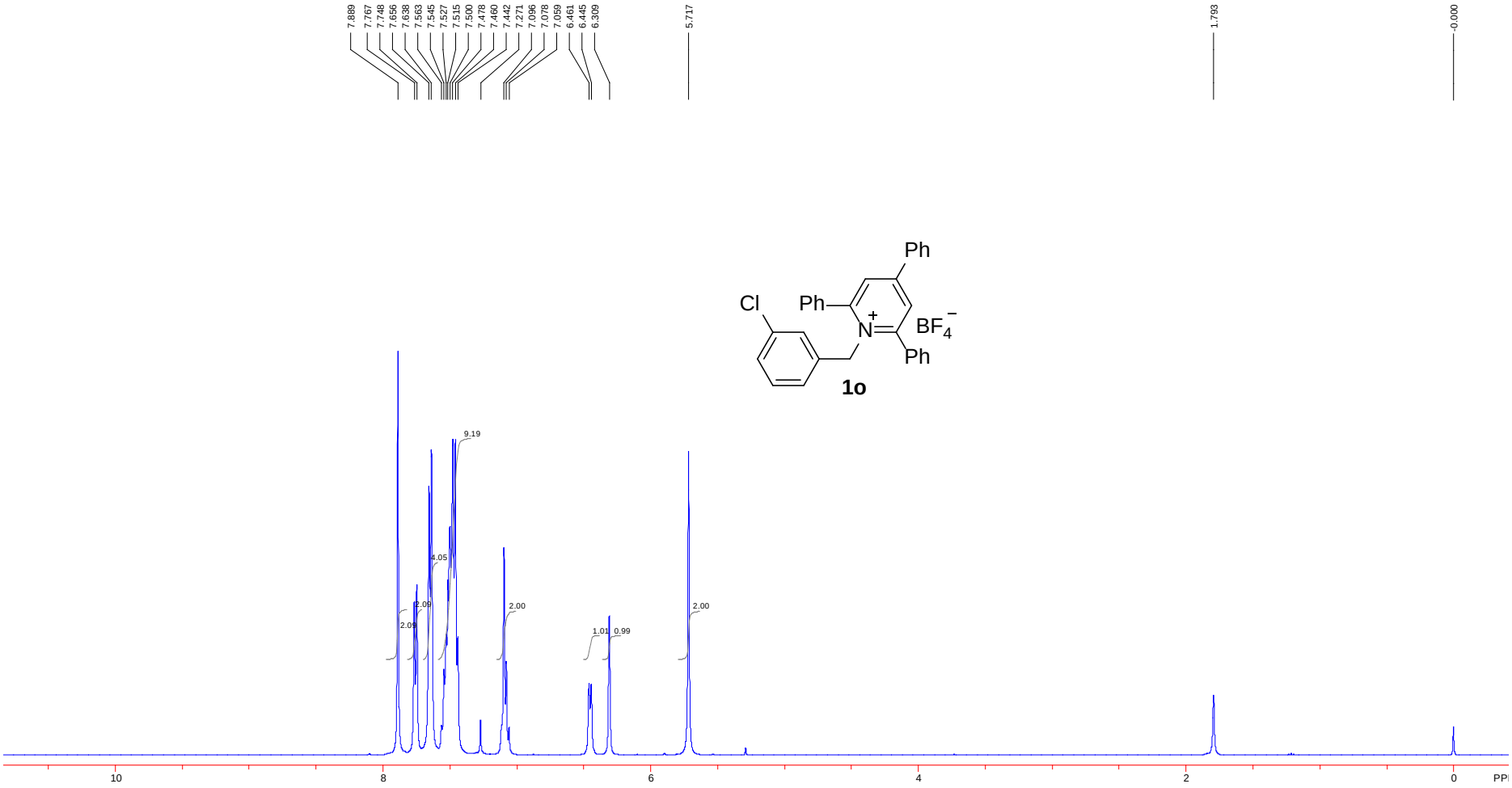

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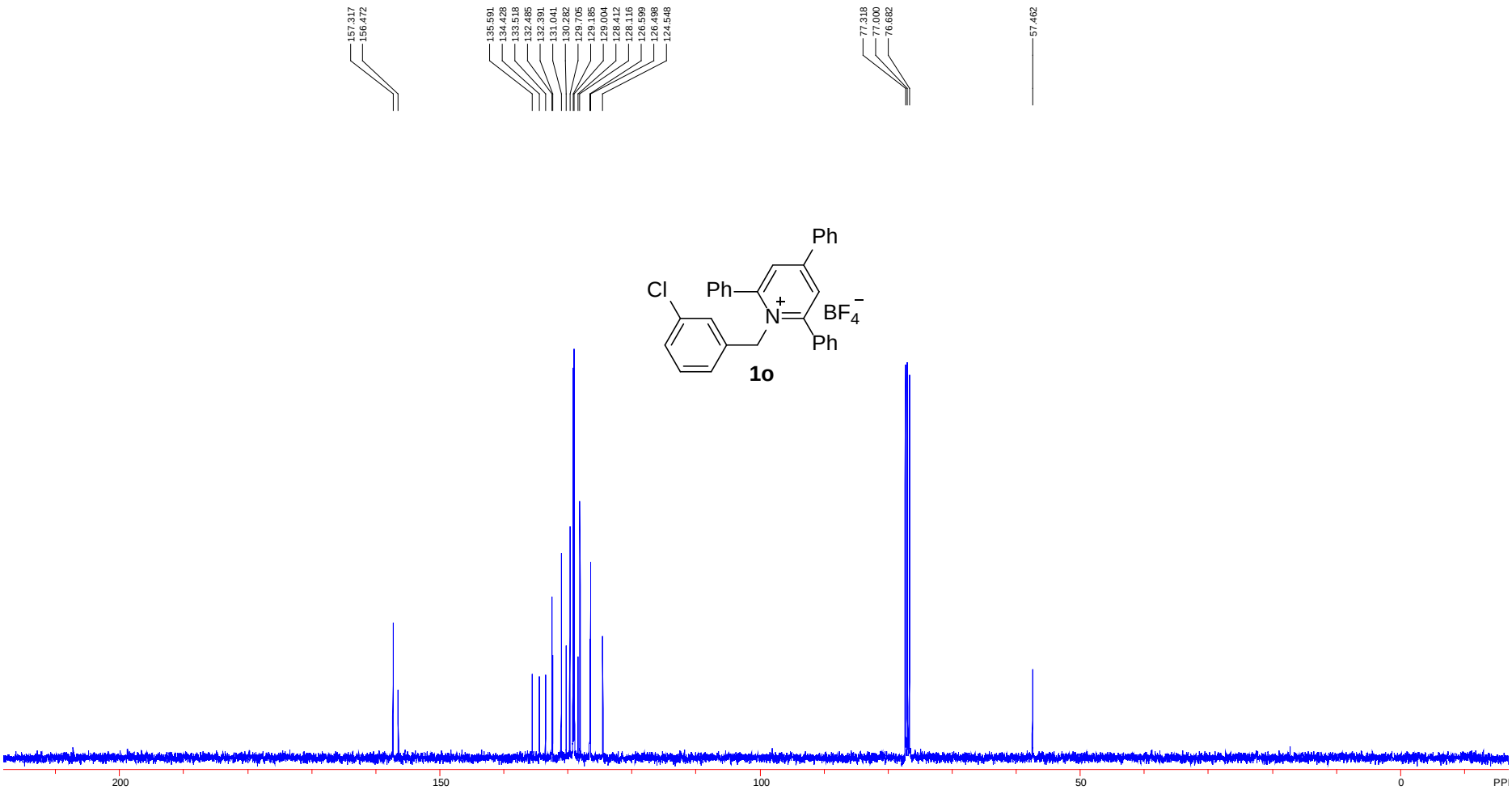

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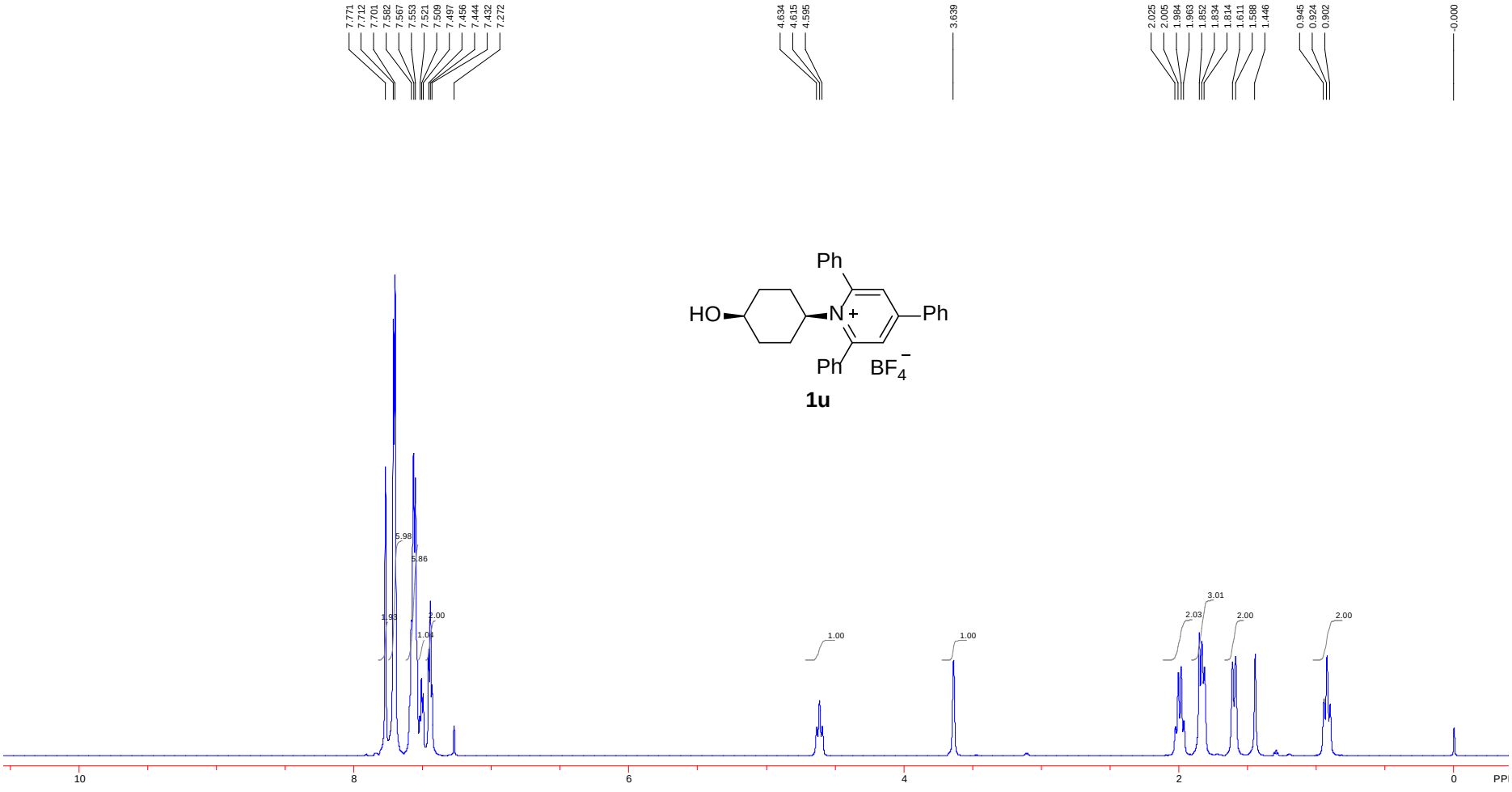
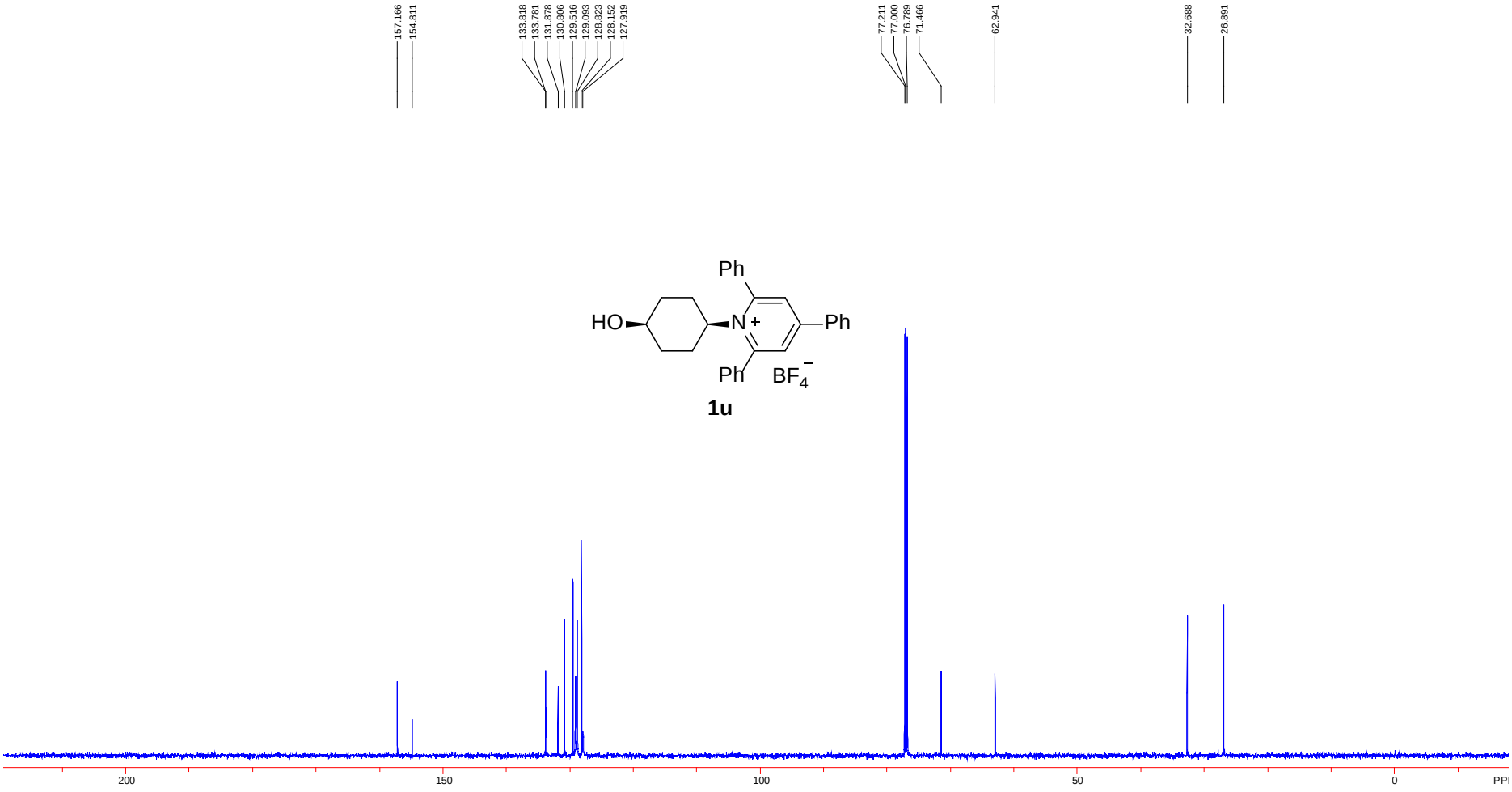


^{13}C NMR (151 MHz, $CDCl_3$)



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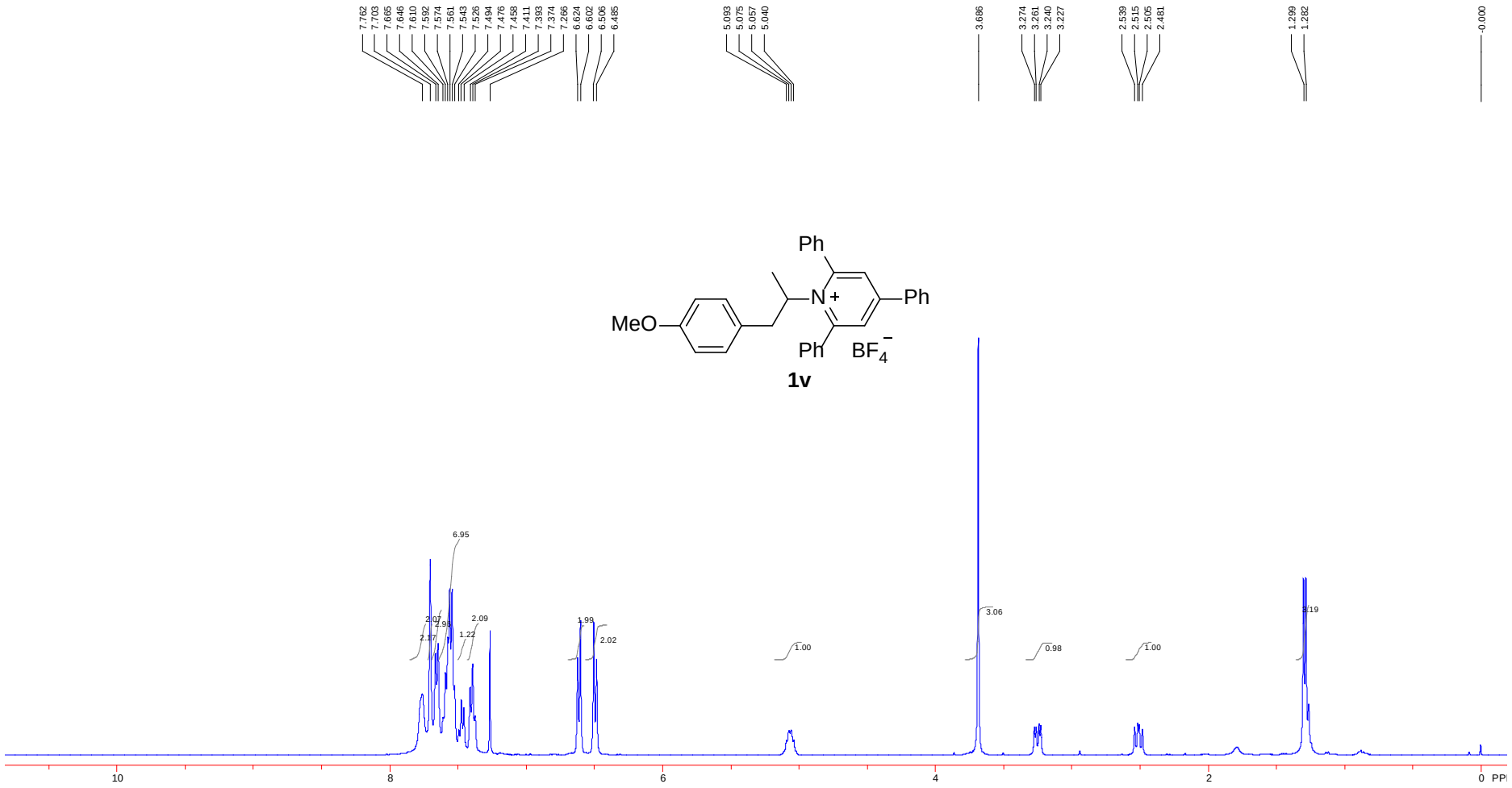

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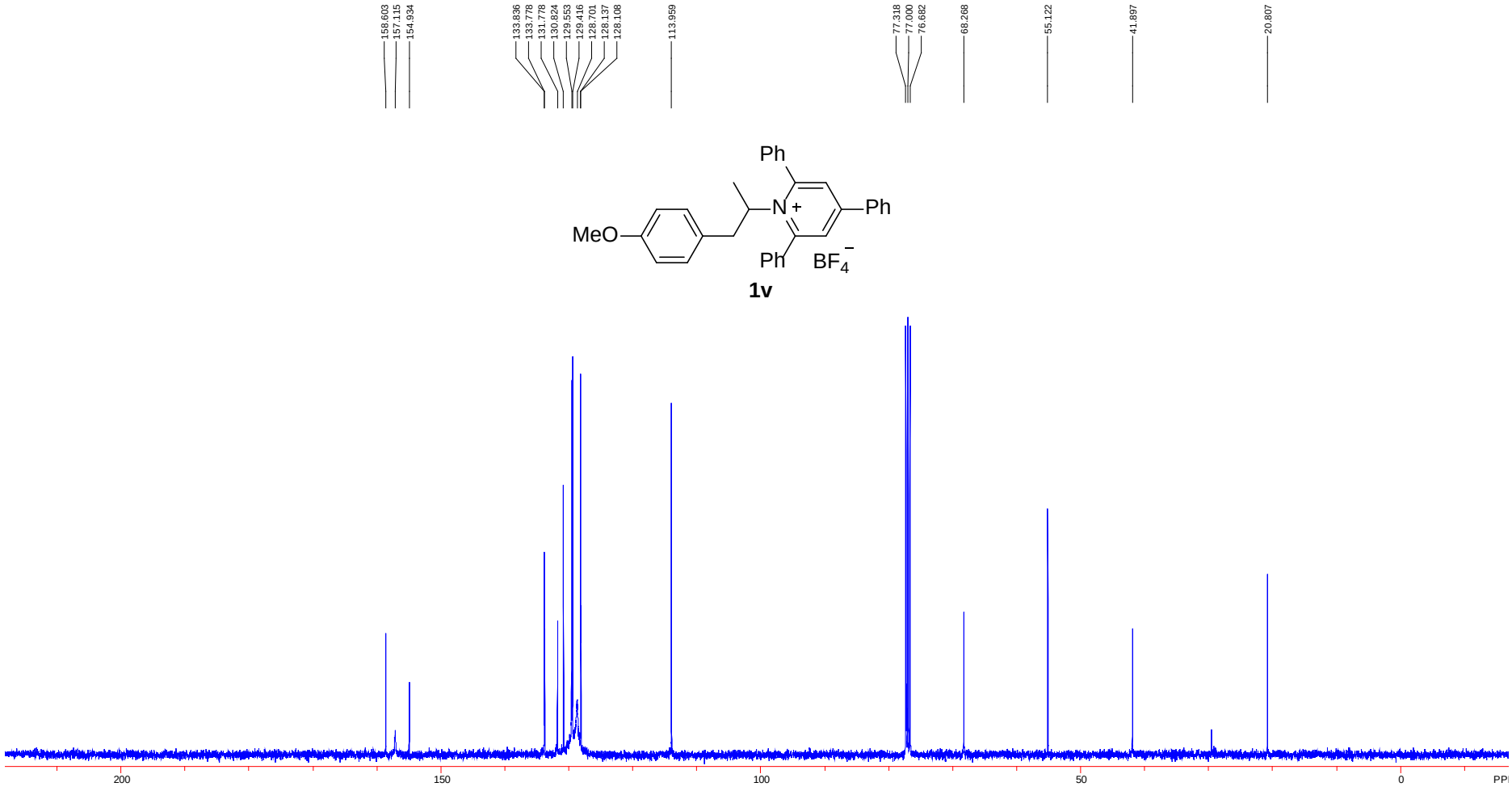

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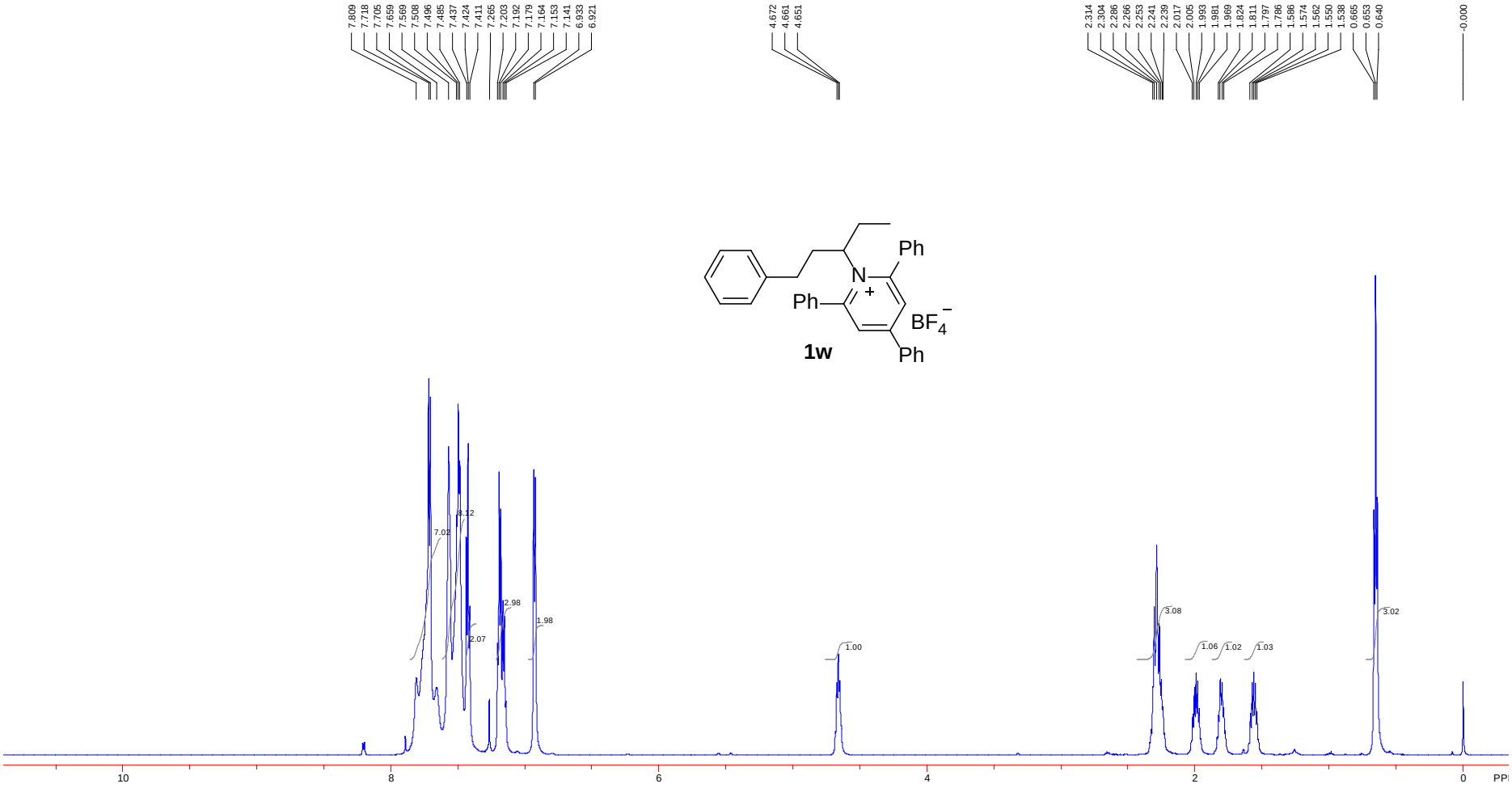

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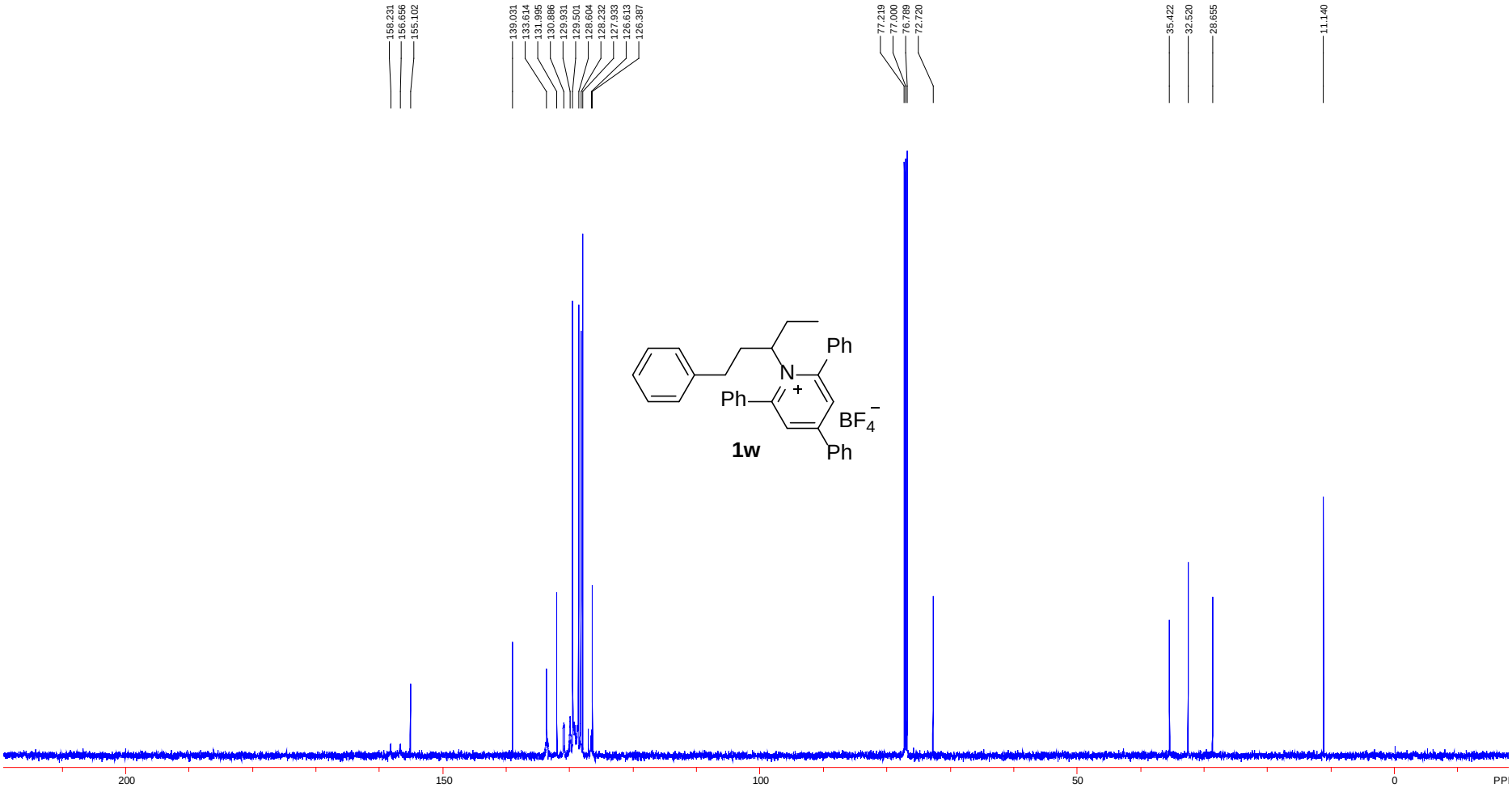

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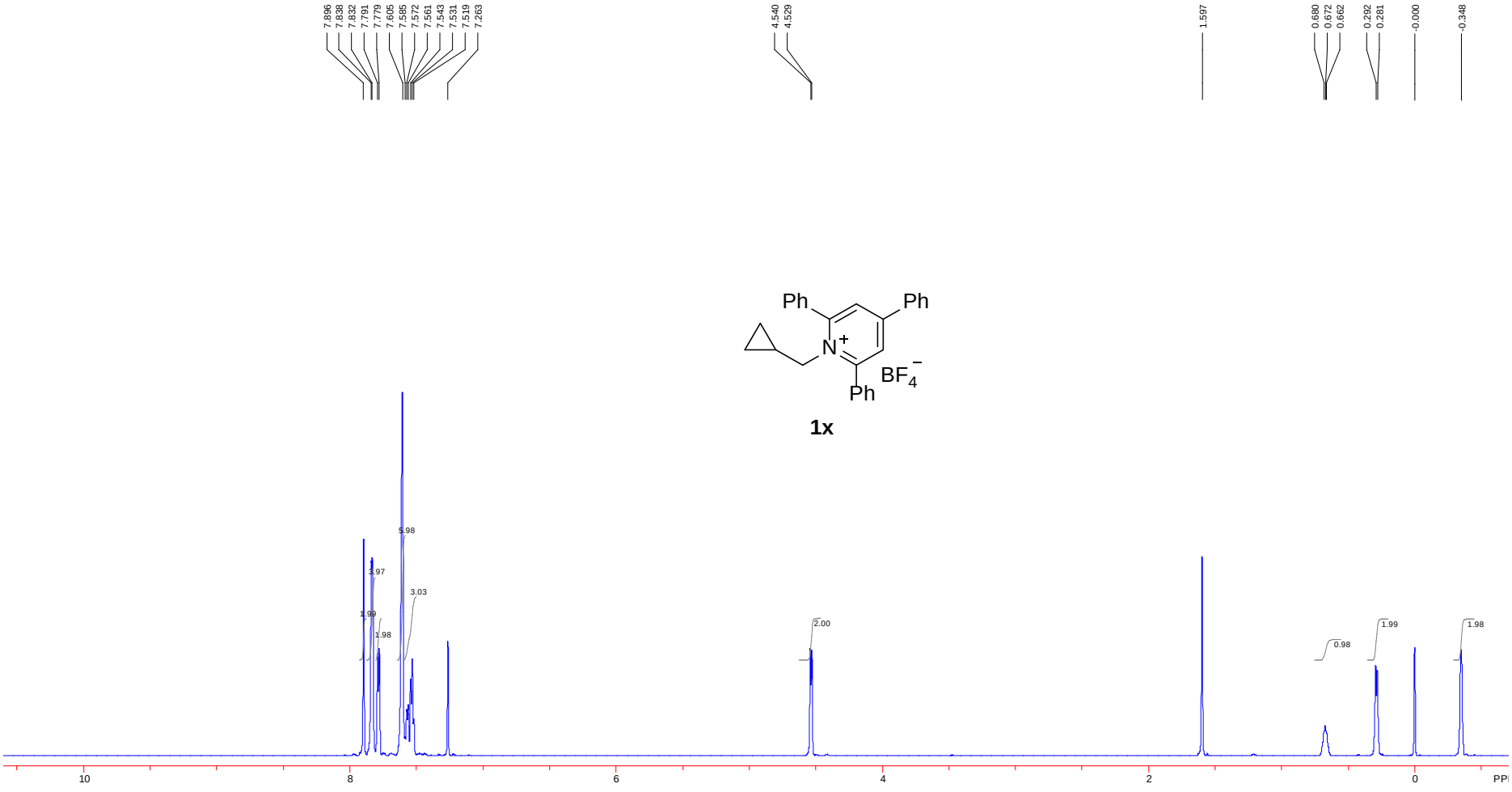
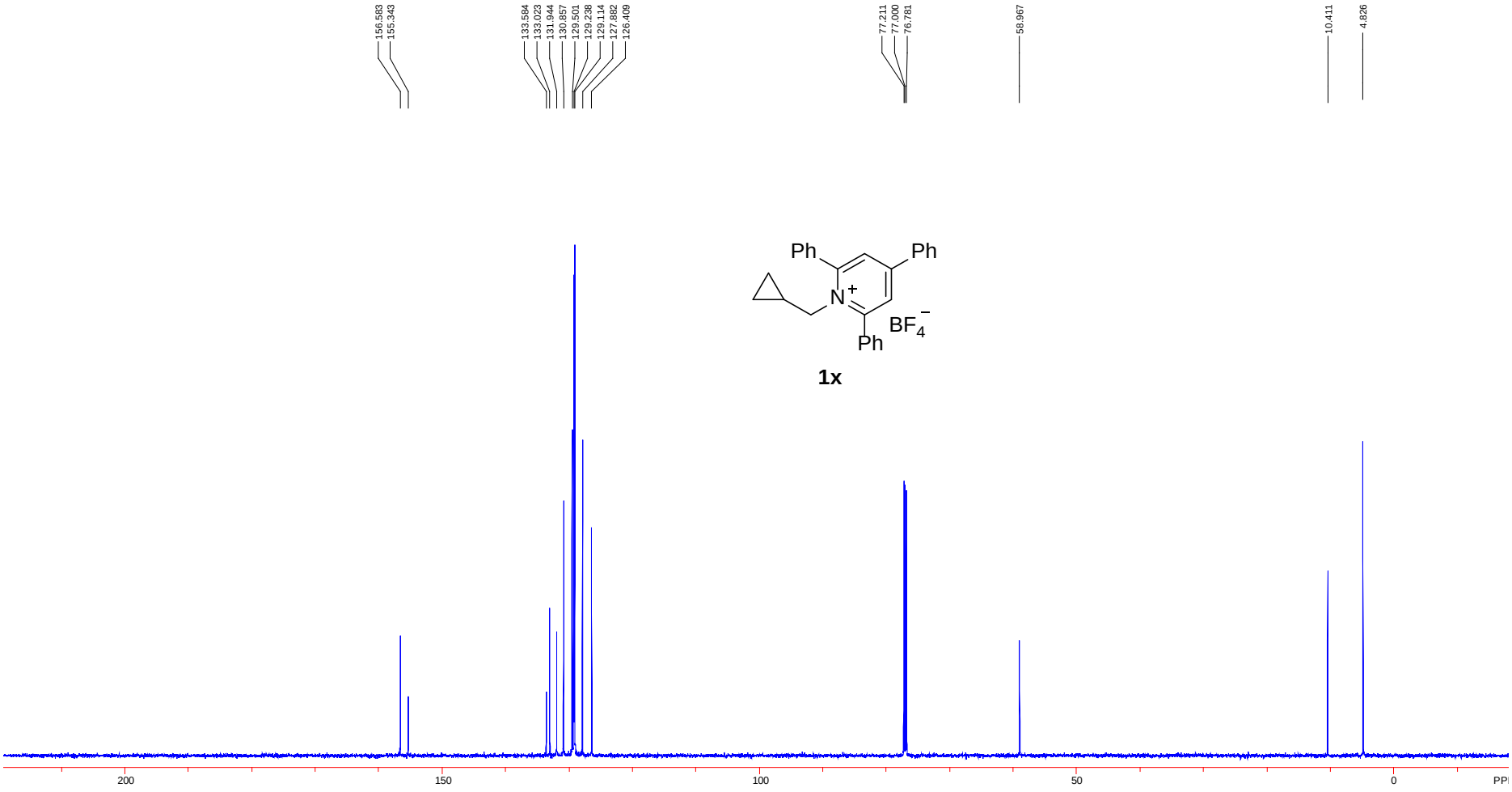
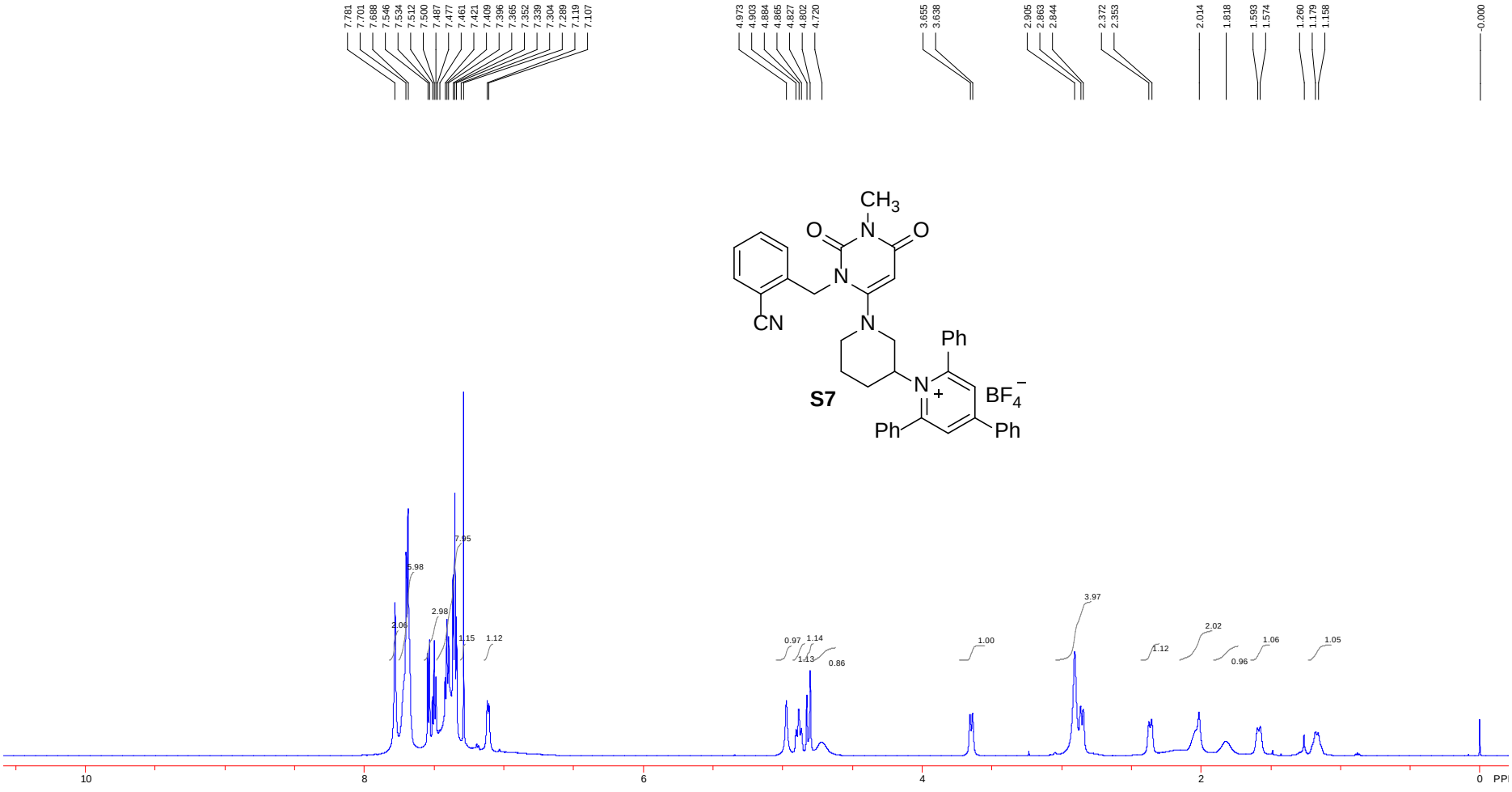


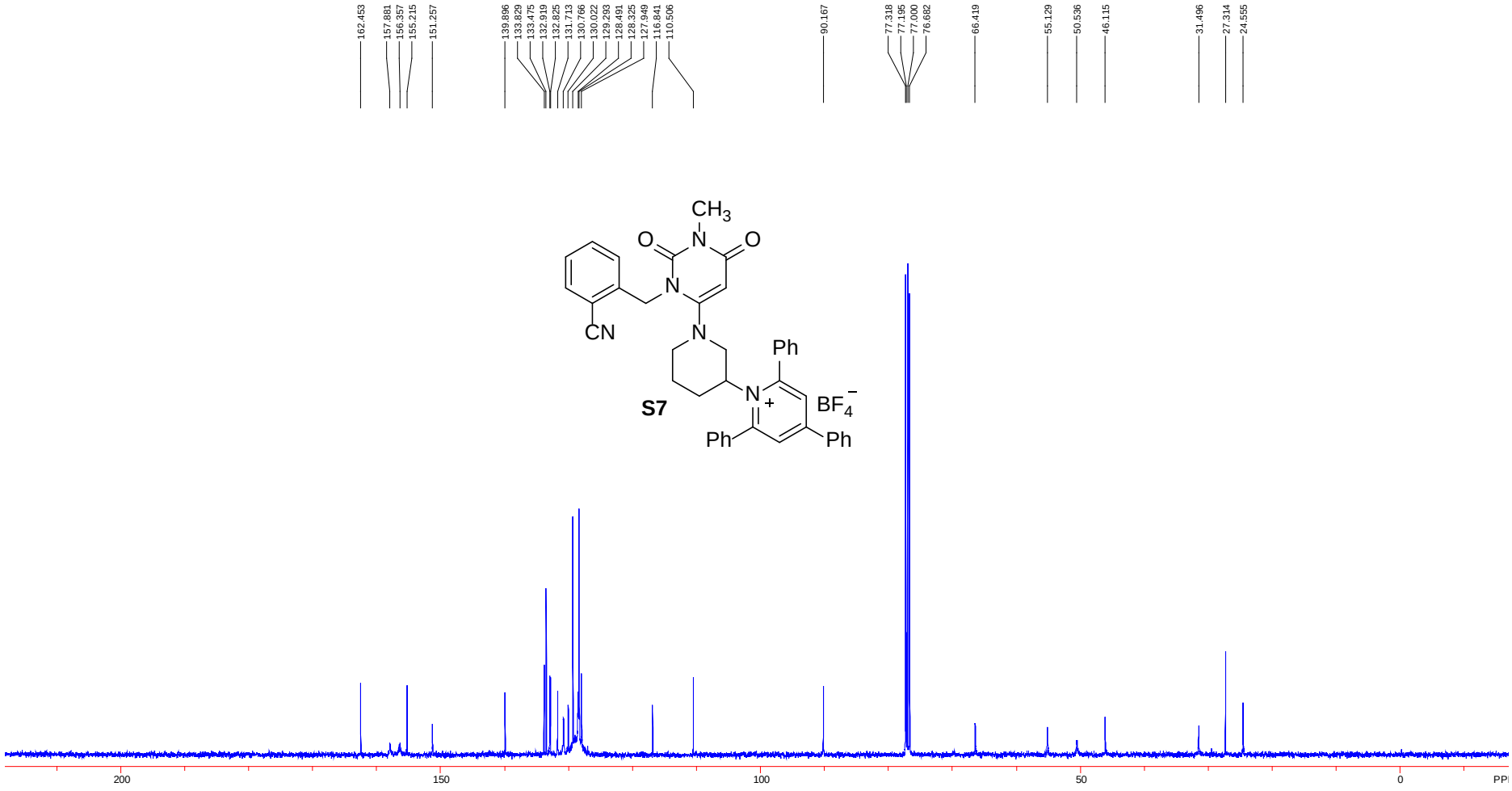
^{13}C NMR (151 MHz, $CDCl_3$)



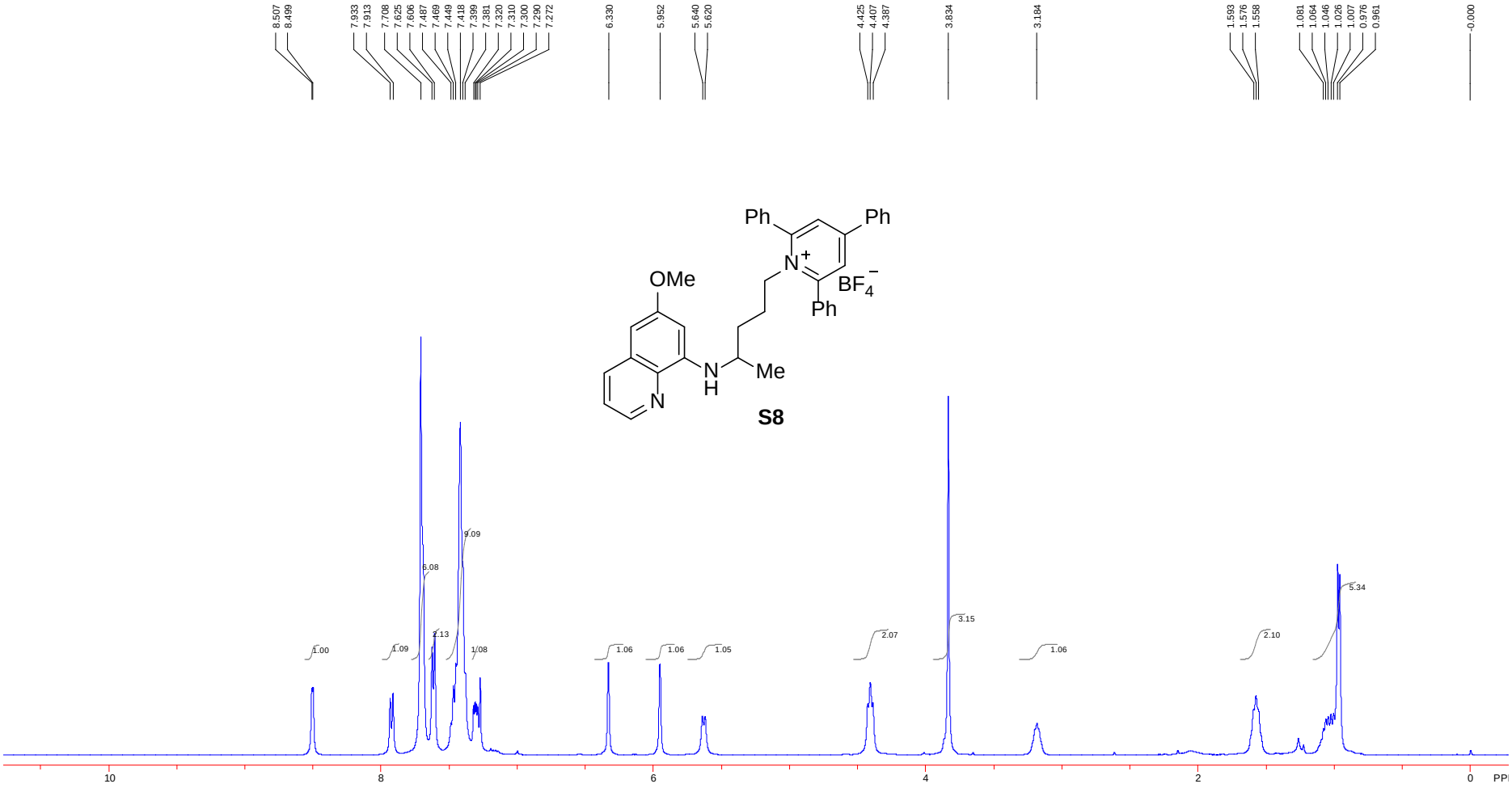
^{1}H NMR (600 MHz, $CDCl_3$)



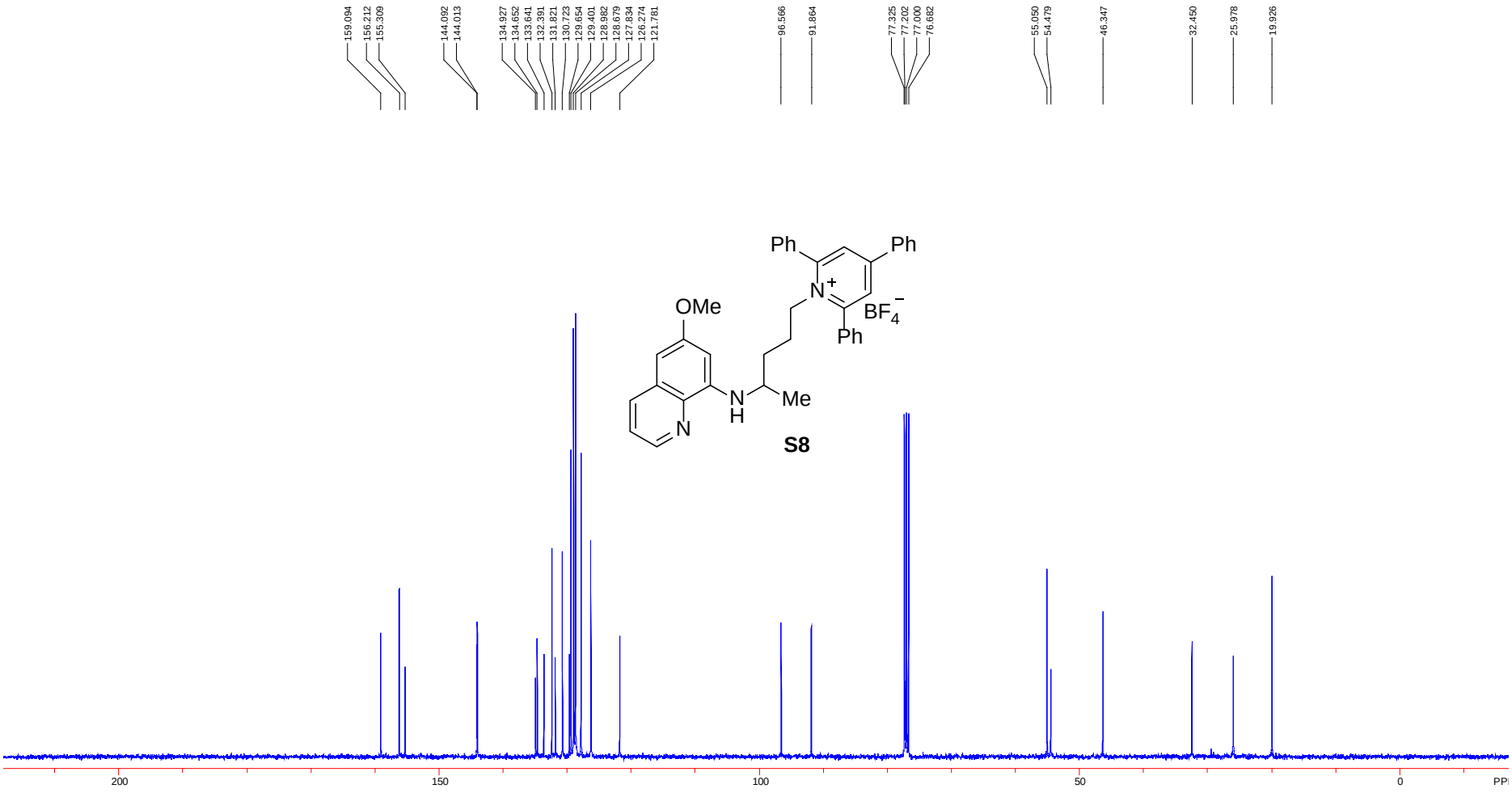
^{13}C NMR (100 MHz, $CDCl_3$)



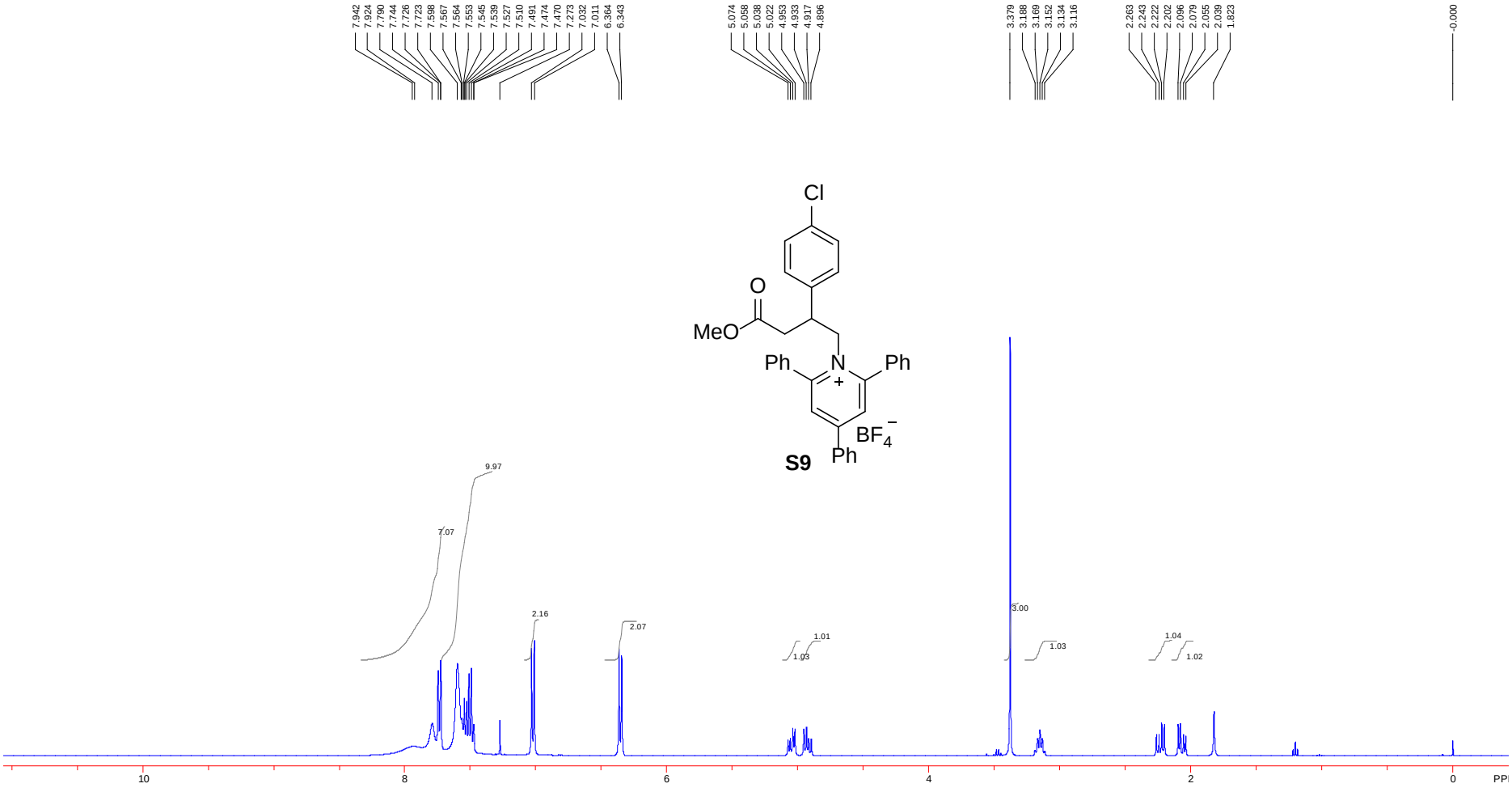
^{1}H NMR(400 MHz, $CDCl_3$)



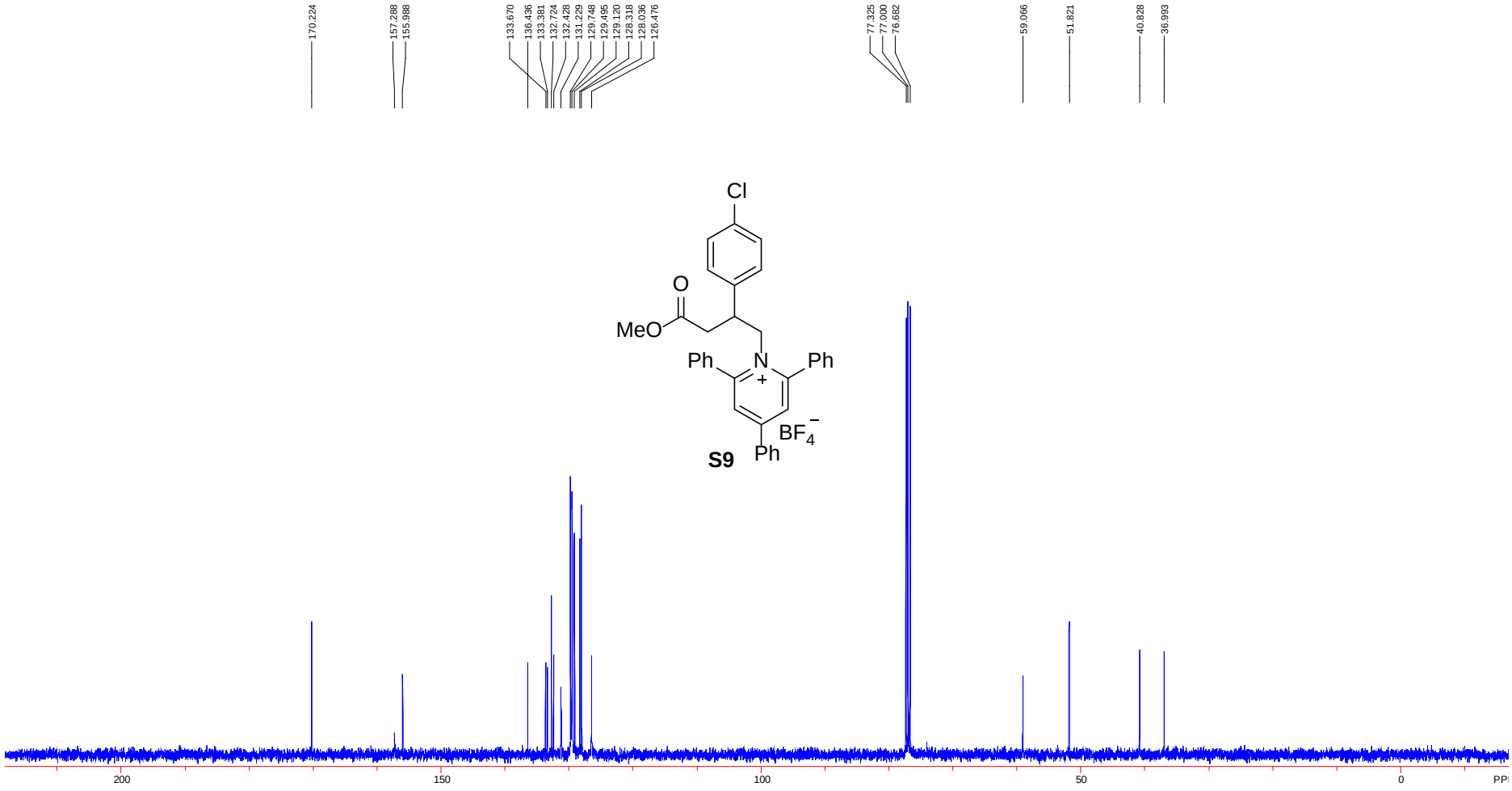
^{13}C NMR(100 MHz, $CDCl_3$)



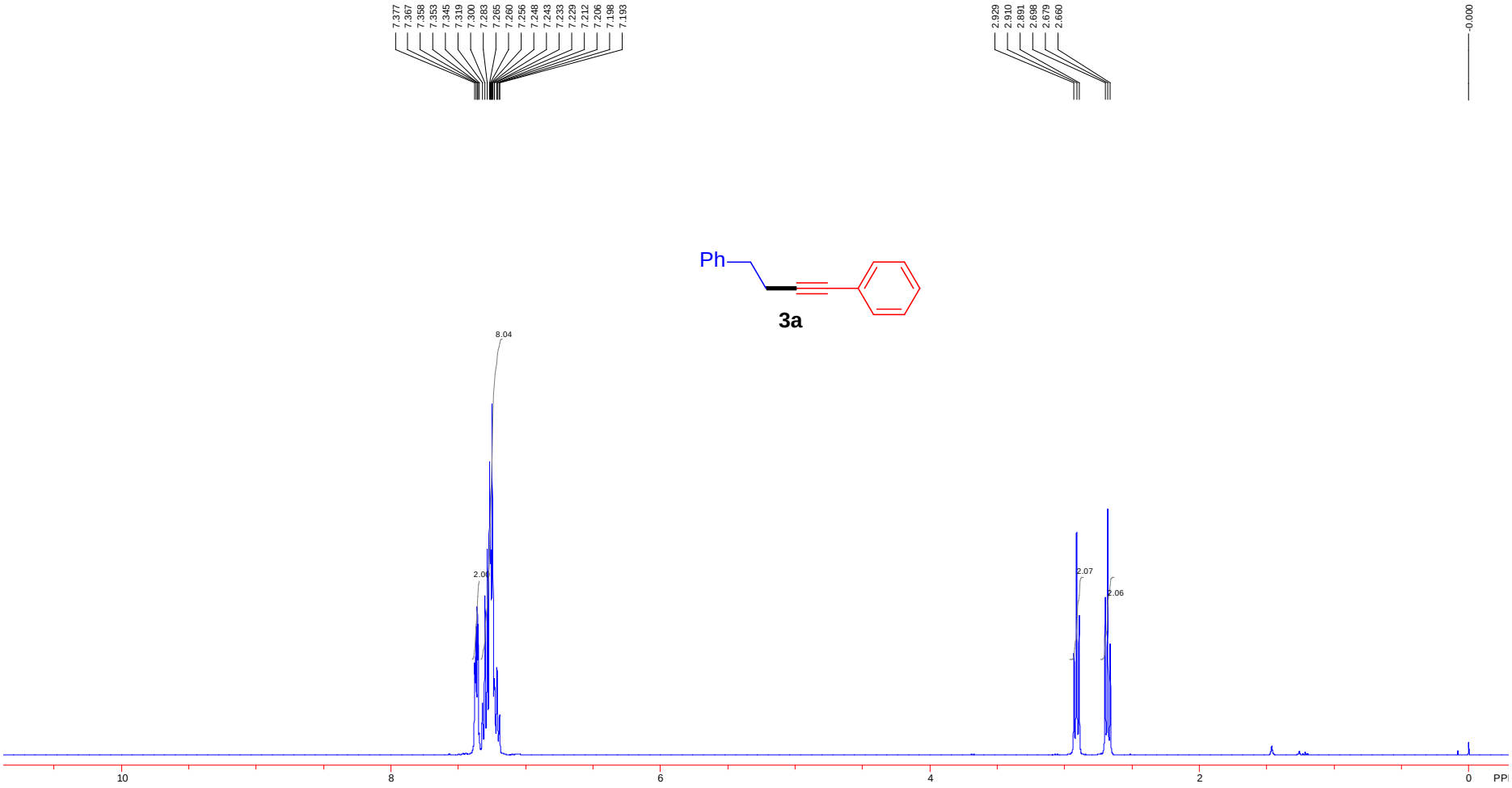
^{1}H NMR(400 MHz, $CDCl_3$)



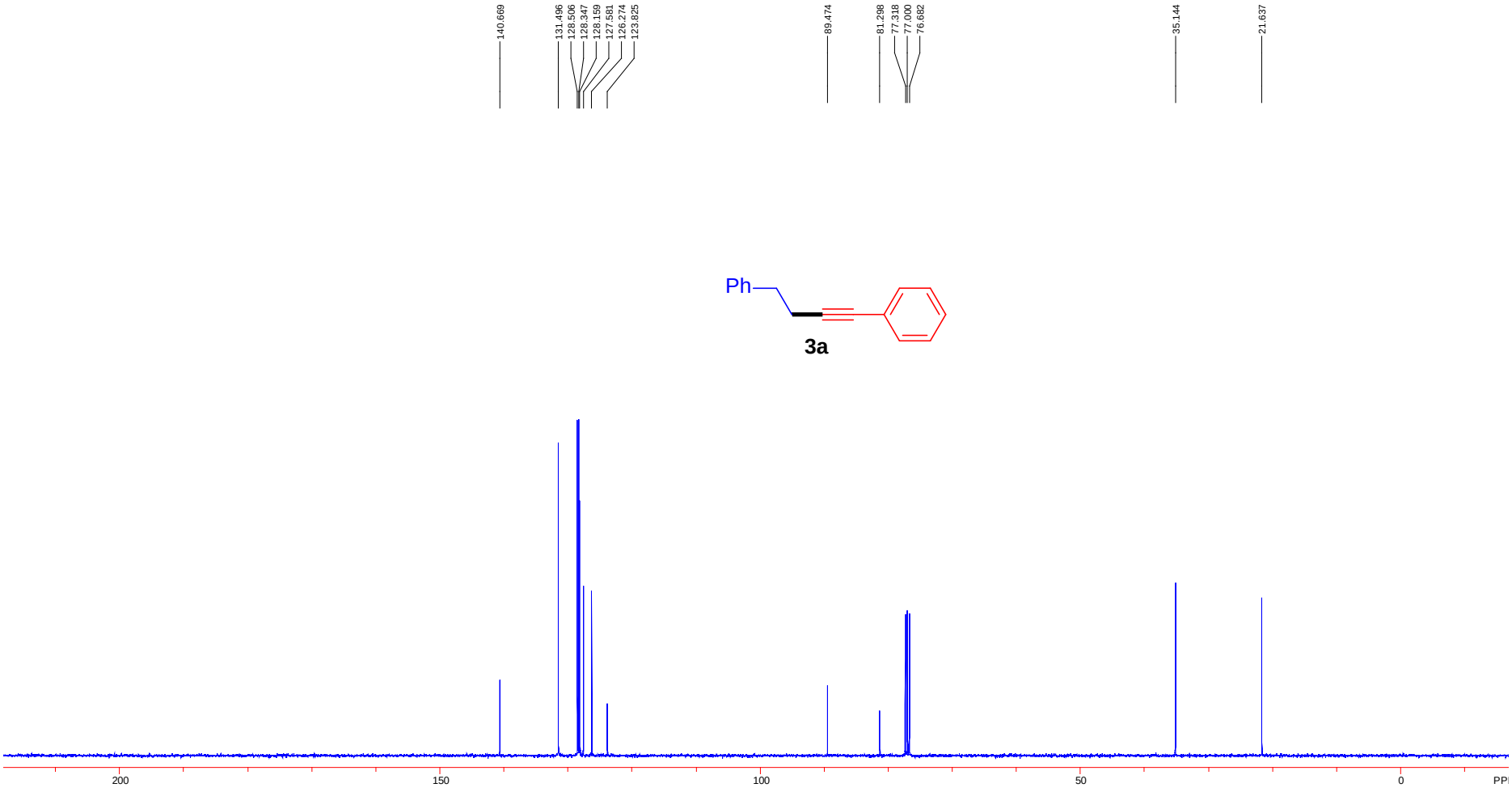
^{13}C NMR(100 MHz, $CDCl_3$)



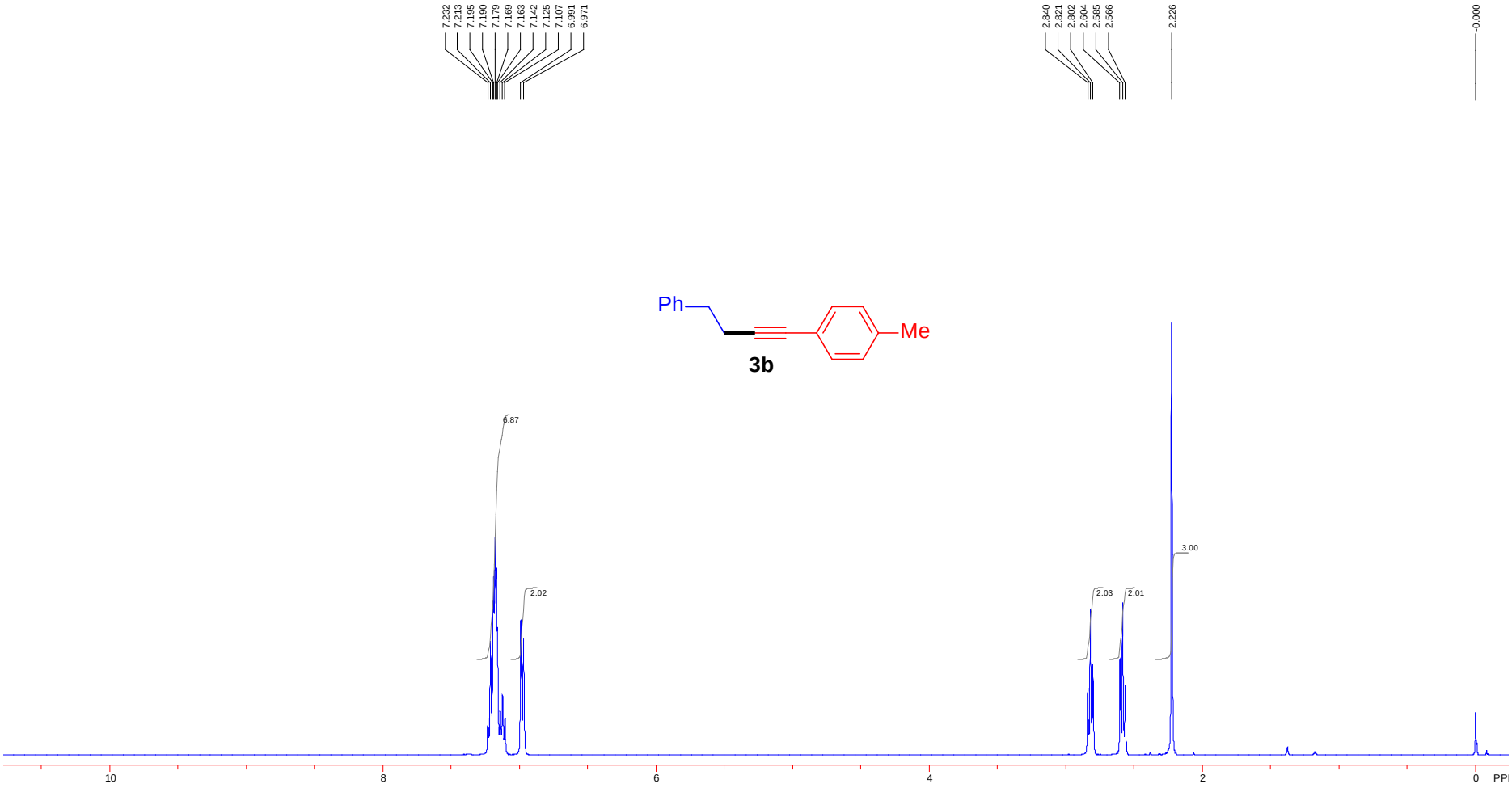
^{1}H NMR(400 MHz, $CDCl_3$)



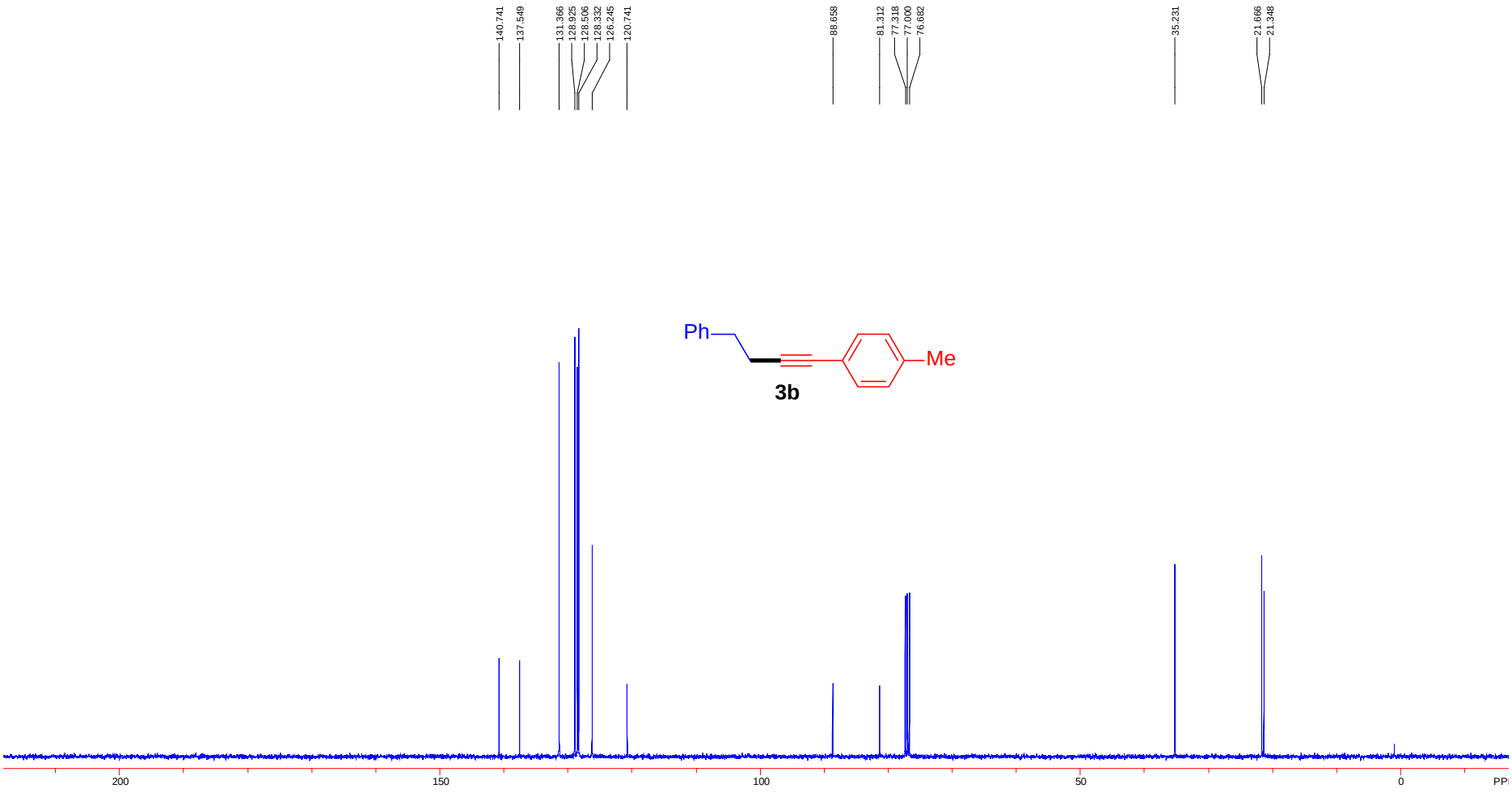
^{13}C NMR(100 MHz, $CDCl_3$)



^{1}H NMR(400 MHz, $CDCl_3$)



^{13}C NMR(100 MHz, $CDCl_3$)



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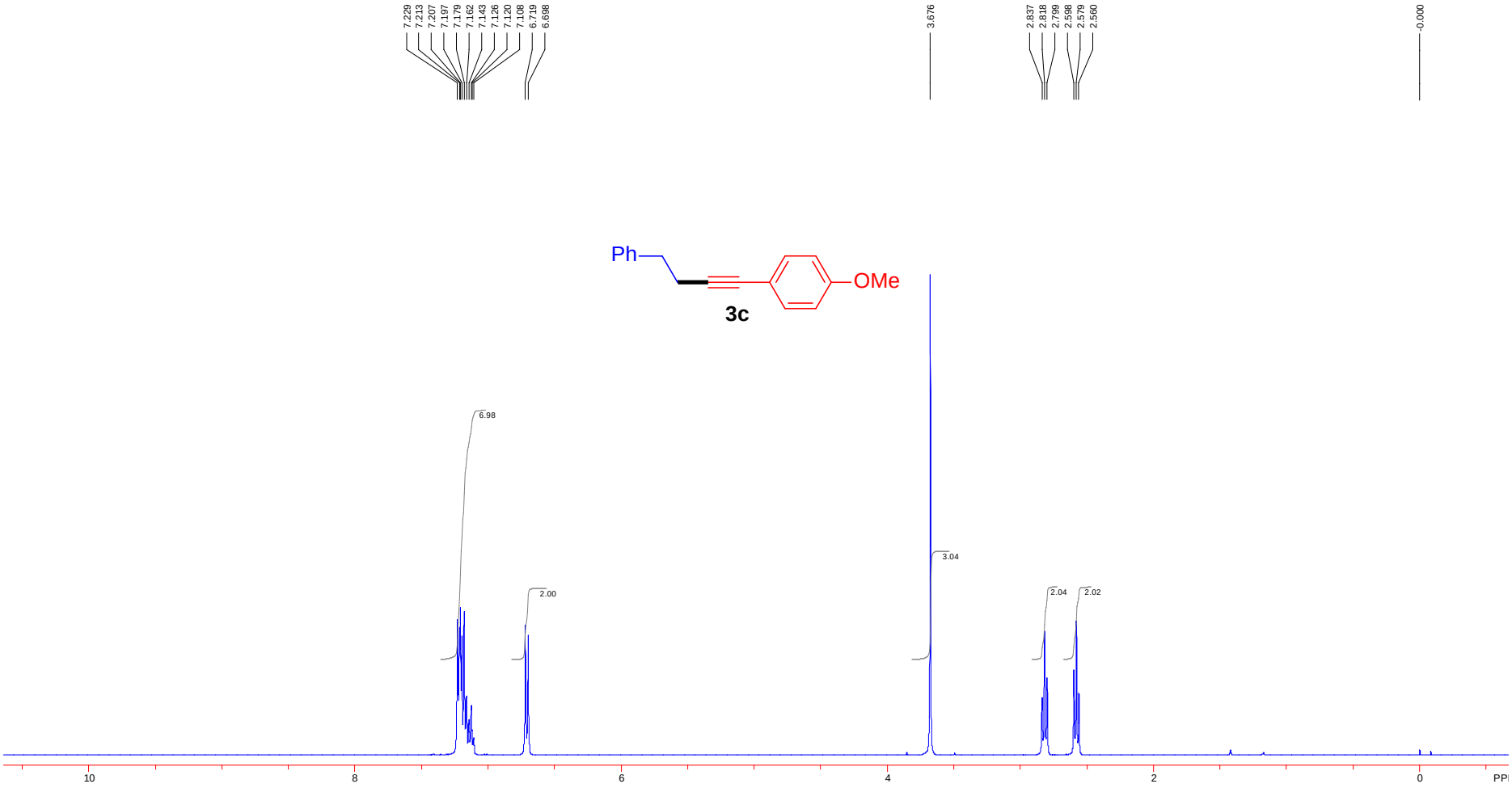
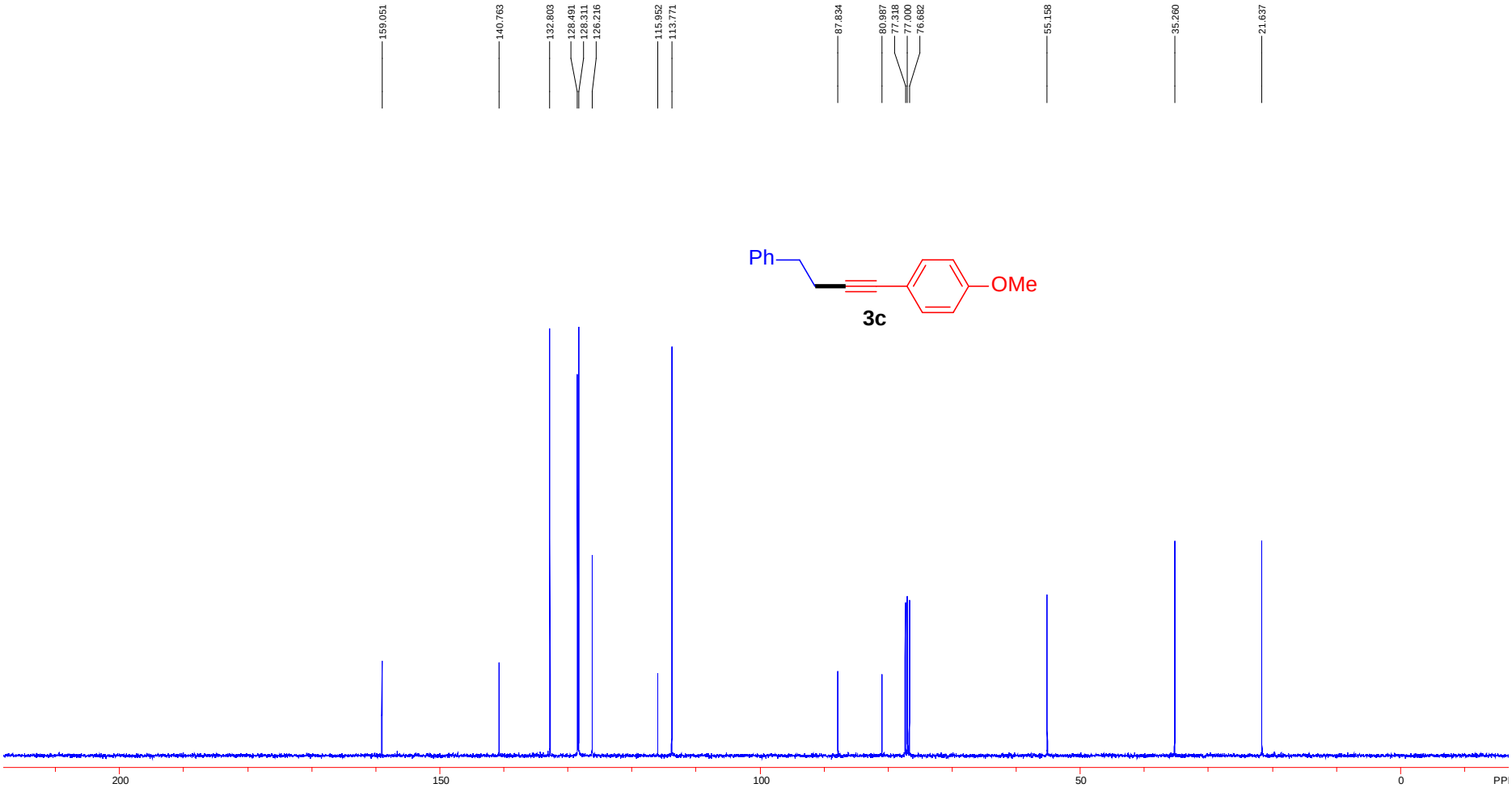
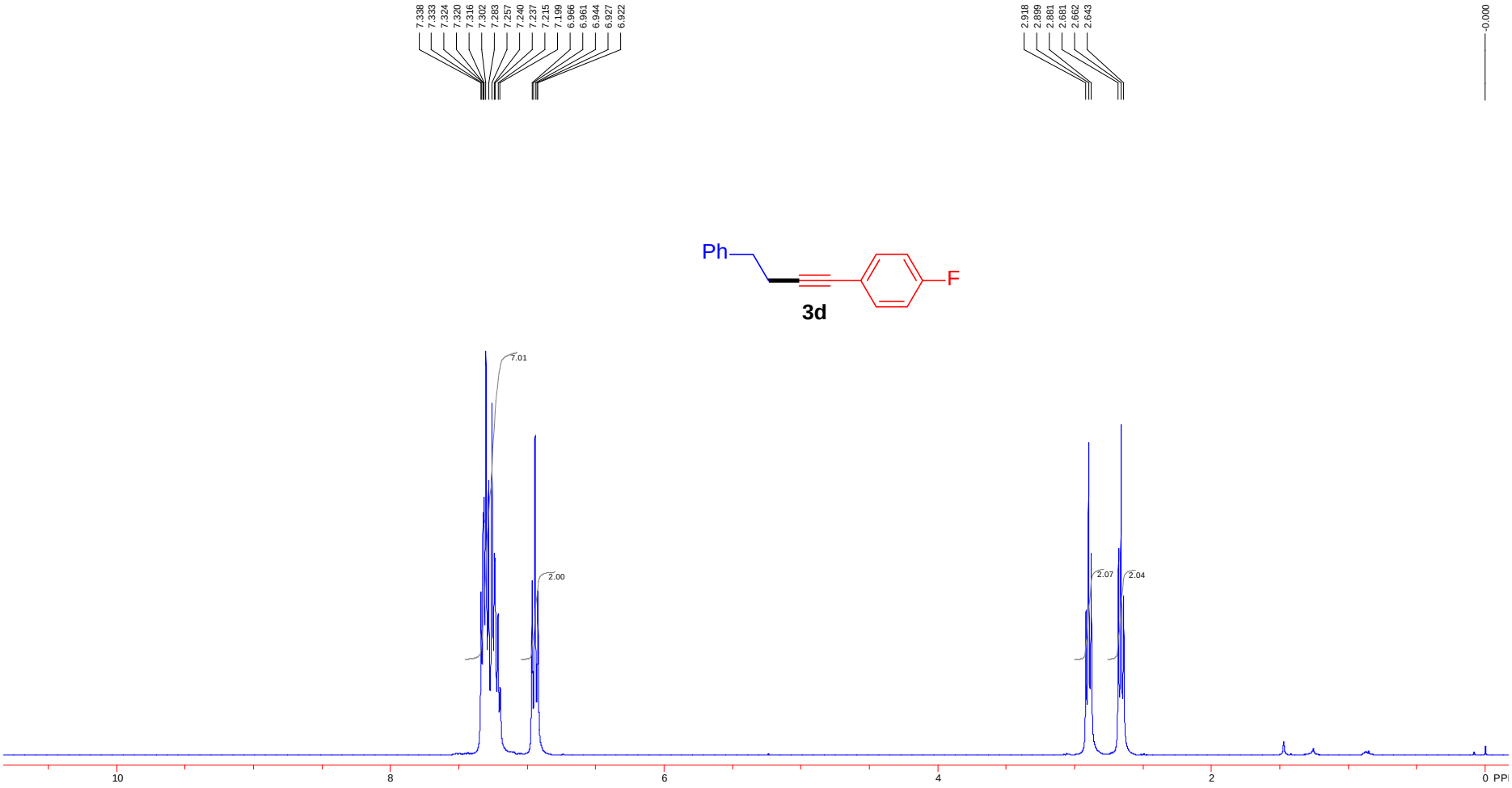


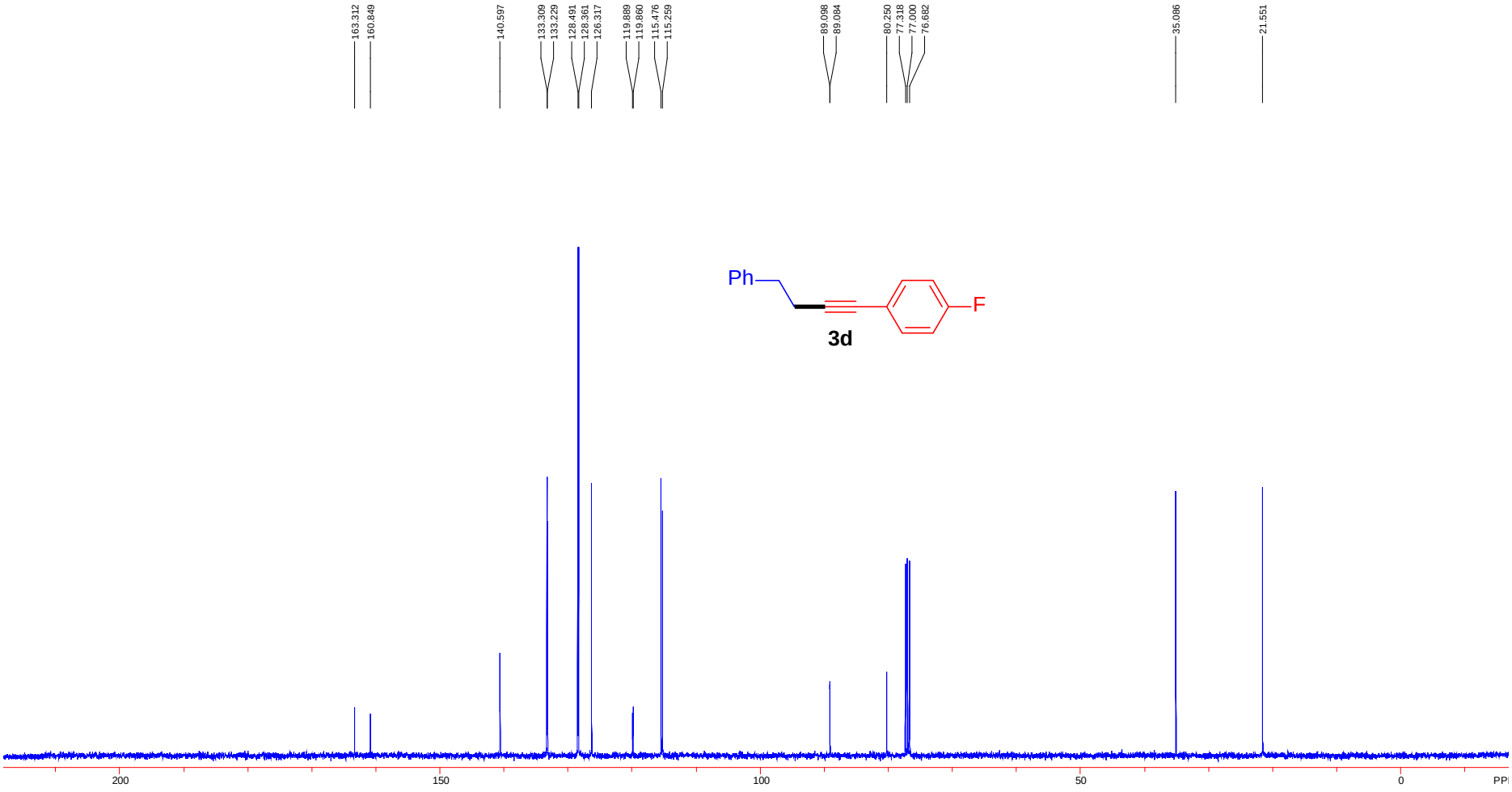
^{13}C NMR(100 MHz, $CDCl_3$)



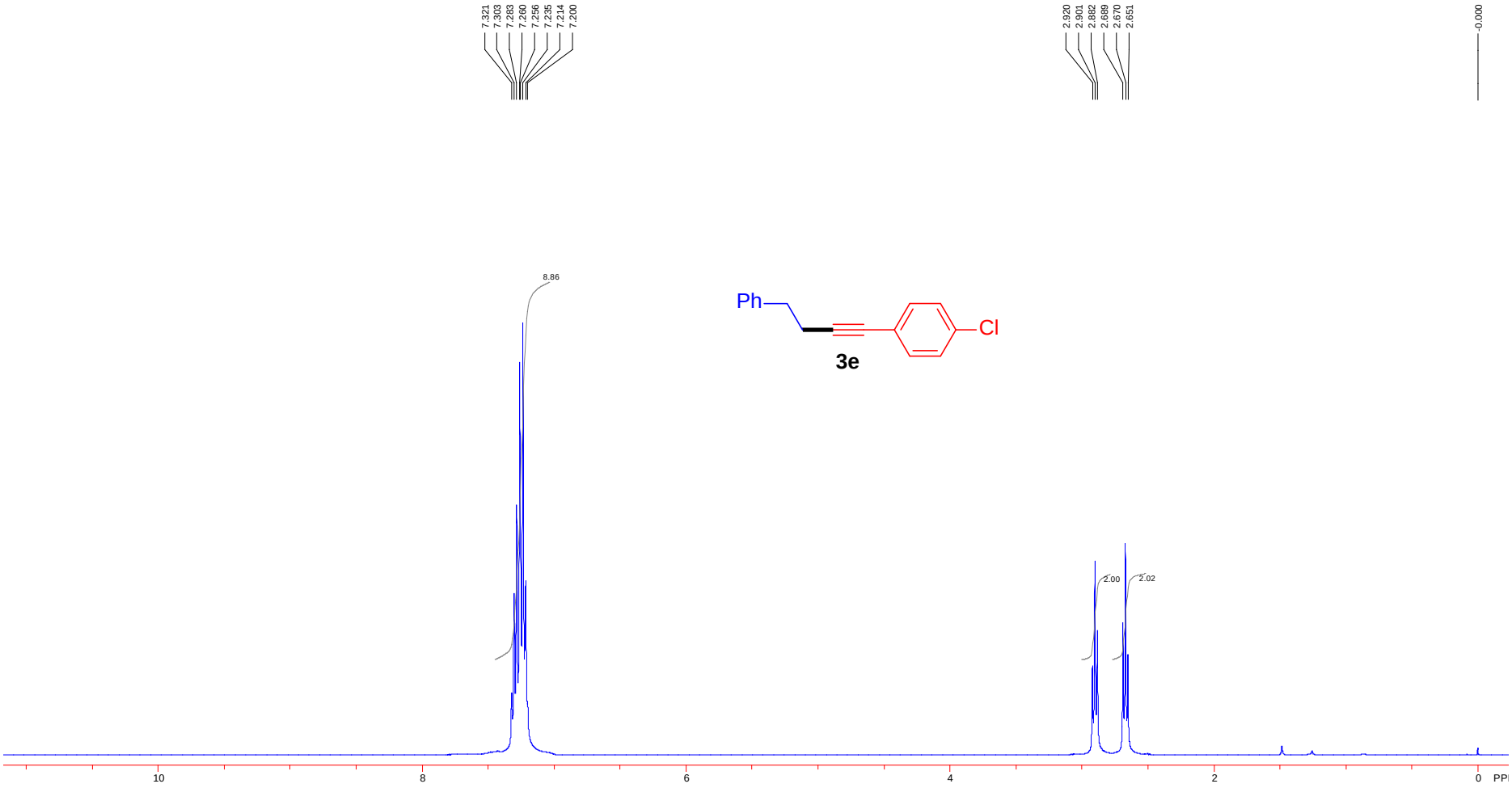
^{1}H NMR(400 MHz, $CDCl_3$)



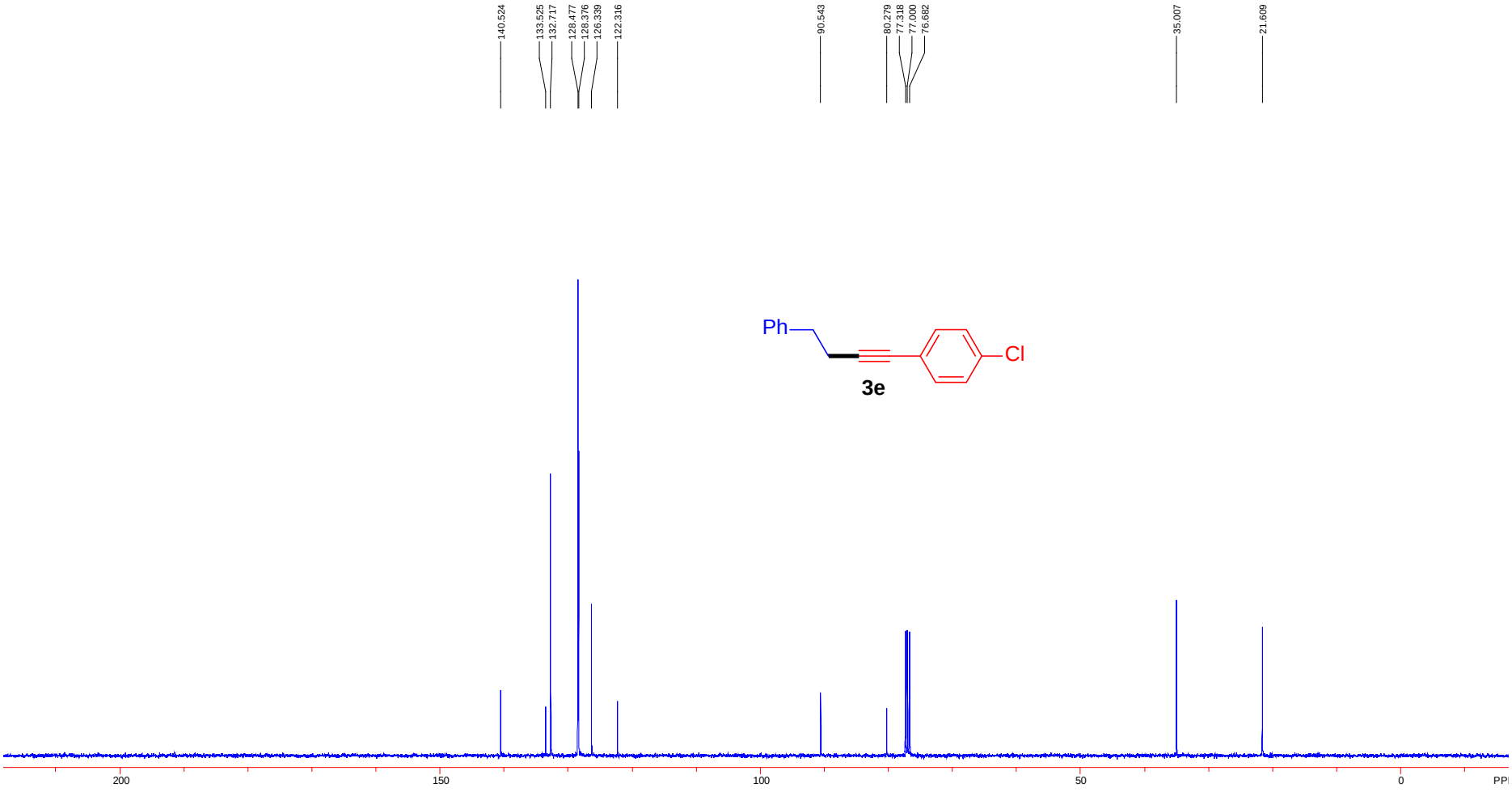
^{13}C NMR(100 MHz, $CDCl_3$)



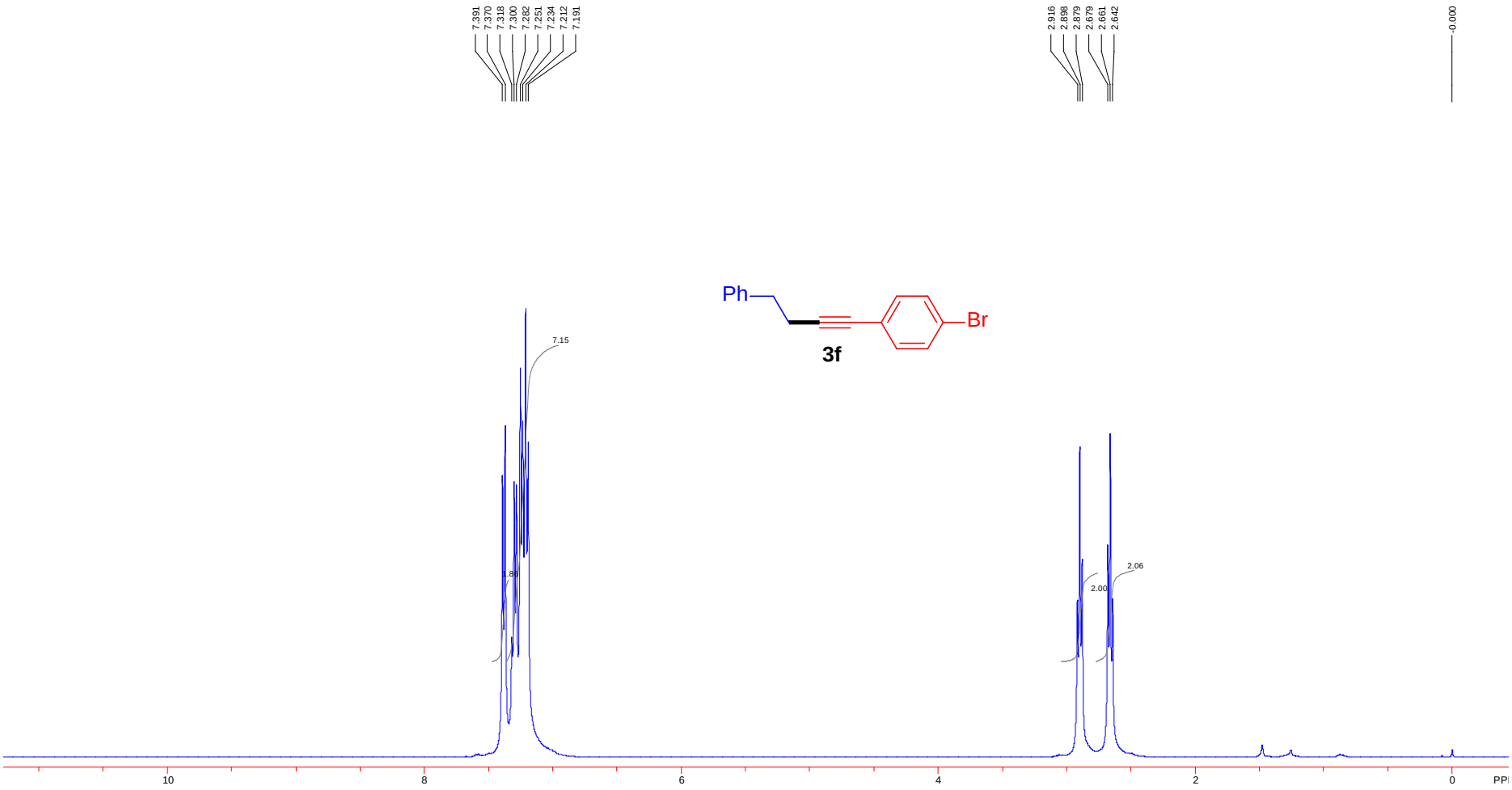
^{1}H NMR(400 MHz, $CDCl_3$)



^{13}C NMR(100 MHz, $CDCl_3$)



^{1}H NMR(400 MHz, $CDCl_3$)



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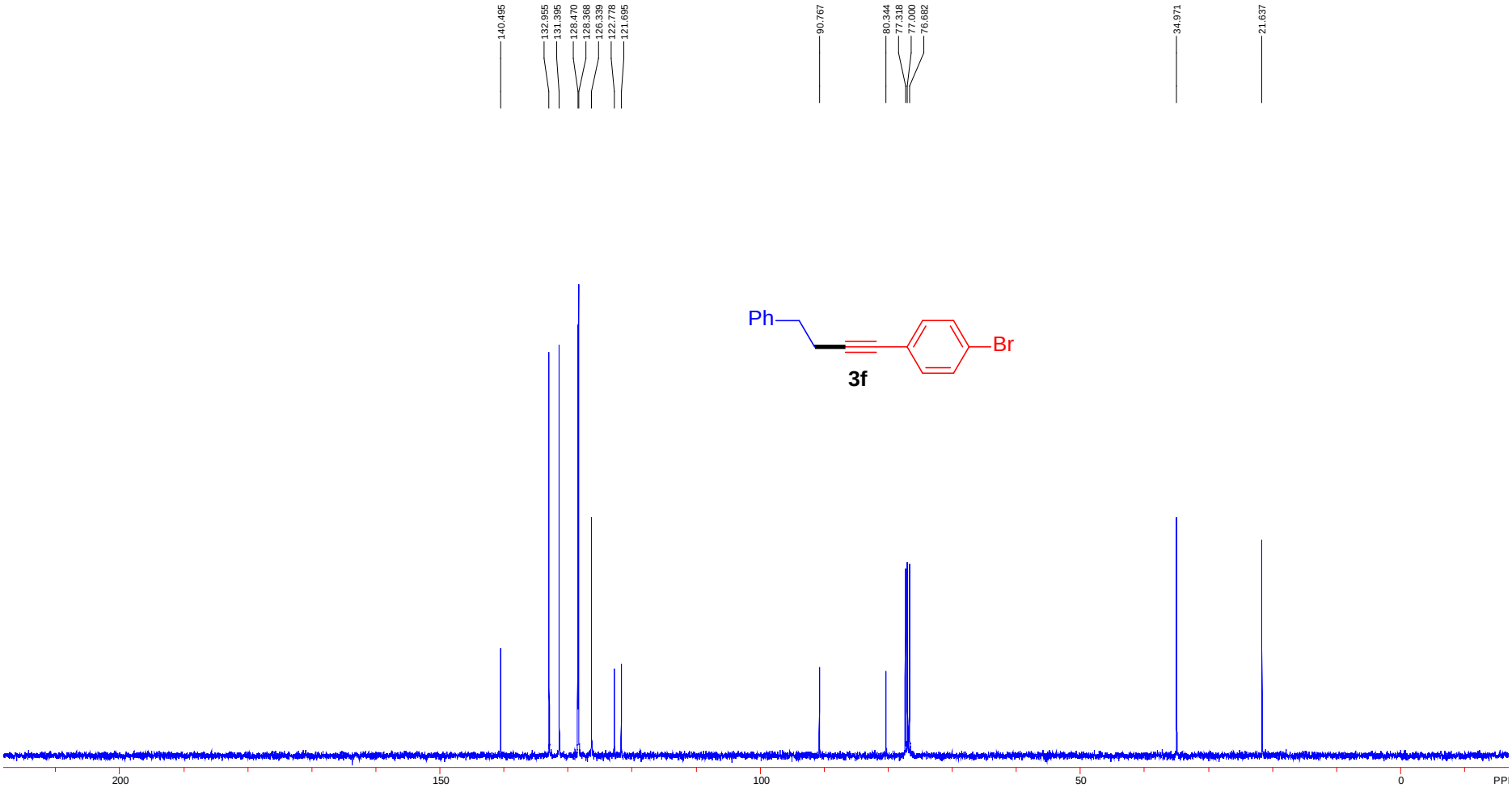

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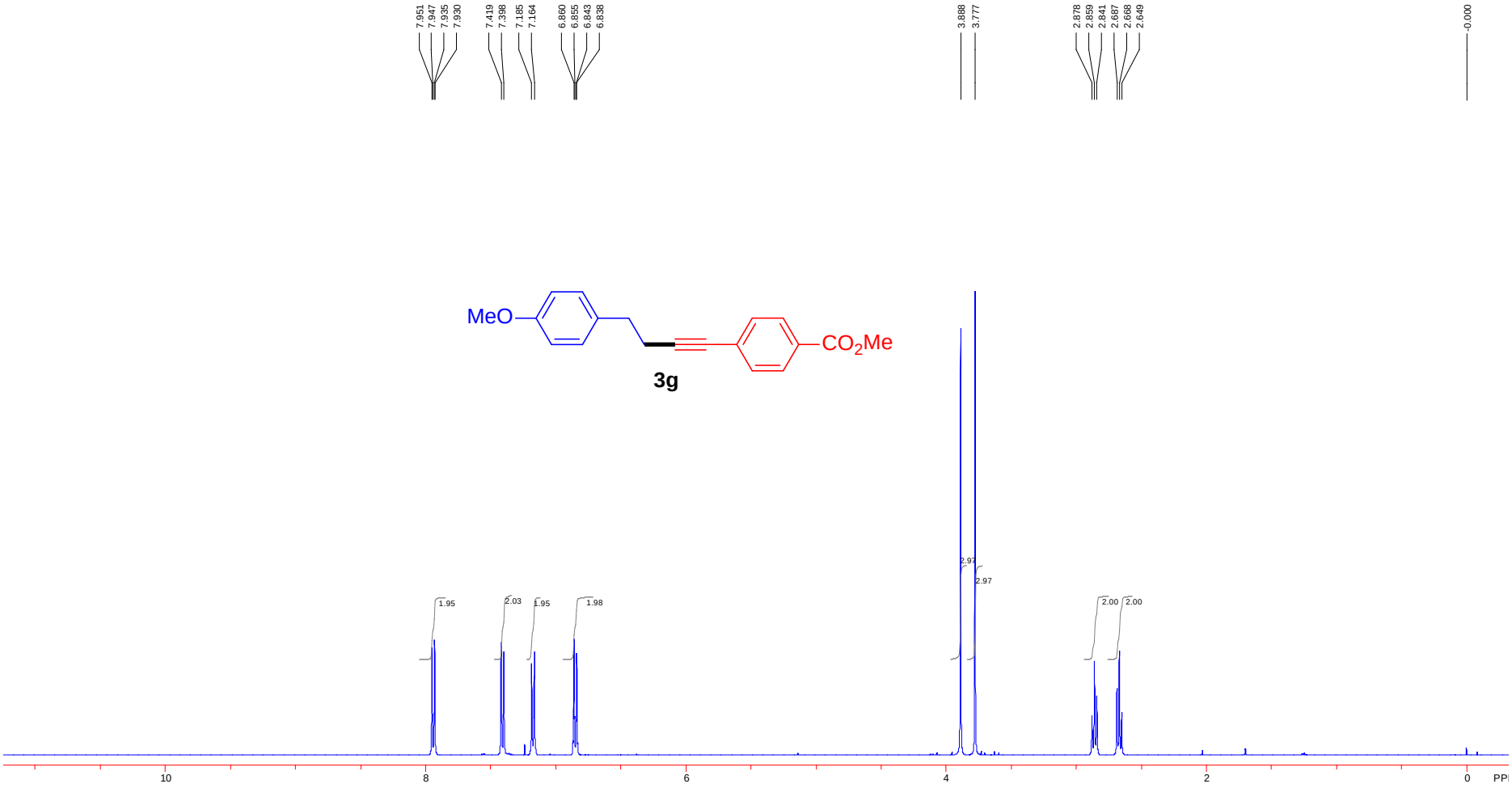

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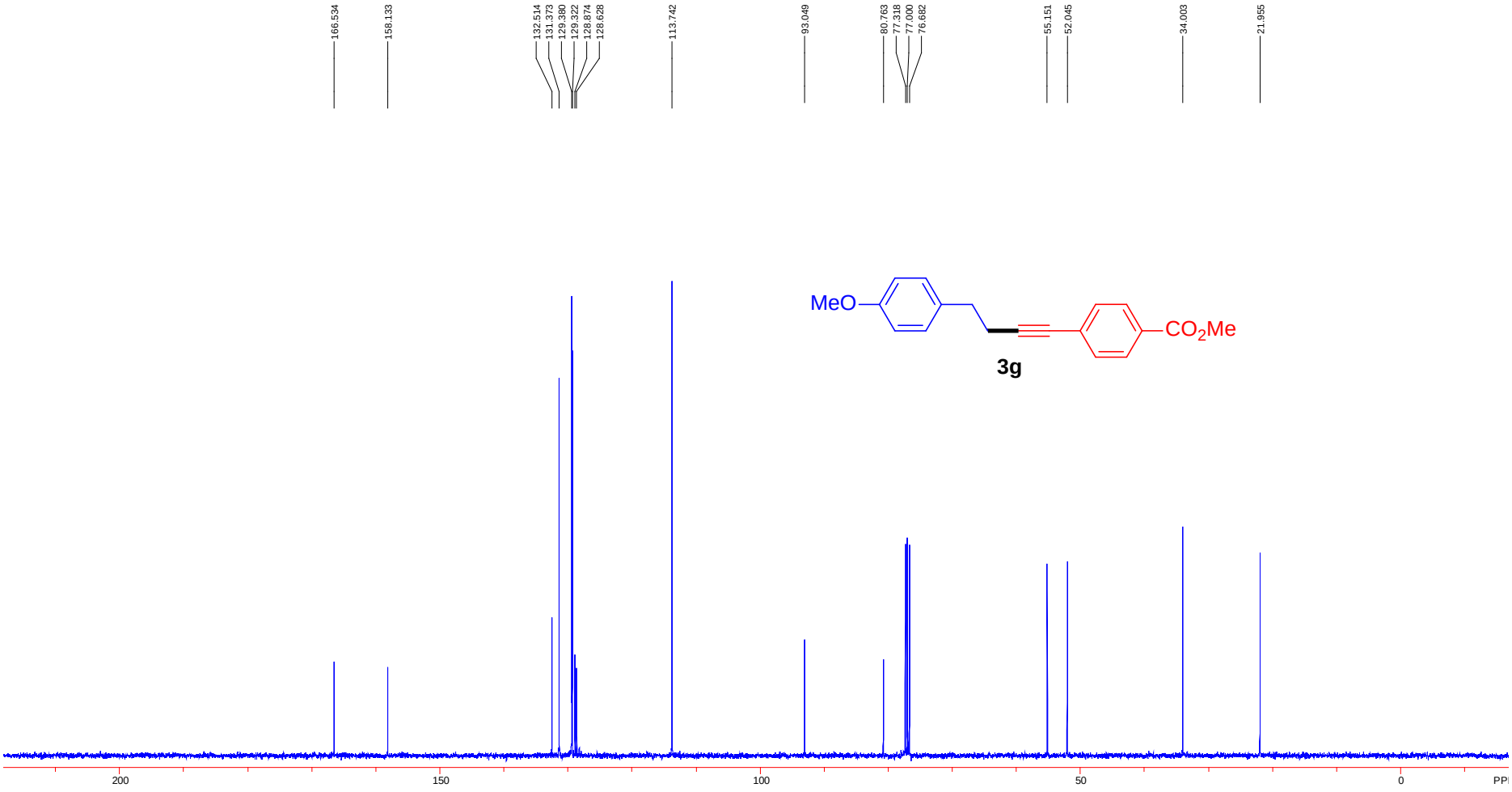

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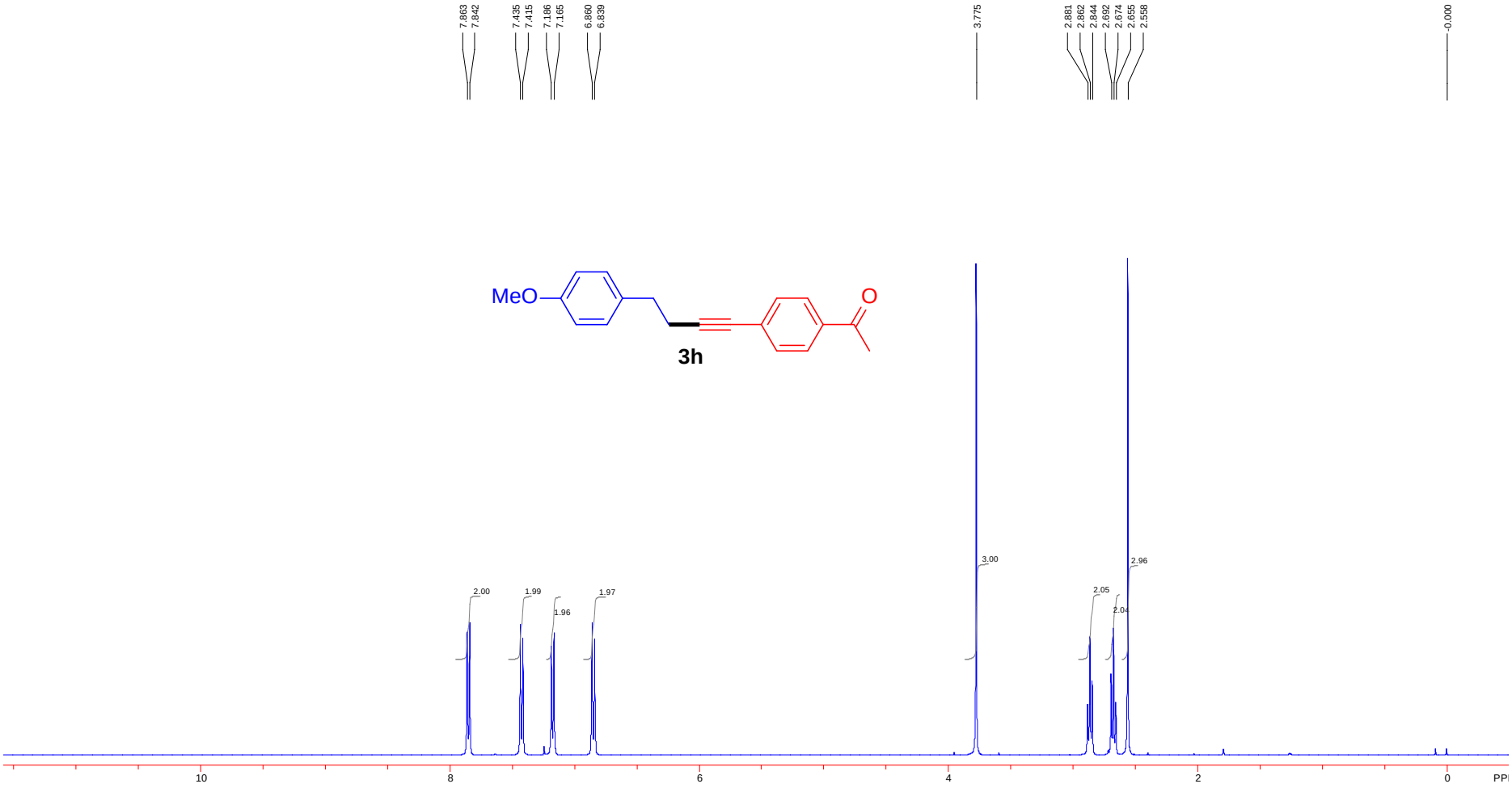

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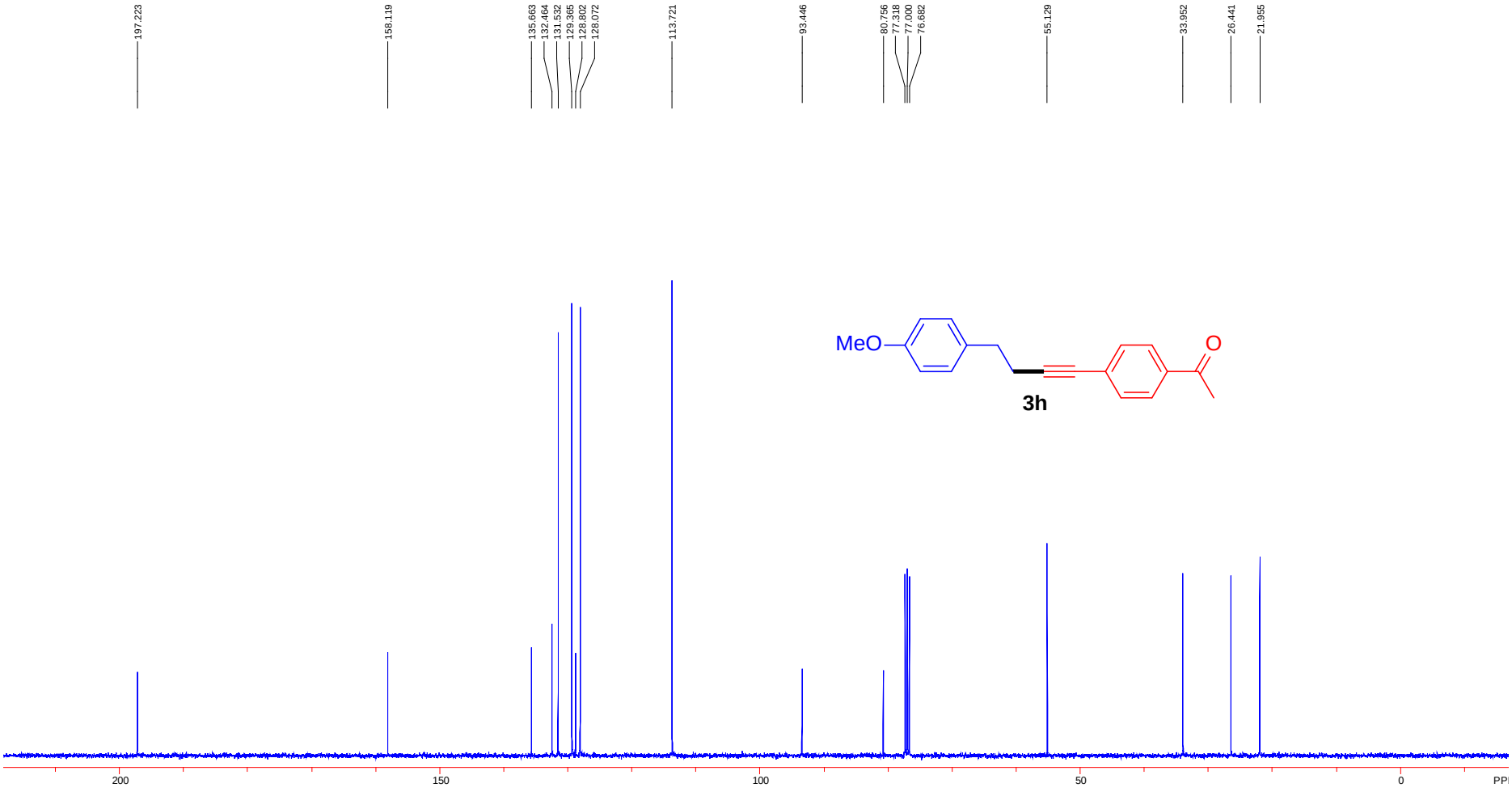

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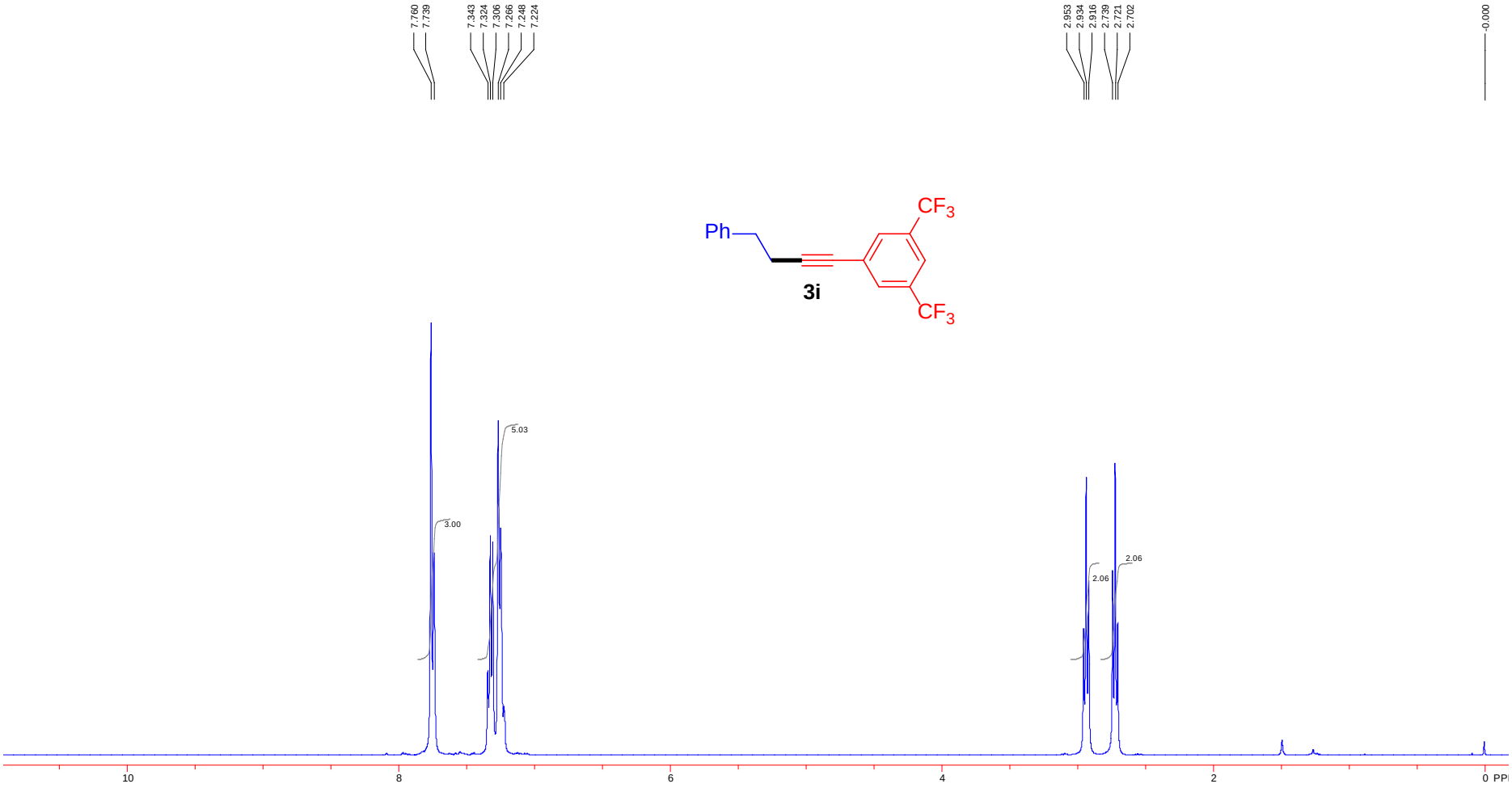
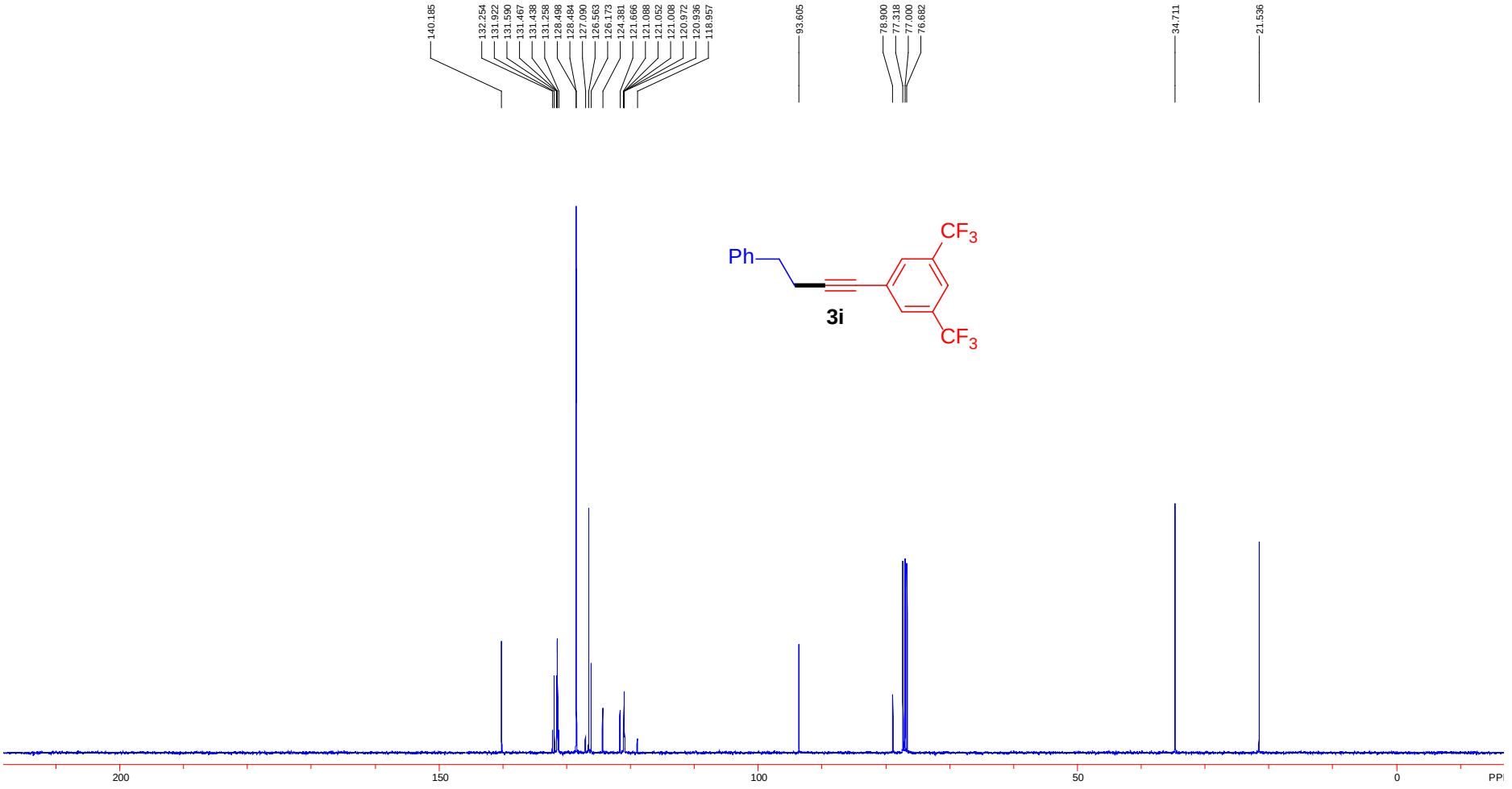
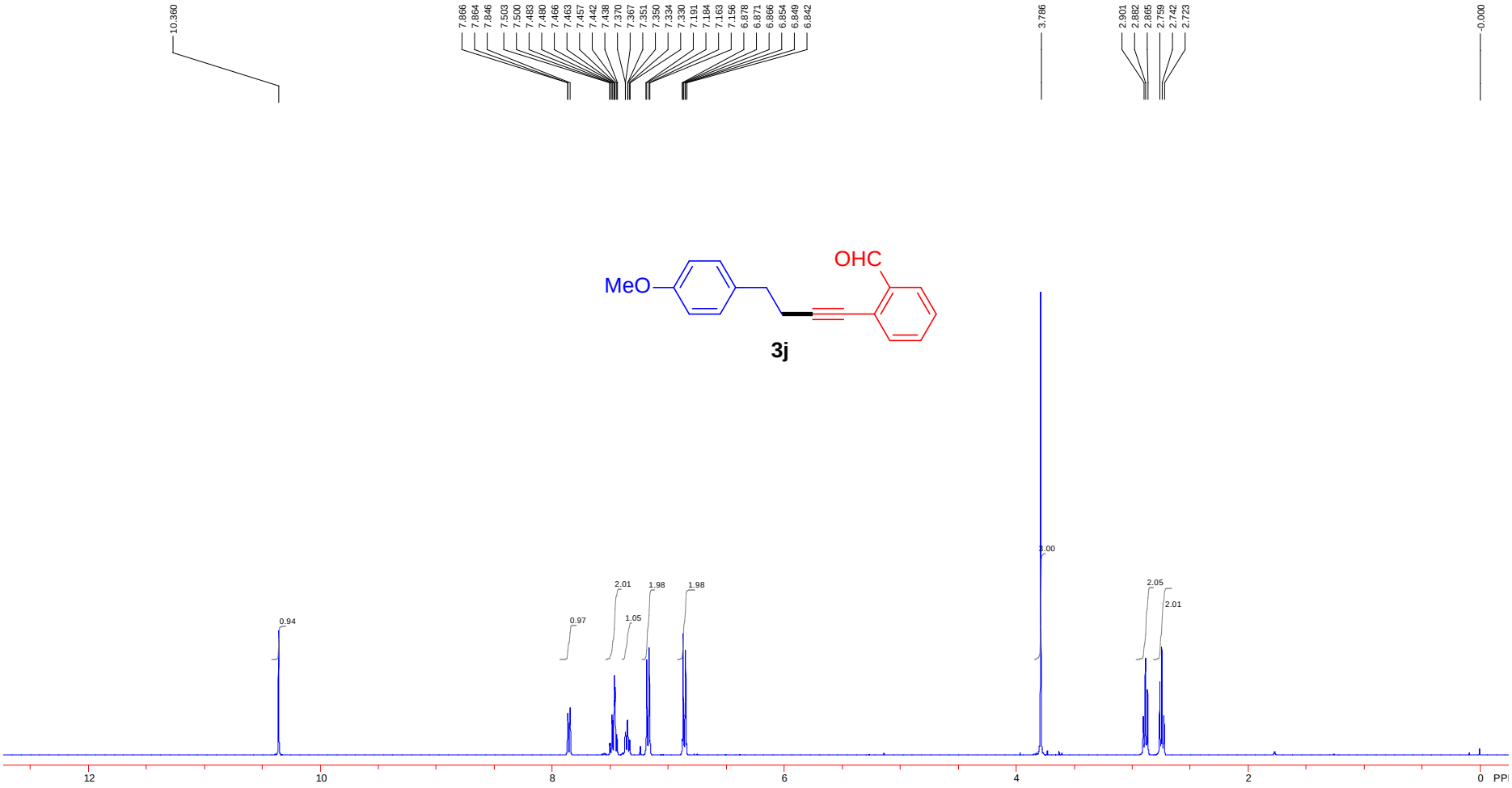


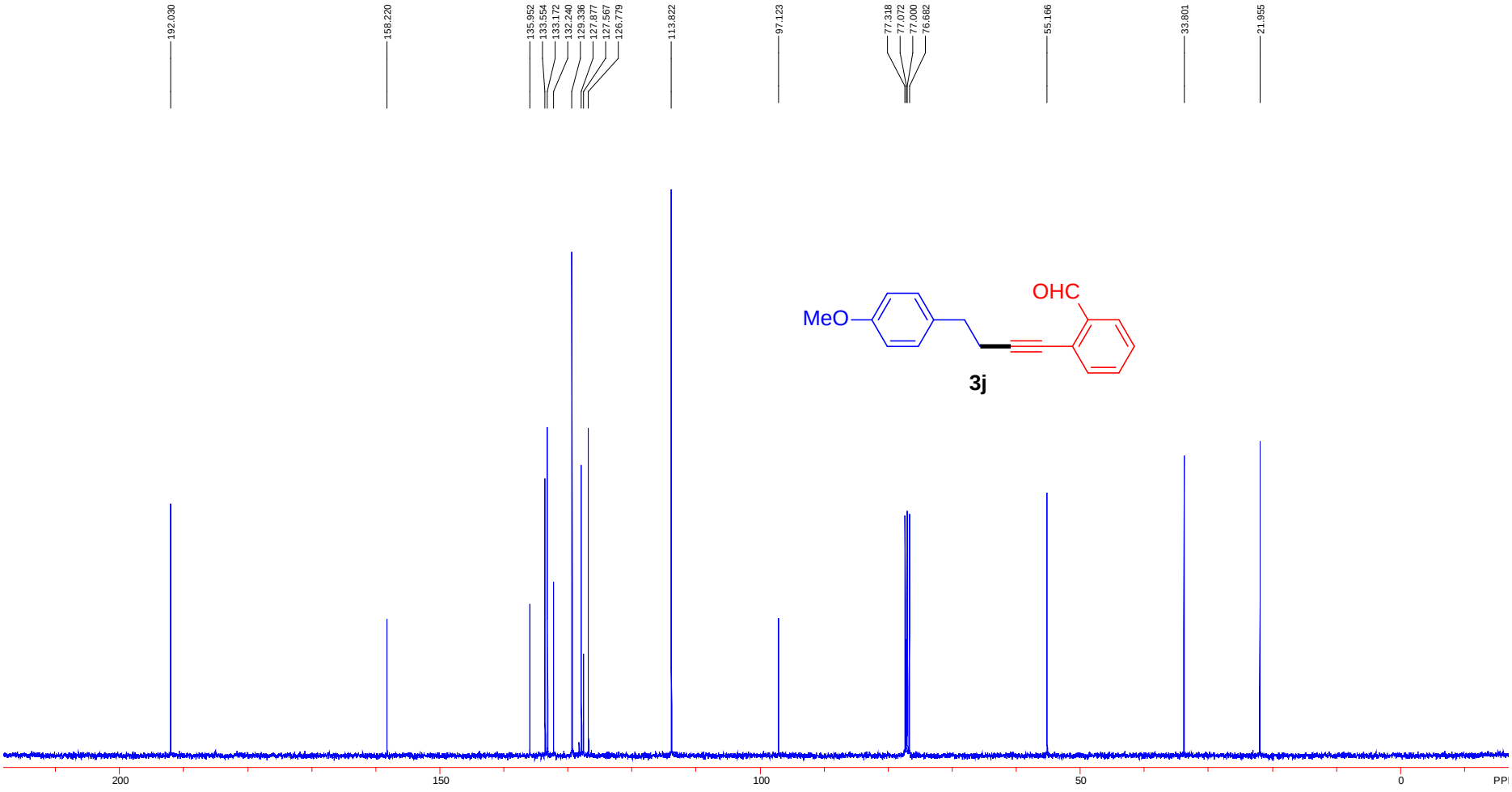
^{13}C NMR(100 MHz, $CDCl_3$)



^{1}H NMR(400 MHz, $CDCl_3$)



^{13}C NMR(100 MHz, $CDCl_3$)



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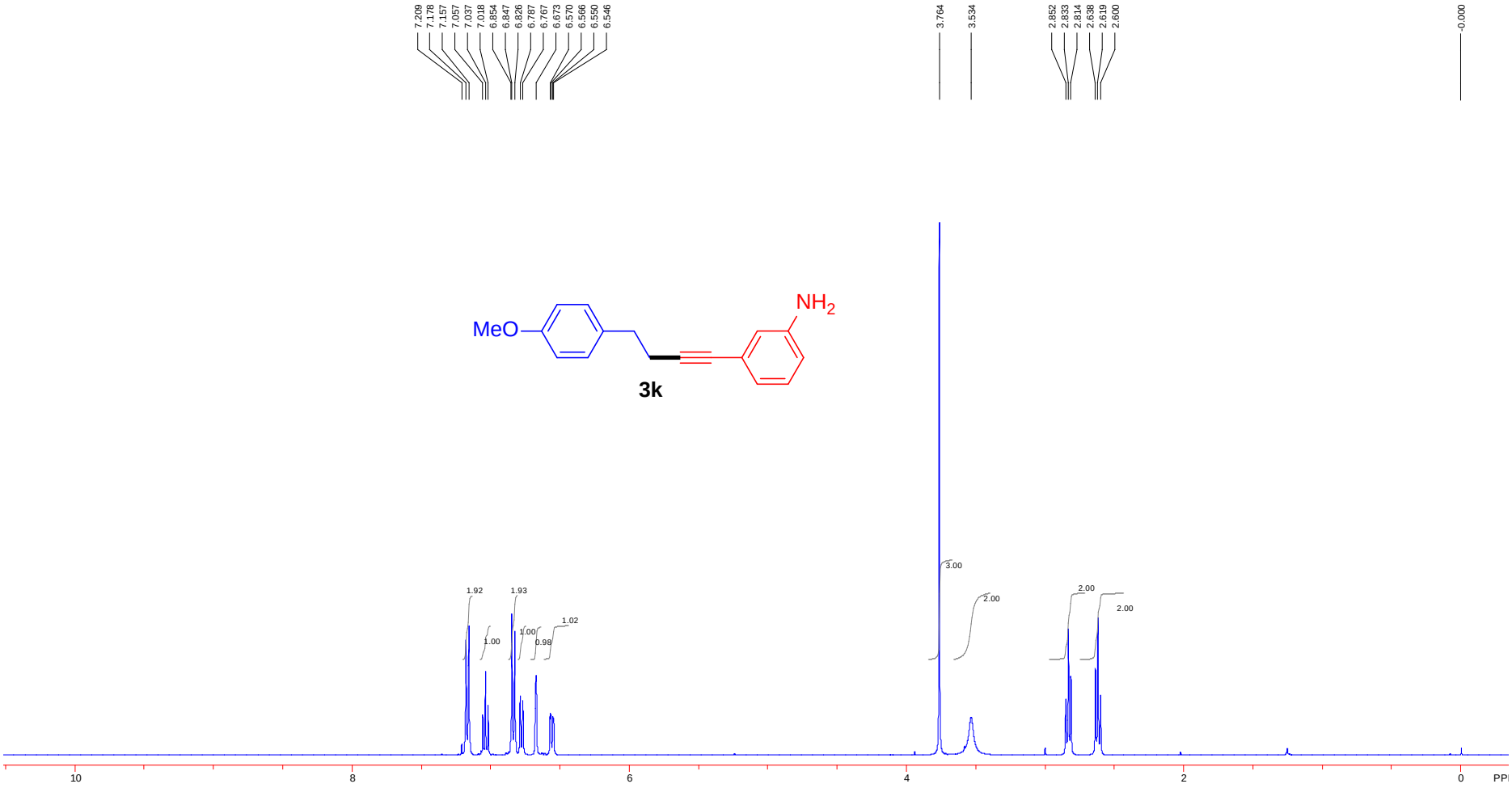

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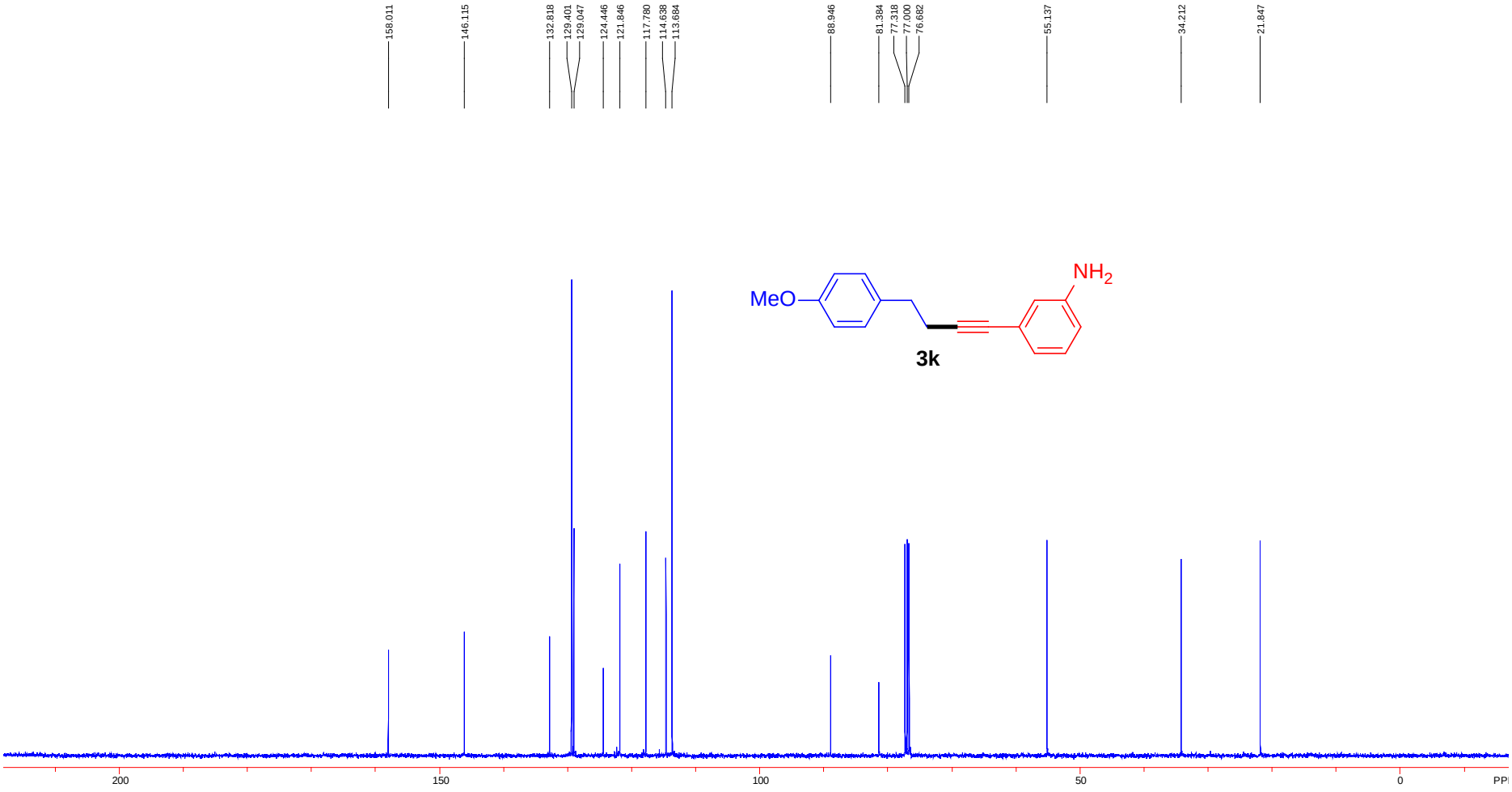

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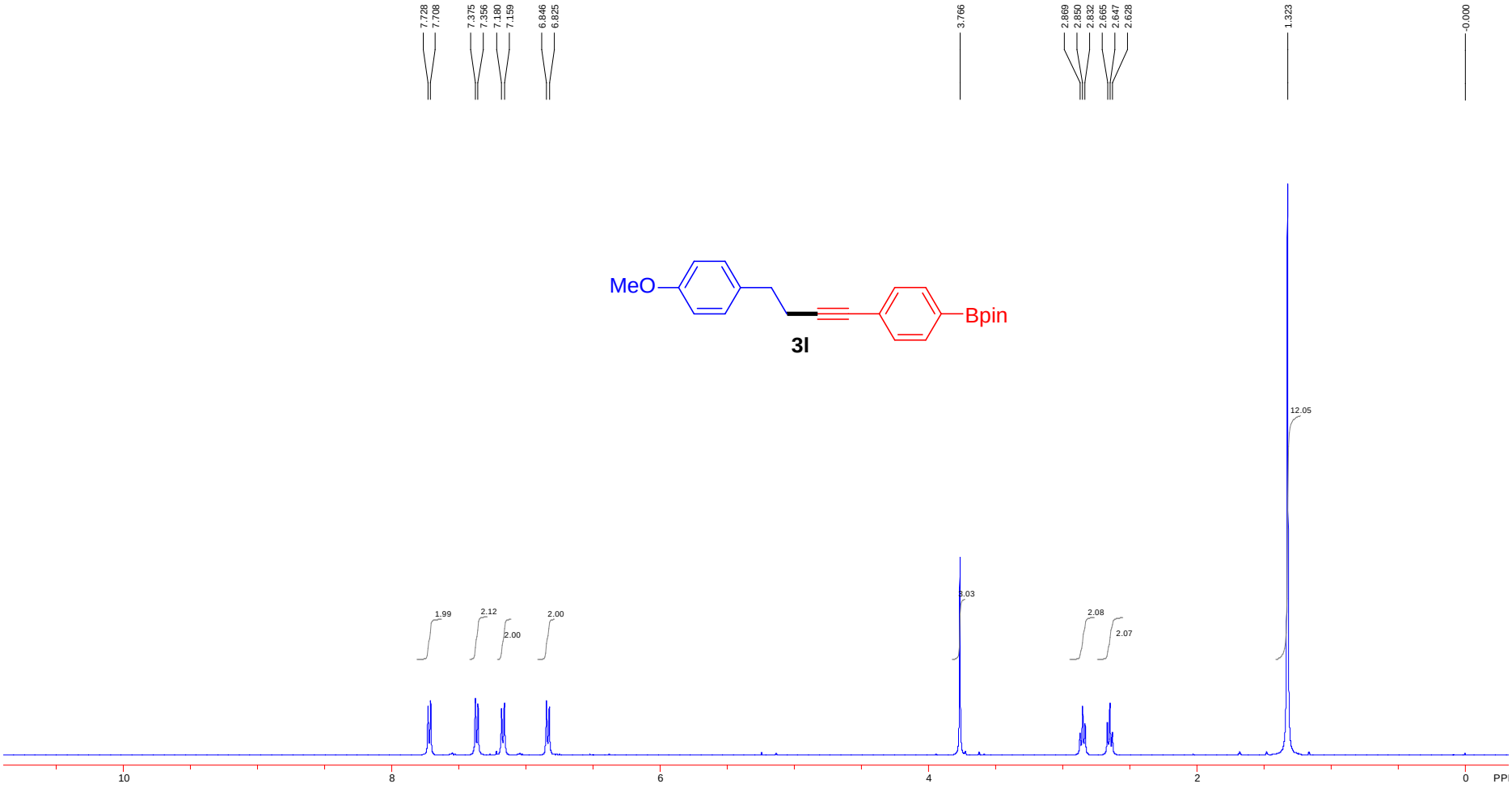

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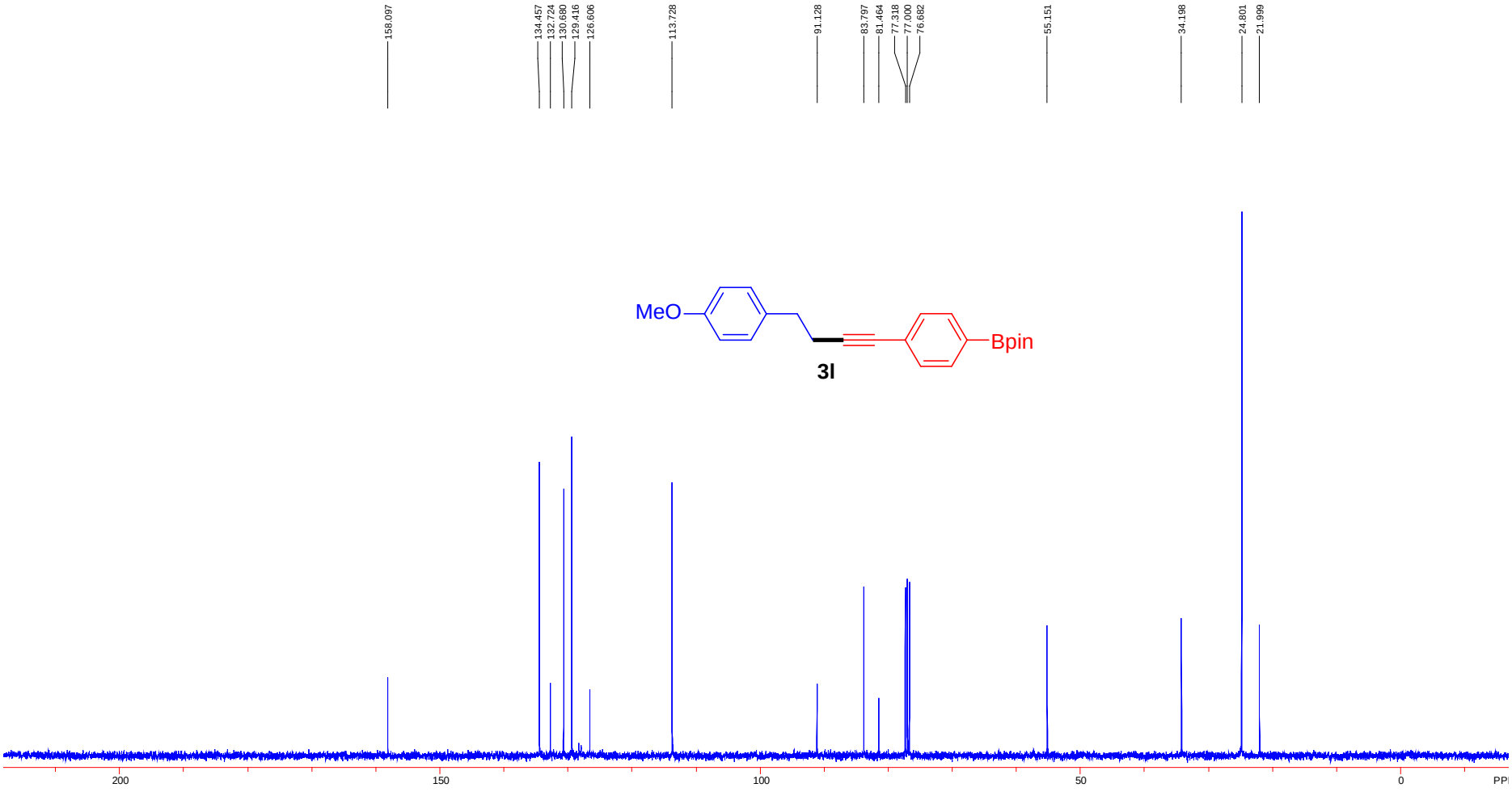
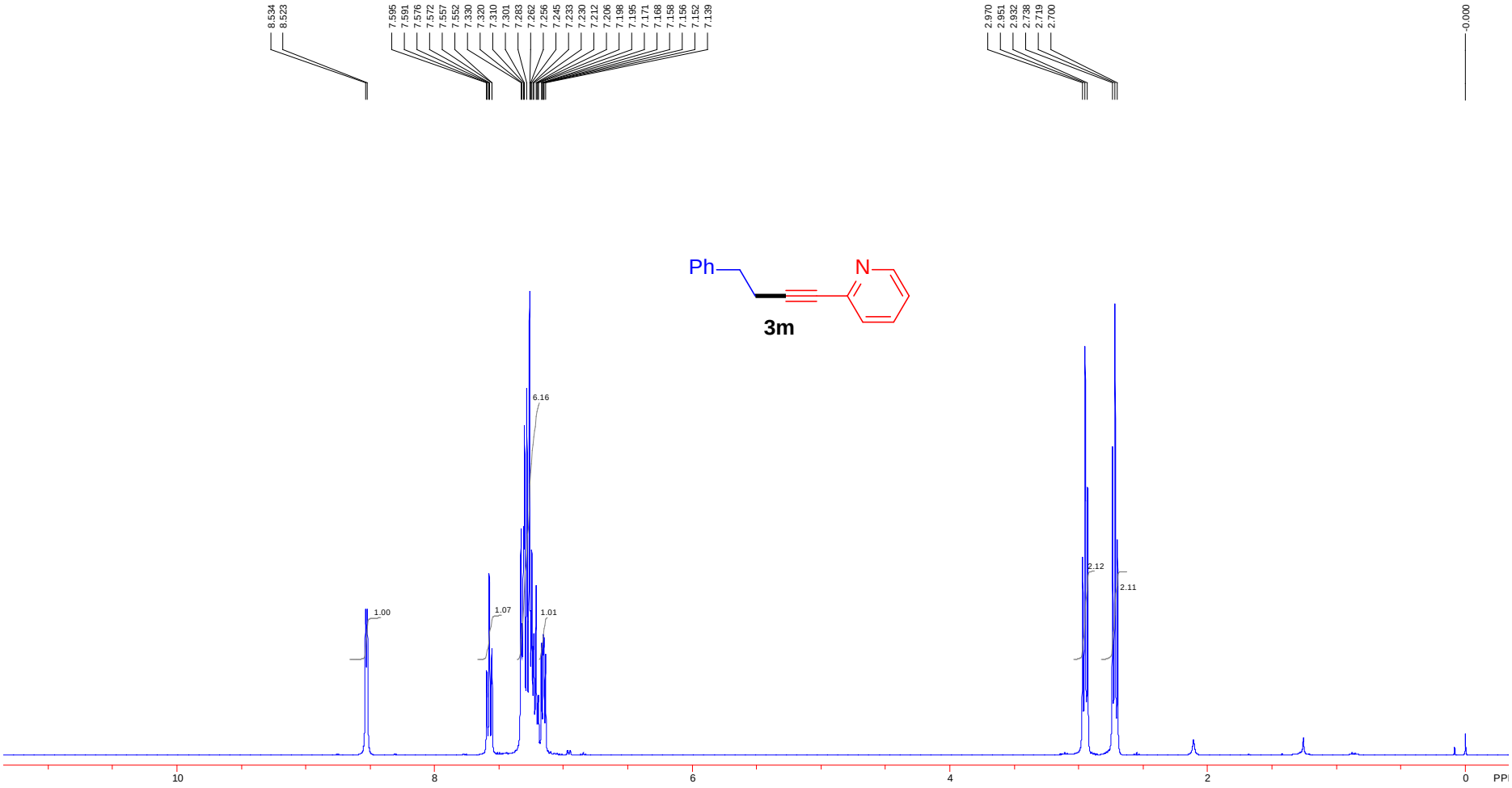


^{1}H NMR(400 MHz, $CDCl_3$)



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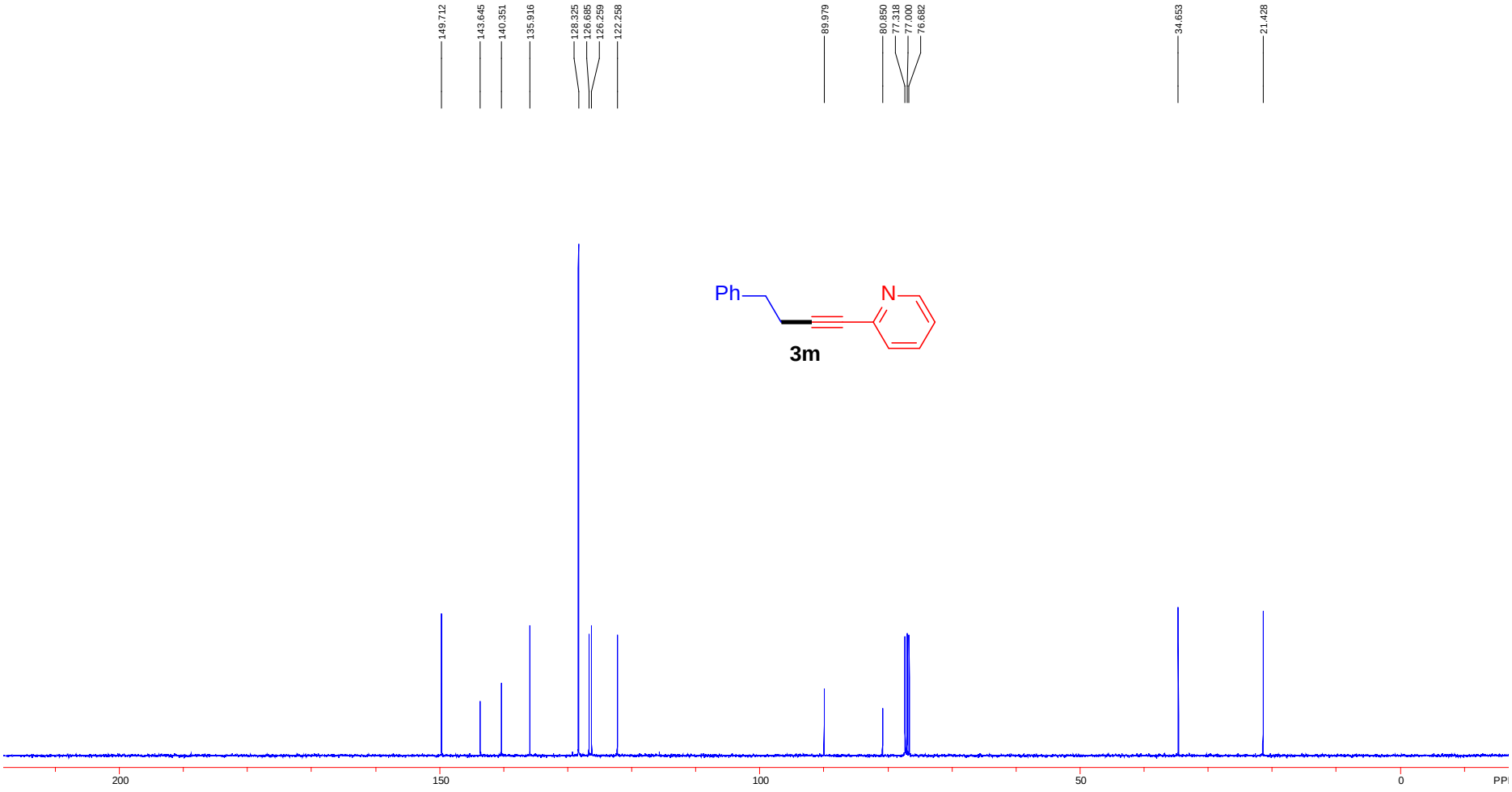
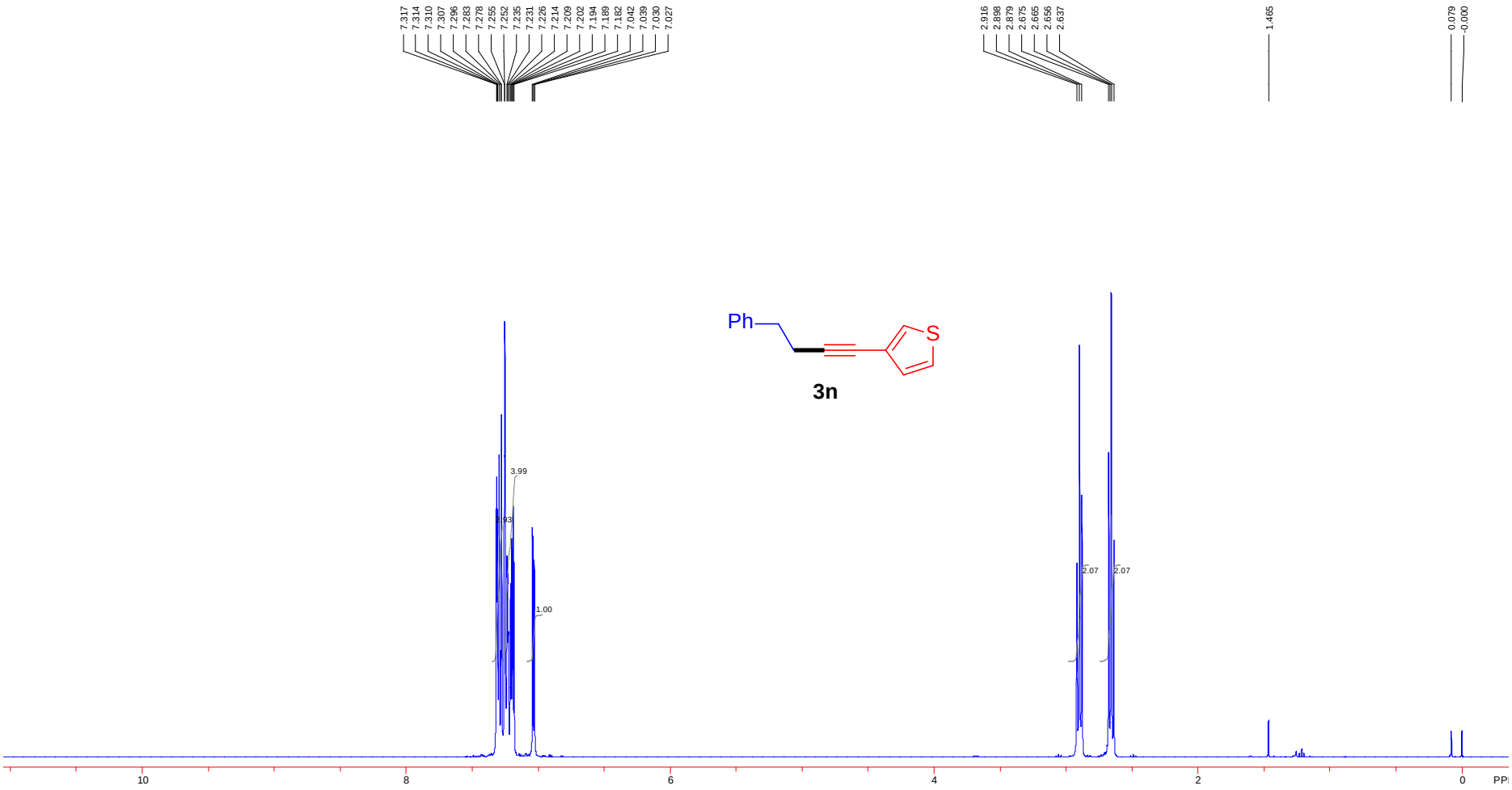
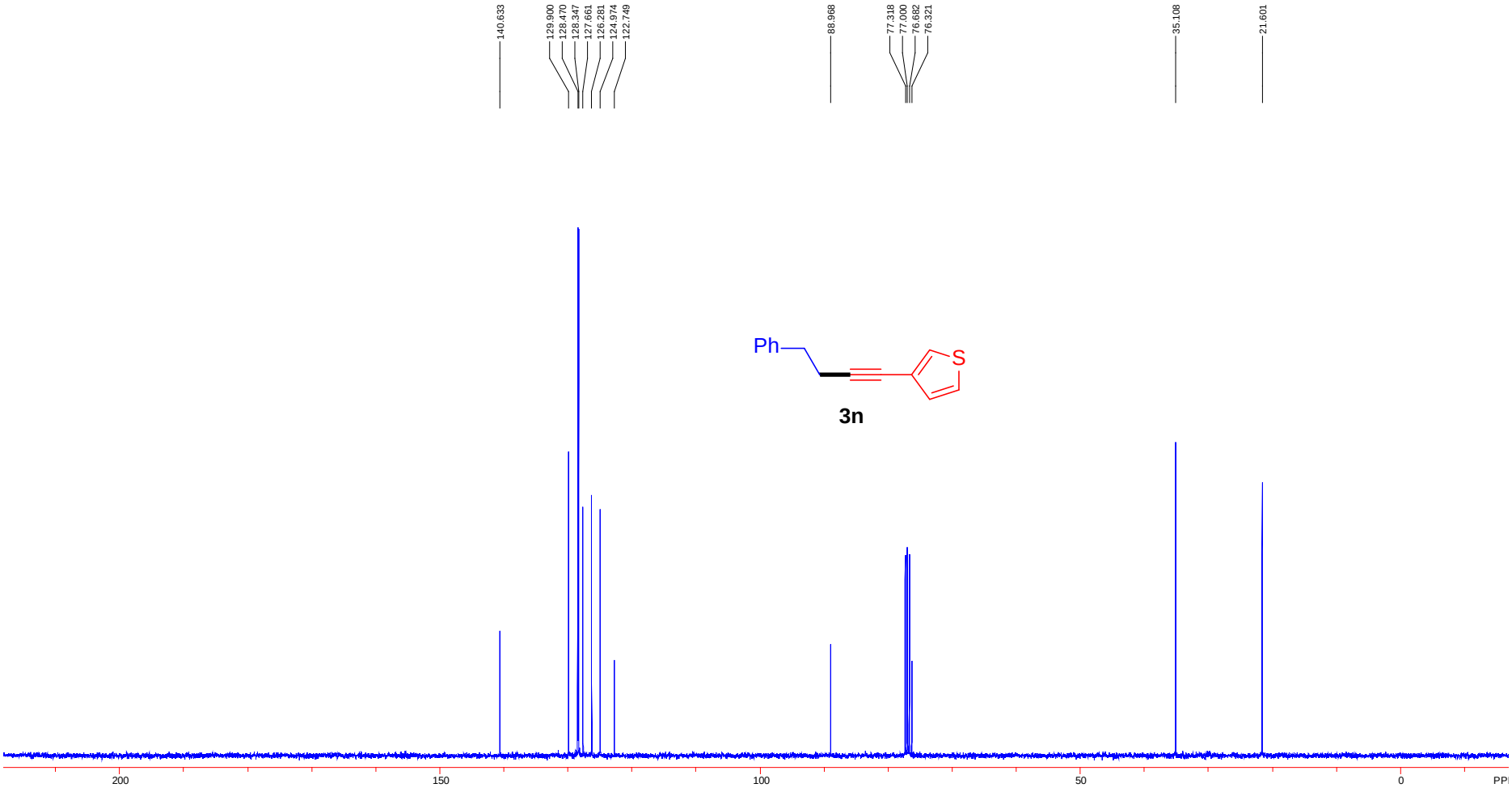


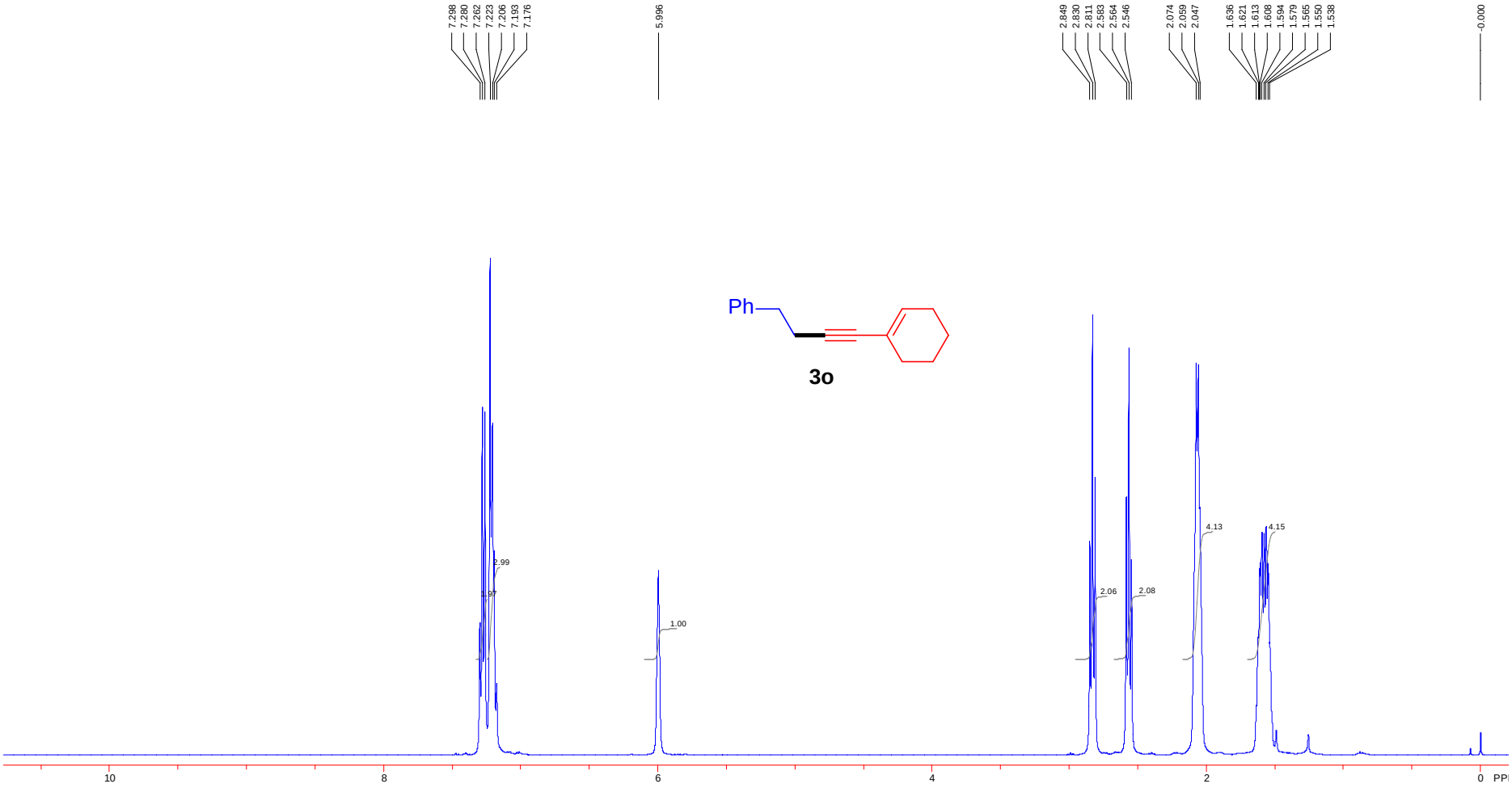
^{1}H NMR(400 MHz, $CDCl_3$)



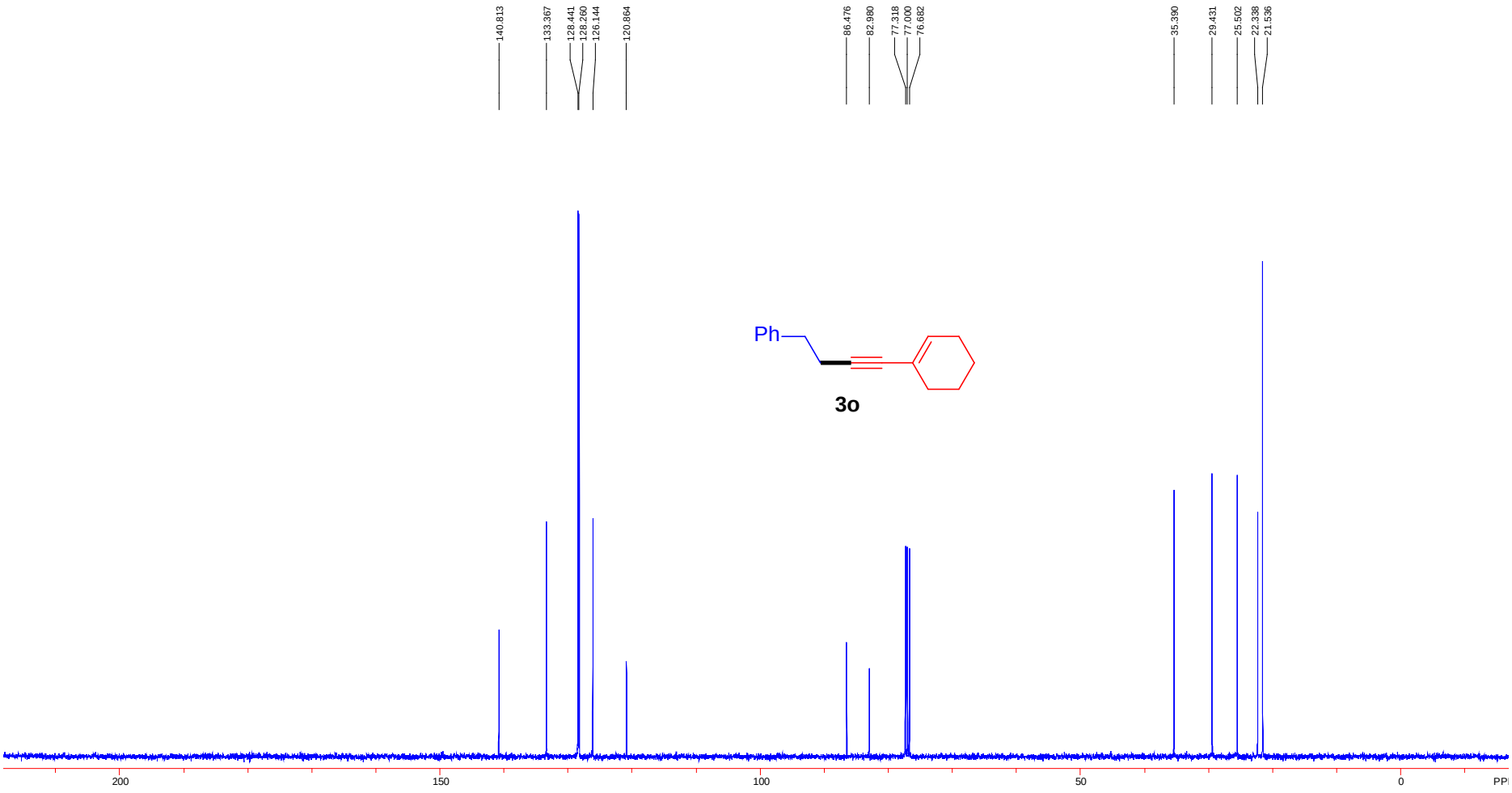
^{13}C NMR(100 MHz, $CDCl_3$)



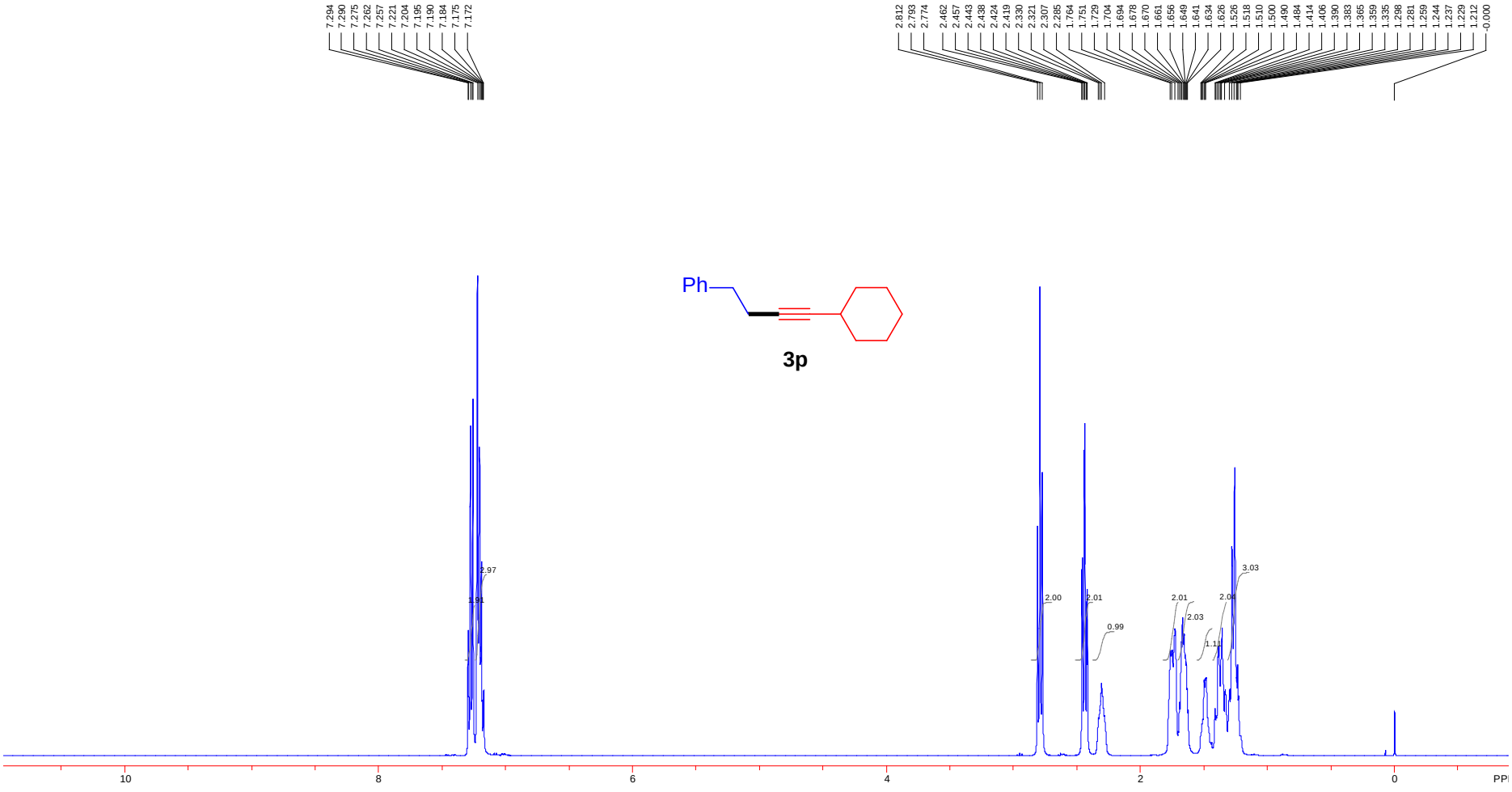
^{1}H NMR(400 MHz, $CDCl_3$)



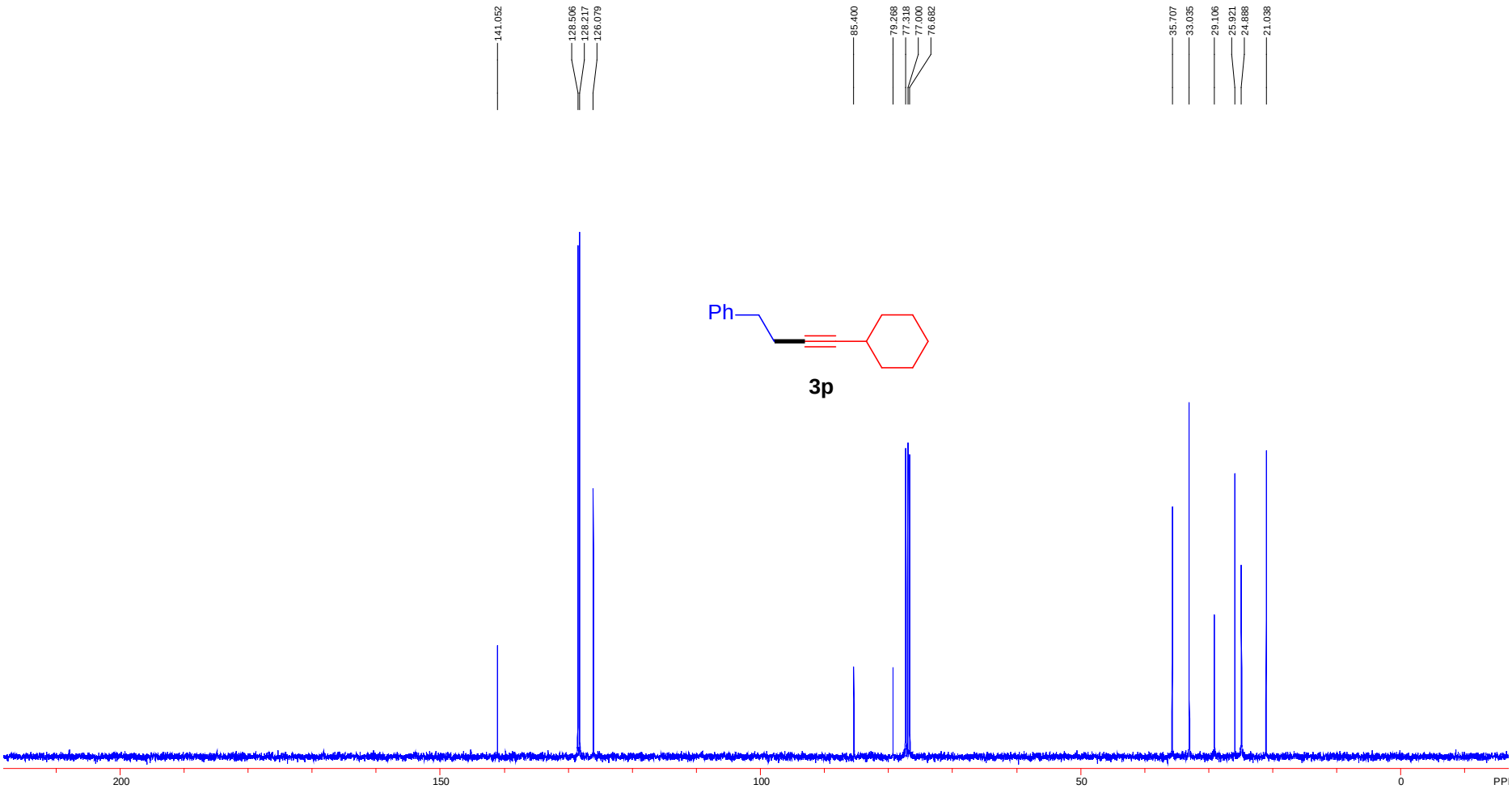
^{13}C NMR(100 MHz, $CDCl_3$)



^{1}H NMR(400 MHz, $CDCl_3$)



^{13}C NMR(100 MHz, $CDCl_3$)



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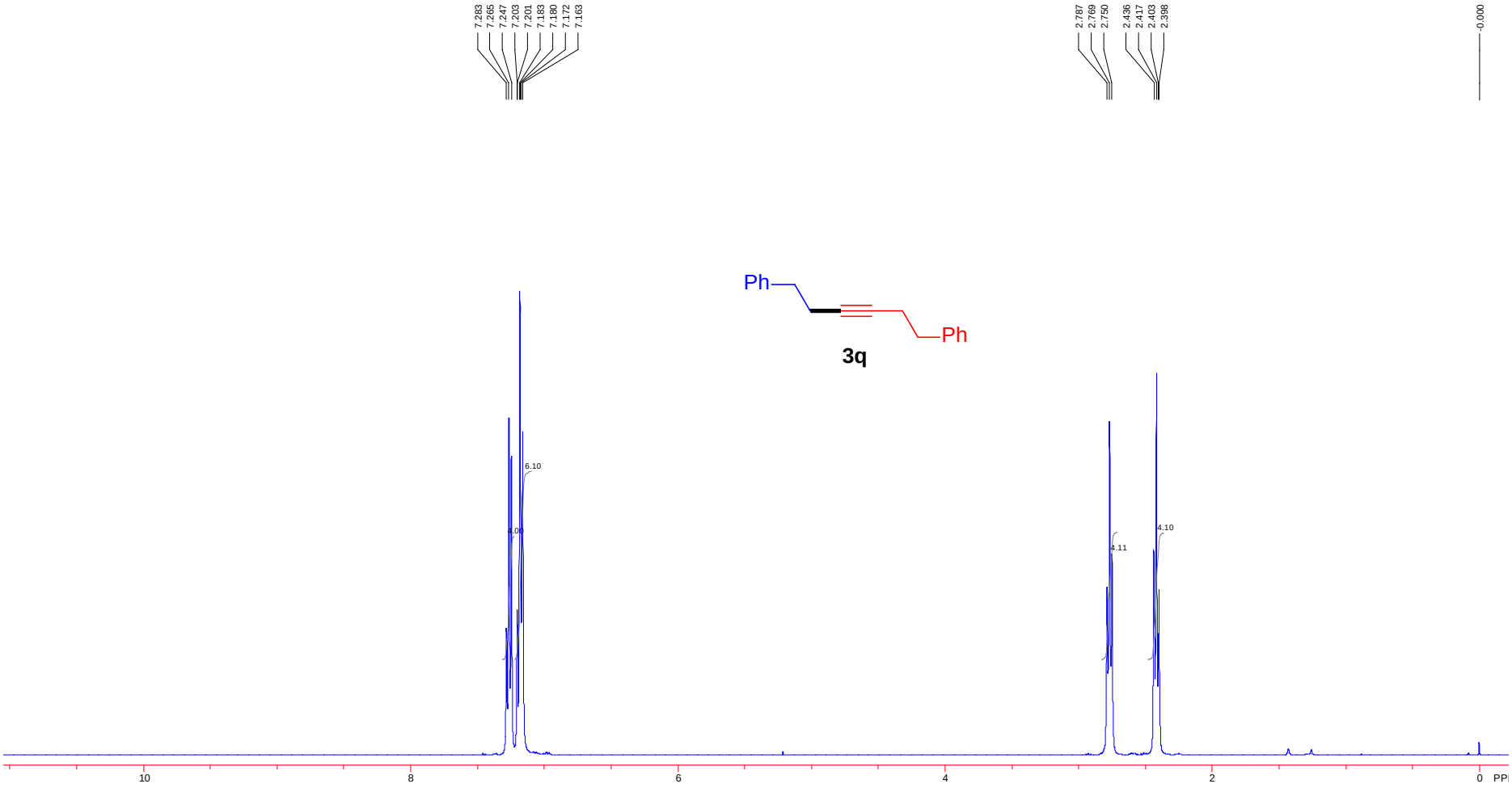
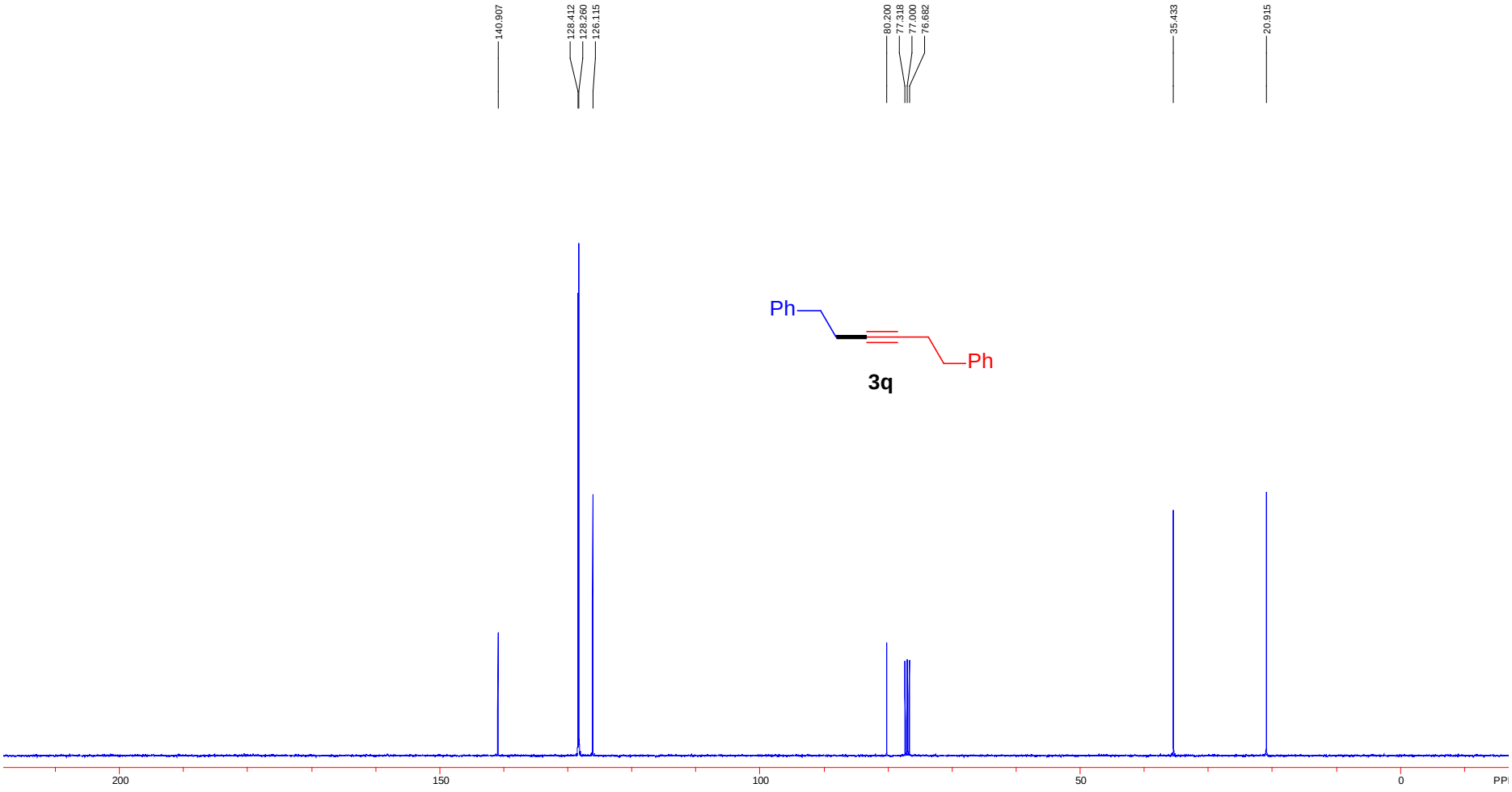
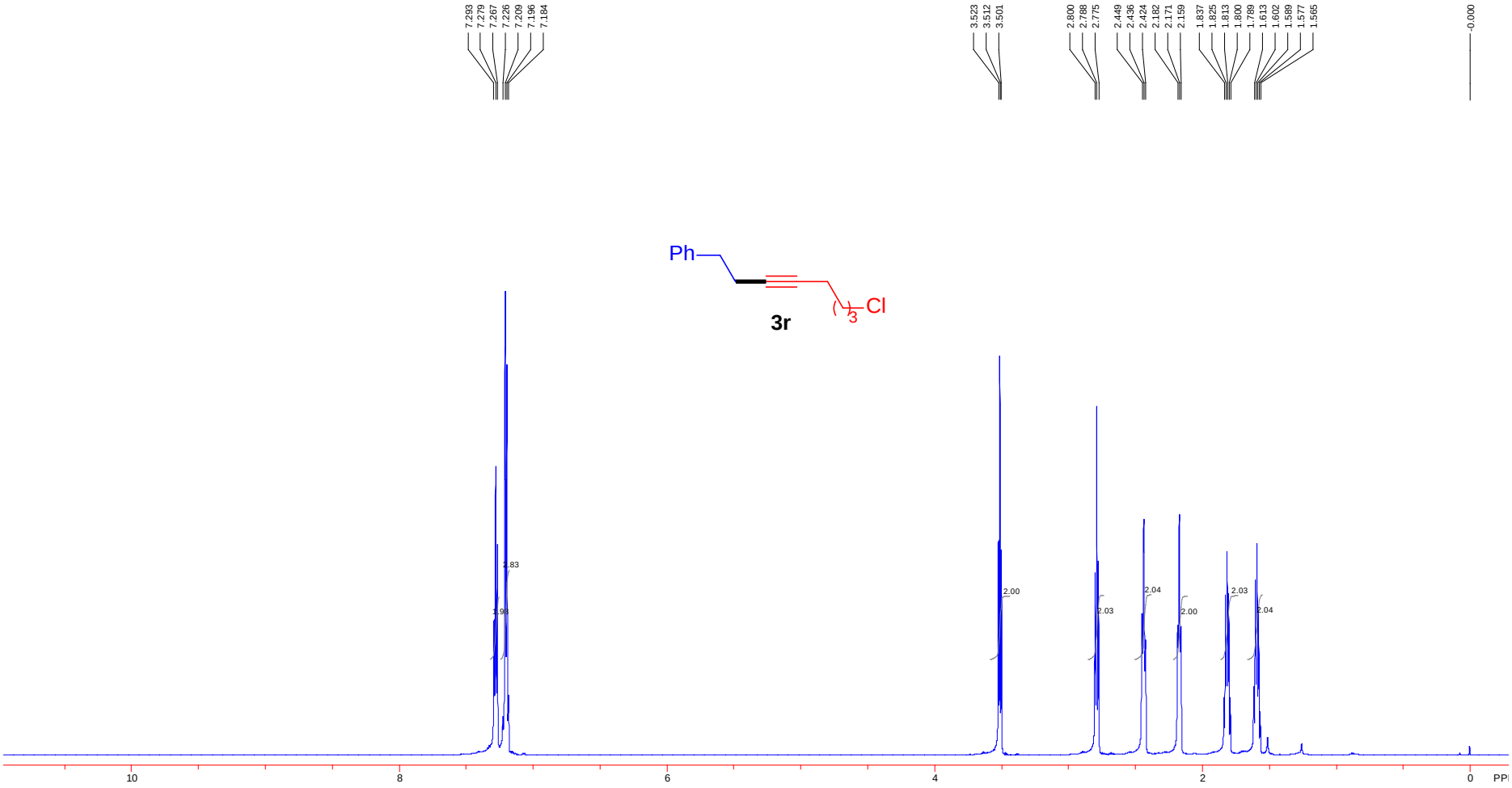


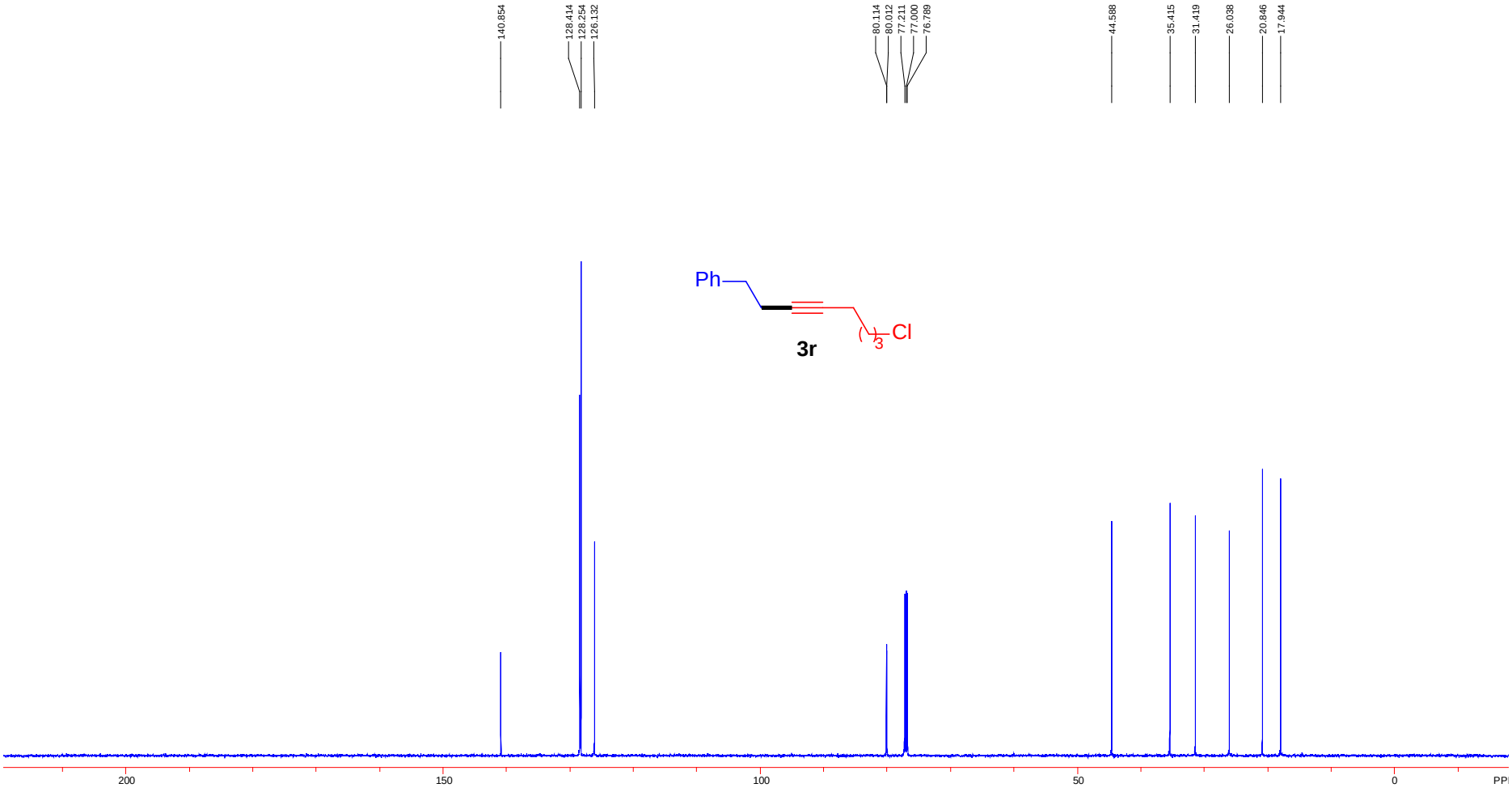
^{13}C NMR(100 MHz, $CDCl_3$)



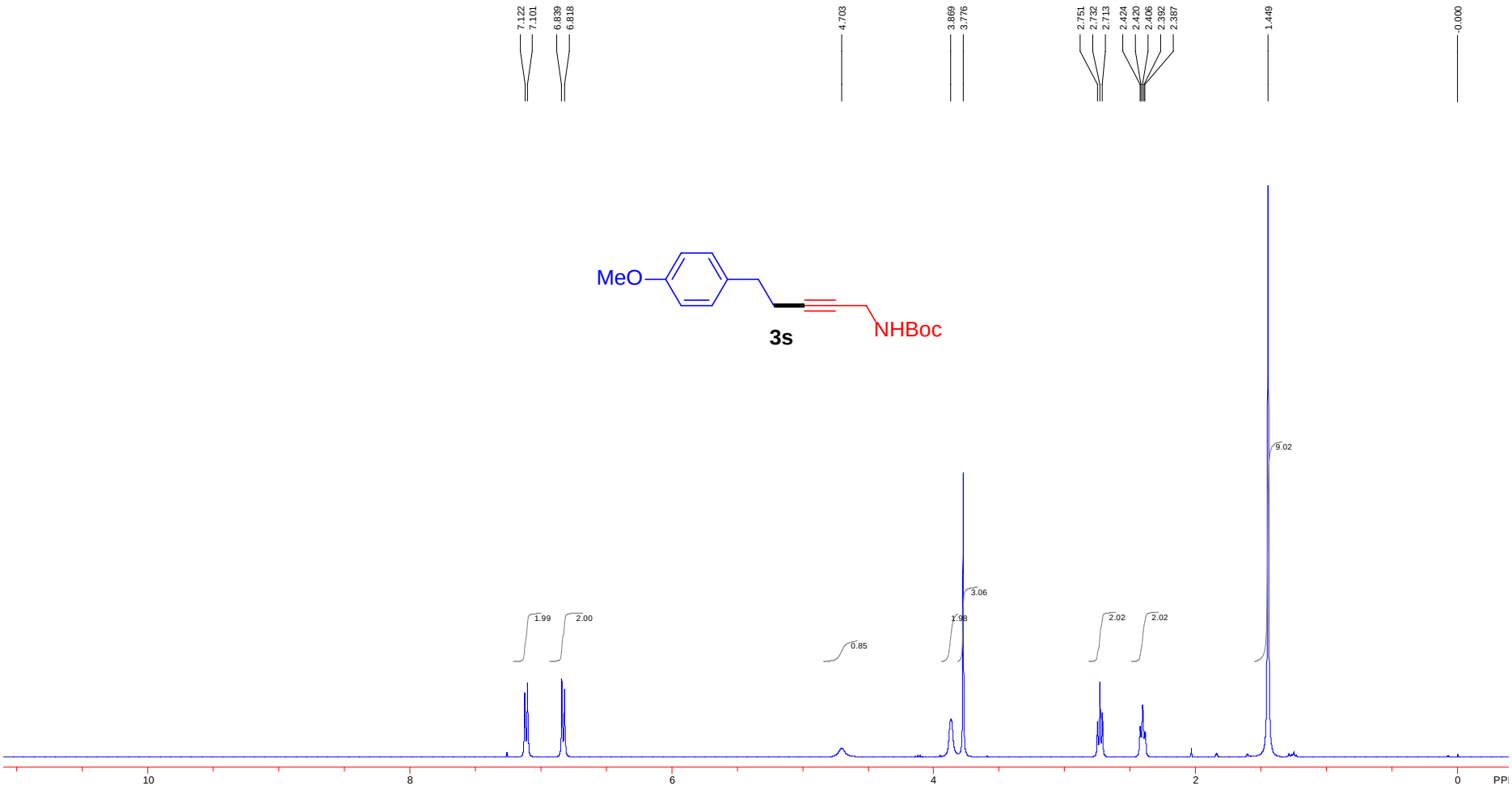
^{1}H NMR(600 MHz, $CDCl_3$)



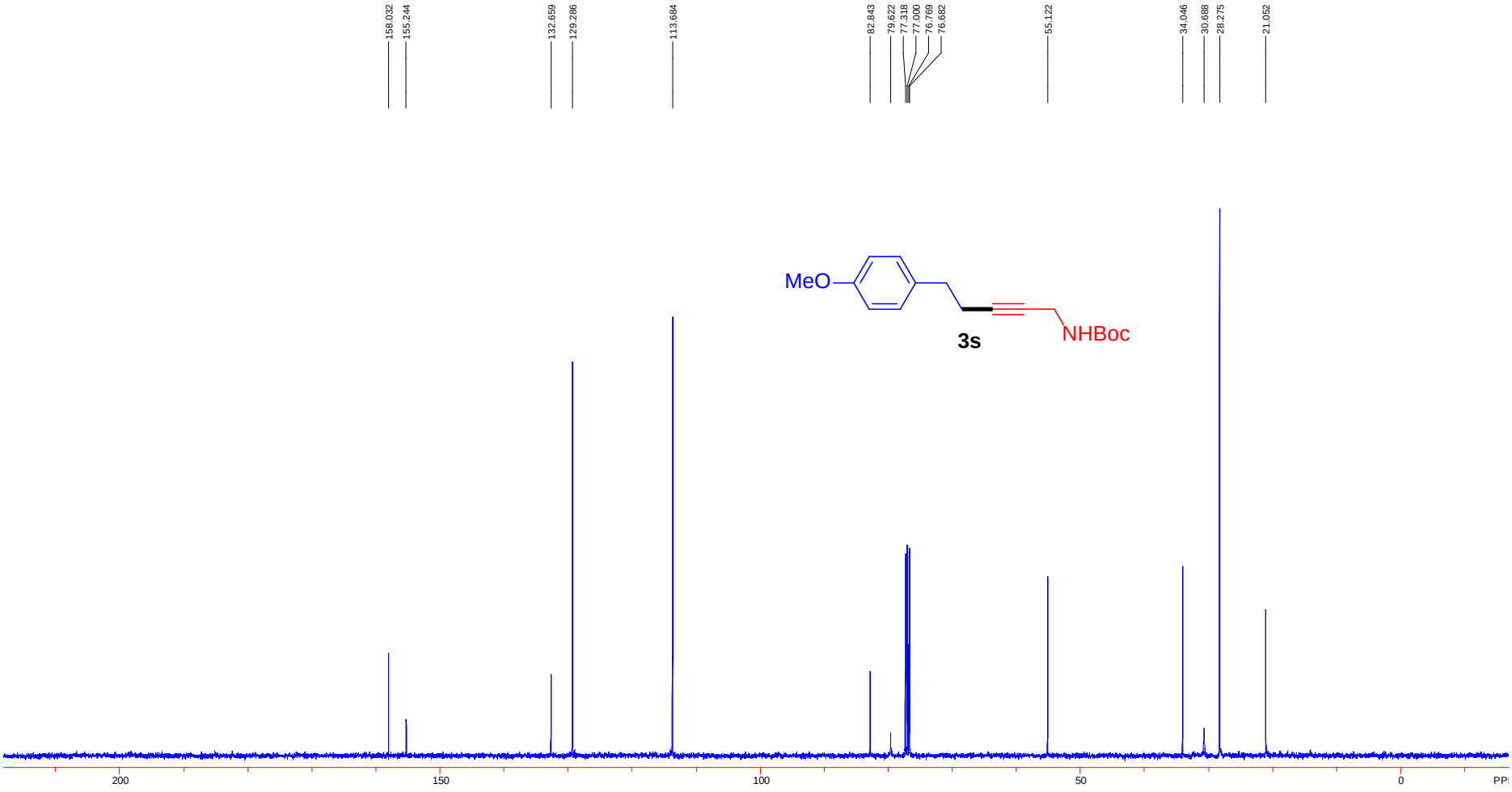
^{13}C NMR(151 MHz, $CDCl_3$)



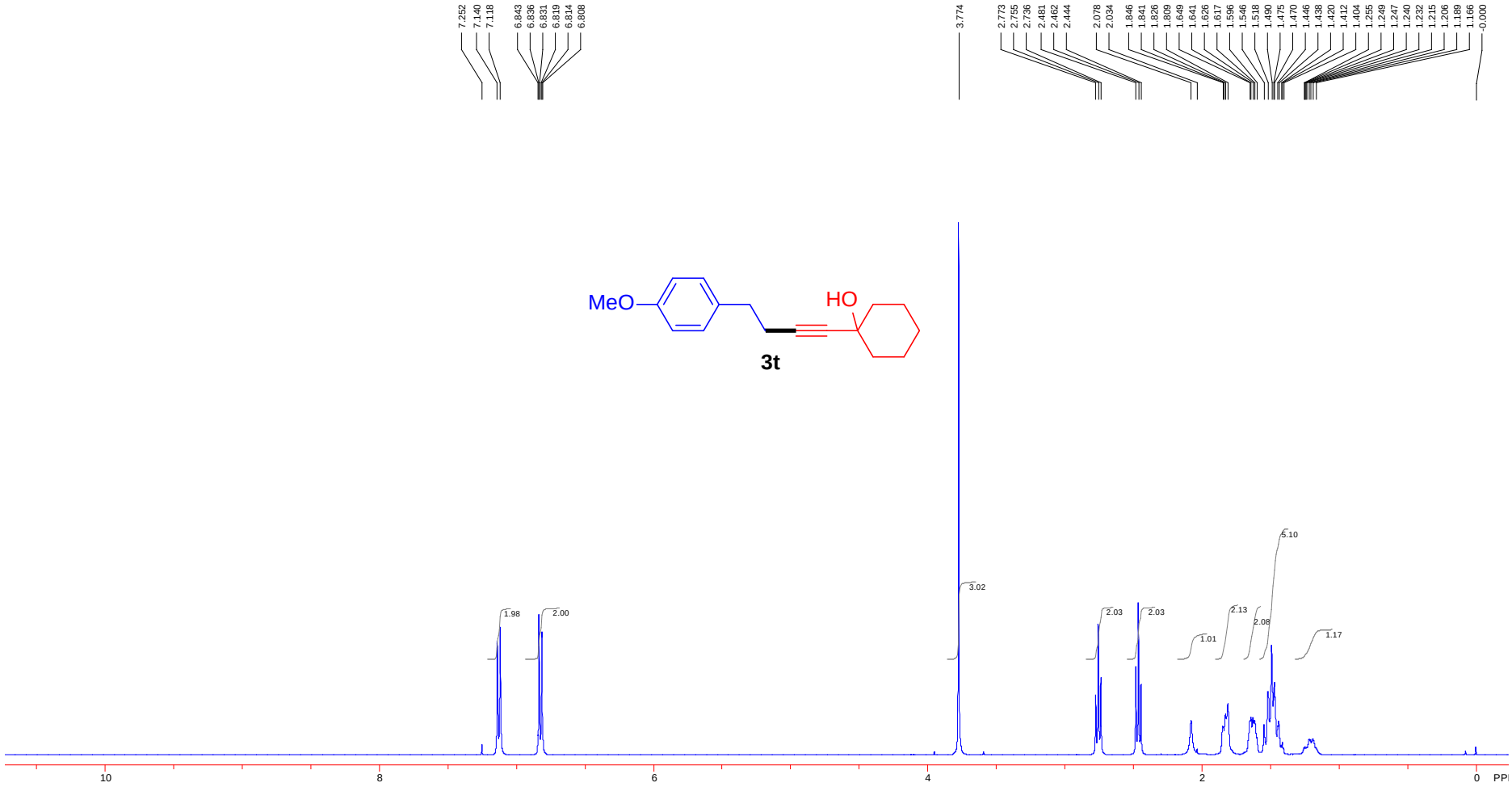
^{1}H NMR(400 MHz, $CDCl_3$)



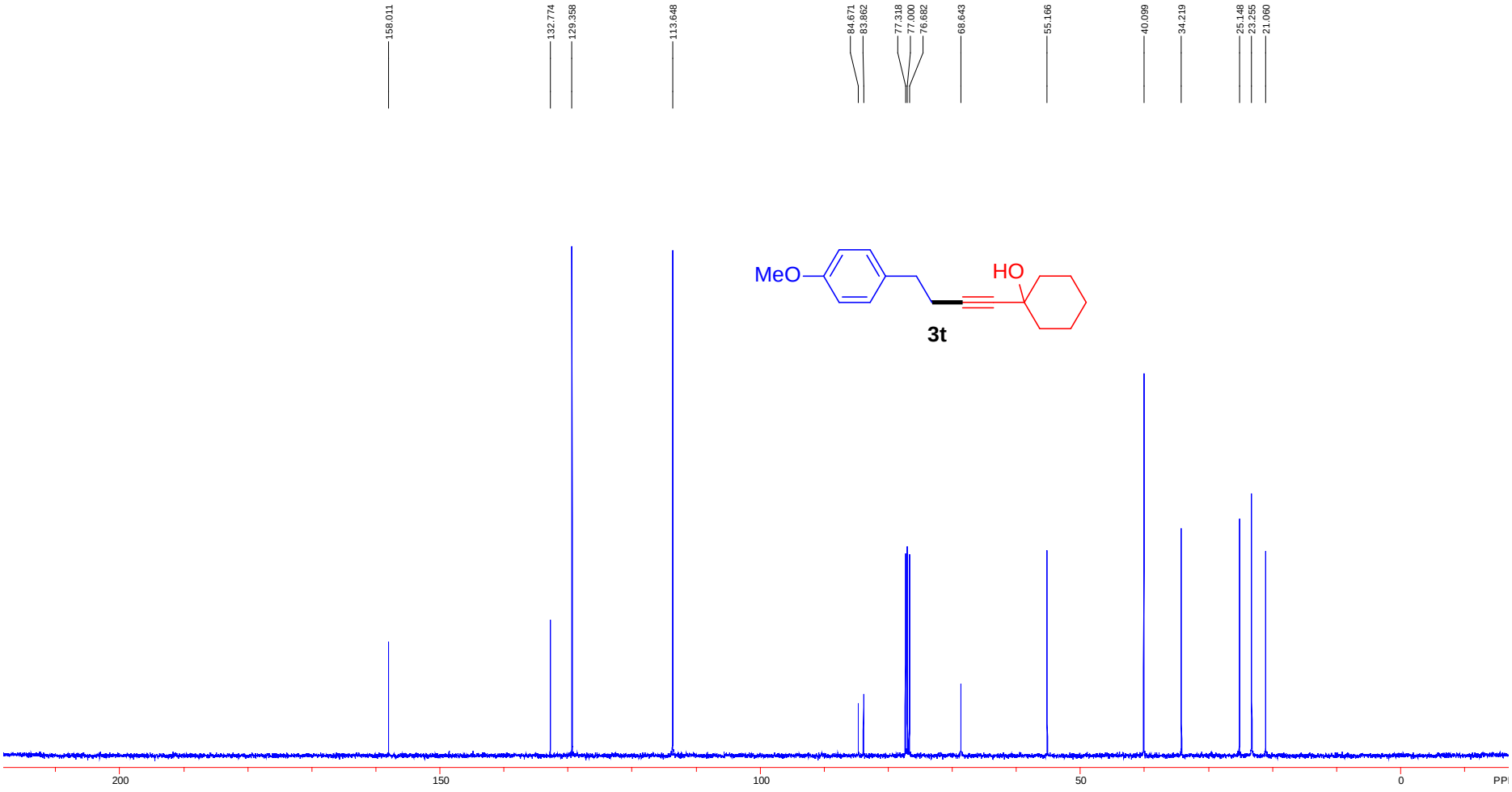
^{13}C NMR(100 MHz, $CDCl_3$)



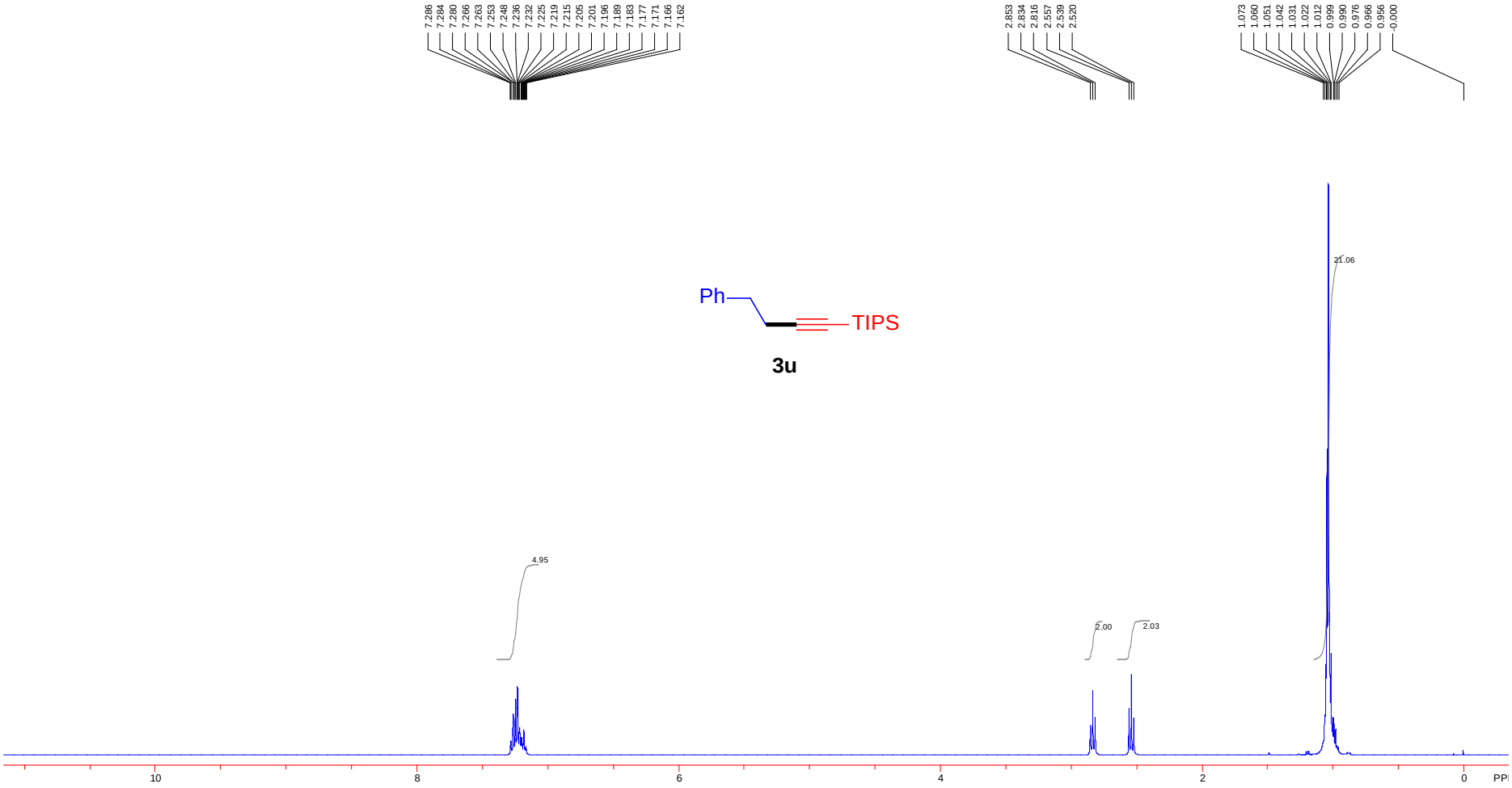
^{1}H NMR(400 MHz, $CDCl_3$)



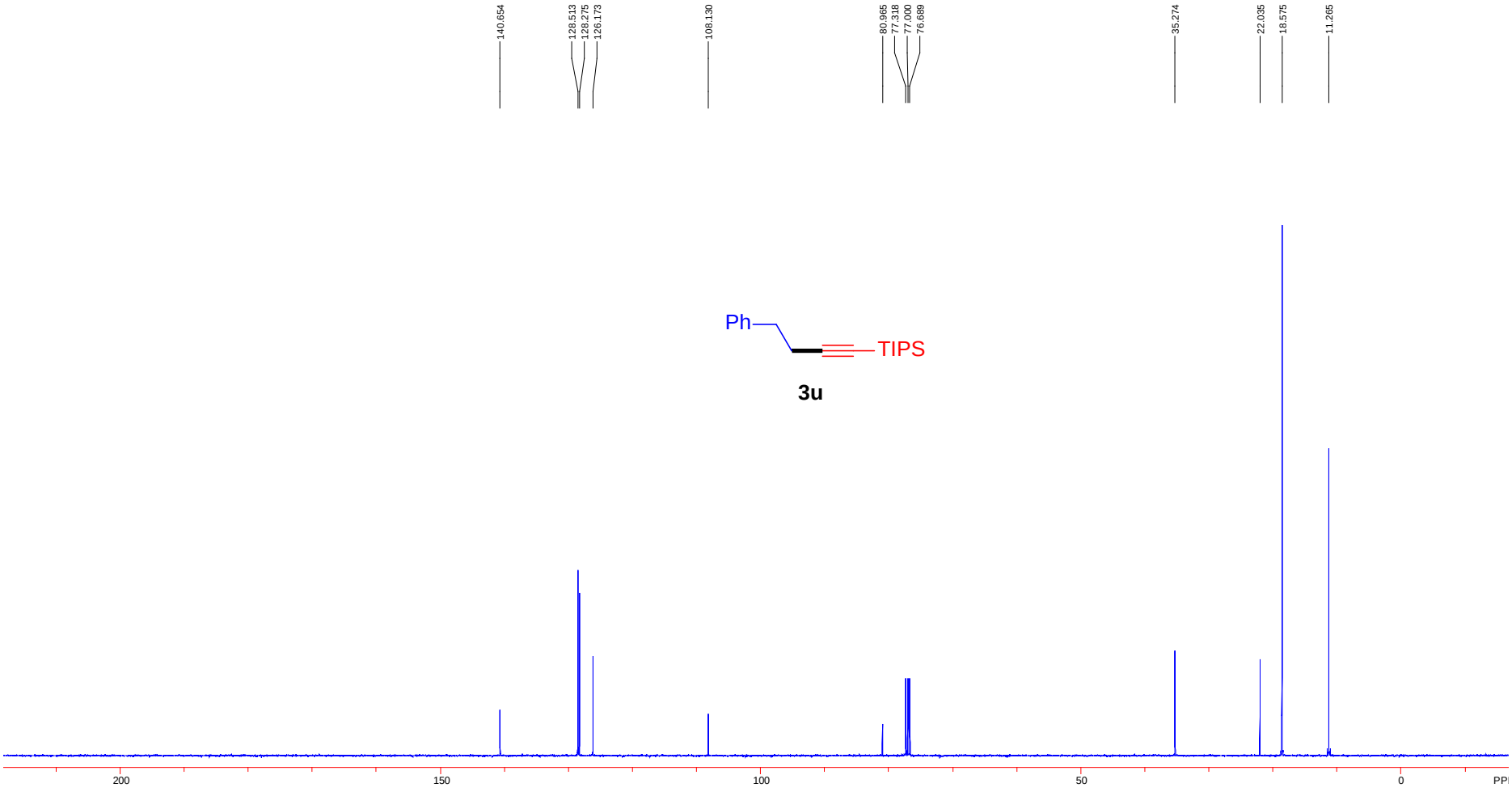
^{13}C NMR(100 MHz, $CDCl_3$)



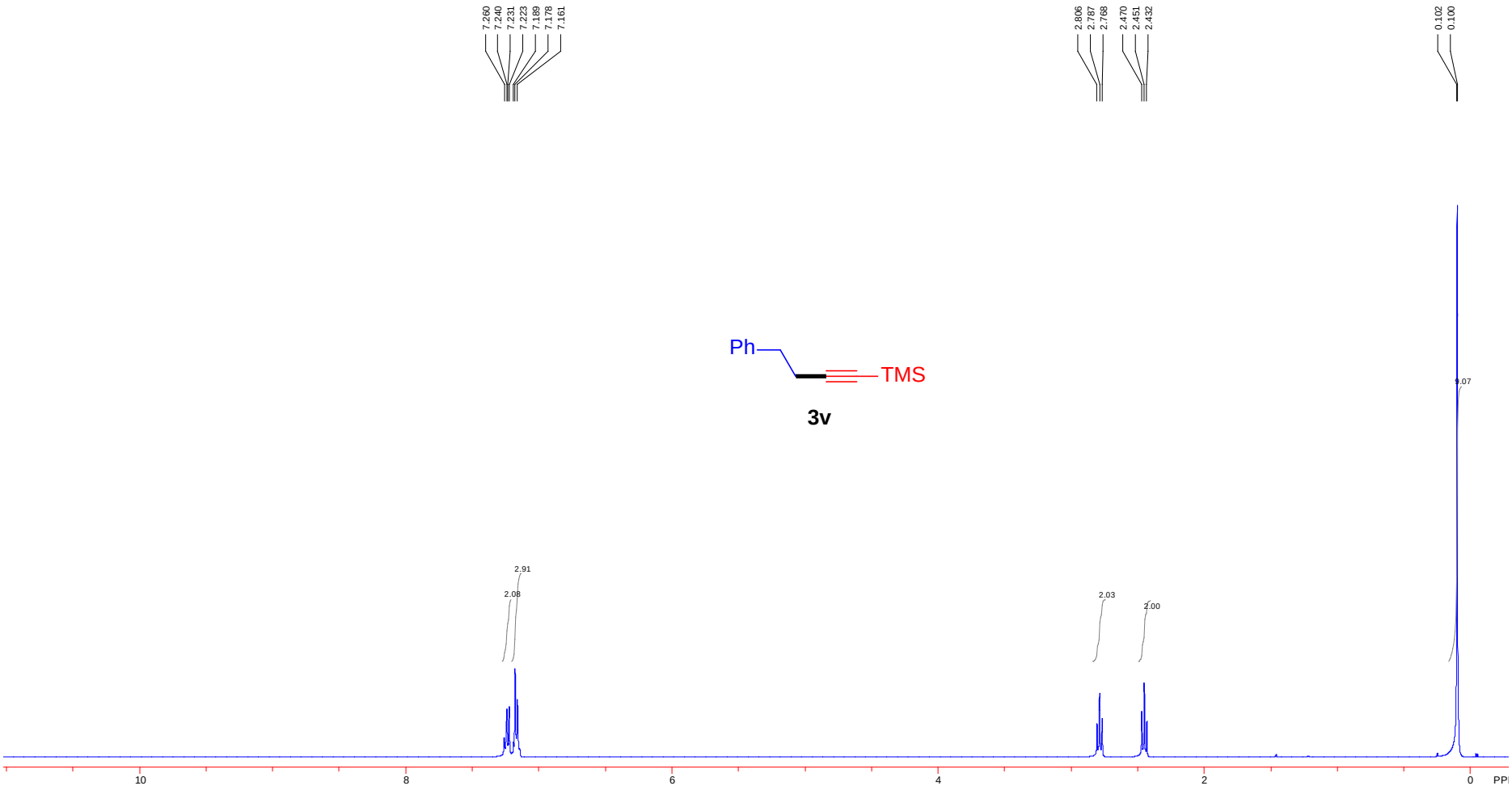
^{1}H NMR(400 MHz, $CDCl_3$)



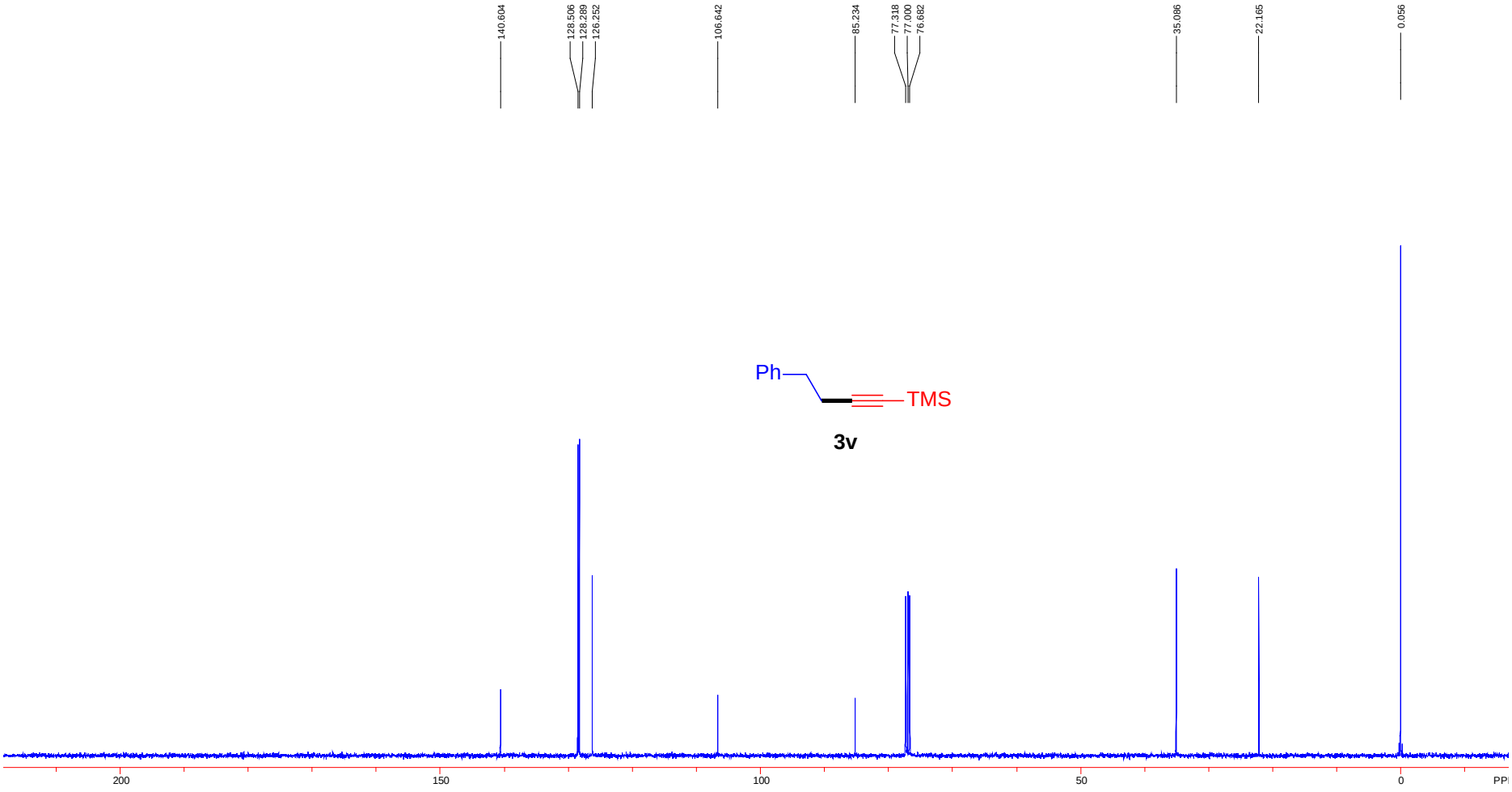
^{13}C NMR(100 MHz, $CDCl_3$)



^{1}H NMR(400 MHz, $CDCl_3$)



^{13}C NMR(100 MHz, $CDCl_3$)



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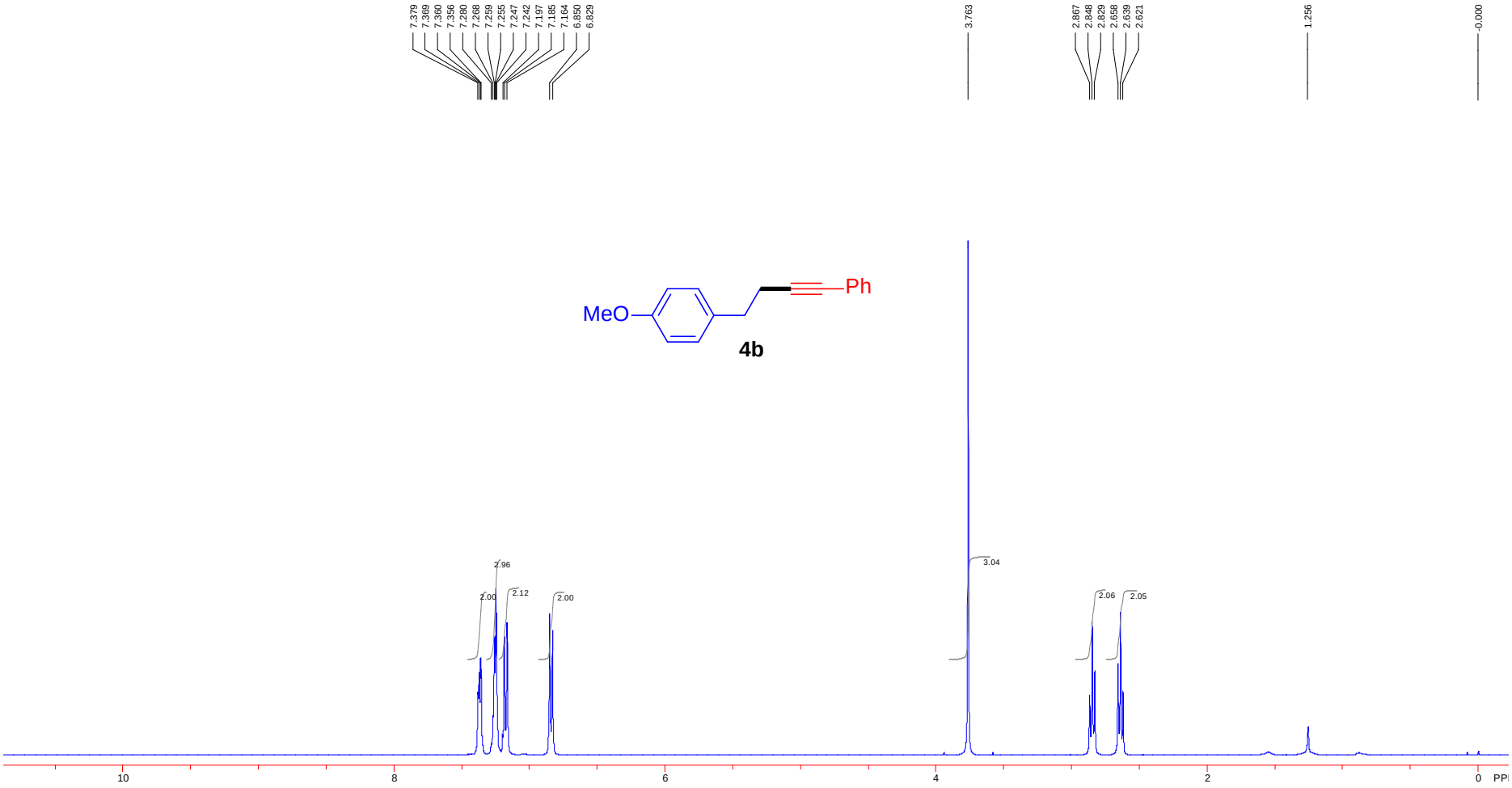
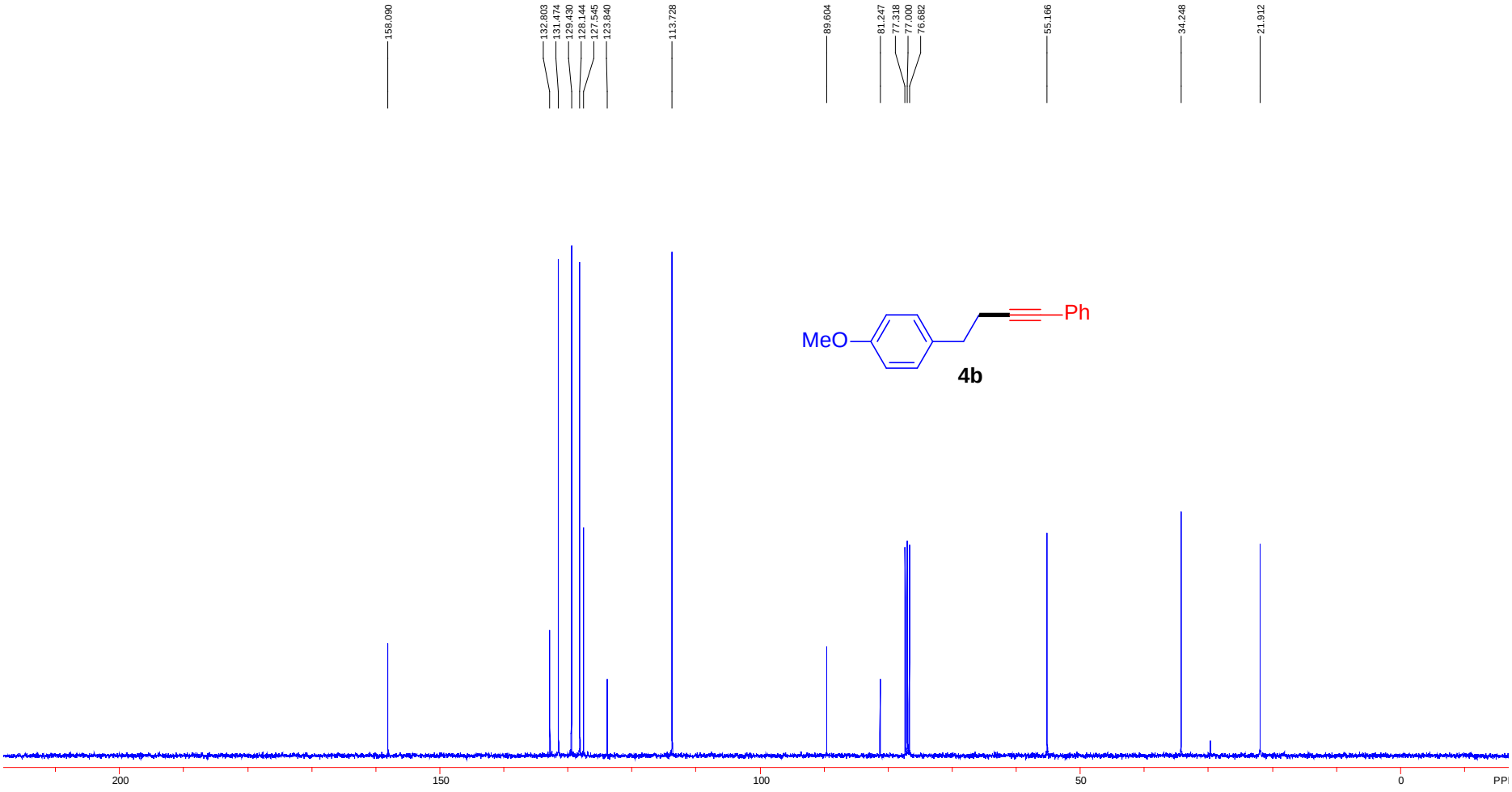
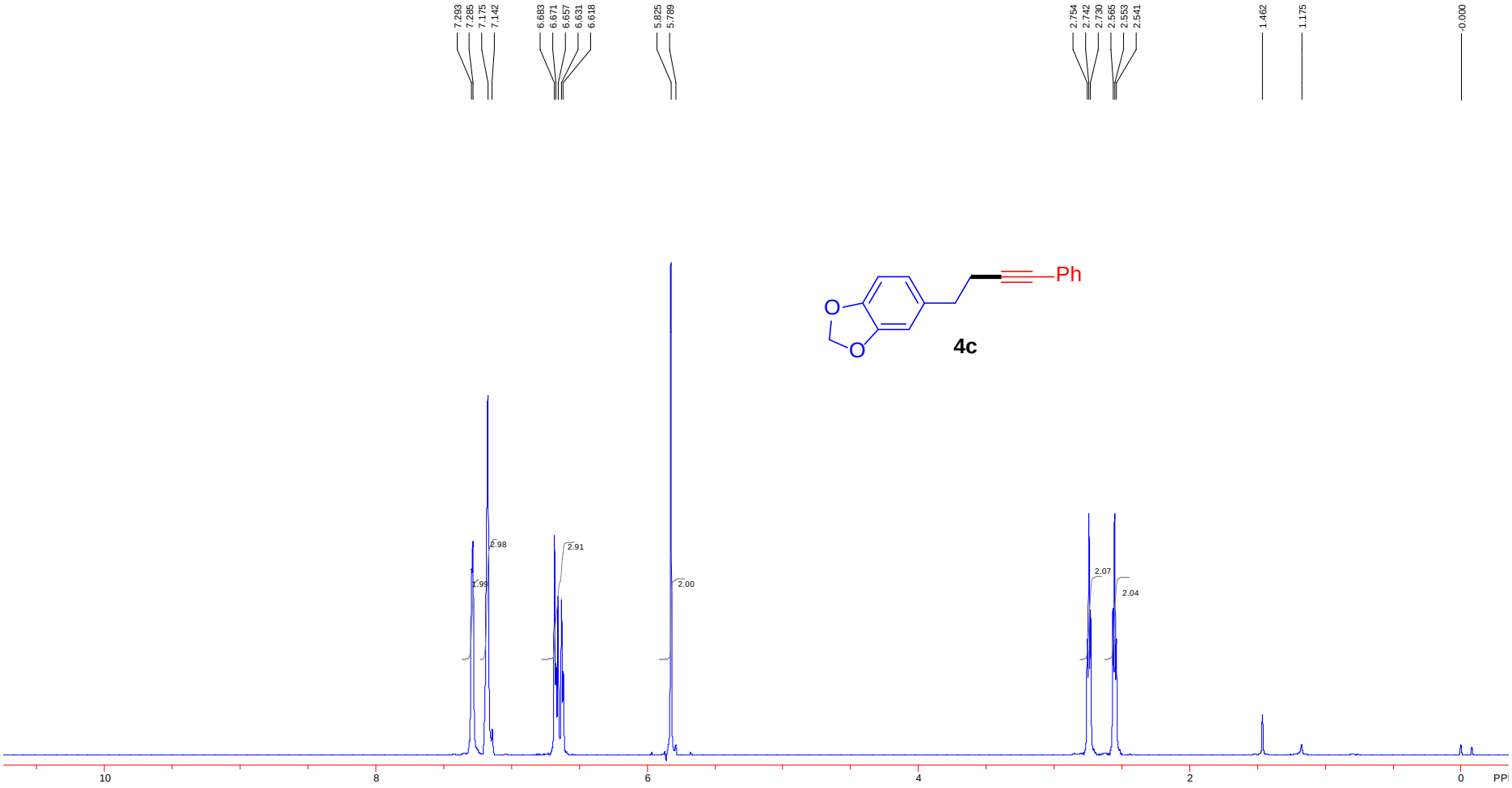


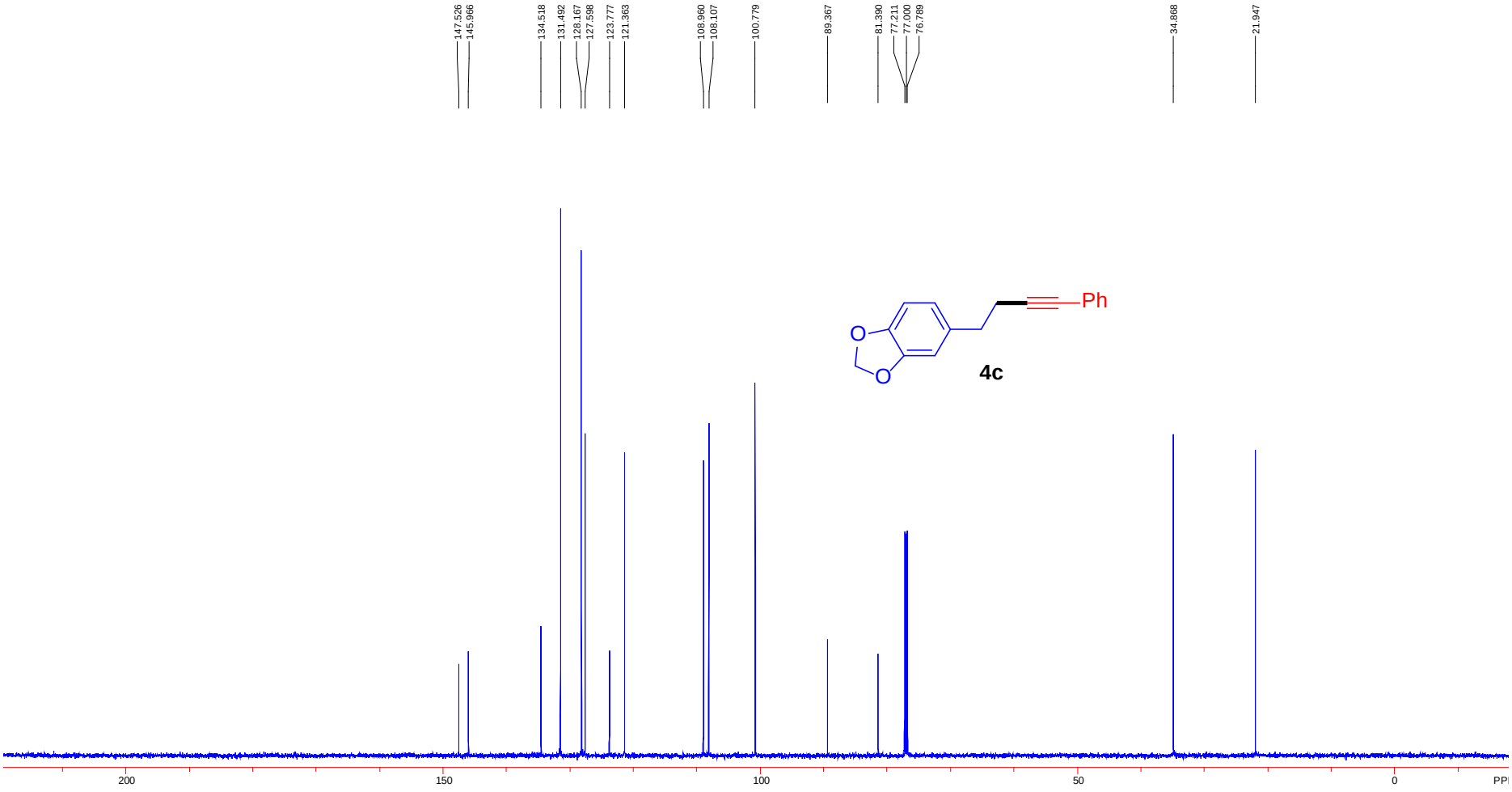
^{13}C NMR(100 MHz, $CDCl_3$)



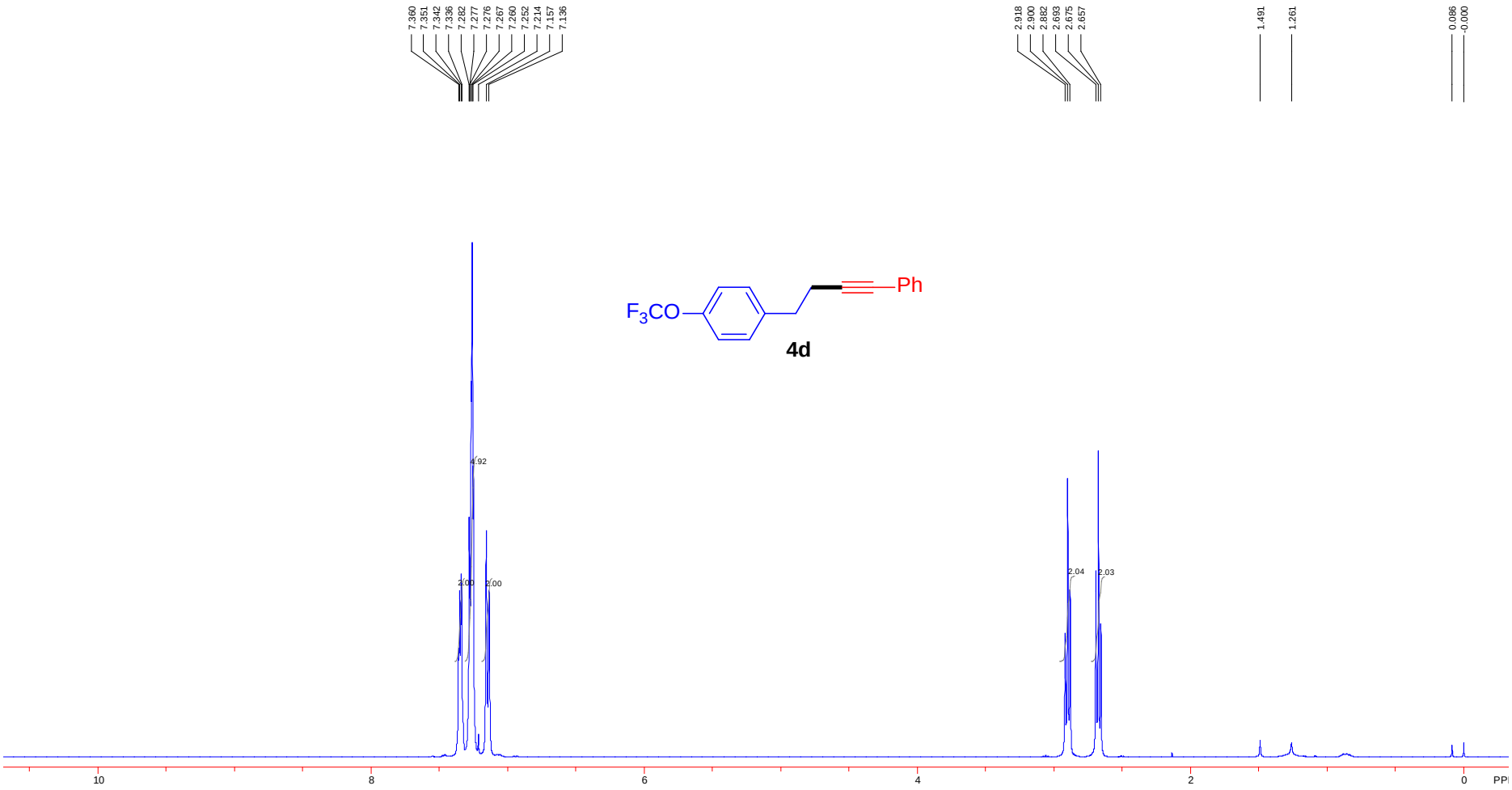
^{1}H NMR (600 MHz, $CDCl_3$)



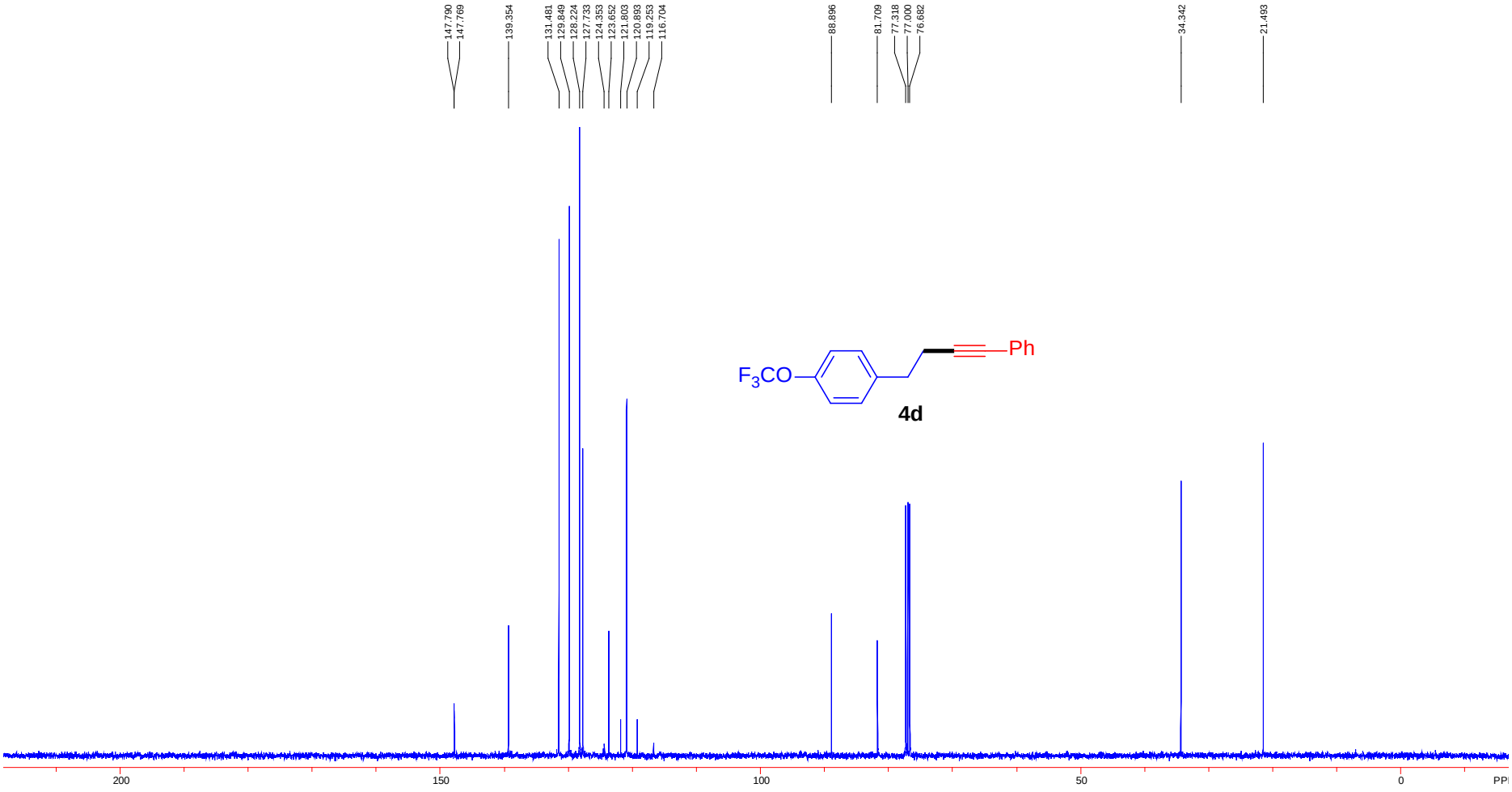
^{13}C NMR (151 MHz, $CDCl_3$)



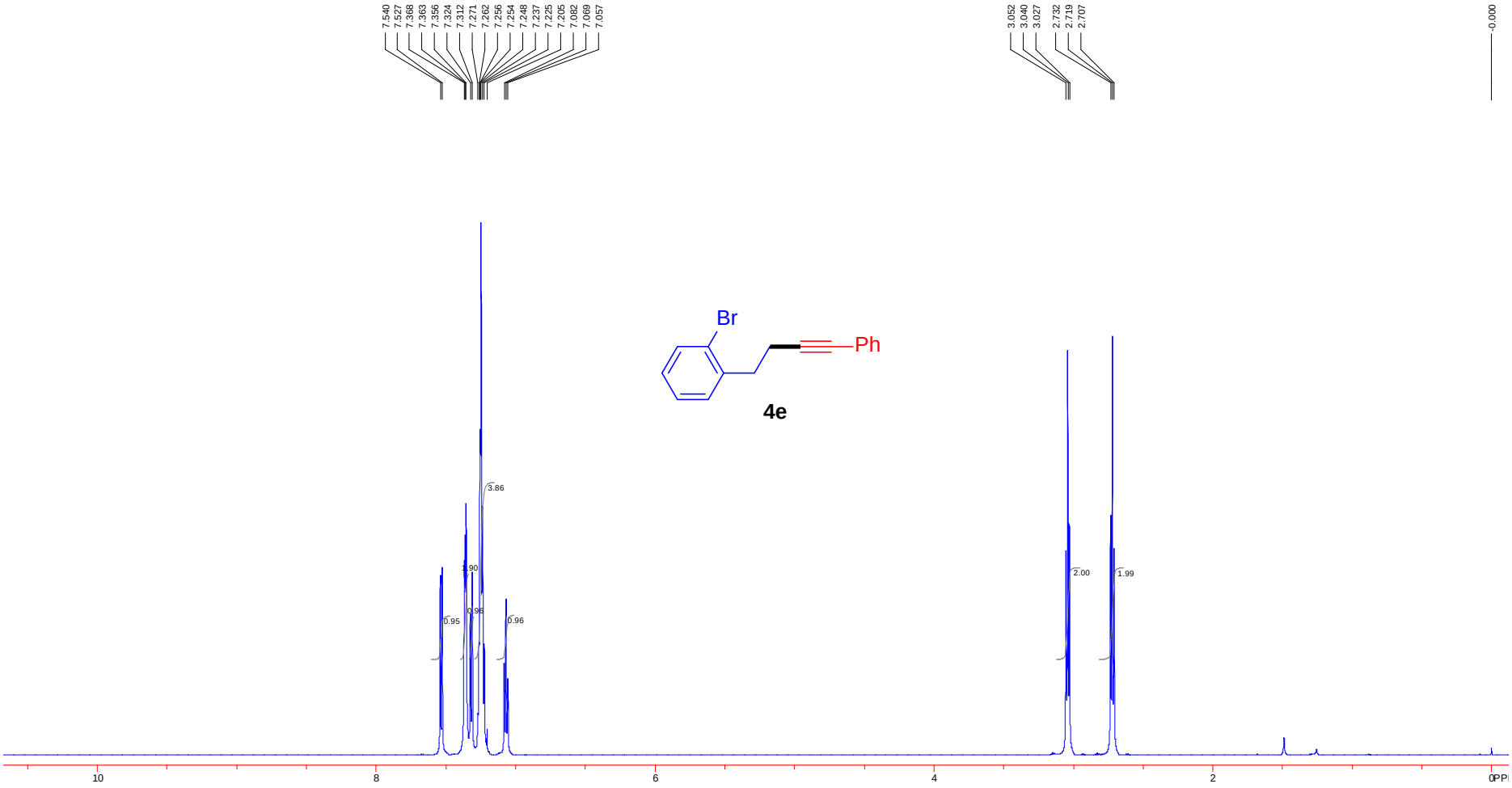
^{1}H NMR(400 MHz, $CDCl_3$)



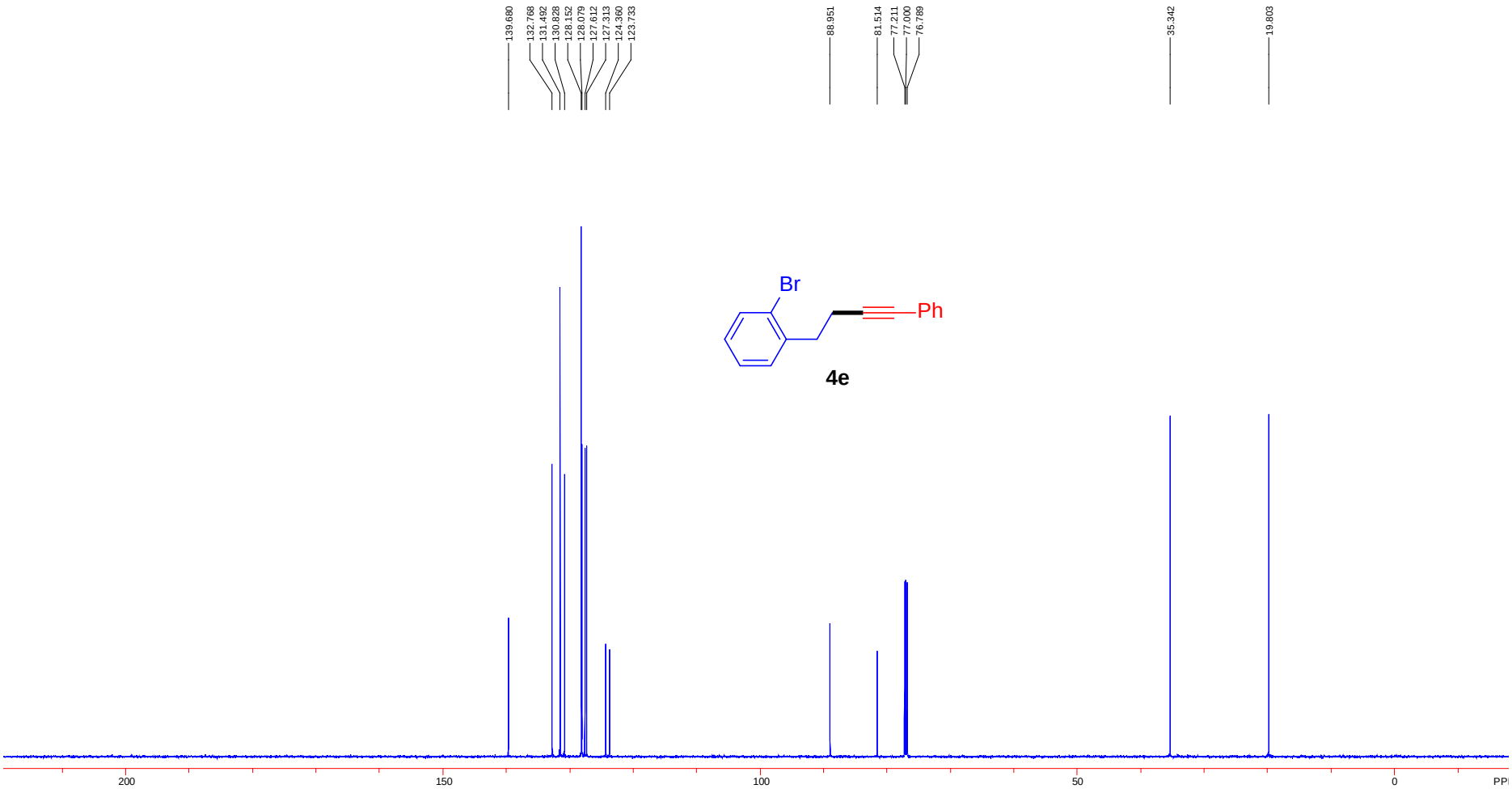
^{13}C NMR(100 MHz, $CDCl_3$)



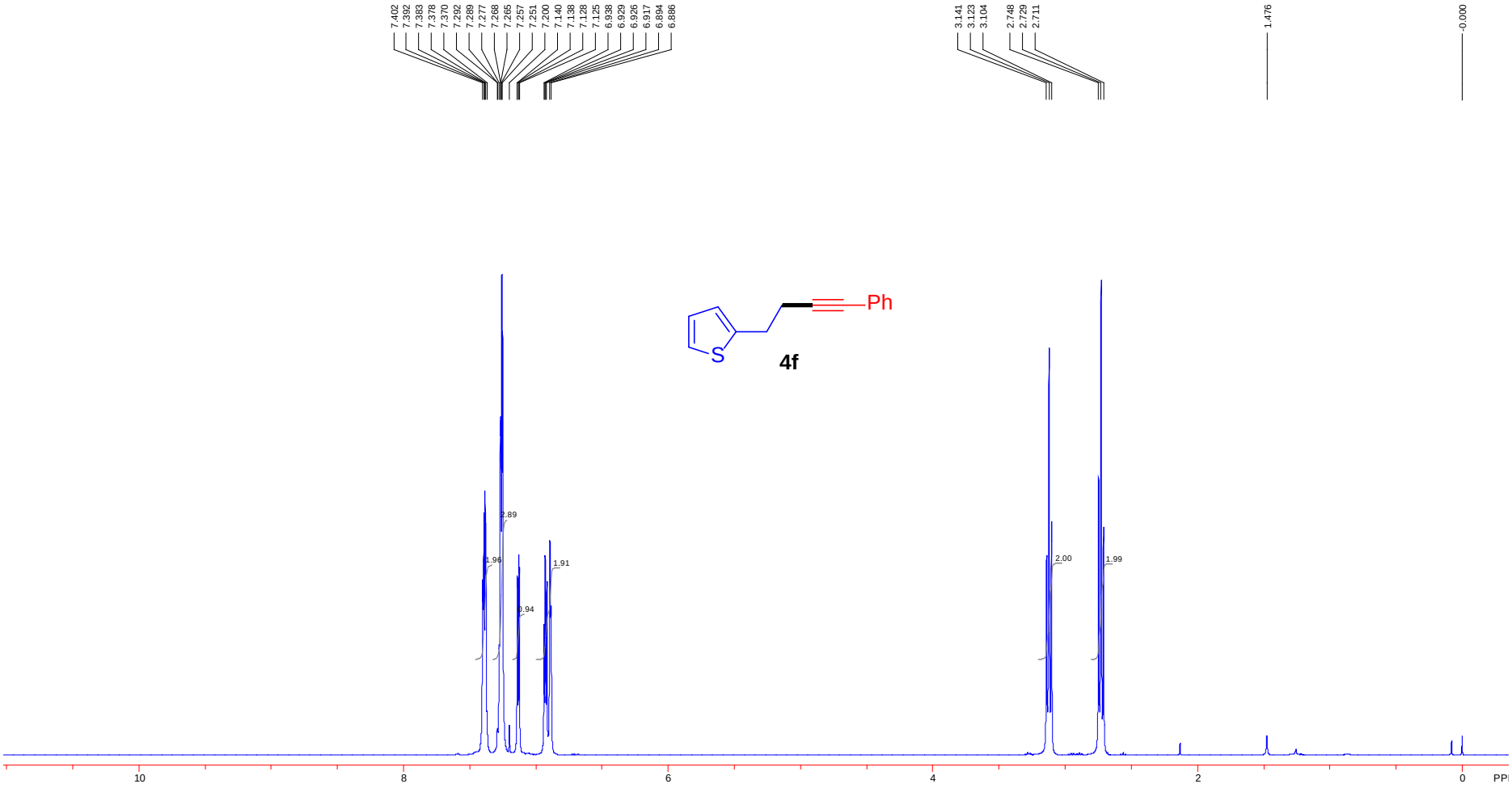
^{1}H NMR (600 MHz, $CDCl_3$)



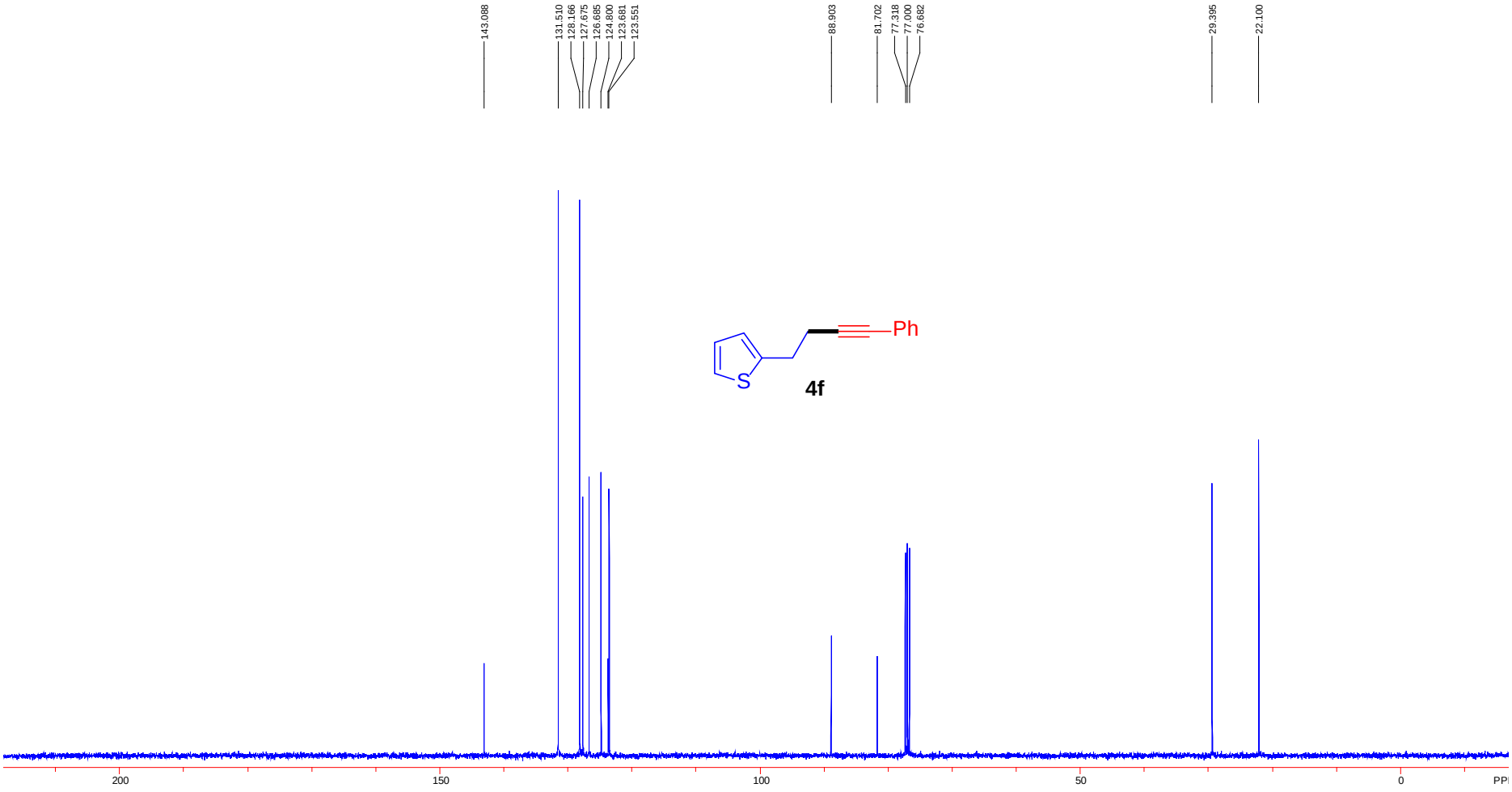
^{13}C NMR (151 MHz, $CDCl_3$)



^{1}H NMR(400 MHz, $CDCl_3$)



^{13}C NMR(100 MHz, $CDCl_3$)



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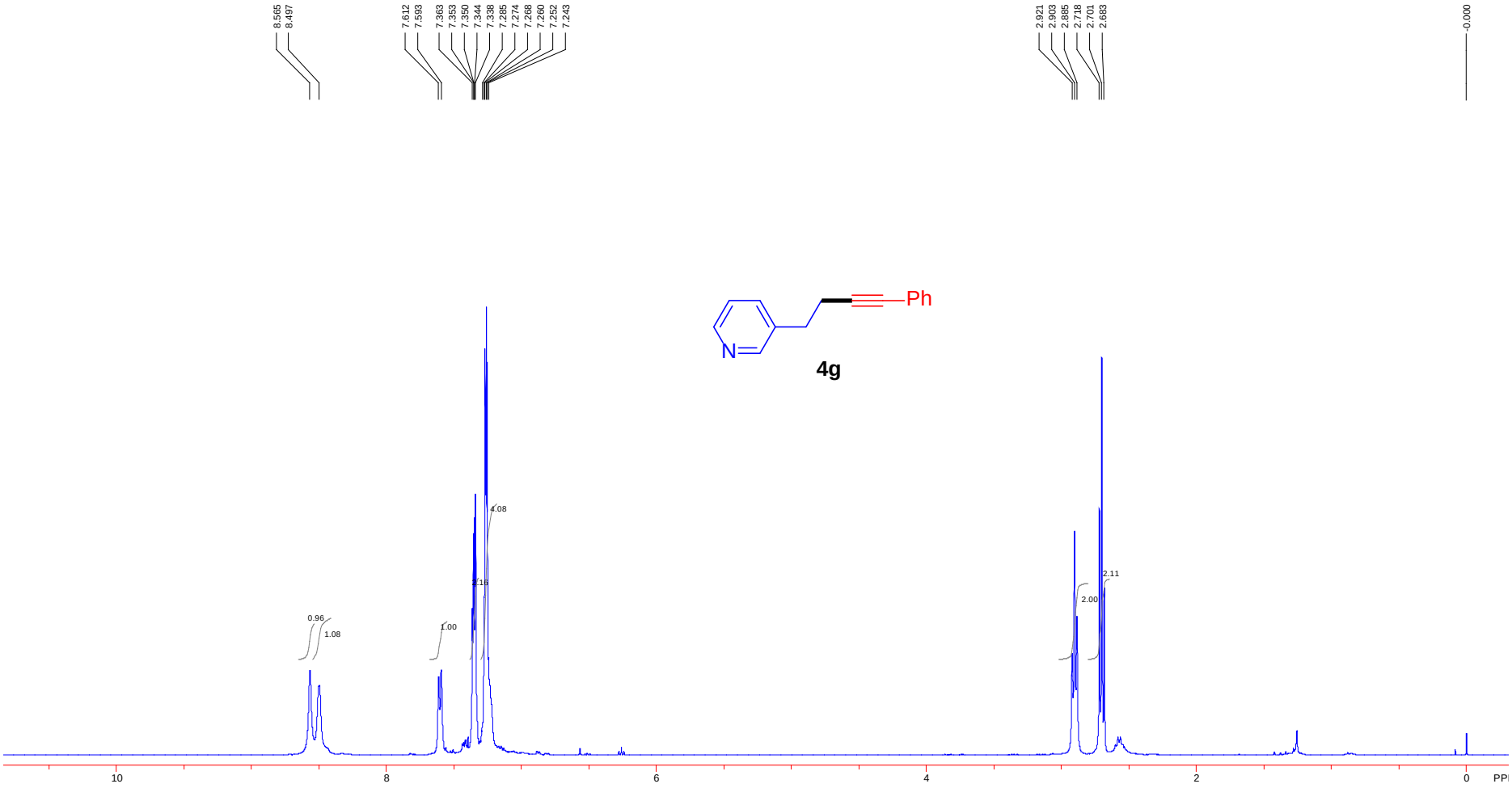
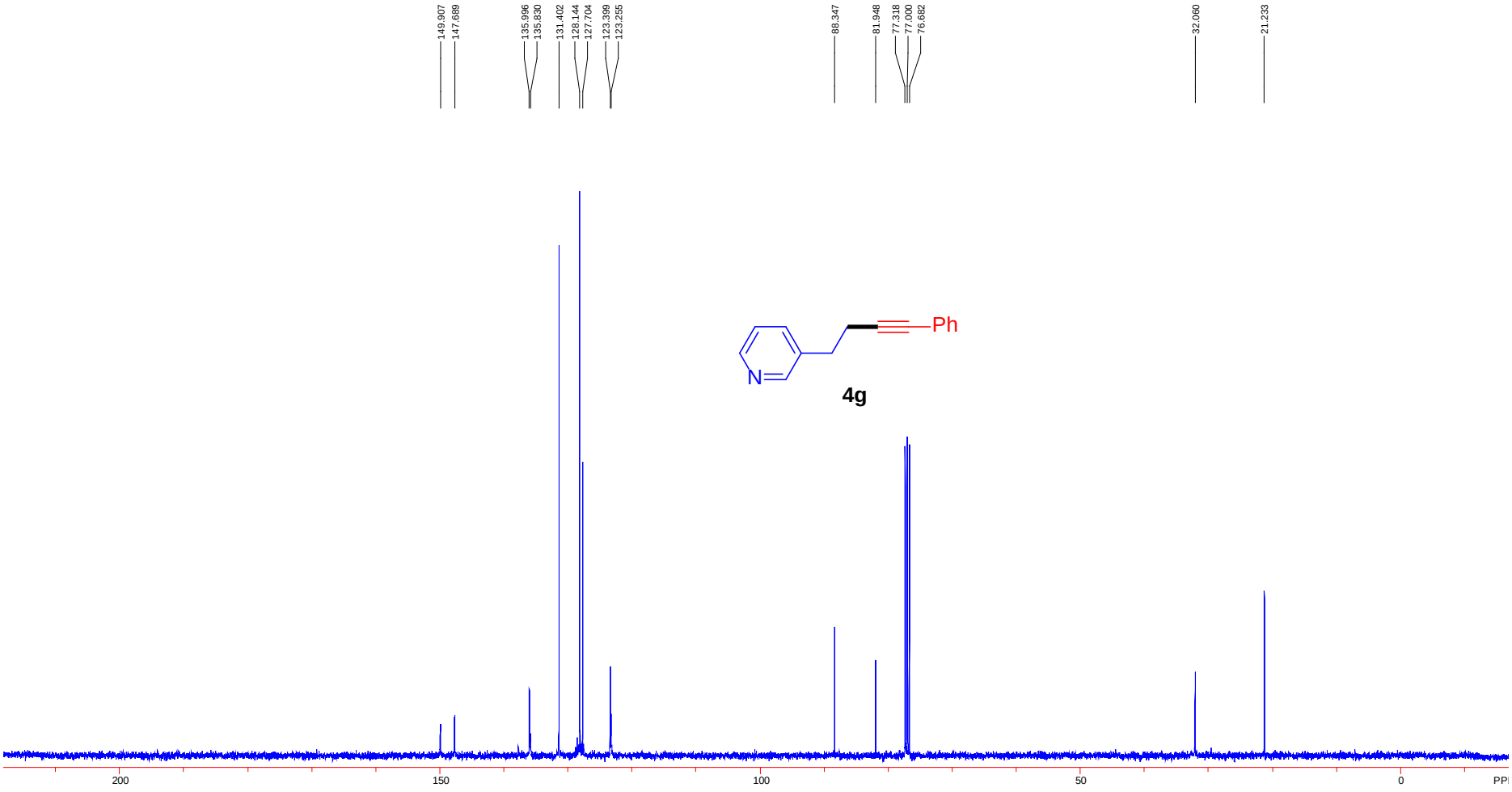
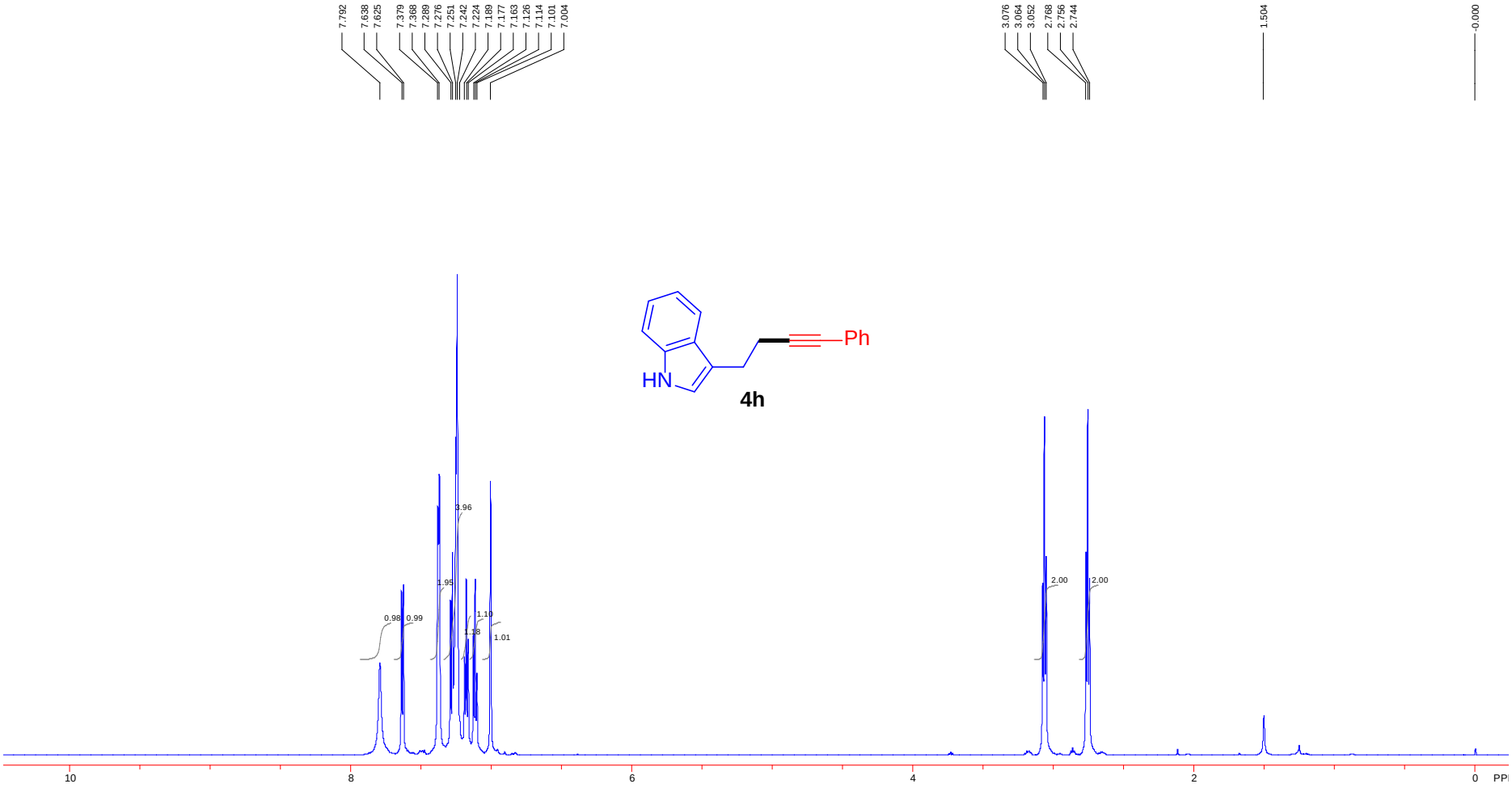


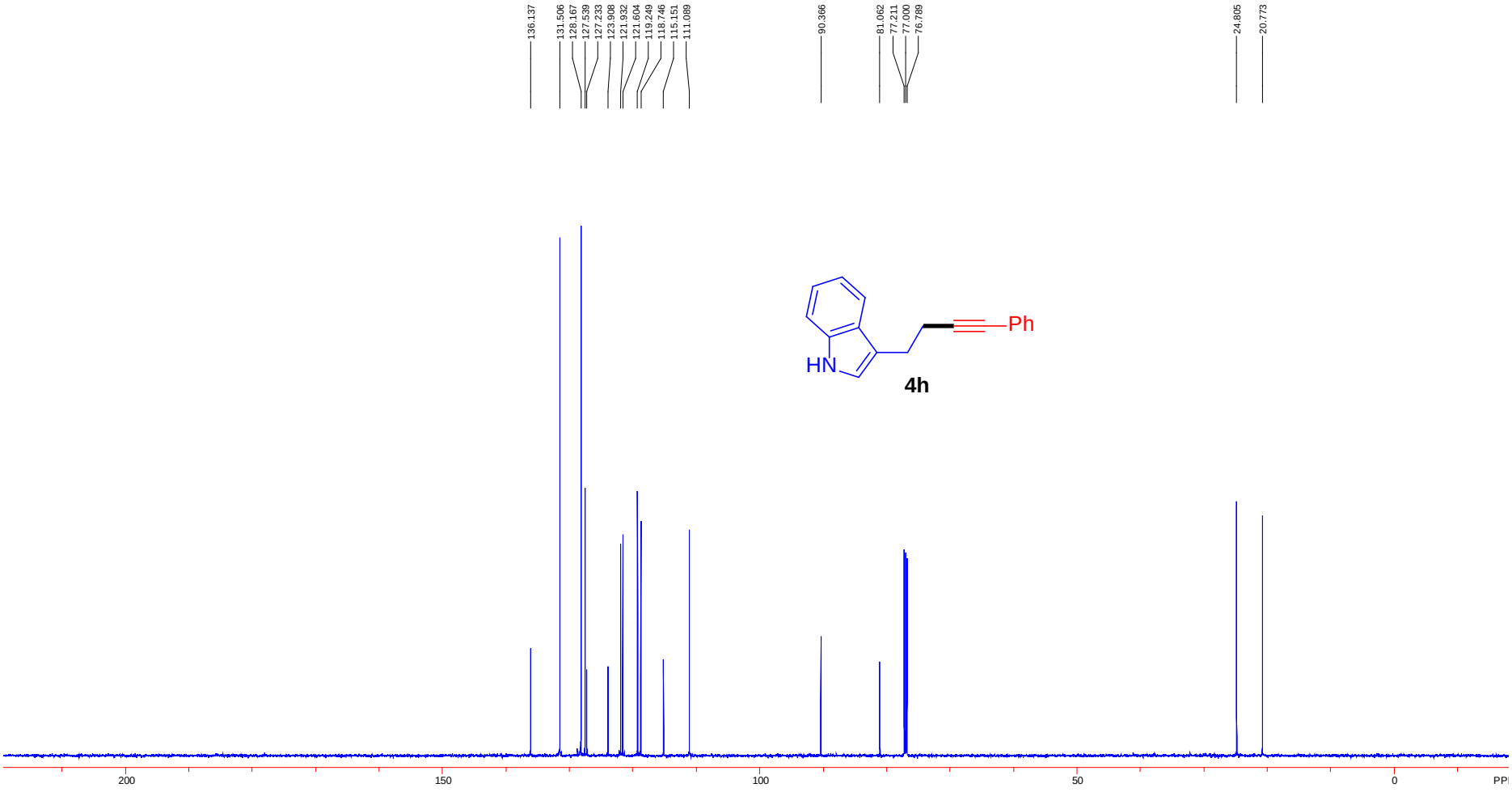
^{13}C NMR(100 MHz, $CDCl_3$)



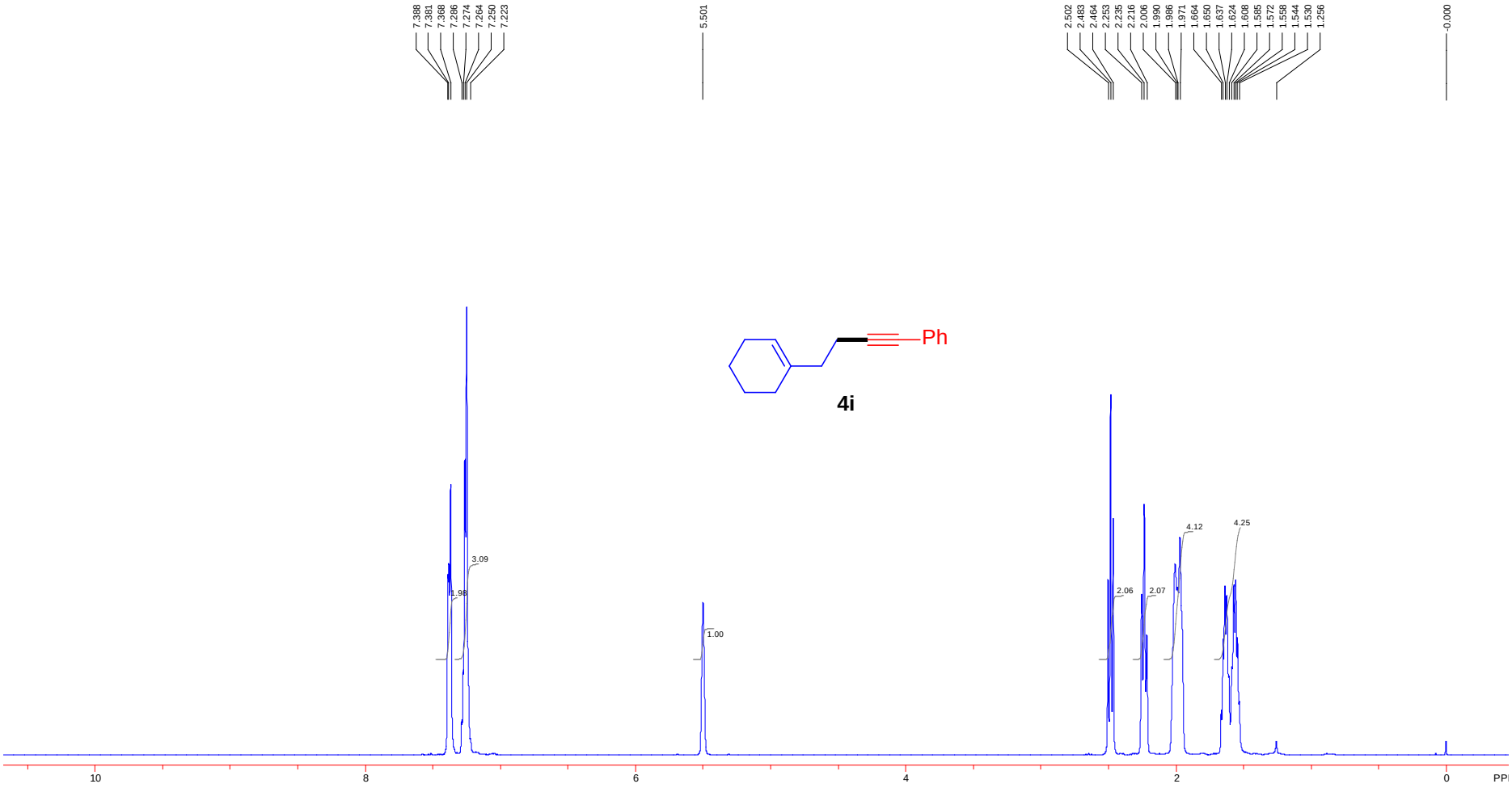
^{1}H NMR (600 MHz, $CDCl_3$)



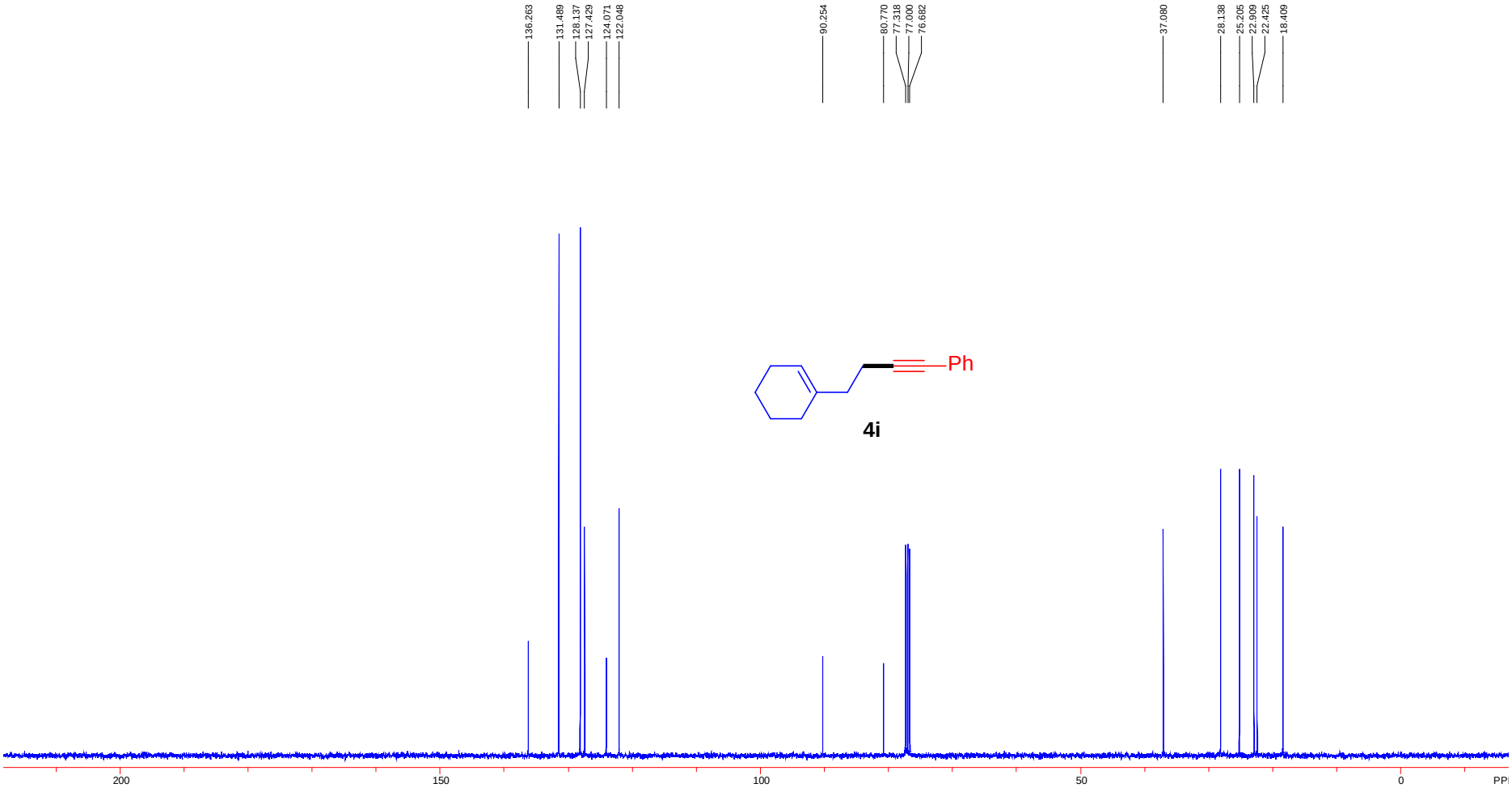
^{13}C NMR (151 MHz, $CDCl_3$)



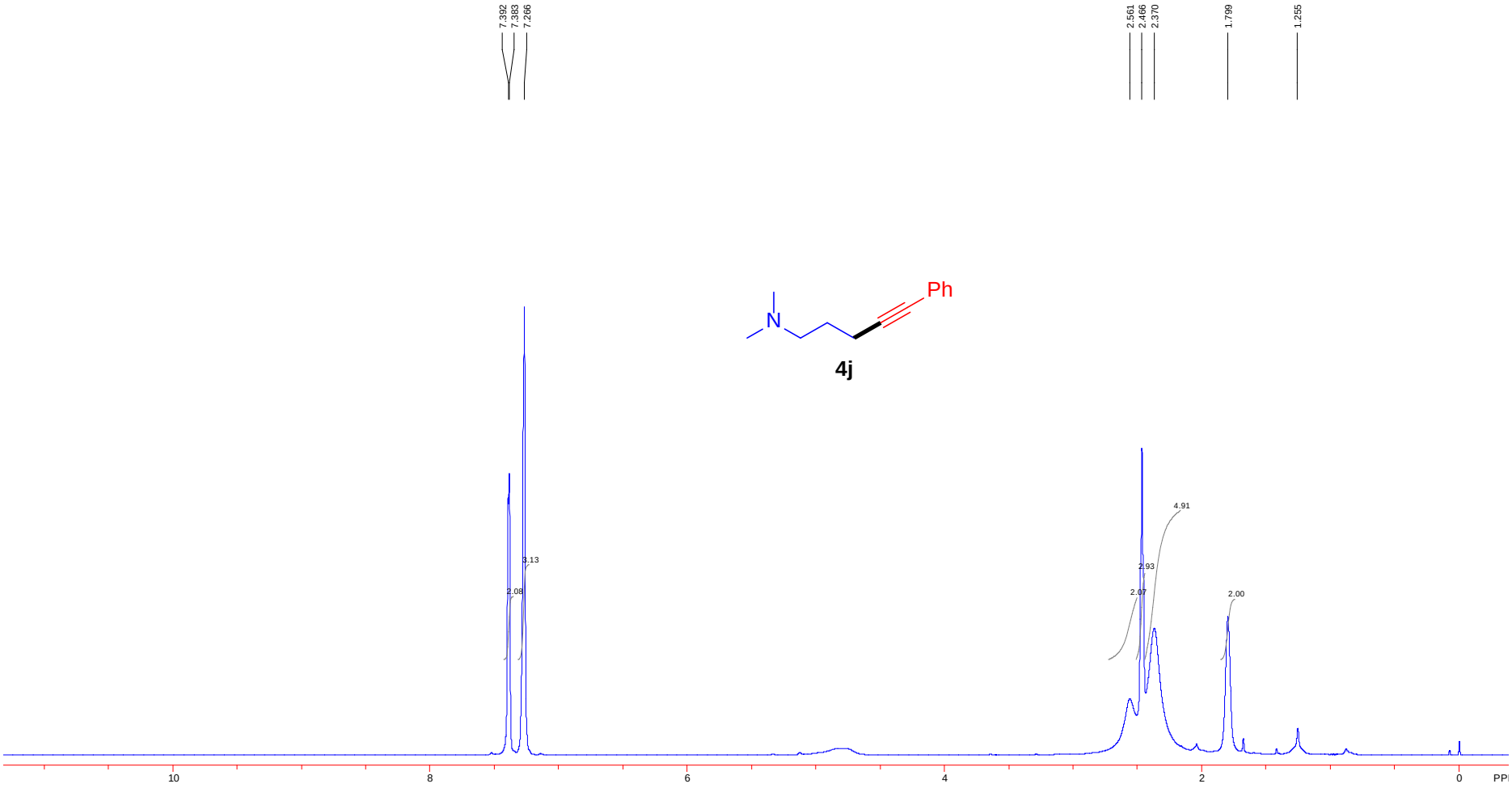
^{1}H NMR(400 MHz, $CDCl_3$)



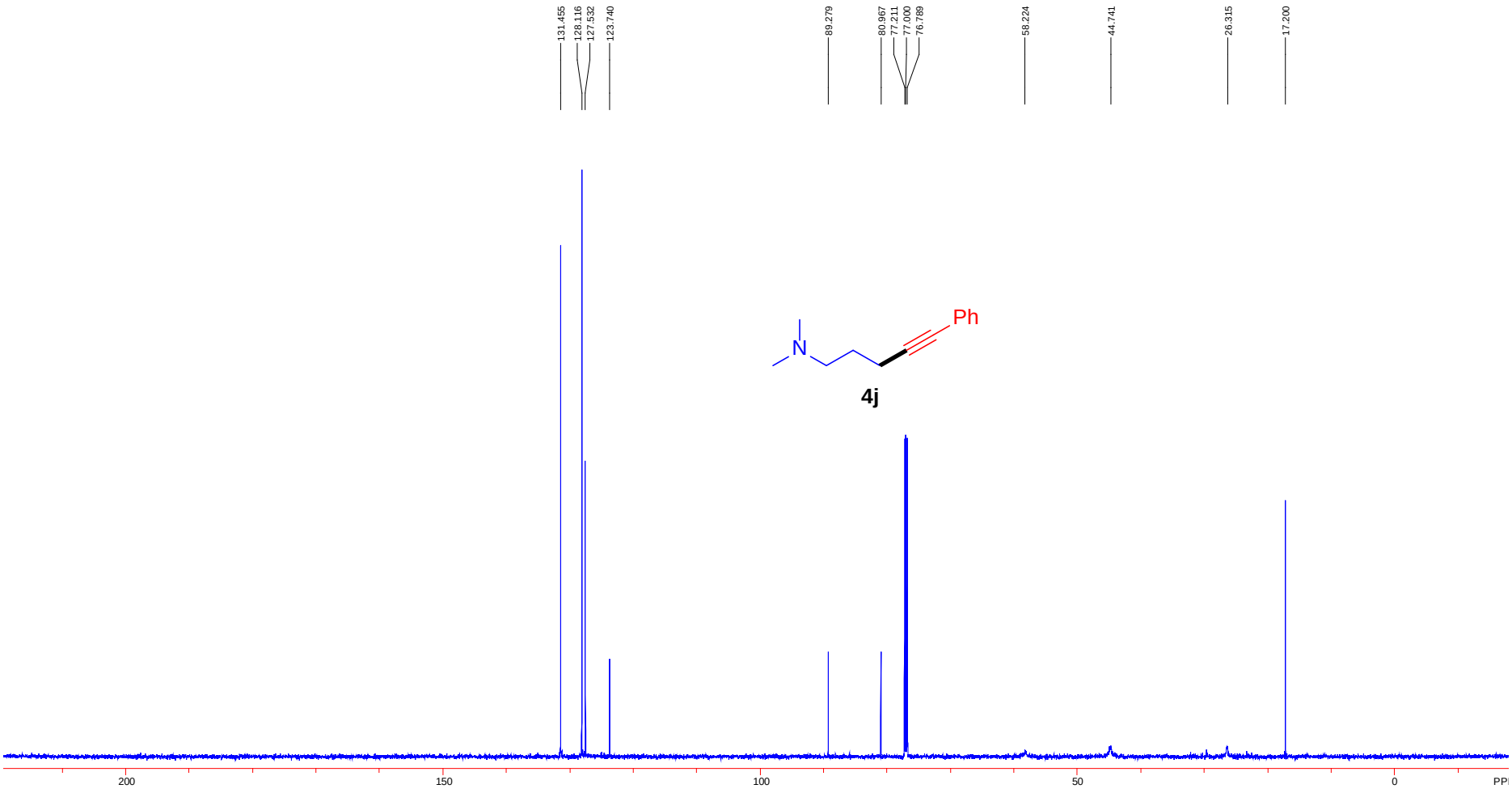
^{13}C NMR(100 MHz, $CDCl_3$)



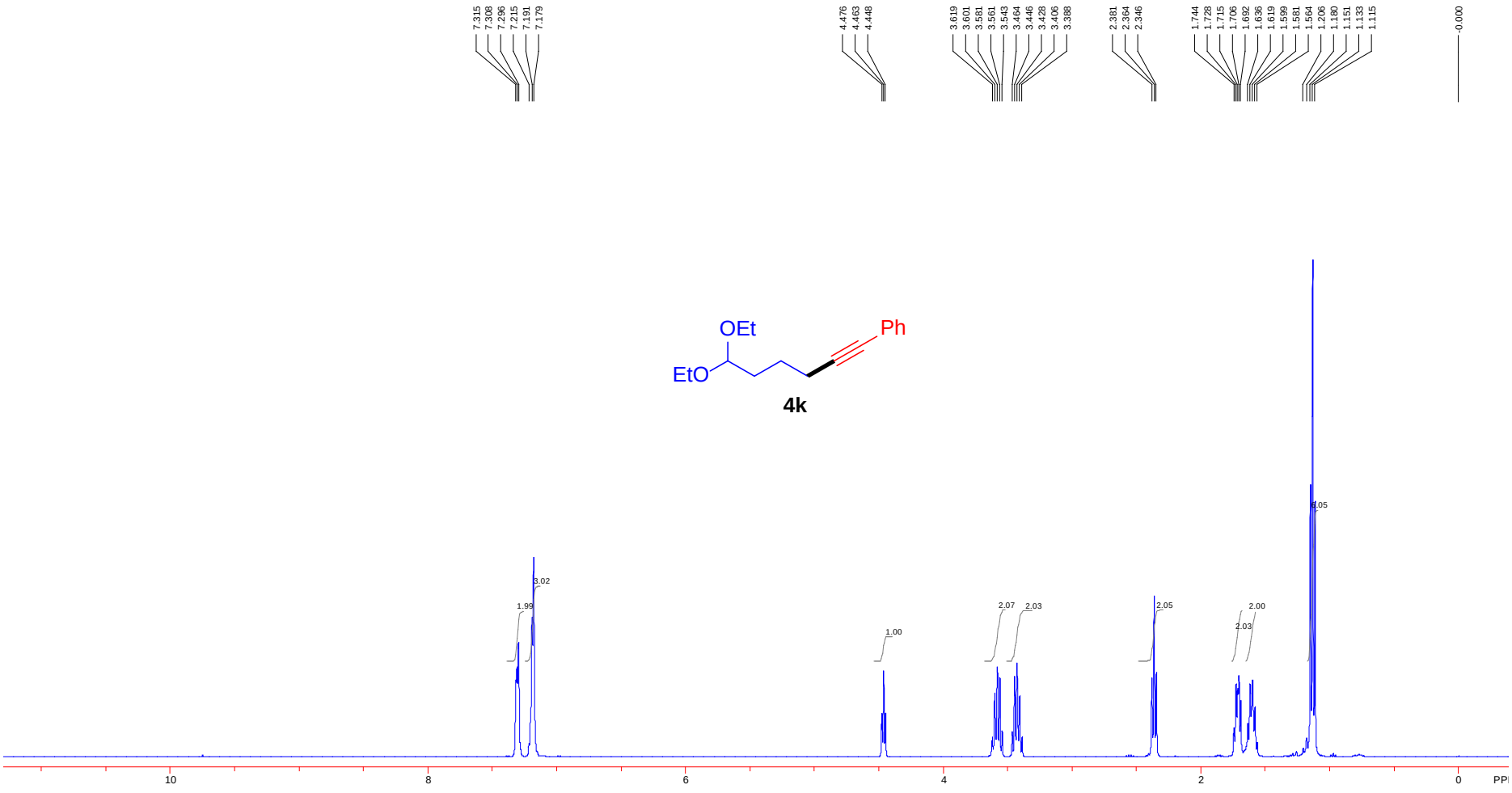
^{1}H NMR (600 MHz, $CDCl_3$)



^{13}C NMR (151 MHz, $CDCl_3$)



^{1}H NMR(400 MHz, $CDCl_3$)



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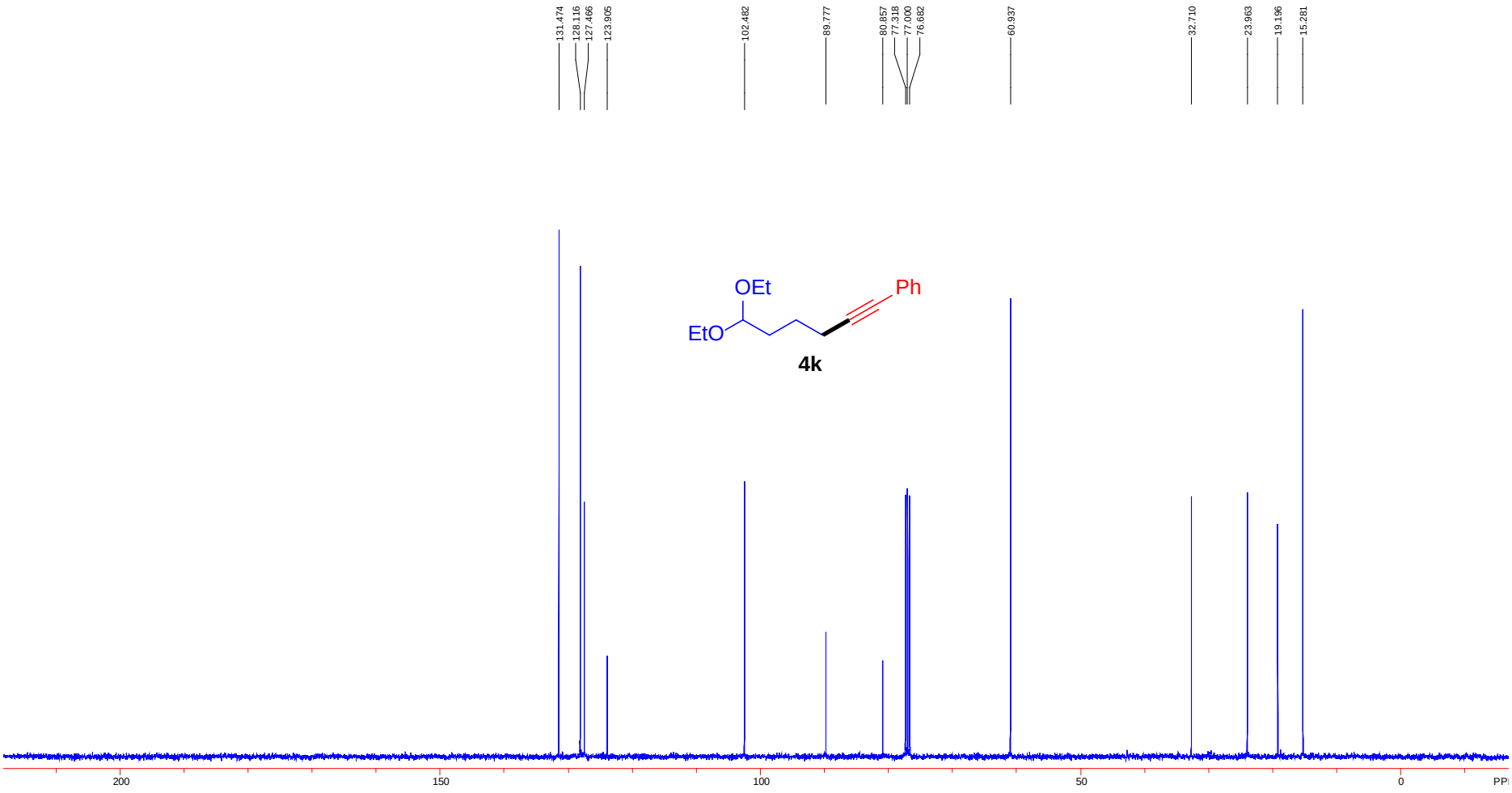
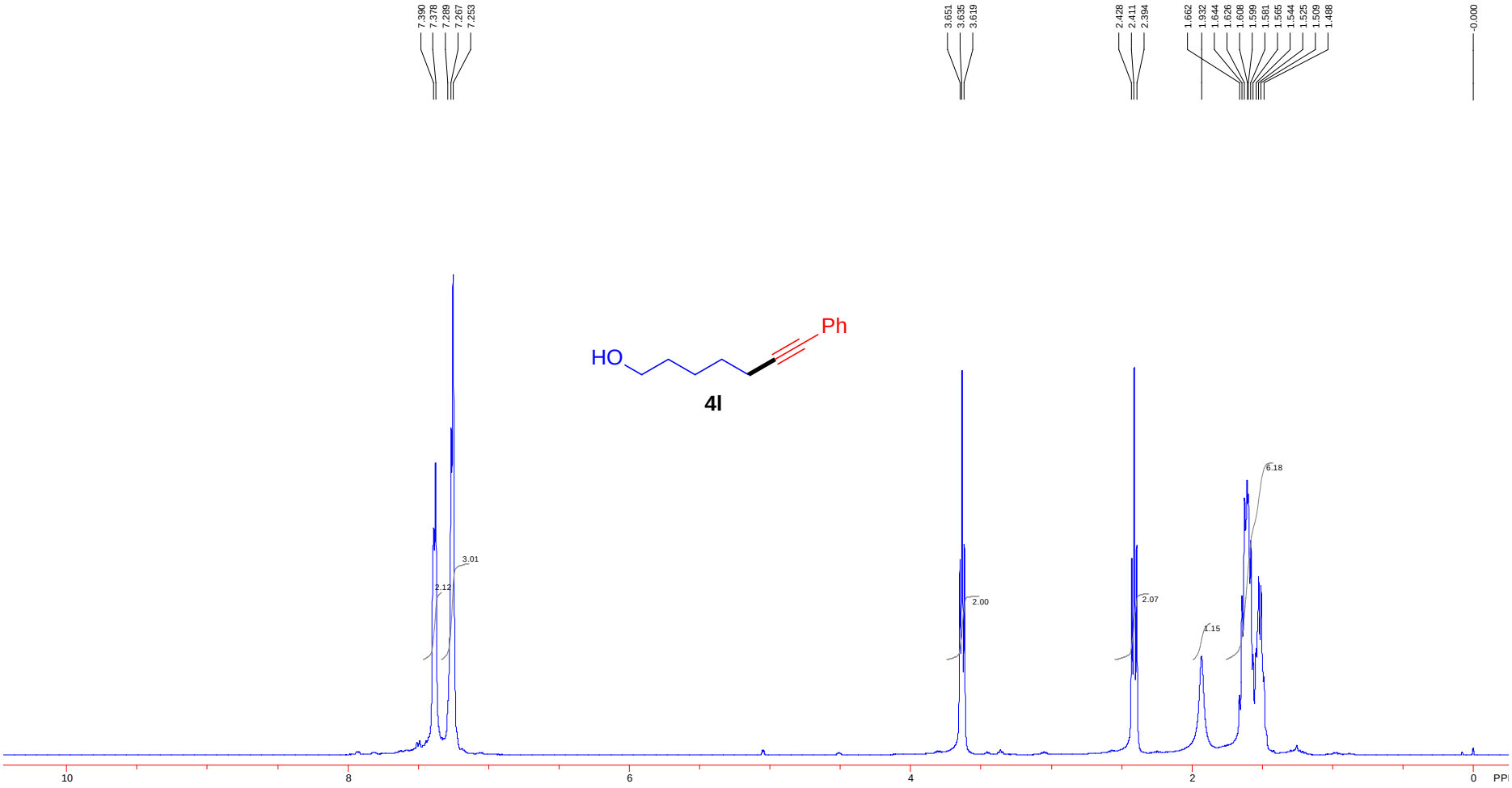


^{1}H NMR(400 MHz, $CDCl_3$)



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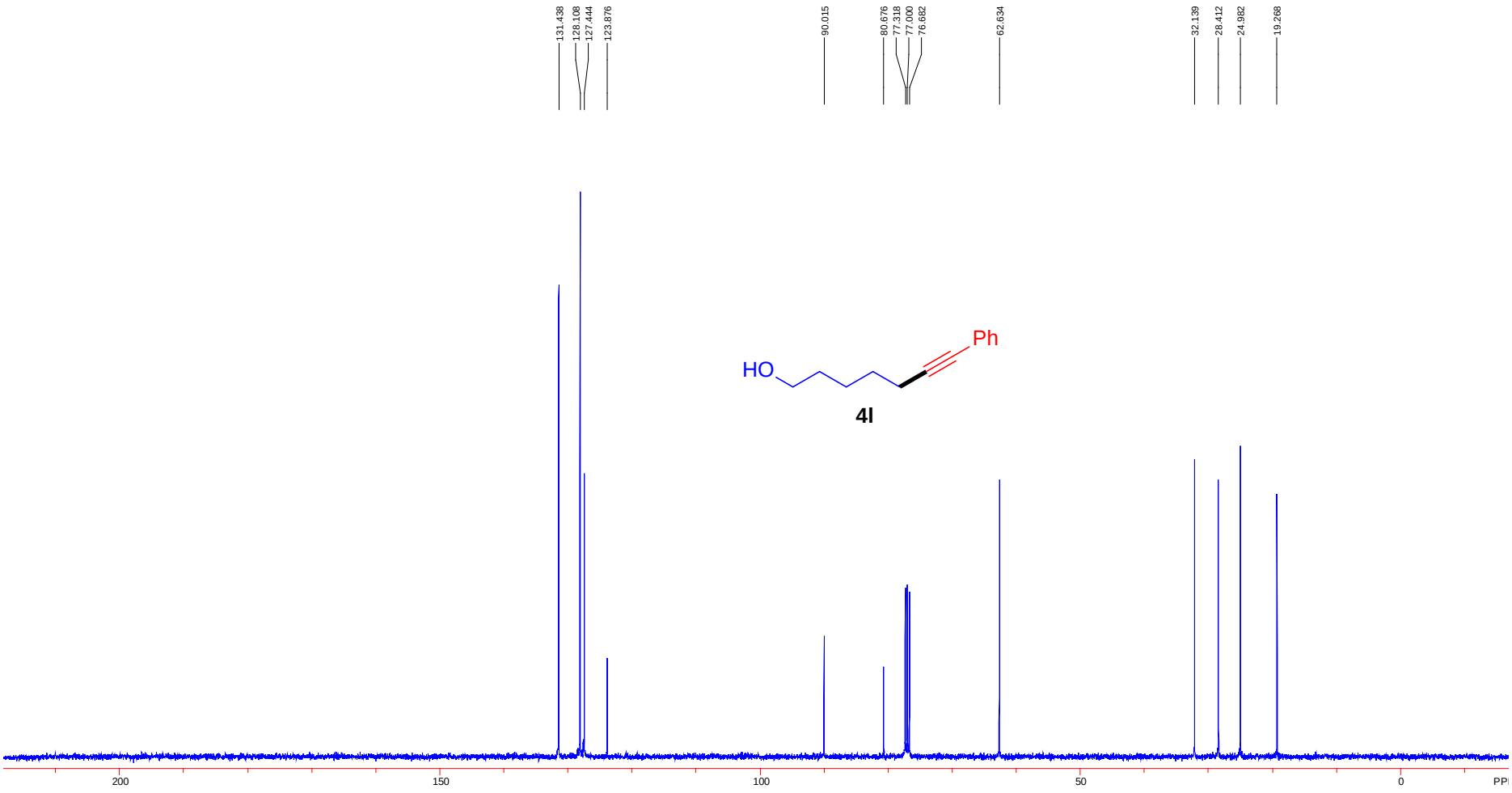

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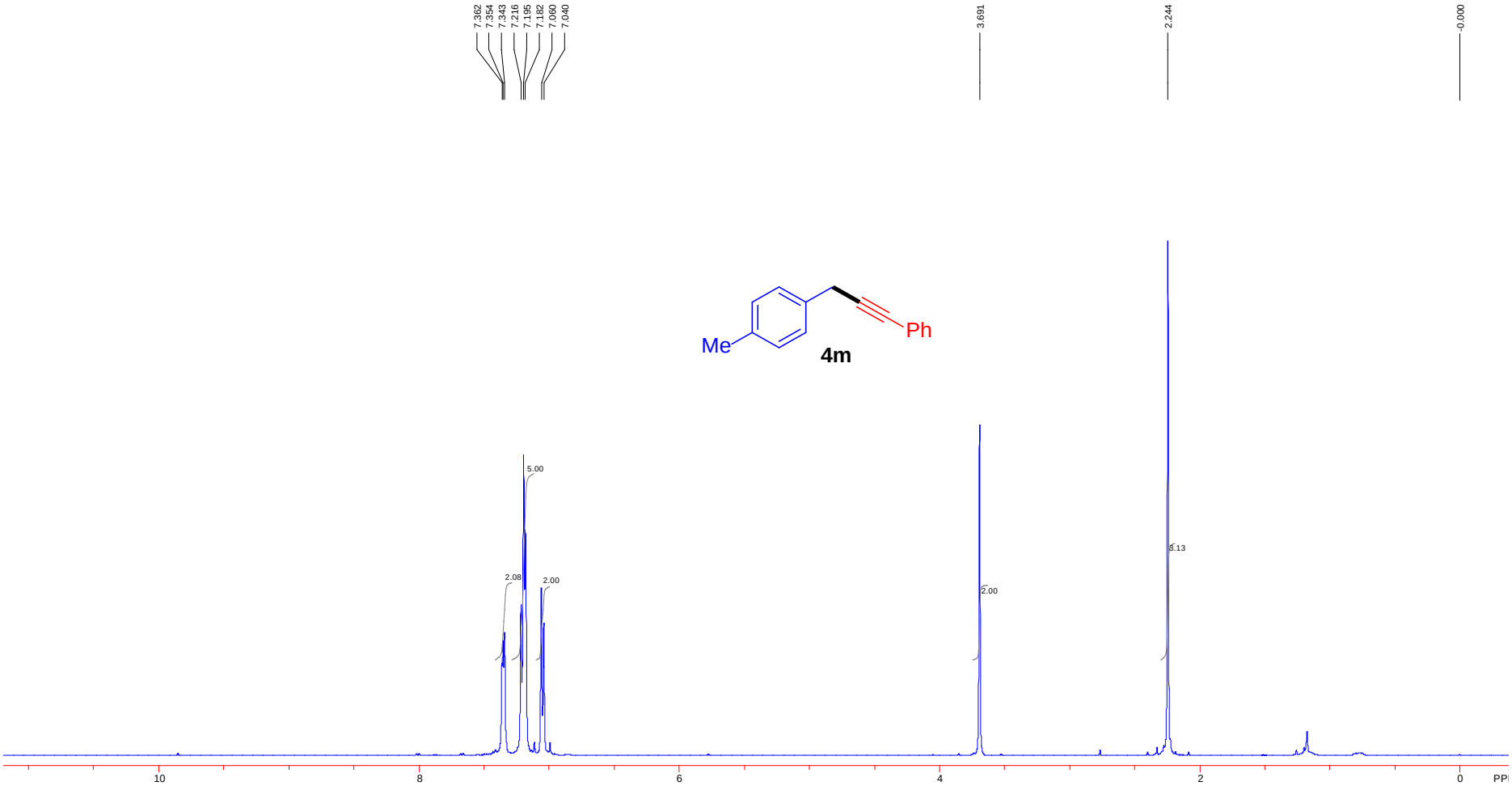
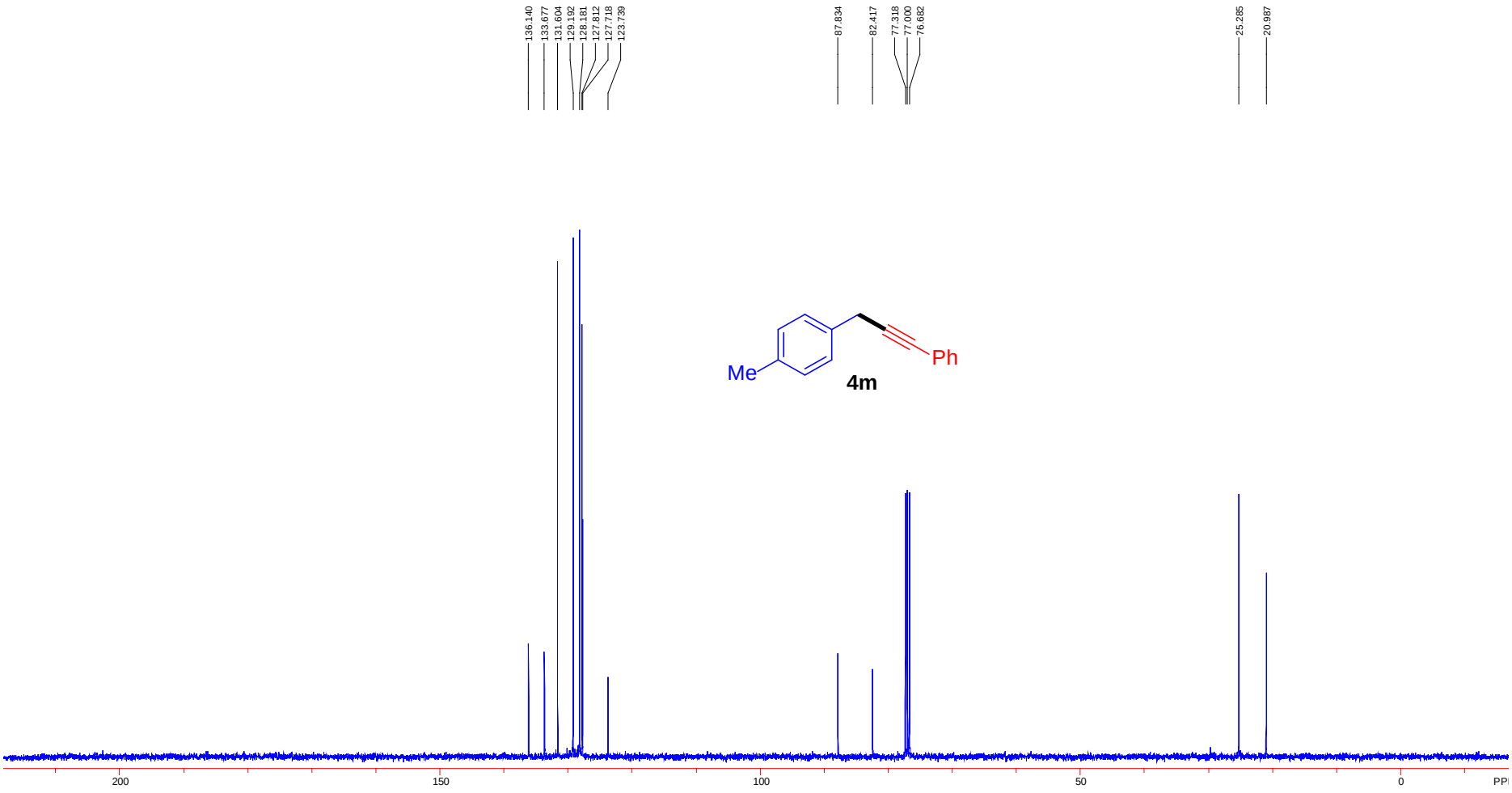
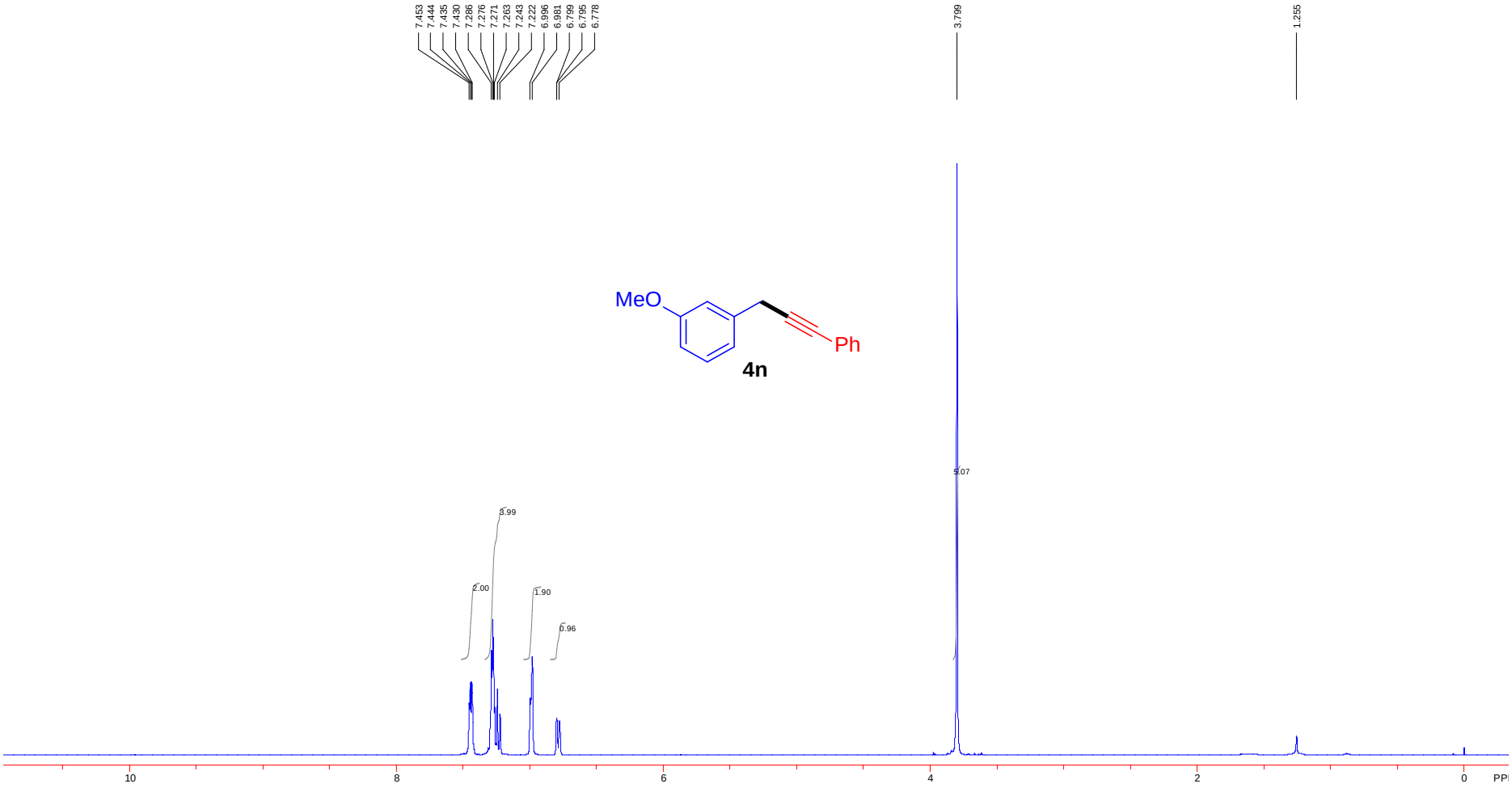


^{13}C NMR(100 MHz, $CDCl_3$)



^{1}H NMR(400 MHz, $CDCl_3$)



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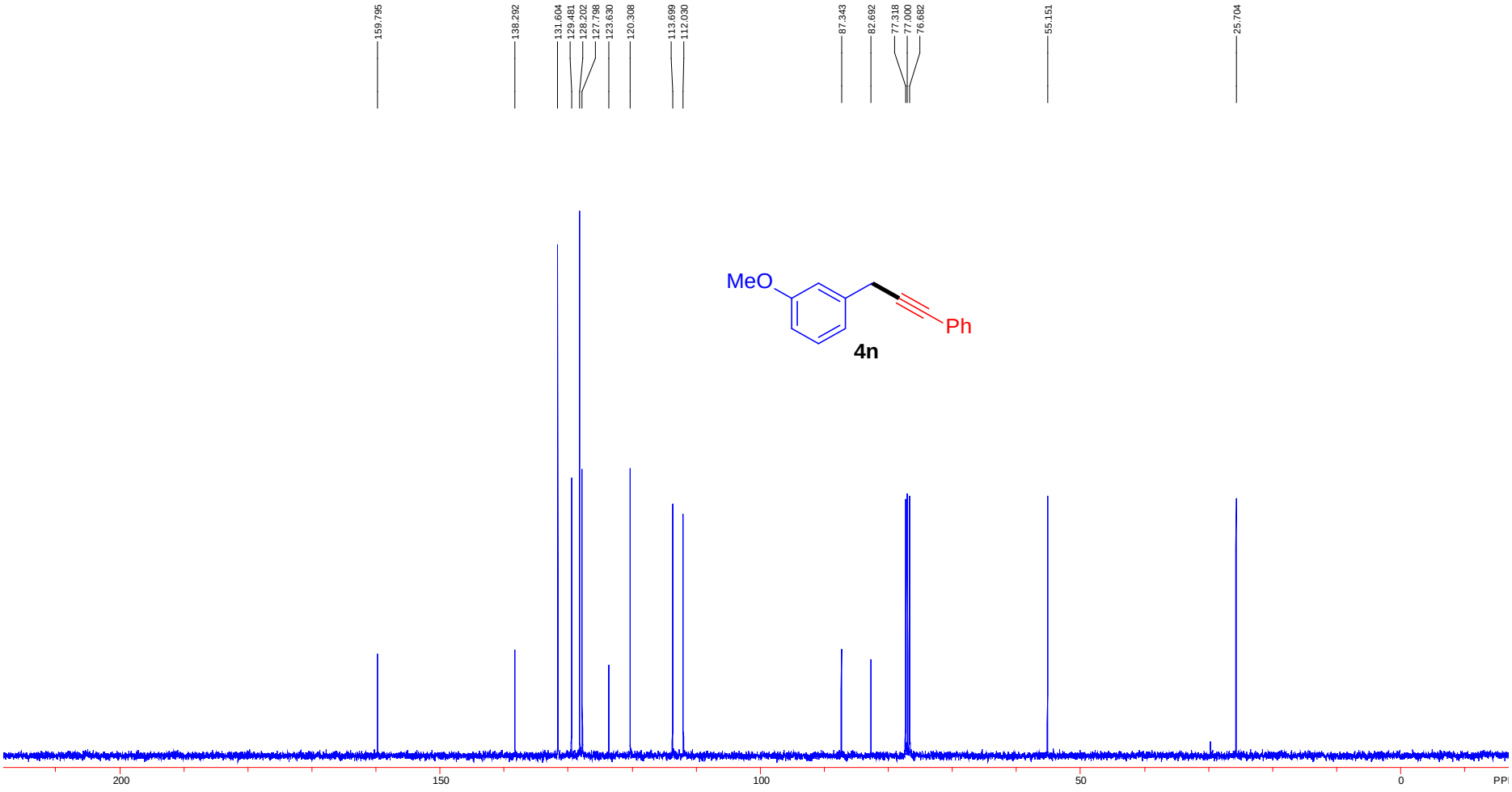
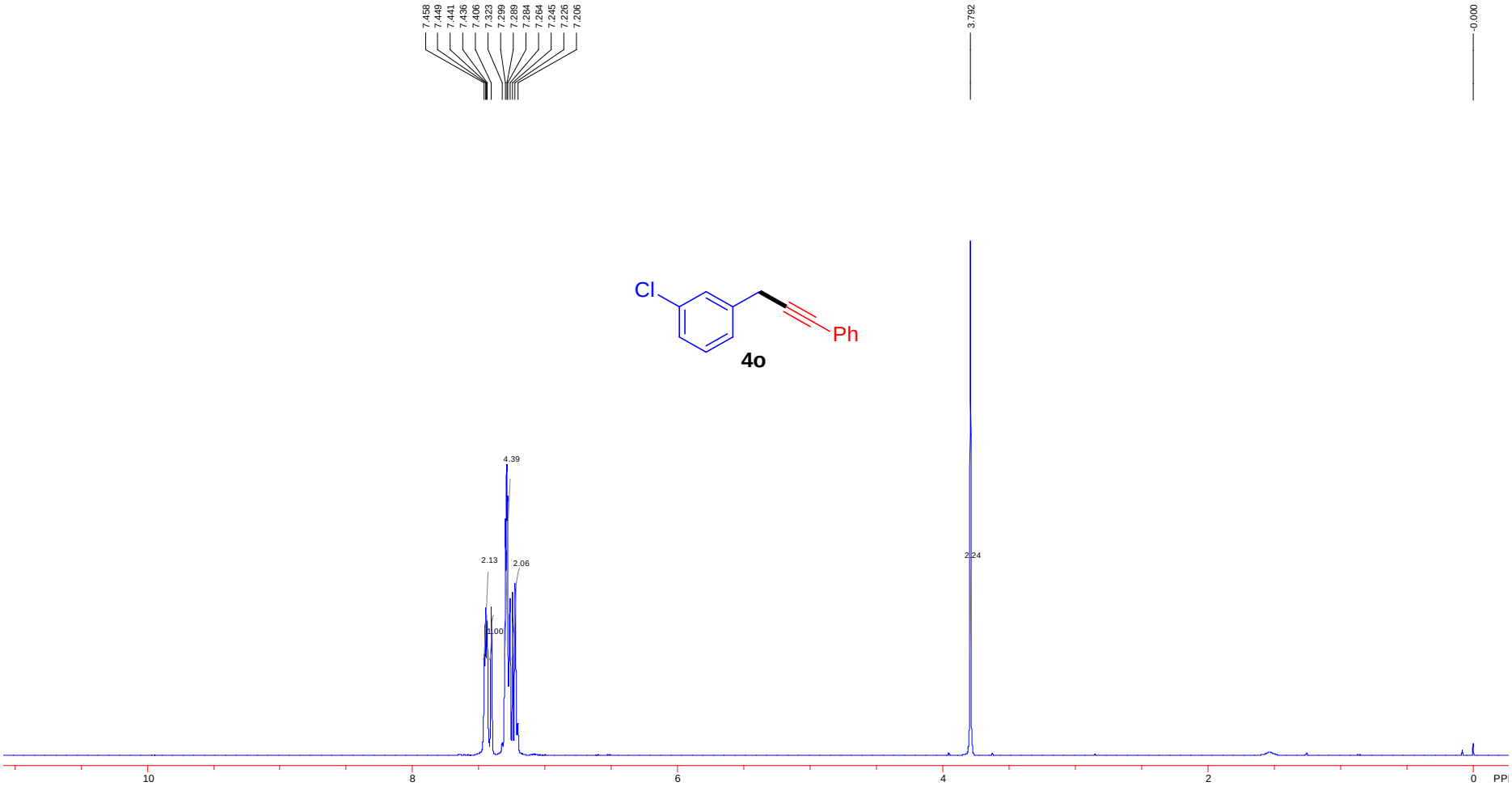
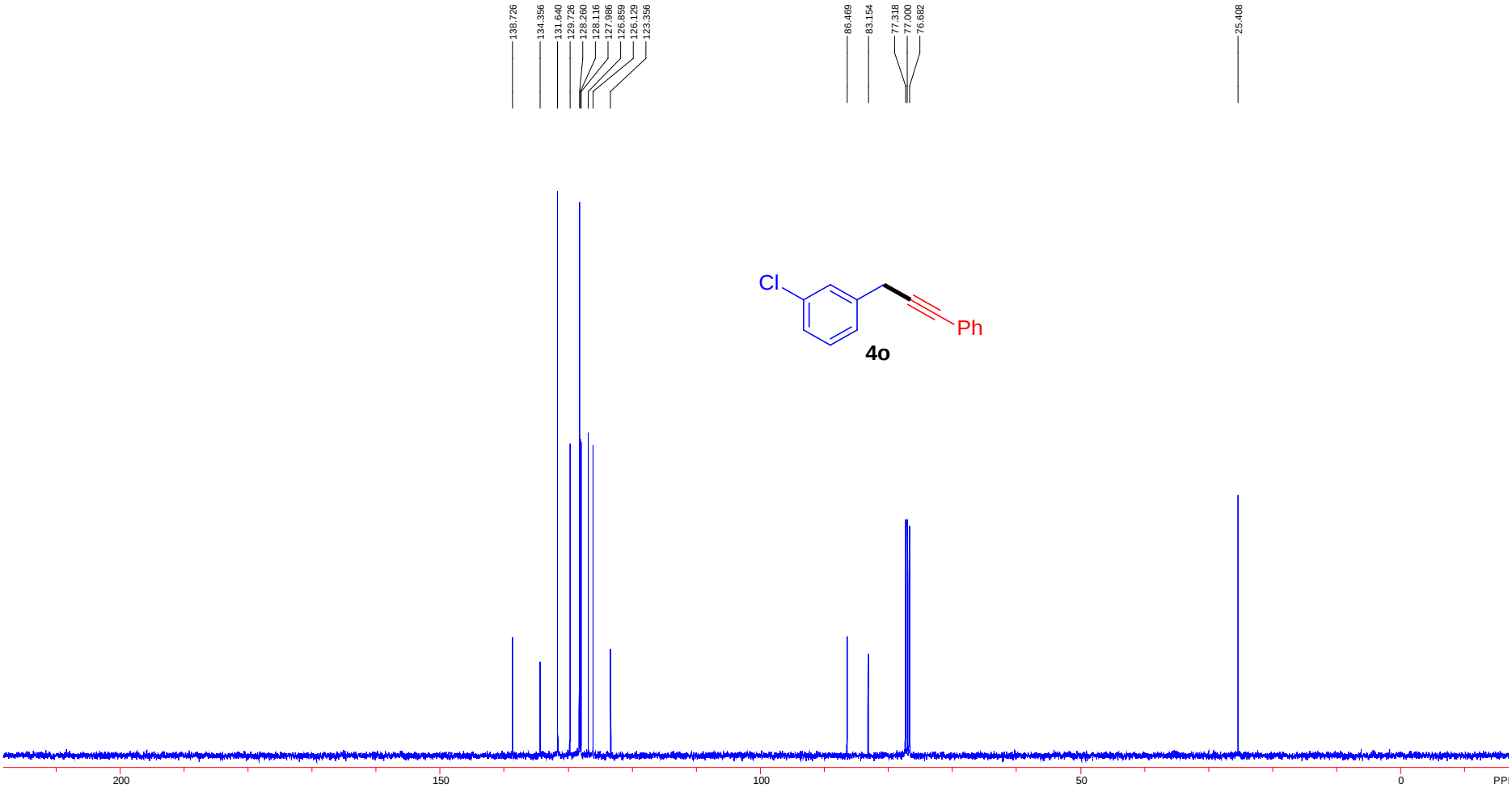


^{1}H NMR(400 MHz, $CDCl_3$)



^{13}C NMR(100 MHz, $CDCl_3$)



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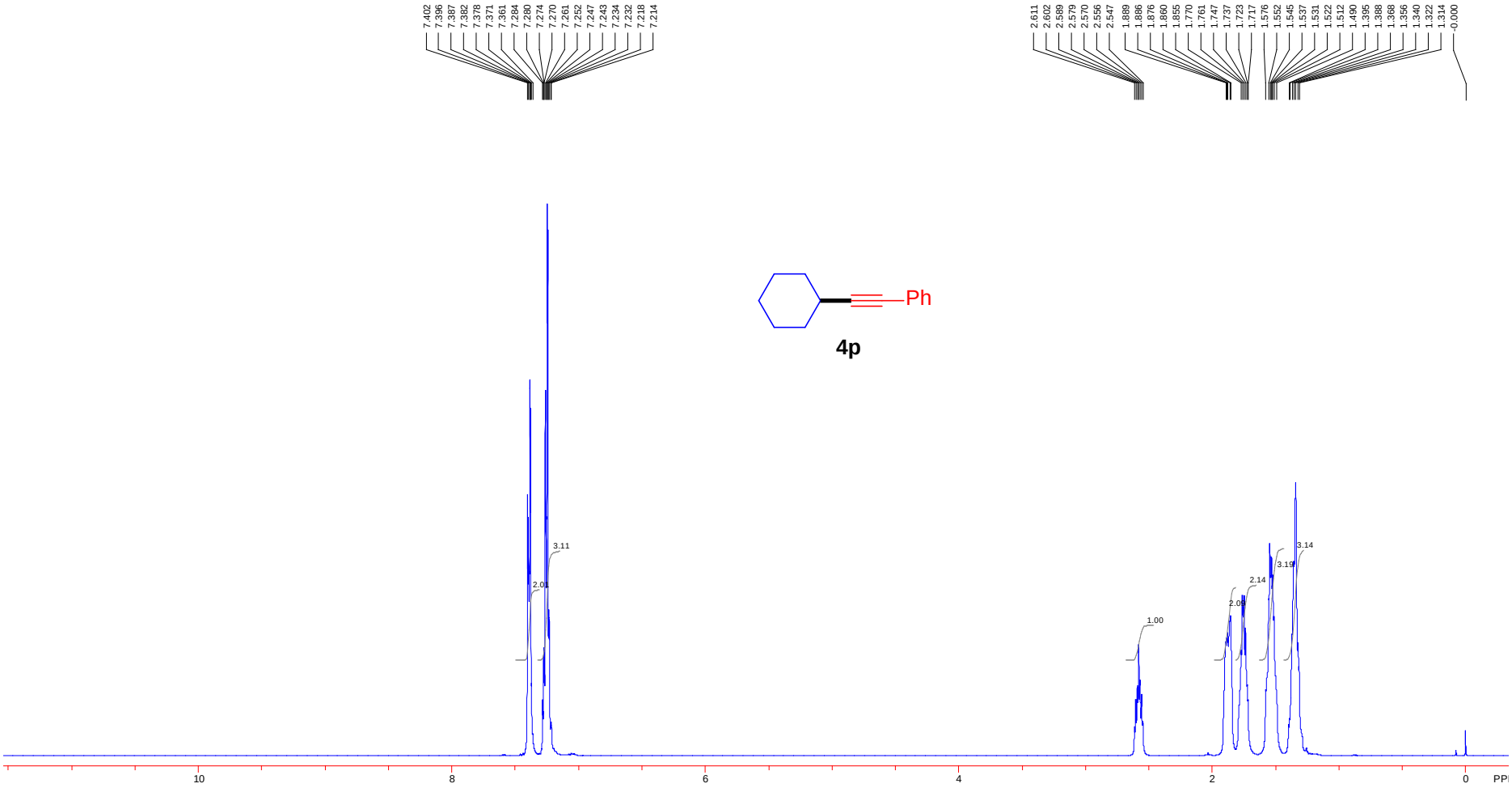
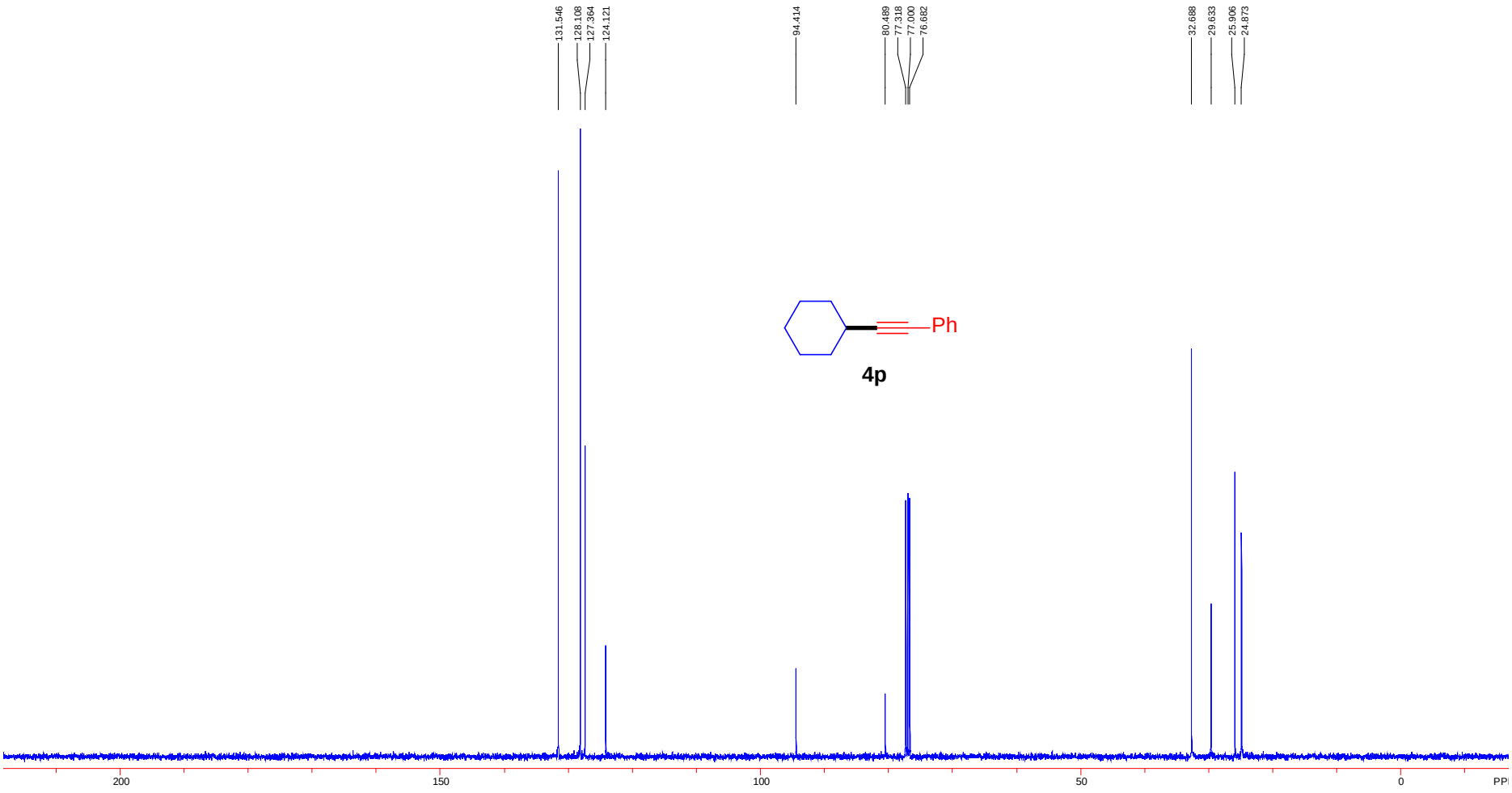


^{13}C NMR(100 MHz, $CDCl_3$)



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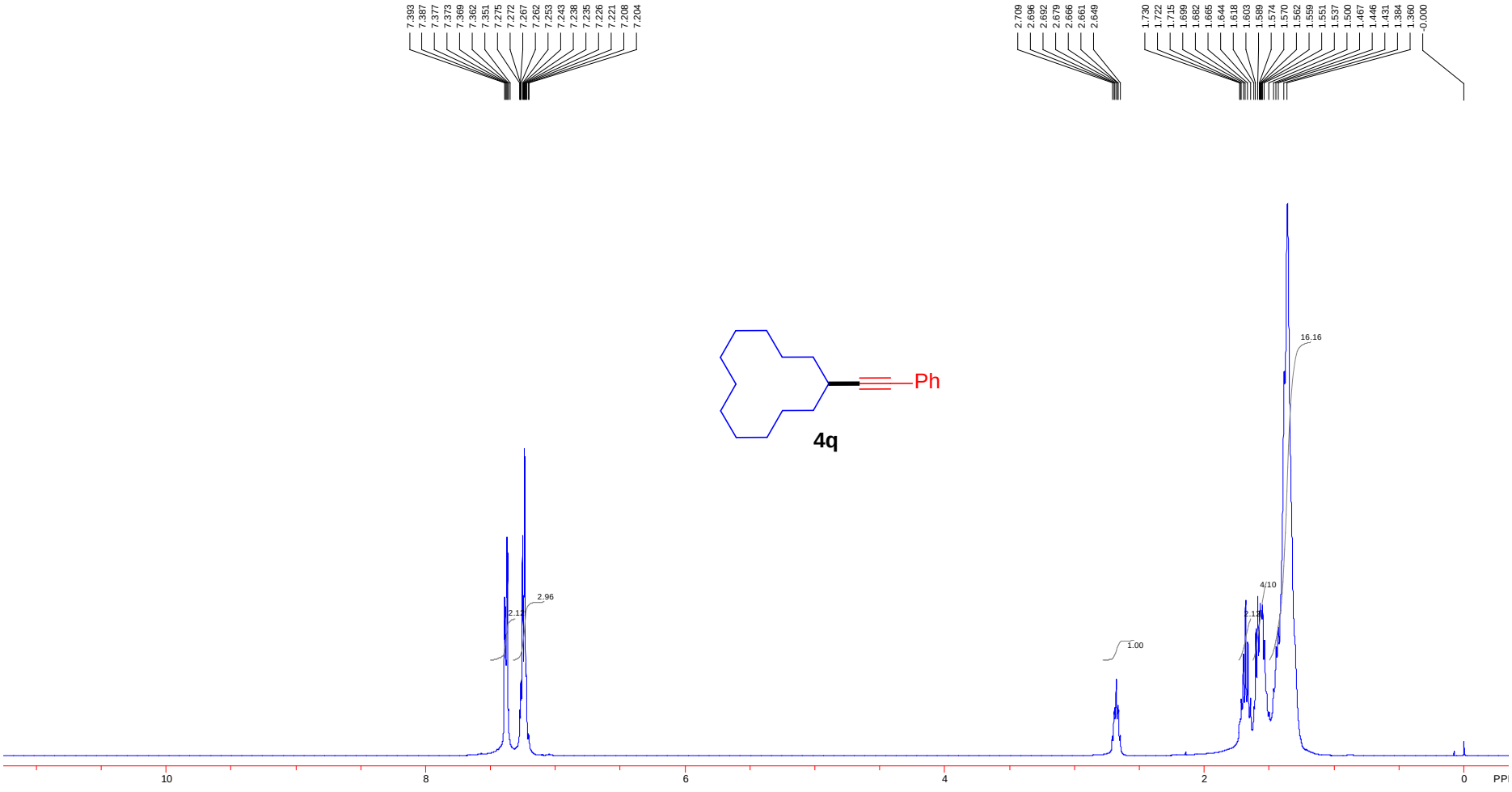
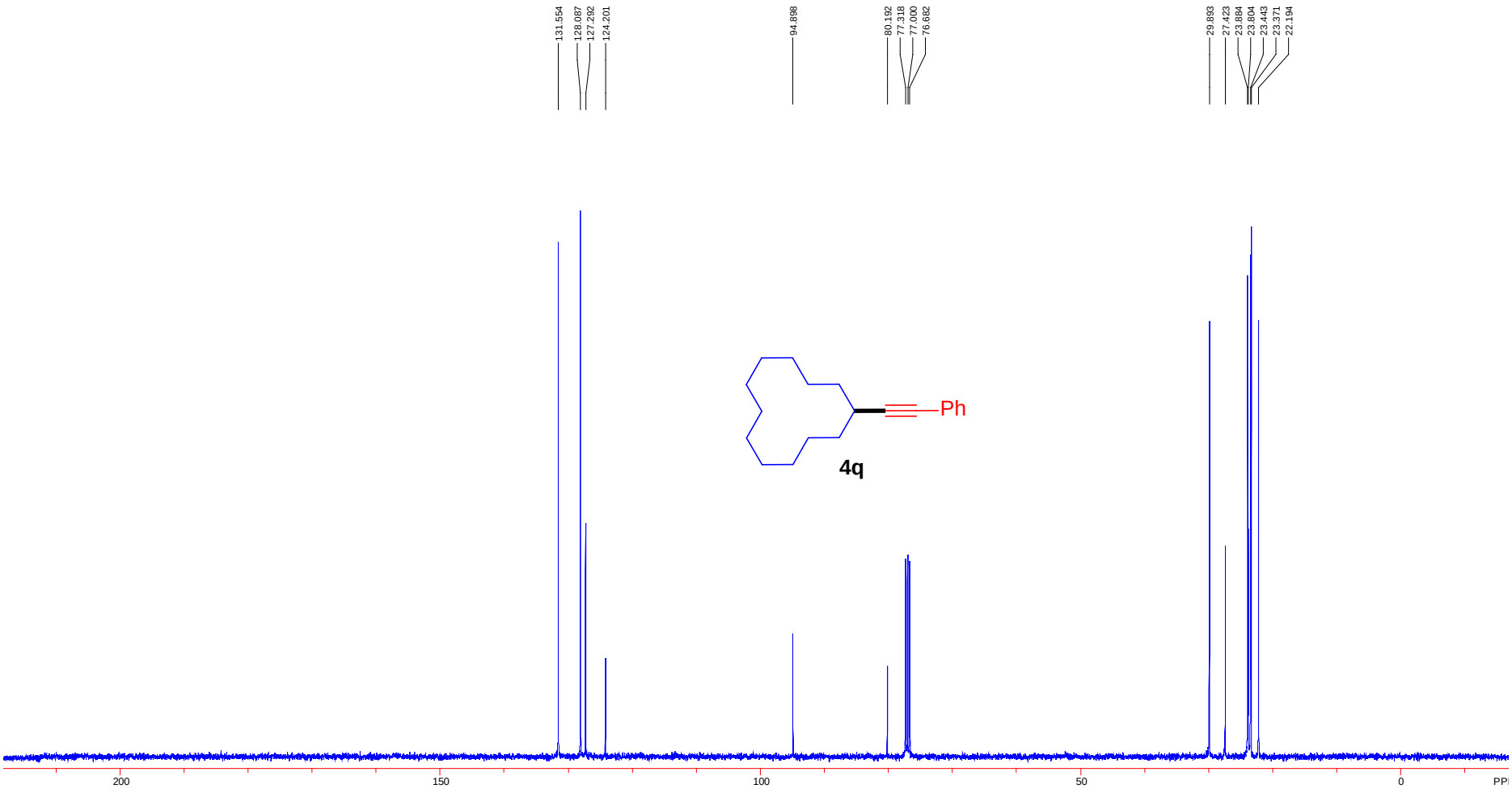
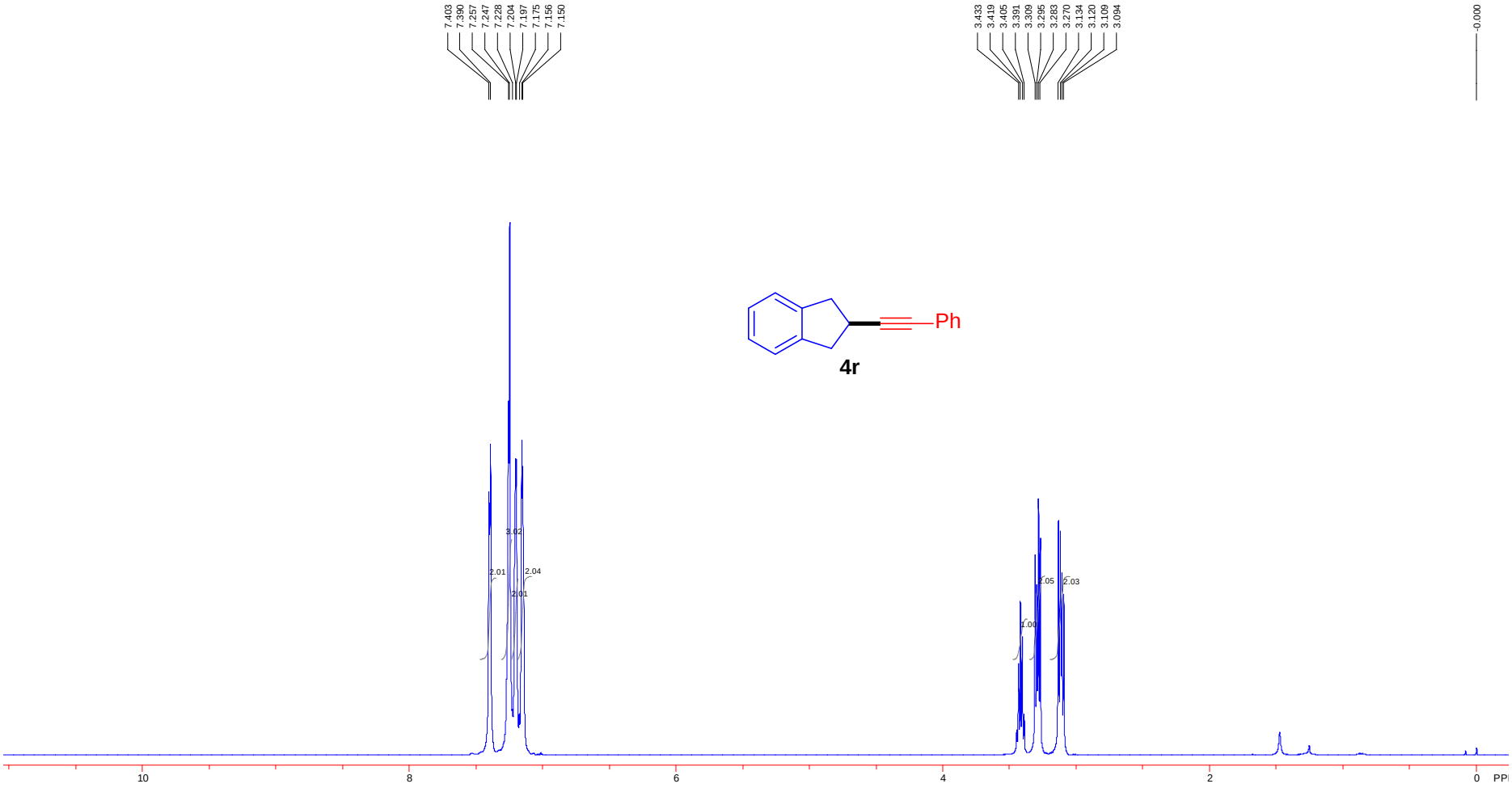


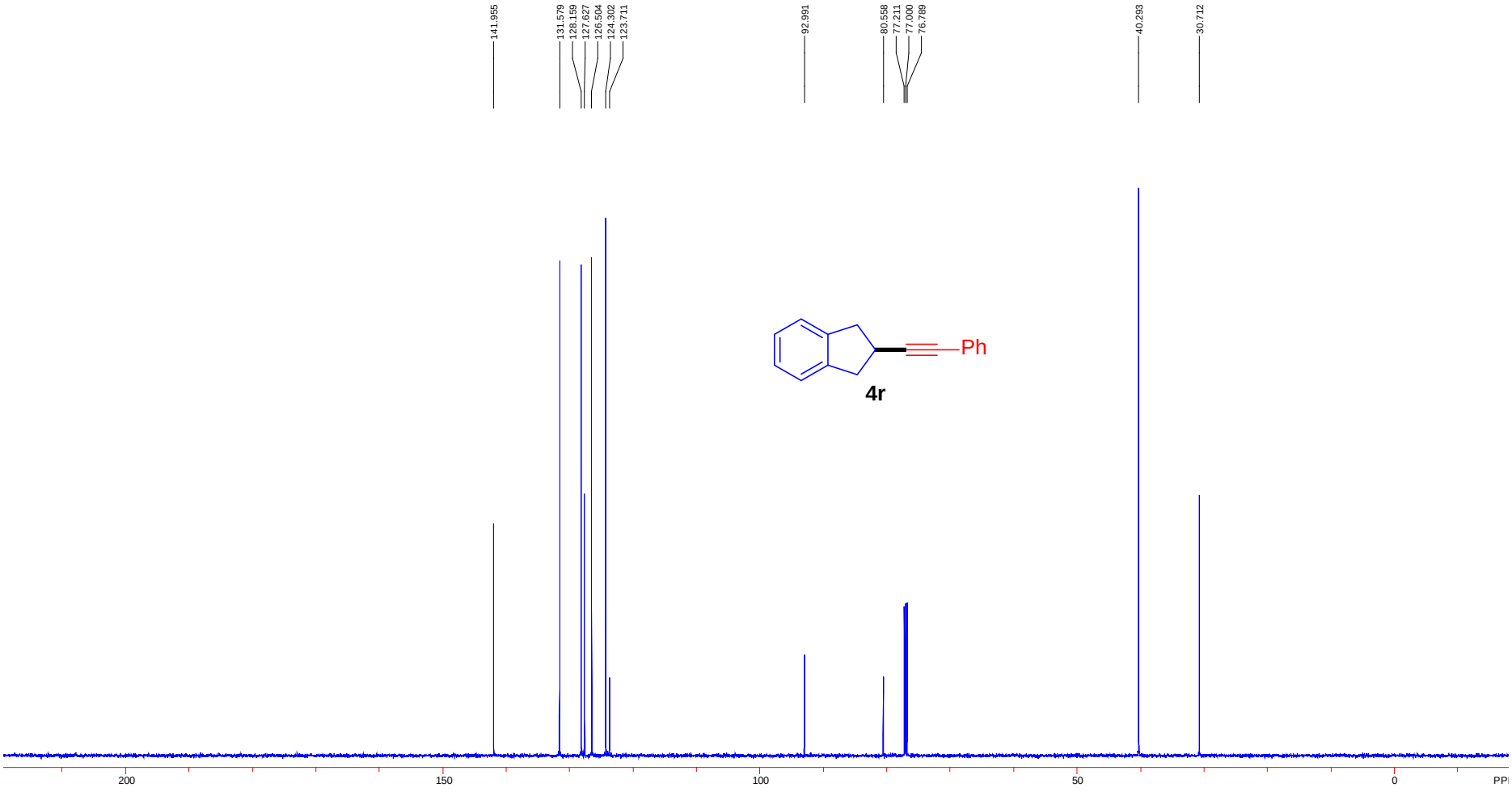
^{13}C NMR(100 MHz, $CDCl_3$)



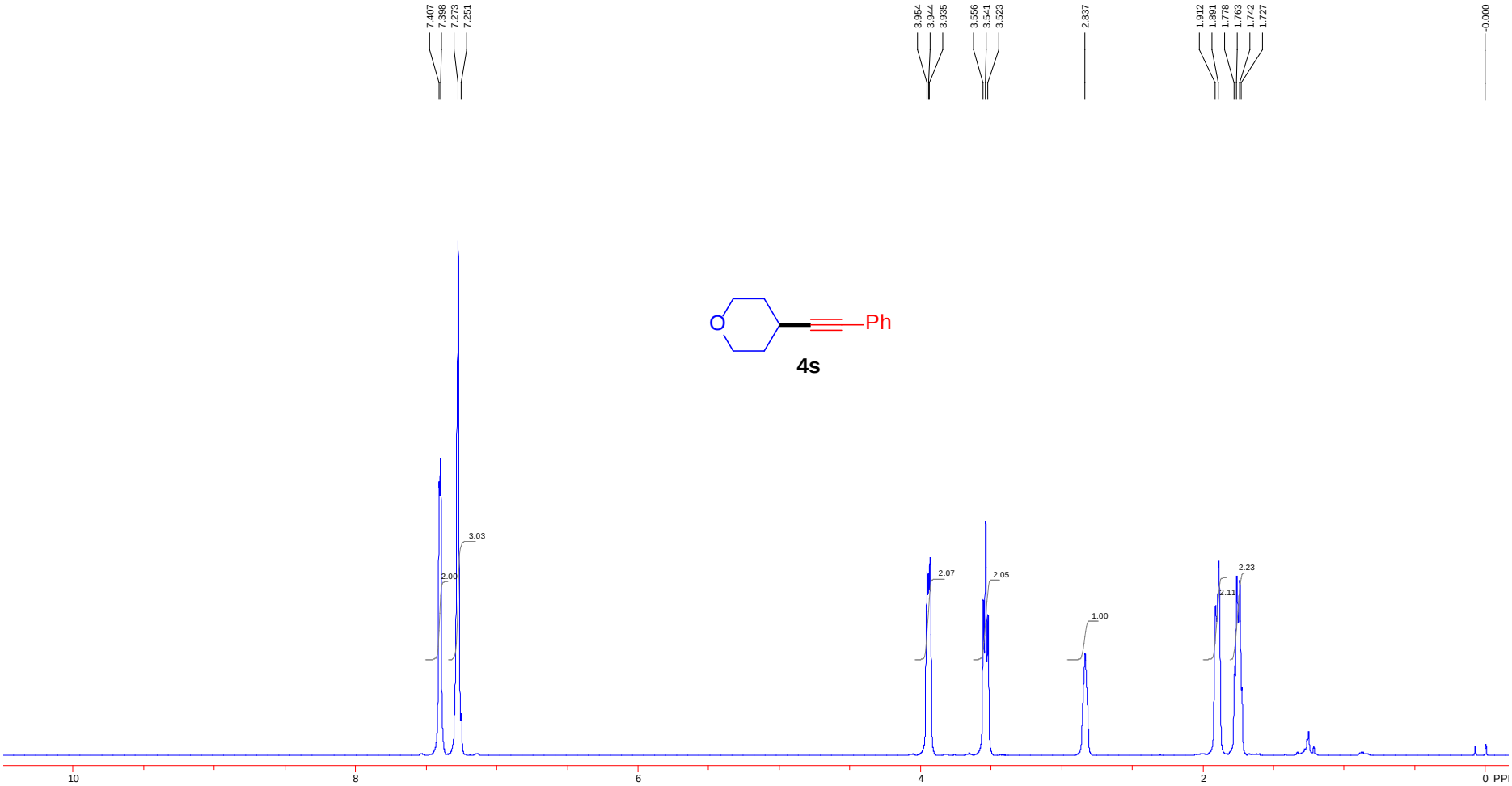
^{1}H NMR (600 MHz, $CDCl_3$)



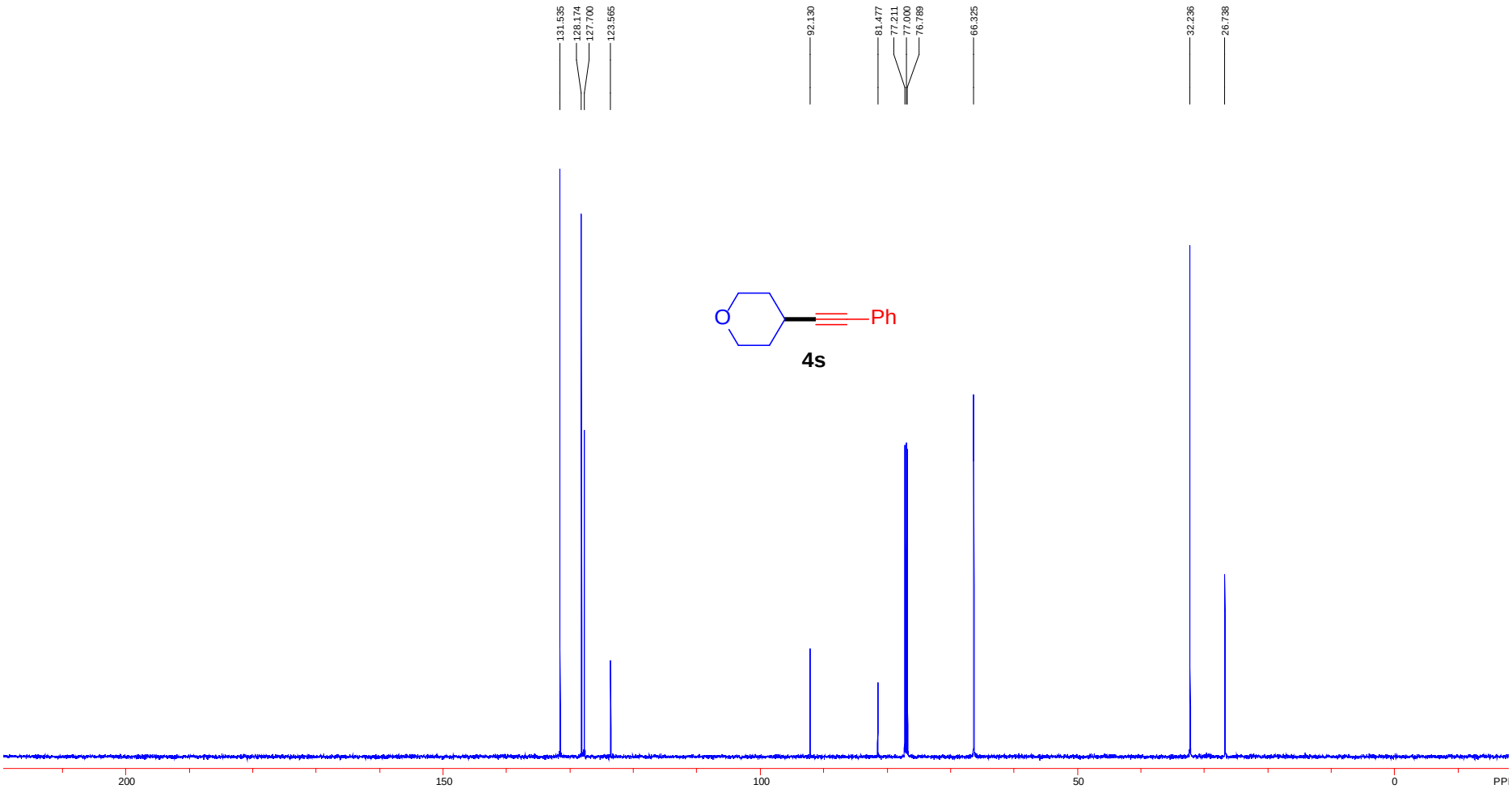
^{13}C NMR (151 MHz, $CDCl_3$)



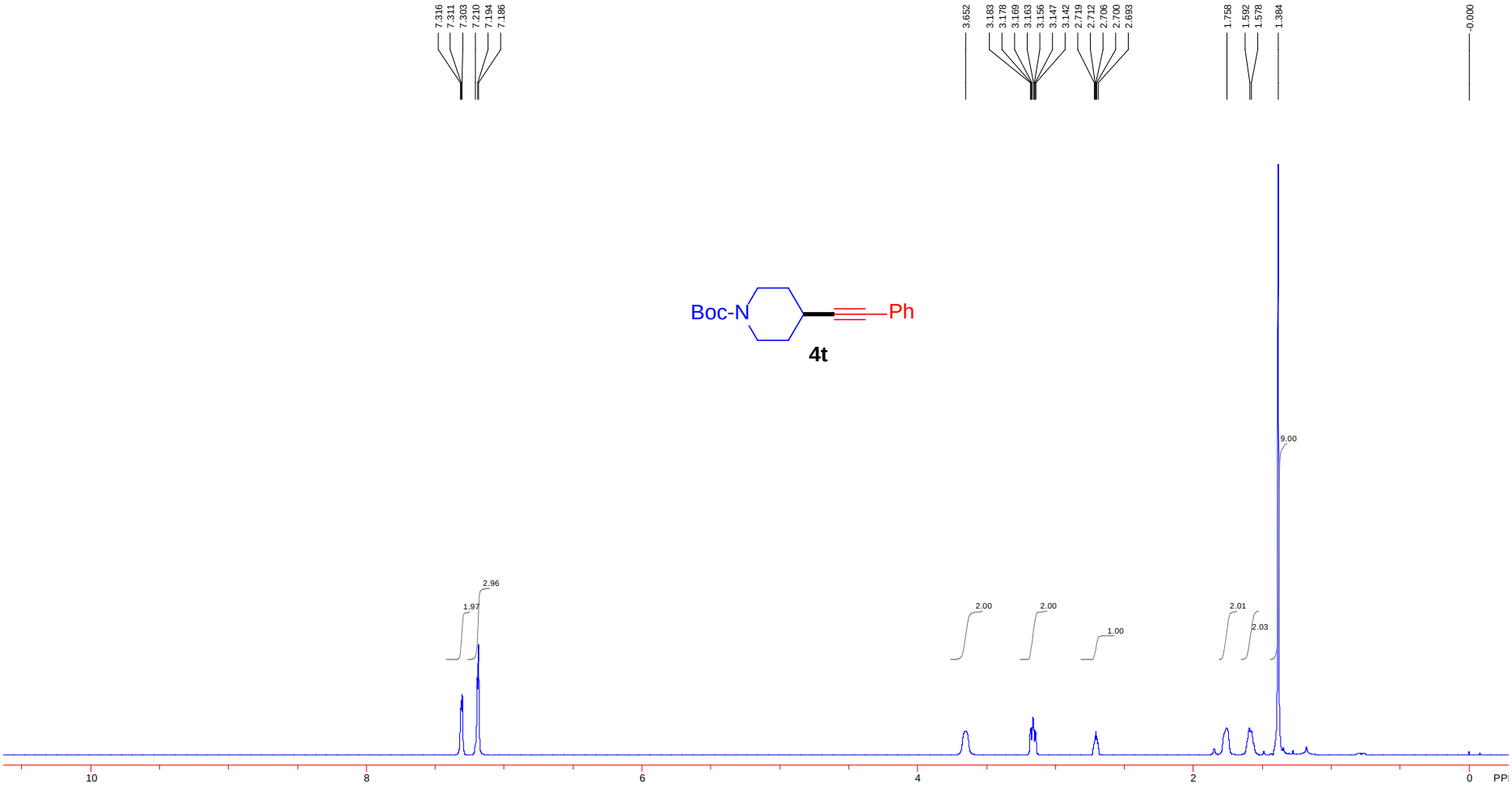
^{1}H NMR (600 MHz, $CDCl_3$)



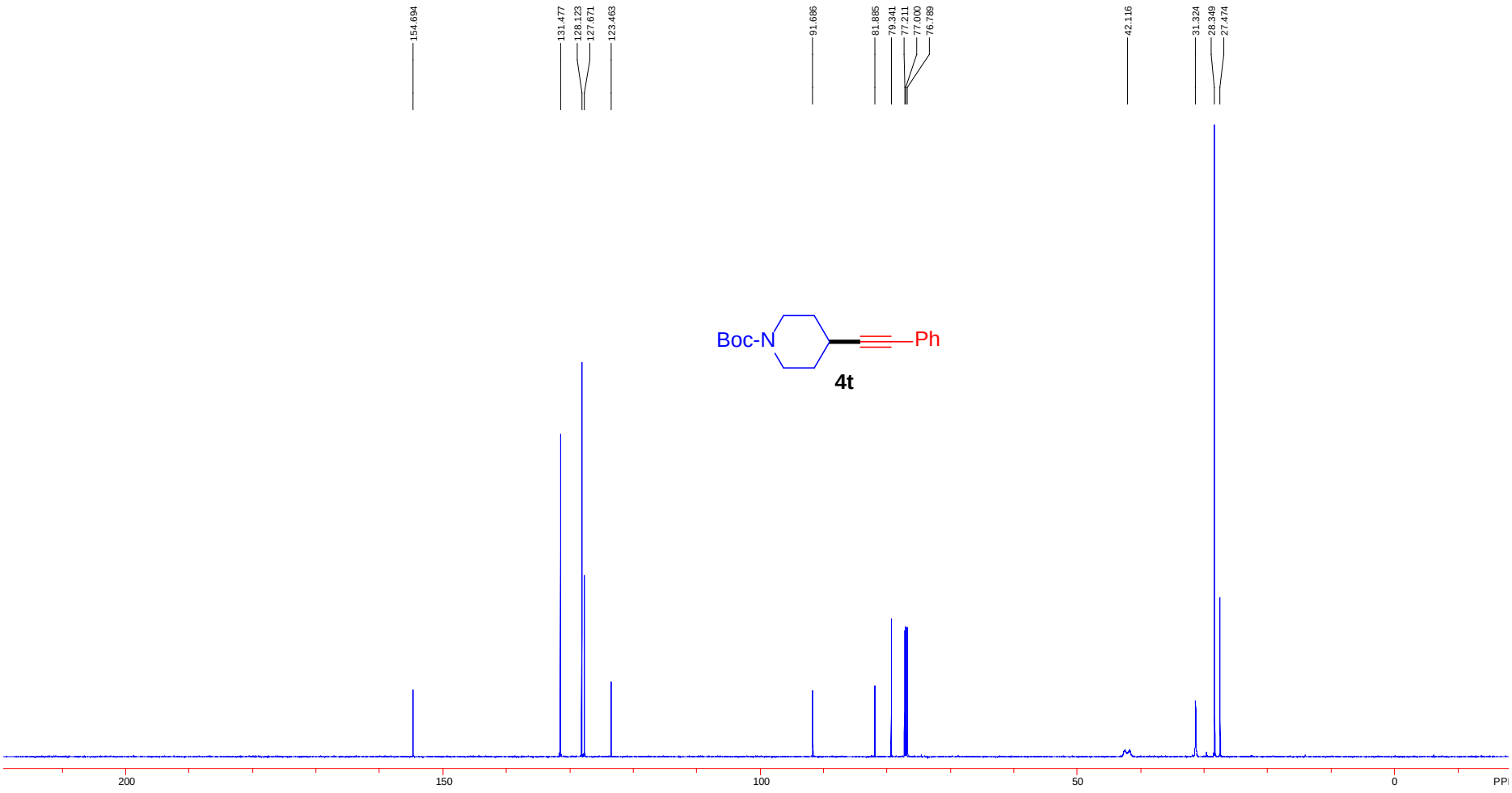
^{13}C NMR (151 MHz, $CDCl_3$)



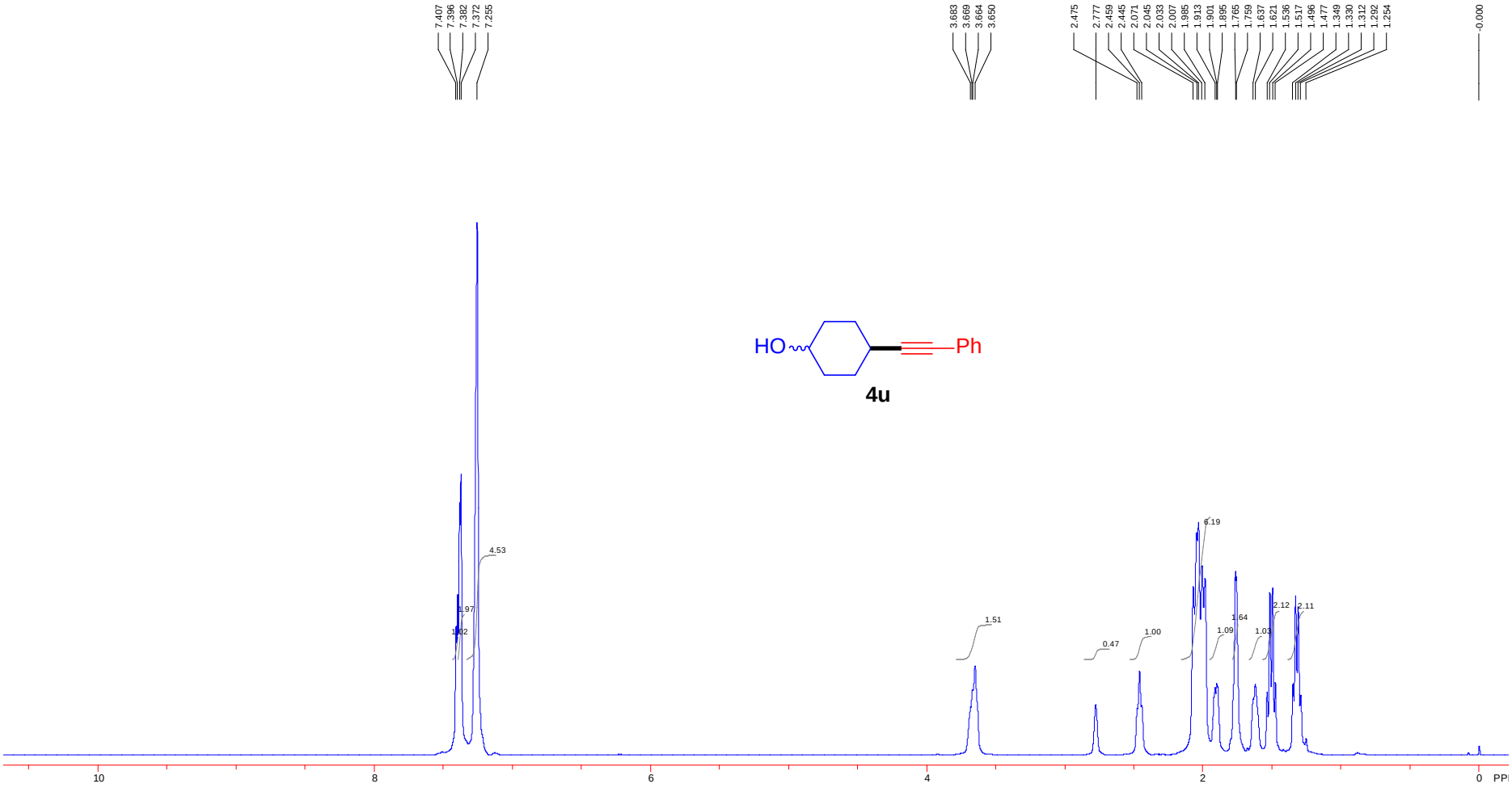
^{1}H NMR (600 MHz, $CDCl_3$)



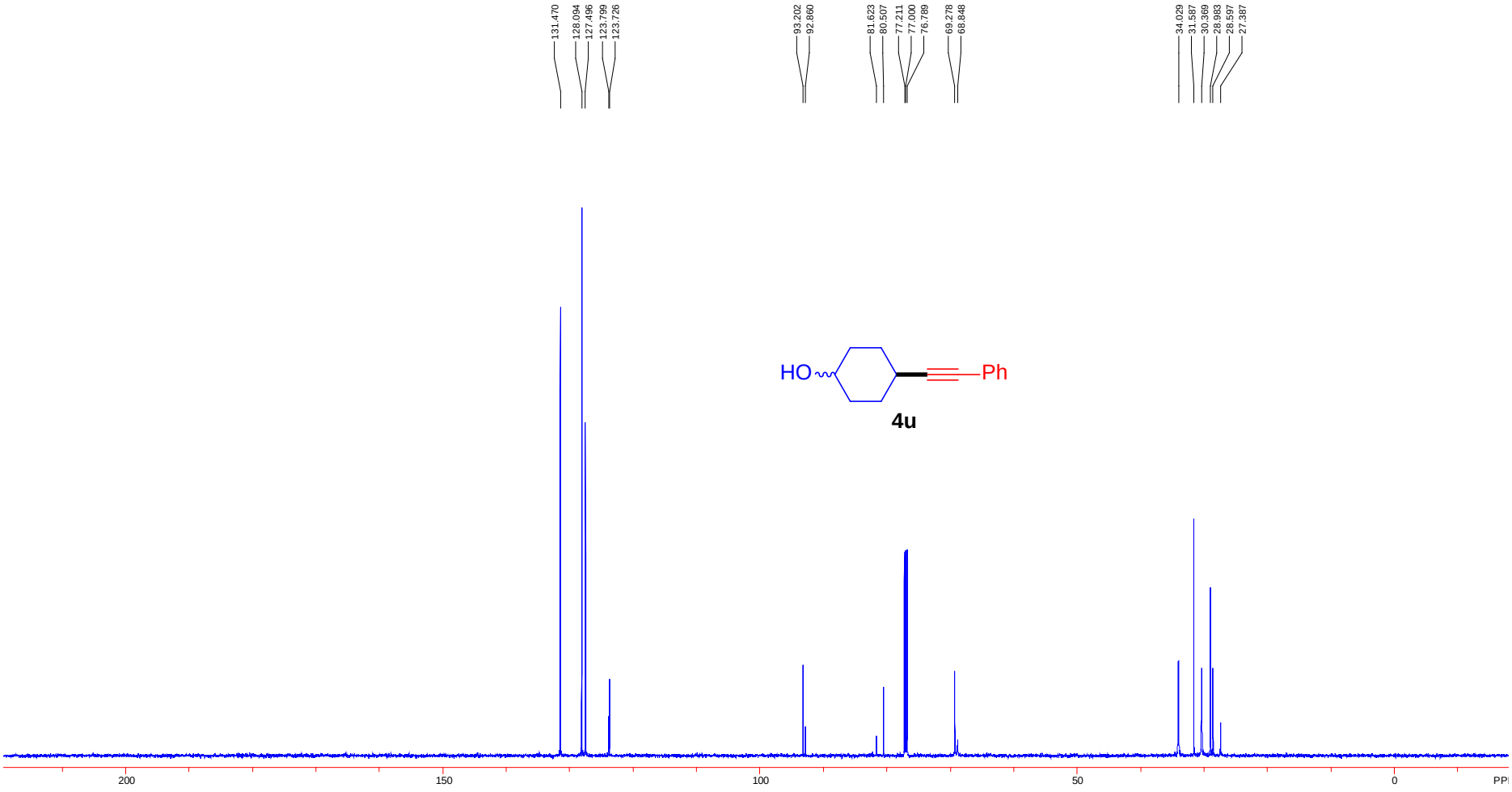
^{13}C NMR (151 MHz, $CDCl_3$)



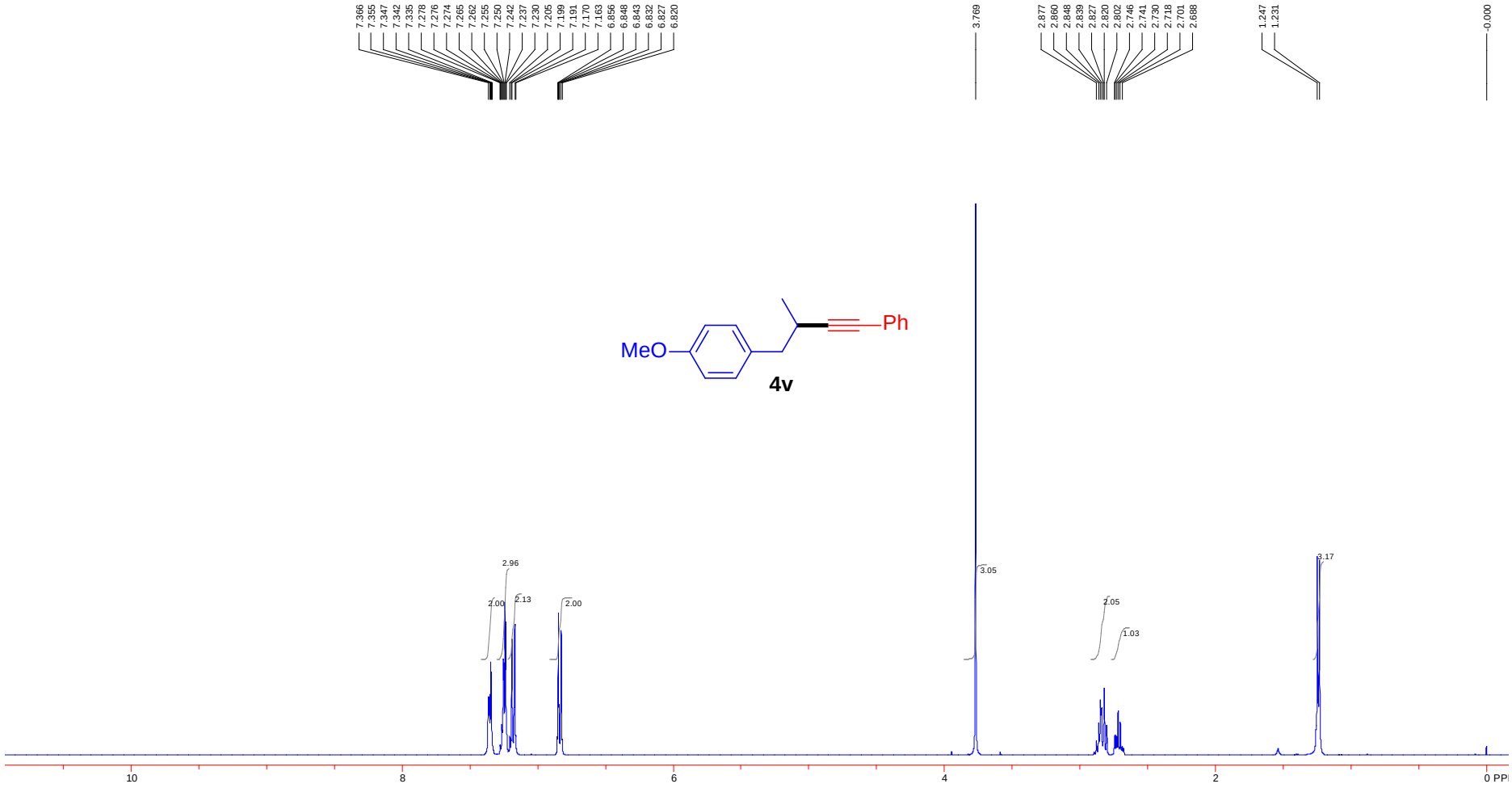
^{1}H NMR (600 MHz, $CDCl_3$)



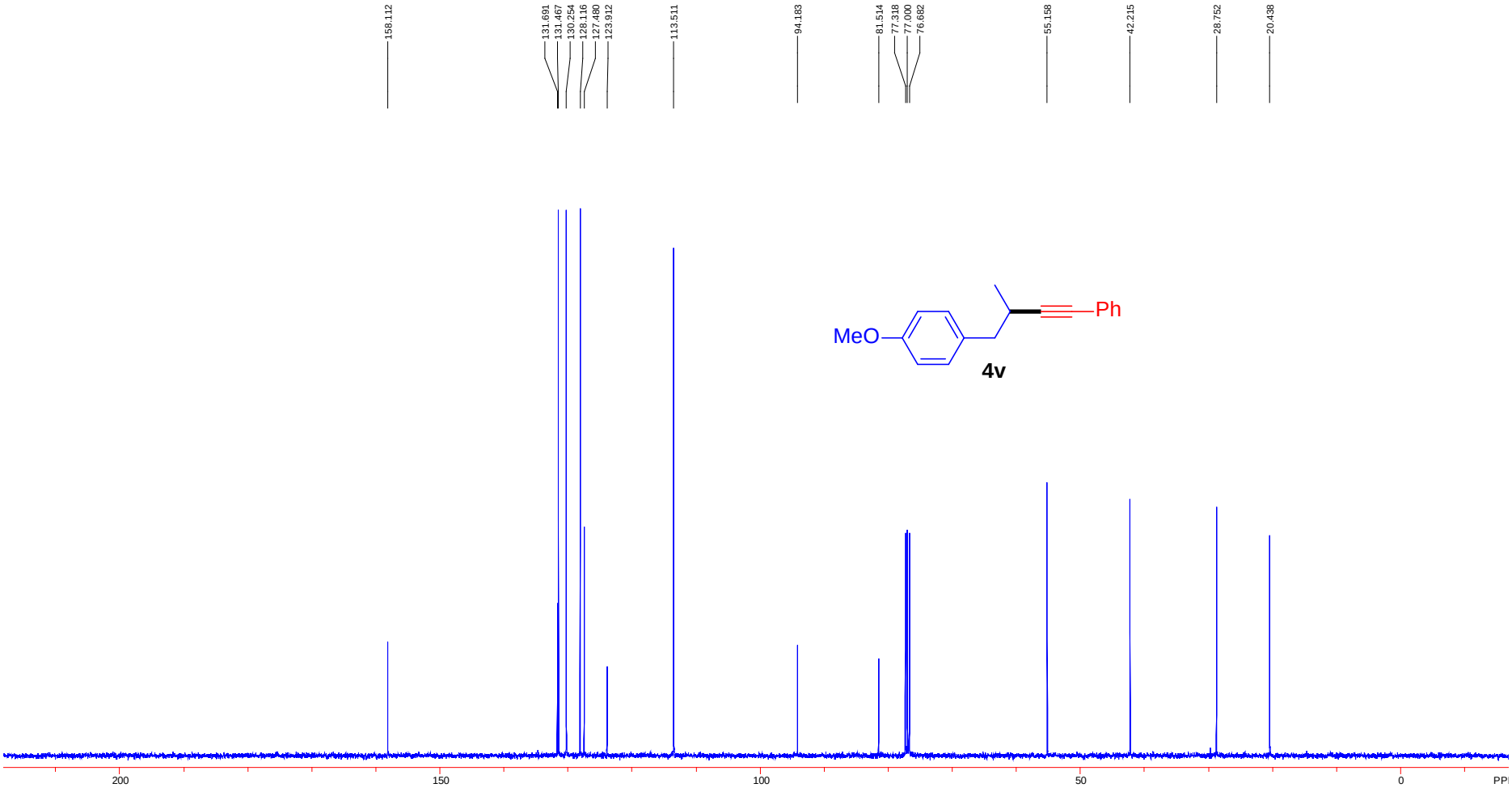
^{13}C NMR (151 MHz, $CDCl_3$)



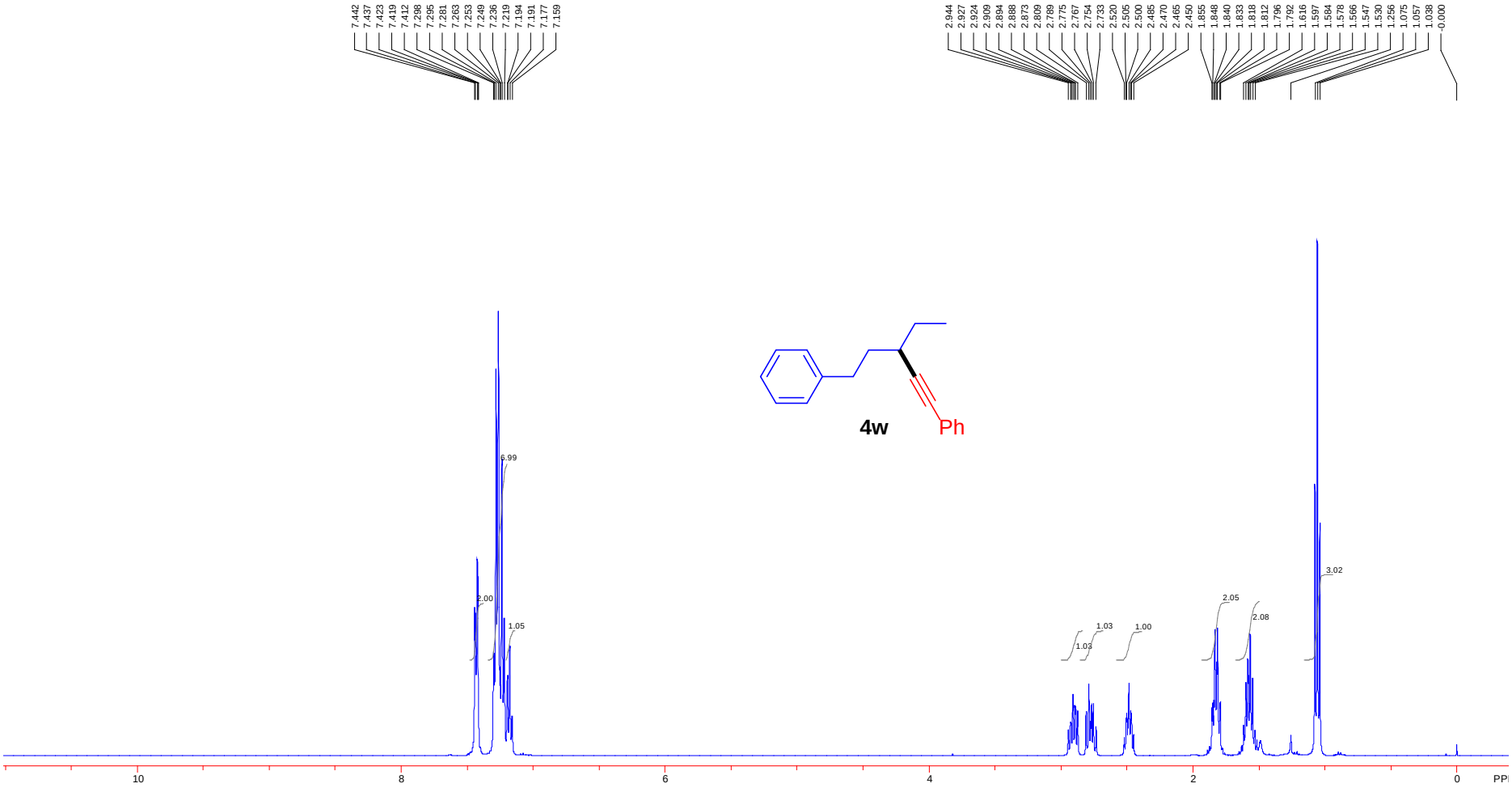
^{1}H NMR(400 MHz, $CDCl_3$)



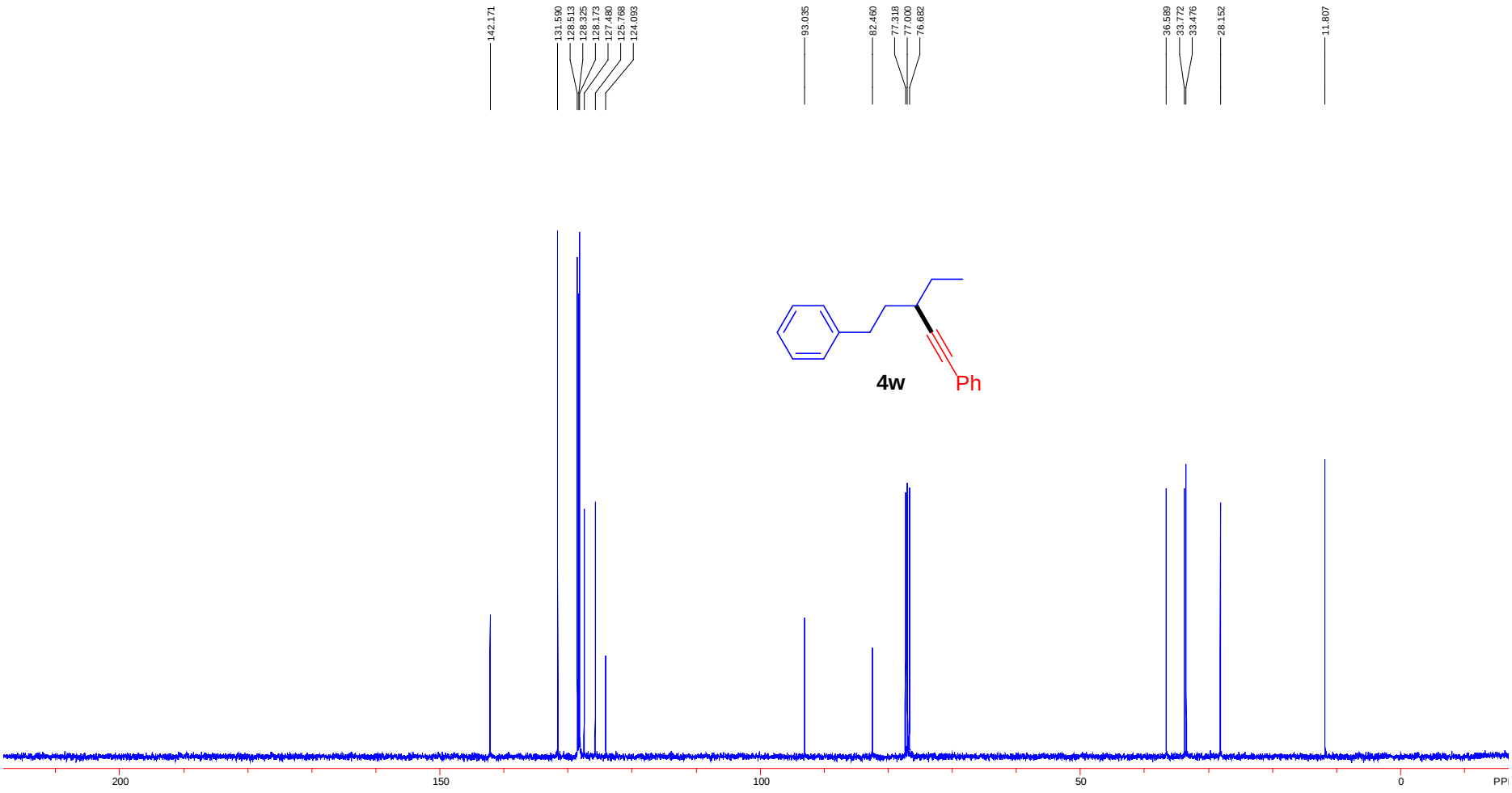
^{13}C NMR(100 MHz, $CDCl_3$)



^{1}H NMR(400 MHz, $CDCl_3$)



^{13}C NMR(100 MHz, $CDCl_3$)



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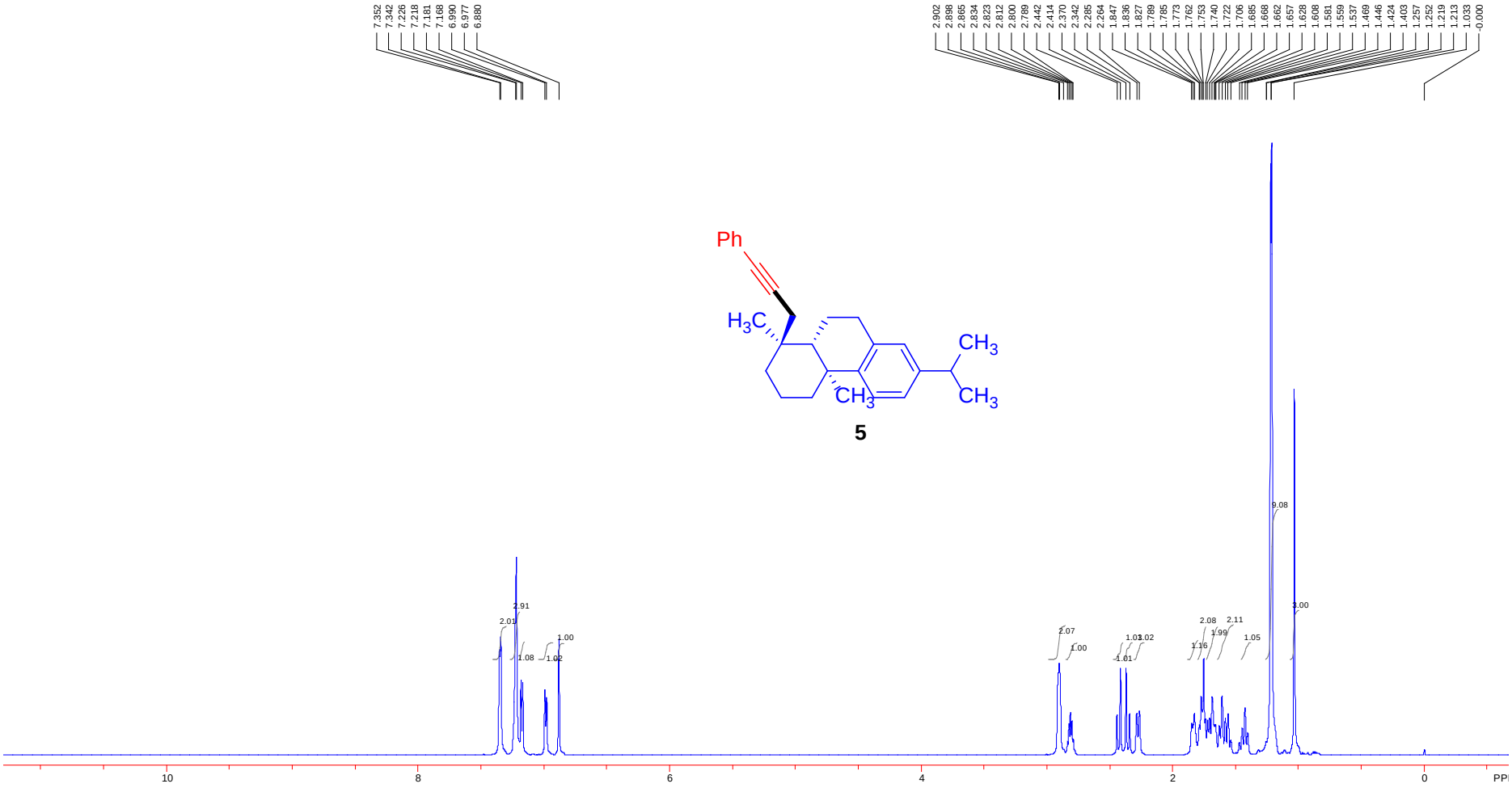
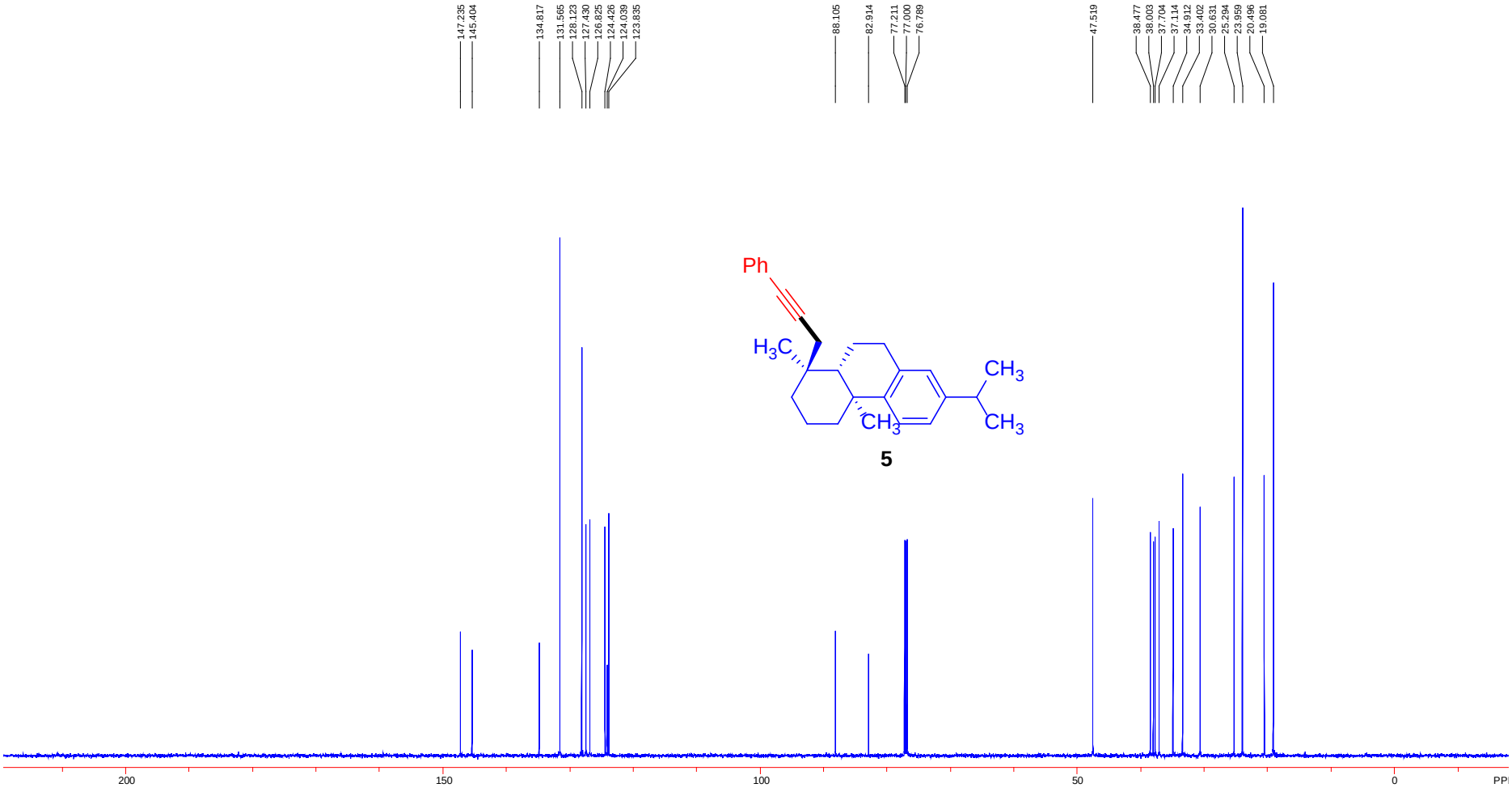
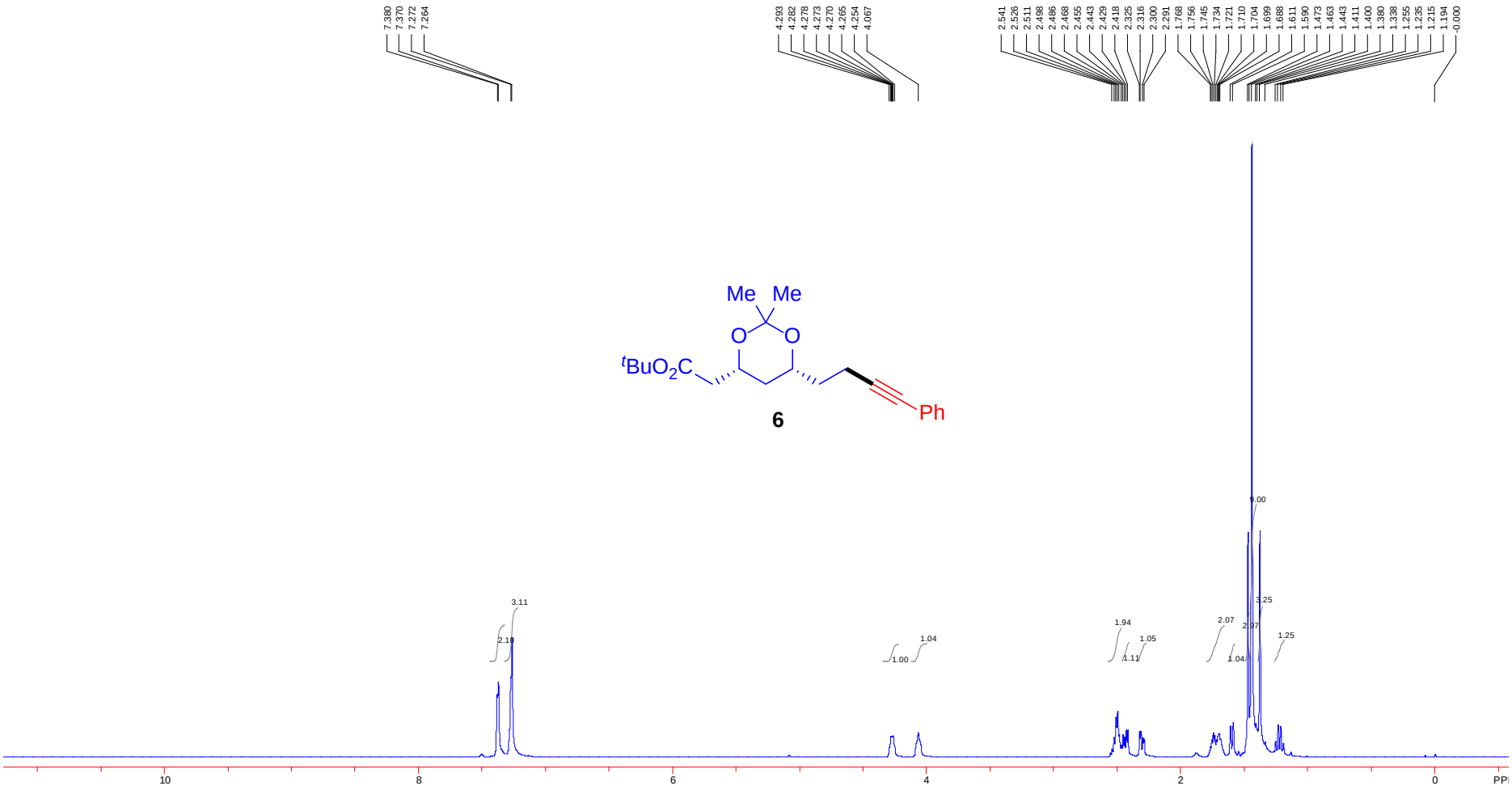


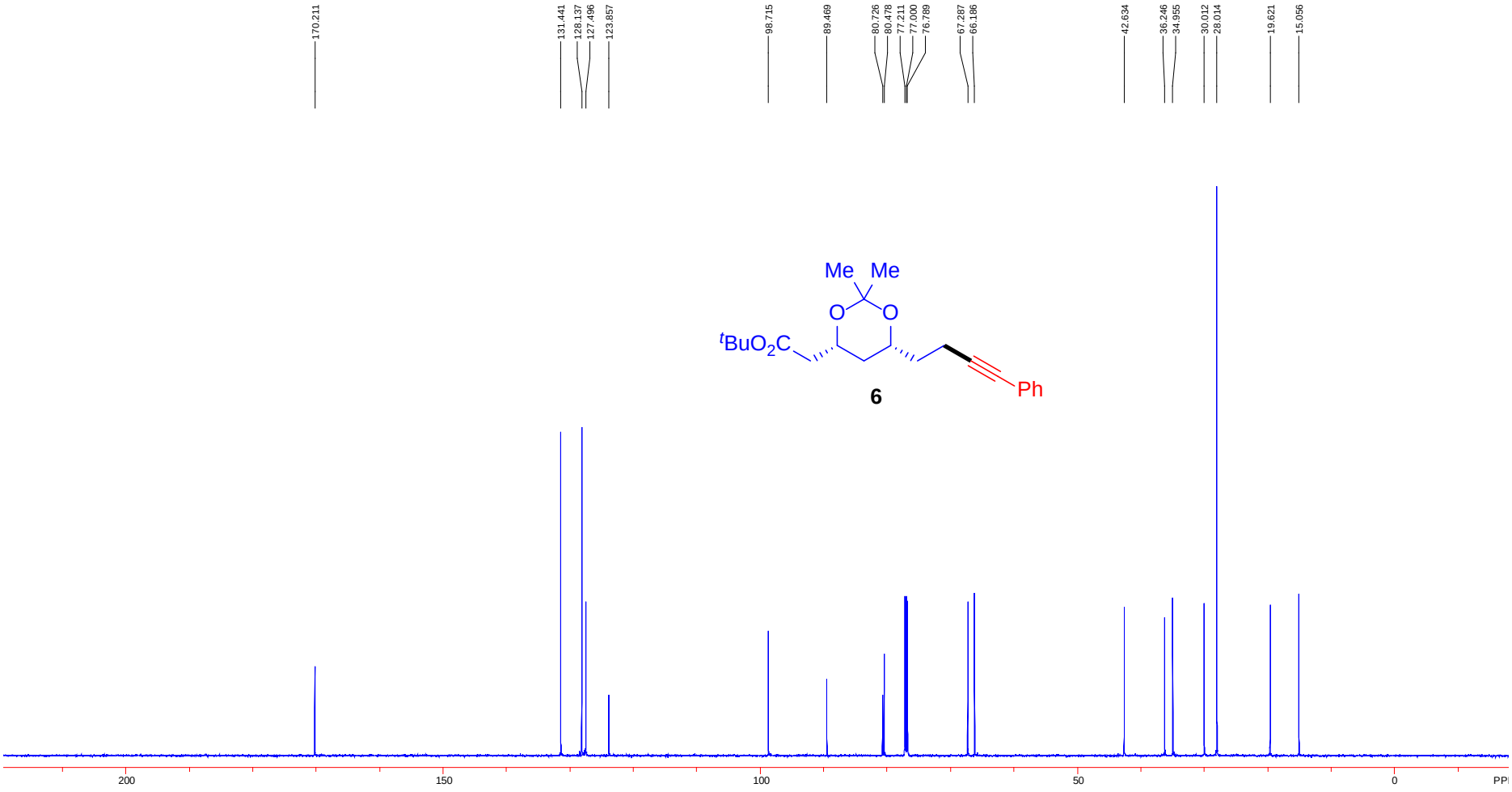
^{13}C NMR (151 MHz, $CDCl_3$)



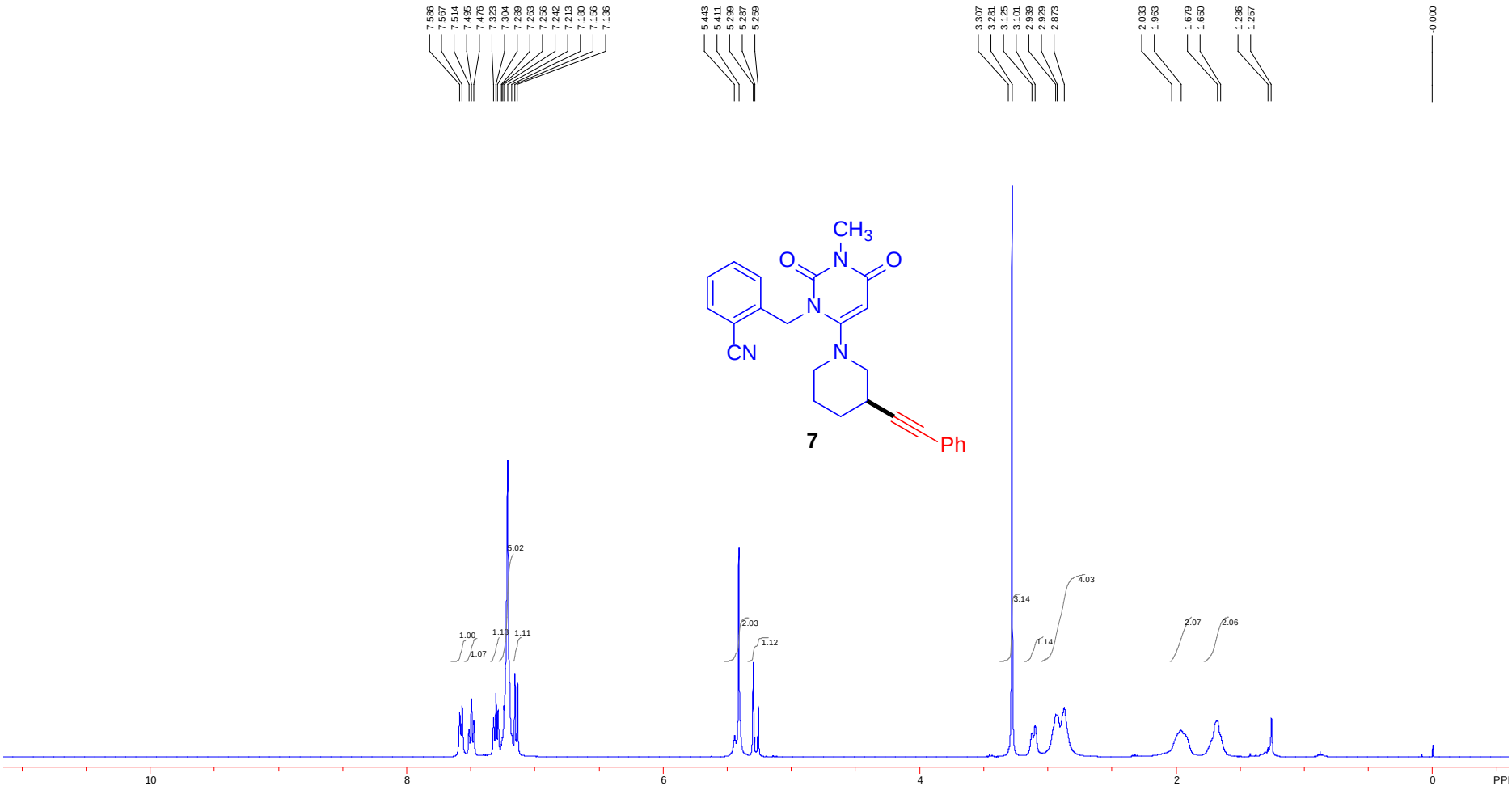
^{1}H NMR (600 MHz, $CDCl_3$)



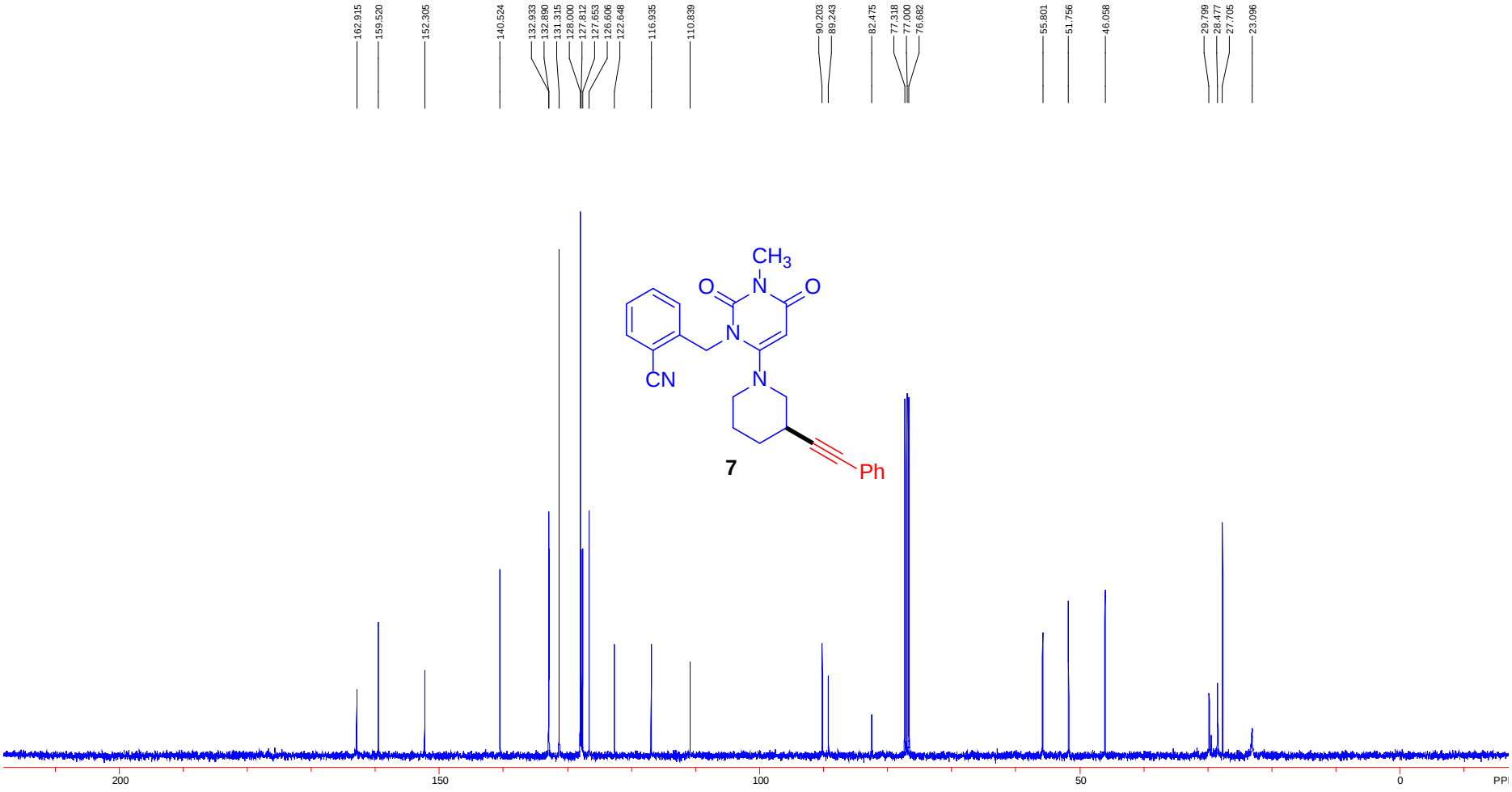
^{13}C NMR (151 MHz, $CDCl_3$)



^{1}H NMR(400 MHz, $CDCl_3$)



^{13}C NMR(100 MHz, $CDCl_3$)



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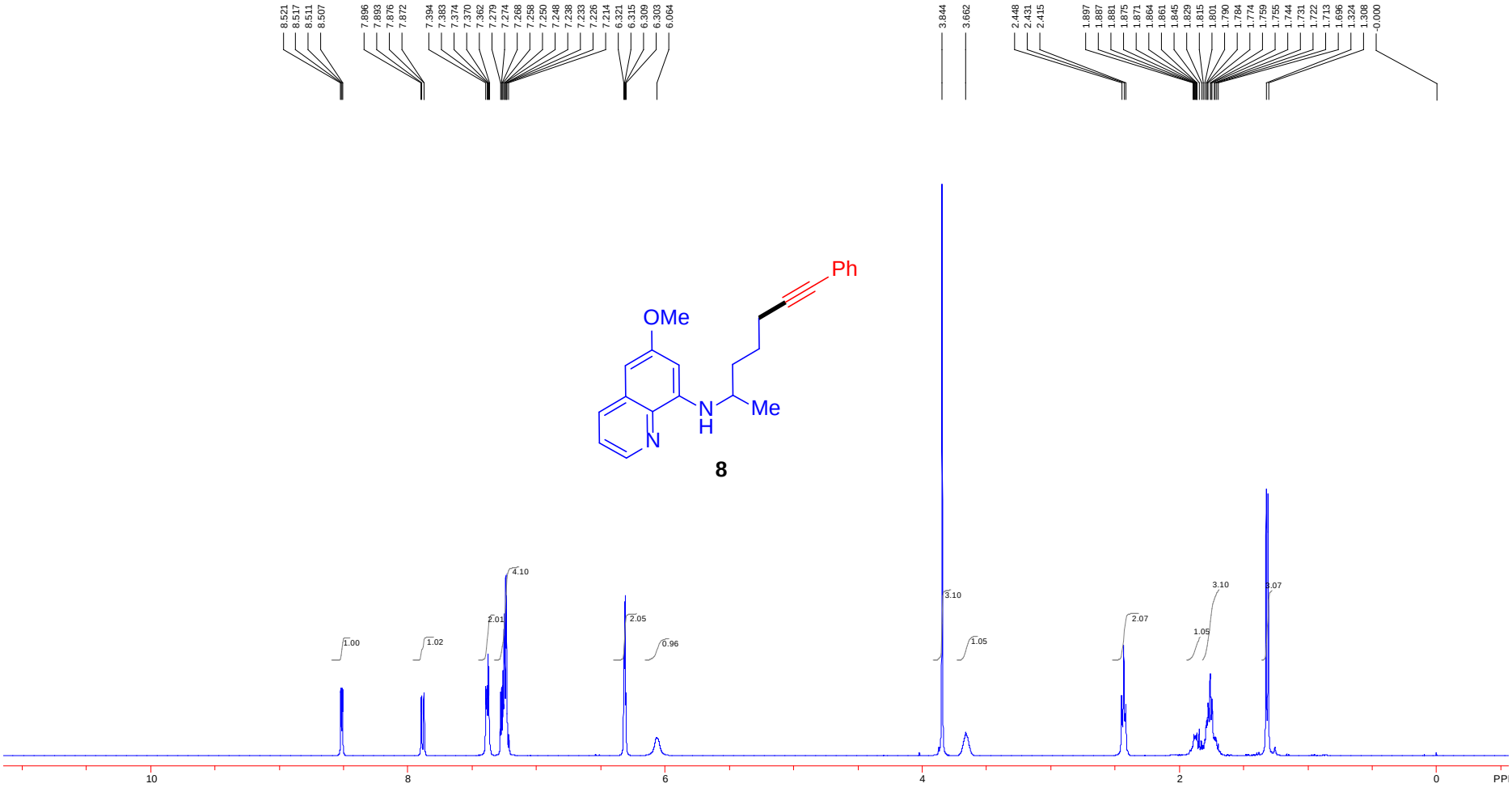

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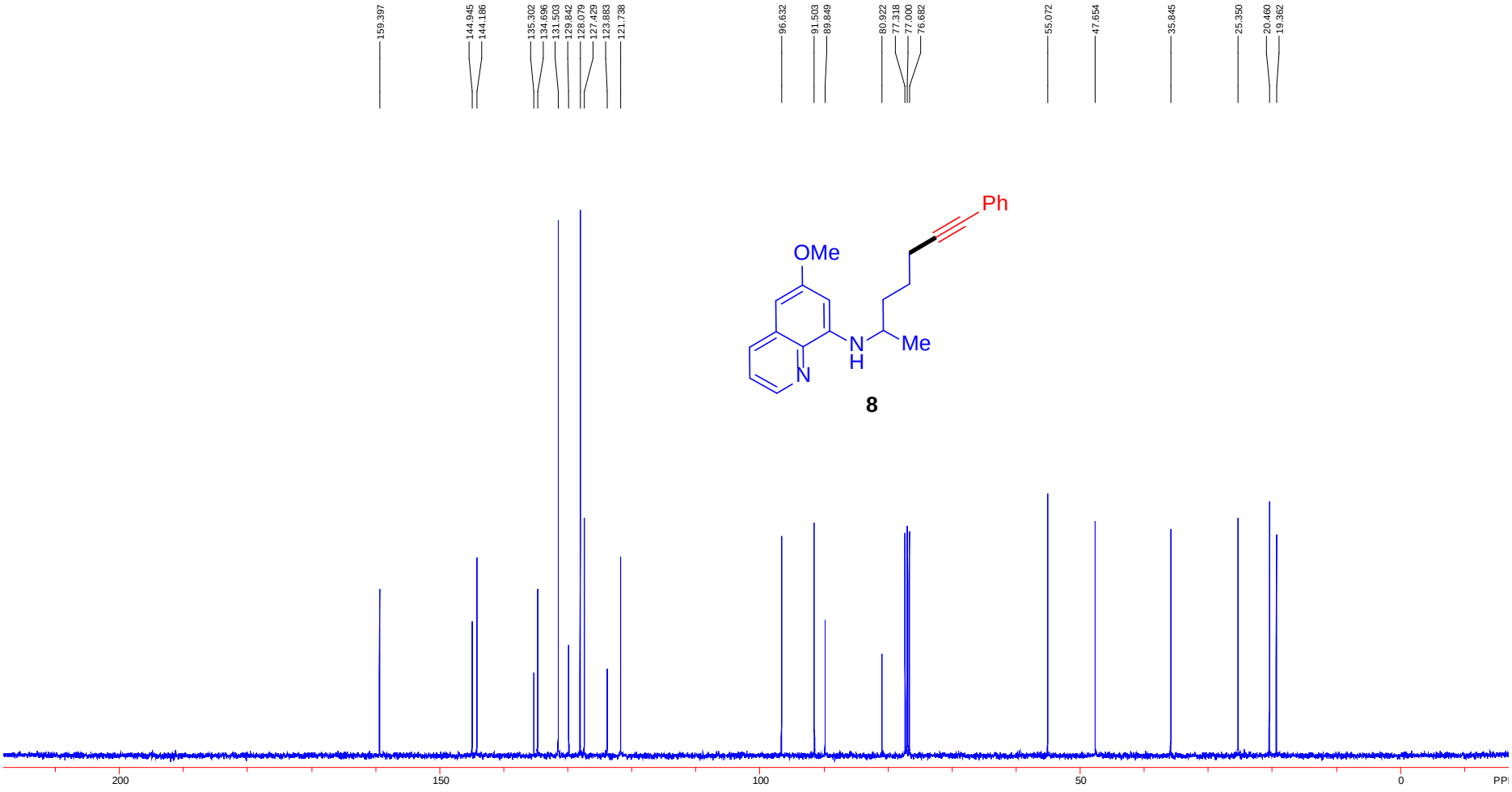

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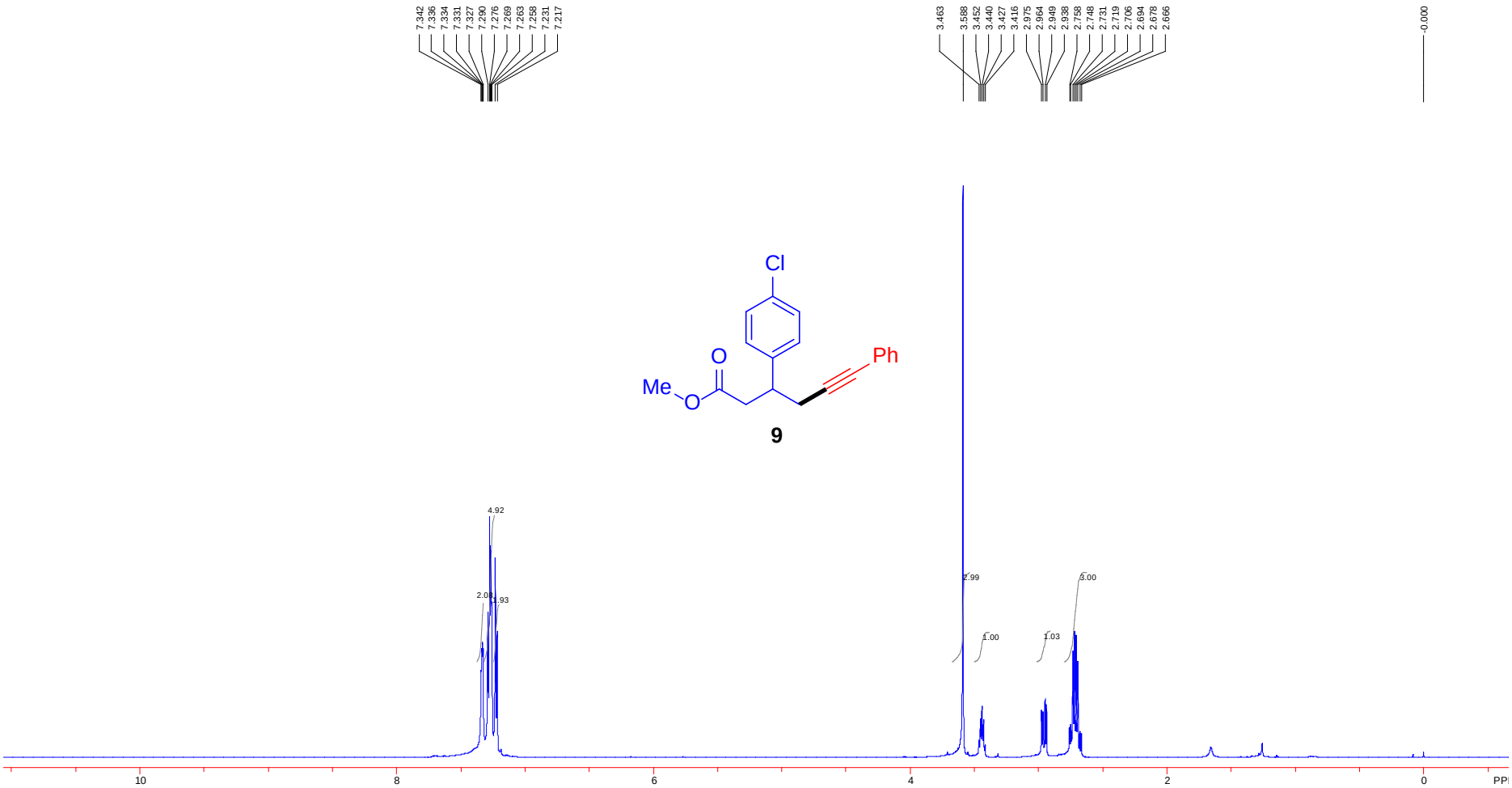

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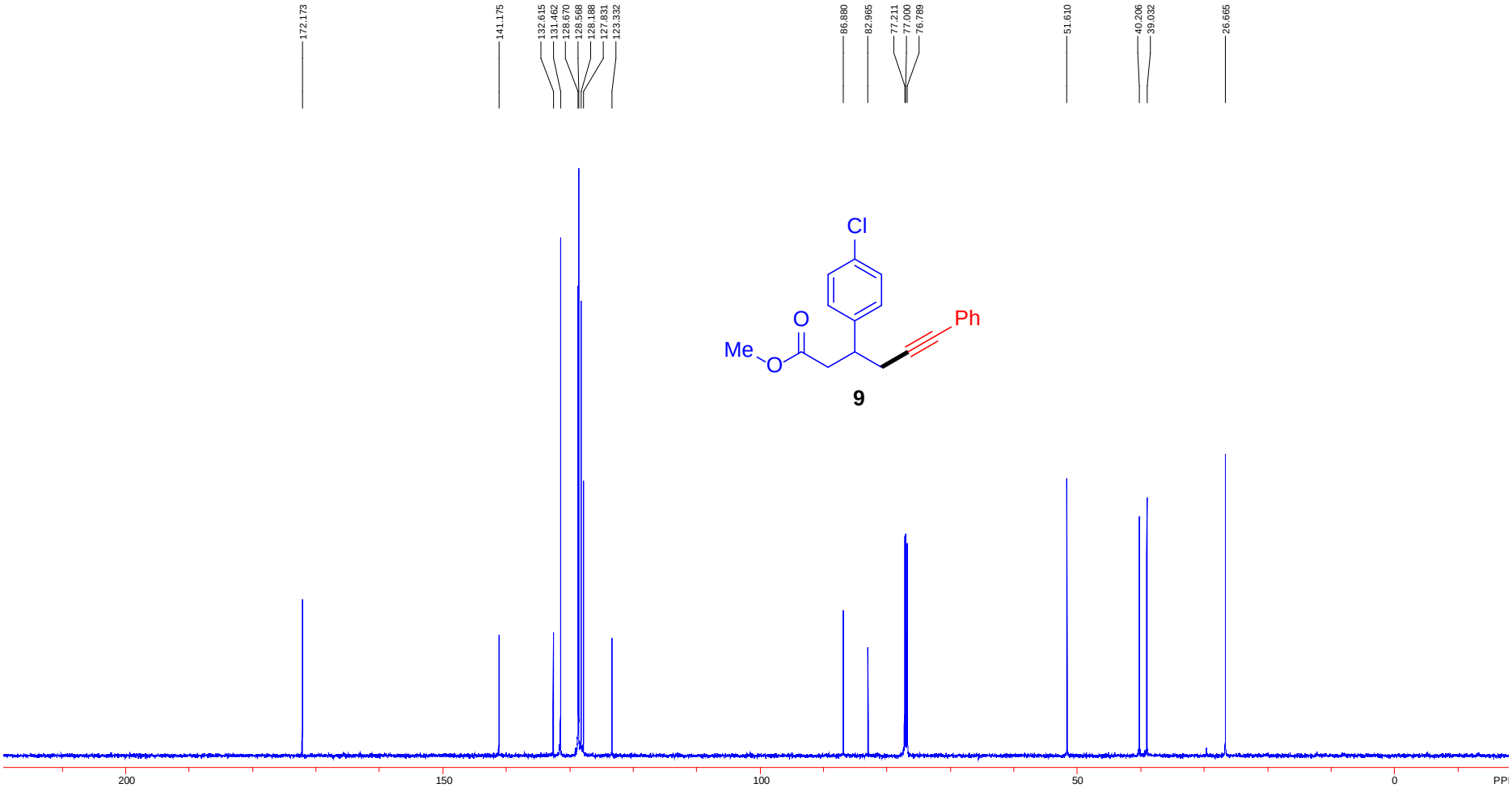

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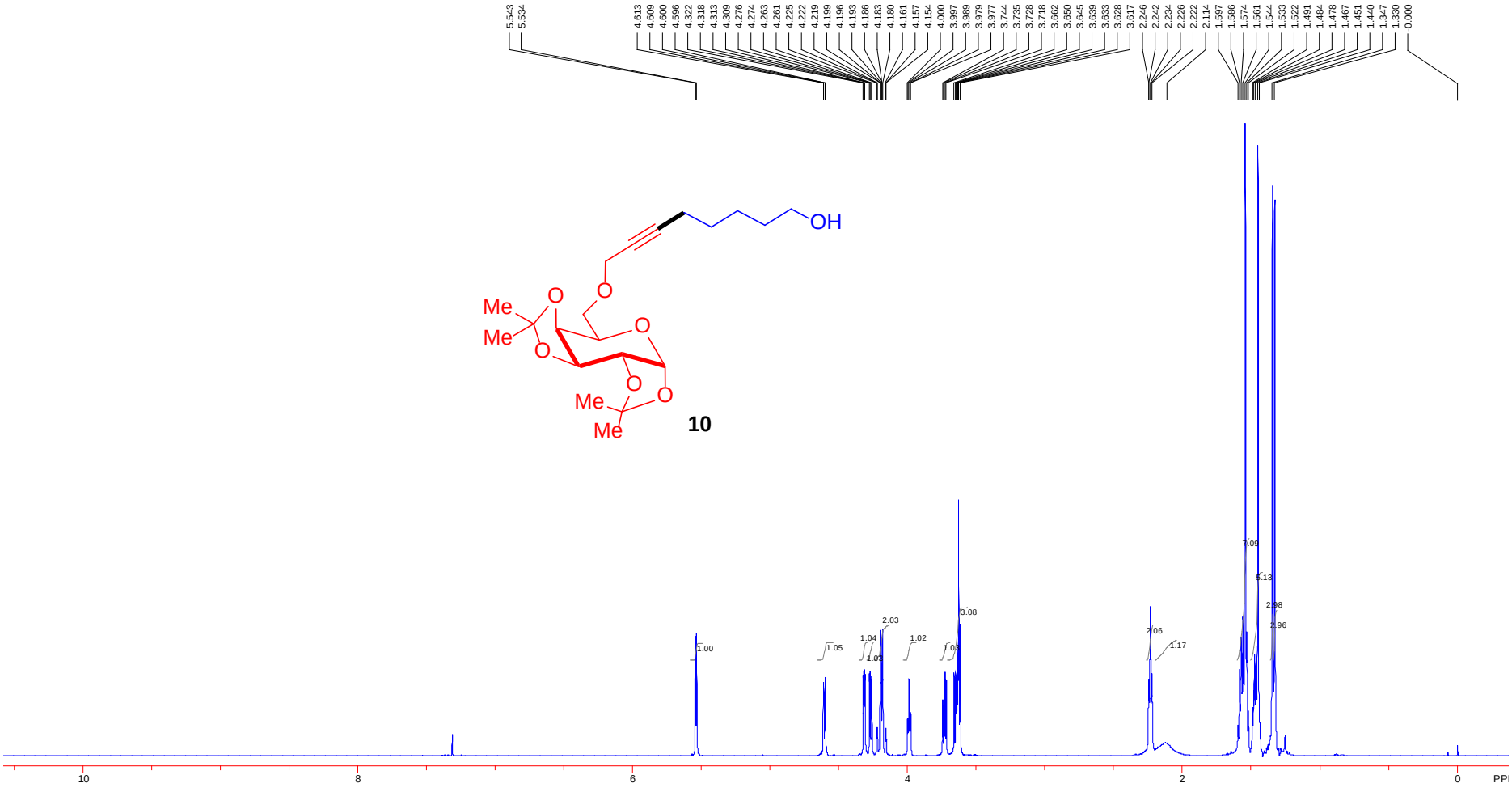

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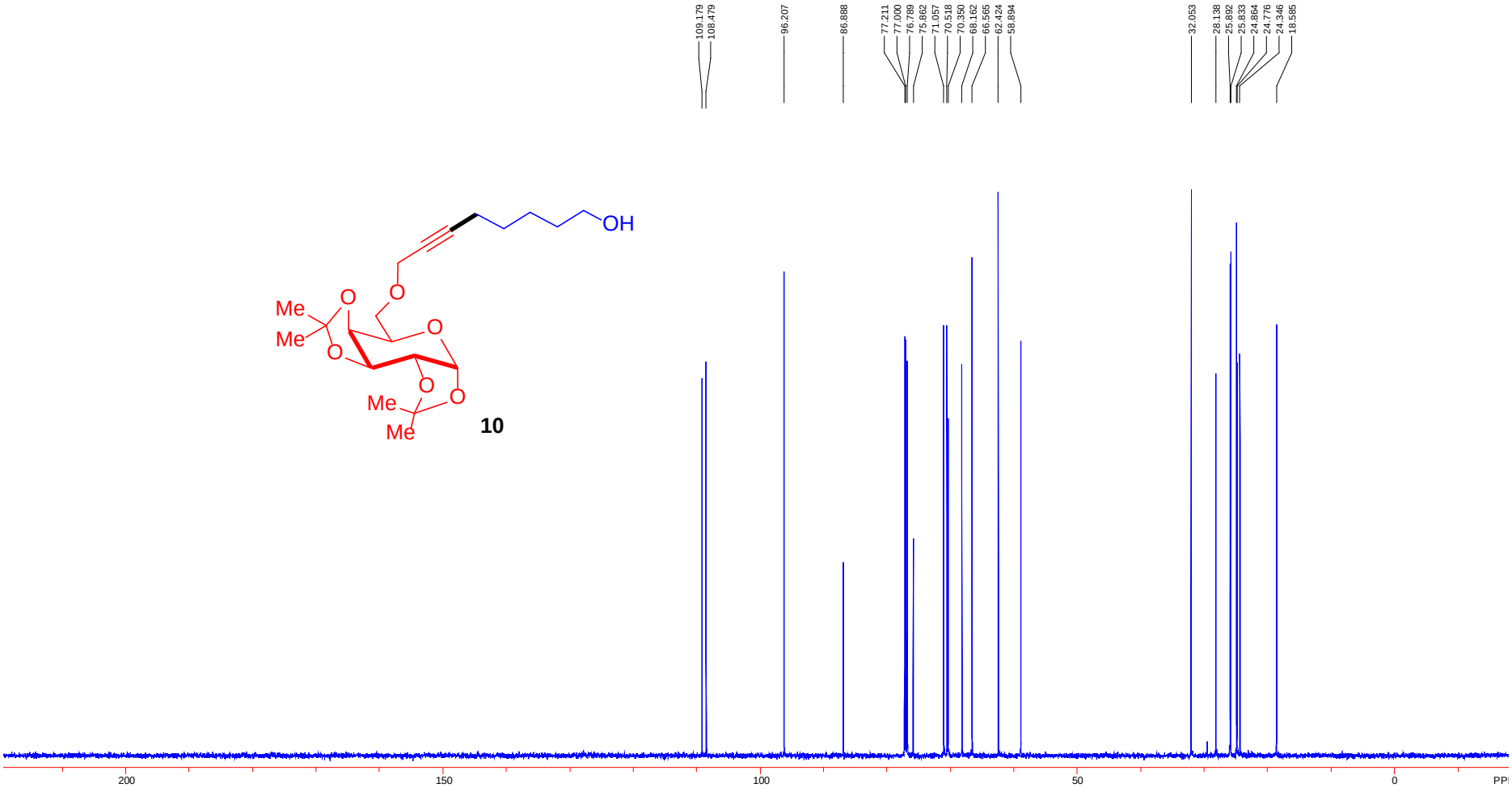
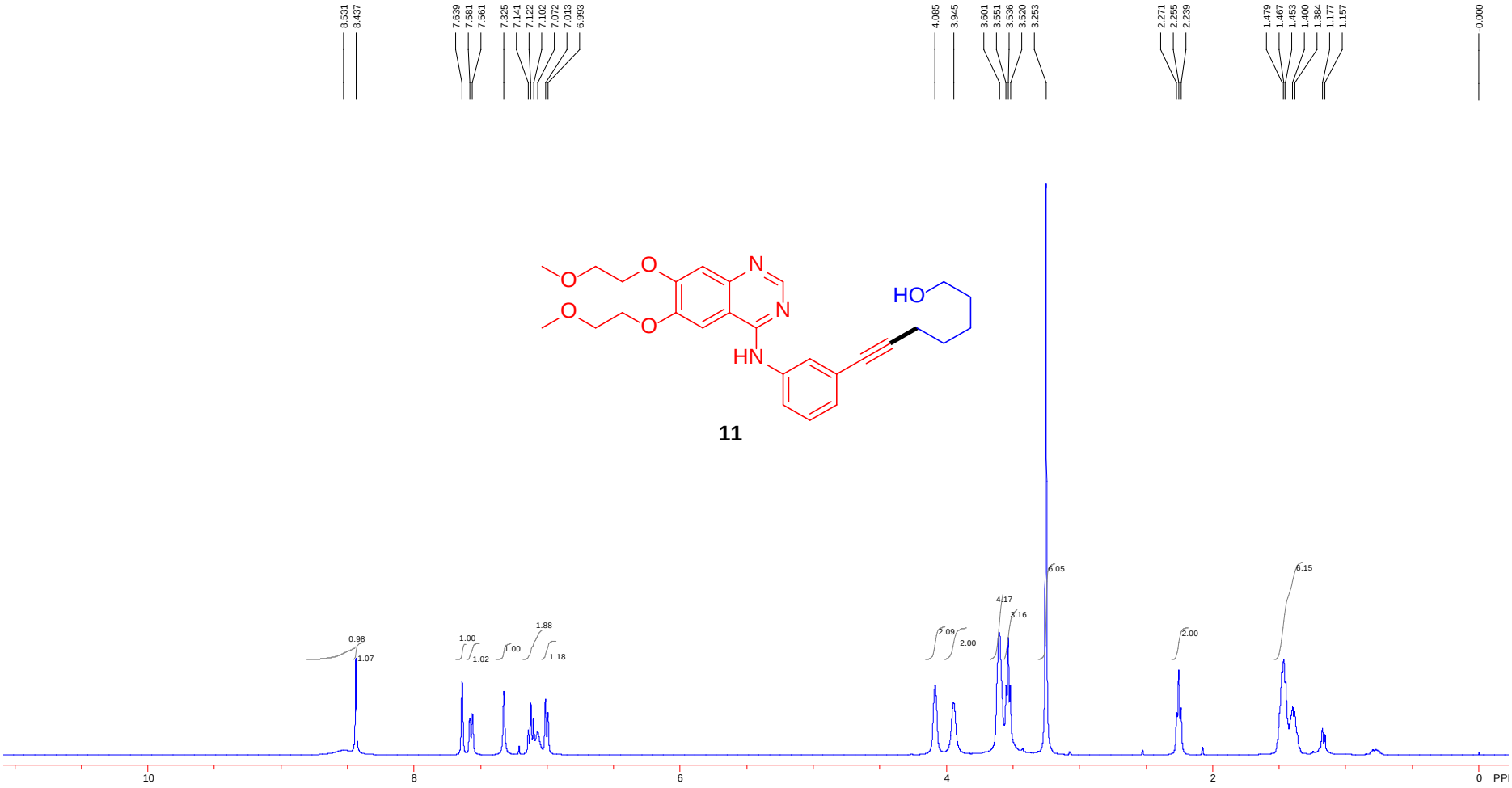
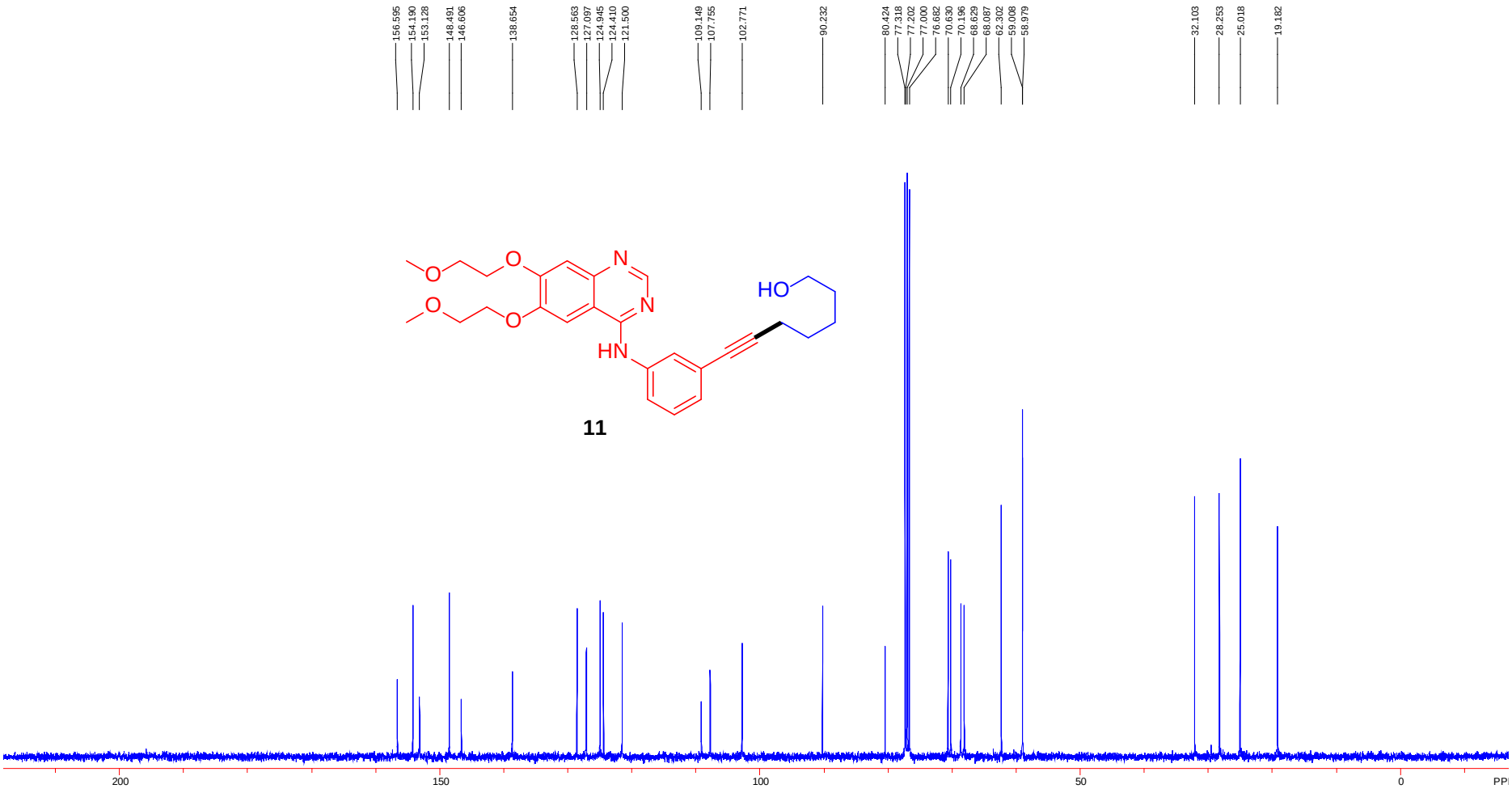


^{1}H NMR(400 MHz, $CDCl_3$)



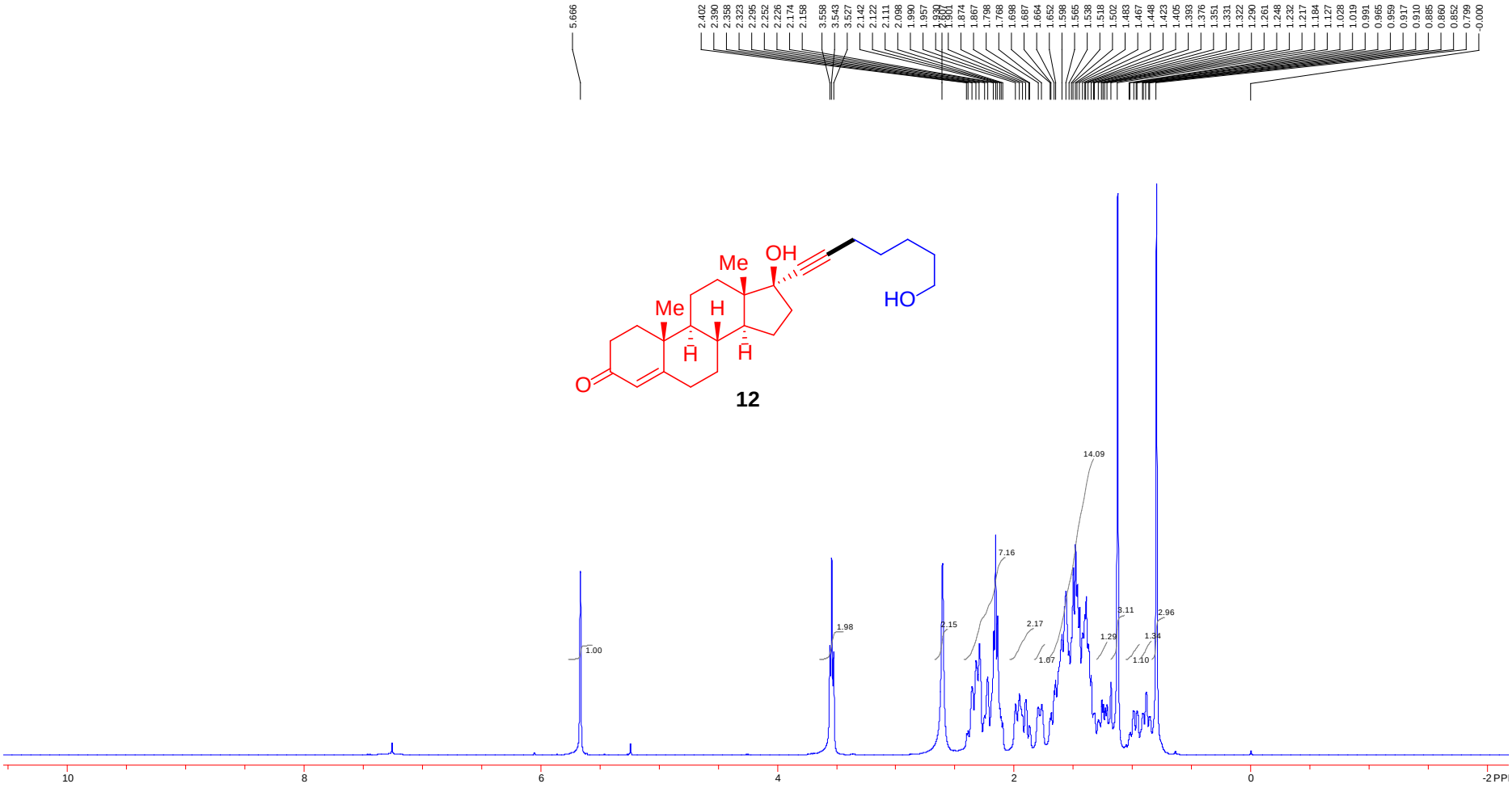
11

^{13}C NMR(100 MHz, $CDCl_3$)

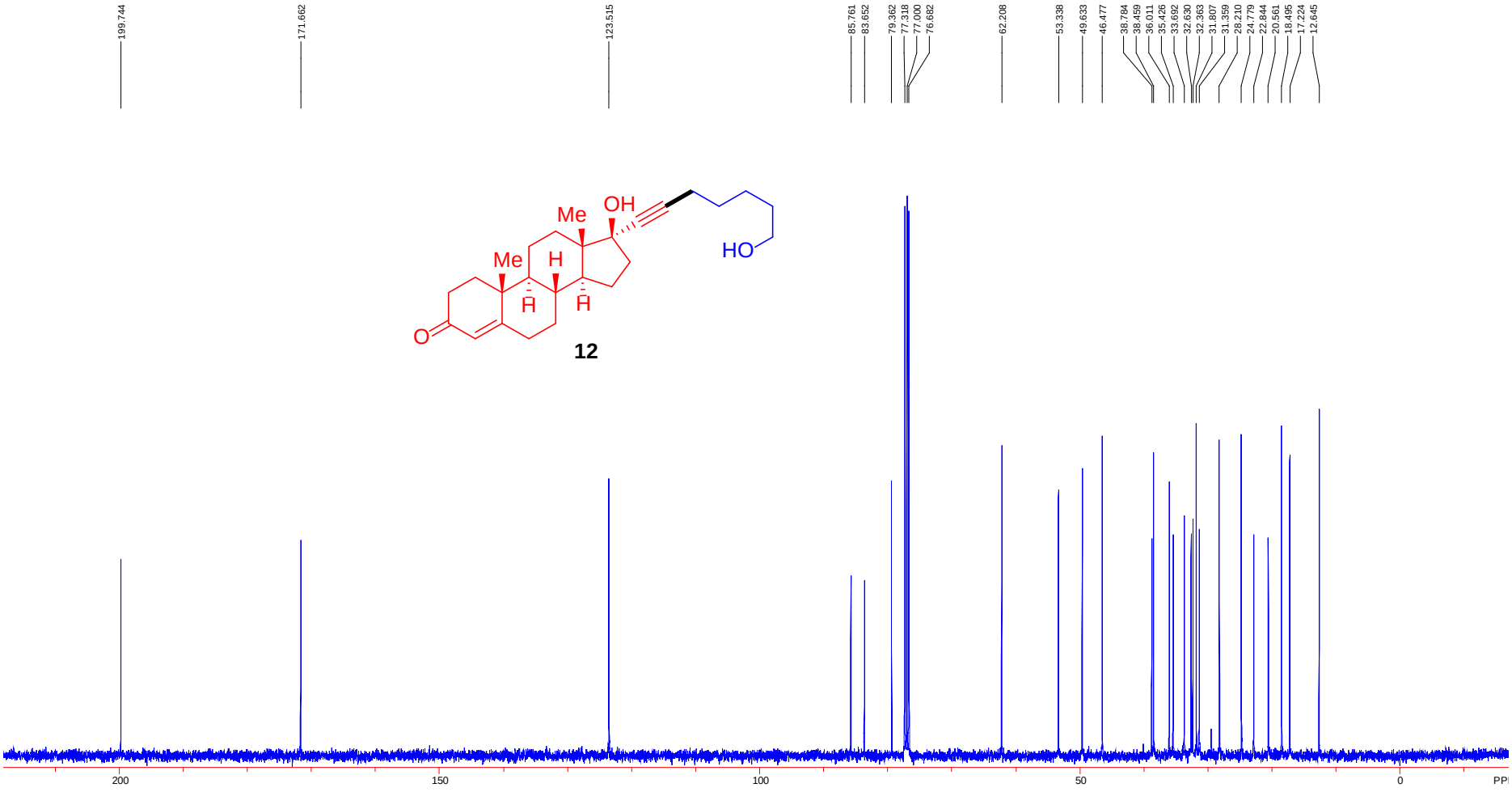


11

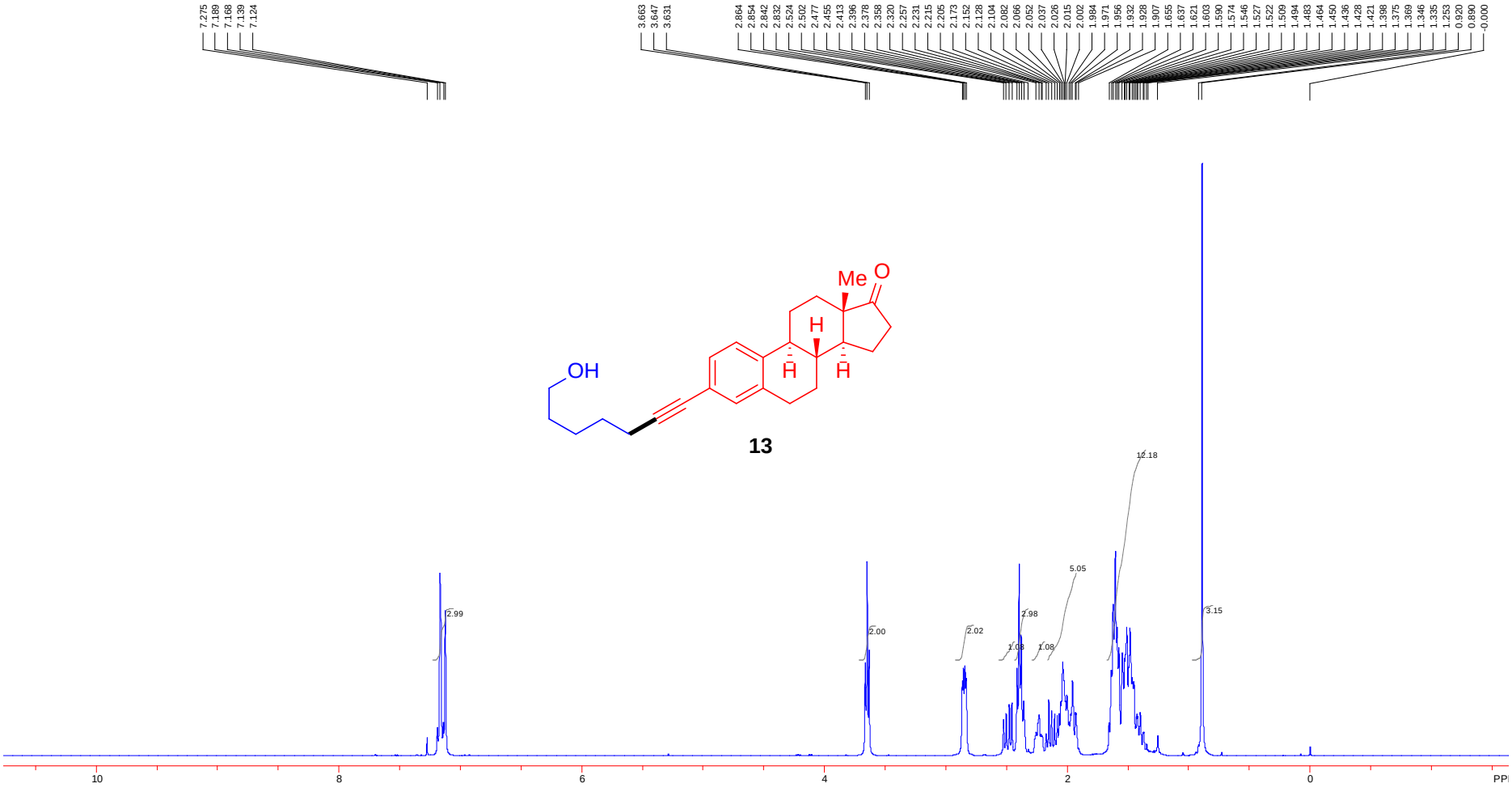
^{1}H NMR(400 MHz, $CDCl_3$)



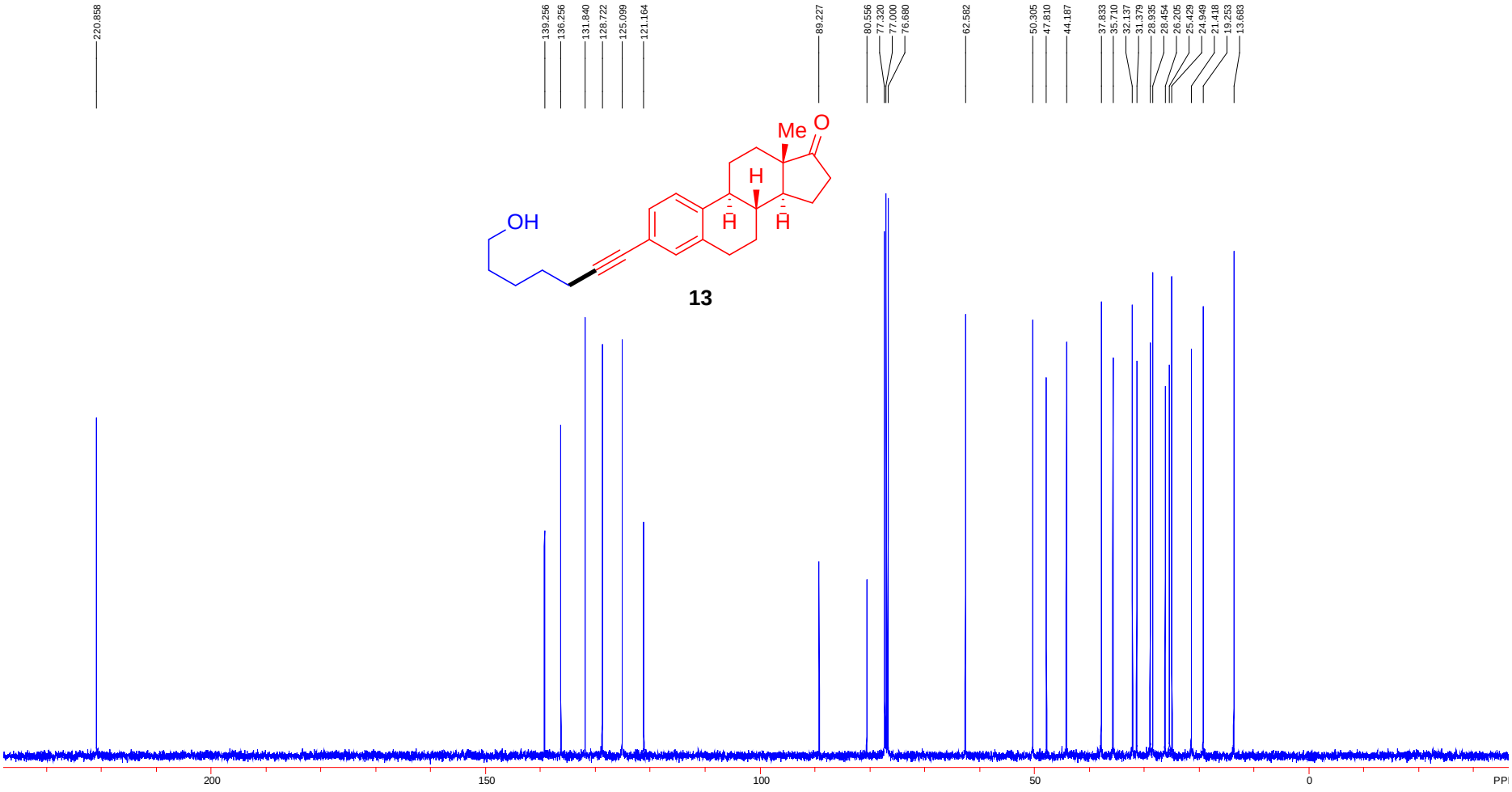
^{13}C NMR(100 MHz, $CDCl_3$)



^{1}H NMR(400 MHz, $CDCl_3$)

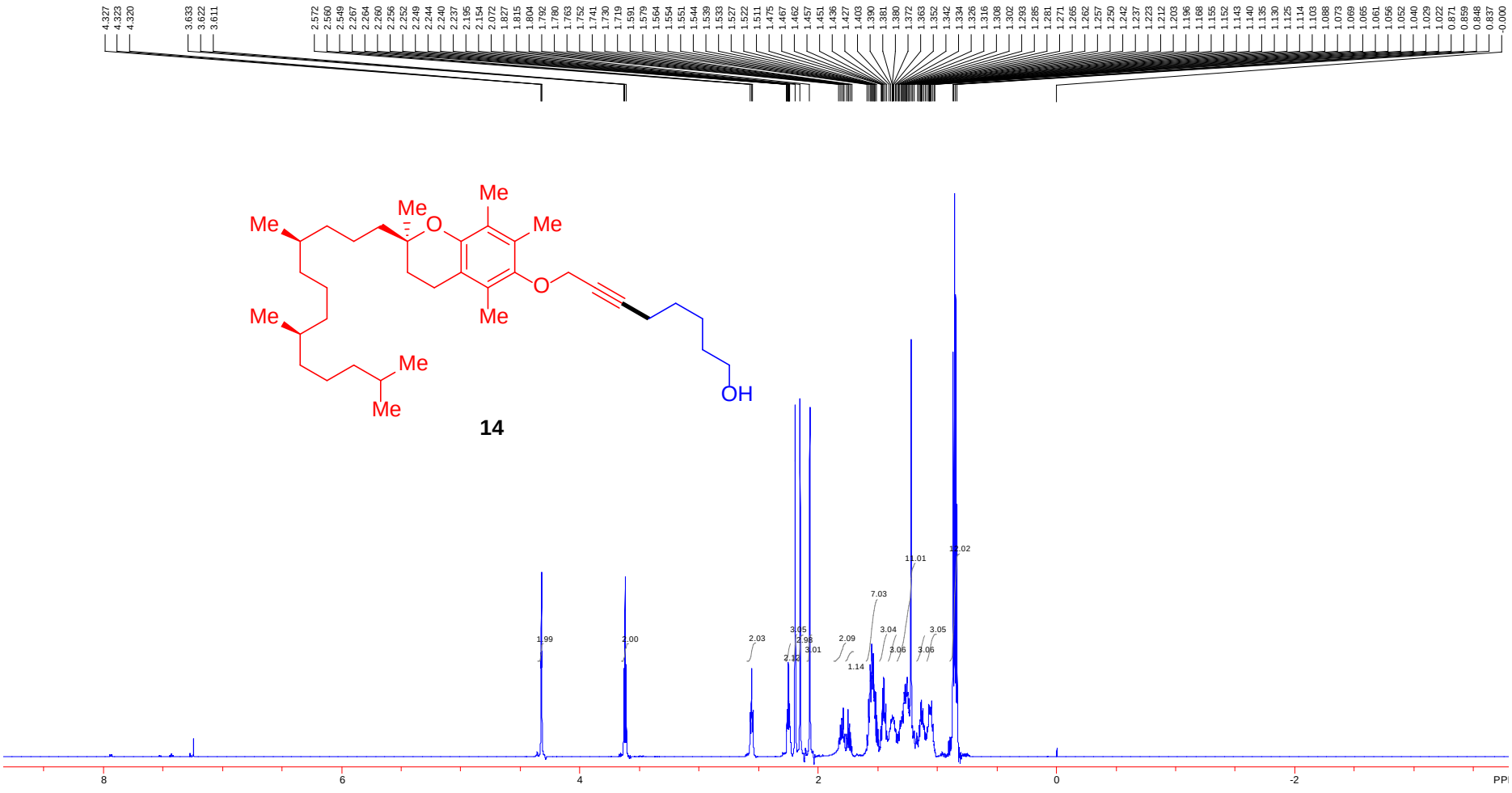


^{13}C NMR(100 MHz, $CDCl_3$)

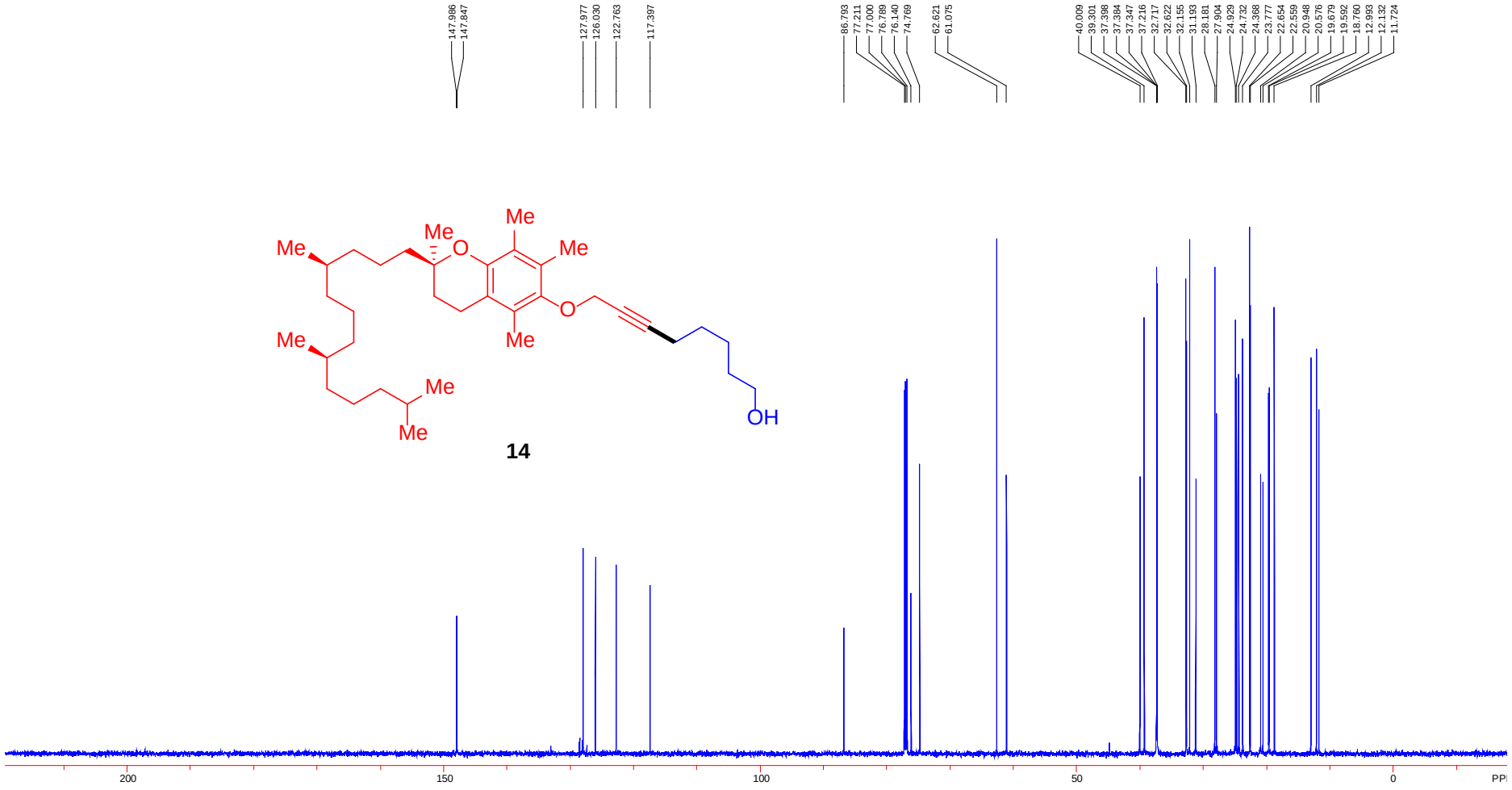


13

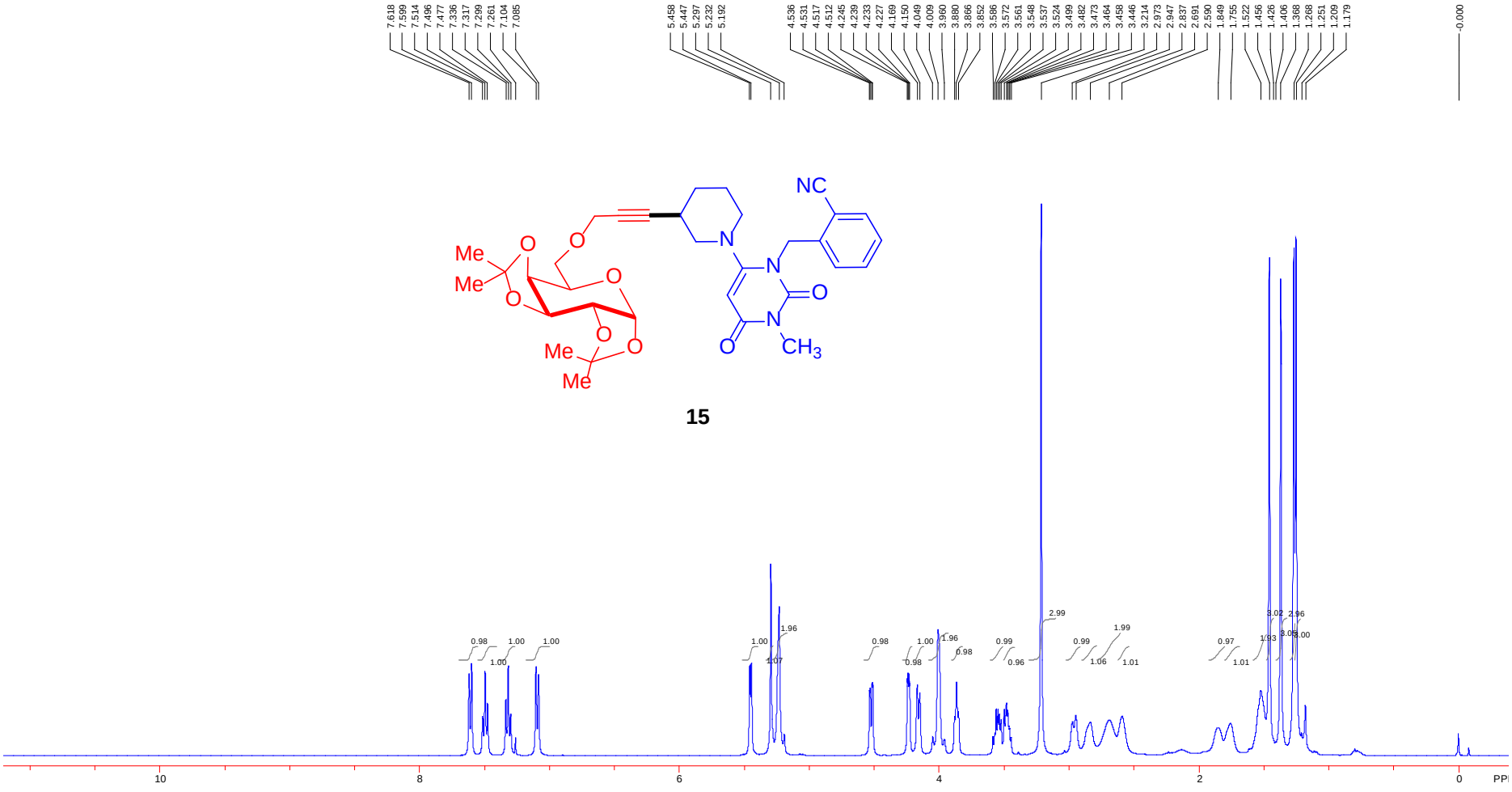
^{1}H NMR (600 MHz, $CDCl_3$)



^{13}C NMR (151 MHz, $CDCl_3$)

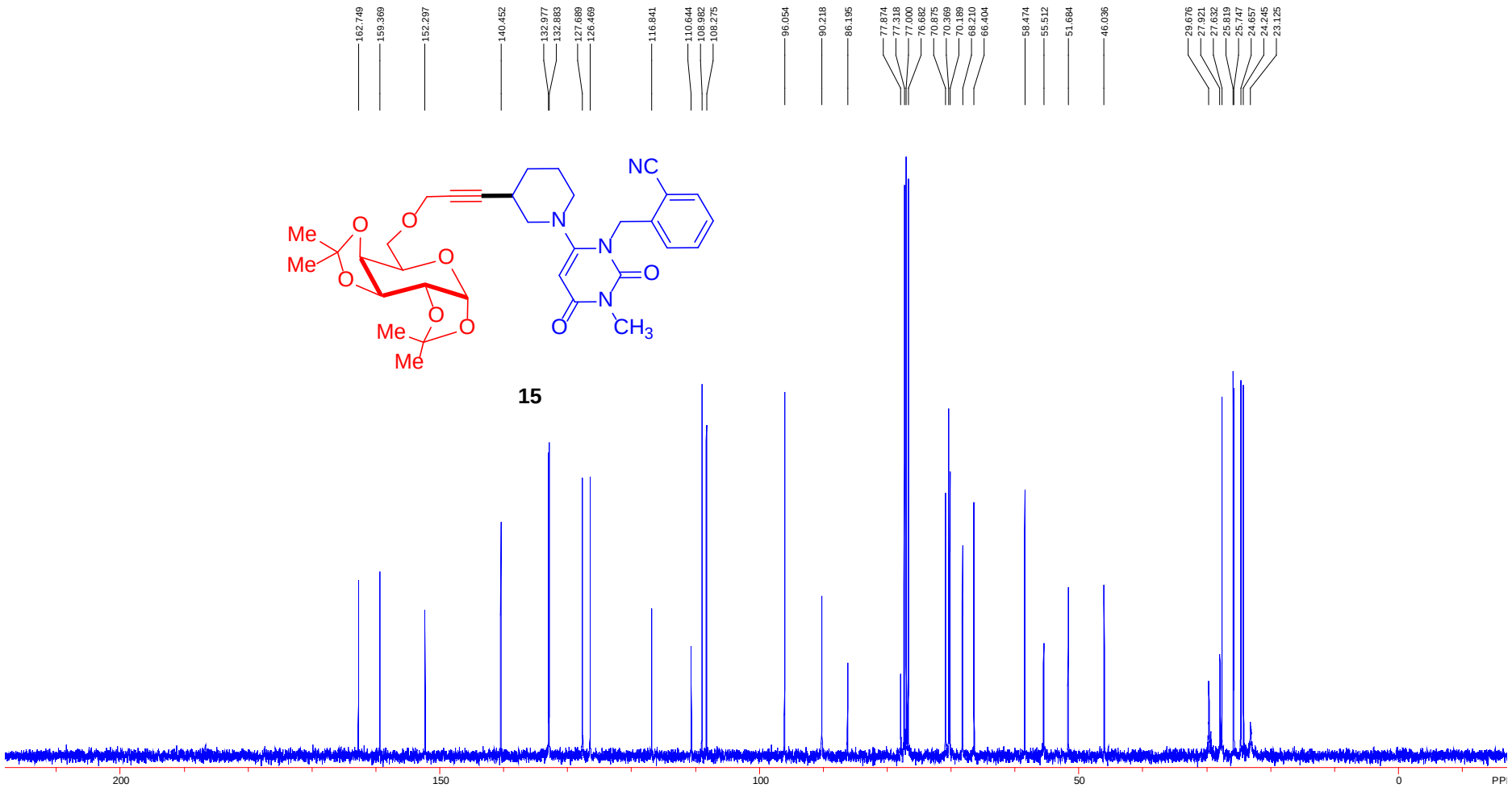


^{1}H NMR(400 MHz, $CDCl_3$)



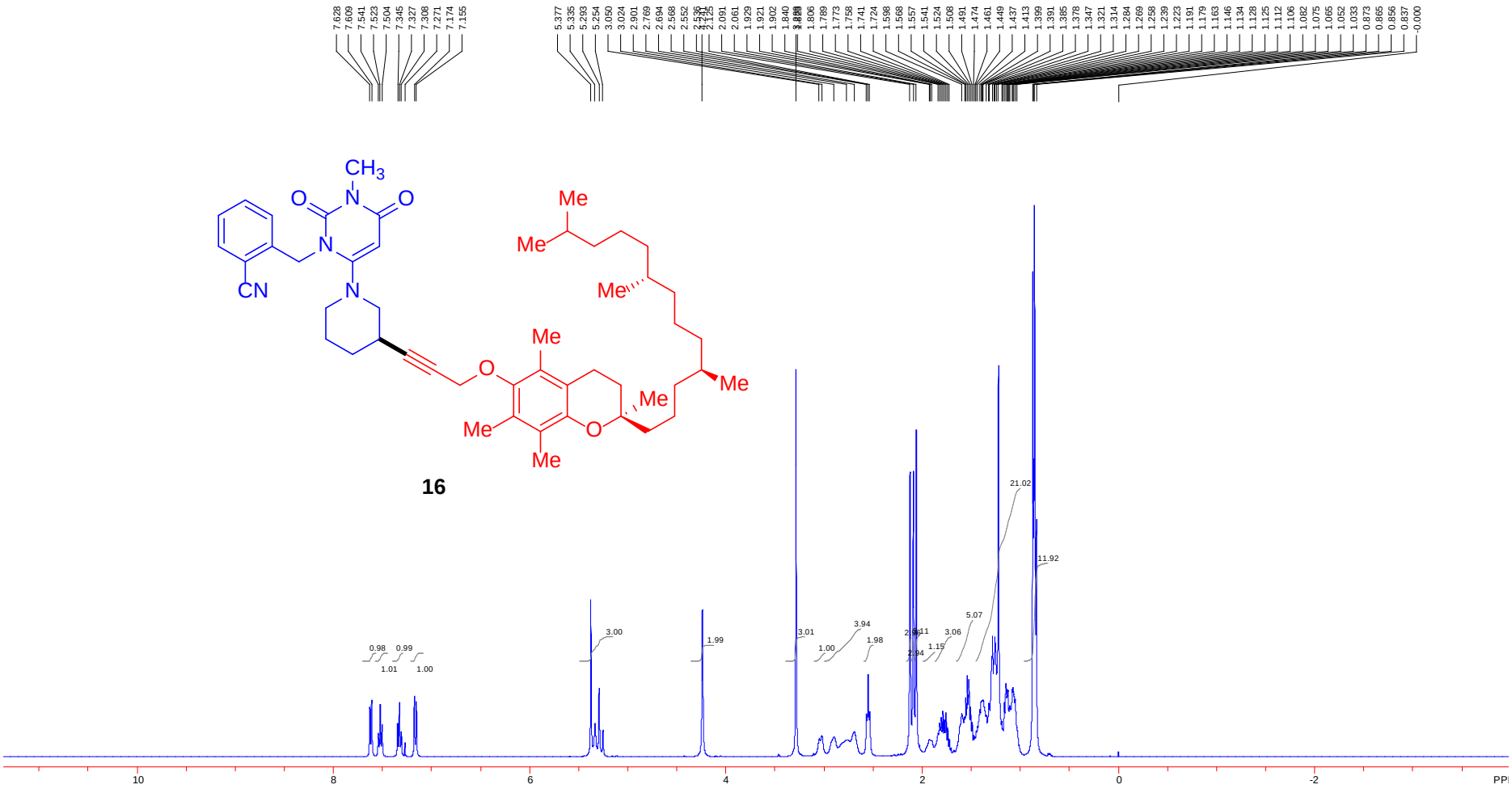
15

^{13}C NMR(100 MHz, $CDCl_3$)

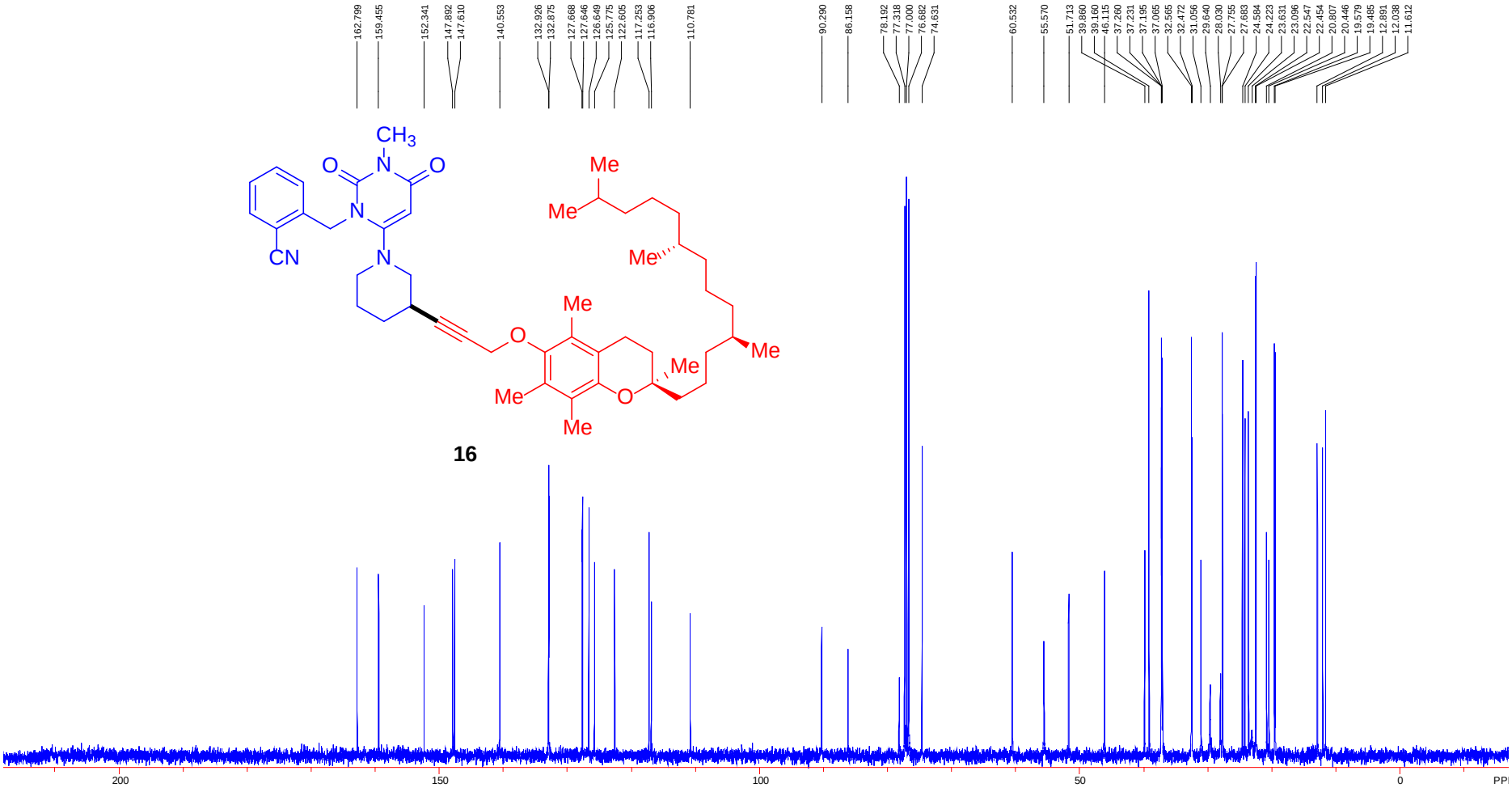


15

^{1}H NMR(400 MHz, $CDCl_3$)

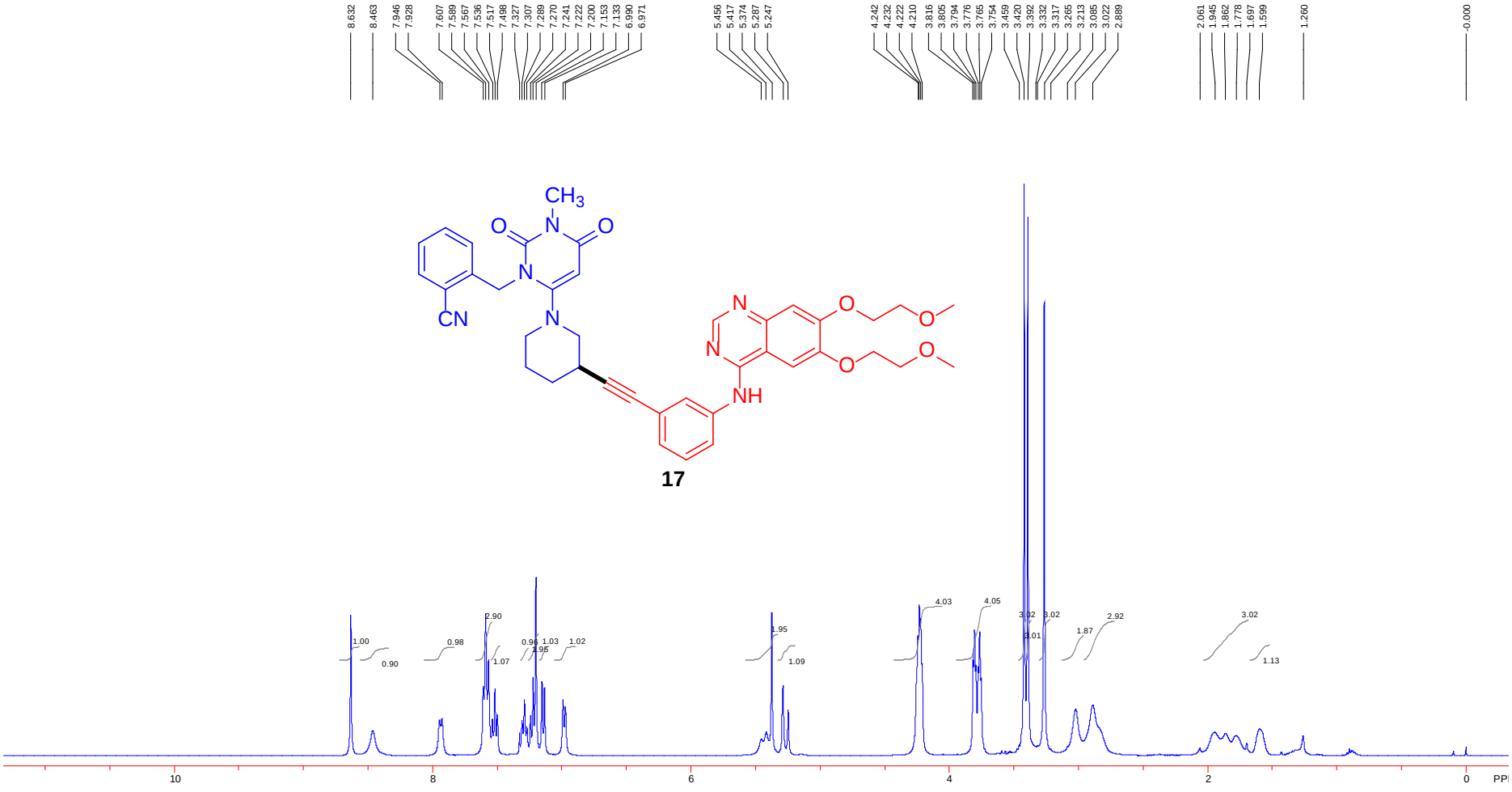


^{13}C NMR(100 MHz, $CDCl_3$)



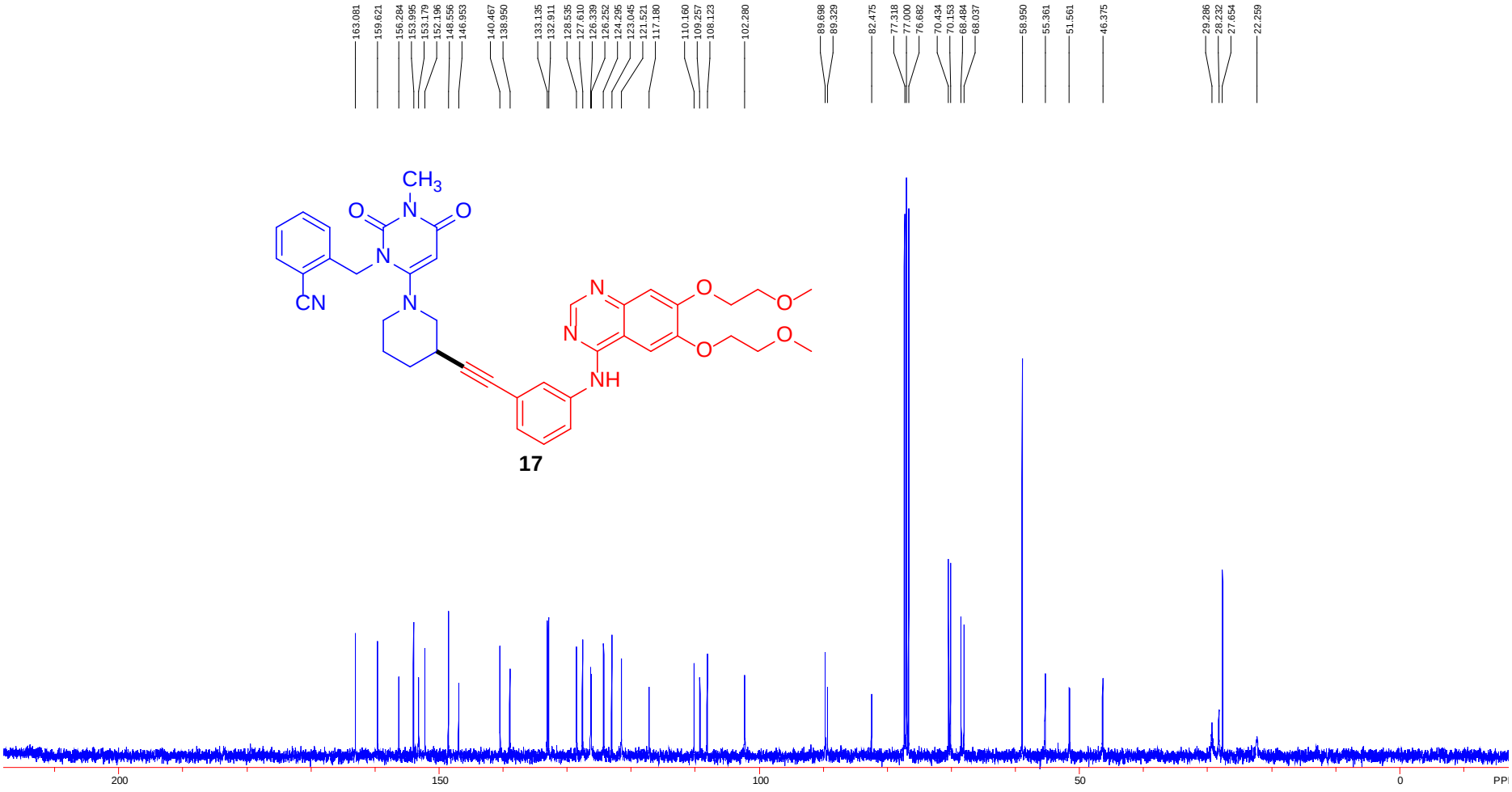
16

^{1}H NMR(400 MHz, $CDCl_3$)



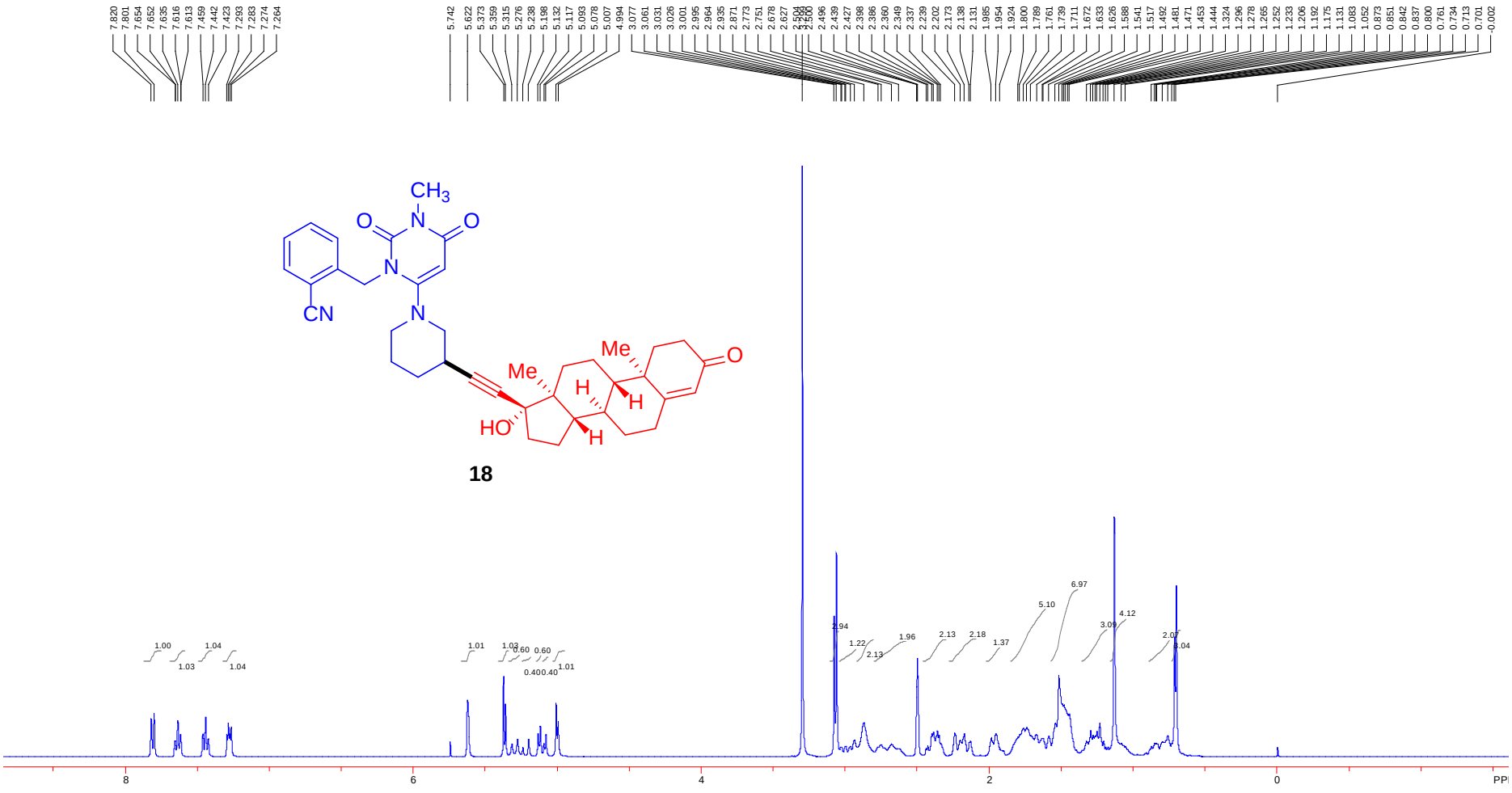
17

^{13}C NMR(100 MHz, $CDCl_3$)

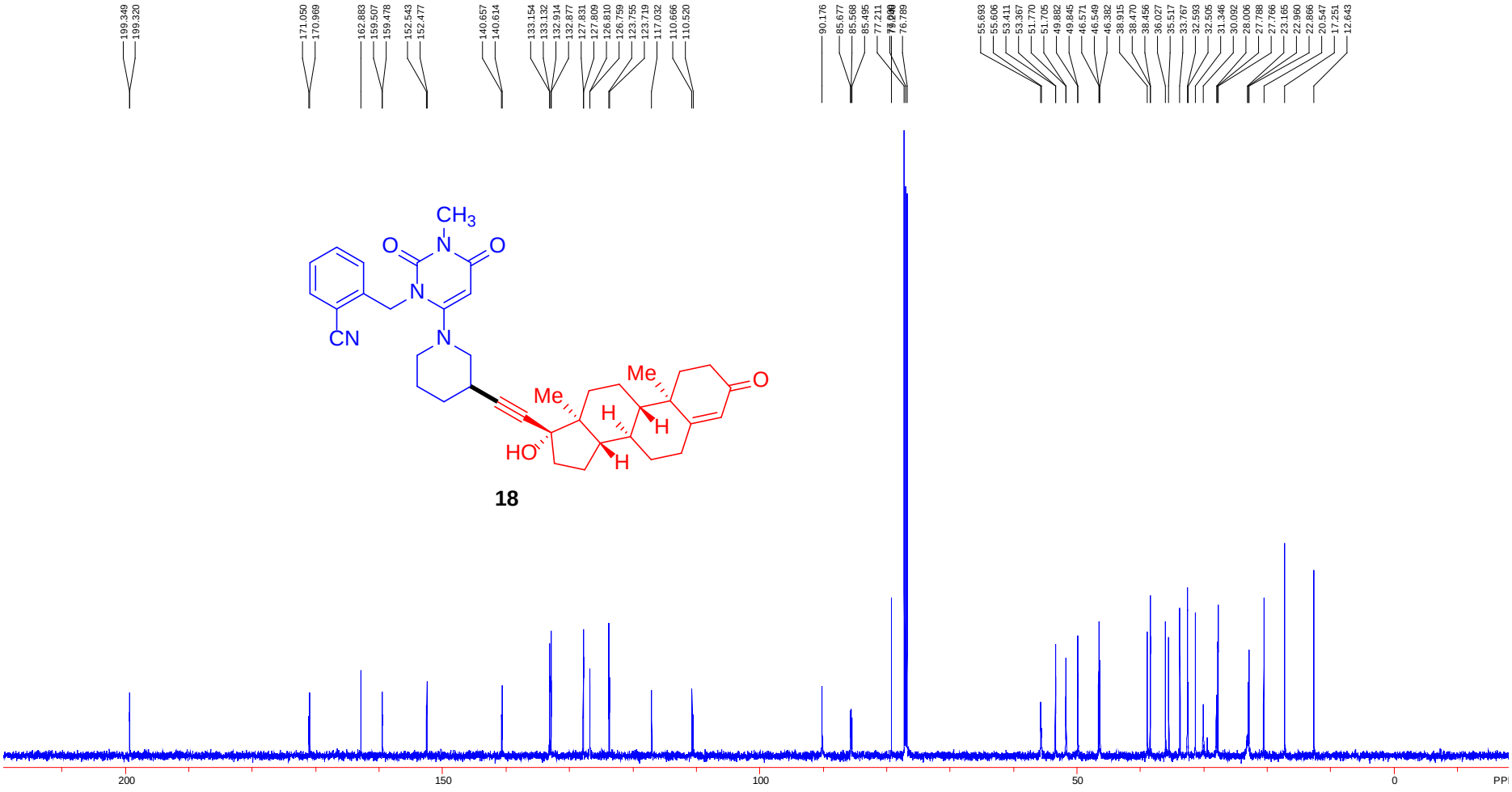


17

^{1}H NMR(400 MHz, DMSO-d_6)

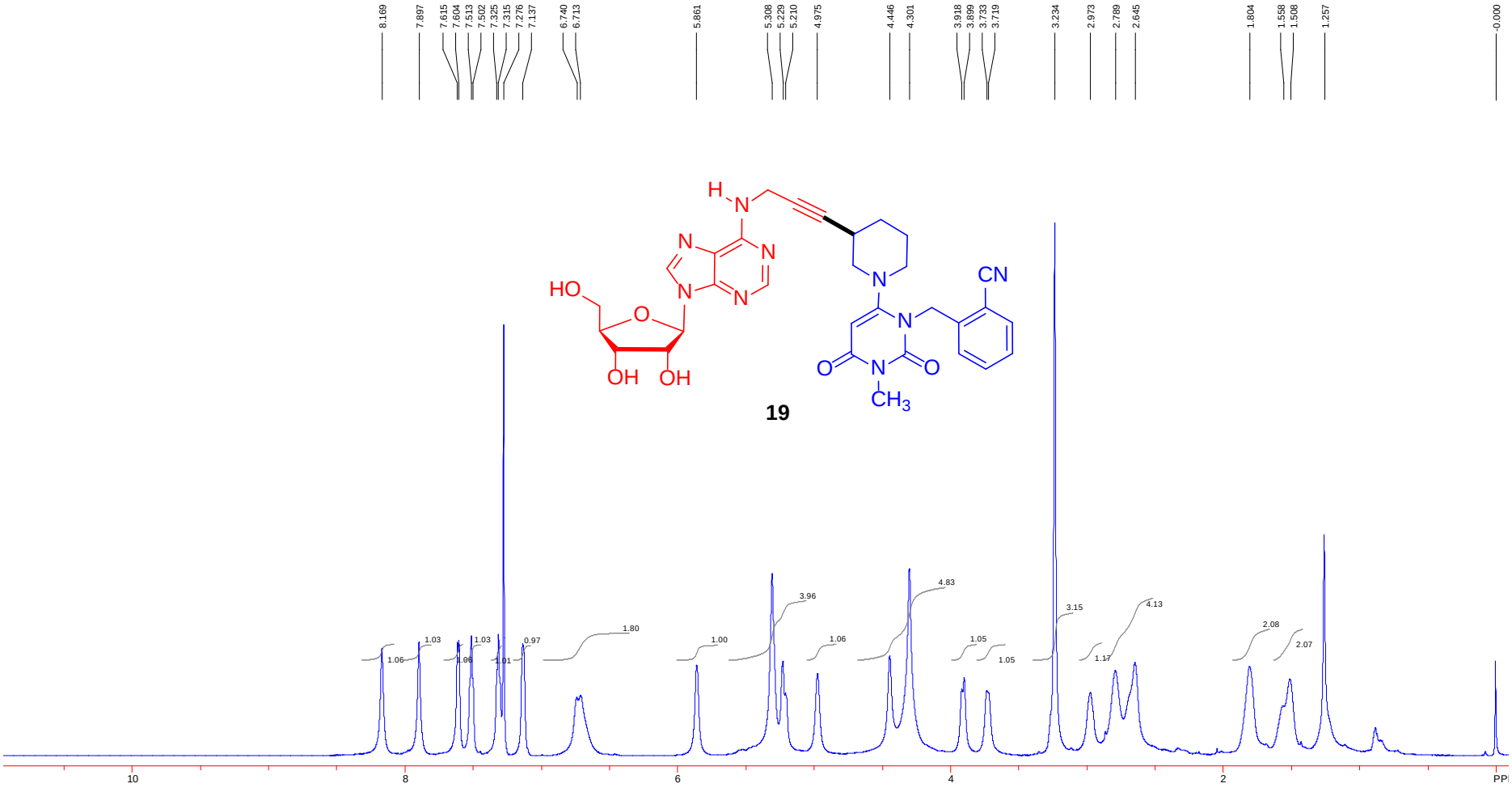


^{13}C NMR (151 MHz, $CDCl_3$)

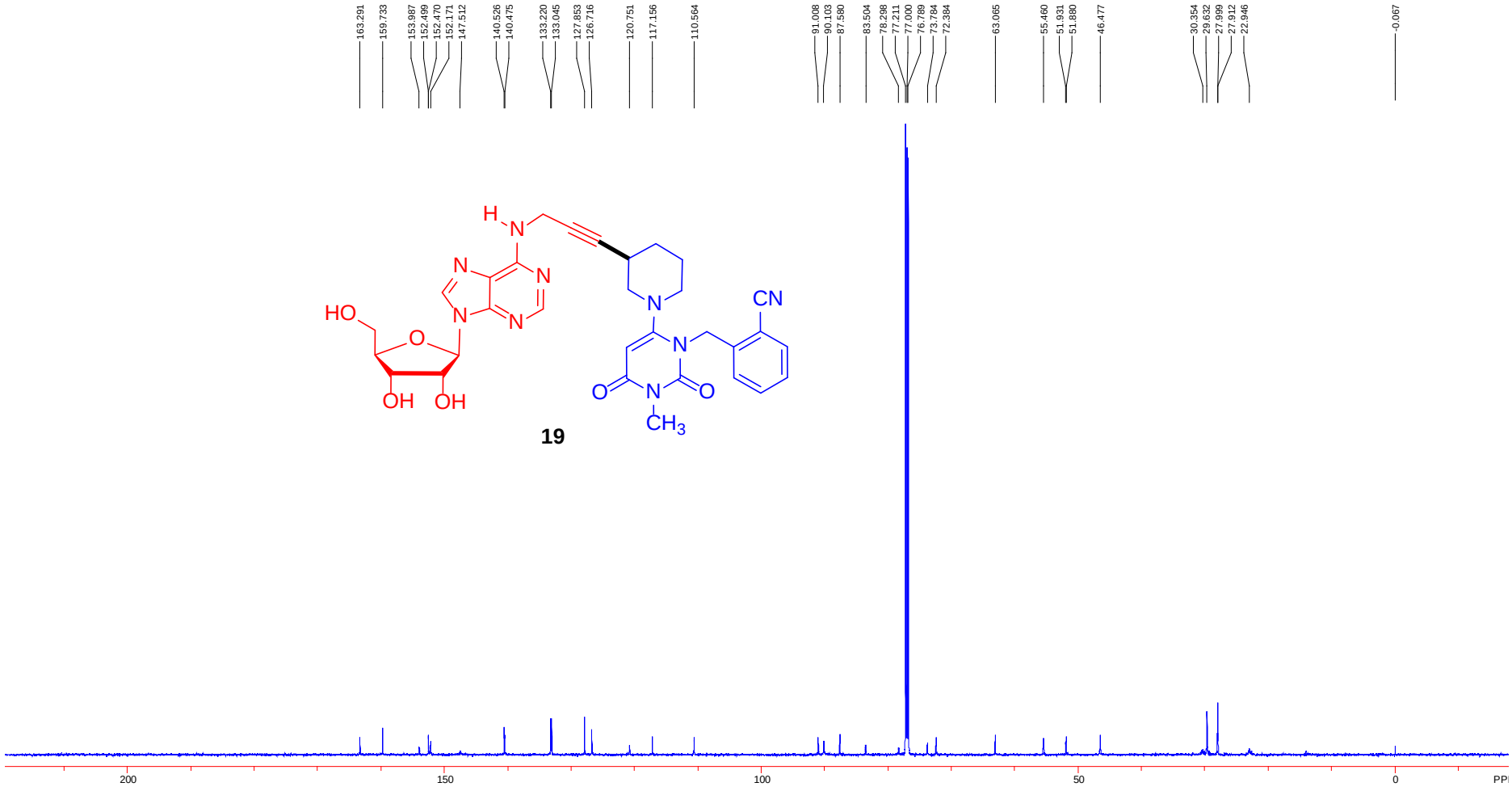


18

^{1}H NMR(600 MHz, $CDCl_3$)

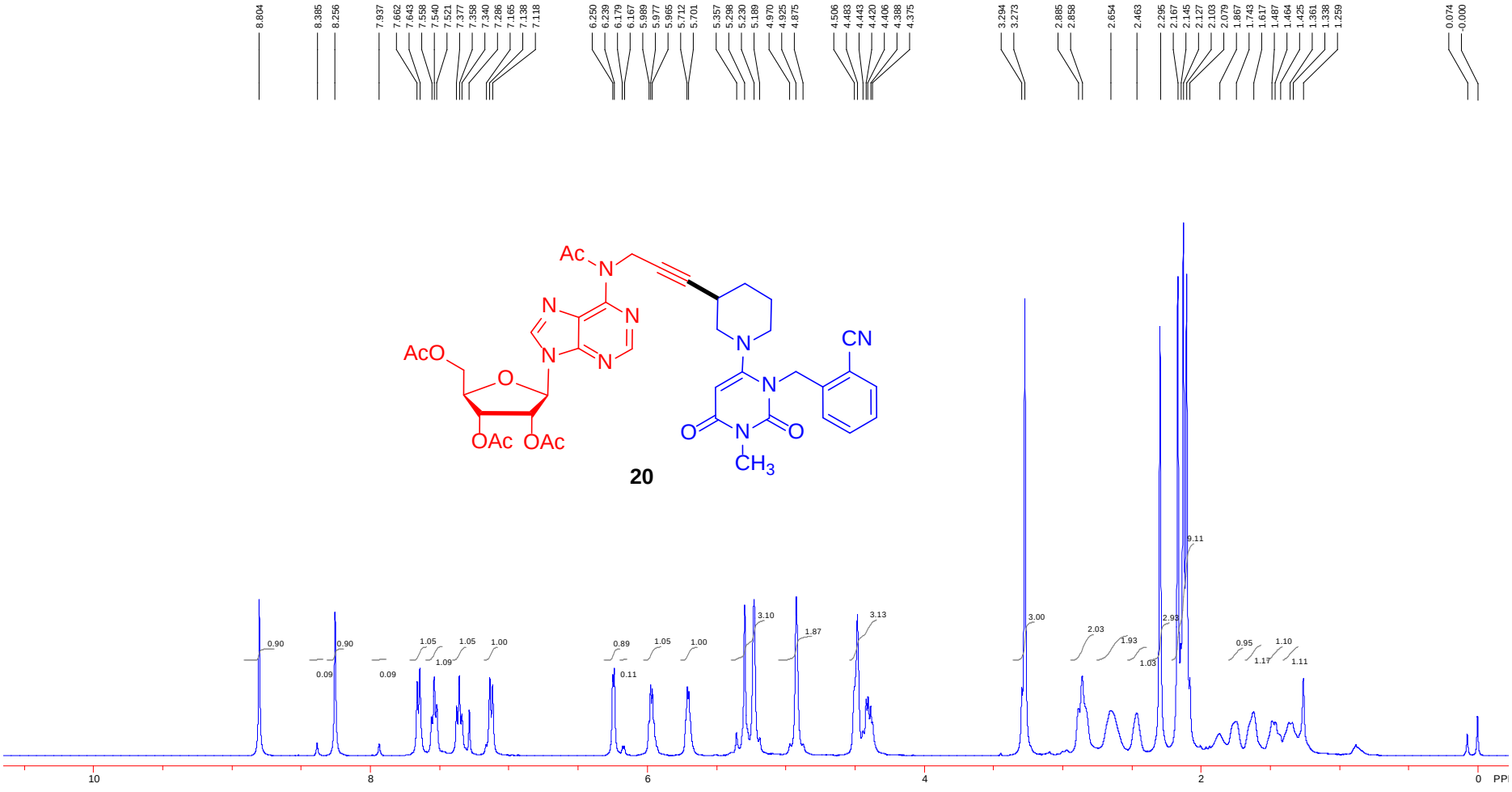


^{13}C NMR (151 MHz, $CDCl_3$)

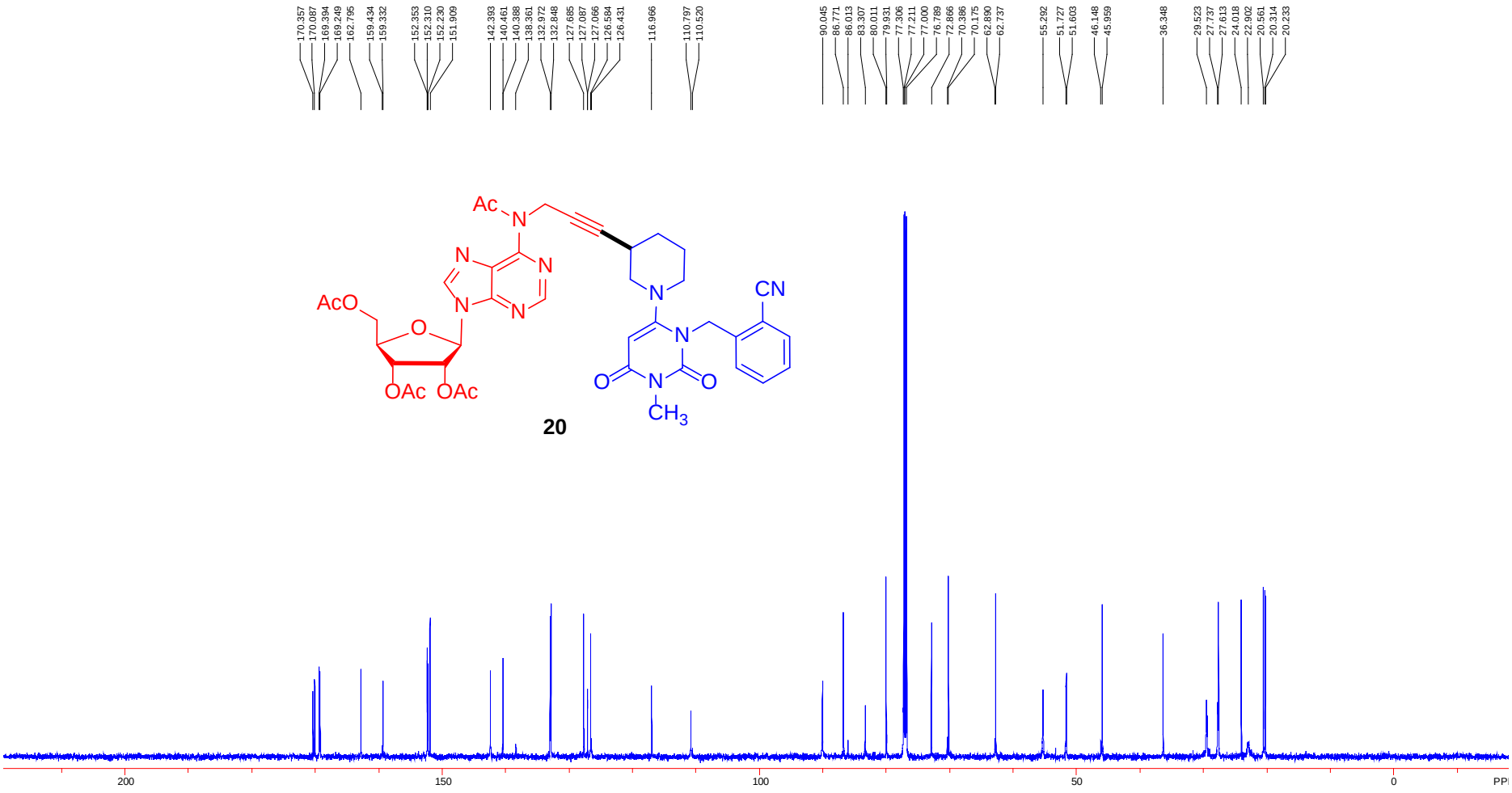


19

^{1}H NMR (400 MHz, $CDCl_3$)

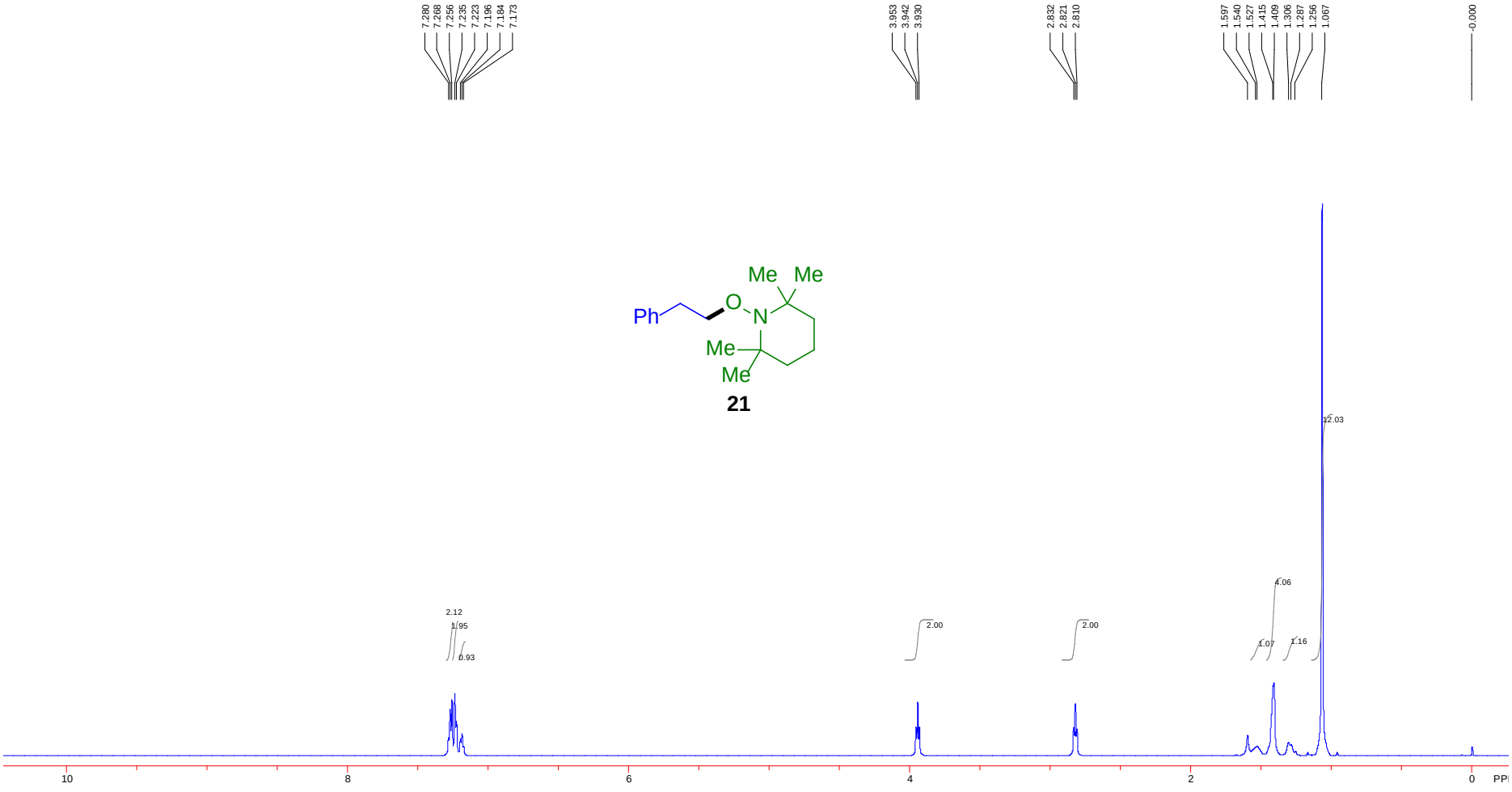


^{13}C NMR (151 MHz, $CDCl_3$)

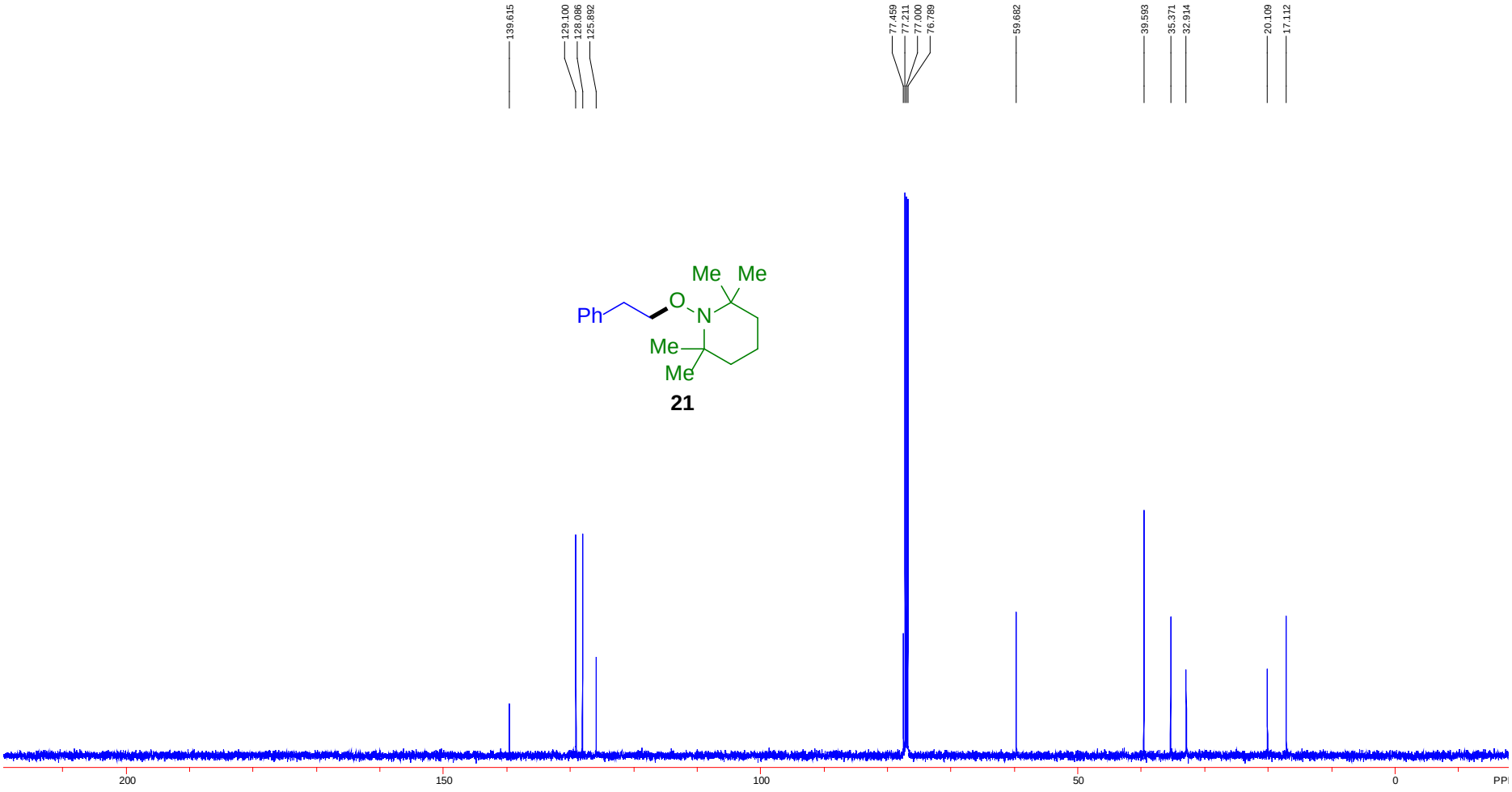


20

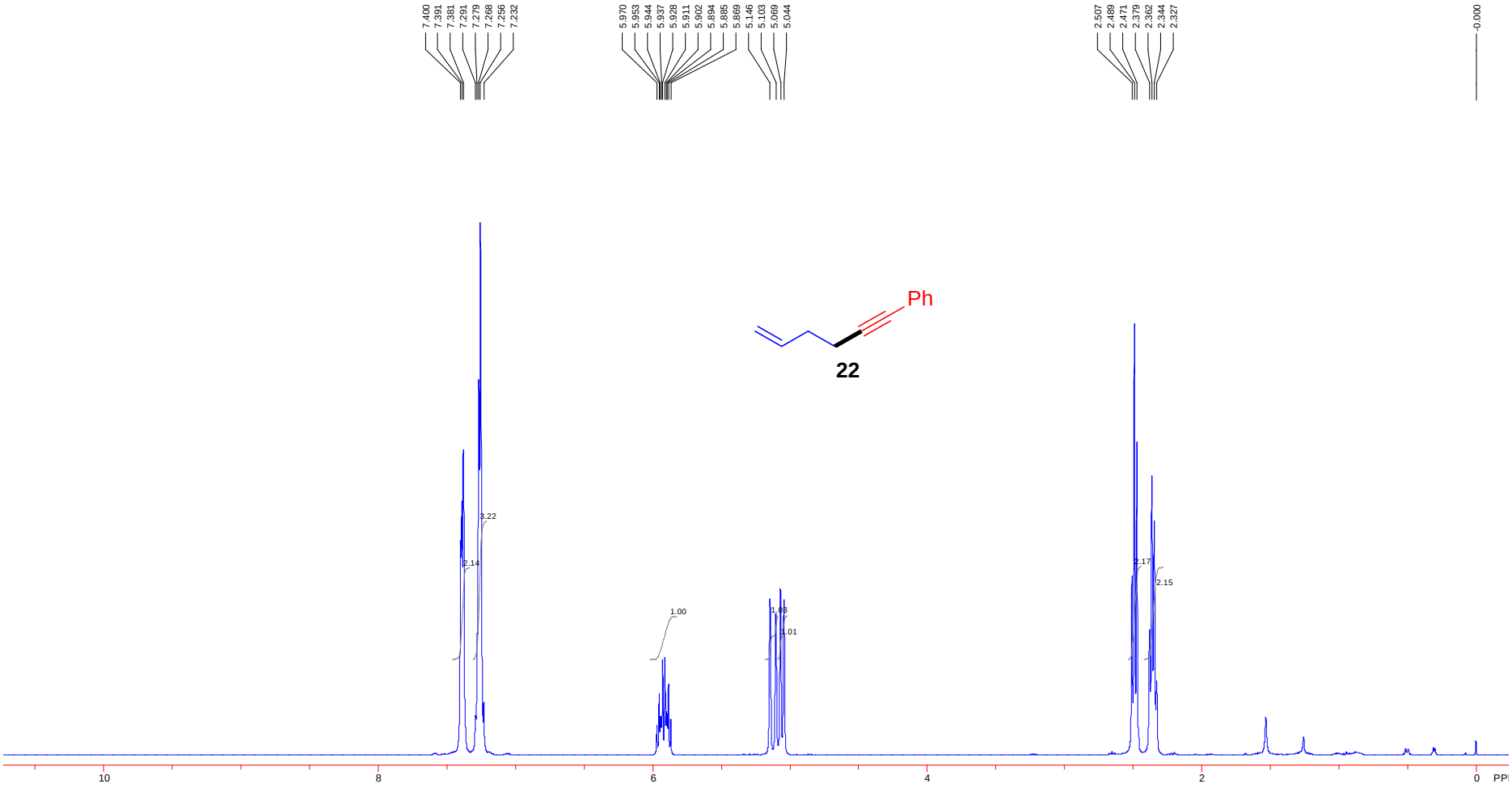
^{1}H NMR(600 MHz, $CDCl_3$)



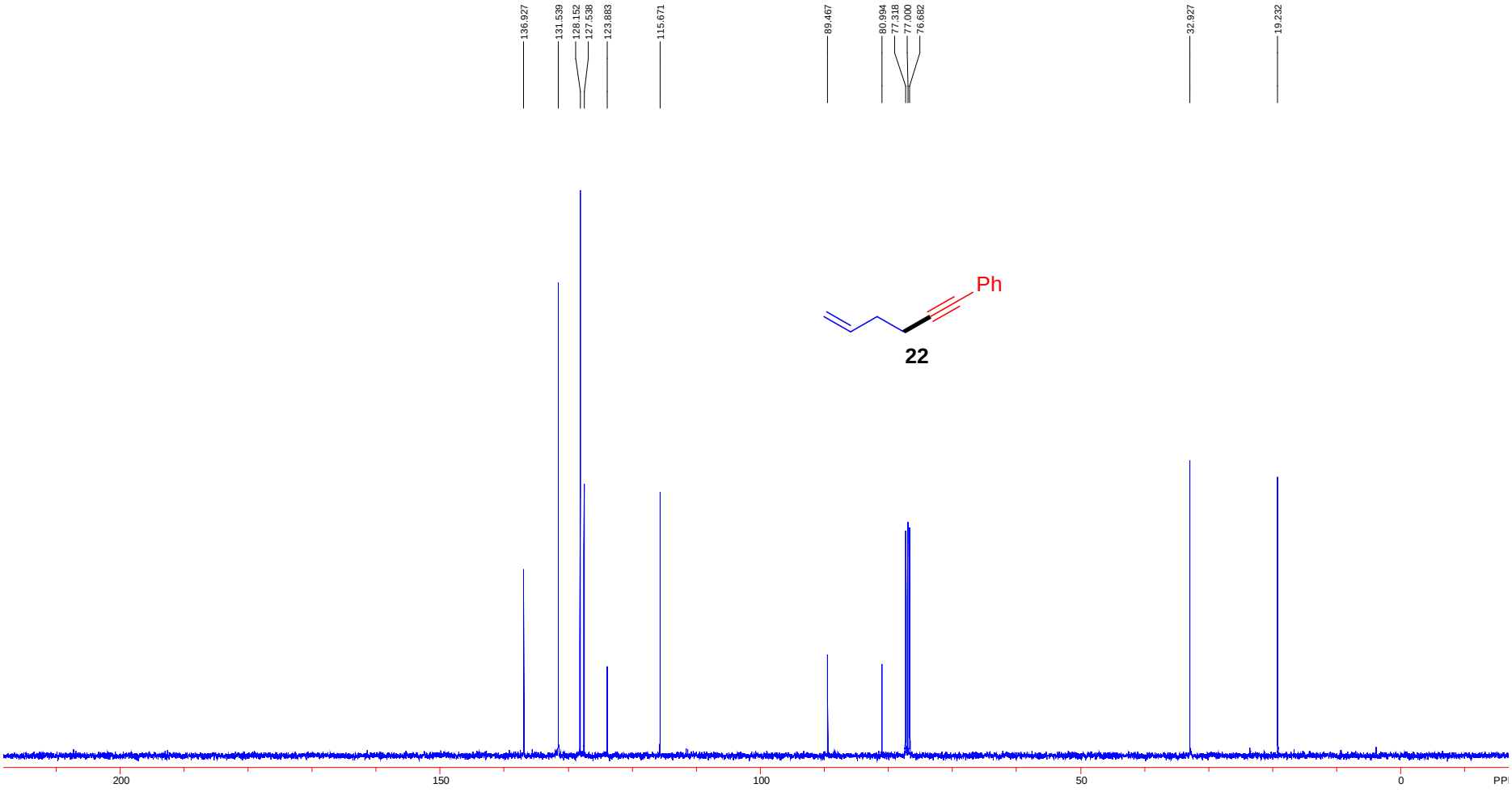
^{13}C NMR (151 MHz, $CDCl_3$)



^{1}H NMR(400 MHz, $CDCl_3$)



^{13}C NMR (100 MHz, $CDCl_3$)



^{1}H NMR(400 MHz, CD_3OD)