Copper(I)-Catalyzed Cycloaddition of 4-Bromo-Sydnones and Alkynes for the Regioselective Synthesis of 1,4,5-Trisubstituted Pyrazoles.

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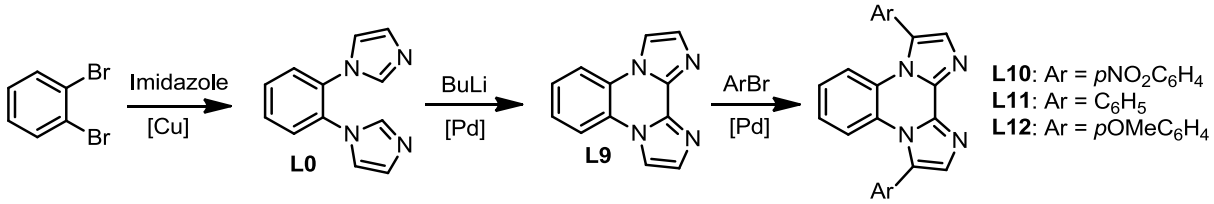
General

Organic solvents (Aldrich) were used without further purification. Purifications of reactions products were carried out by flash chromatography using Merck silica gel (40–63 μm). Infrared spectra (IR) were obtained on a Perkin Elmer UATR TWO FTIR spectrophotometer and are reported as wavelength numbers (cm^{-1}). Infrared spectra prepared with a KBr or NaCl pellet containing the title compound were obtained on a Perkin Elmer system 2000 FTIR spectrophotometer. ^{1}H NMR (400 MHz), ^{13}C NMR (100 MHz) were measured on a Brucker Avance 400 MHz spectrometer. Chemical shifts are reported in parts per million (ppm, δ) downfield from residual solvents peaks and coupling constants are reported as Hertz (Hz). Splitting patterns are designated as singlet (s), doublet (d), triplet (t), …. Splitting patterns that could not be interpreted or easily visualized are designated as multiplet (m). Electrospray mass spectra were obtained using an ESI/TOF Mariner Mass Spectrometer. High resolution mass spectra were obtained using a LCT PREMIER/XE WATERS TOF. Isotopic enrichments were calculated using direct injection ESI mass spectrometer. Unless otherwise noted, all other commercially available reagents and solvents were used without further purification.

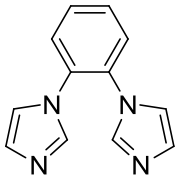
Synthesis and analytical data of ligands L9-L12

Ligands **L9**-**L12** were synthesised according to a described synthetic route (scheme S1).[1]



Scheme S1. General route to ligands L9-12

- 1-[2-(1H-imidazol-1-yl)phenyl]-1H-imidazole (**L0**)



M = 210.23 g/mol
$C_{12}H_{10}N_4$

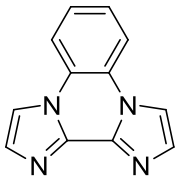
In a round-bottom flask were added 1,2-dibromobenzene (10.0 g, 42.4 mmol), imidazole (7.21 g, 106 mmol), K_2CO_3 (11.7 g, 84.8 mmol), Cu_2O (0.303 g, 2.12 mmol), and DMSO (20 mL). The mixture was stirred at 150 °C overnight. The resultant mixture was cooled to room temperature and filtered off through Celite with EtOAc. To the organic solution was added H_2O and the mixture was extracted with EtOAc. The combined organic layer were dried over $MgSO_4$ and evaporated under vacuum. A recristallisation was performed with $CHCl_3$ and heptane to give 3.30 g of compound **L0** (white powder) with 45% yield.

^{1}H NMR ($CDCl_3$, 400MHz): δ = 7.53–7.60 (m, 2 H), 7.46–7.52 (m, 2 H), 7.41–7.46 (m, 2 H), 7.11 (s, 2 H), 6.74 (s, 2 H) ppm ;

[1]Matsumoto, S., Batmunkh, E., Akazome, M., Takata, Y., Tamano, M. *Org. Bio. Chem.* **2011**, 9, 5941**.**

^{13}C NMR ($CDCl_3$, 101MHz): δ = 136.7 (2C), 132.1 (2C), 130.5 (2C), 129.7 (2C), 127.1 (2C), 119.4 (2C) ppm ;
IR (NaCl, cm^{-1}) : 3101, 2919, 2850, 1682, 1600, 1520, 1487, 1368, 1304, 1247, 1177, 1112, 1090, 1065, 965, 904, 835, 780 ;
MS (ESI) *m/z* : 211 $[M+H]^+$.

- diimidazo[1,2-a:2',1'-c]quinoxaline **(L9)**



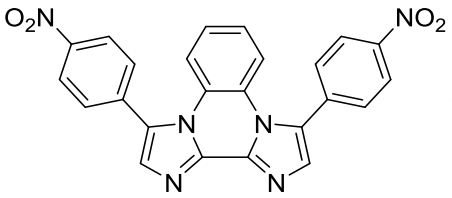
M = 208.07 g/mol
$C_{12}H_8N_4$

L0 (400 mg, 1.90 mmol) was dissolved in 8 mL of dried THF. The reaction was cooled to -78 °C and BuLi (1.6 M solution, 2.85 mL) was added dropwise. The reaction mixture was stirred for 60 min, then a solution of $Pd(PPh_3)_4$ (43.9 mg, 0.0380 mmol) in THF (5 mL) was added. The solution was slowly warmed to room temperature, and stirred for 19 h under argon atmosphere. Then a solution of brine was added and extraction was carried out with ethyl acetate. The organic layer was dried with magnesium sulfate, and then evaporated under vacuum. A recrystallization was performed in $CHCl_3$ and heptane to give 341 mg of compound **L9** (bright yellow powder) in 86% yield.

^{1}H NMR ($CDCl_3$, 400MHz): δ = 7.89–7.66 (m, 4 H), 7.628–7.625 (m, 2 H), 7.55–7.53 (m, 2 H) ppm ;
^{13}C NMR ($CDCl_3$, 101MHz): δ = 135.8 (2C), 132.6 (2C), 126.3 (2C), 124.4 (2C), 116.6 (2C), 112.4 (2C) ppm ;
IR (NaCl, cm^{-1}) : 1633, 1574, 1509, 1463, 1410, 1348, 1326, 1116, 931, 759, 685 ;
MS (ESI) *m/z* : 231 $[M+Na]^+$.

General Procedure A for arylation of compound L9:
Into a round bottom flask, dried K_2CO_3 (4 equiv.), **L9** (1 equiv.), bromoaryl (3 equiv.), $Pd(OAc)_2$ (0.1 equiv.) and dppe (0.2 equiv.) were mixed in DMF (final concentration 0.1 M). The mixture was stirred at 140 °C for 48 h under argon atmosphere. The resultant mixture was cooled down to room temperature and subsequently filtered off through celite with $CHCl_3$ three times. To the organic solution was added brine. The combined mixture was extracted with $CHCl_3$. The combined organic layers were dried over magnesium sulfate and evaporated. A column chromatography was performed (EtOAc/Heptane : 9/1).

- 3,10-bis(4-nitrophenyl)diimidazo[1,2-a:2',1'-c]quinoxaline **(L10)**

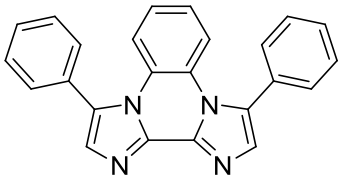


M = 450.41 g/mol
$C_{24}H_{14}N_6O_4$

Compound **L10** was obtained in 59% yield, 127 mg (orange solid) from compound **L9** (100 mg, 0.48 mmol), 1-bromo-4-nitrobenzene (388 mg, 1.92 mmol), using general procedure **A** and purified by column chromatography (Heptane/ Ethyl acetate : 1/9).

Mp : decomp. > 315 °C ;
^{1}H NMR ($CDCl_3$, 400MHz): δ = 8.42 (d, *J* = 8.4 Hz, 4 H), 7.79 (d, *J* = 8.4 Hz, 4 H), 7.68 (s, 2 H), 7.49–7.47 (m, 2 H), 7.22–7.20 (m, 2 H) ppm ;
^{13}C NMR ($CDCl_3$, 101MHz): δ = 147.8 (2C), 138.3 (2C), 136.5 (2C), 135.6 (2C), 129.5 (4C), 128.4 (2C), 126.1 (2C), 125.6 (2C), 124.5 (4C), 118.9 (2C) ppm ;
IR (v, cm^{-1}): 3102, 1916, 1596, 1515, 1492, 1474, 1375, 1342, 1299, 1139, 1108, 1014, 973, 909, 852, 753, 731, 697 ;
MS (ESI) *m/z* : 451 $[M+H]^+$.

- 3,10-diphenyldiimidazo[1,2-a:2',1'-c]quinoxaline (**L11**)

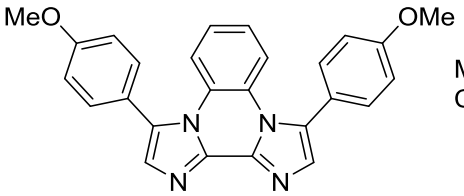


M = 360.14 g/mol
$C_{24}H_{16}N_4$

Compound **L11** was obtained in 84% yield, 400 mg (yellow solid) from compound **L9** (275 mg, 1.32 mmol) and bromobenzene (416 µL, 3.96 mmol), using general procedure **A** and purified by column chromatography (Heptane/ Ethyl acetate : 1/9).

Mp : 219–221 °C
^{1}H NMR ($CDCl_3$, 400MHz): δ = 7.45–7.59 (m, 14 H), 6.99–7.07 (m, 2 H) ppm ;
^{13}C NMR ($CDCl_3$, 101MHz): δ = 137.2 (2C), 133.6 (2C), 130.6 (2C), 130.2 (2C) , 129.6 (4C), 129.1 (6C), 126.0 (2C), 125.2 (2C), 118.5 (2C) ppm
IR (v, cm^{-1}): 3057, 1708, 1623, 1572, 1523, 1494, 1476, 1445, 1376, 1347, 1283, 1161, 1073, 953, 848, 761, 731, 702, 645 ;
MS (ESI) *m/z* : 361 $[M+H]^+$.

- 3,10-bis(4-methoxyphenyl)diimidazo[1,2-a:2',1'-c]quinoxaline (**L12**)



M = 420.16 g/mol
$C_{26}H_{20}N_4O_2$

Compound **L12** was obtained in 40% yield, 82 mg (brown solid) from compound **L9** (100 mg, 0.48 mmol) and bromoanisole (240 µL, 1.92 mmol), using general procedure **A** and purified by column chromatography (Heptane/ Ethyl acetate : 1/9).

Mp : 189–191 °C
^{1}H NMR ($CDCl_3$, 400MHz): δ = 7.53– 7.51 (m, 3 H), 7.46–7.43 (m, 5 H), 7.05–7.03 (m, 6 H), 3.51 (s, 6 H) ppm ;
^{13}C NMR ($CDCl_3$, 400MHz): δ = 160.2 (2C), 136.9 (2C), 133.3 (2C), 131.1 (4C), 129.8 (2C), 126.2 (2C), 125.1 (2C), 122.8 (2C), 118.3 (2C), 114.5 (4C), 55.6 (2C) ppm ;
IR (v, cm^{-1}): 3004, 2960, 2838, 2545, 2231, 2045, 1894, 1681, 1610, 1573, 1556, 1505, 1494, 1473, 1463, 1441, 1416, 1376, 1347, 1297, 1249, 1177, 1109, 1083, 1029, 954, 909, 8333, 754, 731, 678 ;
MS (ESI) *m/z* : 421 $[M+H]^+$.

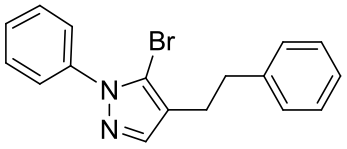
Synthesis and analytical data of 5-bromopyrazoles:

Sydnones were synthesized according to our previously described procedure.[2]

General procedure B:
To a solution of sydnone (1 equiv.) in acetone, NBS (1.2 equiv.) was added. The reaction mixture was stirred 2h and acetone was removed by evaporation under vacuum. To the latter flask containing the bromosydnone a solution of alkyne (1.2 equiv.) and sodium ascorbate (2 equiv.) in *tert*-butanol/water (55/45) were added a freshly prepared aqueous solution of $CuSO_4.5H_2O$ (0.2 equiv., 0.1 M final concentration), ligand (0.2 equiv., 0.1 M final concentration) and triethanolamine (1 equiv., 0.5 M final concentration). The reaction mixture was stirred at 60 °C overnight. Afterwards the reaction mixture was quenched with an aqueous solution of HEDTA (0.05 M) and extracted with dichloromethane. The organic layer were combined, dried over anhydrous magnesium sulfate and evaporated under vacuum. The crude mixture was purified by column chromatography.

General Procedure C:
To a solution of sydnone (1 equiv.) in acetone, NBS (1.2 equiv.) was added. The reaction mixture was stirred 2h and acetone was removed by evaporation under vacuum. To the latter flask containing bromosydnone a solution of alkyne (1.2 equiv.) and sodium ascorbate (2 equiv.) in *tert*-butanol/water (55/45) were added in four subsequent equal portions a freshly prepared aqueous solution of $CuSO_4.5H_2O$ (0.2 equiv., 0.1 M final concentration), ligand (0.2 equiv., 0.1 M final concentration) and triethanolamine (1 equiv., 0.5 M final concentration) every 2 hours. The reaction mixture was stirred at 60 °C overnight. Afterwards the reaction mixture was quenched with an aqueous solution of HEDTA (0.05 M) and extracted with dichloromethane. The organic layer were combined, dried over anhydrous magnesium sulfate and evaporated under vacuum. The crude mixture was purified by column chromatography.

- 5-bromo-4-phenethyl-1-phenyl-1H-pyrazole (**3a**)



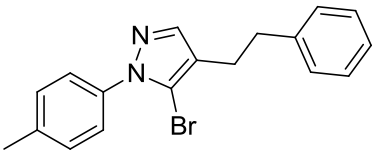
M = 327.22 g/mol
$C_{17}H_{15}BrN_2$

Compound **3a** was obtained in 74% yield, 111 mg (yellow solid) from 3-phenyl-4-bromo-sydnone (110.8 mg, 0.46 mmol) using general procedure **B** and purified by column chromatography (Heptane/ Ethyl acetate : 95/5).

^{1}H NMR ($CDCl_3$, 400MHz): δ = 7.38–7.55 (m, 6 H), 7.28–7.34 (m, 2 H), 7.19–7.25 (m, 3 H), 2.89–2.95 (m, 2 H), 2.77–2.83 (m, 2 H) ppm ;
^{13}C NMR ($CDCl_3$, 101MHz): δ = 141.4, 140.9, 139.4, 129.0, 128.6, 128.6, 128.3, 126.3, 125.6, 122.3, 112.6, 36.3, 26.7 ppm ;
IR (NaCl, cm^{-1}) : 3062, 3027, 2923, 2856, 1598, 1556, 1499, 1455, 1407, 1391, 1241, 1087, 1068, 961, 911, 851, 836, 760, 694 ;
MS (ESI) *m/z* : 327 [M(^{79}Br) + H]$^+$, 329 [M(^{81}Br) + H]$^+$;
HRMS (ESI) m/z calcd for C17H16N2Br [M+H] + (79Br): 327.0497; found: 327.0499.

[2] S. Specklin, E. Decuypere, L. Plougastel, S. Aliani, F. Taran. *J. Org. Chem.* **2014**, 79 (16), 7772–7777

- 5-bromo-1-(4-methylphenyl)-4-(2-phenylethyl)-1H-pyrazole (**3b**)

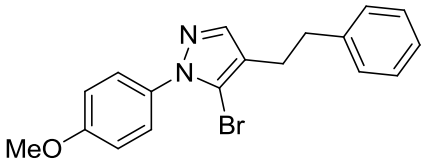


M = 341.25 g/mol
$C_{18}H_{17}BrN_2$

Compound **3b** was obtained in 80% yield, 85 mg (yellow solid) from 3-tolyl-4-bromo-sydnone (74.7 mg, 0.31 mmol) using general procedure **C** and purified by column chromatography (Heptane/ Ethyl acetate : 95/5).

Mp : 114–116 °C ;
^{1}H NMR ($CDCl_3$, 400MHz): δ = 7.50 (s, 1 H), 7.4 (d, *J* = 8.5 Hz, 2 H), 7.33–7.28 (m, 4 H), 7.24–7.20 (m, 3 H), 2.96–2.90 (m, 2 H), 2.81–2.77 (m, 2 H), 2.42 (s, 3 H) ppm ;
^{13}C NMR ($CDCl_3$, 101MHz): δ = 141.2, 140.4, 138.2, 136.8, 129.4 (2C), 128.4 (2C), 128.3 (2C), 126.0, 125.3 (2C), 121.8, 112.5, 36.1, 26.5, 21.1 ppm ;
IR (v, cm^{-1}): 3026, 2922, 2858, 1603, 1516, 1496, 1453, 1390, 1241, 1077, 961, 904, 818, 724, 697, 650 ;
MS (ESI) *m/z* : 341 [M(^{79}Br) + H]$^+$, 343 [M(^{81}Br) + H]$^+$;
HRMS (ESI) *m/z* calcd for $C_{18}H_{18}N_2Br$ [M+H] $^+$ (^{79}Br): 341.0653; found: 341.0648.

- 5-bromo-1-(4-methoxyphenyl)-4-(2-phenylethyl)-1H-pyrazole (**3c**)

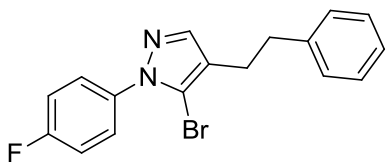


M = 357.24 g/mol
$C_{18}H_{17}BrN_2O$

Compound **3c** was obtained in 70% yield, 78 mg (yellow solid) from 3-(*p*-methoxy-phenyl)-4-bromo-sydnone (84.0 mg, 0.31 mmol) using general procedure **B** and purified by column chromatography (Heptane/ Ethyl acetate : 95/5).

Mp : 139-141 °C
^{1}H NMR ($CDCl_3$, 400MHz): δ = 7.49 (s, 1 H), 7.39–7.44 (m, 2 H), 7.28–7.34 (m, 2 H), 7.19–7.25 (m, 3 H), 6.95–7.01 (m, 2 H), 3.86 (s, 3 H), 2.88–2.95 (m, 2 H), 2.75–2.82 (m, 2 H) ppm ;
^{13}C NMR ($CDCl_3$, 101MHz): δ = 159.4, 141.3, 140.3, 132.4, 128.6 (2C), 128.4 (2C), 127.0 (2C), 126.1, 121.7, 114.0 (2C), 112.9, 55.6, 36.1, 26.7 ppm ;
IR (v, cm^{-1}) : 3004, 2911, 2634, 1609, 1588, 1512, 1493, 1453, 1440, 1395, 1302, 1244, 1174, 1149, 1110, 1029, 960, 853, 834, 800, 765, 748, 719, 667, 654 ;
MS (ESI) *m/z* : 357 [M(^{79}Br) + H]$^+$, 359 [M(^{81}Br) + H]$^+$;
HRMS (ESI) *m/z* calcd for $C_{18}H_{18}N_2OBr$ [M+H] $^+$ (^{79}Br): 357.0602; found: 357.0601.

- 5-bromo-1-(4-fluorophenyl)-4-(2-phenylethyl)-1H-pyrazole (**3d**)

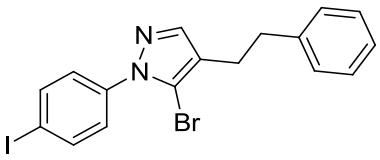


M = 345.22 g/mol
$C_{17}H_{14}BrFN_2$

Compound **3d** was obtained in 55% yield, 59 mg (yellow solid) from 3-(*p*-fluoro-phenyl)-4-bromo-sydnone (74.7 mg, 0.31 mmol) using general procedure **C** and purified by column chromatography (Heptane/ Ethyl acetate : 95/5).

Mp : 120–122 °C ;
^{1}H NMR ($CDCl_3$, 400MHz): δ = 7.52–7.49 (m, 3 H), 7.33–7.30 (m, 2 H), 7.24–7.22 (m, 3 H), 7.19–7.14 (m, 2 H), 2.94–2.90 (m, 2 H), 2.82–2.78 (m, 2 H) ppm ;
^{13}C NMR ($CDCl_3$, 101MHz): δ = 162.1 (d, $J_{C\text{-}F}$ = 247 Hz, 1C), 141.1, 140.1, 135.4 (d, $J_{C\text{-}F}$ = 3.1 Hz, 1C), 128.43 (2C), 128.37 (2C), 127.3 (d, $J_{C\text{-}F}$ = 8.5 Hz, 2C), 126.1, 122.3, 115.8 (d, $J_{C\text{-}F}$ = 23.1 Hz, 2C), 112.6, 36.0, 26.5 ppm ;
IR (v, cm^{-1}): 3061, 3024, 2921, 2852, 1740, 1604, 1512, 1453, 1394, 1290, 1231, 1151, 1098, 1078, 1028, 1012, 963, 836, 817, 752, 735, 718, 653 ;
MS (ESI) *m/z* : 345 [M(^{79}Br) + H]$^+$, 347 [M(^{81}Br) + H]$^+$;
HRMS (ESI) *m/z* calcd for $C_{17}H_{14}BrFN_2$ [M+H] $^+$ (^{79}Br): 345.0403; found: 345.0400.

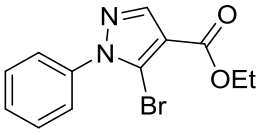
- 5-bromo-1-(4-iodophenyl)-4-(2-phenylethyl)-1H-pyrazole (**3e**)



M = 453.11 g/mol
$C_{17}H_{14}BrIN_2$

Compound **3e** was obtained in 72% yield, 101 mg (yellow solid) from 3-(*p*-iodo-phenyl)-4-bromo-sydnone (113.8 mg, 0.31 mmol) using general procedure **B** and purified by column chromatography (Heptane/ Ethyl acetate : 95/5).
Mp : 108–110 °C ;
^{1}H NMR ($CDCl_3$, 400MHz): δ = 7.8 (d, *J* = 7.3 Hz, 2 H), 7.5 (s, 1 H), 7.33–7.29 (m, 4H), 7.24–7.21 (m, 3 H), 2.93–2.89 (m, 2 H), 2.82–2.78 (m, 2 H) ppm;
^{13}C NMR ($CDCl_3$, 101MHz): δ = 141.1, 141.0, 138.9, 137.9 (2C), 128.41 (2C), 128.37 (2C), 126.9 (2C), 126.1, 125.6, 112.2, 93.3, 35.9, 26.5 ppm;
IR (v, cm^{-1}) : 3086, 3026, 2923, 2857, 1603, 1586, 1495, 1454, 1387, 1303, 1240, 1055, 1009, 959, 824, 740, 698 ;
MS (ESI) *m/z* : 454 [M(^{79}Br) + H]$^+$, 456 [M(^{81}Br) + H]$^+$.

- ethyl 5-bromo-1-phenyl-1H-pyrazole-4-carboxylate (**3f**)

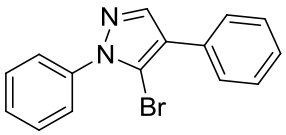


M = 295.14 g/mol
$C_{12}H_{11}BrN_2O_2$

Compound **3f** was obtained in 38% yield, 35 mg (white solid) from 3-phenyl-4-bromo-sydnone (74.7 mg, 0.31 mmol) using general procedure **C** and purified by column chromatography (Heptane/ Ethyl acetate : 95/5).

Mp :86-88 °C ;
^{1}H NMR ($CDCl_3$, 400MHz): δ = 8.14 (s, 1 H), 7.53–7.94 (m, 5 H), 4.37 (q, *J* = 7.2 Hz, 2 H), 1.4 (t, *J* = 7.2 Hz, 3 H) ppm ;
^{13}C NMR ($CDCl_3$, 101MHz): δ = 161.7, 143.1, 138.3, 129.2, 129.0 (2C), 126.1 (2C), 117.8, 115.1, 60.5, 14.3 ppm ;
IR (v, cm^{-1}): 2981, 1713, 1597, 1530, 1499, 1458, 1399, 1372, 1296, 1238, 1222, 1171, 1066, 1047, 955, 904, 833, 762, 727, 692, 650 ;
MS (ESI) *m/z* : 295 [M(^{79}Br) + H]$^+$, 297 [M(^{81}Br) + H]$^+$;
HRMS (ESI) *m/z* calcd for $C_{12}H_{11}BrN_2O_2$ [M+H] $^+$ (^{79}Br): 295.0082; found: 295.0076.

- 5-bromo-1,4-diphenyl-1H-pyrazole (**3g**)

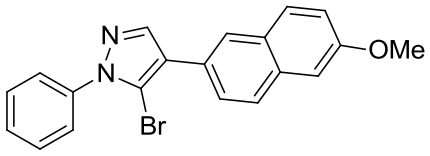


M = 299.17 g/mol
$C_{15}H_{11}BrN_2$

Compound **3g** was obtained in 63% yield, 58 mg (yellow solid) from 3-phenyl-4-bromo-sydnone (74.7 mg, 0.31 mmol) using general procedure **B** and purified by column chromatography (Heptane/ Ethyl acetate : 95/5).

Mp: 161–163 °C ;
^{1}H NMR (CDCl3, 400MHz): δ = 7.89 (s, 1 H), 7.65–7.63 (m, 2 H), 7.61–7.58 (m, 2 H), 7.54–7.50 (m, 2 H), 7.48–7.44 (m, 3 H) ppm ;
^{13}C NMR (CDCl3, 101MHz) : δ = 140.4, 139.1, 131.4, 129.4, 128.9 (2C), 128.6 (2C), 127.7 (2C), 127.3, 125.9 (2C), 125.7, 119.0 ppm ;
IR (v, cm^{-1}**) :** 2920, 1768, 1597, 1553, 1499, 1385, 1073, 981, 945, 862, 756, 717, 693, 642 ;
MS (ESI) *m/z* : 299 [M(^{79}Br) + H]$^+$, 301 [M(^{81}Br) + H]$^+$;
HRMS (ESI) *m/z* calcd for $C_{15}H_{12}N_2Br$ [M+H] $^+$ (^{79}Br): 299.0184; found: 299.0193.

- 5-bromo-4-(6-methoxynaphthalen-2-yl)-1-phenyl-1H-pyrazole (**3h**)

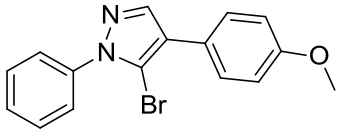


M = 379.26 g/mol
$C_{20}H_{15}BrN_2O$

Compound **3h** was obtained in 77% yield, 91 mg (white solid) from 3-phenyl-4-bromo-sydnone (74.7 mg, 0.31 mmol) using general procedure **C** and purified by column chromatography (Heptane/ Ethyl acetate : 95/5).

Mp : 145–147 °C
^{1}H NMR ($CDCl_3$, 400MHz): δ = 8.03 (s, 1 H), 7.98 (s, 1 H), 7.83–7.78 (m, 2 H), 7.71 (dd, *J* = 1.3 Hz, *J* = 8.4 Hz, 1 H), 7.62 (d, *J* = 7.9 Hz, 2 H), 7.55–7.45 (m, 3 H), 7.20–7.17 (m, 2 H), 3.95 (s, 3 H) ppm ;
^{13}C NMR ($CDCl_3$, 101MHz): δ = 157.9, 140.6, 139.2, 133.7, 129.5, 129.0 (2C), 128.6, 127.1, 126.6, 126.4, 126.3, 126.0 (2C), 123.6, 119.2, 111.3, 105.7, 55.4 ppm ;
IR (v, cm-1): 3053, 2955, 1773, 2629, 1597, 1499, 1479, 1386, 1359, 1262, 1218, 1198, 1165, 1026, 961, 903, 890, 851, 843, 756, 694, 654, 533, 476 ;
MS (ESI) *m/z* : 379 [M(^{79}Br) + H]$^+$, 381 [M(^{81}Br) + H]$^+$;
HRMS (ESI) *m/z* calcd for $C_{20}H_{16}N_2OBr$ [M+H] $^+$ (^{79}Br): 379.0446; found: 379.0446.

- 5-bromo-4-(4-methoxyphenyl)-1-phenyl-1H-pyrazole (**3i**)



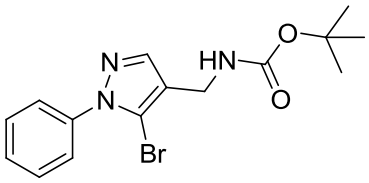
M = 329.20 g/mol
$C_{16}H_{13}BrN_2O$

Compound **3i** was obtained in 44% yield, 45 mg (yellow solid) from 3-phenyl-4-bromo-sydnone (74.7 mg, 0.31 mmol) using general procedure **D** and purified by column chromatography (Heptane/ Ethyl acetate : 95/5).

Mp : 174–176 °C ;

^{1}H NMR ($CDCl_3$, 400MHz): δ = 7.85 (s, 1 H), 7.60–7.45 (m, 7 H), 6.99 (d, *J* = 8.5 Hz, 2 H), 3.86 (s, 3 H) ppm ;
^{13}C NMR ($CDCl_3$, 101MHz): δ = 158.9, 140.2, 139.2, 128.92 (2C), 128.87 (2C), 128.7, 128.5, 125.9 (2C), 123.8, 123.2, 114.1 (2C), 55.3 ppm ;
IR (v, cm^{-1}) : 2952, 1598, 1556, 1497, 1456, 1396, 1366, 1306, 1283, 1252, 1180, 1112, 1070, 1031, 948, 907, 835, 756, 730, 693, 645 ;
MS (ESI) *m/z* : 329 [M(^{79}Br) + H]$^+$, 331 [M(^{81}Br) + H]$^+$;
HRMS (ESI) *m/z* calcd for $C_{16}H_{14}N_2OBr$ [M+H] $^+$ (^{79}Br): 329.0289; found: 329.0294.

- tert-butyl N-[(5-bromo-1-phenyl-1H-pyrazol-4-yl)methyl]carbamate (**3j**)

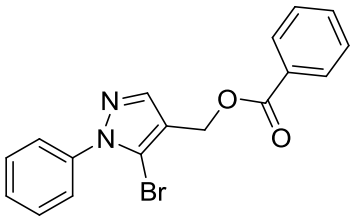


M = 352.23 g/mol
$C_{15}H_{18}BrN_3O_2$

Compound **3j** was obtained in 69% yield, 75 mg (yellow solid) from 3-phenyl-4-bromo-sydnone (74.7 mg, 0.31 mmol) using general procedure **C** and purified by column chromatography (Heptane/ Ethyl acetate : 95/5).

Mp : 11–113 °C ;
^{1}H NMR ($CDCl_3$, 400MHz): δ = 7.74 (s br., 1 H), 7.56–7.38 (m, 5 H), 4.84 (s br., 1 H), 4.22 (d, *J* = 4.0 Hz, 2 H), 1.47 (s, 9 H) ppm ;
^{13}C NMR ($CDCl_3$, 101MHz): δ = 155.6, 140.9, 138.9, 128.9 (2C), 128.4, 125.4 (2C), 120.2, 112.5, 79.6, 35.3, 28.4 (3C) ppm ;
IR (v, cm^{-1}) : 3355, 2985, 1689, 1598, 1523, 1499, 1388, 1366, 1344, 1275, 1247, 1166, 1140, 1087, 1064, 1043, 1026, 963, 914, 812, 755, 692, 645 ;
MS (ESI) *m/z* : 374 [M(^{79}Br) + Na]$^+$, 376 [M(^{81}Br) + Na]$^+$.

- (5-bromo-1-phenyl-1H-pyrazol-4-yl)methyl benzoate (**3k**)

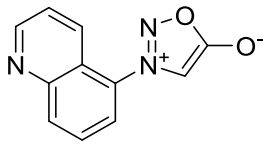


M = 357.21 g/mol
$C_{17}H_{13}BrN_2O_2$

Compound **3k** was obtained in 52% yield, 58 mg (white solid) from 3-phenyl-4-bromo-sydnone (74.7 mg, 0.31 mmol) using general procedure **B** and purified by column chromatography (Heptane/ Ethyl acetate : 95/5

Mp : 111-113 °C
^{1}H NMR ($CDCl_3$, 400MHz): δ = 8.08 (d, *J* = 7.3 Hz, 2 H), 7.88 (s, 1 H), 7.58–7.42 (m, 8 H), 5.30 (s, 2 H) ppm ;
^{13}C NMR ($CDCl_3$, 101MHz): δ = 166.4, 141.9, 138.8, 133.0, 129.9, 129.7 (2C), 128.9 (2C), 128.6, 128.3 (2C), 125.6 (2C), 117.9, 114.7, 57.5 ;
IR (v, cm-1): 3059, 2922, 1713, 1595, 1556, 1498, 1541, 1404, 1385, 1343, 1314, 1178, 1103, 1069, 1025, 960, 951, 851, 767, 751, 710, 697, 690, 649, 551 ;
MS (ESI) *m/z* : 357 [M(^{79}Br) + H]$^+$, 359 [M(^{81}Br) + H]$^+$;
HRMS (ESI) *m/z* calcd for $C_{17}H_{14}N_2O_2Br$ [M+H] $^+$ (^{79}Br): 357.0239; found: 357.0255.

- **5-(4H-sydnone)quinoline**

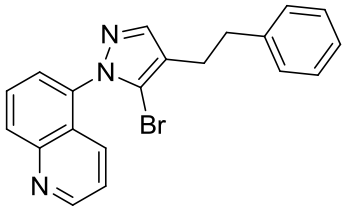


M = 213.2 g/mol
$C_{11}H_7N_3O_2$

5-(4H-sydnone)quinoline was obtained in 71 % yield, 74 mg (red solid) according our previously described procedure using 5-aminoquinoline (100 mg, 0.49 mmol), tert-butylnitrite (65 µL, 0.54 mmol) and trifluoroacetic acid (173 µL, 1.23 mmol) and purified by column chromatography (Dichloromethane/Ethyl acetate : 4/6).[3]

Mp : 172–173 °C ;
^{1}H NMR ($CDCl_3$, 400MHz): 9.10 (d br., *J* = 3.6 Hz, 1 H), 8.45 (d, *J* = 8.5 Hz, 1 H), 8.17 (d, *J* = 8.5 Hz, 1 H), 7.93–7.87 (m, 1 H), 7.83–7.81 (m, 1 H), 7.62 (dd, *J* = 4.3, 8.5 Hz, 1 H), 6.61 (s, 1 H) ppm ;
^{13}C NMR ($CDCl_3$, 101MHz): 168.4, 152.2, 148.1, 134.5, 130.6, 129.6, 128.3, 123.7, 123.6, 122.4, 98.1 ppm ;
IR (v, cm^{-1}): 3104, 1775, 1620, 1596, 1567, 1506, 1423, 1346, 1317, 1249, 1208, 1183, 1170, 1122, 1068, 1029, 971, 937, 870, 826, 801, 727, 644 ;
MS (ESI) *m/z* : 214 $[M + H]^+$.

- 5-(5-bromo-4-phenethyl-1H-pyrazol-1-yl)quinoline (**3l**)

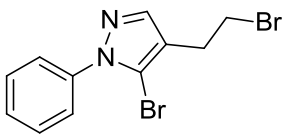


M = 377,05 g/mol
$C_{20}H_{16}BrN_3$

Compound **3l** was obtained in 33% yield, 37 mg (red oil) from 4-bromo-sydnone-5-quinoline (87.7 mg, 0.3 mmol) using general procedure **B** and purified by column chromatography (Heptane/ Ethyl acetate : 7/3

^{1}H NMR ($CDCl_3$, 400MHz): 8.98–8.96 (dd, *J* = 1.6, 4.5 Hz, 1 H), 8.27–8.25 (d, *J* = 8.6 Hz, 1 H), 7.82–7.81 (dd, *J* = 7.4, 8.6 Hz, 1 H), 7.65–7.63 (m, 2 H), 7.59–7.57 (d, *J* = 7.4 Hz, 1 H), 7.43–7.39 (dd, *J* = 4.5, 8.6 Hz, 1 H), 7.34–7.31 (m,2 H), 7.25–7.22 (m, 3 H), 3.01–2.97 (m, 2 H), 2.89–2.85 (m, 2H) ppm ;
^{13}C NMR ($CDCl_3$, 101MHz): 150.9, 148.4, 141.2, 140.9, 135.2, 131.8, 131.3, 128.6 (2C), 128.4 (2C), 128.3, 126.2, 126.1, 125.8, 122.1, 121.4, 115.2, 36.1, 26.4 ppm ;
IR (v, cm^{-1}): 3062, 3026, 2923, 2856, 1720, 1619, 1596, 1570, 1496, 1474, 1453, 1422, 1390, 1316, 1257, 1209, 1119, 940, 828, 801, 749, 699 ;
MS (ESI) *m/z* : 378 $[M(^{79}Br) + H]^+$, 380 $[M(^{81}Br) + H]^+$;

- 5-bromo-4-(2-bromoethyl)-1-phenyl-1H-pyrazole (**3m**)



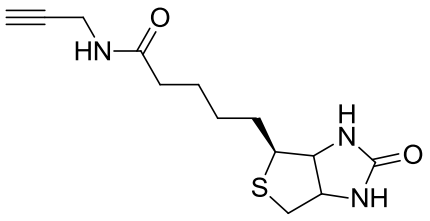
M = 330.02 g/mol
$C_{11}H_{10}Br_2N_2$

[3] S. Specklin, E. Decuypere, L. Plougastel, S. Aliani, F. Taran. *J. Org. Chem.* **2014**, 79 (16), 7772–7777

Compound **3m** was obtained in 63% yield, 65 mg (beige oil) from 3-phenyl-4-bromo-sydnone (74.7 mg, 0.31 mmol) using general procedure **C** and purified by column chromatography (Heptane/ Ethyl acetate : 95/5).

^{1}H NMR ($CDCl_3$, 400MHz): δ = 7.67 (s, 1 H), 7.55–7.42 (m, 5 H), 3.55 (t, *J* = 7.4 Hz, 2 H), 3.08 (t, *J* = 7.4 Hz, 2 H) ppm ;
^{13}C NMR ($CDCl_3$, 101MHz): δ = 140.8, 139.0, 128.9 (2C), 128.4, 125.4 (2C), 119.8, 112.9, 31.3, 28.4 ppm ;
IR (v, cm^{-1}): 3062, 2963, 1596, 1555, 1498, 1457, 1446, 1429, 1407, 1388, 1268, 1212, 1175, 1085, 1024, 1002, 959, 912, 876, 853, 759, 715, 691, 652 ;
MS (ESI) *m/z* : 329 [M(^{79}Br) + H]$^+$, 331 [M(^{81}Br) + H]$^+$;
HRMS (ESI) *m/z* calcd for $C_{11}H_{10}Br_2N_2$ [M+H] $^+$ (^{79}Br): 328.9289; found: 332.89286.

- **5-{2-oxo-hexahydro-1H-thieno[3,4-d]imidazolidin-4-yl}-N-(prop-2-yn-1-yl)pentanamide**.

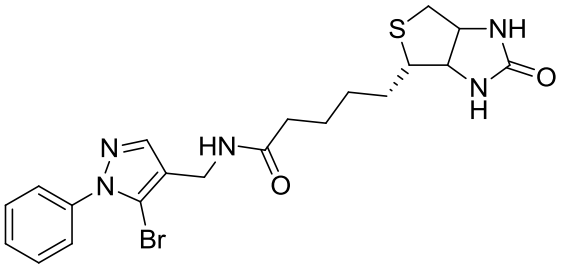


M = 281.37 g/mol
$C_{13}H_{19}N_3O_2S$

Into a dried round bottom flask, ester succinimide activated biotine (341 mg, 1.0 mmol) and propargylamine (70.5 µL, 1.1 mmol) were stirred in DMF overnight at room temperature. The reaction mixture was then evaporated under vacuum, and a column chromatography was performed in AcOEt/MeOH (9/1). 273 mg of a white powder was obtained (97% yield)

Mp : 163–165 °C ;
^{1}H NMR (MeOD ,400MHz): δ = 4.51–4.74 (m, 1 H), 4.32–4.29 (m, 1 H), 3.94 (d, *J* = 2.9 Hz, 2 H), 3.23–3.18 (m, 1 H), 2.95–2.91 (m, 1 H), 2.72 (s, 1 H), 2.69–2.68 (m, 1 H), 2.56 (t, *J* = 2.6 Hz, 1 H), 2.22 (t, *J* = 7.5 Hz, 2 H), 1.77–1.57 (m, 6 H), 1.48–1.43 (m, 2 H) ppm ;
^{13}C NMR (MeOD ,101MHz): δ = 174.4, 164.6, 79.2, 70.6, 61.9, 60.2, 55.5, 39.6, 35.0, 28.2, 27.99, 27.92, 25.2 ppm ;
IR (v, cm^{-1}): 3285, 1689, 1637, 1541, 1465, 1322, 1263, 1158, 1062, 950, 825, 655 ;
MS (ESI) *m/z* : 304 [M+ Na]$^+$.

- N-[(5-bromo-1-phenyl-1H-pyrazol-4-yl)methyl]-5-{2-methylidene-hexahydro-1H-thieno[3,4-d]imidazolidin-4-yl}pentanamide (**3n**)



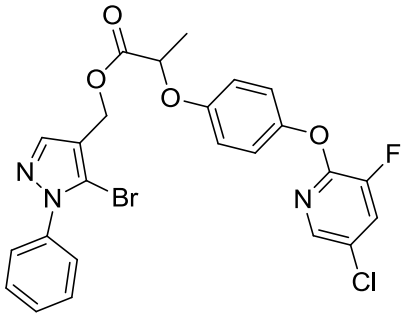
M = 478.41 g/mol
$C_{20}H_{24}BrN_5O_2S$

Compound **3n** was obtained in 65% yield, 96 mg (white solid) from 3-phenyl-4-bromo-sydnone (74.7 mg, 0.31 mmol) using general procedure **C** and purified by column chromatography (Heptane/ Ethyl acetate : 95/5).

Mp : 157–159 °C ;

^{1}H NMR (MeOD , 400MHz) : δ = 7.74 (s, 1 H), 7.54 –7.49 (m, 5 H), 4.47 (dd, *J* = 4.9, 7.9 Hz, 1 H), 4.32–4.27 (m, 3 H), 3.19 (ddd, *J* = 4.5, 5.9, 8.9 Hz, 1 H), 2.91 (dd, *J* = 4.9, 12.6 Hz, 1 H), 2.69 (d, *J* = 12.6 Hz, 1 H), 2.25 (t, *J* = 7.3 Hz, 2 H), 1.770 – 1.40 (m, 6 H) ppm ;
^{13}C NMR ($CDCl_3$, 101MHz): δ = 174.4, 164.6, 140.8, 136.7, 128.8 (2C), 125.5 (2C), 120.0, 113.5, 61.9, 60.1, 55.5, 39.6, 35.1, 33.3, 28.3, 28.0, 25.4, 7.8 ppm ;
IR (v, cm^{-1}) : 3287, 1695, 1664, 1629, 1542, 1498, 1459, 1389, 1263, 1068, 959, 756, 692.
MS (ESI) *m/z* : 478 [M(^{79}Br) + H]$^+$, 480 [M(^{81}Br) + H]$^+$;
HRMS (ESI) *m/z* calcd for $C_{20}H_{25}BrN_5O_2S$ [M+H] $^+$ (^{79}Br): 478.0912; found: 478.0905.

- 5-bromo-1-phenyl-1H-pyrazol-4-yl-2-{4-[(5-chloro-3-fluoropyridin-2-yl)oxy]phenoxy} propanoate (**3o**)

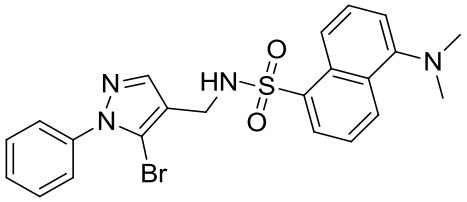


M = 546.78 g/mol
$C_{24}H_{18}BrClFN_3O_4$

Compound **3o** was obtained in 55% yield, 94 mg (yellow oil) from 3-phenyl-4-bromo-sydnone (74.7 mg, 0.31 mmol) using general procedure **C** and purified by column chromatography (Heptan/ Ethyl acetate : 95/5).

^{1}H NMR ($CDCl_3$, 400MHz): δ = 7.83 (d, *J* = 2.2 Hz, 1 H), 7.73 (s, 1 H), 7.54–7.41 (m, 6 H), 7.06–7.02 (m, 2 H), 6.91–6.87 (m, 2 H), 5.12 (ABq, $\Delta\delta_{AB}$ = 0.03, J_{AB} = 12.6 Hz, 2 H), 4.77 (q, *J* = 6.8 Hz, 1 H), 1.64 (d, *J* = 6.8 Hz, 3 H) ppm ;
^{13}C NMR ($CDCl_3$, 101MHz): δ = 168.8, 151.7, 148.2 (d, *J*=11.6 Hz), 143.9, 143.8 (d, *J*=266.8 Hz), 138.7, 136.9 (d, *J*=6.2 Hz), 135.7, 125.8 (2C), 125.6, 122.4 (2C), 121.8 (d, *J*=3.8 Hz), 121.7, 119.2 (2 C), 114.1, 112.9 (2C), 111.8, 69.9, 54.7, 15.4 ppm ;
IR (v, cm^{-1}): 1752, 1734, 1688, 1597, 1576, 1556, 1530, 1500, 1445, 1412, 1288, 1272, 1235, 1193, 1157, 1128, 1091, 1040, 1009, 953, 927, 886, 862, 843, 760, 734, 692, 650 ;
MS (ESI) *m/z* : 546 [M(^{79}Br) + H]$^+$, 548 [M(^{81}Br) + H]$^+$;
HRMS (ESI) *m/z* calcd for $C_{24}H_{18}BrClFN_3O_4$ [M+H] $^+$ (^{79}Br): 546.0231; found: 546.0233.

- N-[(5-bromo-1-phenyl-1H-pyrazol-4-yl)methyl]-5-(dimethylamino)naphthalene-1-sulfonamide (**3p**)



M = 485.40 g/mol
$C_{22}H_{21}BrN_4O_2S$

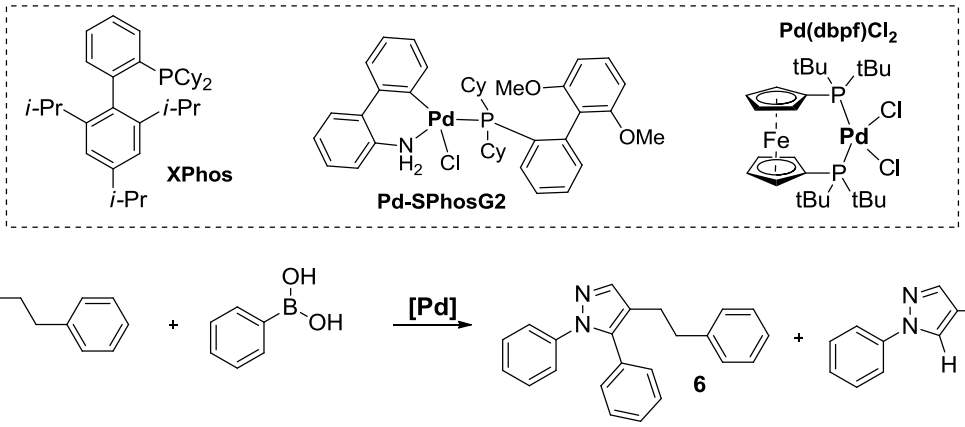
Compound **3p** was obtained in 52% yield, 78 mg (bright green solid) from 3-phenyl-4-bromo-sydnone (74.7 mg, 0.31 mmol) using general procedure **C** and purified by column chromatography (Heptane/ Ethyl acetate : 95/5).

Mp : 121–123 °C ;
^{1}H NMR ($CDCl_3$, 400MHz): δ = 8.51 (d, *J* = 8.6 Hz, 1 H), 8.28 (dd, *J* = 7.5, 1.2 Hz, 1 H), 8.24 (d, *J* = 8.6 Hz, 1 H), 7.58–7.49 (m, 2 H), 7.43–7.39 (m, 3 H), 7.29–7.27 (m, 2 H), 7.22 (s, 1 H), 7.16 (d, *J* = 7.5 Hz, 1 H), 4.99 (t, *J* = 6.1 Hz, 1 H), 4.06 (d, *J* = 6.1 Hz, 2 H), 2.83 (s, 6 H) ppm ;

^{13}C NMR ($CDCl_3$, 101MHz): δ = 151.9, 140.7, 138.5, 134.6, 130.6, 129.8, 129.7, 129.5, 128.8 (2C), 128.45, 128.38, 125.3 (2C), 123.0, 118.5, 117.8, 115.1, 112.9, 53.4, 45.2, 37.8 ppm ;
IR (v, cm^{-1}): 1575, 1501, 1395, 1338, 1313, 1141, 1093, 1056, 969, 942, 856, 797, 757, 698, 650.
MS (ESI) *m/z* : 486 [M(^{79}Br) + H]$^+$, 488 [M(^{81}Br) + H]$^+$;
HRMS (ESI) *m/z* calcd for $C_{22}H_{21}BrN_4O_2S$ [M+H] $^+$ (^{79}Br): 485.0647; found: 485.0663.

Optimization of Suzuki coupling on 5-bromopyrazoles

Table S1. Suzuki coupling of bromopyrazole **3** with boronic acids.[a]



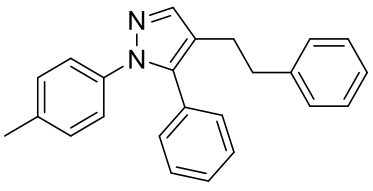
Entry	Catalyst	Base	Conditions	6 (%)[b]	5 (%)[b]
1	$Pd(PPh_3)_4$	K_3PO_4	Dioxane/H_2O (1/1) -100°C	50	50
2	Pd_2dba_3 / $P(cyhexyl)_3$	K_3PO_4	Dioxane/H_2O (1/1) - 100°C	60	40
3	$Pd(OAc)_2$ / XPhos	K_3PO_4	MeCN /H_2O (1/1)- 60 °C	42	58
4	$Pd(OAc)_2$ / SPhosG2	K_3PO_4	Dioxane/H_2O (1/1) - 100°C	67	33
5	**$Pd(dbpf)Cl_2$**	**K_2CO_3**	**MeCN /H_2O (1/1)- 60°C**	**75**	**25**
7	$Pd(dbpf)Cl_2$	K_2CO_3	MeCN /H_2O (1/1)- 25°C	0	40

[a]reactions were conducted at 0.1M using 1 equiv. of reactant, 10% mol of Pd and 1.5 equiv. of base.
[b]LCMS yields

Procedure and analytical data of 1,4,5-trisubstituted Pyrazoles

General Procedure D:
In a screw cap tube, bromopyrazole (1 equiv.), phenylboronic acid (1.2 equiv.), $Pd(dtbpf)Cl_2$ (0.1 equiv.) and K_2CO_3 (1.5 equiv.), were added in acetonitrile/water (1/1, 0.1 M). The reaction mixture was stirred at 100 °C overnight, then filtered on celite and washed with ethyl acetate. The filtrate was then washed with brine. The organic layer were collected, dried over anhydrous magnesium sulfate and evaporated under vacuum. The crude mixture was purified by column chromatography.

- 1-(4-methylphenyl)-5-phenyl-4-(2-phenylethyl)-1H-pyrazole (**6a**)

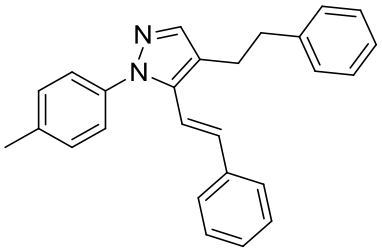


M = 338.45 g/mol
$C_{24}H_{22}N_2$

Compound **6a** was obtained with 41 mg, **75%** yield (bright yellow solid) from **3b** (55 mg, 0.16 mmol) and phenylboronic acid (24 mg, 0.20 mmol) using general procedure **D** and purified by column chromatography (Heptane/Ethyl acetate : 95/05).

Mp : 119-121 °C
^{1}H NMR ($CDCl_3$, 400MHz): δ = 7.61 (s, 1 H), 7.32–7.05 (m, 14 H), 2.89–2.77 (m, 4 H), 2.31 (s, 3 H) ppm ;
^{13}C NMR ($CDCl_3$, 101MHz): δ = 141.6, 139.9, 139.8, 137.8, 136.5, 130.7, 129.9 (2C), 129.2 (2C), 128.5 (2C), 128.4 (2C), 128.3 (2C), 128.0, 125.9, 124.4 (2C), 120.7, 31.1, 26.0, 21.0 ppm ;
IR (ν, cm-1): 3027, 2921, 2857, 1604, 1516, 1496, 1444, 1454, 1384, 1090, 1071, 964, 819, 772, 697, 659, 583, 551, 515 ;
MS (ESI) *m/z* : 339 $[M + H]^+$.

- 1-(4-methylphenyl)-5-[(E)-2-phenylethenyl]-4-(2-phenylethyl)-1H-pyrazole (**6b**)

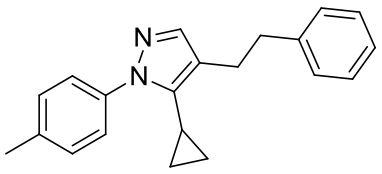


M = 364.49 g/mol
$C_{26}H_{24}N_2$

Compound **6b** was obtained in 38 mg, **66% yield** (bright yellow solid) from **3b** (55 mg, 0.16 mmol) and vinylphenylboronic acid (30 mg, 0.20 mmol) using general procedure **D** and purified by column chromatography (Heptane/Ethyl acetate : 95/05).

Mp: 114–116 °C
^{1}H NMR ($CDCl_3$, 400MHz): δ = 7.55 (s, 1 H), 7.39–7.21 (m, 14 H), 6.85–6.72 (m, 2 H), 3.06–2.97 (m, 4 H), 2.42 (s, 3 H) ppm ;
^{13}C NMR ($CDCl_3$, 101MHz): δ = 141.6, 140.1, 137.7, 137.5, 136.9, 136.8, 132.1, 129.7 (2C), 128.7 (2C), 128.5 (2C), 128.4 (2C), 128.1, 126.4 (2C), 126.1, 125.0 (2C), 120.1, 116.6, 36.6, 27.2, 21.1 ppm ;
IR (ν, cm^{-1}): 3026, 2923, 2859, 1603, 1516, 1496, 1454, 1390, 1089, 970, 822, 750, 697, 508 ;
MS (ESI) *m/z* : 365 $[M + H]^+$;
HRMS (ESI) *m/z* calcd for $C_{26}H_{24}N_2$ $[M+H]^+$: 365.2018; found: 365.2020.

- 5-cyclopropyl-1-(4-methylphenyl)-4-(2-phenylethyl)-1H-pyrazole (**6c**)



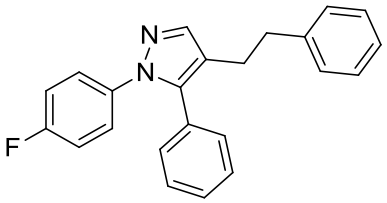
M = 302.42 g/mol
$C_{21}H_{22}N_2$

Compound **6c** was obtained in 54% yield, 26 mg (red oil) from **3b** (55 mg, 0.16 mmol) and cyclopropylboronic acid (16 mg, 0.19 mmol) using general procedure **D** and purified by column chromatography (Heptane/Ethyl acetate : 95/05).

^{1}H NMR ($CDCl_3$, 400MHz): δ =7.44 (s, 1 H), 7.40 (d, *J* = 8.3 Hz, 2 H), 7.33–7.29 (m, 2 H), 7.24–7.22 (m, 5 H), 2.95–2.91 (m, 2 H), 2.86–2.82 (m, 2 H), 2.41 (s, 3 H), 1.61–1.54 (m, 1 H), 0.79–0.75 (m, 2 H), 0.41–0.37 (m, 2 H) ppm ;

^{13}C NMR ($CDCl_3$, 101MHz): δ = 141.89, 139.8, 139.4, 138.0, 136.7, 129.1 (2C), 128.5 (2C), 128.3 (2C), 125.1, 124.4 (2C), 120.9, 37.2, 26.2, 21.0, 6.6 (2C), 5.9 ppm ;
IR (v, cm^{-1}): 3025, 2922, 2857, 1720, 1603, 1516, 1496, 1453, 1386, 1207, 1091, 1029, 976, 904, 818, 729, 698, 660 ;
MS (ESI) *m/z* : 303 $[M + H]^+$;
HRMS (ESI) *m/z* calcd for $C_{21}H_{22}N_2$ $[M+H]^+$: 303.1861; found: 303.1868.

- 1-(4-fluorophenyl)-5-phenyl-4-(2-phenylethyl)-1H-pyrazole (**6d**)

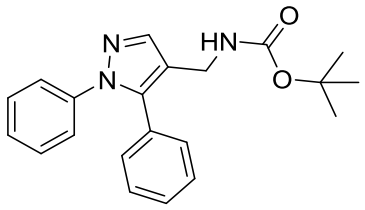


M = 342.42 g/mol
$C_{23}H_{19}FN_2$

Compound **6d** was obtained in 75% yield, 37 mg (bright yellow solid) from **3d** (50 mg, 0.14 mmol) and phenylboronic acid (21 mg, 0.17 mmol) using general procedure **D** and purified by column chromatography (Heptane/Ethyl acetate : 95/05).

Mp : 114–116 °C
^{1}H NMR ($CDCl_3$, 400MHz): δ = 7.60 (s, 1 H), 7.33–7.31 (m, 3 H), 7.27–7.24 (m, 2 H), 7.20–7.15 (m, 3 H), 7.12–7.10 (m, 2 H), 7.06–7.03 (m, 2 H), 6.97–6.93 (m, 2 H), 2.88–2.84 (m, 2 H), 2.80–2.76 (m, 2 H) ppm ;
^{13}C NMR $CDCl_3$, 101MHz): δ = 161.2 (d, $J_{C\text{-}F}$ = 247 Hz, 1C), 141.5, 140.2, 139.9, 136.3 (d, $J_{C\text{-}F}$ = 3.1 Hz, 1C), 130.2, 129.8, 128.5, 128.4 (2C), 128.3 (2C), 128.2, 126.3 (d, $J_{C\text{-}F}$ = 8.5 Hz, 2C), 125.9, 120.5, 115.5 (d, $J_{C\text{-}F}$ = 23.1 Hz, 2C), 37.1, 25.9 ppm ;
IR (v, cm^{-1}) : 3061, 3026, 2924, 2857, 1603, 1510, 1453, 1444, 1385, 1218, 1153, 1087, 1070, 963, 909, 836, 819, 773, 731, 696 ;
MS (ESI) *m/z* : 343 $[M + H]^+$;
HRMS (ESI) *m/z* calcd for $C_{23}H_{19}FN_2$ $[M+H]^+$: 343.1611; found: 343.1607.

- *tert*-butyl *N*-[(1,5-diphenyl-1H-pyrazol-4-yl)methyl]carbamate (**6e**)

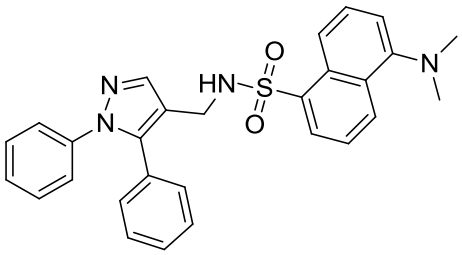


M = 349.43 g/mol
$C_{21}H_{23}N_3O_2$

Compound **6e** was obtained in 42% yield, 16 mg (red oil) from **3j** (40 mg, 0.11 mmol) and phenylboronic acid (17 mg, 0.14 mmol) using general procedure **D** and purified by column chromatography (Heptane/Ethyl acetate : 7/3).

^{1}H NMR ($CDCl_3$, 400MHz): δ = 7.77 (s, 1 H), 7.35–7.34 (m, 3 H), 7.29–7.16 (m, 7H), 4.66 (br. s, 1 H), 4.21 (d, *J* = 4.2 Hz, 2 H), 1.45 (s, 9 H) ppm ;
^{13}C NMR ($CDCl_3$, 101MHz): δ = 155.5, 140.4, 140.2, 139.8, 129.8 (2C), 129.5, 128.7 (2C), 127.1, 124.7 (2C), 118.7, 79.6, 34.9, 28.3 (3C) ppm ;
IR (v, cm^{-1}):3334, 3056, 2976, 2930, 1693, 1597, 1503, 118, 1384, 1365, 1268, 1248, 1165, 1069, 1046, 1021, 963, 914, 864, 772, 762, 736, 698 ;
MS (ESI) *m/z* 350 $[M + H]^+$;
HRMS (ESI) *m/z* calcd for $C_{21}H_{23}N_3O_2$ $[M+H]^+$: 350.1869; found: 350.1860.

- 5-(dimethylamino)-N-[(1,5-diphenyl-1H-pyrazol-4-yl)methyl]naphthalene-1-sulfonamide (**6f**)

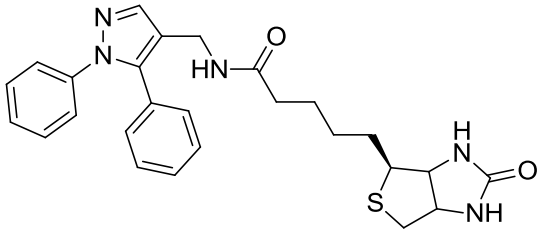


M = 482.60 g/mol
$C_{28}H_{26}N_4O_2S$

Compound **6f** was obtained with 55 % yield, 40 mg (bright yellow solid) from **3p** (74 mg, 0.15 mmol) and phenylboronic acid (22 mg, 0.18 mmol) using general procedure **D** and purified by column chromatography (Heptane/Ethyl acetate : 7/3).

Mp : 181–183 °C ;
^{1}H NMR ($CDCl_3$, 400MHz): δ = 8.55–8.53 (d, *J* = 8.3 Hz, 1 H), 8.24–8.20 (m, 2 H), 7.57–7.53 (dd, *J* = 8.3 Hz, 8.2 Hz, 1 H), 7.51–7.47 (dd, *J* = 8.0 Hz, 7.7 Hz, 1 H), 7.36 (s, 1 H), 7.24–7.20 (m, 5 H), 7.11–7.05 (m, 4 H), 6.86 (d, *J* = 7.2 Hz, 2 H), 4.72–4.70 (t, *J* = 5.7 Hz, 1 H), 4.00–3.97 (d, *J* = 5.7 Hz, 2 H), 2.90 (s, 6 H) ppm ;
^{13}C NMR $CDCl_3$, 101MHz): δ = 140.8, 140.3, 139.5, 134.2, 130.6, 129.9, 129.8, 129.5, 129.4 (2C), 128.7, 128.6 (2C), 128.5, 128.48 (2C), 128.43, 127.2, 124.7 (2C), 123.1, 118.6, 116.2, 115.9, 115.1, 45.4 (2C), 37.7 ppm ;
IR (v, cm^{-1}): 1574, 1504, 1450, 1385, 1329, 1229, 1161, 1141, 1060, 962, 948, 836, 785, 696, 624 ;
MS (ESI) *m/z* : 483 $[M + H]^+$;
HRMS (ESI) *m/z* calcd for $C_{28}H_{26}N_4O_2S$ $[M+H]^+$: 483.1855; found: 483.1855.

- N-[(1,5-diphenyl-1H-pyrazol-4-yl)methyl]-5-{2-methylidene-hexahydro-1H-thieno[3,4-d]imidazolidin-4-yl}pentanamide (**6g**)

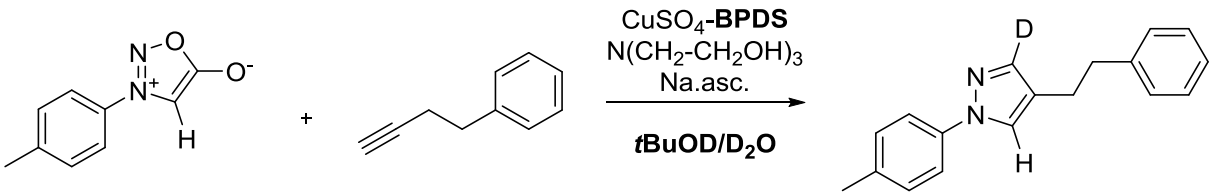


M = 475.61 g/mol
$C_{26}H_{29}N_5O_2S$

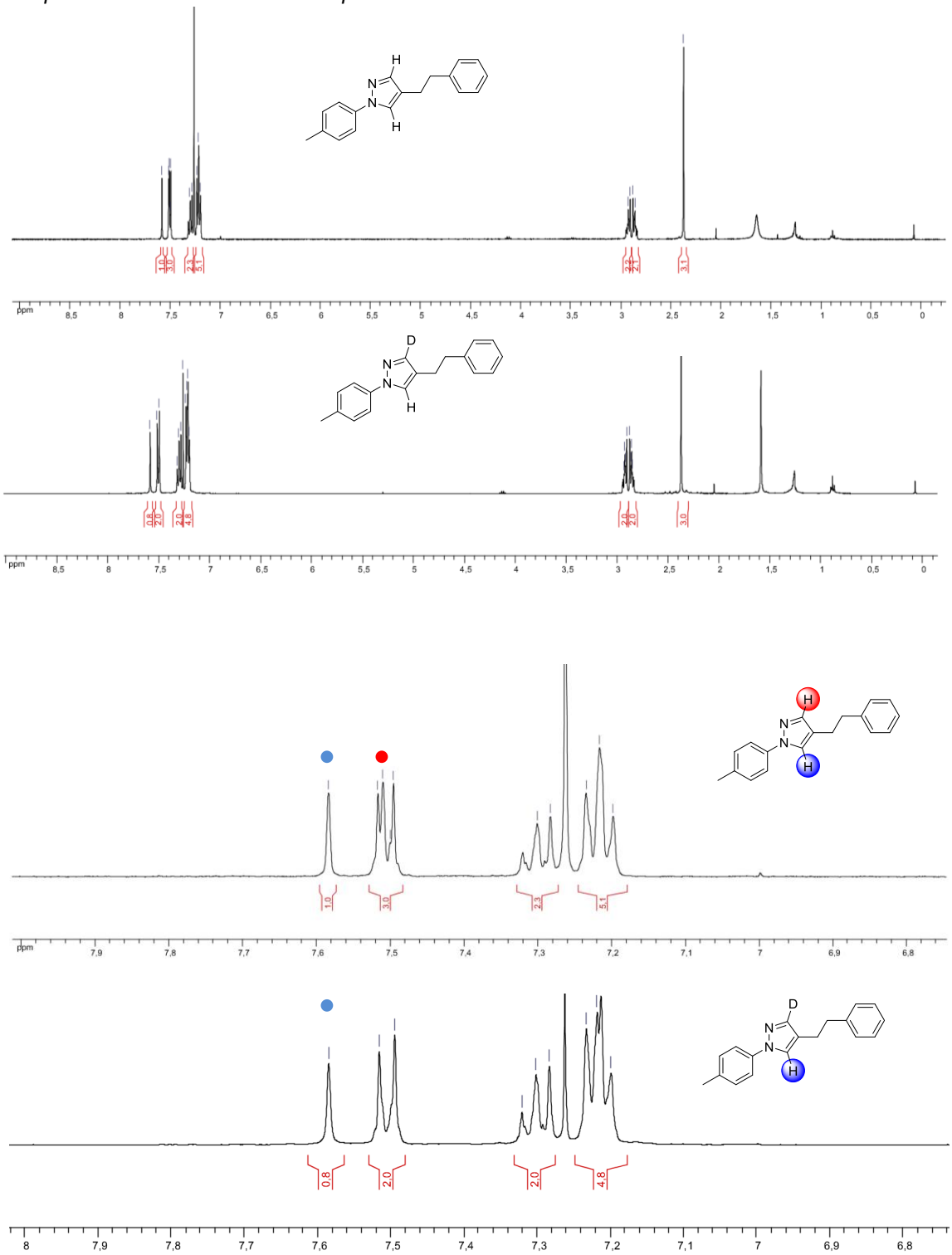
Compound **6g** was obtained in 34% yield, 25 mg (white oil) from **3n** (75 mg, 0.16 mmol) and phenylboronic acid (23 mg, 0.19 mmol) using general procedure **D** and purified by column chromatography (Ethyl acetate/Methanol : 9/1).

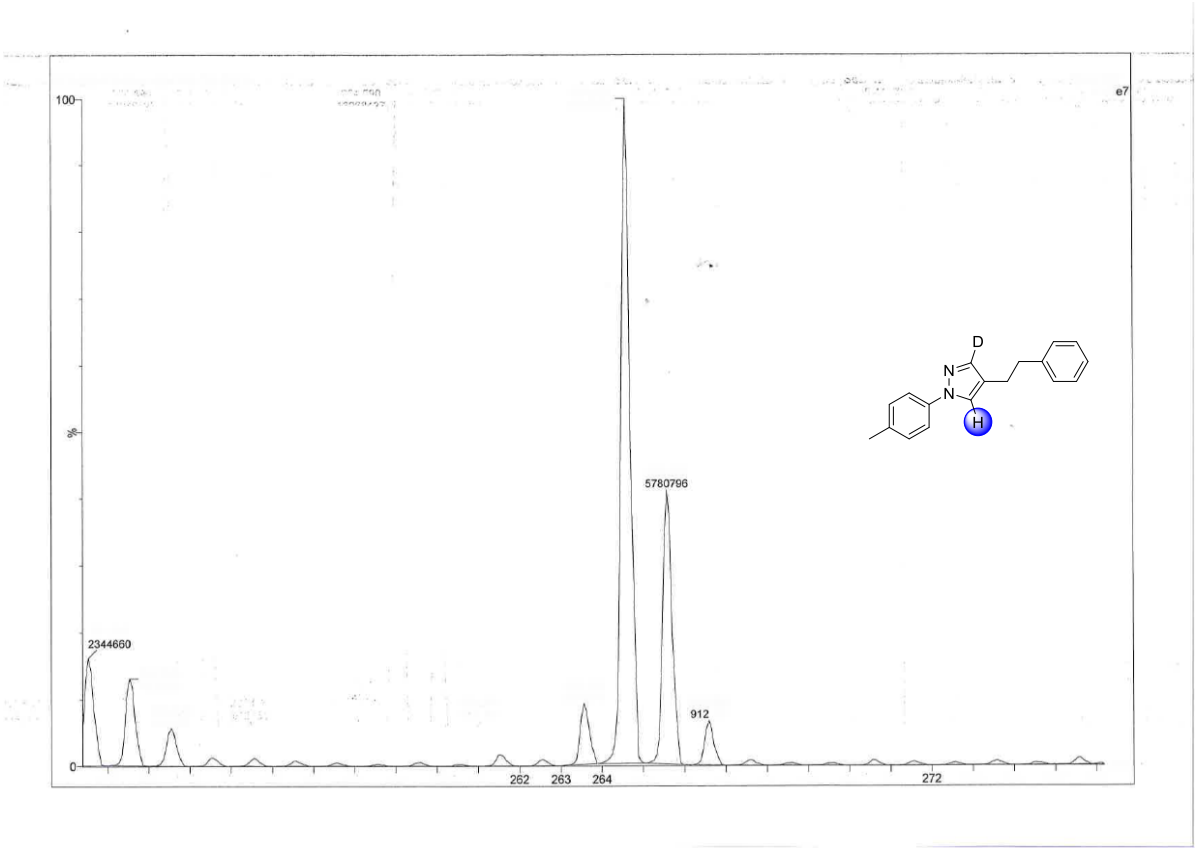
^{1}H NMR (MeOD, 400MHz): δ = 8.42 (br. S, 2 H), 7.77 (s, 1 H), 7.38–7.30 (m, 6 H), 7.25–7.19 (m, 4 H), 4.49–4.46 (m, 1 H), 4.30–4.27 (m, 1 H), 4.25 (d, *J* = 1.9 Hz, 2 H), 3.21–3.16 (m, 1 H), 2.92 (dd, *J* = 5.0, 13 Hz, 1 H), 2.71–2.68 (d, *J* = 13 Hz, 1 H), 2.19 (t, *J* = 7.3 Hz, 2 H), 1.77–1.54 (m,6 H), 1.45–1.37 (m, 2 H) ppm ;
^{13}C NMR (MeOD, 101MHz): δ = 174.3, 164.6, 141.1, 140.0, 139.5, 129.7 (2C), 129.2, 128.5 (2C), 128.4, 128.3 (2C), 127.4, 125.0 (2C), 118.2, 61.9, 60.2, 55.5, 39.6, 35.1, 33.1, 28.3, 28.0, 25.3 ppm ;
IR (v, cm^{-1}): 3357, 2479, 2242, 2071, 1671, 1451, 119, 972, 822 ;
MS (ESI) *m/z* : 476 $[M + H]^+$;
HRMS (ESI) *m/z* calcd for $C_{26}H_{29}N_5O_2S$ $[M+H]^+$: 476.2120 ; found: 476.2118.

Mechanism study of the CuSAC reaction



This experiment was conducted with procedure B in deuterated solvents.





	M+1	M+2 (1D)	M+3 (2D)	M+4 (3D)	M+5 (4D)	M+6 (5D)
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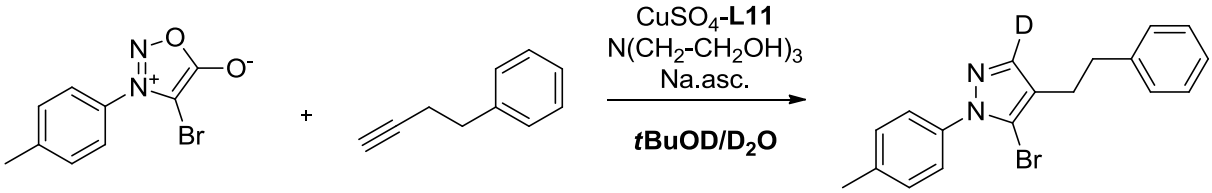
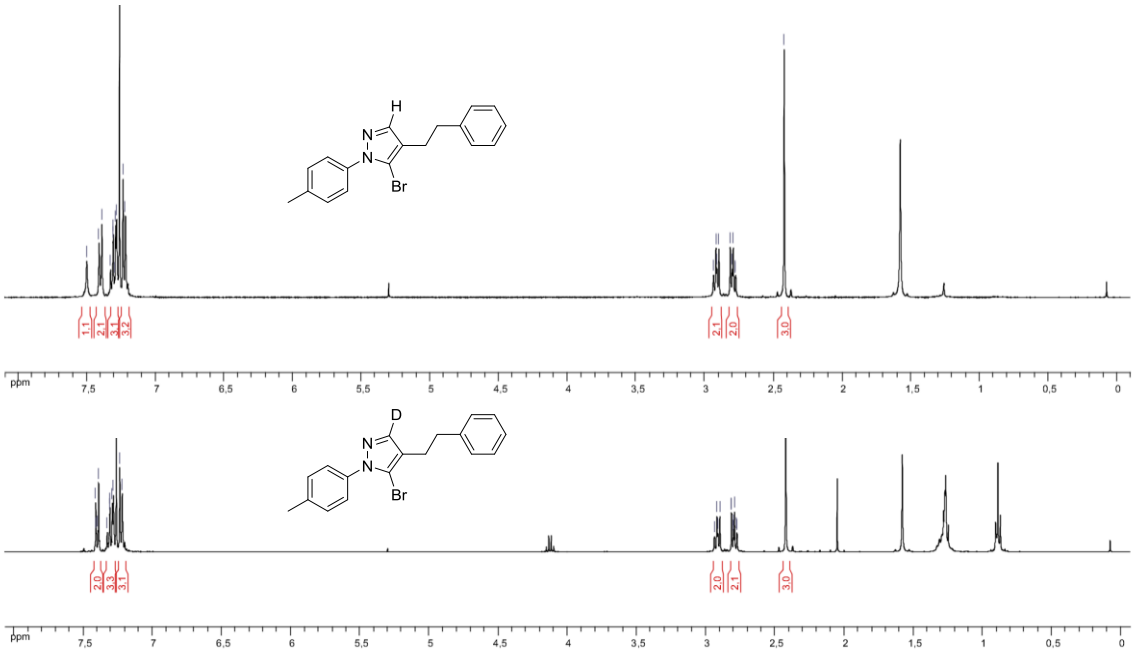
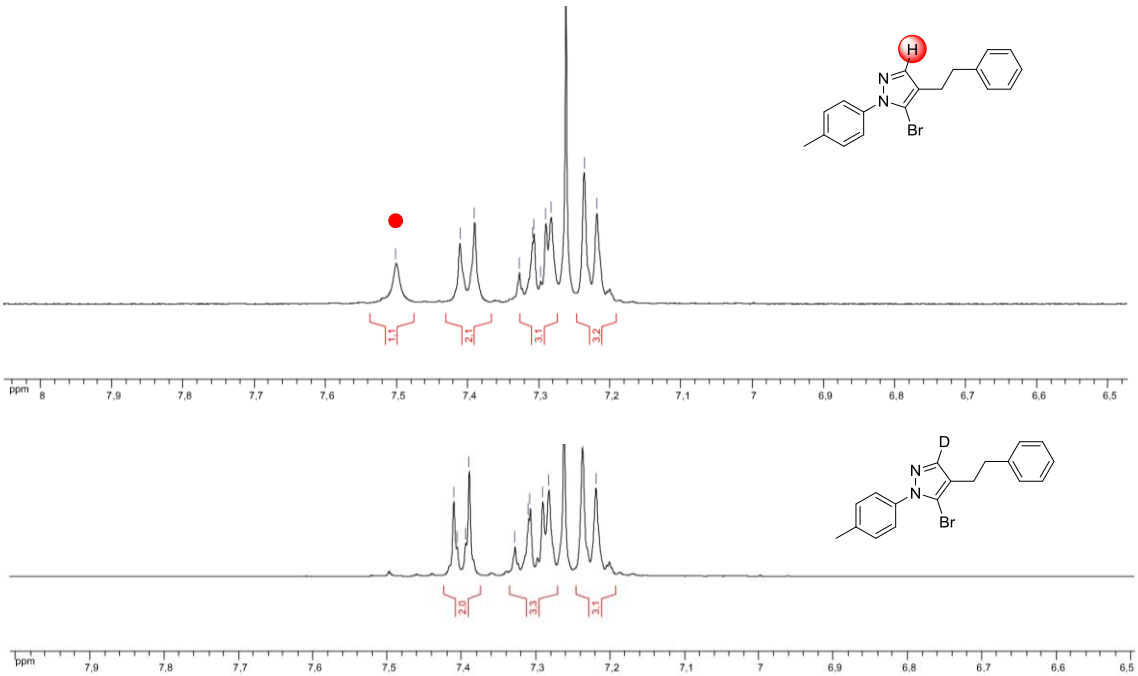
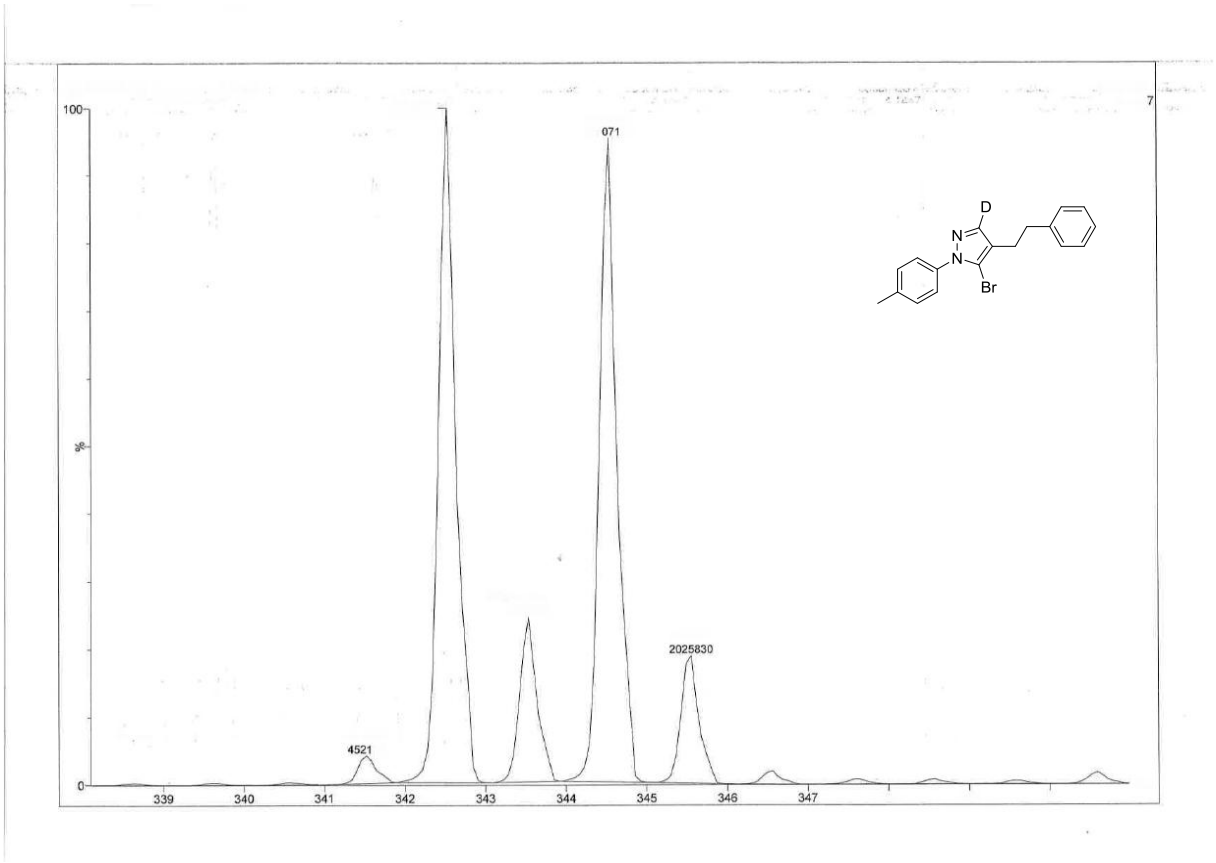
area tot	1274248	13968427	5780796	912161		
Σ contrib	0	262495	2848907	878088	65657	-12844
area D	0	13705932	2931889	34073	-65657	12844
% D	0	76,6%	16,4%	0,2%	-0,4%	0,1%



This experiment was conducted with procedure B using deuterated solvents.

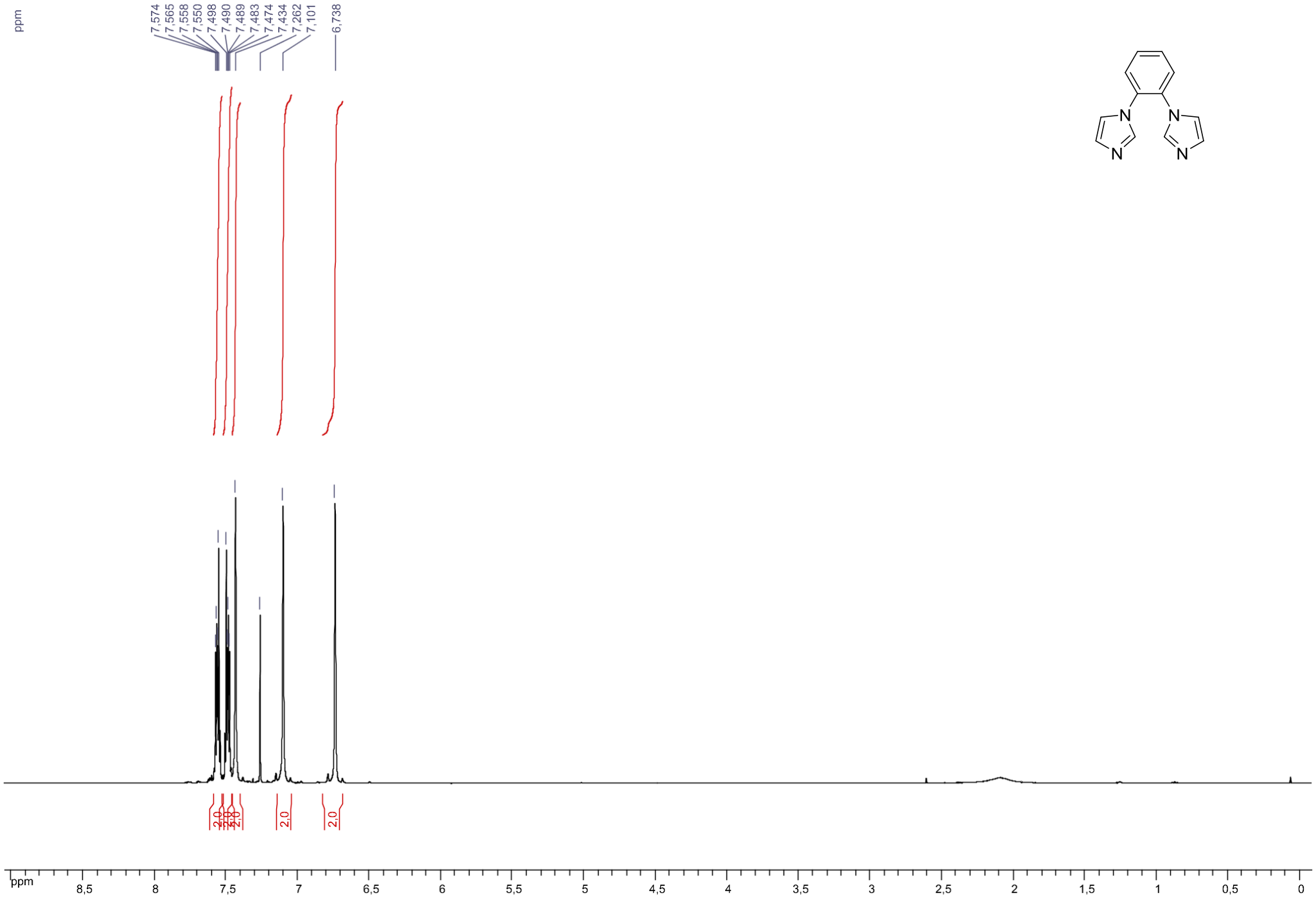






	M+1	M+2 (1D)	M+3 (2D)	M+4 (3D)	M+5 (4D)	M+6 (5D)
	341	342	343	344	345	346
area tot	452107	10438404	2513561	10107113	2025830	209610
Σ contrib	0	92230	2557301	10304377	2005435	-199568
area D	0	10346174	-43740	-197264	20395	409178
% D	0	97,3%	-0,4%	-1,9%	0,2%	3,8%

NMR spectra of Imidazoquinoxalines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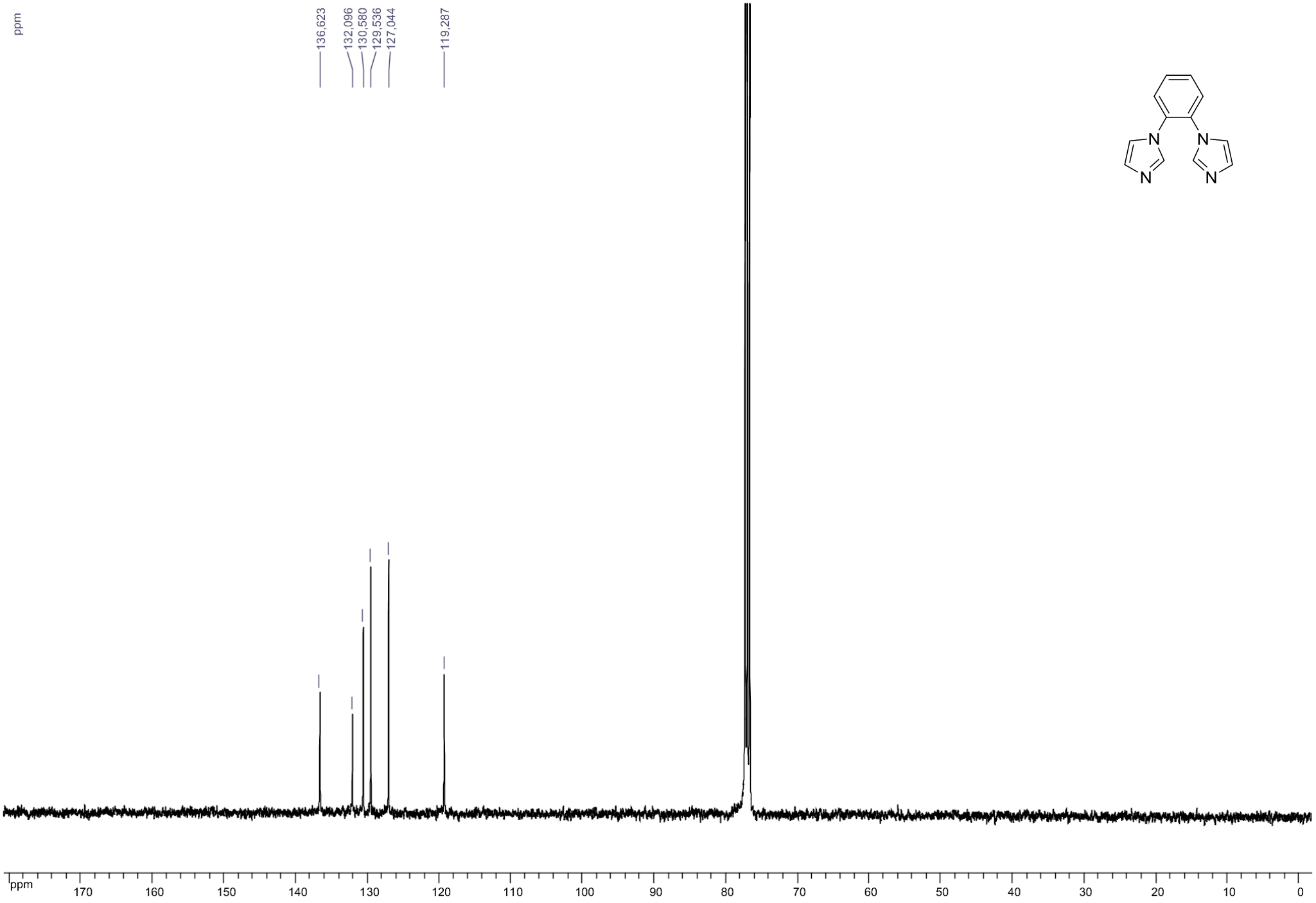
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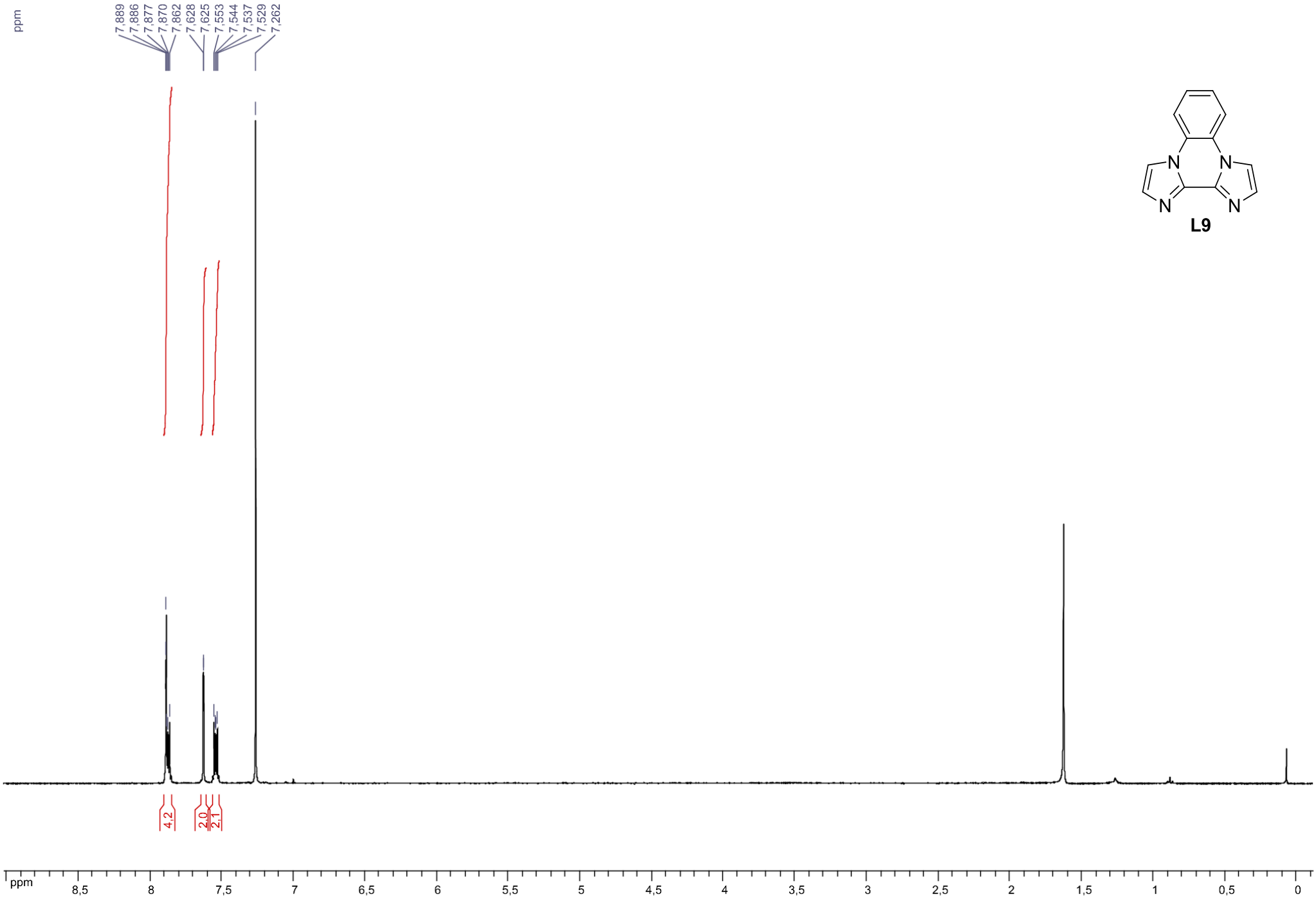
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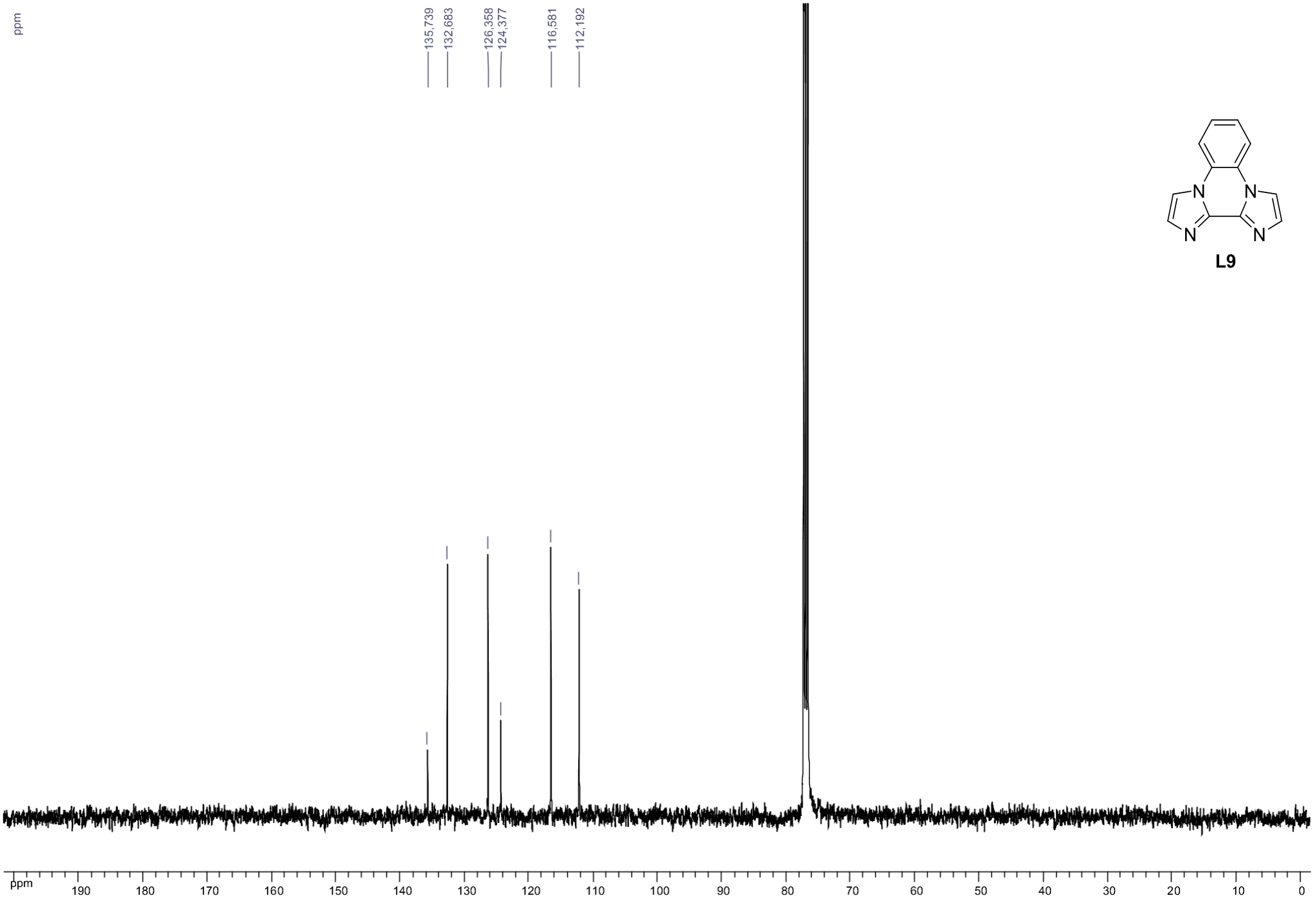
L9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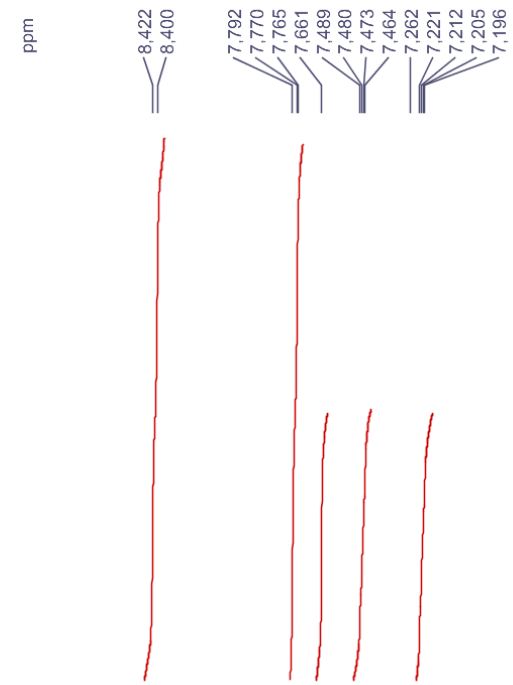
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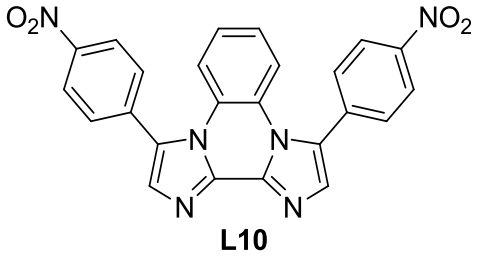
O2N
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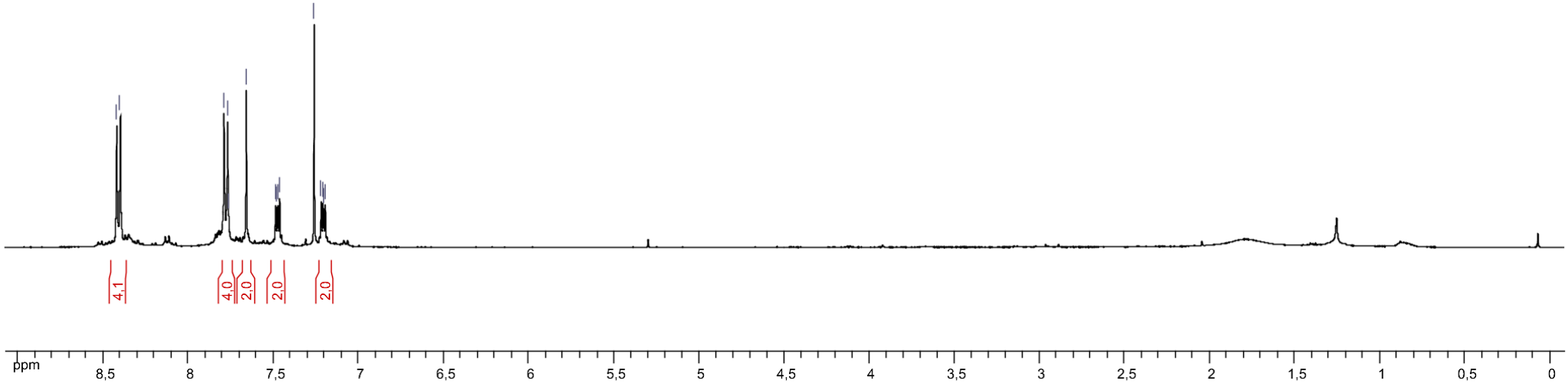
L10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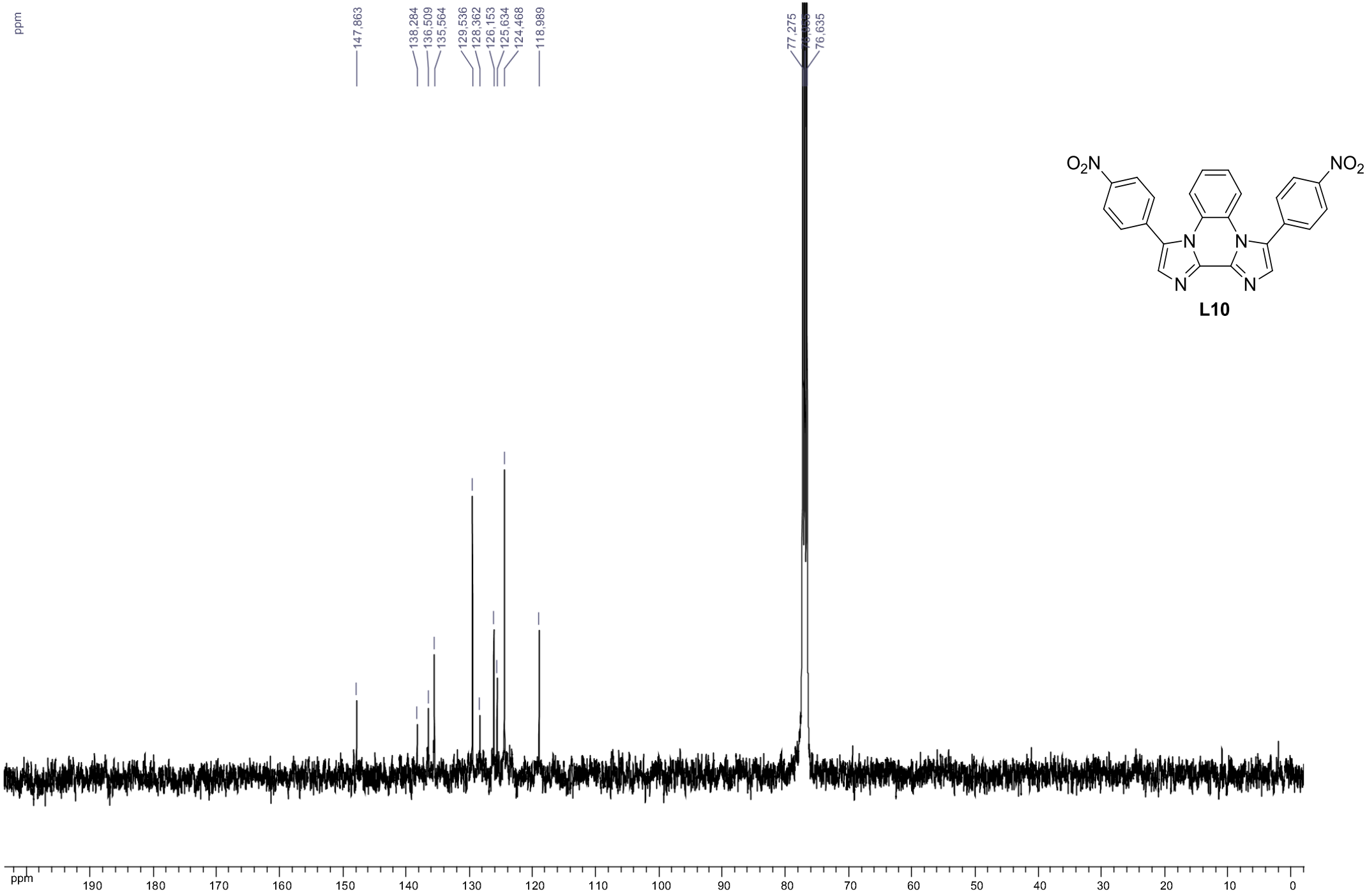
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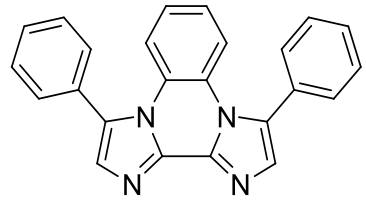
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0

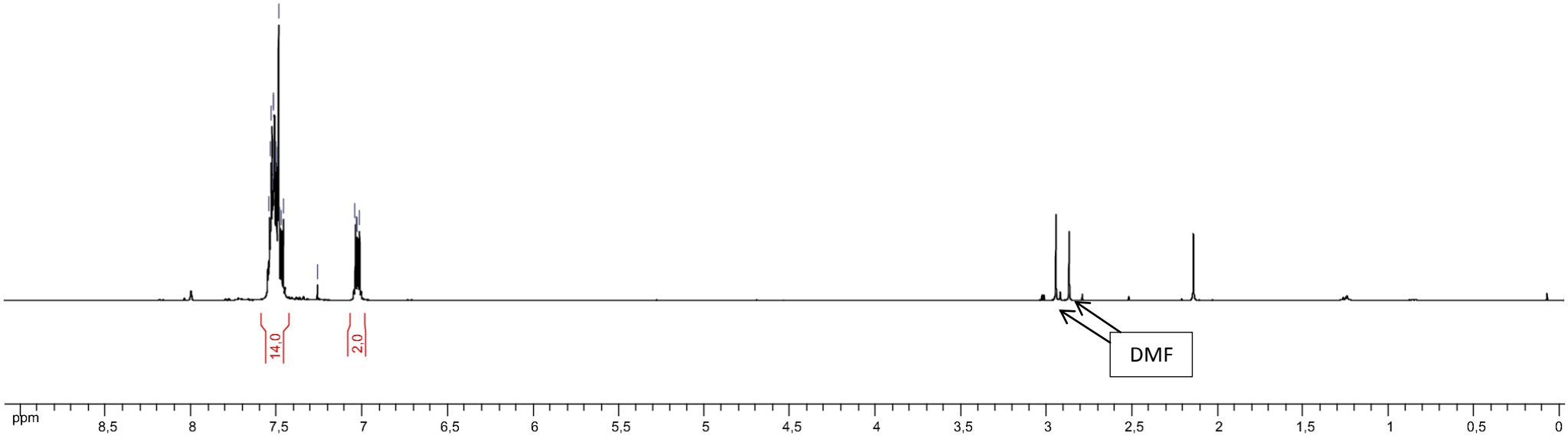
O2N
NO2
N
N
N
N

L10


ppm
7,542
7,532
7,527
7,522
7,518
7,514
7,513
7,504
7,501
7,495
7,490
7,478
7,470
7,462
7,262
7,040
7,032
7,024
7,016


N
N
N
N

L11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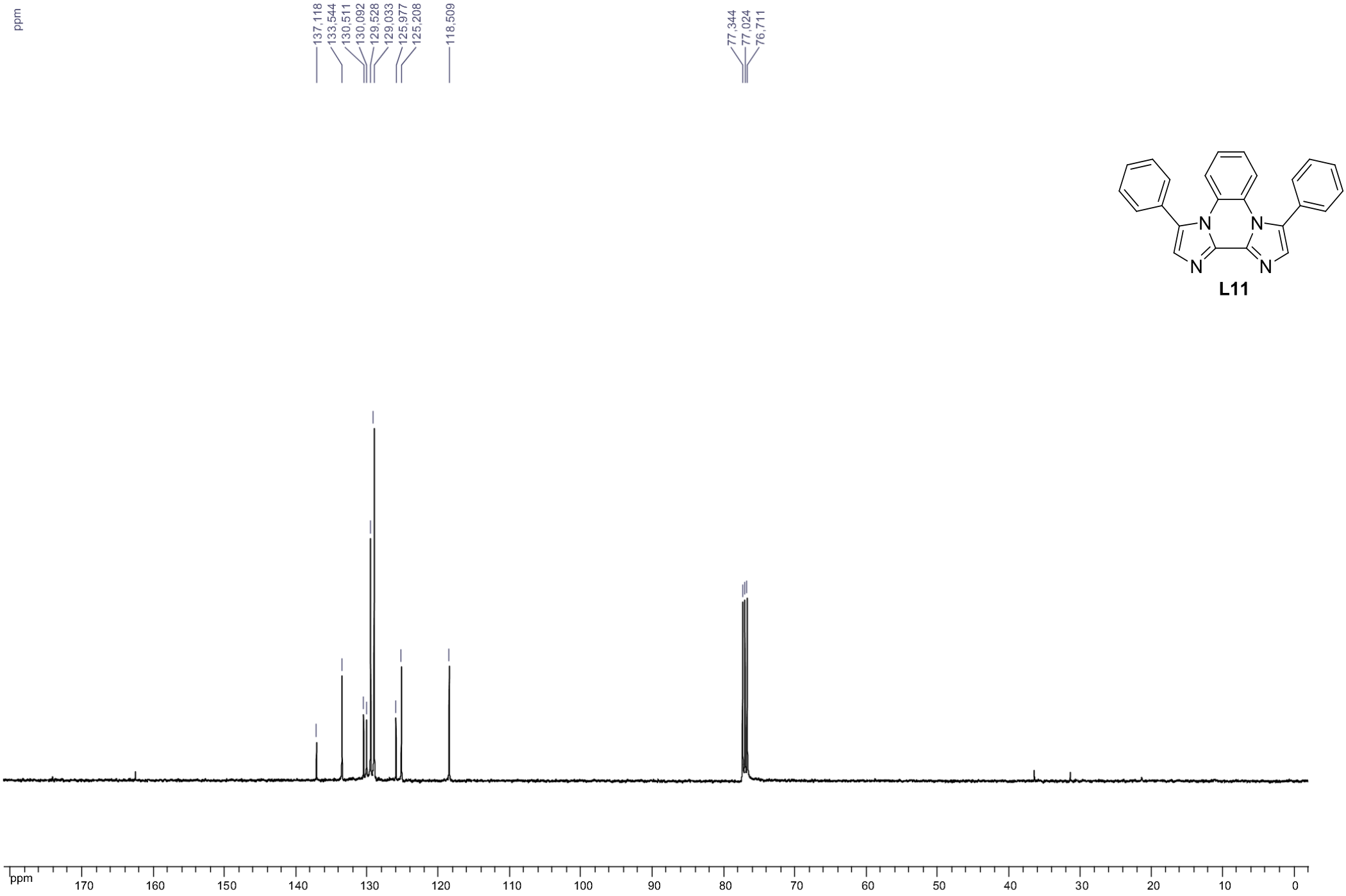
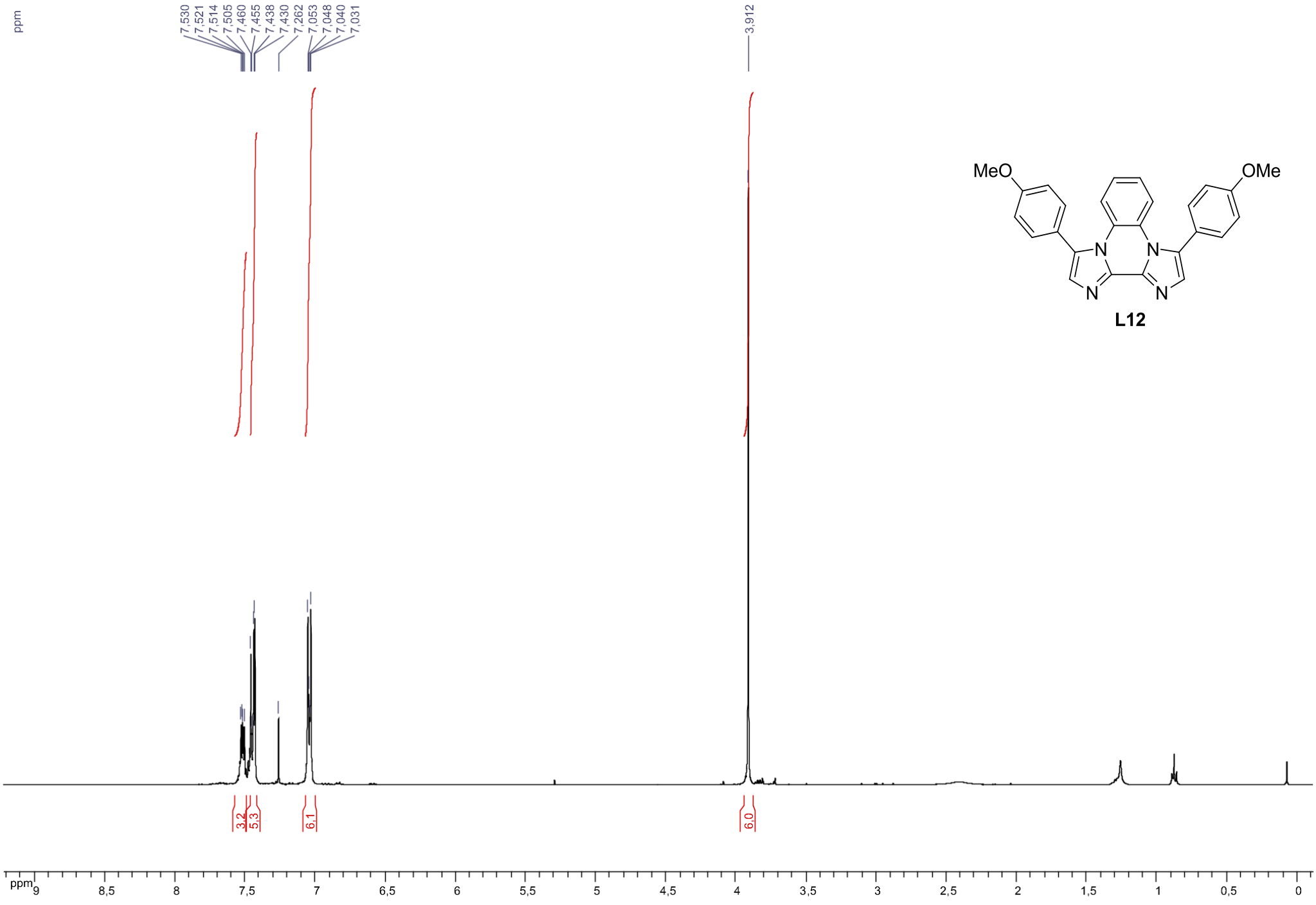
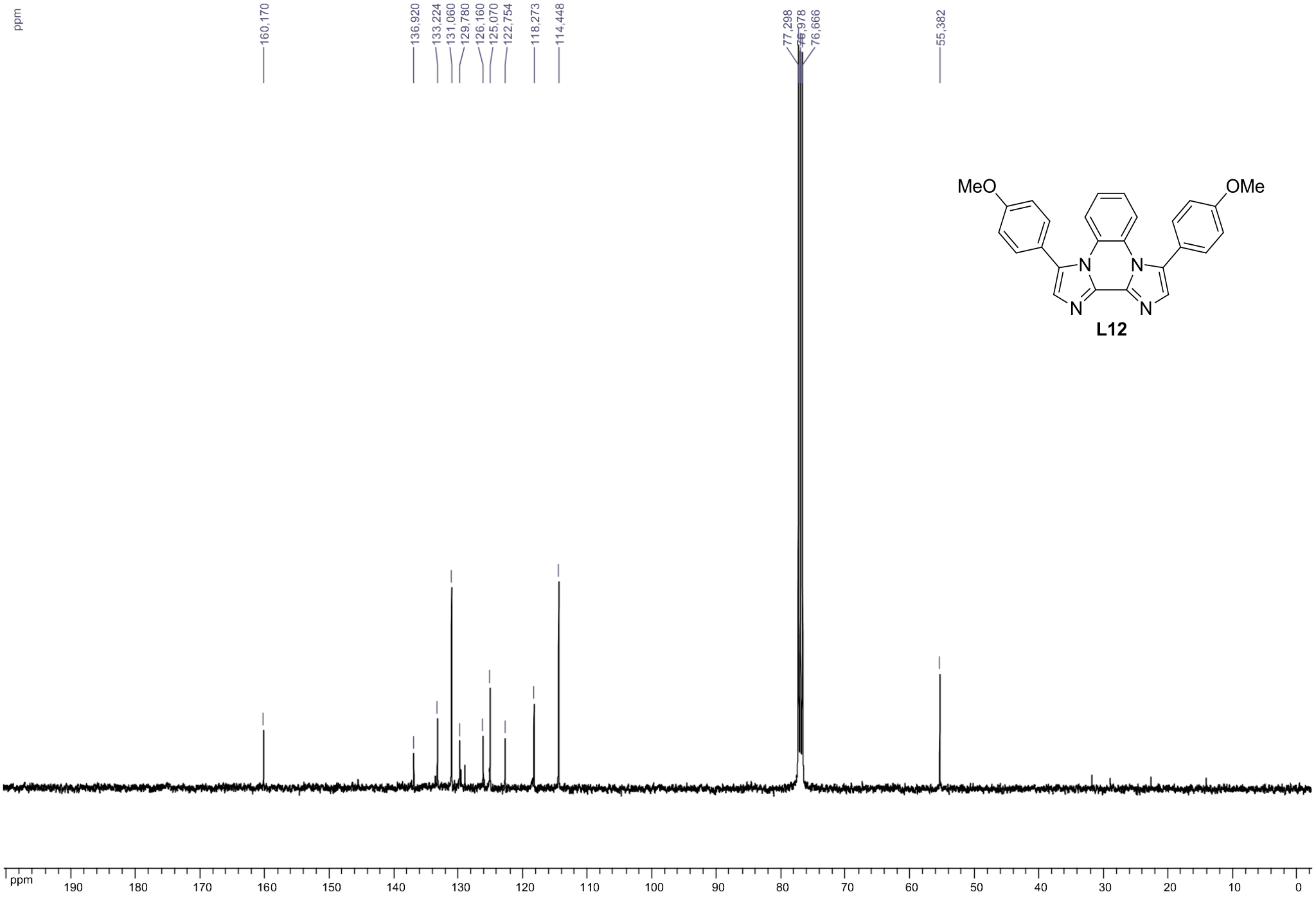
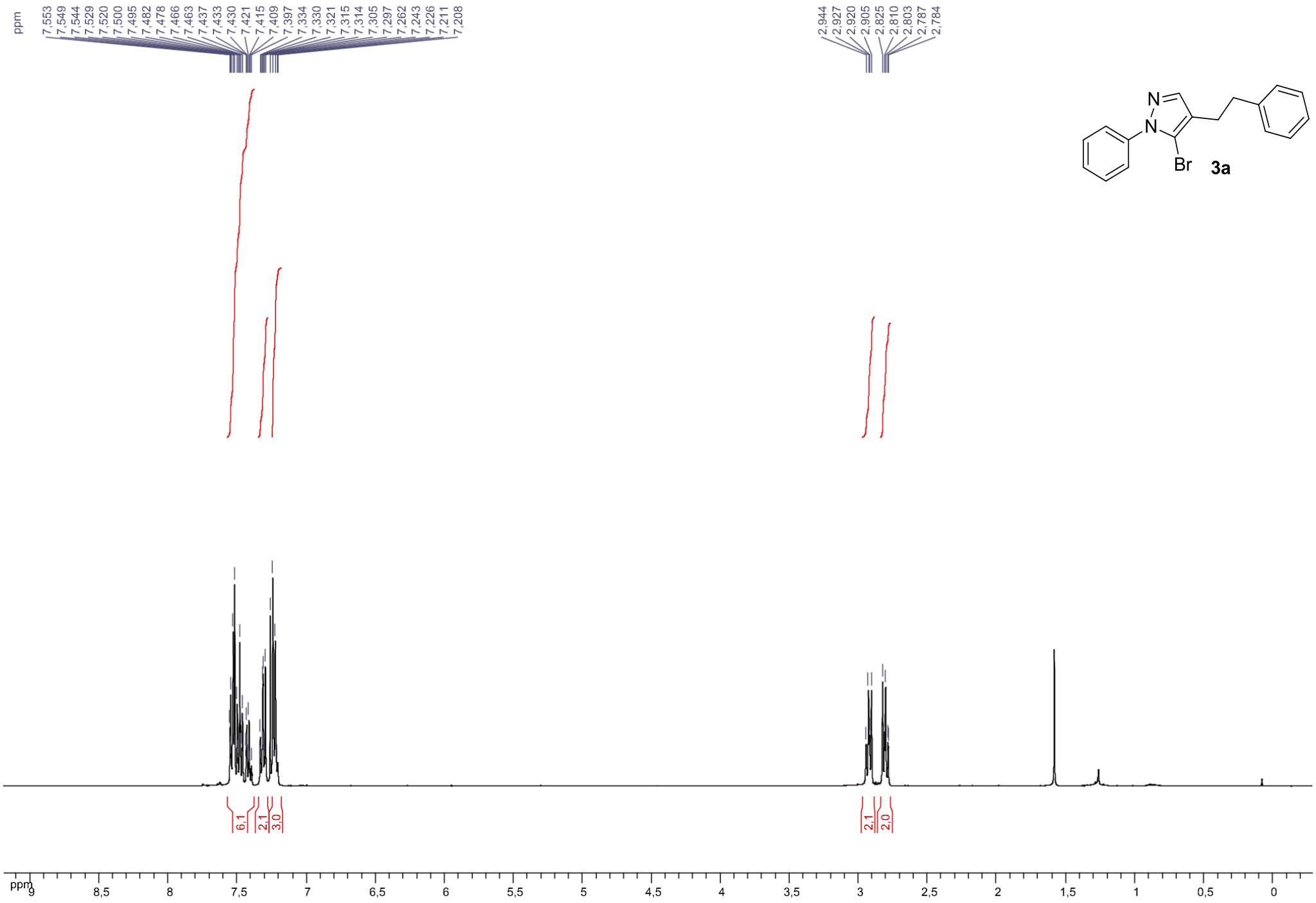
2,0
DMF
ppm
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0

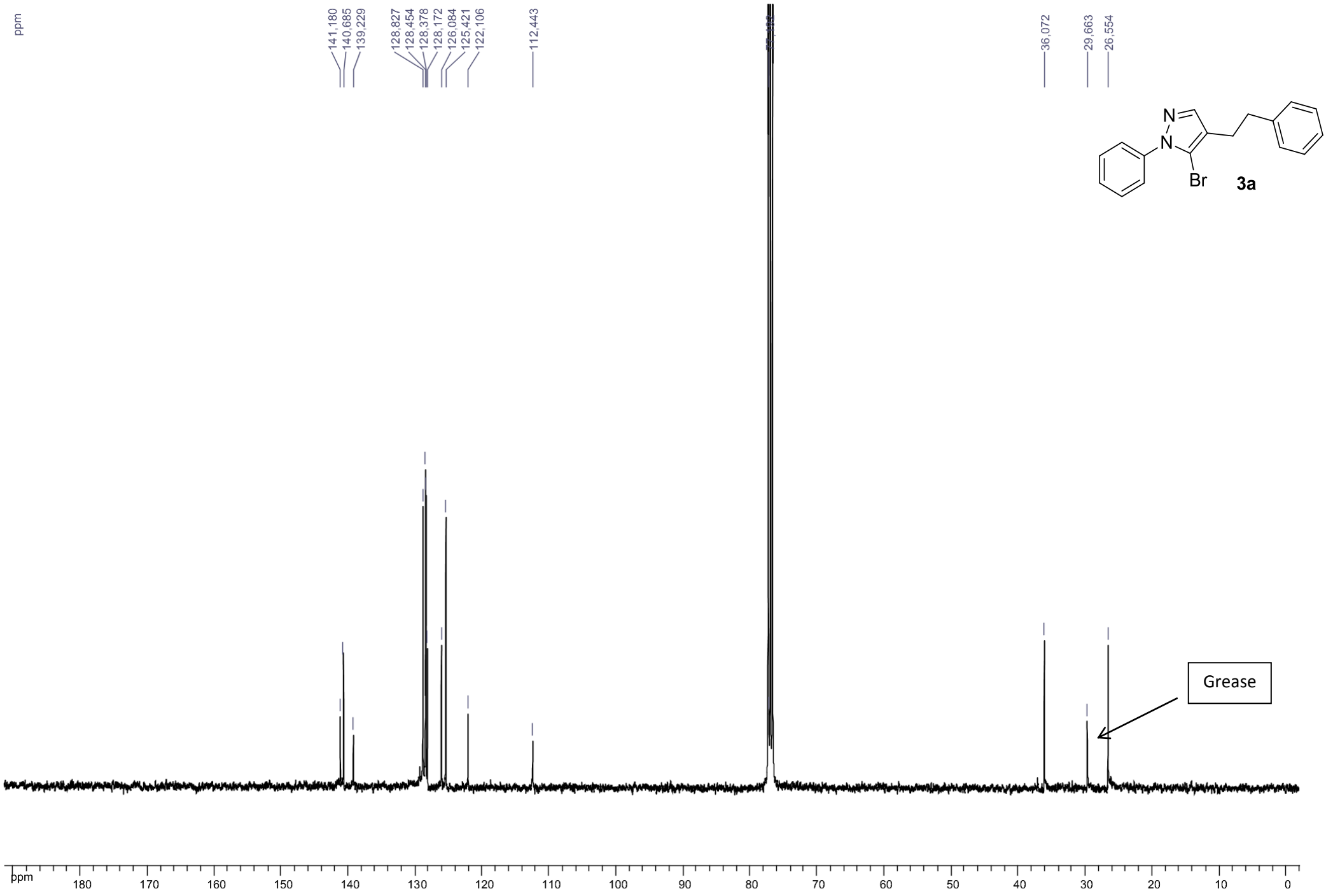

ppm
137,118
133,544
130,511
130,092
129,528
129,033
125,977
125,208
118,509
77,344
77,024
76,711
N
N
N
N
L11
ppm
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0

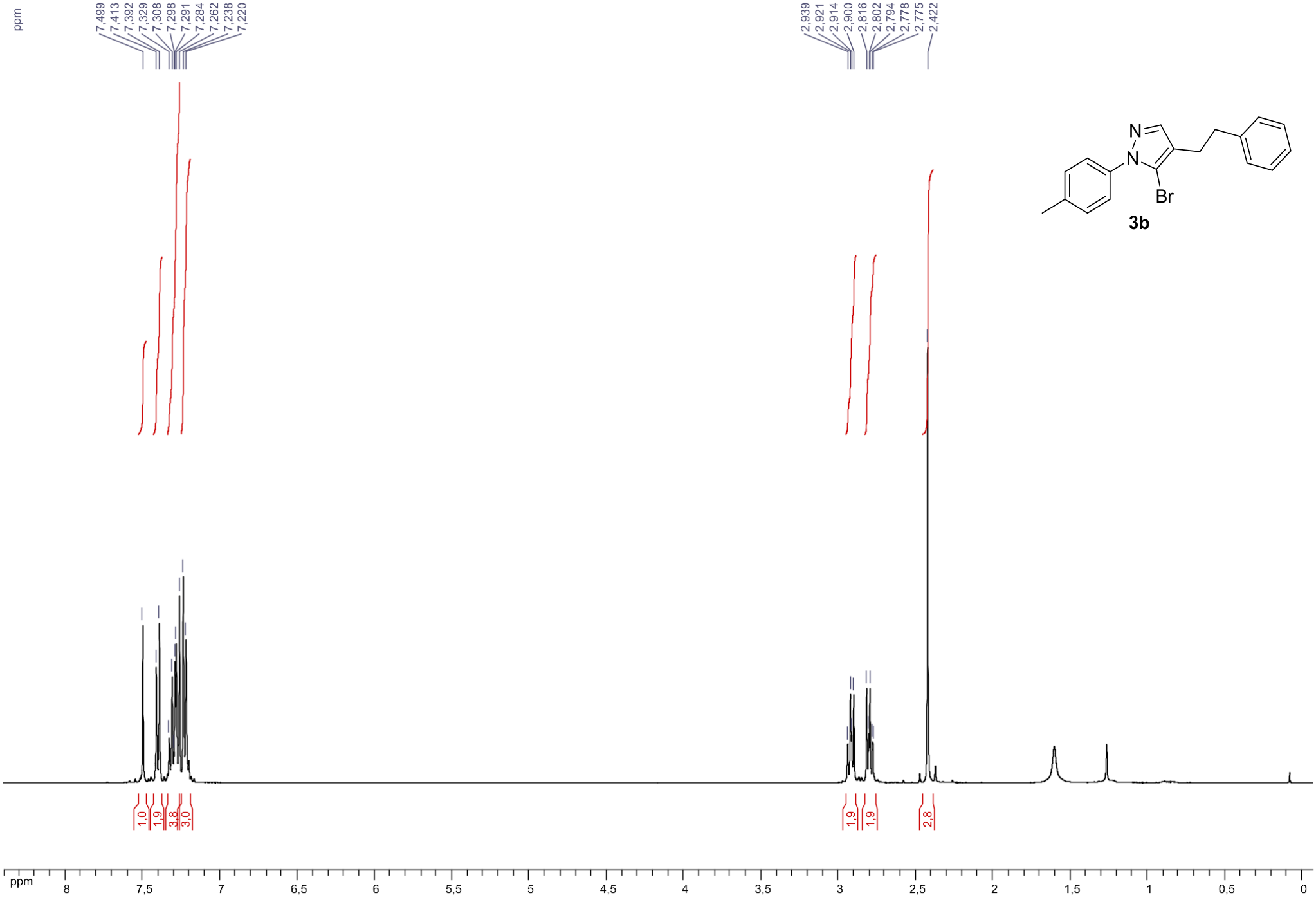

ppm
7,530
7,521
7,514
7,505
7,460
7,455
7,438
7,430
7,262
7,053
7,048
7,040
7,031
3,912
MeO
OMe
N
N
N
N
L12
3,2
5,3
6,1
6,0
ppm
9
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0

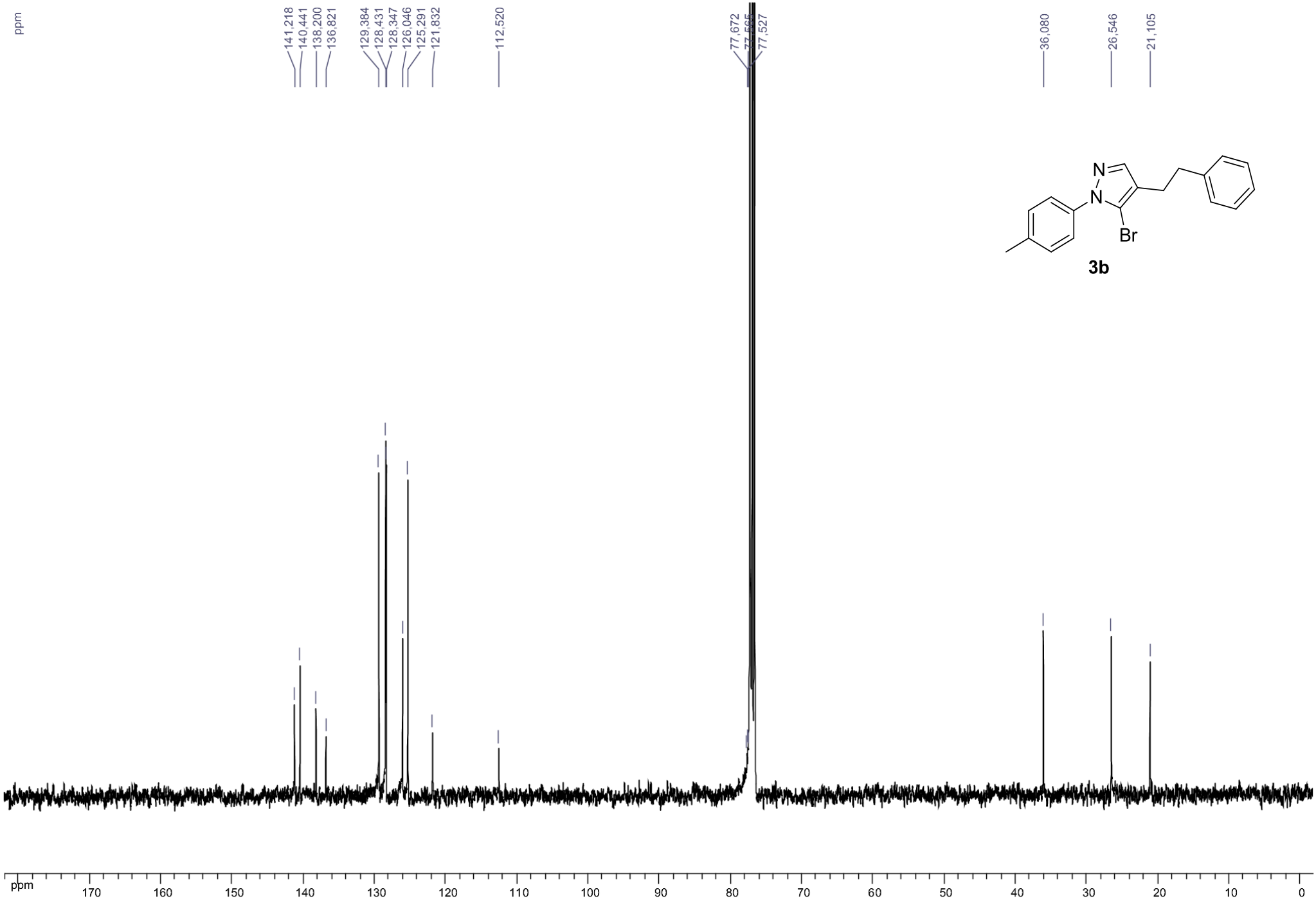

ppm
160,170
136,920
133,224
131,060
129,780
126,160
125,070
122,754
118,273
114,448
77,298
76,978
76,666
55,382
MeO
OMe
N
N
N
N
L12
ppm
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0

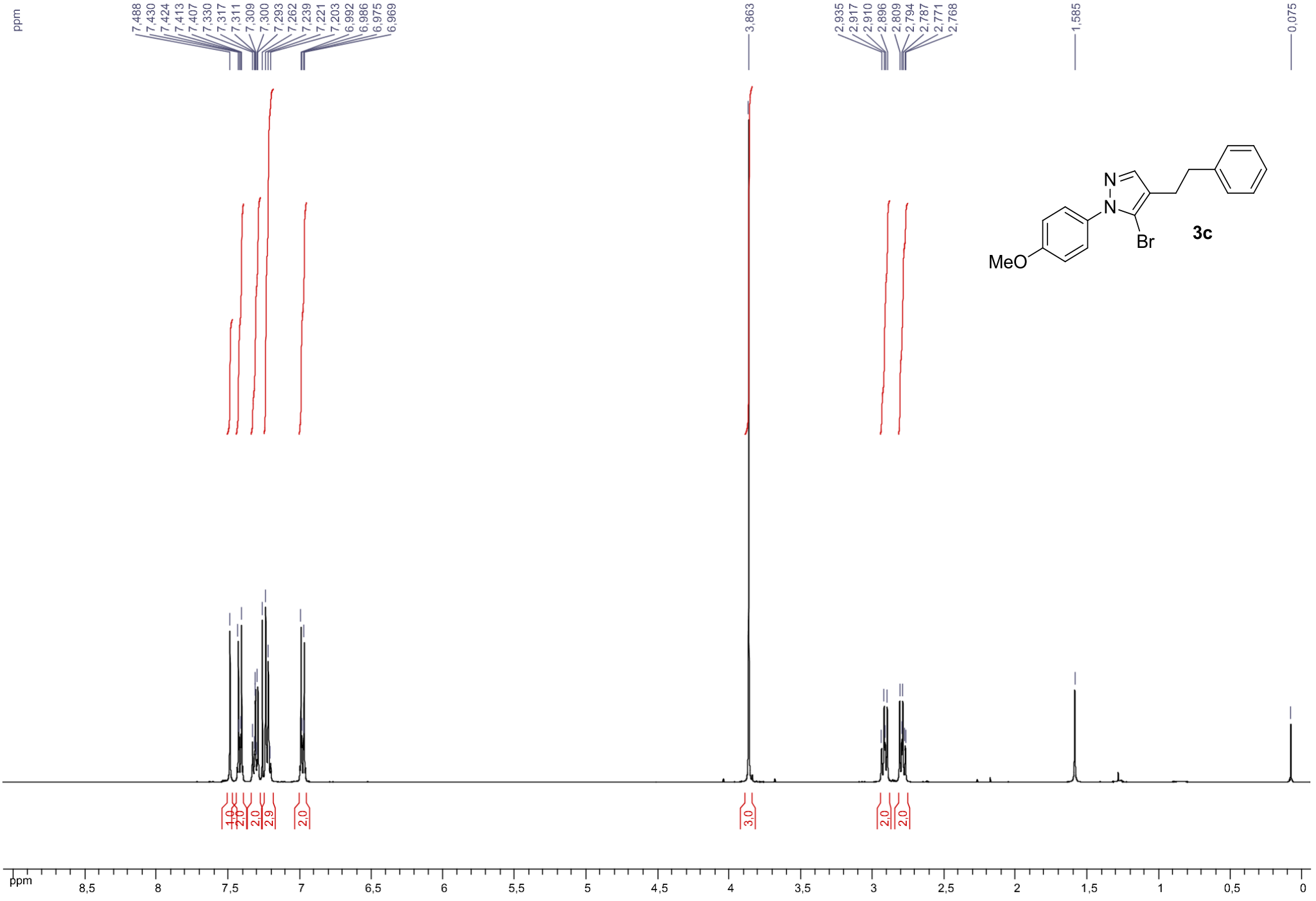
NMR spectra of Pyrazoles

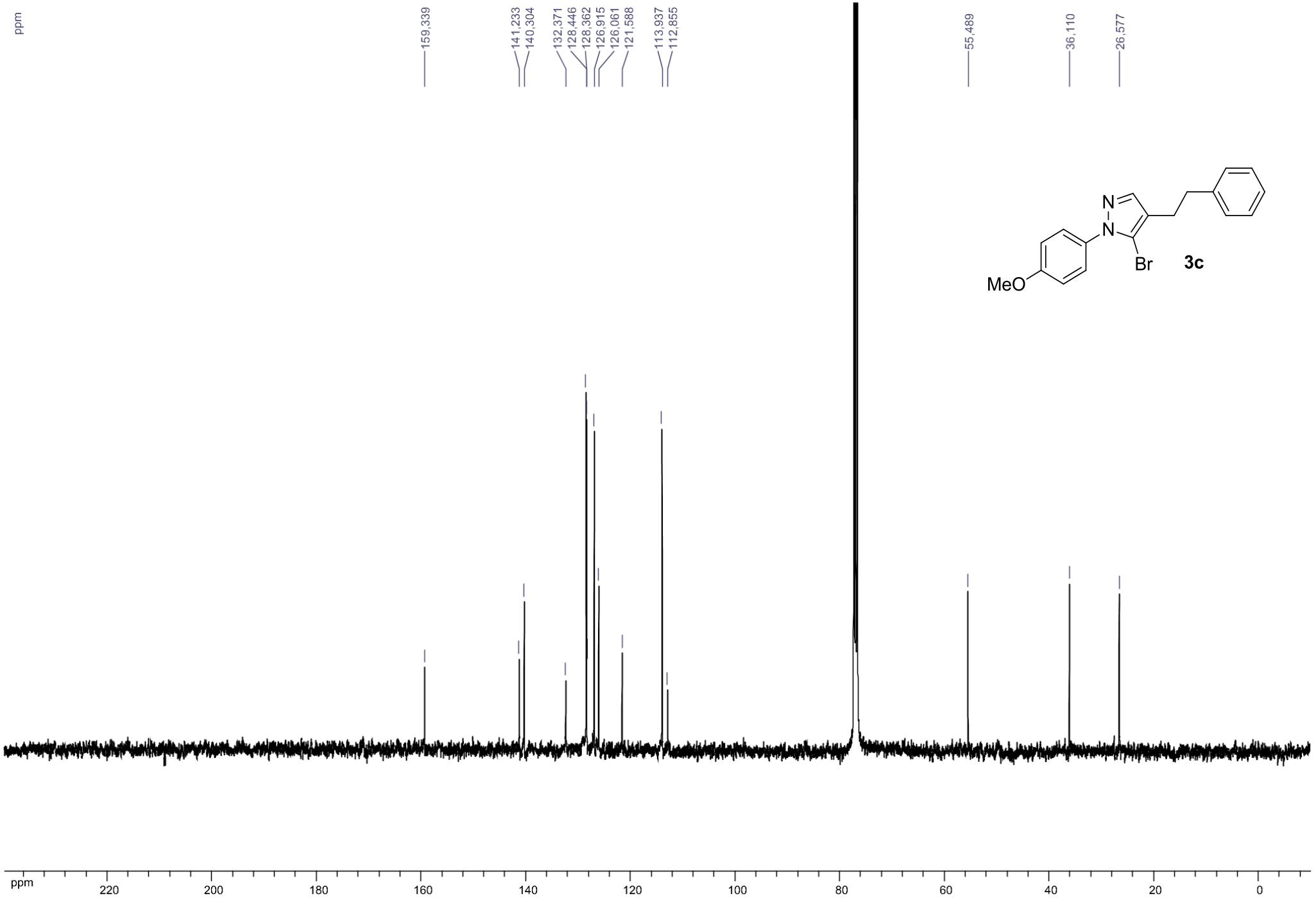

ppm
7,553
7,549
7,544
7,529
7,520
7,500
7,495
7,482
7,478
7,466
7,463
7,437
7,433
7,430
7,421
7,415
7,409
7,397
7,334
7,330
7,321
7,315
7,314
7,305
7,297
7,262
7,243
7,226
7,211
7,208
2,944
2,927
2,920
2,905
2,825
2,810
2,803
2,787
2,784
N
N
Br
3a
6,1
2,1
3,0
2,1
2,0
ppm
9
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0

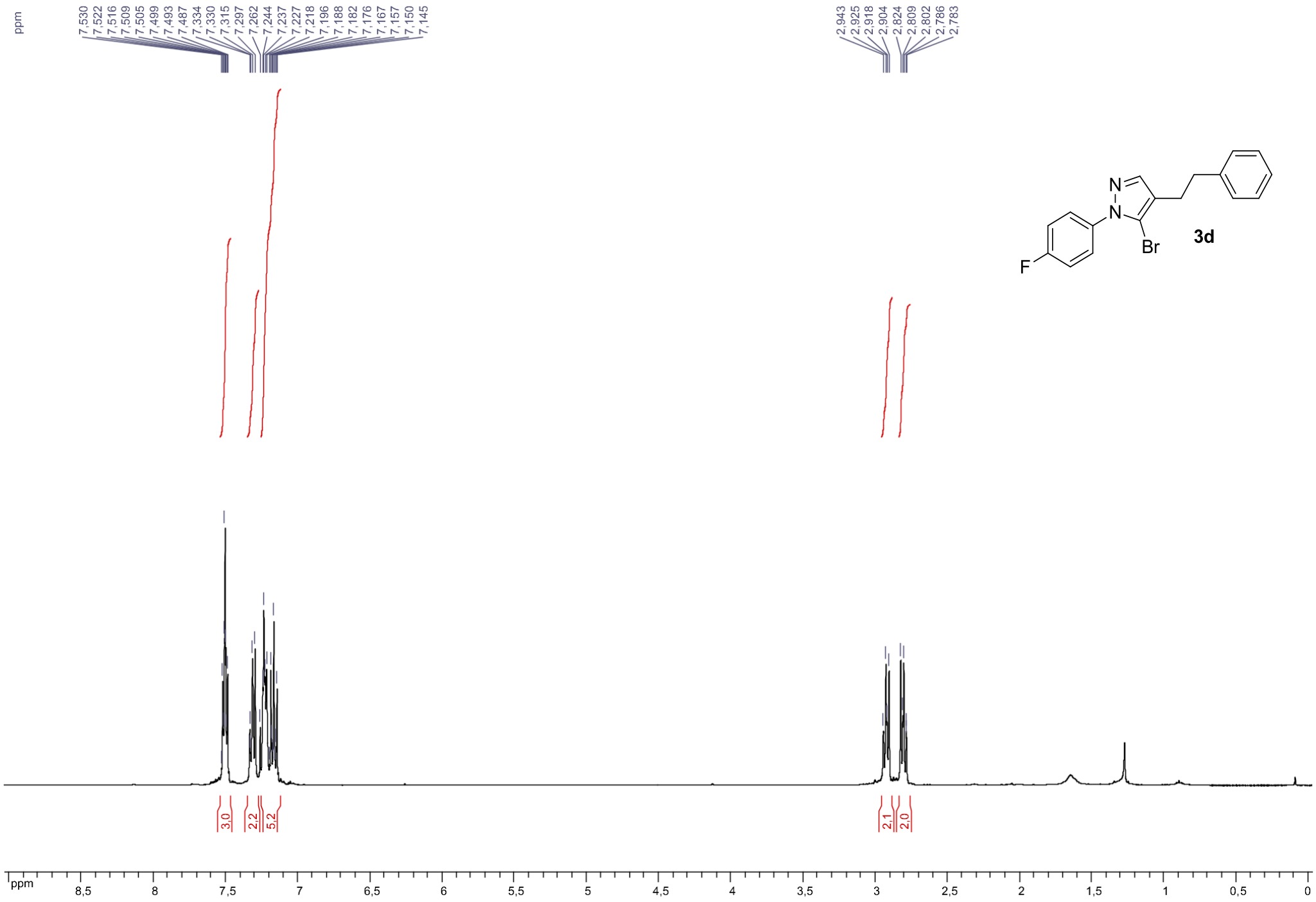

ppm
141,180
140,685
139,229
128,827
128,454
128,378
128,172
126,084
125,421
122,106
112,443
36,072
29,663
26,554
N
N
Br
3a
Grease
ppm
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0

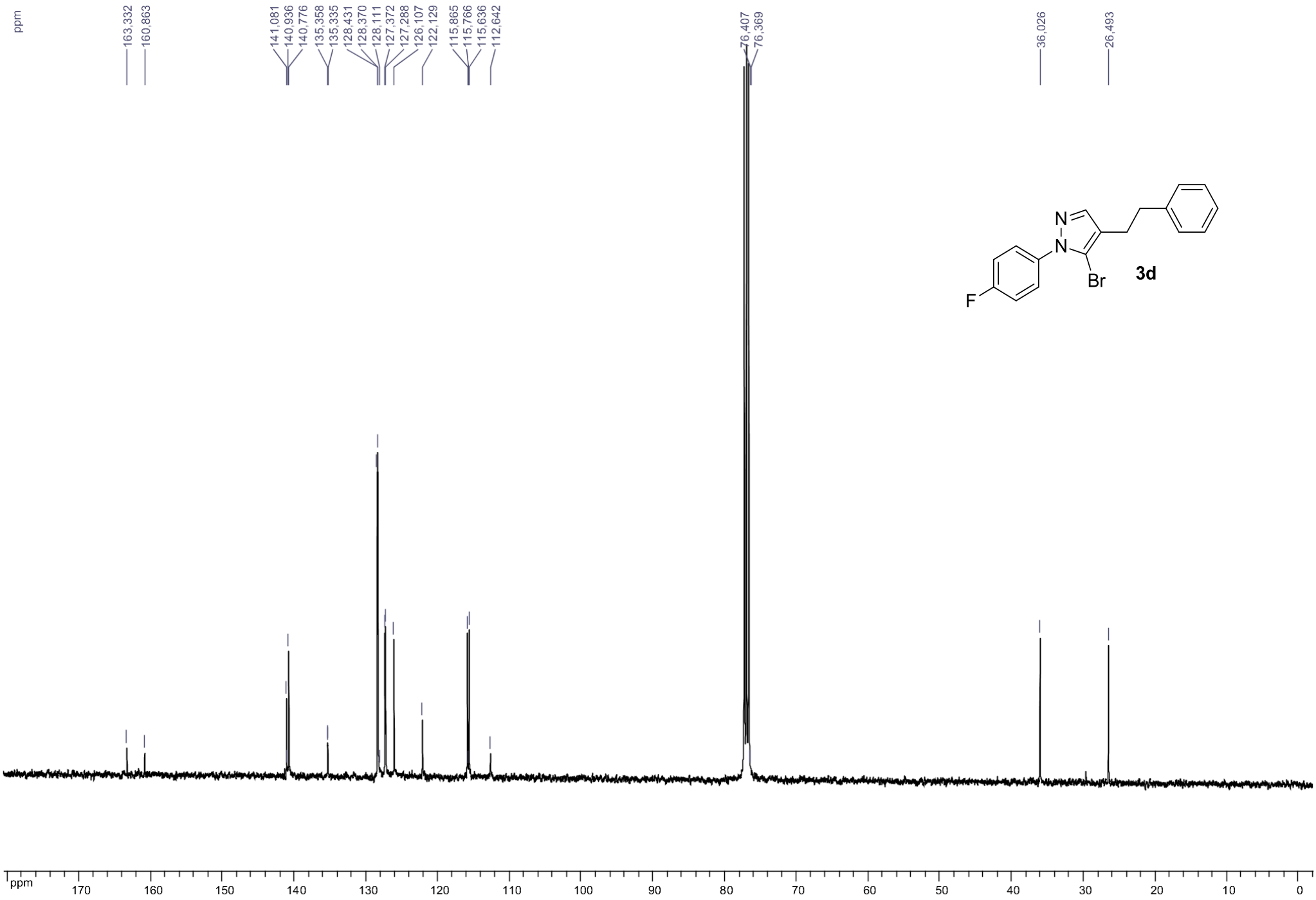

ppm
7.499
7.413
7.392
7.329
7.308
7.298
7.291
7.284
7.262
7.238
7.220
2.939
2.921
2.914
2.900
2.816
2.802
2.794
2.778
2.775
2.422
N
N
Br
3b
1,0
1,9
3,8
3,0
1,9
1,9
2,8
ppm
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0

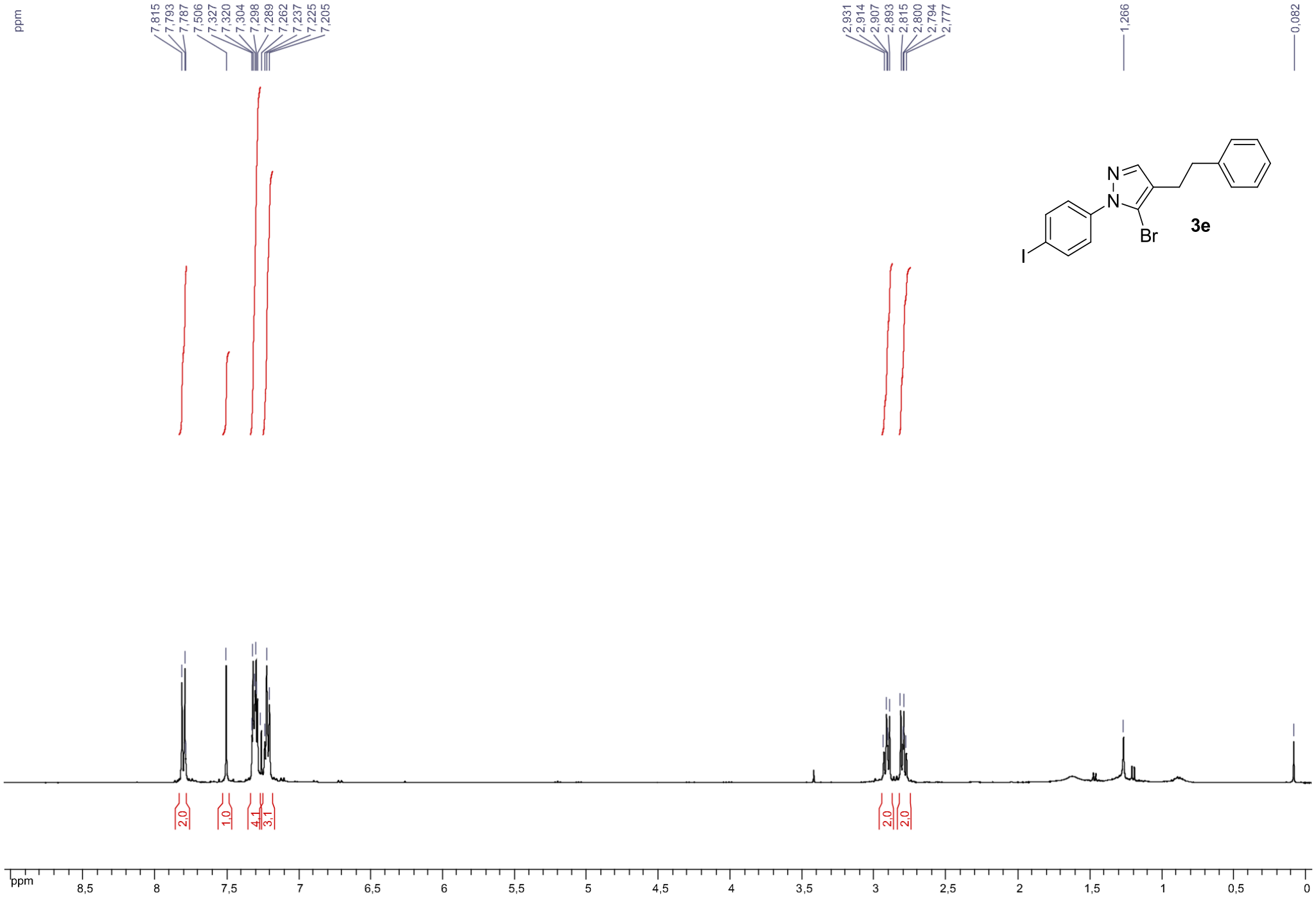

ppm
141,218
140,441
138,200
136,821
129,384
128,431
128,347
126,046
125,291
121,832
112,520
77,672
77,565
77,527
36,080
26,546
21,105
N
N
Br
3b
ppm
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0

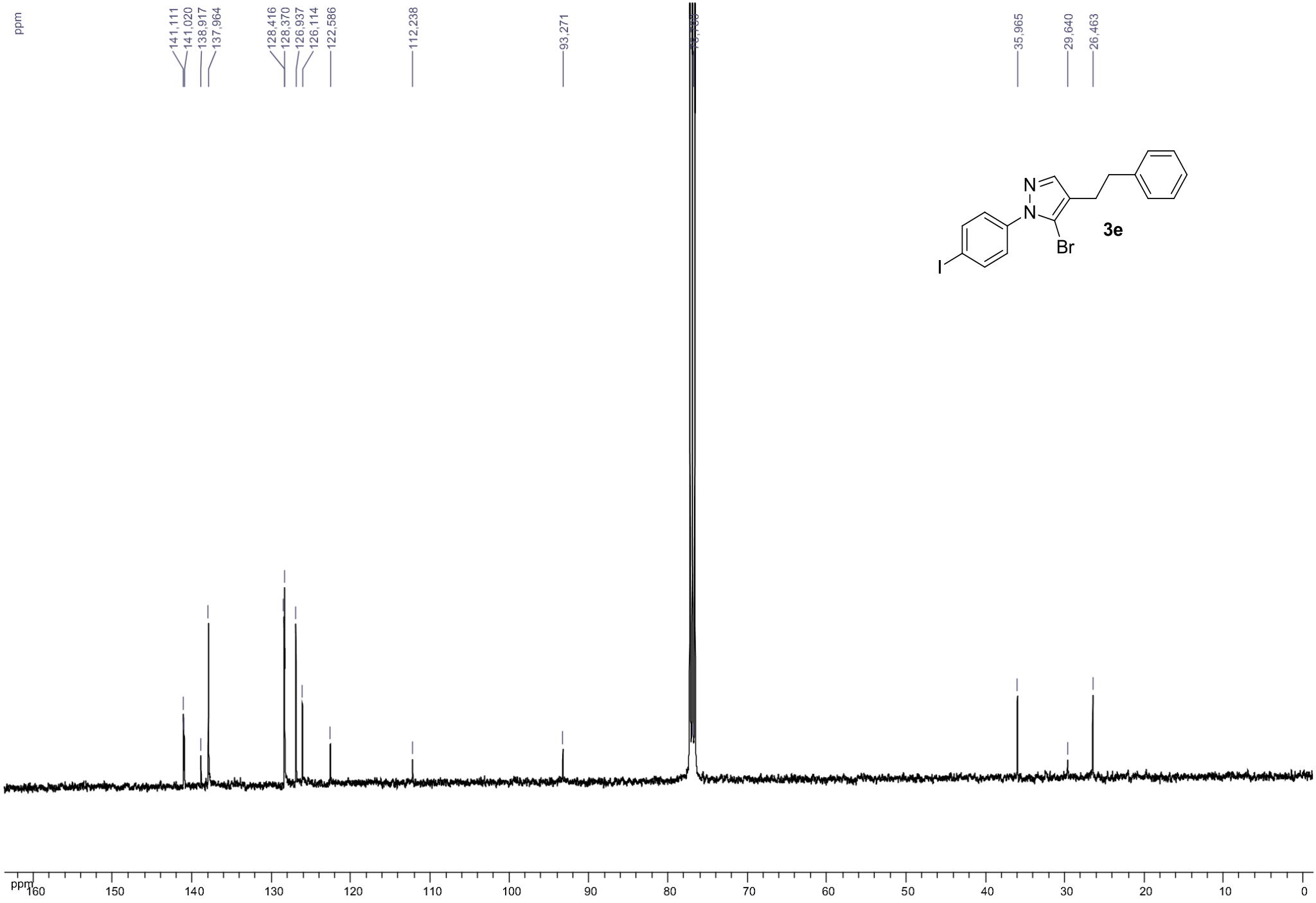

ppm
7,488
7,430
7,424
7,413
7,407
7,330
7,317
7,311
7,309
7,300
7,293
7,262
7,239
7,221
7,203
6,992
6,986
6,975
6,969
3,863
2,935
2,917
2,910
2,896
2,809
2,794
2,787
2,771
2,768
1,585
0,075
N
N
Br
MeO
3c
1,0
2,0
2,0
2,9
2,0
3,0
2,0
2,0
ppm
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0

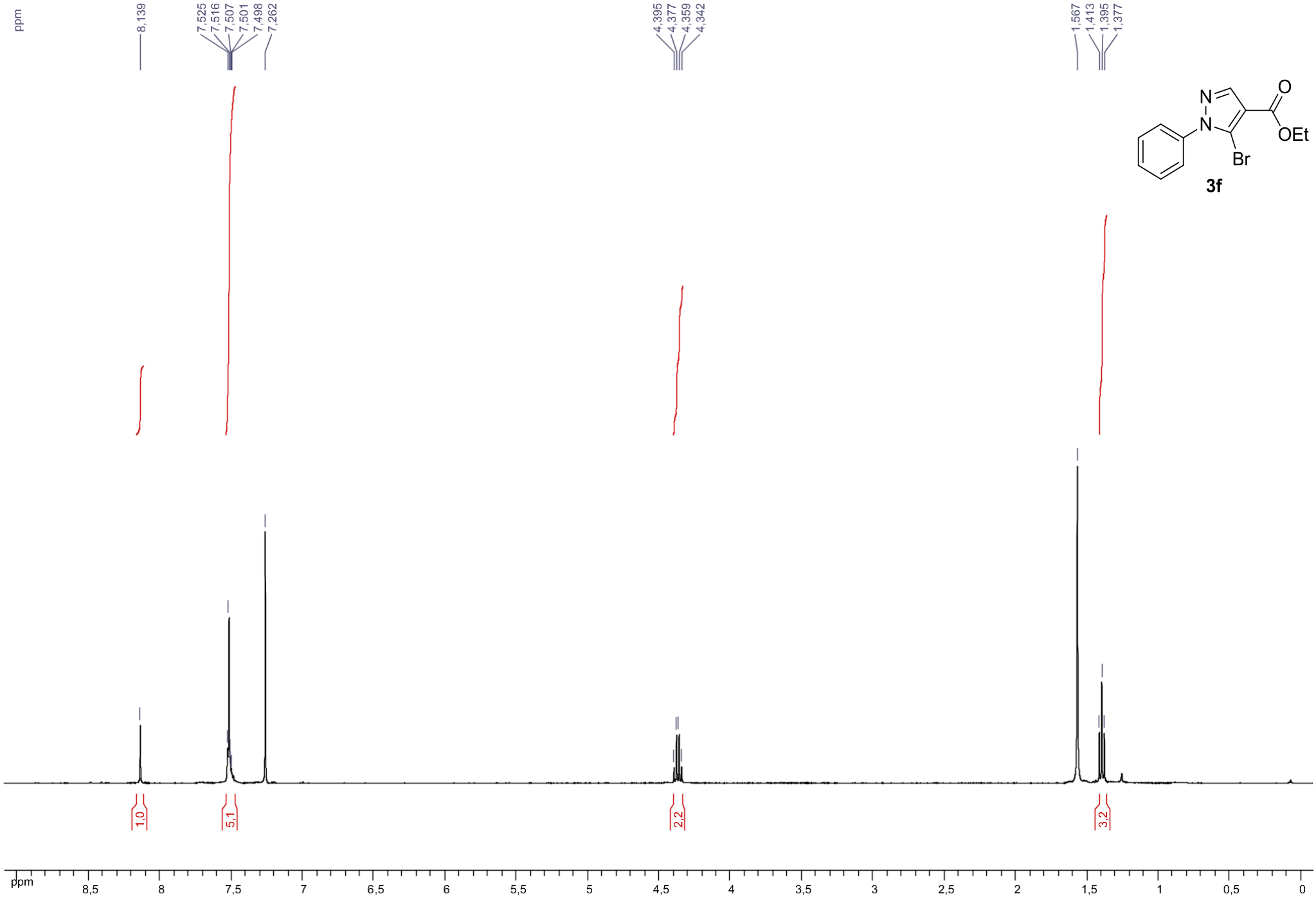

ppm
159,339
141,233
140,304
132,371
128,446
128,362
126,915
126,061
121,588
113,937
112,855
55,489
36,110
26,577
N
N
Br
MeO
3c
ppm
220
200
180
160
140
120
100
80
60
40
20
0

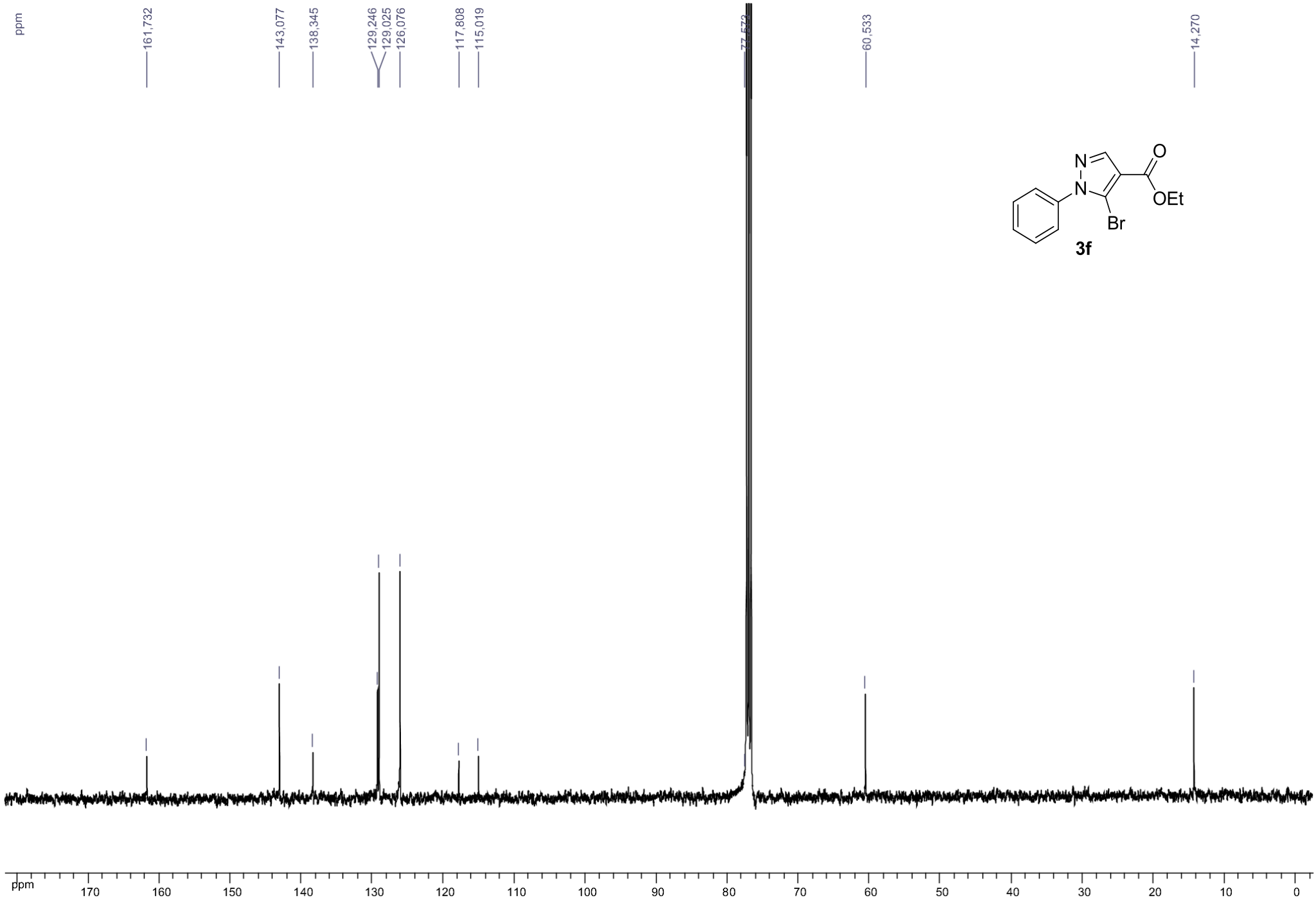

ppm
7.530
7.522
7.516
7.509
7.505
7.499
7.493
7.487
7.334
7.330
7.315
7.297
7.262
7.244
7.237
7.227
7.218
7.196
7.188
7.182
7.176
7.167
7.157
7.150
7.145
2.943
2.925
2.918
2.904
2.824
2.809
2.802
2.786
2.783
N
N
Br
F
3d
3,0
2,2
5,2
2,1
2,0
ppm
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0

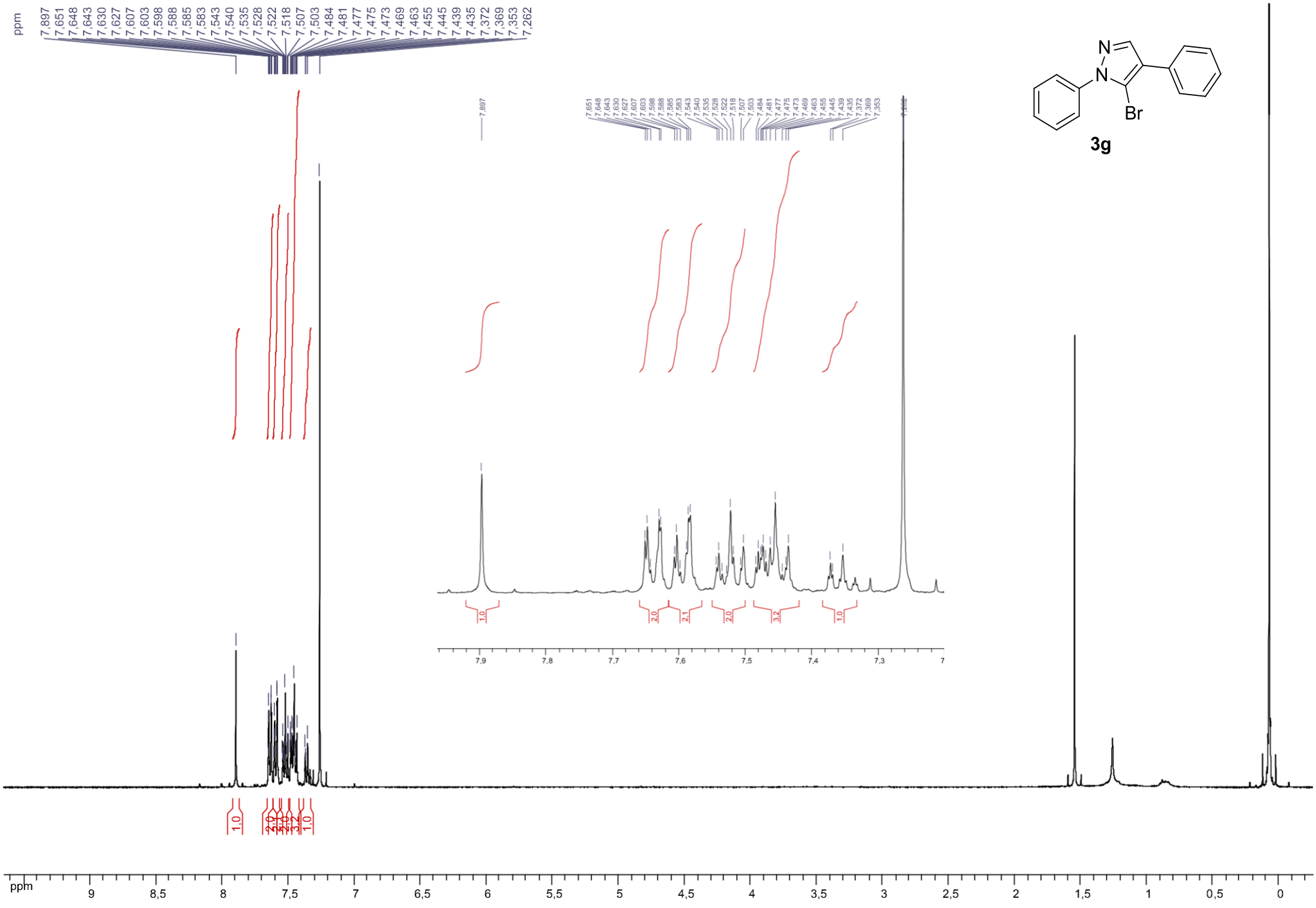

ppm
163.332
160.863
141.081
140.936
140.776
135.358
135.335
128.431
128.370
128.111
127.372
127.288
126.107
122.129
115.865
115.766
115.636
112.642
76.407
76.369
36.026
26.493
N
N
Br
F
3d
ppm
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0

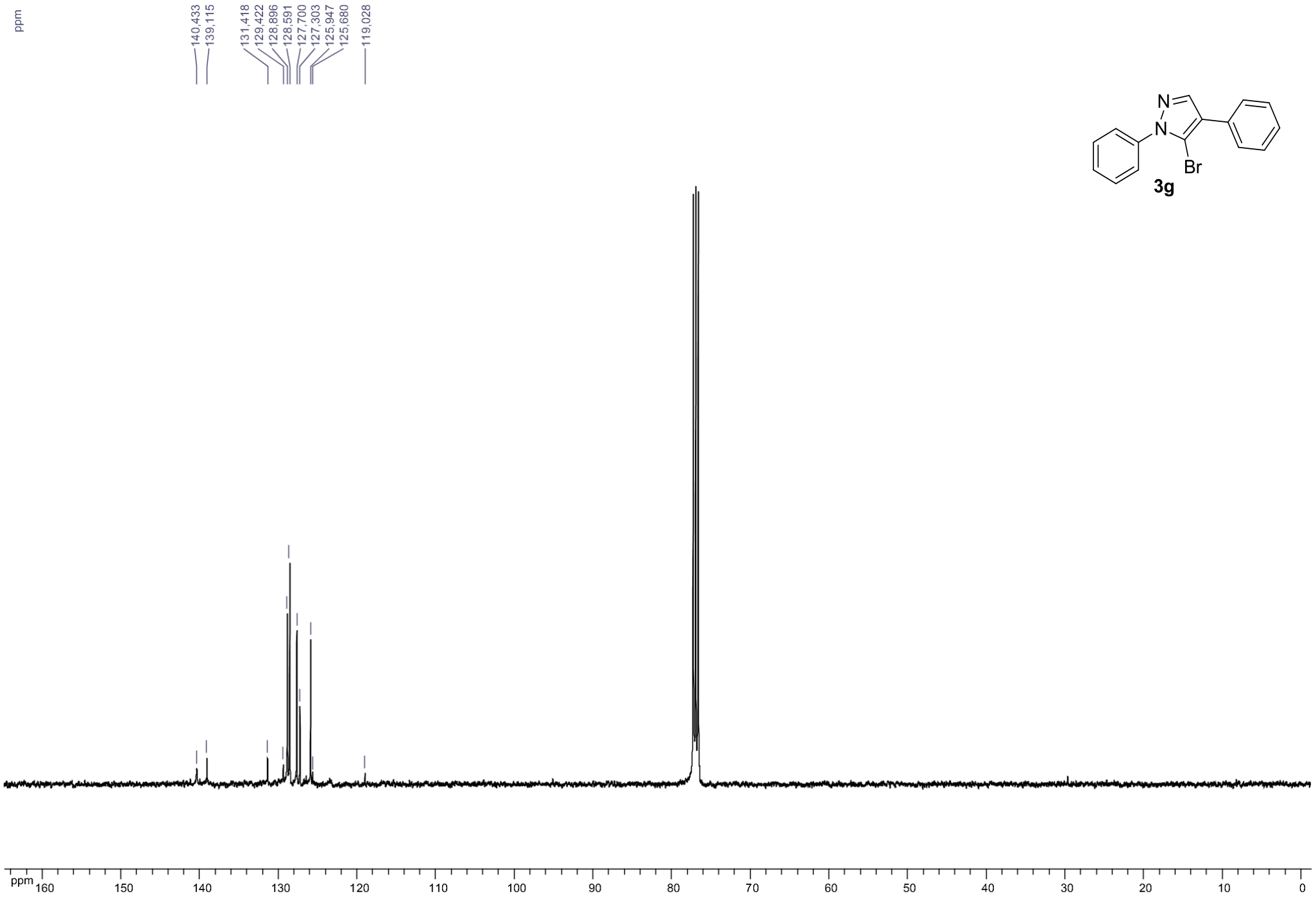

ppm
7,815
7,793
7,787
7,506
7,327
7,320
7,304
7,298
7,289
7,262
7,237
7,225
7,205
2,931
2,914
2,907
2,893
2,815
2,800
2,794
2,777
1,266
0,082
N
N
Br
I
3e
2,0
1,0
4,1
3,1
2,0
2,0
ppm
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0

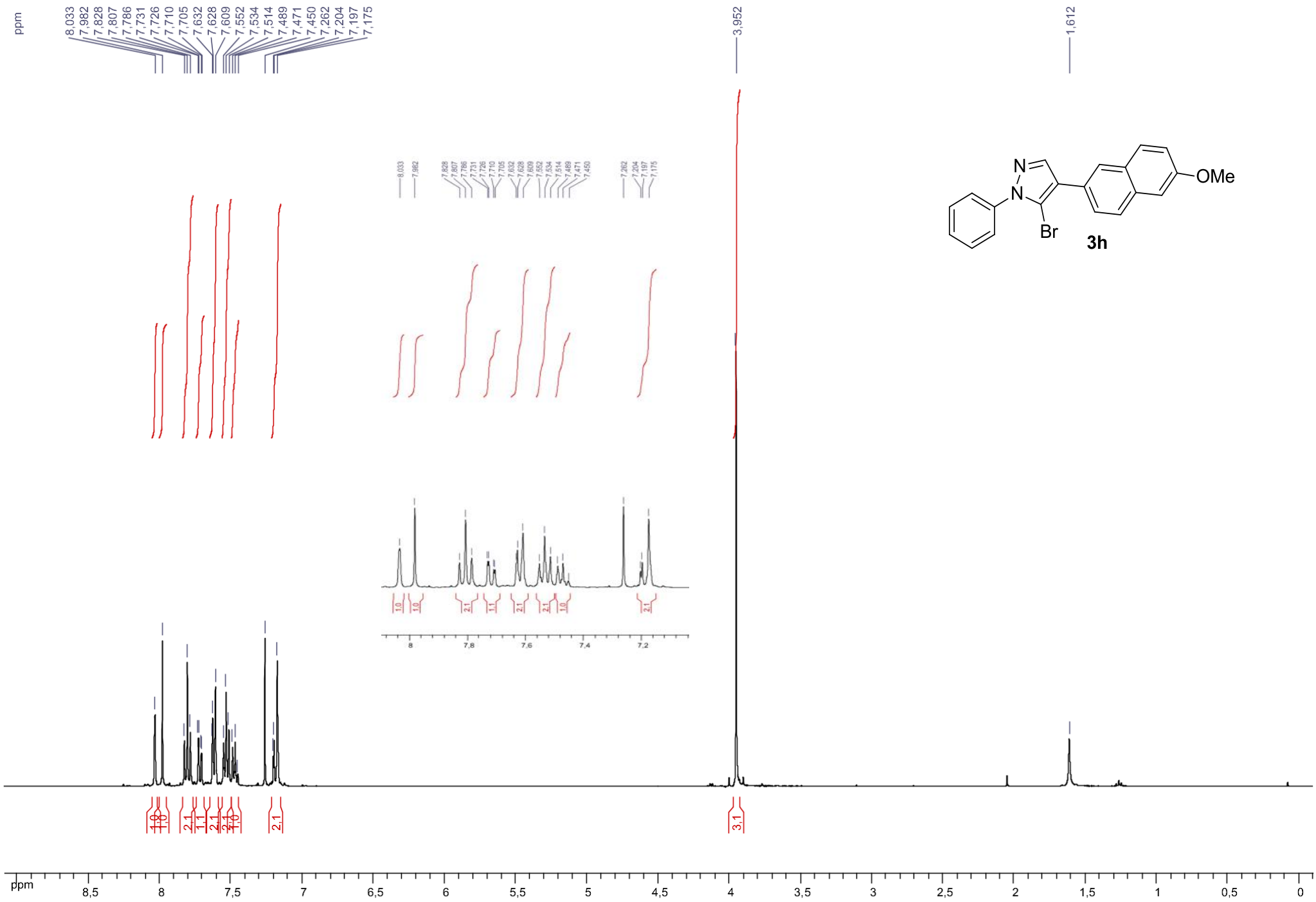

ppm
141,111
141,020
138,917
137,964
128,416
128,370
126,937
126,114
122,586
112,238
93,271
35,965
29,640
26,463
N
N
Br
I
3e
ppm
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0


ppm
8,139
7,525
7,516
7,507
7,501
7,498
7,262
4,395
4,377
4,359
4,342
1,567
1,413
1,395
1,377
N
N
O
OEt
Br
3f
1,0
5,1
2,2
3,2
ppm
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0


ppm
161,732
143,077
138,345
129,246
129,025
126,076
117,808
115,019
77,572
60,533
14,270
N
N
O
OEt
Br
3f
ppm
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0


ppm
7,897
7,651
7,648
7,643
7,630
7,627
7,607
7,603
7,598
7,588
7,585
7,583
7,543
7,540
7,535
7,528
7,522
7,518
7,507
7,503
7,484
7,481
7,477
7,475
7,473
7,469
7,463
7,455
7,445
7,439
7,435
7,372
7,369
7,353
7,262
N
N
Br
3g
1,0
2,0
2,1
2,0
3,2
1,0
ppm
9
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0


ppm
140,433
139,115
131,418
129,422
128,896
128,591
127,700
127,303
125,947
125,680
119,028
N
N
Br
3g
ppm
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0


ppm
8,033
7,982
7,828
7,807
7,786
7,731
7,726
7,710
7,705
7,632
7,628
7,609
7,552
7,534
7,514
7,489
7,471
7,450
7,262
7,204
7,197
7,175
3,952
1,612
N
N
Br
OMe
3h
1,0
1,0
2,1
1,1
2,1
2,1
1,0
2,1
3,1
ppm
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
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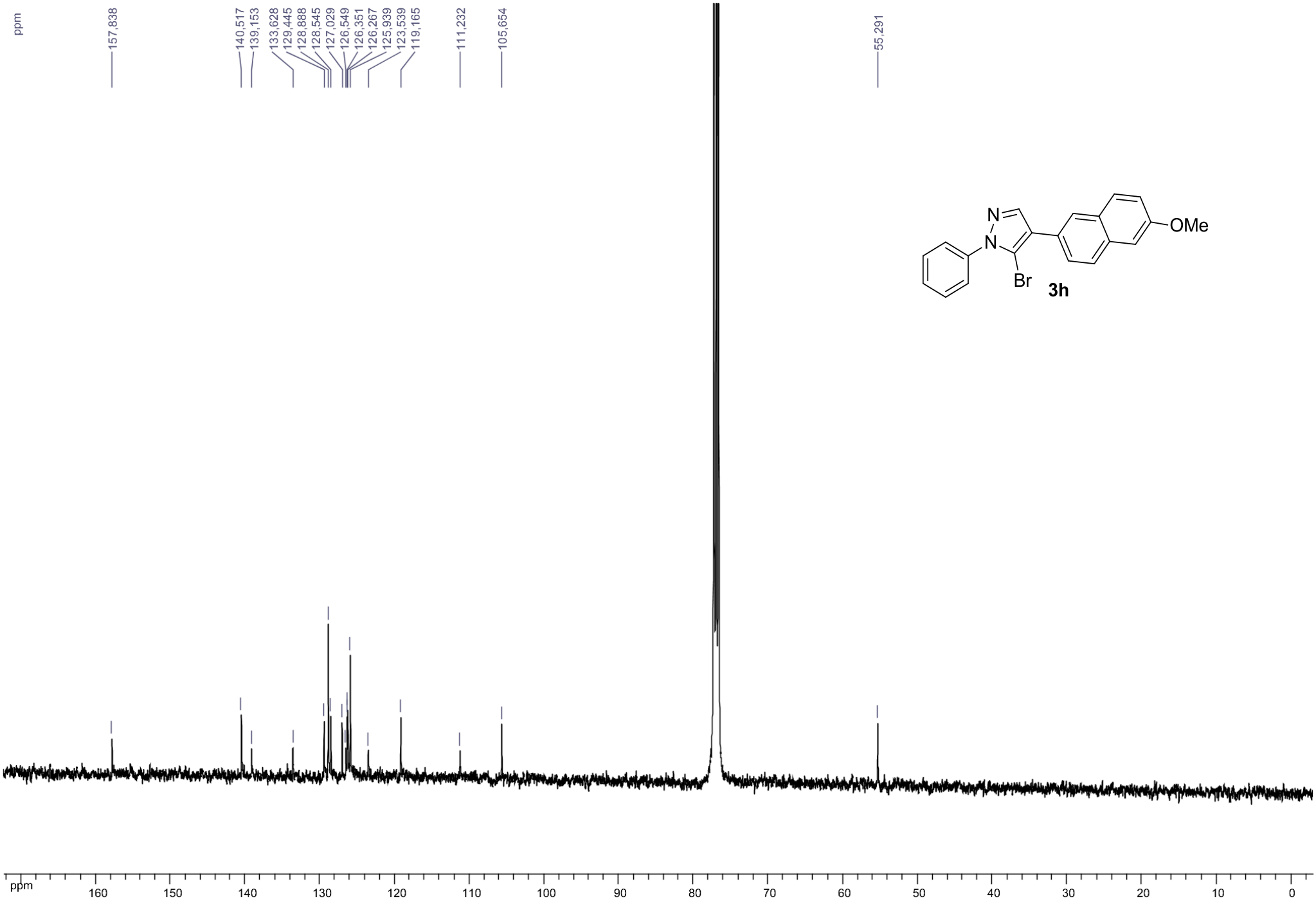
ppm
157,838
140,517
139,153
133,628
129,445
128,888
128,545
127,029
126,549
126,351
126,267
125,939
123,539
119,165
111,232
105,654
55,291
N
N
Br
OMe
3h
ppm
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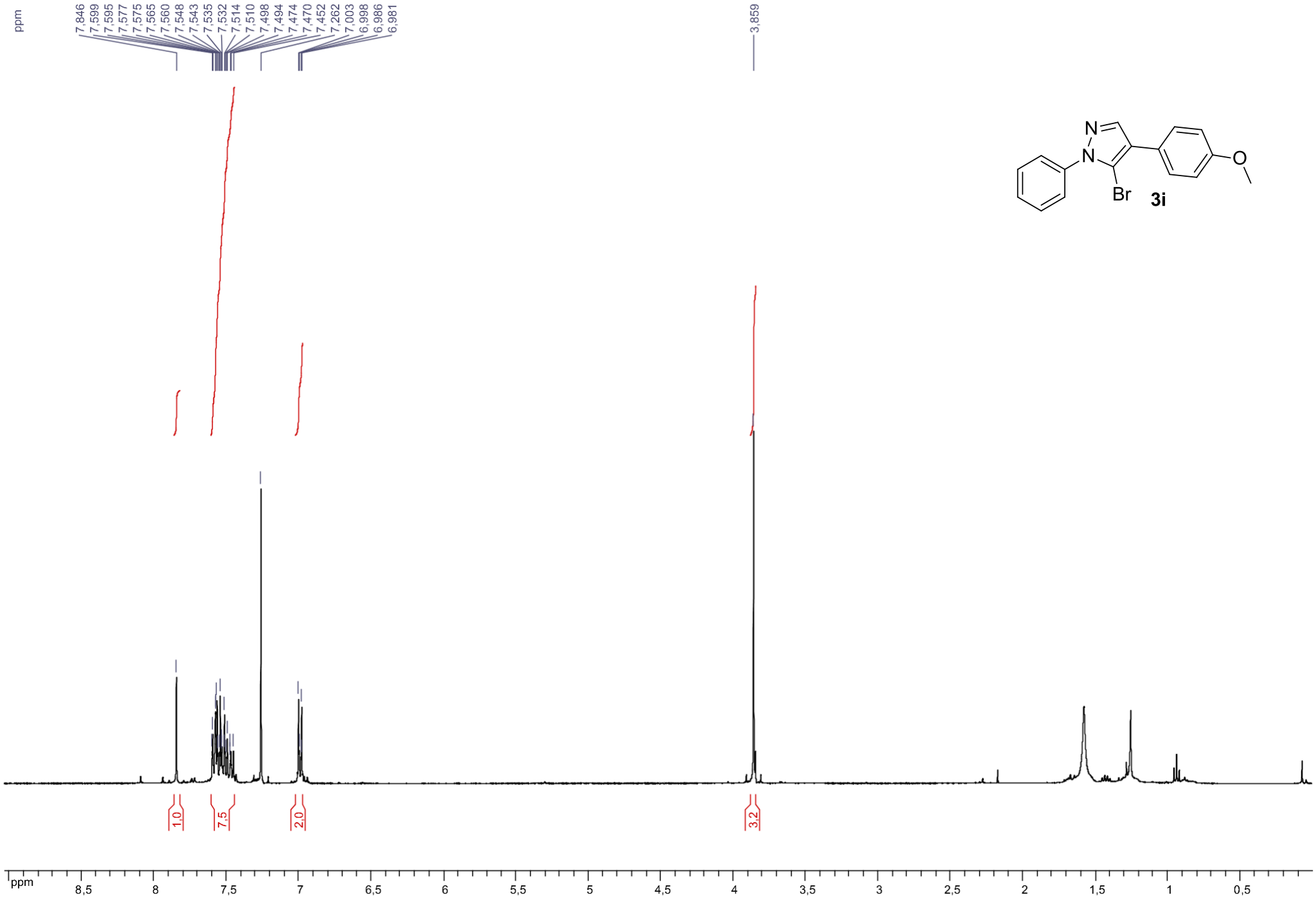
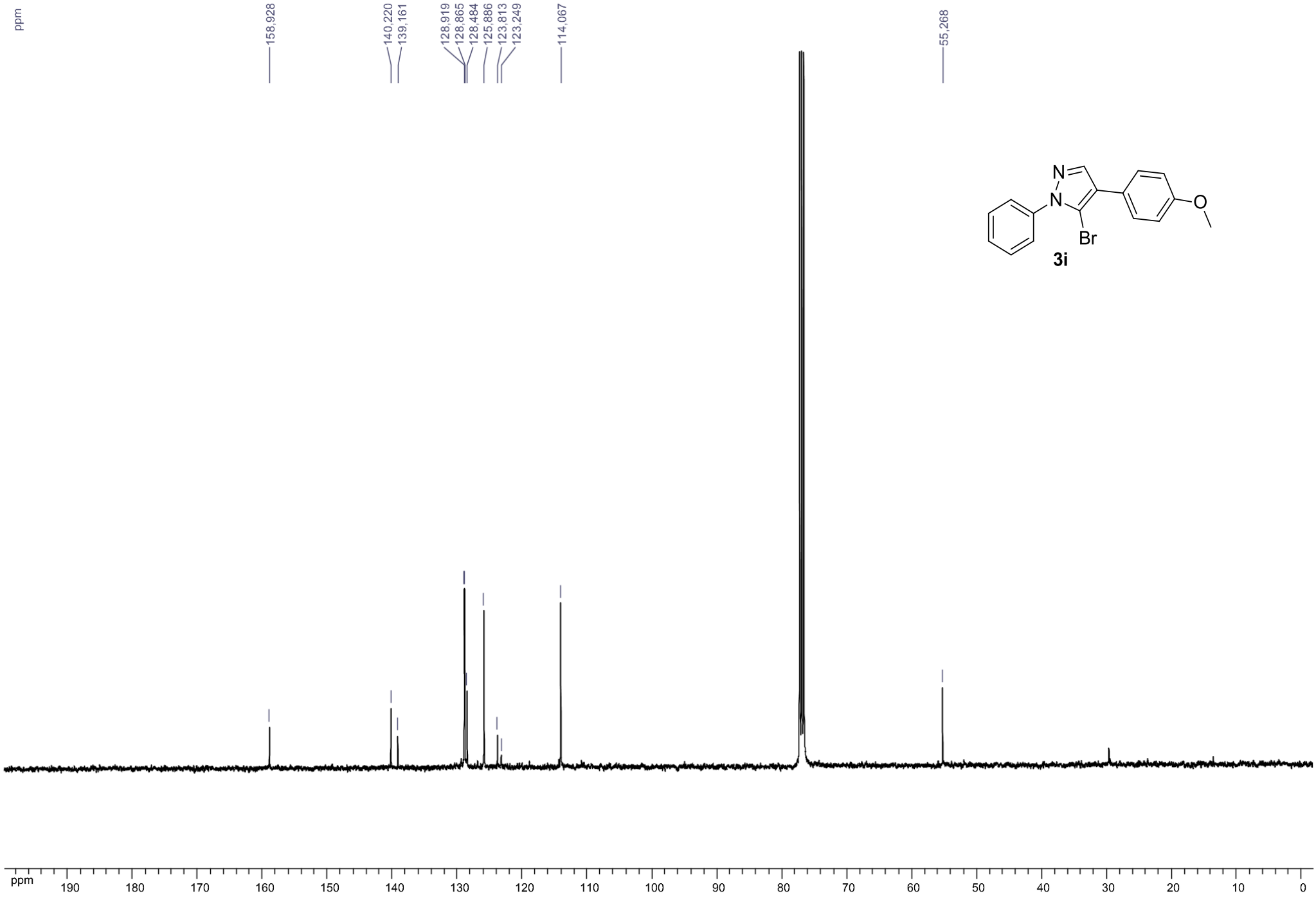
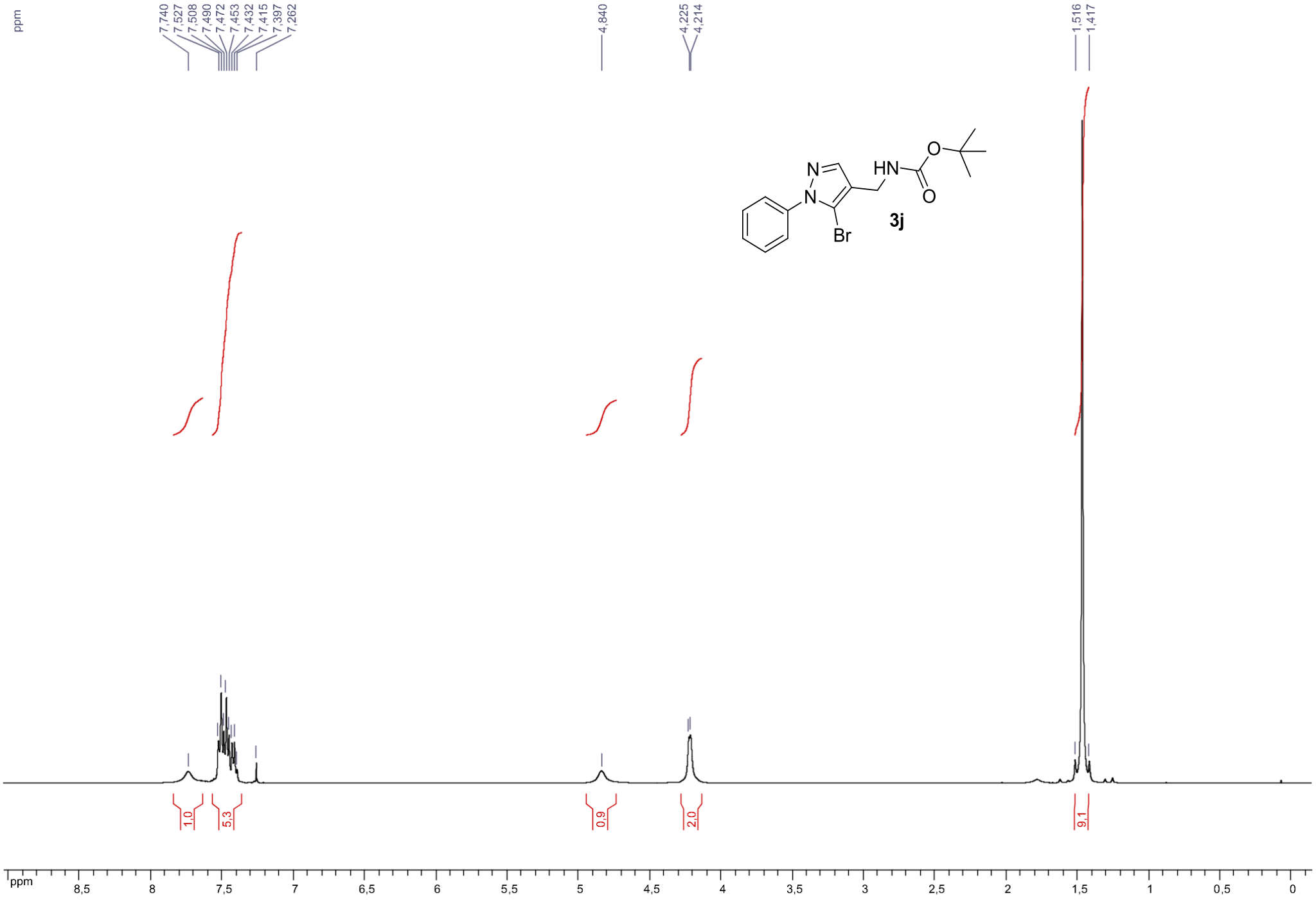
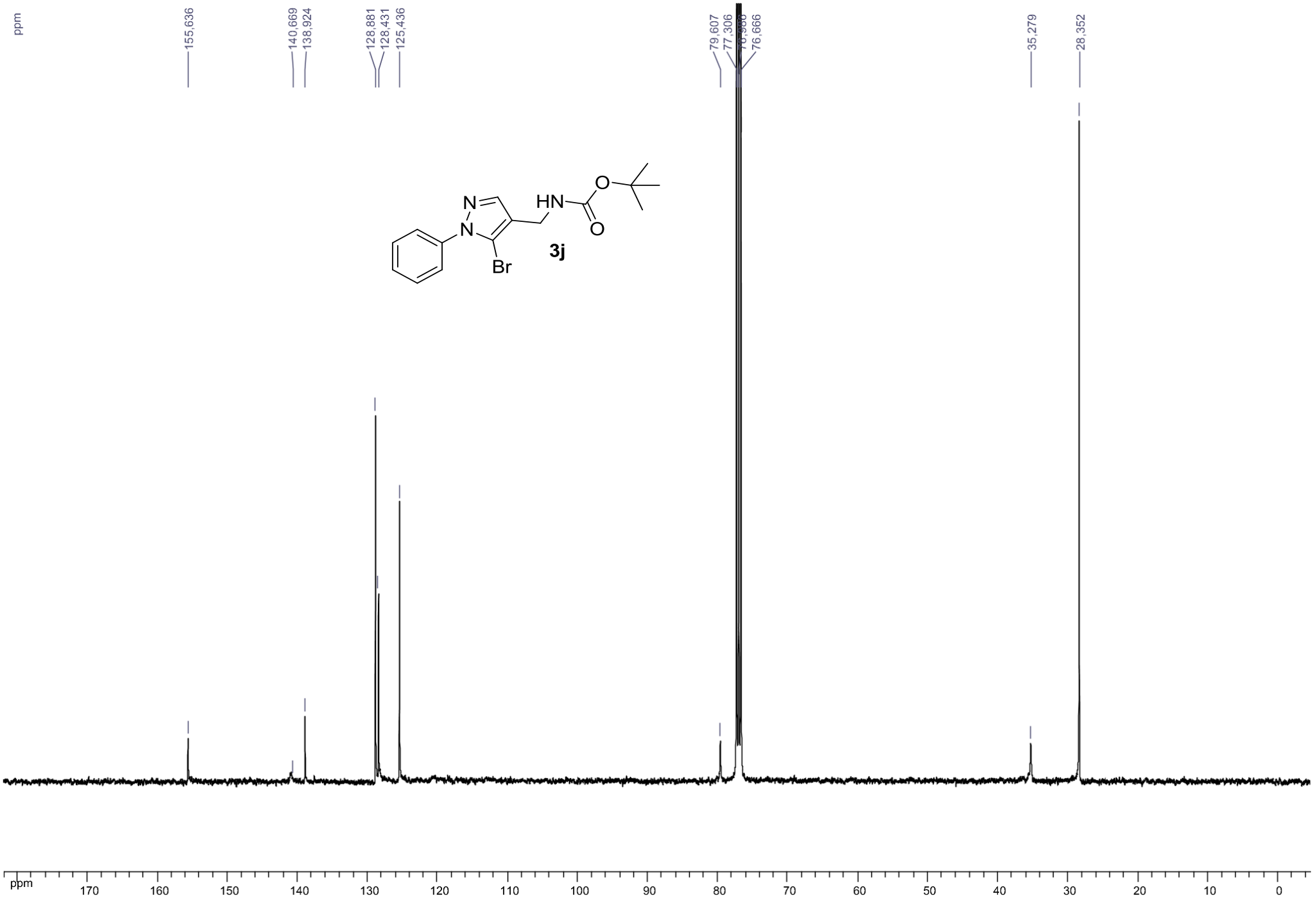
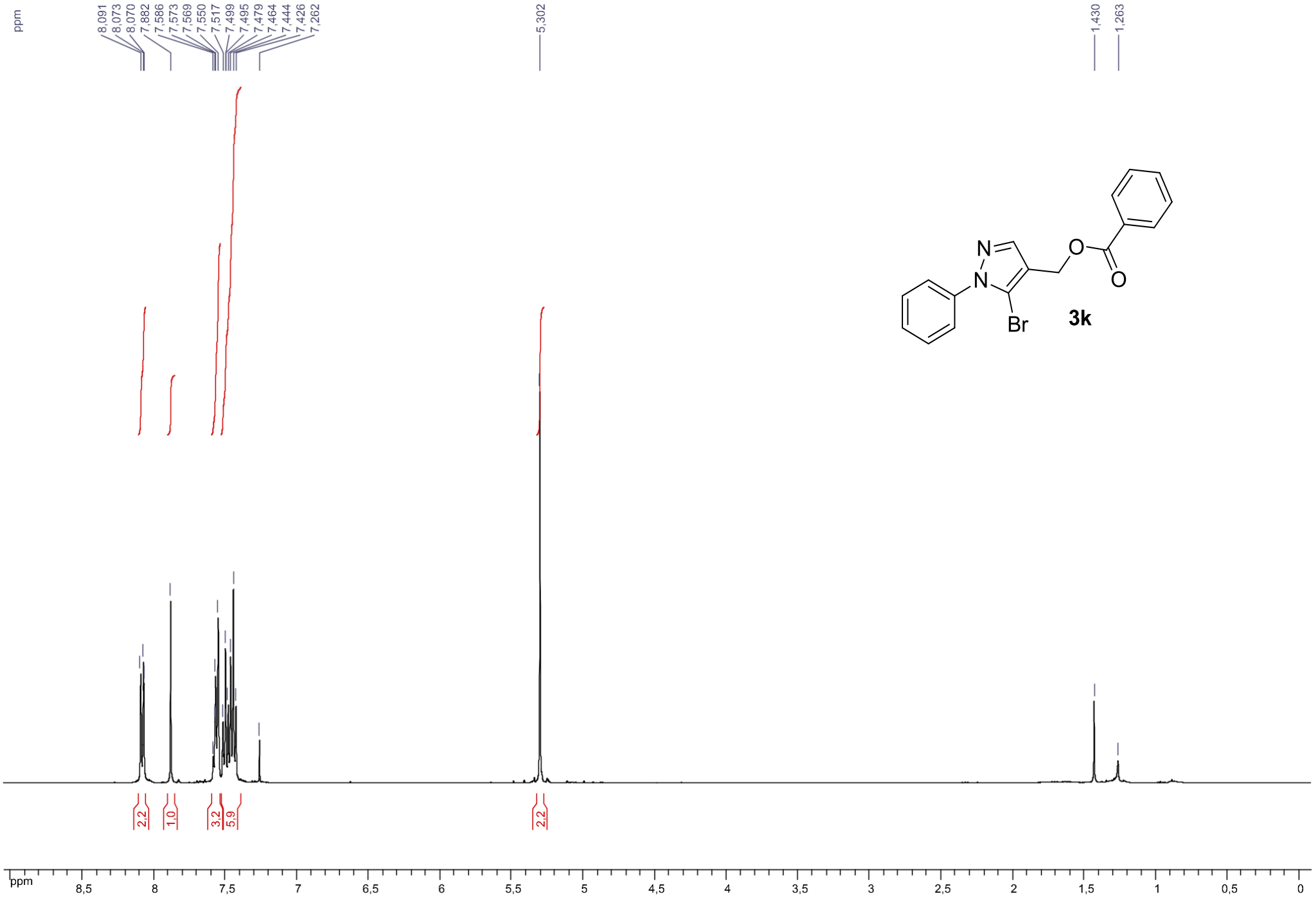
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0


ppm
7,846
7,599
7,595
7,577
7,575
7,565
7,560
7,548
7,543
7,535
7,532
7,514
7,510
7,498
7,494
7,474
7,470
7,452
7,262
7,003
6,998
6,986
6,981
3,859
N
N
Br
O
3i
1,0
7,5
2,0
3,2
ppm
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5


ppm
158,928
140,220
139,161
128,919
128,865
128,484
125,886
123,813
123,249
114,067
55,268
N
N
O
Br
3i
ppm
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0


ppm
7,740
7,527
7,508
7,490
7,472
7,453
7,432
7,415
7,397
7,262
4,840
4,225
4,214
1,516
1,417
N
N
HN
O
O
Br
3j
1,0
5,3
0,9
2,0
9,1
ppm
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0


ppm
155.636
140.669
138.924
128.881
128.431
125.436
79.607
77.306
76.666
35.279
28.352
HN
O
O
N
N
Br
3j
ppm
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0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8,091
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8,070
7,882
7,586
7,573
7,569
7,550
7,517
7,499
7,495
7,479
7,464
7,444
7,426
7,262
5,302
1,430
1,263
N
N
O
O
Br
3k
2,2
1,0
3,2
5,9
2,2
ppm
8,5
8
7,5
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6,5
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5,5
5
4,5
4
3,5
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2,5
2
1,5
1
0,5
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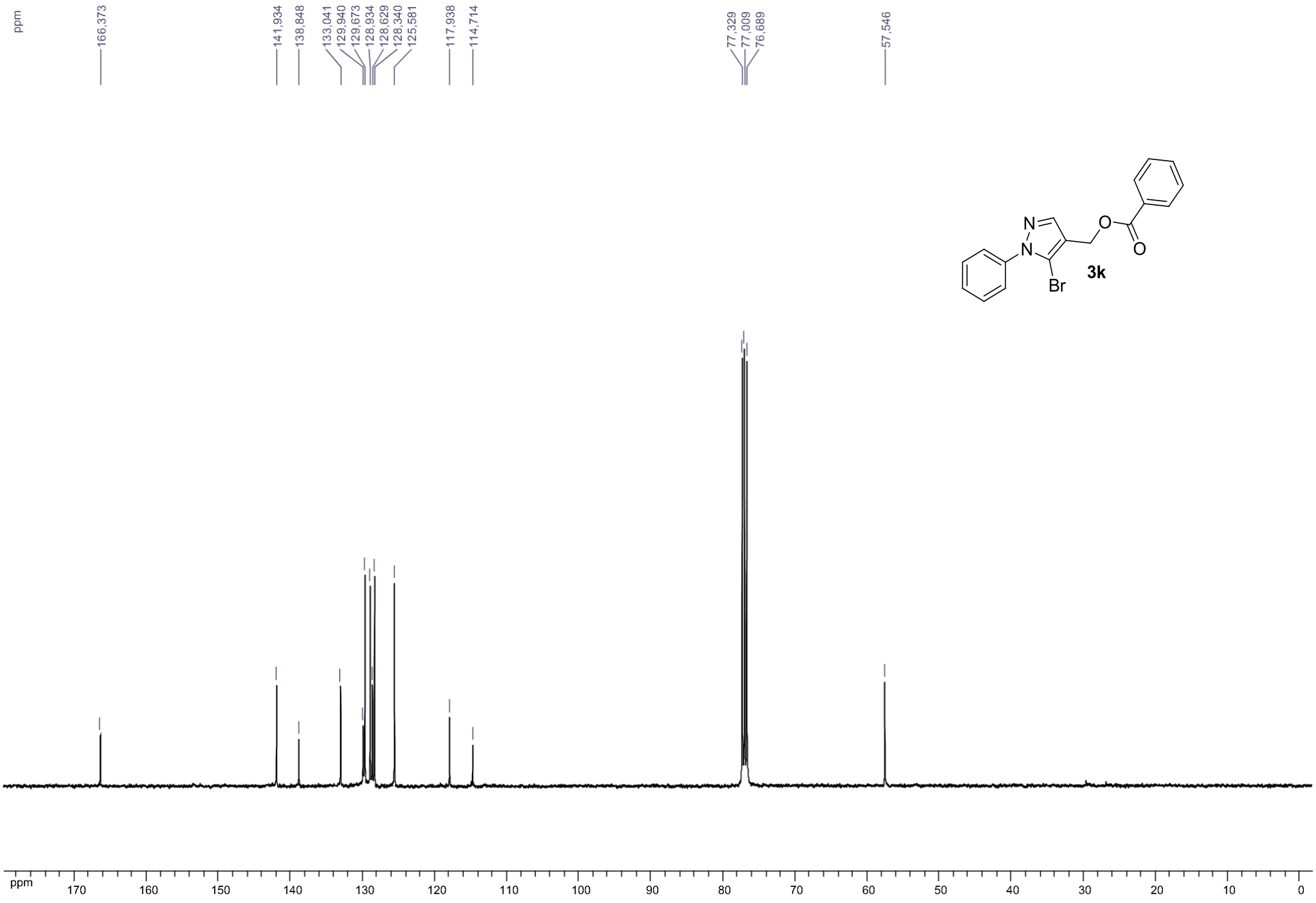
ppm
166.373
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138.848
133.041
129.940
129.673
128.934
128.629
128.340
125.581
117.938
114.714
77.329
77.009
76.689
57.546
N
N
O
O
Br
3k
ppm
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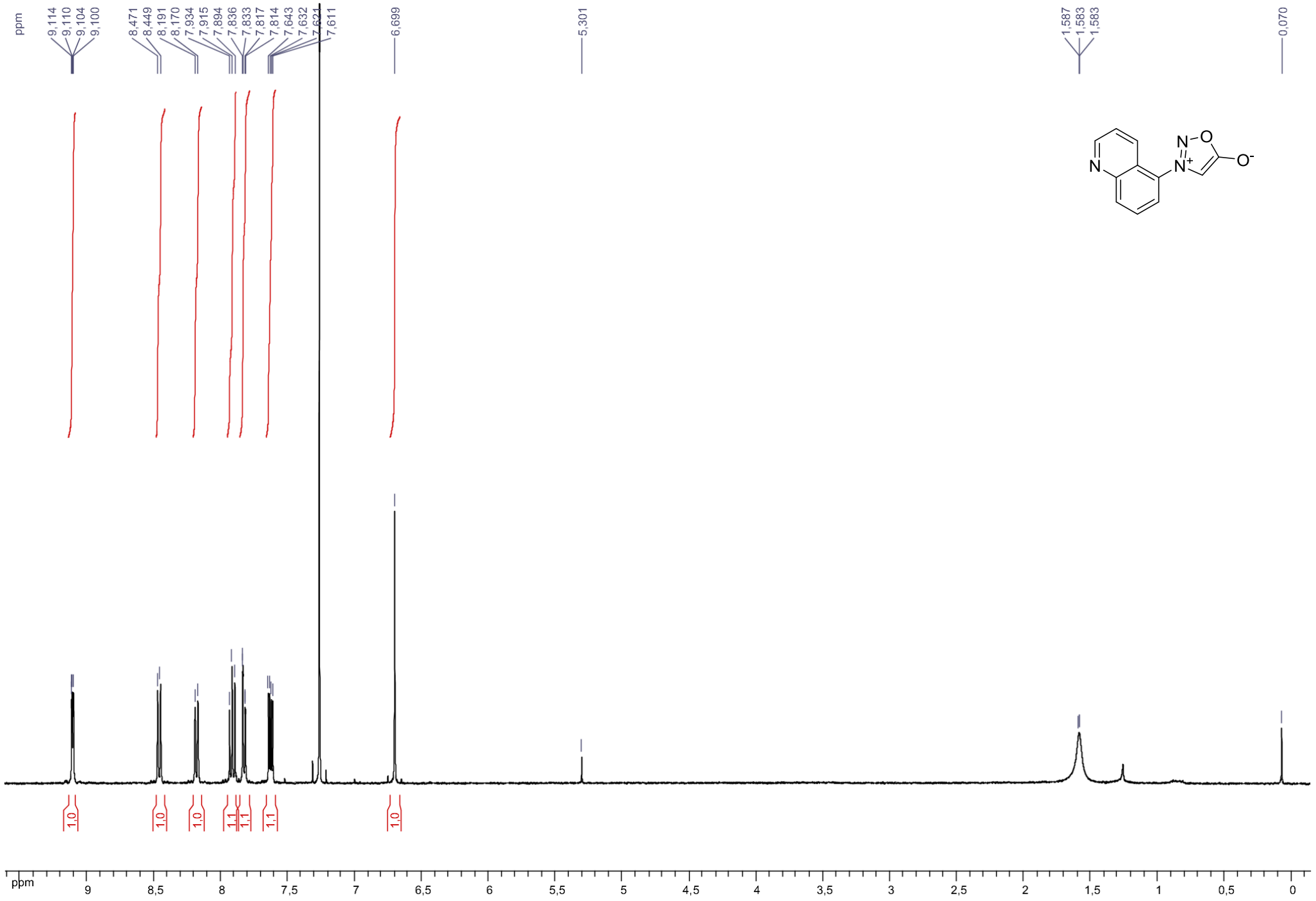
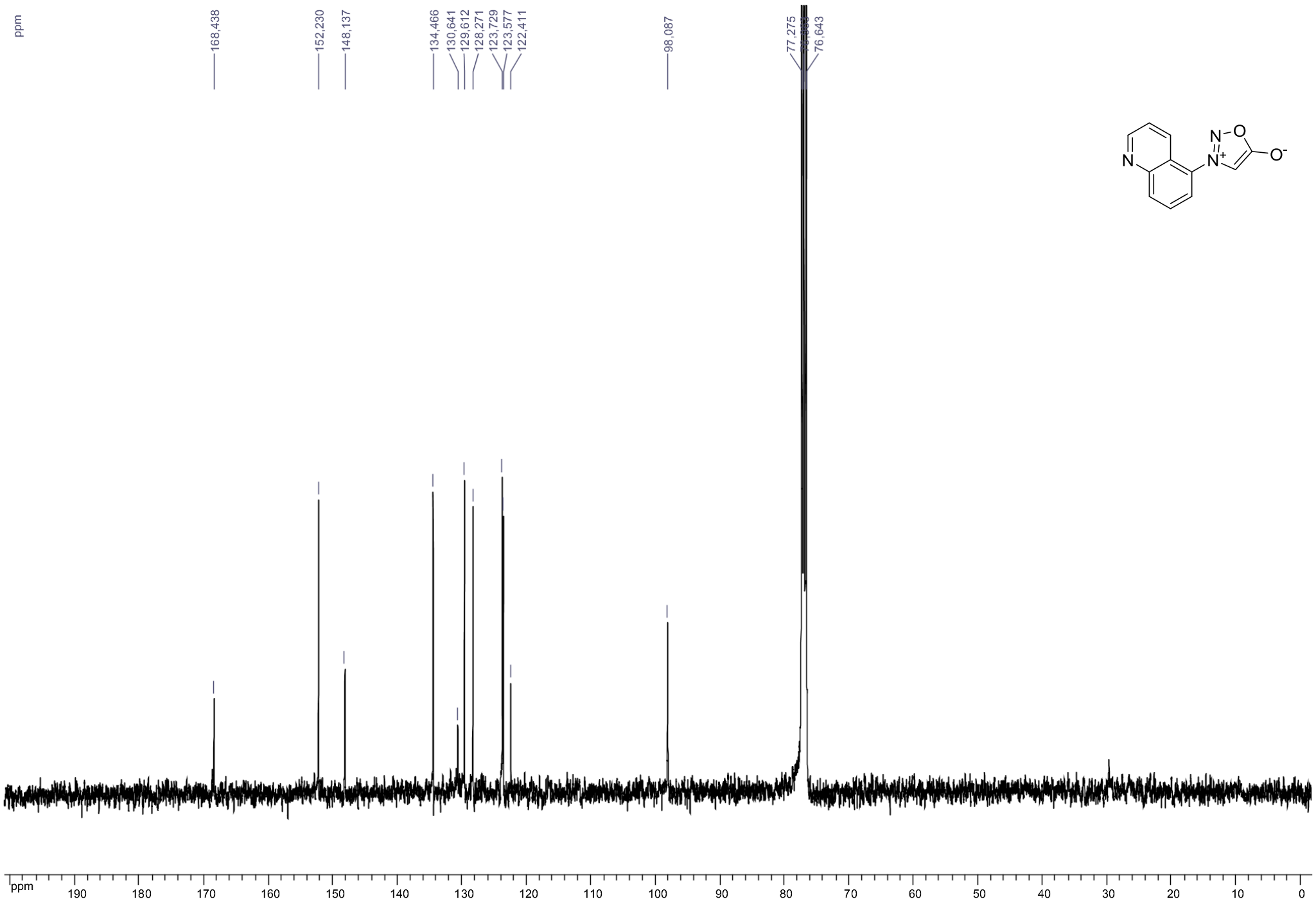
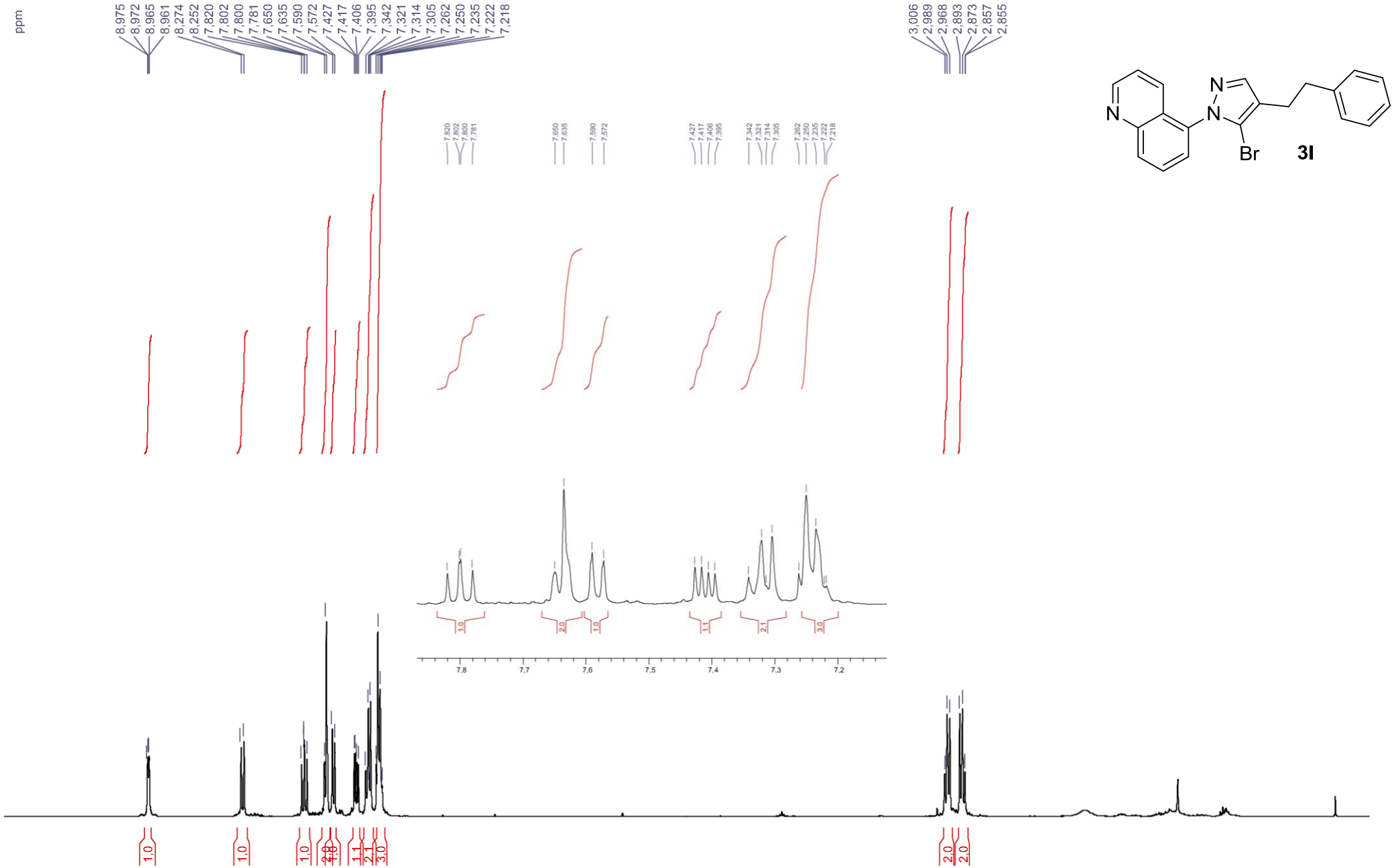
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0


ppm
9,114
9,110
9,104
9,100
8,471
8,449
8,191
8,170
7,934
7,915
7,894
7,836
7,833
7,817
7,814
7,643
7,632
7,621
7,611
6,699
5,301
1,587
1,583
1,583
0,070
1,0
1,0
1,0
1,1
1,1
1,1
1,0
ppm
9
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0


ppm
168,438
152,230
148,137
134,466
130,641
129,612
128,271
123,729
123,577
122,411
98,087
77,275
76,643
N
N+
O
O-
ppm
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0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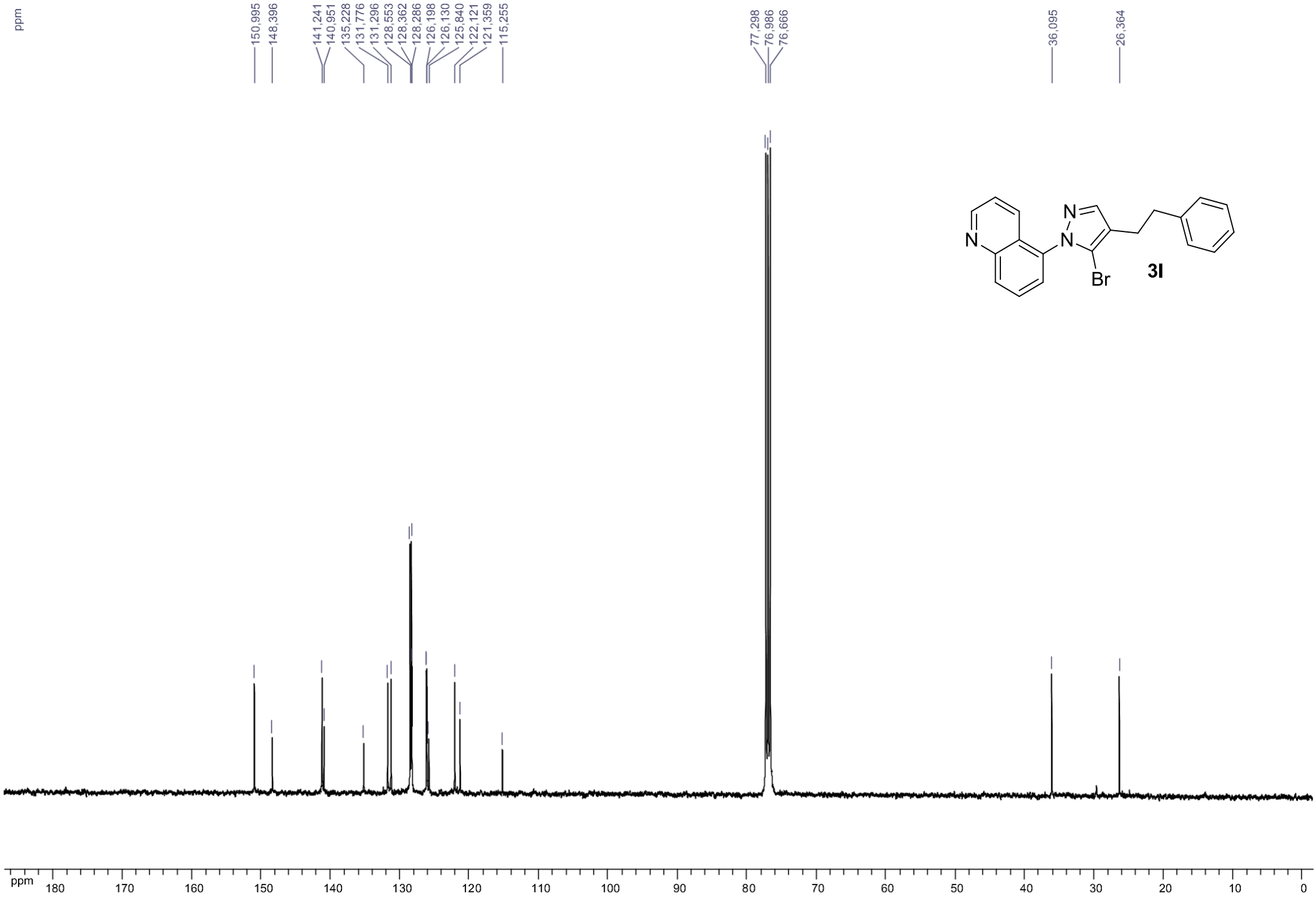
8,975
8,972
8,965
8,961
8,274
8,252
7,820
7,802
7,800
7,781
7,650
7,635
7,590
7,572
7,427
7,417
7,406
7,395
7,342
7,321
7,314
7,305
7,262
7,250
7,235
7,222
7,218
3,006
2,989
2,968
2,893
2,873
2,857
2,855
N
N
Br
3l
1,0
1,0
1,0
2,8
1,0
1,1
2,1
3,0
2,0
2,0
ppm
9,5
9
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0


ppm
150,995
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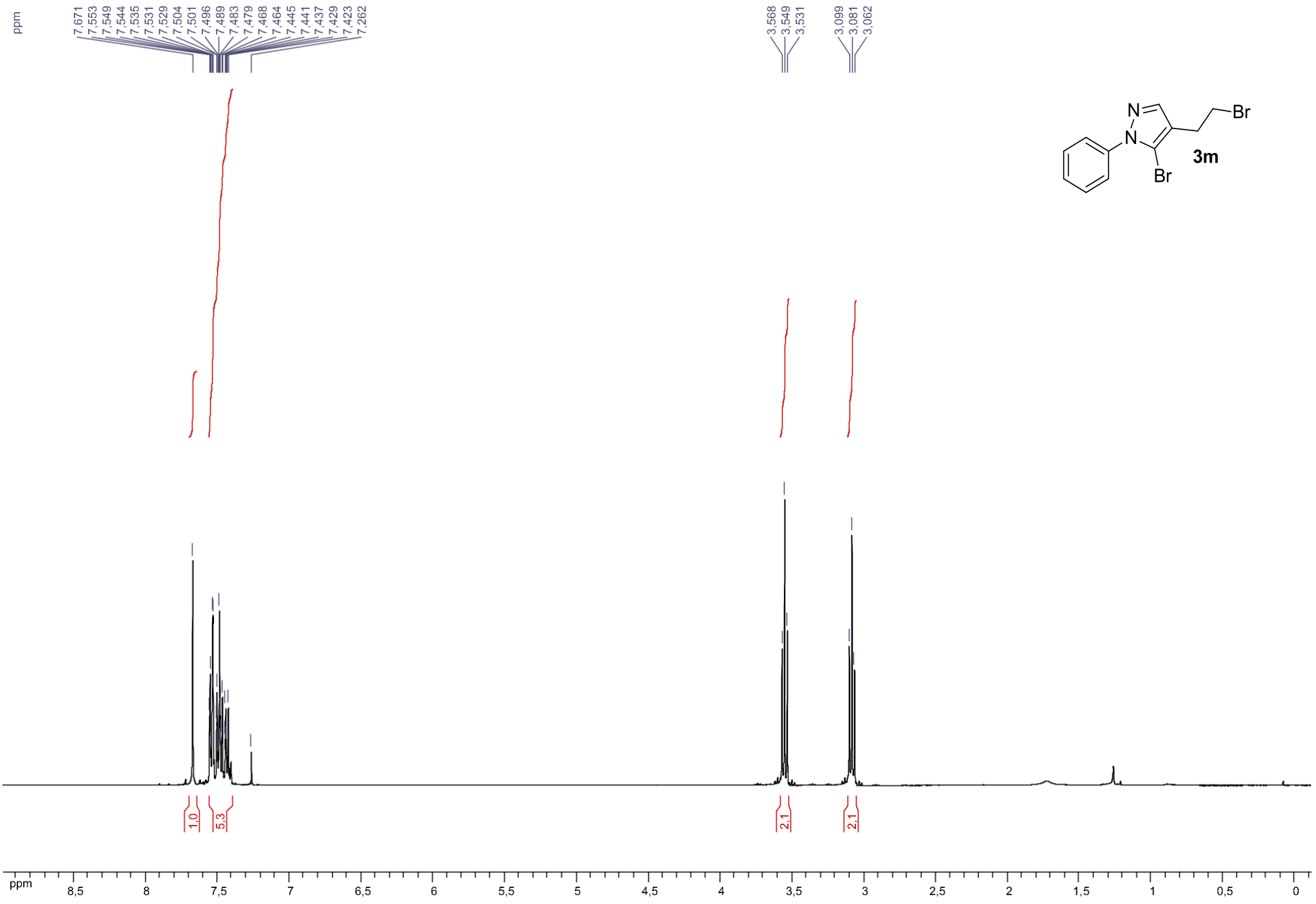
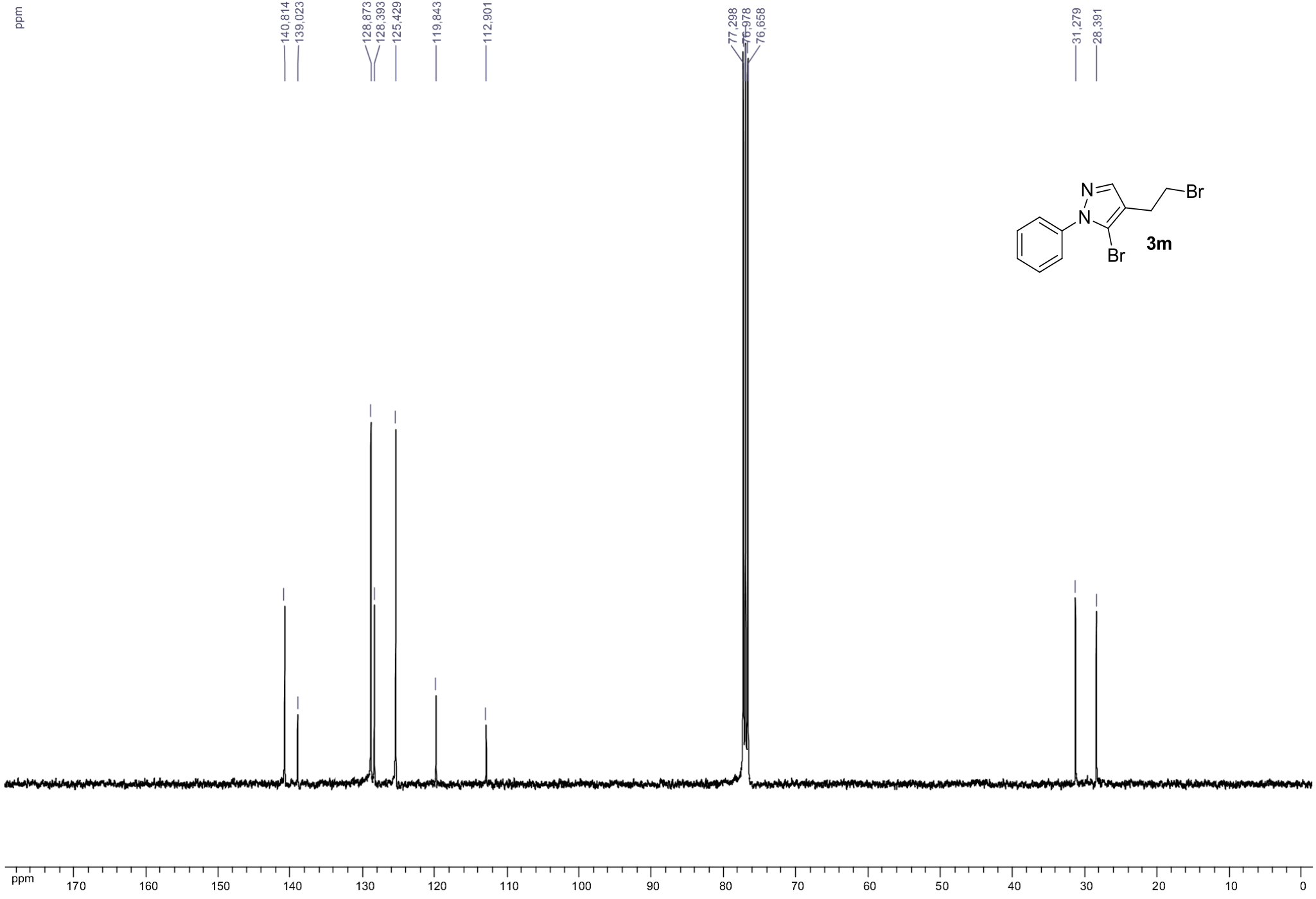
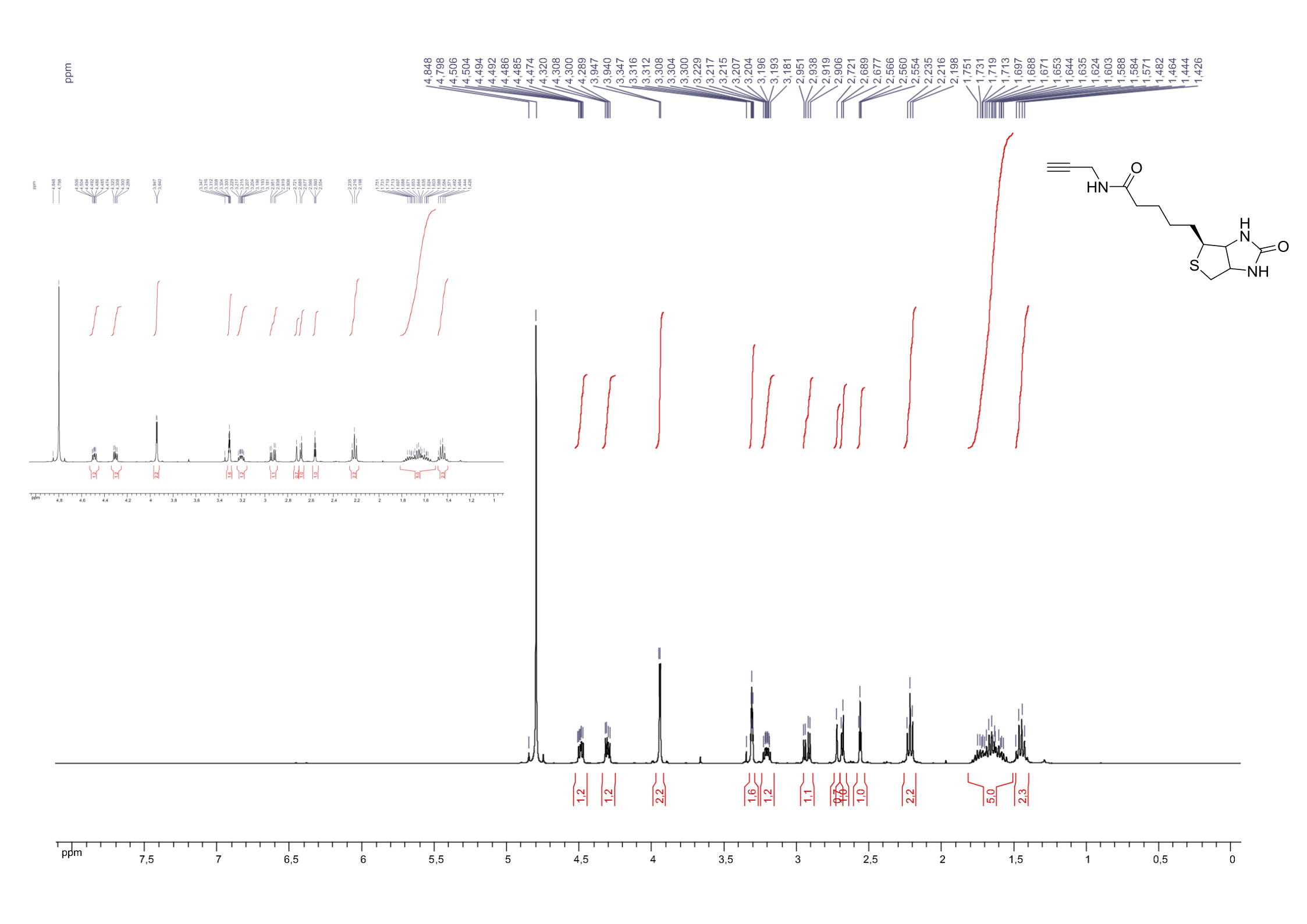
141,241
140,951
135,228
131,776
131,296
128,553
128,362
128,286
126,198
126,130
125,840
122,121
121,359
115,255
77,298
76,986
76,666
36,095
26,364
N
N
Br
3l
ppm
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0


ppm
7,671
7,553
7,549
7,544
7,535
7,531
7,529
7,504
7,501
7,496
7,489
7,483
7,479
7,468
7,464
7,445
7,441
7,437
7,429
7,423
7,262
3,568
3,549
3,531
3,099
3,081
3,062
N
N
Br
Br
3m
1,0
5,3
2,1
2,1
ppm
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0


ppm
140,814
139,023
128,873
128,393
125,429
119,843
112,901
77,298
76,978
76,658
31,279
28,391
N
N
Br
Br
3m
ppm
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0


ppm
4,848
4,798
4,506
4,504
4,494
4,492
4,486
4,485
4,474
4,320
4,308
4,300
4,289
3,947
3,940
3,347
3,316
3,312
3,308
3,304
3,300
3,229
3,217
3,215
3,207
3,204
3,196
3,193
3,181
2,951
2,938
2,919
2,906
2,721
2,689
2,677
2,566
2,560
2,554
2,235
2,216
2,198
1,751
1,731
1,719
1,713
1,697
1,688
1,671
1,653
1,644
1,635
1,624
1,603
1,588
1,584
1,571
1,482
1,464
1,444
1,426
HN
O
H
N
O
S
NH
1,2
1,2
2,2
1,6
1,2
1,1
0,7
1,0
1,0
2,2
5,0
2,3
ppm
7,5
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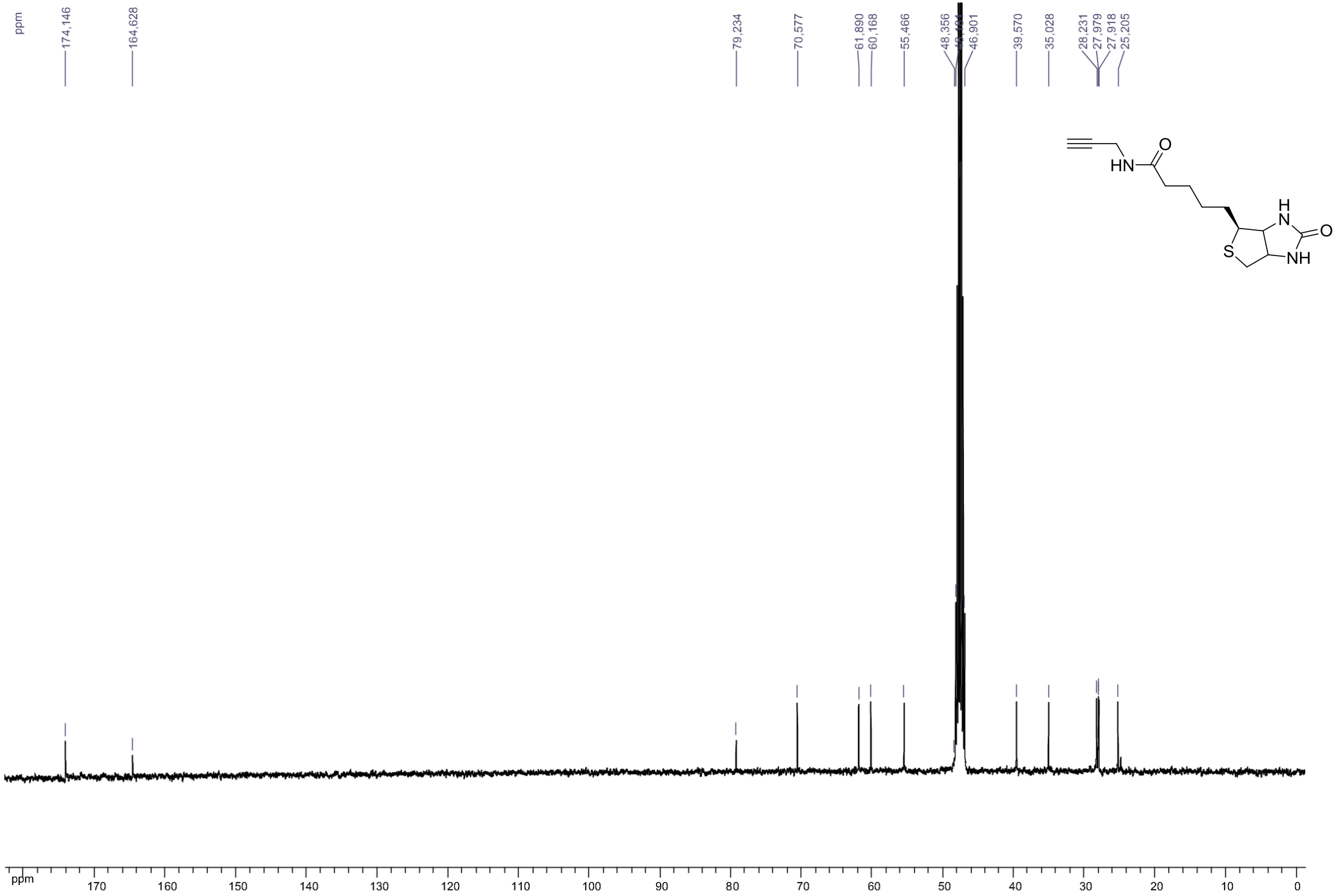
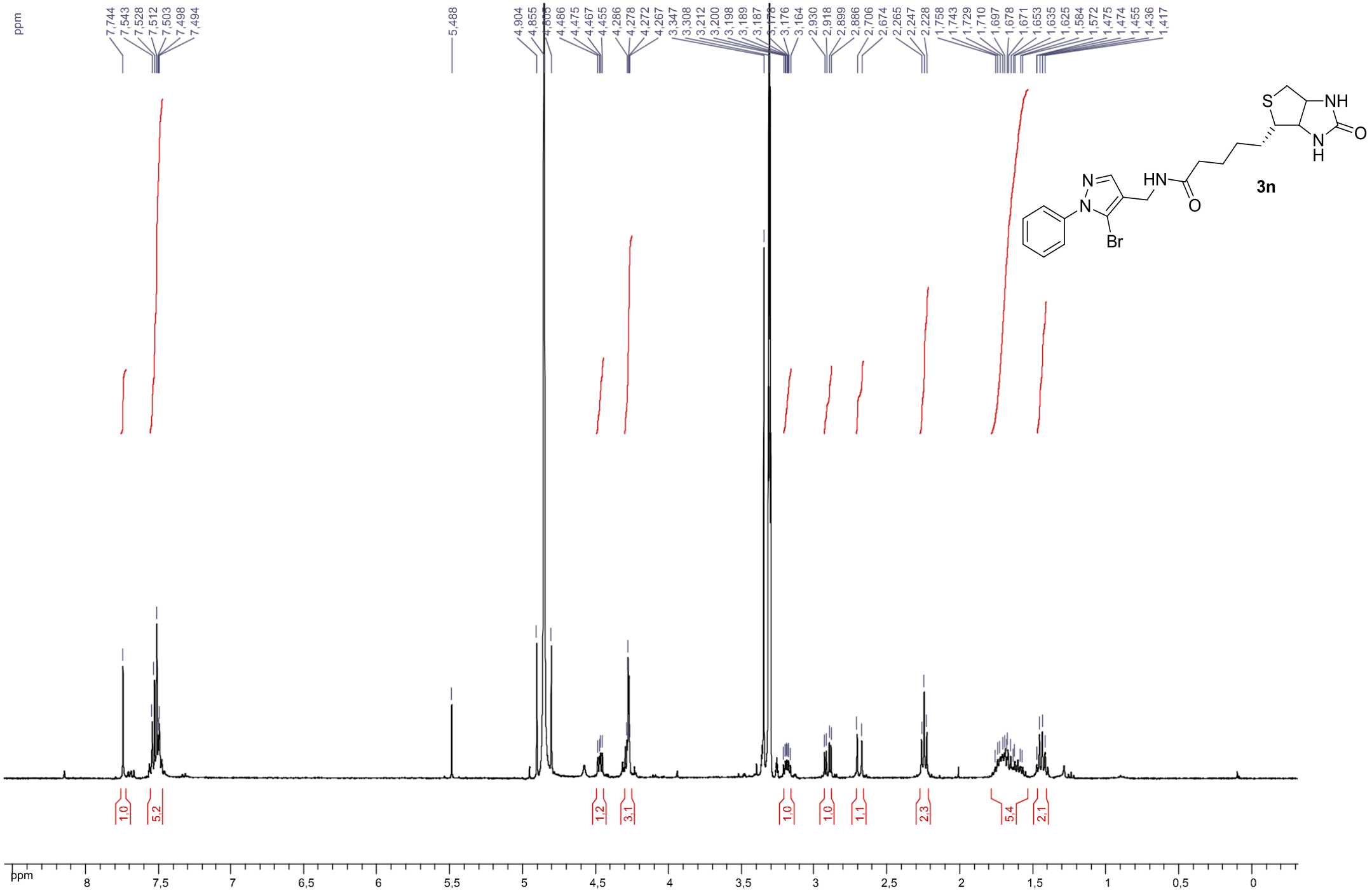
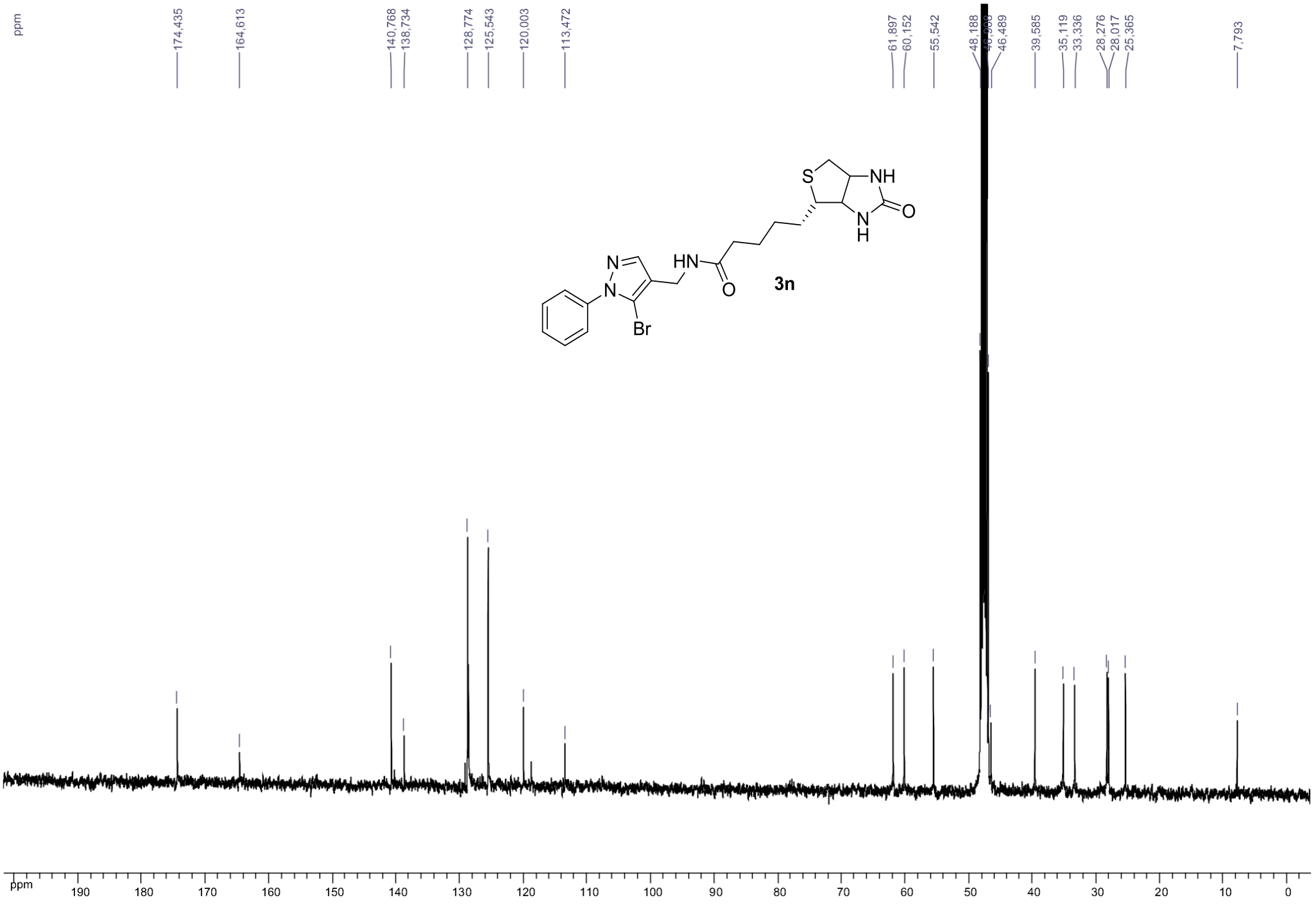
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0


ppm
174,146
164,628
79,234
70,577
61,890
60,168
55,466
48,356
46,901
39,570
35,028
28,231
27,979
27,918
25,205
HN
O
H
N
O
S
NH
ppm
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0


ppm
7.744
7.543
7.528
7.512
7.503
7.498
7.494
5.488
4.904
4.855
4.806
4.486
4.475
4.467
4.455
4.286
4.278
4.272
4.267
3.347
3.308
3.212
3.200
3.198
3.189
3.187
3.176
3.164
2.930
2.918
2.899
2.886
2.706
2.674
2.265
2.247
2.228
1.758
1.743
1.729
1.710
1.697
1.678
1.671
1.653
1.635
1.625
1.584
1.572
1.475
1.474
1.455
1.436
1.417
1,0
5,2
1,2
3,1
1,0
1,0
1,1
2,3
5,4
2,1
ppm
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
S
NH
O
N
H
N
HN
O
N
Br
3n


ppm
174,435
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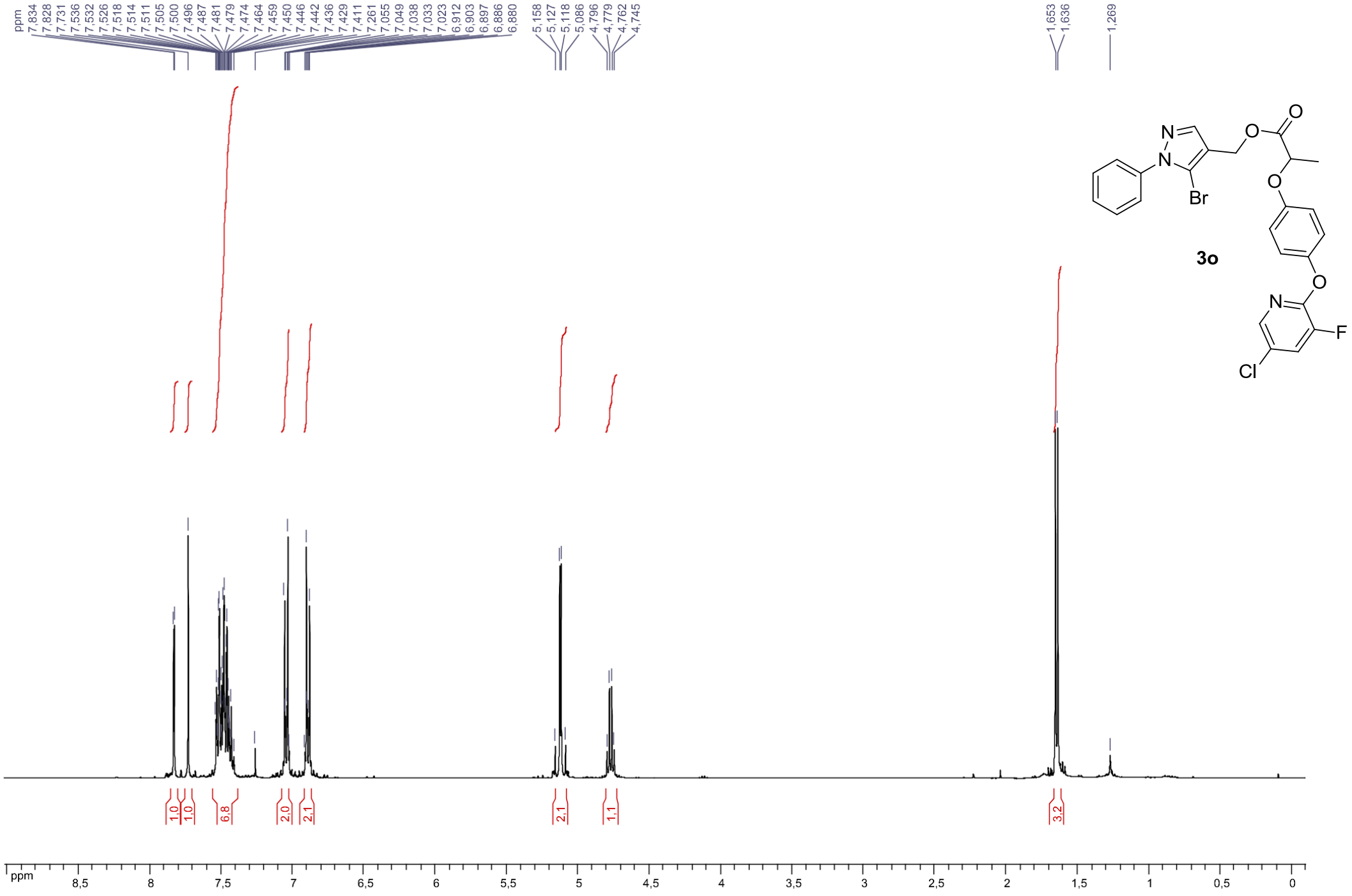
140,768
138,734
128,774
125,543
120,003
113,472
61,897
60,152
55,542
48,188
46,489
39,585
35,119
33,336
28,276
28,017
25,365
7,793
S
NH
O
N
H
HN
O
N
N
Br
3n
ppm
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0


ppm
7,834
7,828
7,731
7,536
7,532
7,526
7,518
7,514
7,511
7,505
7,500
7,496
7,487
7,481
7,479
7,474
7,464
7,459
7,450
7,446
7,442
7,436
7,429
7,411
7,261
7,055
7,049
7,038
7,033
7,023
6,912
6,903
6,897
6,886
6,880
5,158
5,127
5,118
5,086
4,796
4,779
4,762
4,745
1,653
1,636
1,269
N
N
Br
O
O
O
O
N
F
Cl
3o
1,0
1,0
6,8
2,0
2,1
2,1
1,1
3,2
ppm
8,5
8
7,5
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6,5
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5,5
5
4,5
4
3,5
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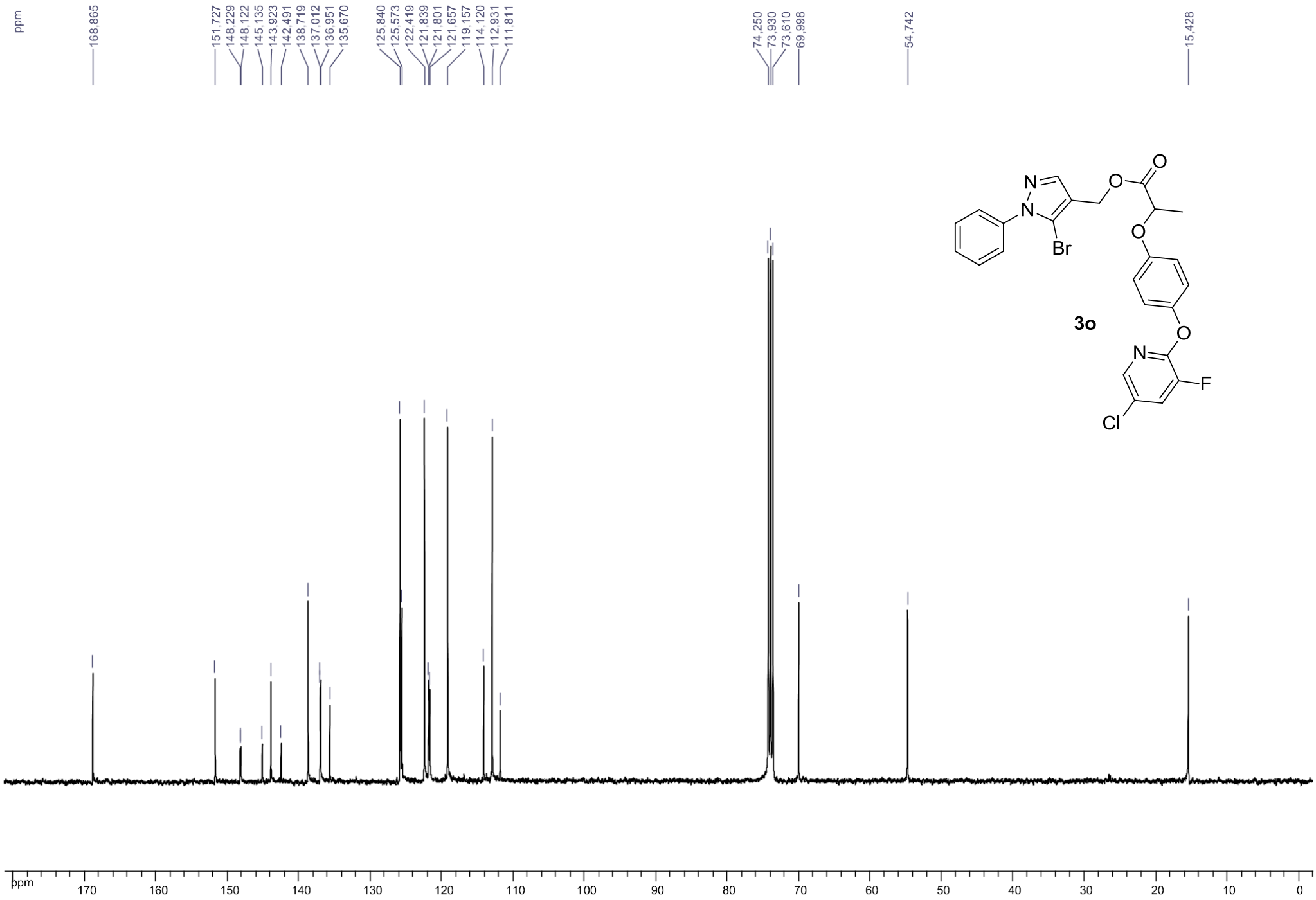
2,5
2
1,5
1
0,5
0


ppm
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148.122
145.135
143.923
142.491
138.719
137.012
136.951
135.670
125.840
125.573
122.419
121.839
121.801
121.657
119.157
114.120
112.931
111.811
74.250
73.930
73.610
69.998
54.742
15.428
N
N
Br
O
O
O
O
N
F
Cl
3o
ppm
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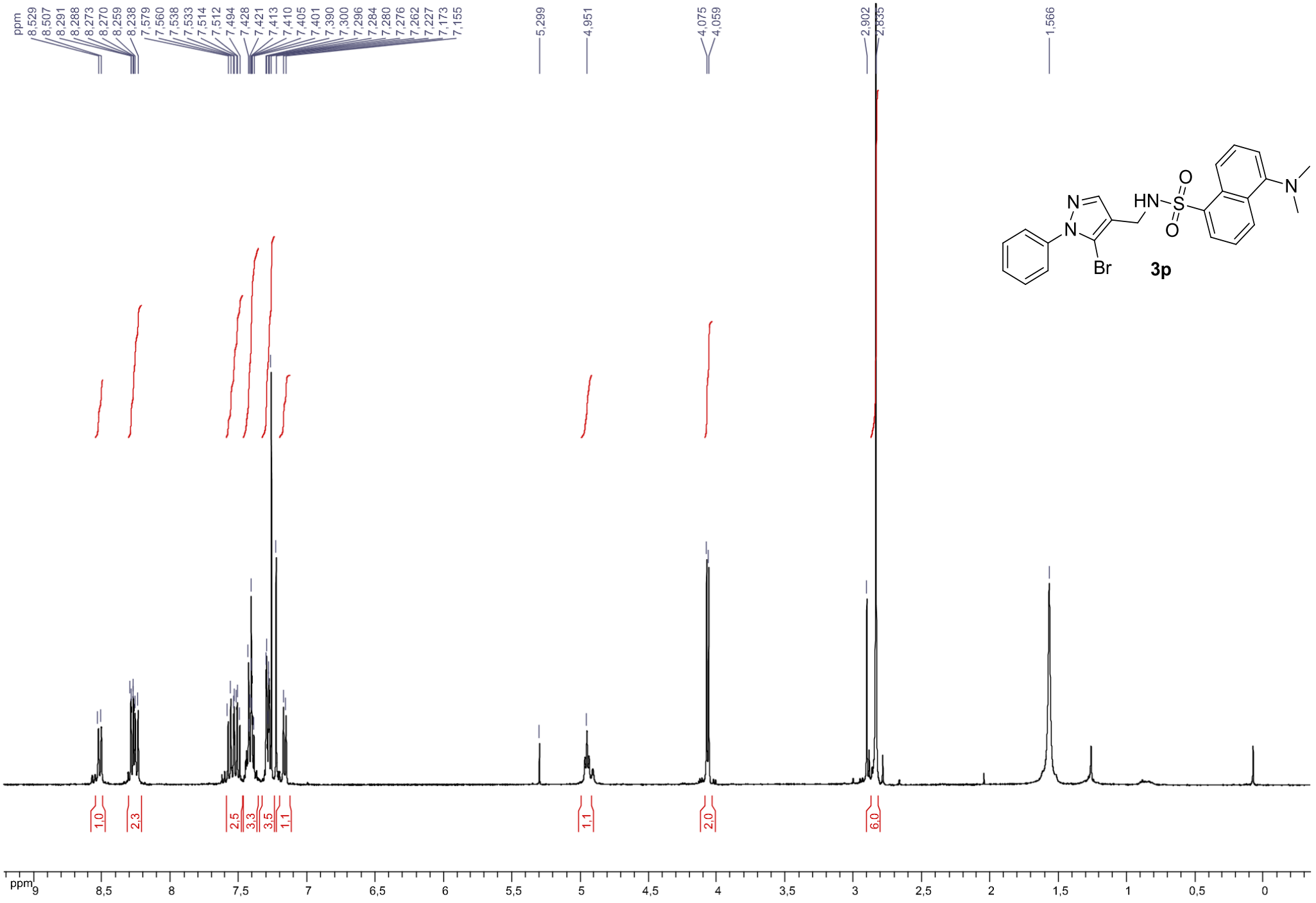
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0


ppm
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8.291
8.288
8.273
8.270
8.259
8.238
7.579
7.560
7.538
7.533
7.514
7.512
7.494
7.428
7.421
7.413
7.410
7.405
7.401
7.390
7.300
7.296
7.284
7.280
7.276
7.262
7.227
7.173
7.155
5.299
4.951
4.075
4.059
2.902
2.835
1.566
1,0
2,3
2,5
3,3
3,5
1,1
1,1
2,0
6,0
ppm
9
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
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HN
S
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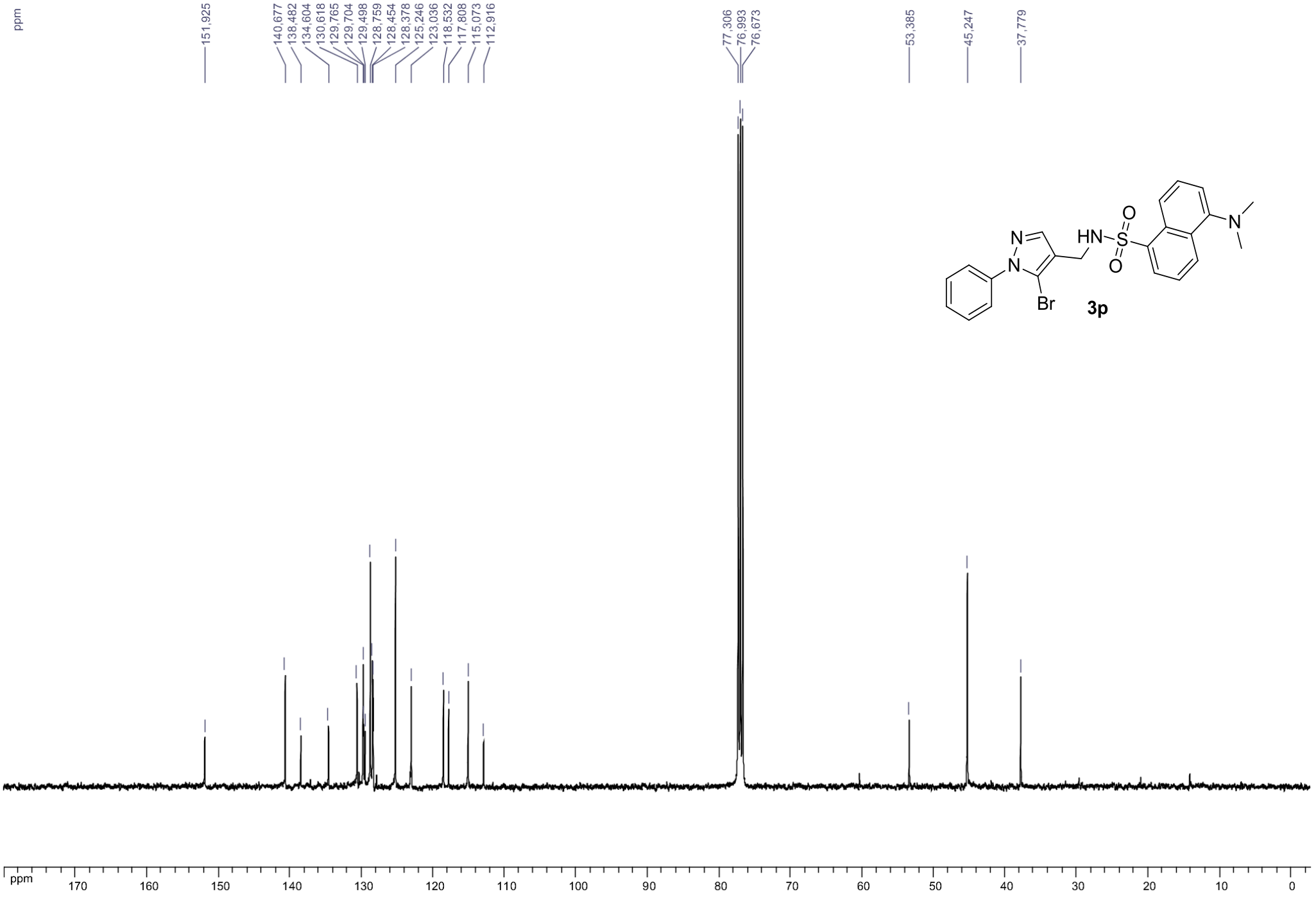
N
N
Br
3p


ppm
151,925
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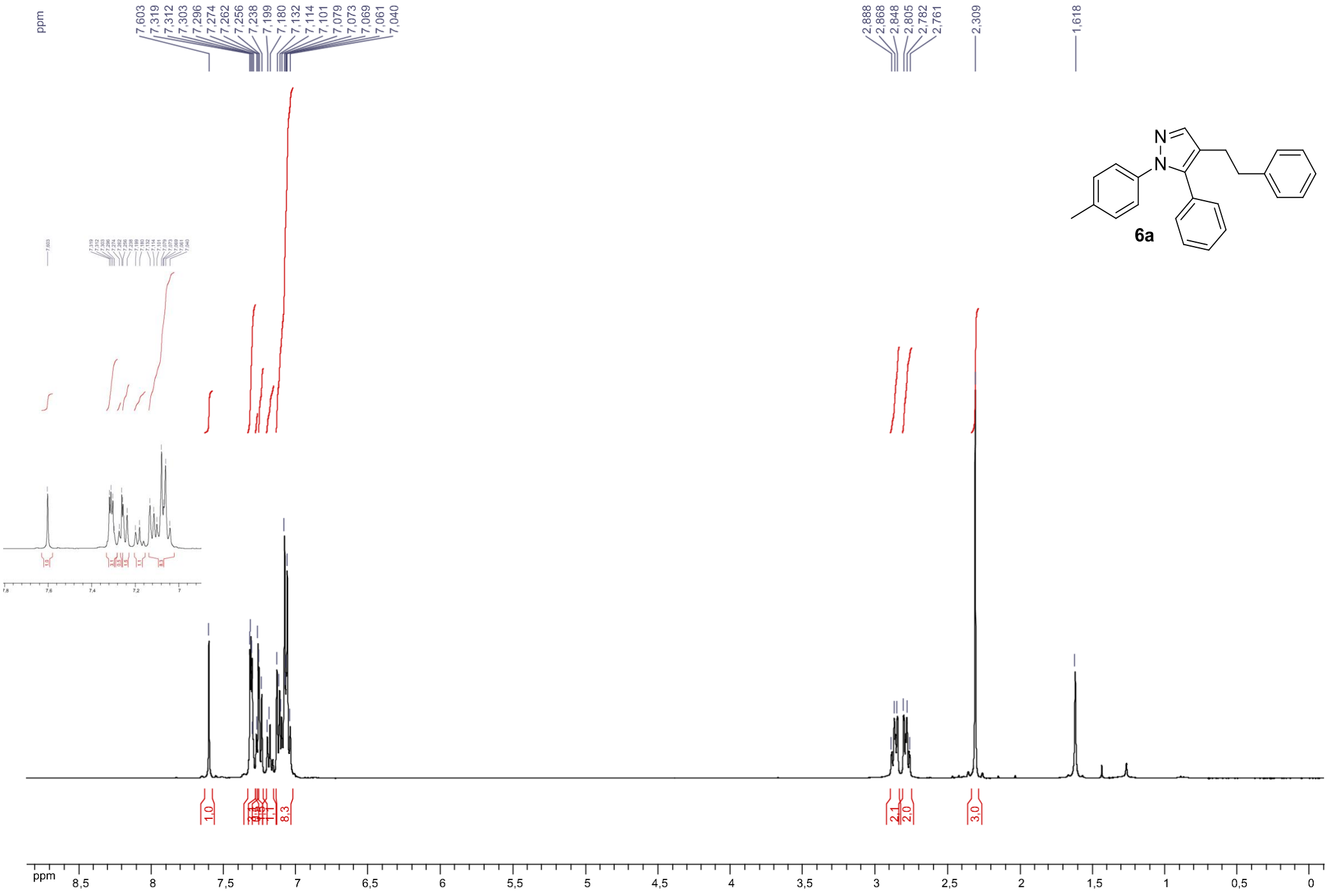
138,482
134,604
130,618
129,765
129,704
129,498
128,759
128,454
128,378
125,246
123,036
118,532
117,808
115,073
112,916
77,306
76,993
76,673
53,385
45,247
37,779
N
N
HN
S
O
O
N
Br
3p
ppm
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0


ppm
7,603
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7,312
7,303
7,296
7,274
7,262
7,256
7,238
7,199
7,180
7,132
7,114
7,101
7,079
7,073
7,069
7,061
7,040
2,888
2,868
2,848
2,805
2,782
2,761
2,309
1,618
N
N
6a
1,0
8,3
2,1
2,0
3,0
ppm
8,5
8
7,5
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6,5
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5,5
5
4,5
4
3,5
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2,5
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1,5
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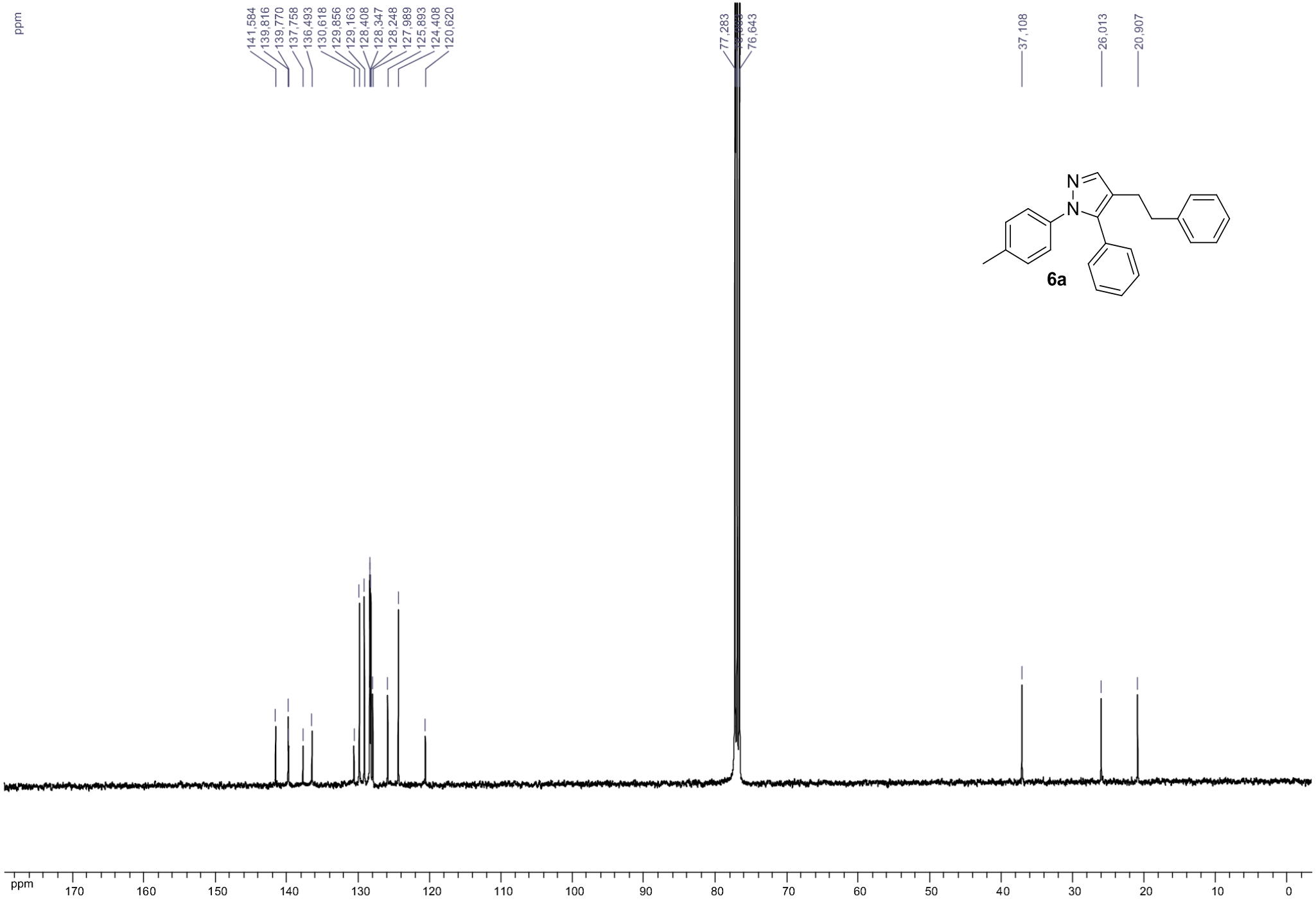
ppm
141.584
139.816
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137.758
136.493
130.618
129.856
129.163
128.408
128.347
128.248
127.989
125.893
124.408
120.620
77.283
76.643
37.108
26.013
20.907
N
N
6a
ppm
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150
140
130
120
110
100
90
80
70
60
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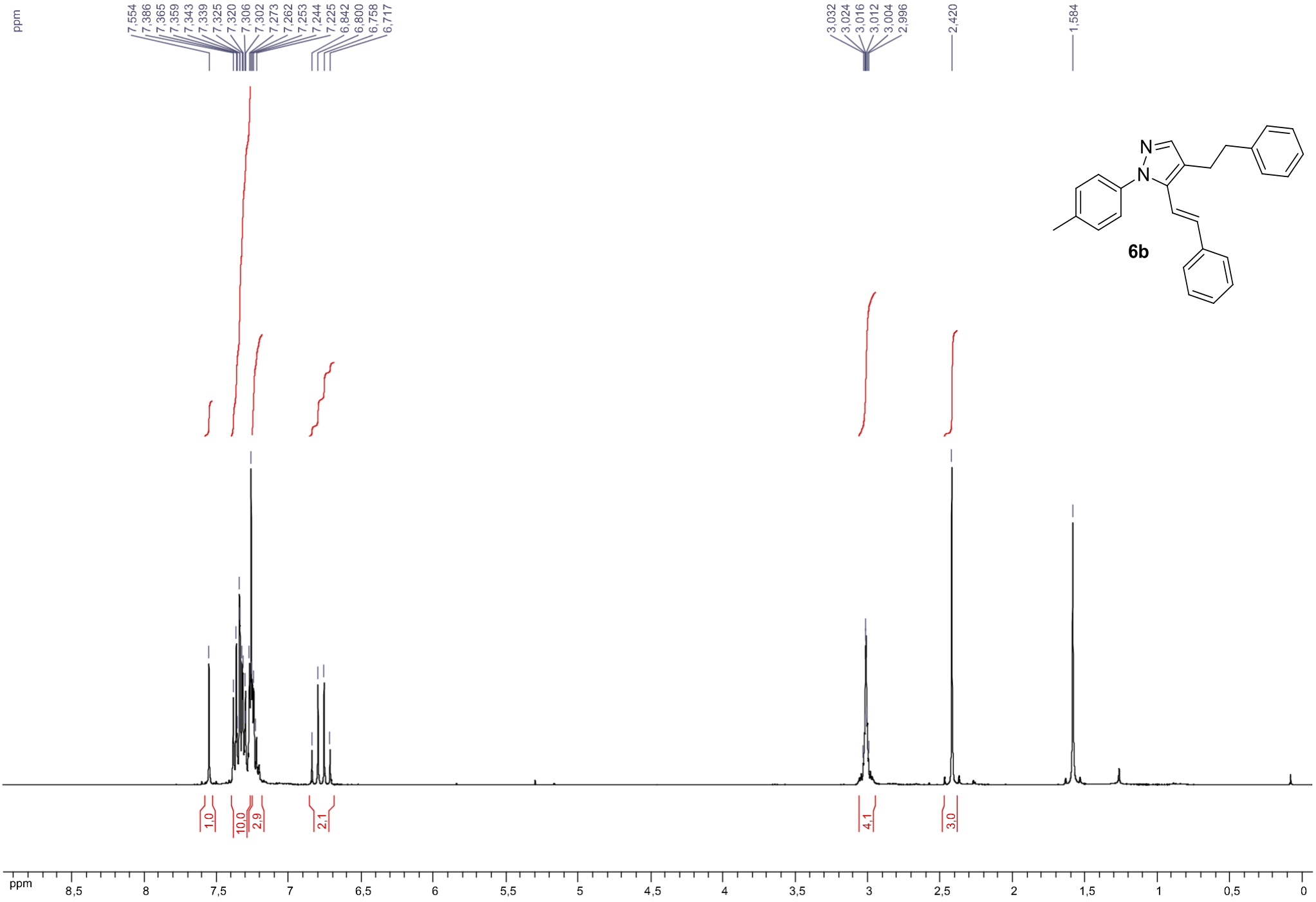
40
30
20
10
0


ppm
7,554
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7,359
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7,339
7,325
7,320
7,306
7,302
7,273
7,262
7,253
7,244
7,225
6,842
6,800
6,758
6,717
3,032
3,024
3,016
3,012
3,004
2,996
2,420
1,584
N
N
6b
1,0
10,0
2,9
2,1
4,1
3,0
ppm
8,5
8
7,5
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6,5
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5,5
5
4,5
4
3,5
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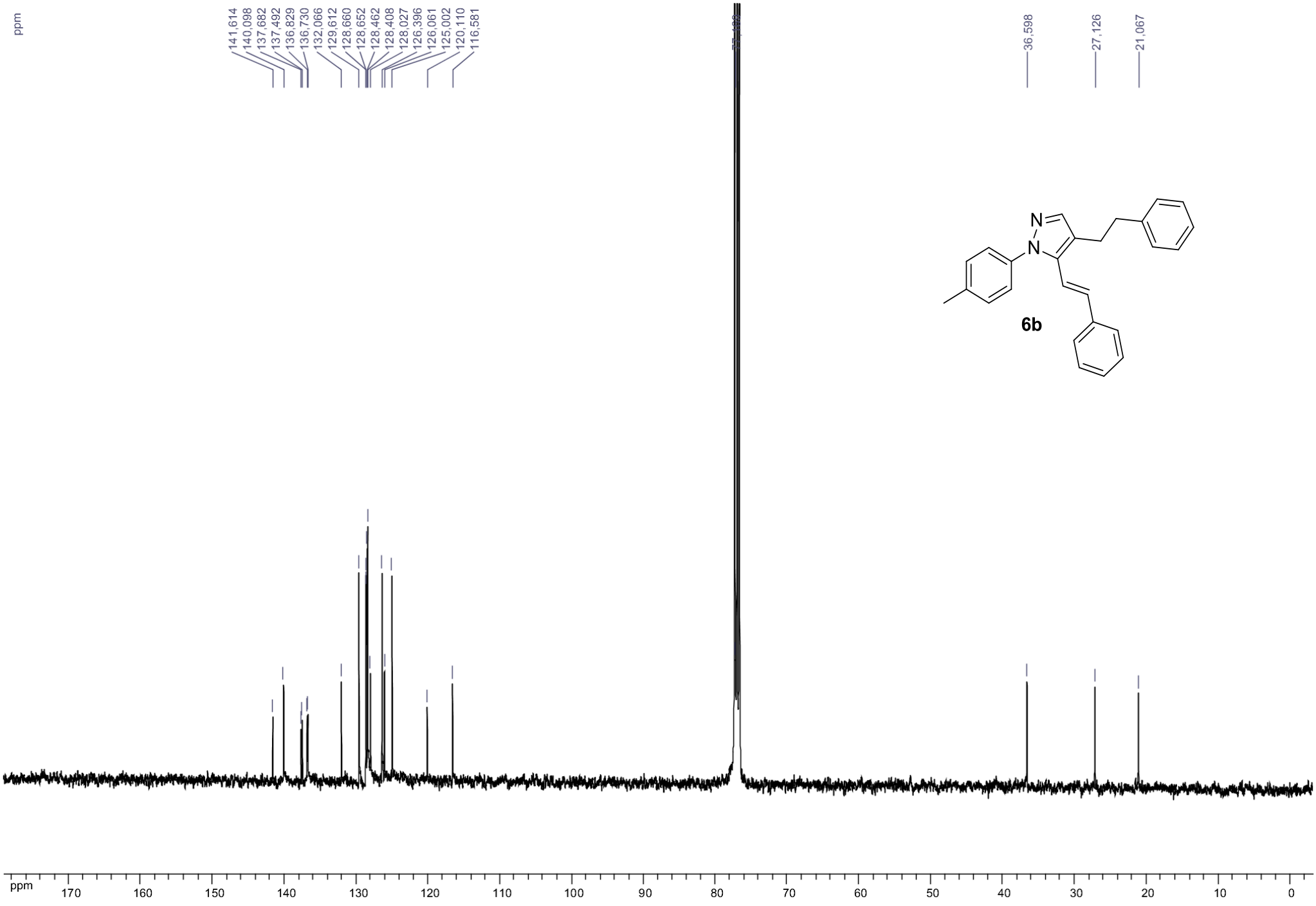
2,5
2
1,5
1
0,5
0


ppm
141,614
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137,682
137,492
136,829
136,730
132,066
129,612
128,660
128,652
128,462
128,408
128,027
126,396
126,061
125,002
120,110
116,581
36,598
27,126
21,067
N
N
6b
ppm
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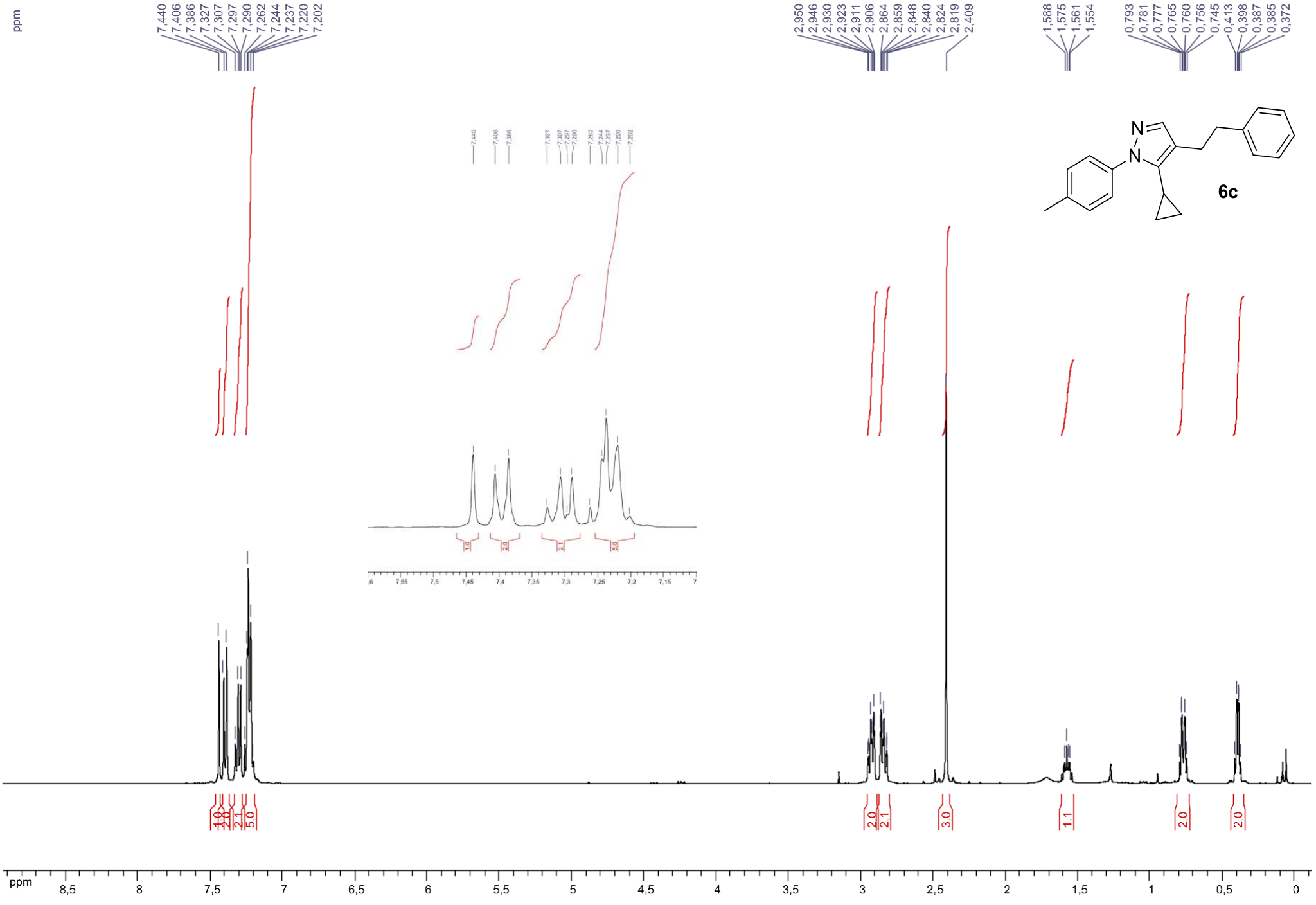
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0


ppm
7,440
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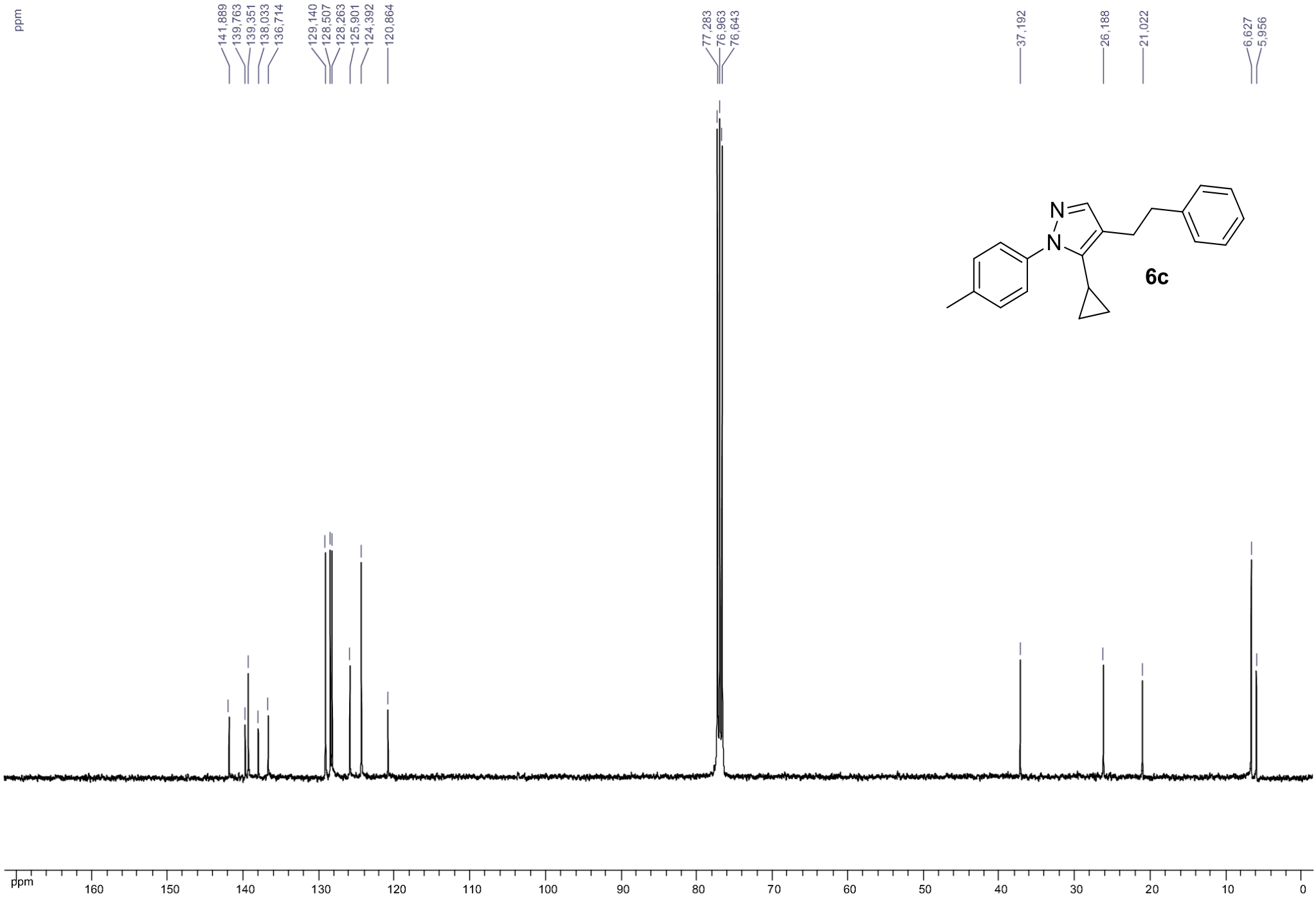
7,386
7,327
7,307
7,297
7,290
7,262
7,244
7,237
7,220
7,202
2,950
2,946
2,930
2,923
2,911
2,906
2,864
2,859
2,848
2,840
2,824
2,819
2,409
1,588
1,575
1,561
1,554
0,793
0,781
0,777
0,765
0,760
0,756
0,745
0,413
0,398
0,387
0,385
0,372
N
N
6c
1,0
2,0
2,1
5,0
2,0
2,1
3,0
1,1
2,0
2,0
ppm
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0


ppm
141,889
139,763
139,351
138,033
136,714
129,140
128,507
128,263
125,901
124,392
120,864
77,283
76,963
76,643
37,192
26,188
21,022
6,627
5,956
N
N
6c
ppm
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150
140
130
120
110
100
90
80
70
60
50
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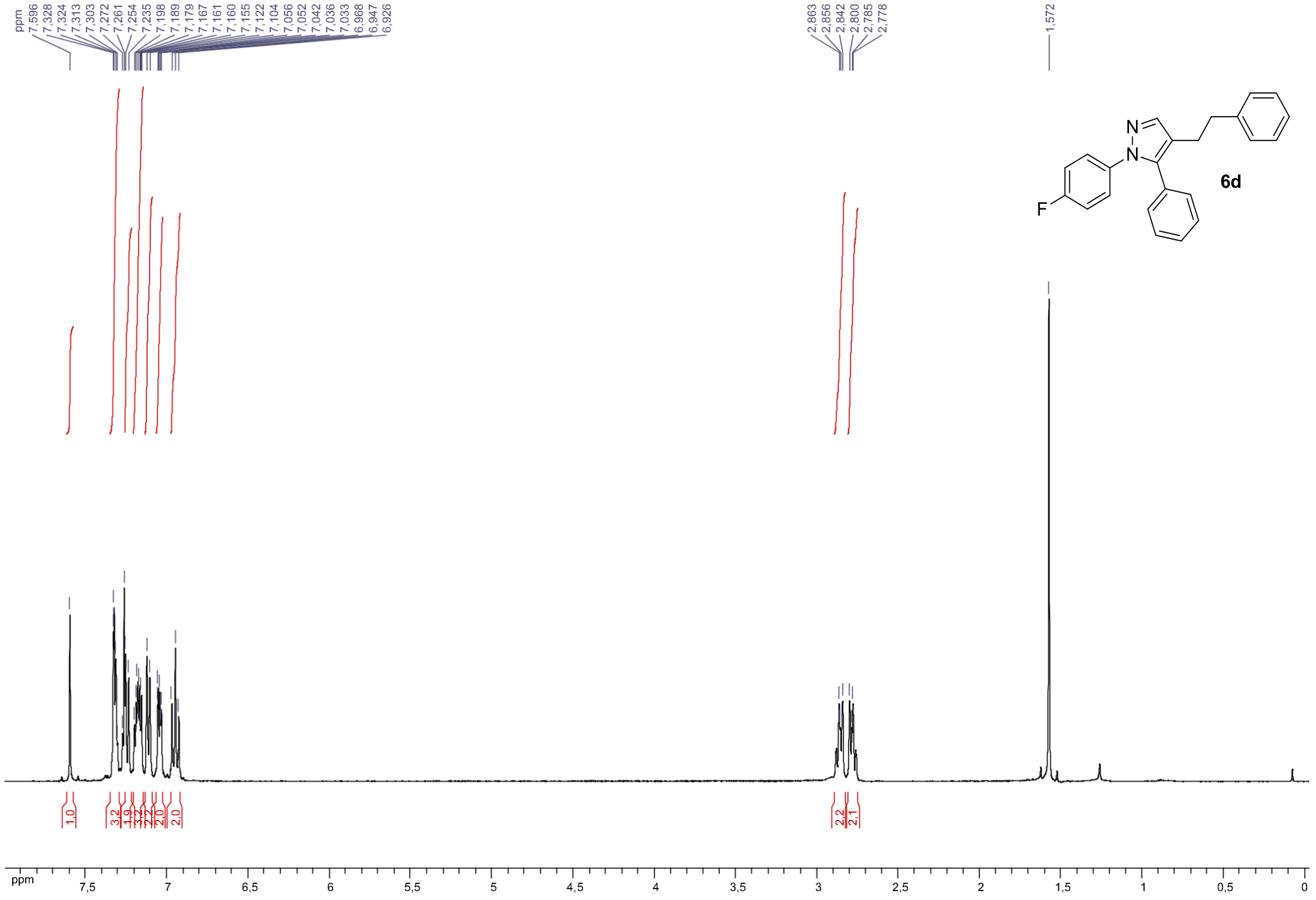
30
20
10
0


ppm
7,596
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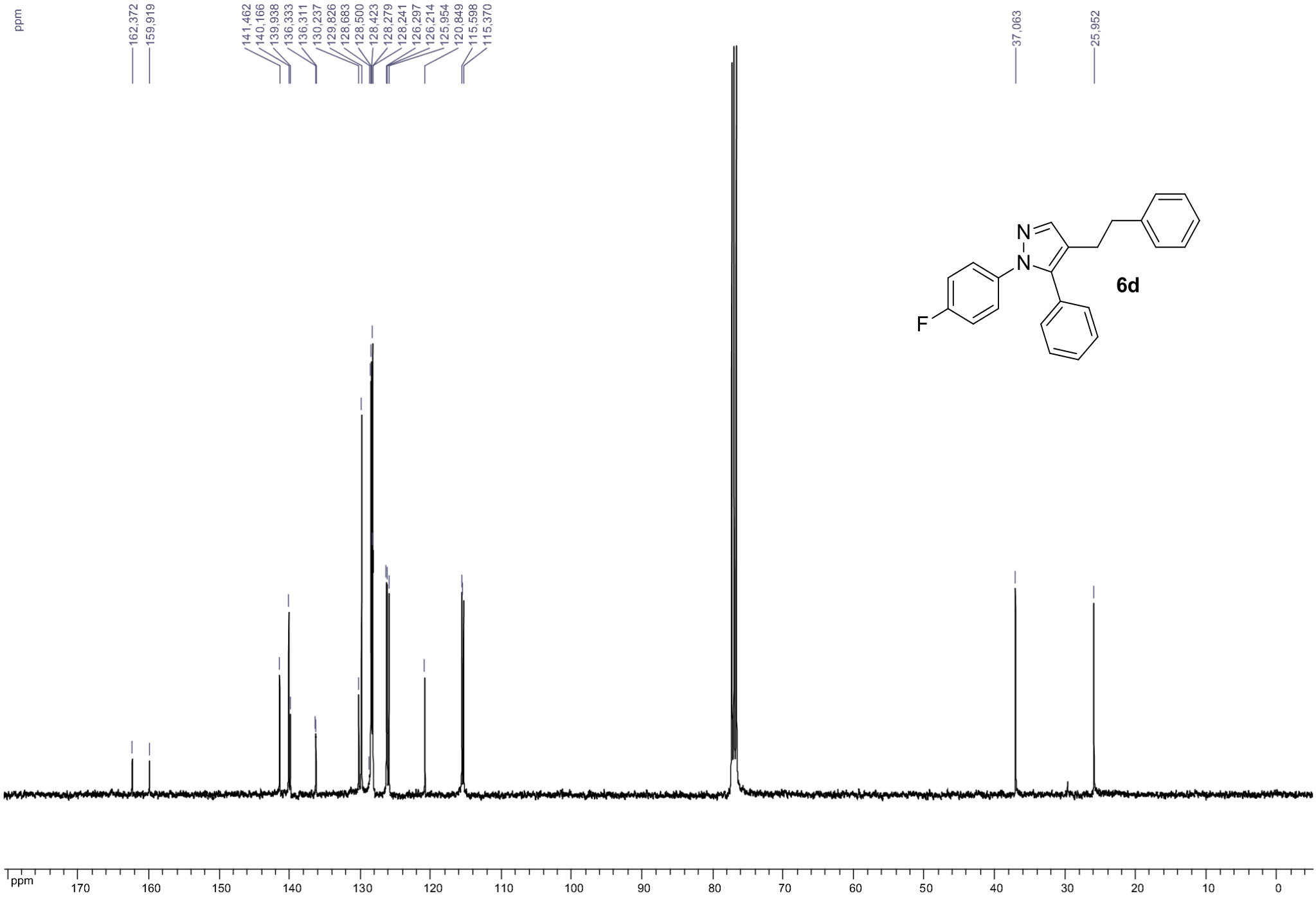
7,324
7,313
7,303
7,272
7,261
7,254
7,235
7,198
7,189
7,179
7,167
7,161
7,160
7,155
7,122
7,104
7,056
7,052
7,042
7,036
7,033
6,968
6,947
6,926
2,863
2,856
2,842
2,800
2,785
2,778
1,572
N
N
F
6d
1,0
3,2
1,9
3,2
2,2
2,0
2,0
2,2
2,1
ppm
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0


ppm
162,372
159,919
141,462
140,166
139,938
136,333
136,311
130,237
129,826
128,683
128,500
128,423
128,279
128,241
126,297
126,214
125,954
120,849
115,598
115,370
37,063
25,952
N
N
F
6d
ppm
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
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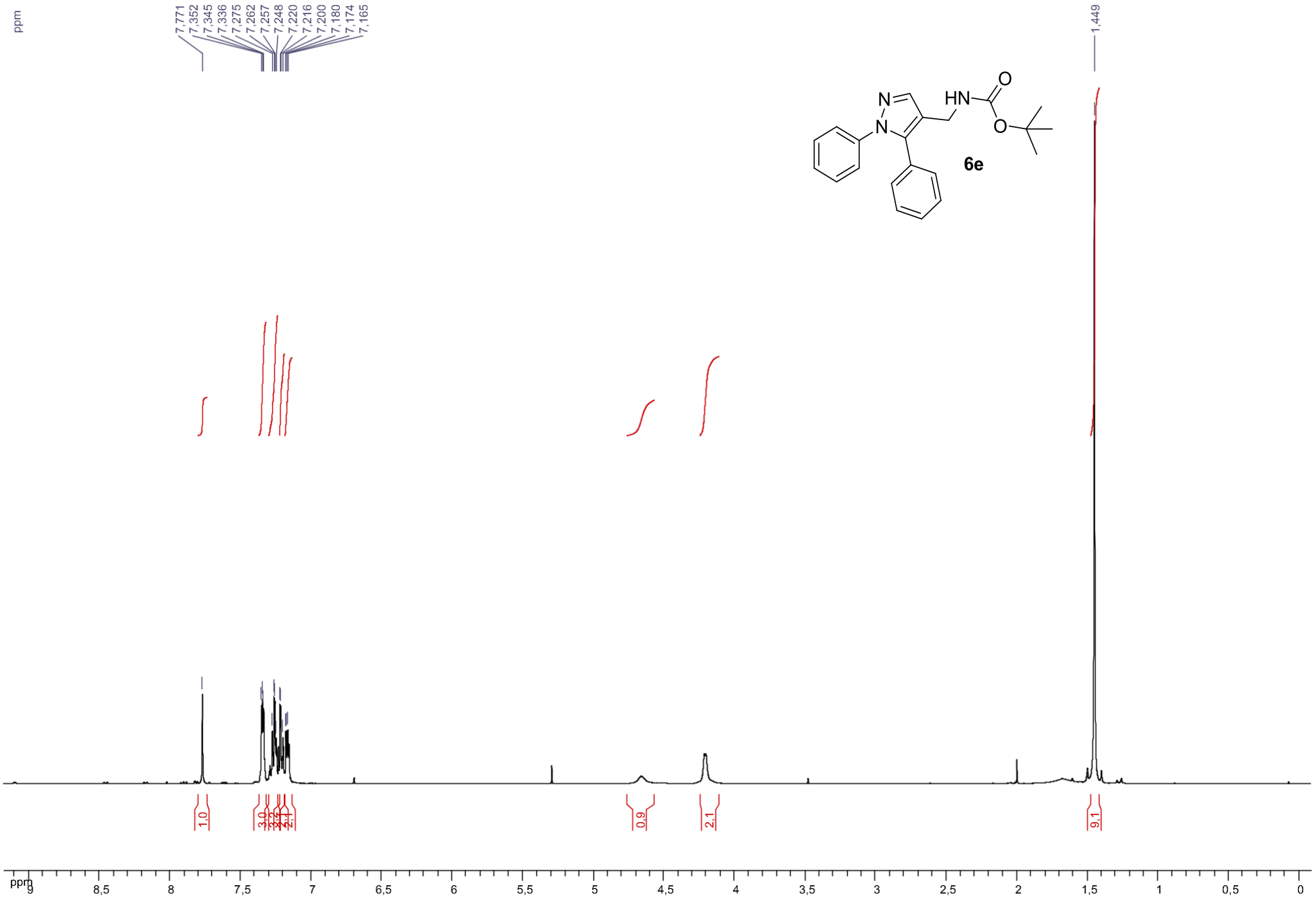
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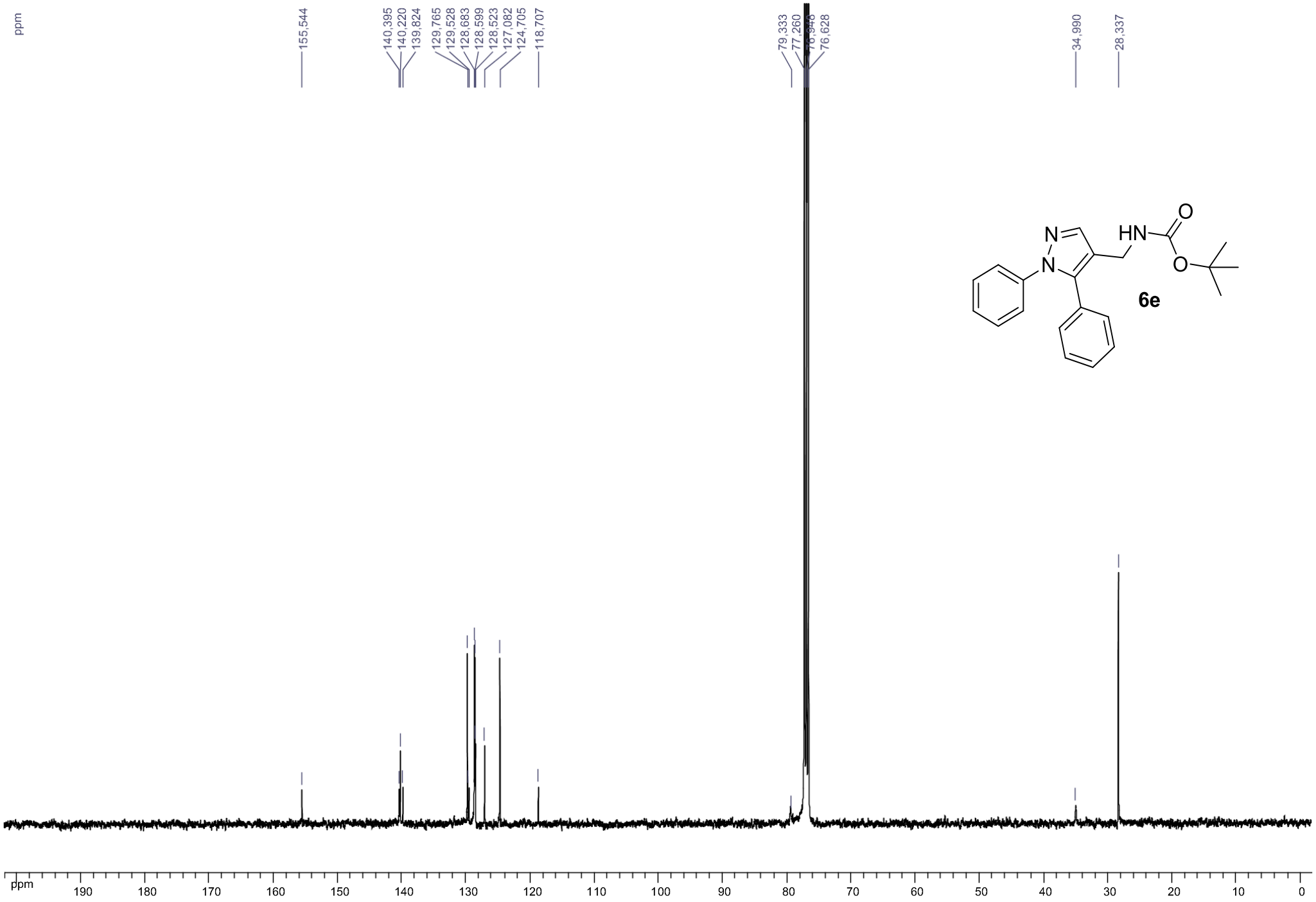
7,345
7,336
7,275
7,262
7,257
7,248
7,220
7,216
7,200
7,180
7,174
7,165
1,449
N
N
HN
O
O
6e
1,0
3,0
2,5
3,5
2,1
0,9
2,1
9,1
ppm
9
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0


ppm
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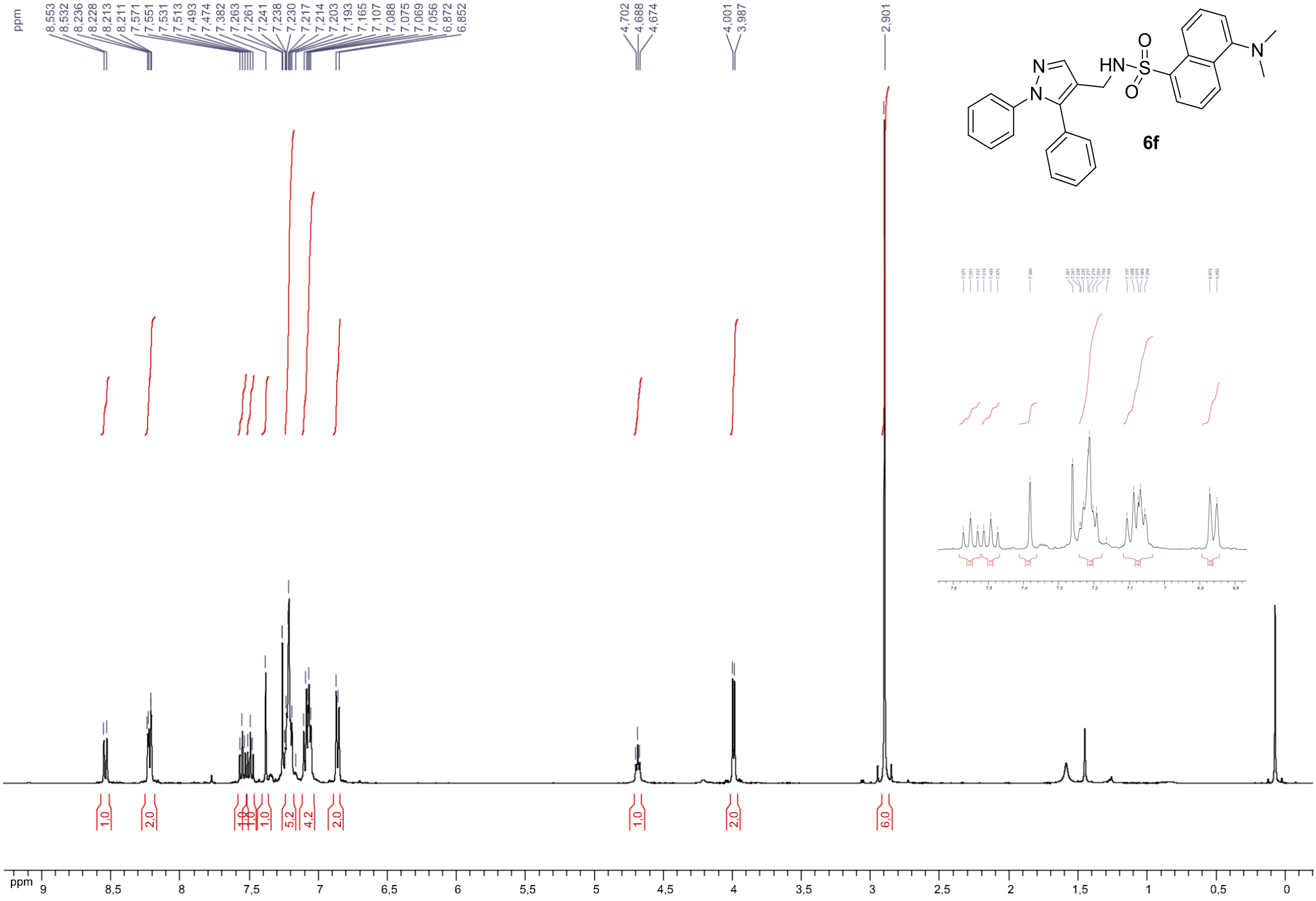
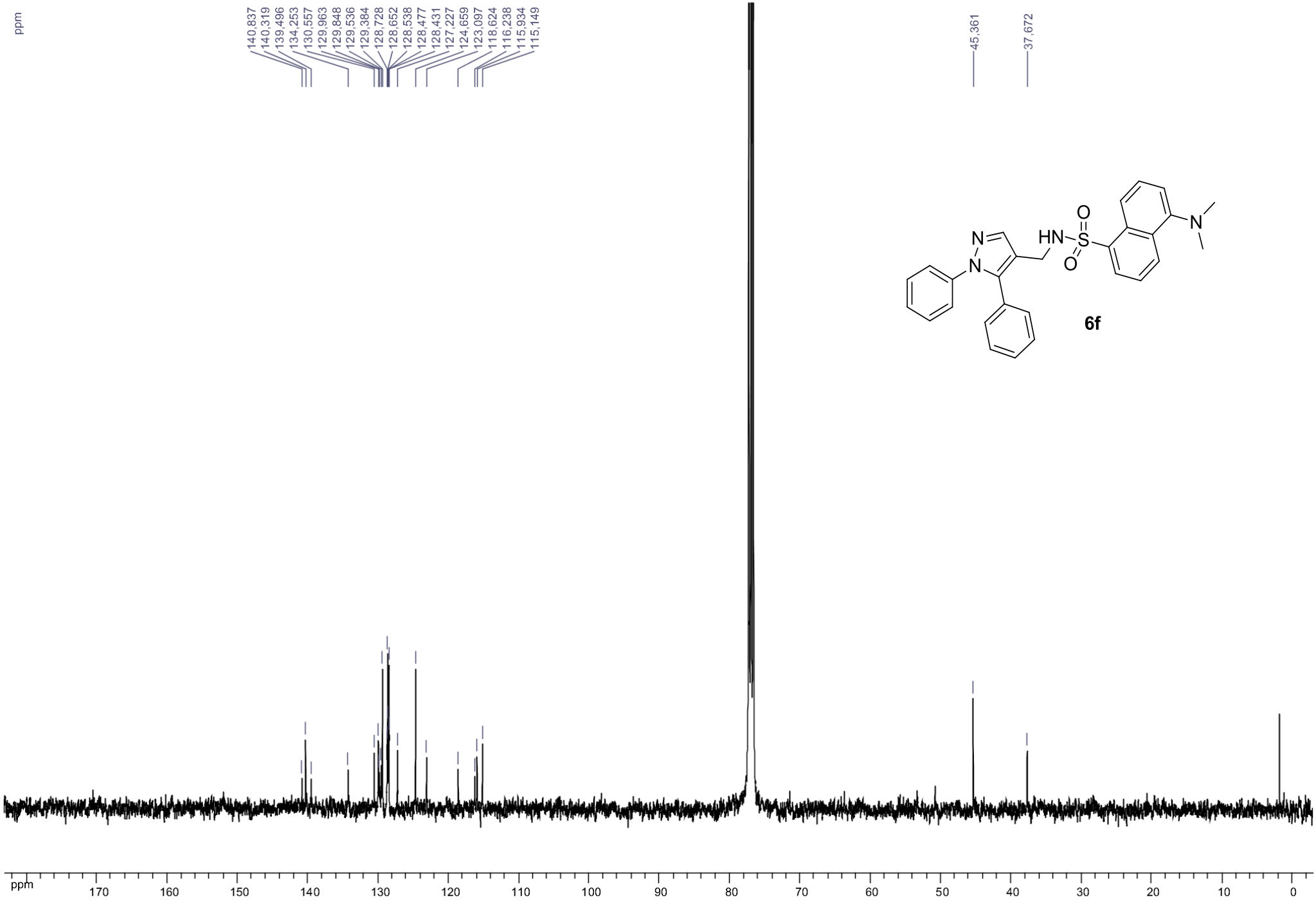
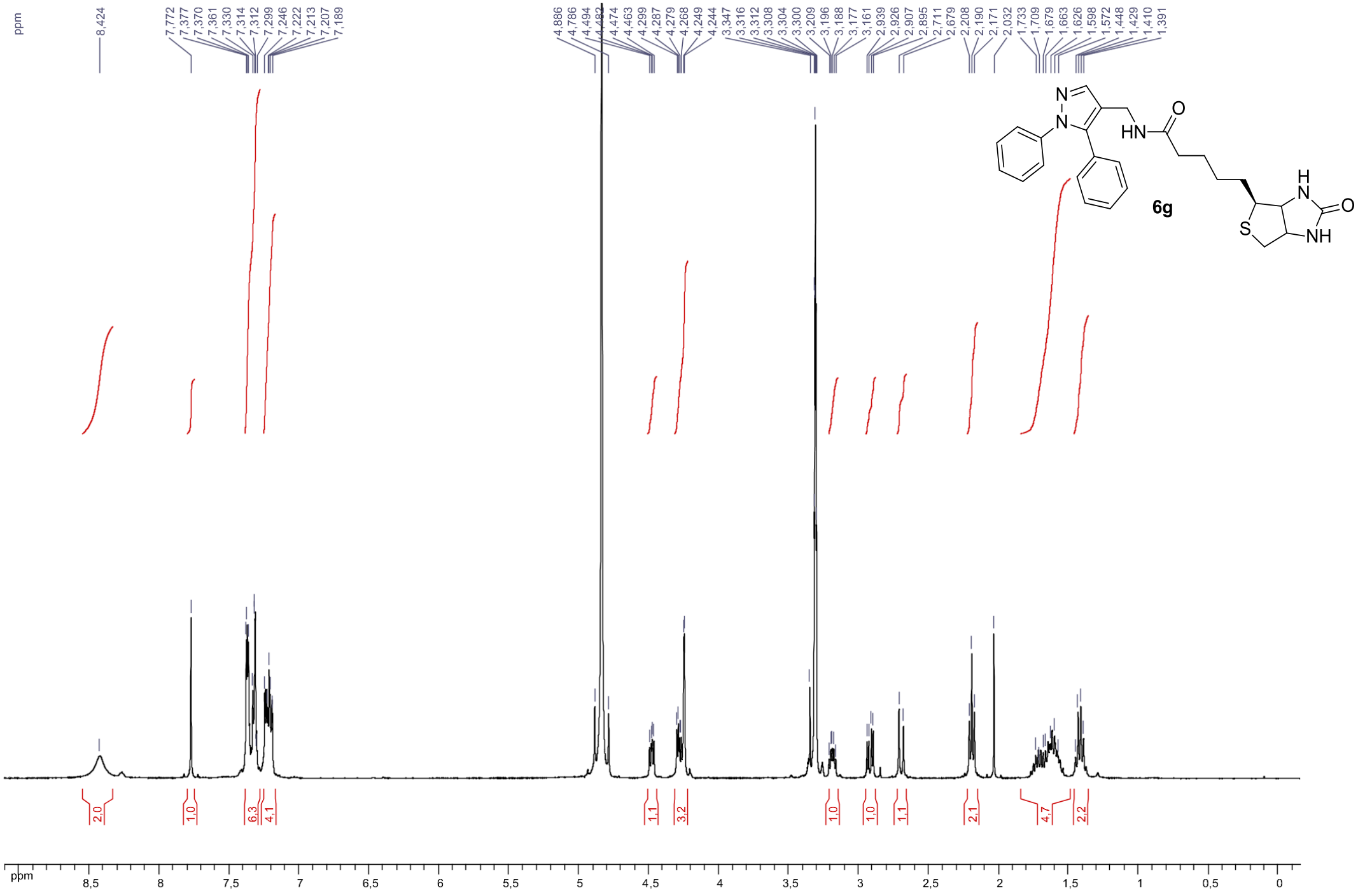
140.395
140.220
139.824
129.765
129.528
128.683
128.599
128.523
127.082
124.705
118.707
79.333
77.260
76.948
76.628
34.990
28.337
N
N
HN
O
O
6e
ppm
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0


ppm
8,553
8,532
8,236
8,228
8,213
8,211
7,571
7,551
7,531
7,513
7,493
7,474
7,382
7,263
7,261
7,241
7,238
7,230
7,217
7,214
7,203
7,193
7,165
7,107
7,088
7,075
7,069
7,056
6,872
6,852
4,702
4,688
4,674
4,001
3,987
2,901
1,0
2,0
1,0
1,0
1,0
5,2
4,2
2,0
1,0
2,0
6,0
ppm
9
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0

6f


ppm
140,837
140,319
139,496
134,253
130,557
129,963
129,848
129,536
129,384
128,728
128,652
128,538
128,477
128,431
127,227
124,659
123,097
118,624
116,238
115,934
115,149
45,361
37,672
N
N
HN
S
O
O
N
6f
ppm
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0


ppm
8,424
7,772
7,377
7,370
7,361
7,330
7,314
7,312
7,299
7,246
7,222
7,213
7,207
7,189
4,886
4,786
4,494
4,482
4,474
4,463
4,299
4,287
4,279
4,268
4,249
4,244
3,347
3,316
3,312
3,308
3,304
3,300
3,209
3,196
3,188
3,177
3,161
2,939
2,926
2,907
2,895
2,711
2,679
2,208
2,190
2,171
2,032
1,733
1,709
1,679
1,663
1,626
1,598
1,572
1,448
1,429
1,410
1,391
N
N
HN
O
H
N
O
S
NH
6g
2,0
1,0
6,3
4,1
1,1
3,2
1,0
1,0
1,1
2,1
4,7
2,2
ppm
8,5
8
7,5
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6,5
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5,5
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4,5
4
3,5
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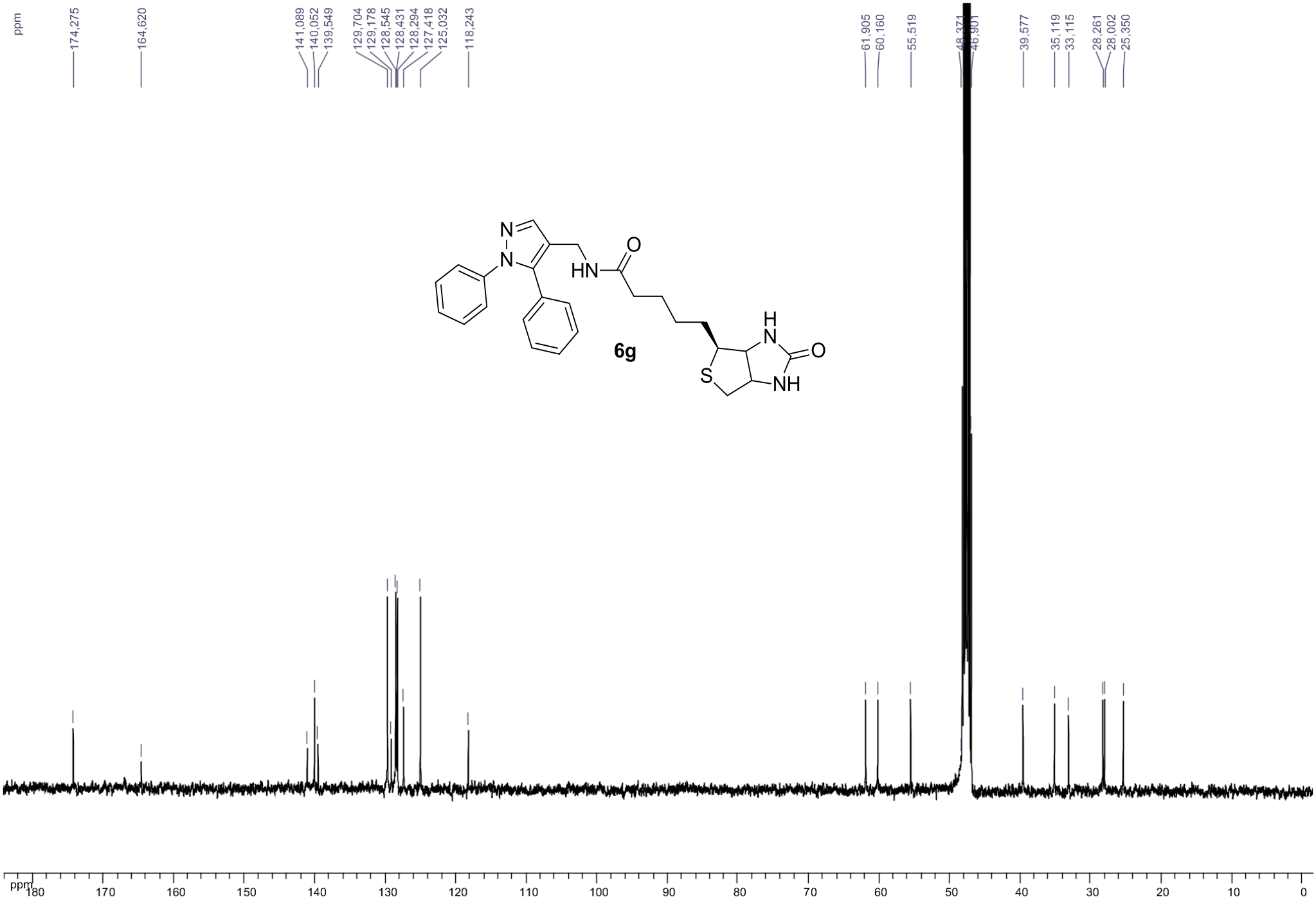
2,5
2
1,5
1
0,5
0


ppm
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141,089
140,052
139,549
129,704
129,178
128,545
128,431
128,294
127,418
125,032
118,243
61,905
60,160
55,519
48,371
46,901
39,577
35,119
33,115
28,261
28,002
25,350
N
N
HN
O
H
N
O
S
NH
6g
ppm
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0