Electronic supplementary information (ESI)

A theophylline based copper *N*-heterocyclic carbene complex: synthesis and activity studies in green media

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1. Equipment and chemicals used

All commercially available compounds and solvents were purchased from Sigma-Aldrich and used as received without further purification. Solvents had HPLC purity. Flash columns were performed using silica gel 60 (230–400 mesh). NMR spectra were recorded in $CDCl_3$, DMSO-d6 and D_2O solvents on Varian 400 MHz. Chemical shifts (δ) are given in ppm relative to TMS, coupling constants are (J) in Hz. In IR spectra wavenumbers are in cm^{-1}. MS spectra were recorded on LCMS-IT TOF Shimadzu spectrometer and AXIMA Performance MALDI TOF/TOF Mass Shimadzu spectrometer. IR spectra were recorded on Thermo Scientific™ Nicolet™ iS™50 FT-IR Spectrometer. Melting points were recorded by MPM-HVZ Paul Marienfeld GmbH & Co. KG Melting Point Meters.

2. Preparative experiments

2.1 Synthesis of compound 3 (*N*-(4-(bromomethyl)benzyl)-*N*,*N*-dimethylethanammonium bromide)

Compound **3** was synthesized on the basis of the literature procedure.[1]

A solution of *N*,*N*-dimethylethylamine (0.48 mL, 4.6 mmol) in 40 mL of MeCN was slowly added to a solution of α,α′-Dibromo-*p*-xylene (6.07 g, 23 mmol) in the mixture of solvents: MeCN/THF (10:1) (150 mL). The mixture was stirred at room temperature for 18 h. Subsequently, solvents were removed on a rotary evaporator. The remaining white solid was purified on column chromatography using mixture of solvents: EtOAc/*n*-hexane (150 mL, v/v = 3:7), pure DCM (100 mL) and DCM/MeOH (300 mL, v/v = 1:1) as eluents. The combined organic layers were concentrated to dryness to give white solid (3.59 mmol, 1.21 g, 78%). ^{1}H NMR (400 MHz, D_2O): δ 7.47 (d, J = 8.2 Hz, 2H), 7.40 (t, J = 8.9 Hz, 2H), 4.51 (s, 2H), 4.33 (s, 2H), 3.29-3.20 (m, 2H), 2.85 (s, 6H), 1.29 (t, J = 7.3 Hz, 3H) ppm; ^{13}C{1H} NMR (100 MHz, D_2O): δ 140.9, 133.3, 129.6, 127.2, 66.7, 59.8, 48.9, 32.6, 7.5 ppm; ESI-HRMS: (*m*/*z*) $[M+H]^+$ calcd for $C_{12}H_{19}BrN$: 256.0693, found 256.0693; IR (diamond tip): *v* 3378, 2994, 2970, 1489, 1467, 1433, 1424, 1414, 1387, 1237, 1216, 1199, 1098, 1027, 974, 994, 907, 862, 878, 825, 813, 796, 739, 700, 616, 589, 470, 452 cm^{-1}.

[1] A. Salmon and P. Jutzi, *Journal of Organometallic Chemistry*, **2001**, 637-639.

2.2 Synthesis of compound 5 (*N*-(4-((1*H*-benzo[d]imidazol-1-yl)methyl)benzyl)-*N*,*N*-dimethylethanammonium bromide)

Under argon atmosphere, a mixture of compound **3** (4.2 mmol, 1.42 g) and KOH (4.2 mmol, 0.24 g) in dry DMF (10 mL) was stirred for 15 minutes. After this time, a theophylline **4** (4.0 mmol, 0.72 g) was added to the flask and the reaction mixture was heated to 40 °C for 16 h. Subsequently, solvent was removed on a rotary evaporator. The remaining white solid was purified on column chromatography using mixture of solvents: pure DCM (100 mL), DCM/MeOH (300 mL, v/v = 9:1) and DCM/MeOH (450 mL, v/v = 3:1) as eluents. The combined organic layers were concentrated to dryness to give white solid (2.84 mmol, 1.24 g, 71%). ^{1}H NMR (400 MHz, D_2O): 7.97 (s, 1H), 7.34 (d, *J* = 7.7 Hz, 2H), 7.18 (d, *J* = 7.5 Hz, 2H), 5.40 (s, 2H), 4.26 (s, 2H), 3.35 (s, 3H), 3.19 (d, *J* = 7.1 Hz, 2H), 3.08 (s, 3H), 2.79 (s, 6H), 1.23 (t, *J* = 6.7 Hz, 3H) ppm; ^{13}C{1H} NMR (100 MHz, D_2O): δ 155.7, 152.4, 148.7, 143.3, 138.5, 133.2, 132.9, 127.6, 127.5, 127.0, 107.0, 66.6, 63.1, 59.8, 49.6, 48.8, 29.8, 27.8, 7.5 ppm; ESI-HRMS: (*m*/*z*) $[M+H]^+$ calcd for $C_{19}H_{26}N_5O_2$: 356.2081, found 356.2079; IR (diamond tip): *v* 1705, 1652, 1601, 1547, 1471, 1425, 1407, 1374, 1345, 1286, 1240, 1221, 1193, 1028, 976, 878, 843, 779, 758, 748, 735, 618, 534, 489 cm^{-1}.

2.3 Synthesis of compound 6 ((1-(4-((ethyldimethylammonium)methyl)benzyl)bromide-3-methyl-1*H*-benzo[d]imidazol-3-ium)iodide)

In Schlenk flask, compound **5** (2.3 mmol, 1.0 g) was placed and dissolved in dry MeCN (4 mL). To this solution, iodomethane (9.2 mmol, 0.57 mL) was added and stirred at 80 °C for 18 h. After this time, solvent was removed on a rotary evaporator and the remaining white solid was washed with *n*-pentane (2×5 mL) and dried on vacuum pump. The compound **6** was obtained as white solid with (2.06 mmol, 1.19 g, 89%). ^{1}H NMR (400 MHz, $(CD_3)_2SO$): δ 8.26 (s, 1H), 7.50 (d, *J* = 8.2 Hz, 2H), 7.42 (d, *J* = 8.2 Hz, 2H), 5.52 (s, 2H), 4.43 (s, 2H), 3.40 (s, 3H), 3.35-3.22 (m, 5H), 3.18 (s, 3H), 2.92-2.81 (m, 6H), 1.28 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C{1H} NMR (100 MHz, $(CD_3)_2SO$): δ 154.9, 151.4, 148.9, 143.1, 139.4, 133.7, 128.4, 128.2, 106.4, 66.2, 65.8, 59.4, 49.1, 49.0, 29.9, 28.0, 8.4 ppm; MALDI-MS: (*m*/*z*) $[M+Li]^+$ calcd for $C_{20}H_{29}N_5O_2$: 378.2475, found 378.0250; IR (diamond tip): *v* 3087, 3064, 2985, 2970, 2934, 2868, 2004, 1978, 1951, 1864, 1779, 1748, 1665, 1573, 1563, 1476, 1447, 1424, 1390, 1370, 1363, 1300, 1275, 1262, 1214, 1196, 1170, 1137, 1124, 1095, 1037, 1024, 977, 940, 893, 798, 777, 771, 739, 709, 656, 630, 571, 520, 480 cm^{-1}.

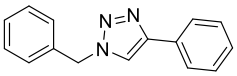
2.4 Synthesis of compound 7

A flask was charged with compound **6** (0.58 g, 1.0 mmol), CuCl (0.099 g, 1.0 mmol) and K_2CO_3 (0.414 g, 1.0 mmol). The mixture was dissolved in acetone 5 mL, (HPLC purity) and refluxed for 20 h. After the completion of reaction, the resultant mixture was filtered through a plug of Celite, and the filtrate was concentrated to about 1 mL under reduced pressure. Upon the addition of *n*-pentane to the crude reaction mixture, complex **7** was slowly precipitated and isolated as a white solid (0.62 mmol, 0.34 g, 62%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.80-7.62 (m, 2H), 7.43-7.27 (m, 2H), 5.53 (s, 2H), 5.00 (s, 2H), 3.78-2.90 (m, 14H), 2.16 (m, 3H), 1.40 (m, 3H) ppm; ^{13}C{1H} NMR (100 MHz, $CDCl_3$): 162.5, 155.2, 151.6, 141.3, 138.8, 133.9, 128.5, 128.1, 127.1, 106.8, 66.6, 59.6, 49.5, 36.5, 31.4, 29.9, 29.8, 28.0, 27.6, 8.7 ppm; MALDI-MS: (*m*/*z*) $[M+H]^+$ calcd for $C_{20}H_{29}ClCuN_5O_2$: 471.1282, found 472.0470; IR (diamond tip): *v* 2963, 1705, 3079, 3067, 1955, 1884, 1845, 1648, 1570, 1474, 1447, 1427, 1316, 1282, 1249, 1176, 1154, 1132, 1104, 1081, 1066, 1027, 999, 882, 839, 771, 756, 741, 711, 681, 648, 614, 584, 565, 502, 489, 449, 415 cm^{-1}; m. p. (degradation) = 230-232 ºC.

2.5 Catalytic activity of complex 7: typical procedure for the three component CuAAC reaction

In a vial fitted with a screw cap, alkyne (1.1 mmol), azide (1.1 mmol) and organic halogen (1.0 mmol) were dissolved in solvent (1 mL). Next, copper catalyst **7** (0.01 mmol) was introduced to the reaction mixture. The reaction was performed at room temperature and was monitored by TLC plate. After completion of the reaction, 2 mL of Et_2O was added to the vial and phases separation was fulfilled. Organic phase was carefully sampled, dried over $MgSO_4$ and evaporated to dryness. The crude product was purified by filtration on short pad of silica gel, using cyclohexane/ethyl acetate 10:1 as eluent, to obtain a corresponding 1,4-disubstituted triazole (73-93% yield).

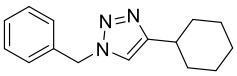
(**1-benzyl-4-phenyl-1*H*-1,2,3-triazole, 11**) white crystals, 62 mg, yield 88%



^{1}H NMR (400 MHz, $CDCl_3$): δ 7.85-7.74 (m, 2H), 7.65 (s, 1H), 7.46-7.27 (m, 8H), 5.57 (s, 2H) ppm; ^{13}C{1H} NMR (100 MHz, $CDCl_3$): δ 148.2, 134.6, 130.5, 129.1, 129.0, 128.8, 128.1, 125.7,

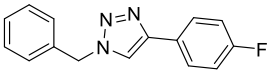
119.4, 54.2 ppm. Spectroscopic data for the compound **11** were consistent with the previously reported ones.[2]

(**1-benzyl-4-cyclohexyl-1*H*-1,2,3-triazole, 12**) white crystals, 61 mg, yield 84%.



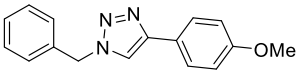
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.43-7.28 (m, 3H), 7.28-7.19 (m, 2H), 7.13 (s, 1H), 5.47 (s, 2H), 2.79-2.66 (m, 1H), 2.10-1.95 (m, 2H), 1.86-1.63 (m, 3H), 1.45-1.12 (m, 5H) ppm; ^{13}C{1H} NMR (100 MHz, $CDCl_3$): δ 154.2, 135.0, 129.0, 128.5, 128.0, 119.1, 53.9, 35.3, 33.0, 26.1, 26.0 ppm. Spectroscopic data for the compound **12** were consistent with the previously reported ones.[3]

(**1-benzyl-4-(4-fluorophenyl)-1*H*-1,2,3-triazole, 13**) white crystals, 60 mg, yield 79%.



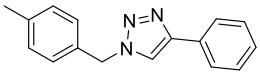
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.84-7.67 (m, 2H), 7.60 (s, 1H), 7.45-7.27 (m, 5H), 7.17-6.95 (m, 2H), 5.56 (s, 2H) ppm; ^{13}C{1H} NMR (100 MHz, $CDCl_3$): δ 163.9, 161.4, 142.5, 139.9, 134.5, 129.2, 128.8, 128.1, 127.4, 127.3, 119.1, 115.9, 115.6, 54.3 ppm; ^{19}F NMR (376 MHz, $CDCl_3$): δ –113.1 ppm. Spectroscopic data for the compound **13** were consistent with the previously reported ones.[4]

(**1-benzyl-4-(4-methoxyphenyl)-1*H*-1,2,3-triazole, 14**) white crystals, 73 mg, yield 91%.



^{1}H NMR (400 MHz, $CDCl_3$): δ 7.71 (d, *J* = 8.9 Hz, 2H), 7.56 (s, 1H), 7.43-7.26 (m, 5H), 6.92 (d, *J* = 8.9 Hz, 2H), 5.55 (s, 2H), 3.81 (s, 3H) ppm; ^{13}C{1H} NMR (100 MHz, $CDCl_3$): δ 159.5, 148.1, 134.7, 129.1, 128.7, 128.0, 127.0, 123.2, 118.6, 114.2, 55.3, 54.2 ppm. Spectroscopic data for the compound **14** were consistent with the previously reported ones.[3,5]

(**1-(4-methylbenzyl)-4-phenyl-1*H*-1,2,3-triazole, 15**) white crystals, 69 mg, yield 92%.



[2] E. Ozkal, P. Llanes, F. Bravo, A. Ferrali and M. A. Perics, *Advanced Synthesis and Catalysis*, **2014** , *356*, 857-869.

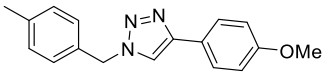
[3] H. J. Kim and S. Kim, *RSC Advances*, **2014**, *4*, 26516-26523.

[4] P. N. Liu, H. X. Sivang, L. Zhang, S. K. S. Tse and G. Jia, *Journal of Organic Chemistry*, **2012**, *77*, 5844-5849.

[5] L. Sun, R. Bai and Y. Gu, *Chemistry - A European Journal*, **2014**, *20*, 549-558.

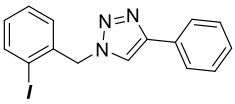
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.83-7.75 (m, 2H), 7.62 (s, 1H), 7.46-7.33 (m, 2H), 7.33-7.27 (m, 1H), 7.23-7.15 (m, 4H), 5.52 (s, 2H), 2.35 (s, 3H) ppm; ^{13}C{1H} NMR (100 MHz, $CDCl_3$): δ 148.1, 138.7, 131.6, 130.6, 129.8, 129.0, 128.8, 128.1, 125.6, 119.3, 54.0, 21.2 ppm. Spectroscopic data for the compound **15** were consistent with the previously reported ones.[3,6]

(**4-(4-methoxyphenyl)-1-(4-methylbenzyl)-1*H*-1,2,3-triazole, 16**) white crystals, 76 mg, yield 90%.



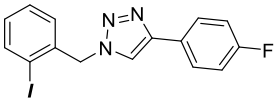
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.70 (d, *J* = 8.9 Hz, 2H), 7.53 (s, 1H), 7.19-7.18 (m, 4H), 6.91 (d, *J* = 8.9 Hz, 2H), 5.50 (s, 2H), 3.81 (s, 3H), 2.34 (s, 3H) ppm; ^{13}C{1H} NMR (100 MHz, $CDCl_3$): δ 159.5, 148.0, 138.7, 131.7, 129.8, 128.1, 127.0, 123.3, 118.5, 114.1, 55.3, 54.0, 21.2 ppm; HRMS-ESI: (*m*/*z*) $[M + H]^+$ calcd for $C_{17}H_{17}ON_3$: 279.1372, found 279.1369; IR (diamond tip): *v* 2919, 1615, 1579, 1559, 1517, 1497, 1469, 1455, 1444, 1417, 1343, 1313, 1301, 1264, 1244, 1222, 1202, 1187, 1136, 1105, 1072, 1051, 1024, 976, 828, 814, 796, 757, 742, 694, 661, 606, 540, 469, 455 cm^{-1}; m.p. 149 ºC.

(**1-(2-iodobenzyl)-4-phenyl-1*H*-1,2,3-triazole, 17**) white crystals, 100 mg, yield 92%.



^{1}H NMR (400 MHz, $CDCl_3$): δ 7.91-7.88 (m, 1H), 7.85-7.78 (m, 2H), 7.76 (s, 1H), 7.37-7.34 (m, 4H), 7.18-7.00 (m, 2H), 5.66 (s, 2H) ppm; ^{13}C{1H} NMR (100 MHz, $CDCl_3$): δ 148.1, 139.9, 137.4, 130.4, 129.6, 129.1, 128.8, 128.2, 125.9, 125.7, 119.8, 98.6, 58.5 ppm. Spectroscopic data for the compound **17** were consistent with the previously reported ones.[7]

(**4-(4-fluorophenyl)-1-(2-iodobenzyl)-1*H*-1,2,3-triazole, 18**) white crystals, 99 mg, yield 87%.



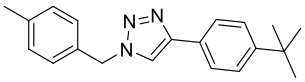
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.89 (dd, *J* = 7.5, 1.2 Hz, 1H), 7.82-7.74 (m, 2H), 7.72 (s, 1 H), 7.33 (dd, *J* = 7.5, 1.2 Hz, 1H), 7.18-7.00 (m, 4H), 5.65 (s, 2H) ppm; ^{13}C{1H} NMR (100 MHz, $CDCl_3$): δ 163.9, 161.4, 147.3, 139.9, 137.3, 130.5, 129.7, 129.1, 127.5 (d, *J* = 8.1 Hz), 126.7 (d, *J*

[6] L. Huang, W. Liu, J. Wu, Y. Fu, K. Wang, C. Huo and Z. Du, *Tetrahedron Letters*, **2014**, *55*, 2312-2316.

[7] F. Vito, G. Marchese, A. Punzi, F. Iannone and G. G. Rafaschieri, *Tetrahedron*, **2010**, *66*, 8846-8853.

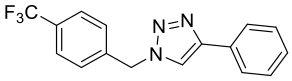
= 3.2 Hz), 119.5, 115.9, 115.7, 98.68, 58.5 ppm; ^{19}F NMR (376 MHz, $CDCl_3$): δ –113.5 ppm; HRMS-ESI: (*m*/*z*) $[M + H]^+$ calcd for $C_{15}H_{11}FIN_3$: 380.0055, found 380.0068; IR (diamond tip): *v* 3100, 1611, 1584, 1560, 1495, 1454, 1423, 1411, 1336, 1295, 1274, 1219, 1156, 1093, 1044, 1013, 980, 934, 821, 776, 739, 693, 672, 659, 647, 630, 606, 585, 523, 487, 477, 425 cm^{-1}; m.p. 229 ºC.

(**4-(4-(*tert*-butyl)phenyl)-1-(4-methylbenzyl)-1*H*-1,2,3-triazole, 19**) white crystals, 82 mg, yield 89%.



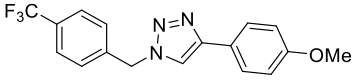
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.71 (d, *J* = 8.5 Hz, 2H), 7.59 (s, 1H), 7.40 (d, *J* = 8.5 Hz, 2H), 7.18 (s, 4H), 5.51 (s, 2H), 2.34 (s, 3H), 1.31 (s, 9H); ^{13}C{1H} NMR (100 MHz, $CDCl_3$): δ 151.2, 148.1, 138.6, 131.7, 129.7, 128.0, 127.7, 125.7, 125.4, 119.1, 54.0, 34.6, 31.3, 21.1 ppm; HRMS-ESI: (*m*/*z*) $[M + H]^+$ calcd for $C_{20}H_{23}N_3$: 306.1965, found 306.1973; IR (diamond tip): *v* 2958, 2866, 1515, 1495, 1426, 1362, 1268, 1219, 1204, 1185, 1116, 1072, 1048, 1021, 976, 824, 807, 770, 762, 751, 730, 711, 3065, 3027, 2962, 2928, 2884, 2850, 2813, 1849, 1732, 1625, 1591, 1563, 1468, 1412, 1342, 1284, 1270, 1200, 1159, 1123, 1051, 1022, 996, 955, 931, 883, 795, 772, 756, 718, 695, 637 559, 532, 489, 473, 426 cm^{-1}; m.p. 223 ºC.

(**4-phenyl-1-(4-(trifluoromethyl)benzyl)-1*H*-1,2,3-triazole, 20**) white crystals, 66 mg, yield 73%.



^{1}H NMR (400 MHz, $CDCl_3$) δ 7.91-7.90 (m, 1H), 7.78-7.76 (m, 2H), 7.72 (s, 1H), 7.34-7.32 (m, 1H), 7.18-7.02 (m, 4H), 5.66 (s, 2H) ppm; ^{13}C{1H} NMR (100 MHz, $CDCl_3$): δ 163.9, 161.4, 147.3, 139.9, 137.3, 130.5, 129.7, 129.1, 127.5, 127.4, 126.7, 126.6, 119.5, 115.9, 115.7, 98.7, 58.5 ppm; ^{19}F NMR (376 MHz, $CDCl_3$): δ –113.5 (d, *J* = 8.6 Hz) ppm. Spectroscopic data for the compound **20** were consistent with the previously reported ones.[8]

(**4-(4-methoxyphenyl)-1-(4-(trifluoromethyl)benzyl)-1*H*-1,2,3-triazole, 21**) white crystals, 66 mg, yield 85%.

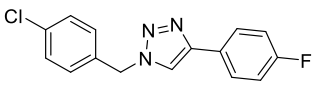


^{1}H NMR (400 MHz, $CDCl_3$) δ 7.72 (d, *J* = 8.9 Hz, 2H), 7.64 (d, *J* = 8.1 Hz, 2H), 7.60 (s, 1H), 7.41 (s, 2H), 6.93 (d, *J* = 8.9 Hz, 2H), 5.62 (s, 2H), 3.82 (s, 3H) ppm; ^{13}C{1H} NMR (100 MHz,

[8] K. Asano and S. Matsubara, *Organic Letters*, **2010**, *12*, 4988-4991.

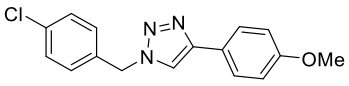
$CDCl_3$): δ 151.2, 148.1, 138.6, 131.7, 129.7, 128.0, 127.7, 125.7, 125.4, 119.1, 54.0, 34.6, 31.3, 21.1 ppm; ^{19}F NMR (376 MHz, $CDCl_3$) δ –62.8 ppm; HRMS-ESI: (*m*/*z*) $[M + H]^+$ calcd for $C_{17}H_{14}N_3OF_3$: 334.1162, found 334.1154; IR (film DCM) ν /cm^{-1} 3131, 3085, 2954, 2916, 2870, 2843, 1620, 1484, 1463, 1419, 1329, 1220, 1167, 1126, 1109, 1070, 1049, 1020, 977, 940, 916, 861, 822, 766, 716, 694, 631, 591, 514; m.p. 227 ºC.

(**1-(4-chlorobenzyl)-4-(4-fluorophenyl)-1*H*-1,2,3-triazole, 22**) white crystals, 75 mg, yield 87%.



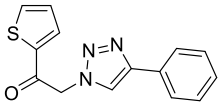
^1H NMR (400 MHz, $CDCl_3$): δ 7.82-7.69 (m, 2H), 7.60 (s, 1H), 7.42-7.31 (m, 2H), 7.42-7.31 (m, 2H), 7.14-7.01 (m, 2H), 5.53 (s, 2H) ppm; $^{13}C\{1H\}$ NMR (100 MHz, $CDCl_3$): δ 164.0, 161.4, 134.7, 133.0, 129.4, 129.4, 127.5, 127.4, 116.1, 115.9, 115.7, 93.6, 53.5 ppm; ^{19}F NMR (376 MHz, $CDCl_3$): δ –113.4 ppm; HRMS-ESI: (*m*/*z*) $[M + H]^+$ calcd for $C_{15}H_{11}N_3FCl$: 288.0698, found 288.0695; IR (film DCM): *v* 3126, 3102, 1915, 1901, 1595, 1559, 1497, 1451, 1436, 1413, 1342, 1220, 1185, 1157, 1094, 1071, 978, 843, 827, 758, 700, 529, 507, 419 cm^{-1}; m.p. 350 ºC.

(**4-(4-methoxyphenyl)-1-(4-chlorobenzyl)-1*H*-1,2,3-triazole, 23**) white crystals, 84 mg, yield 93%.



^1H NMR (400 MHz, $CDCl_3$): δ 7.73-7.68 (m, 2H), 7.56 (s, 1H), 7.38-7.31 (m, 2H), 7.23 (d, *J* = 8.7 Hz, 2H), 6.95-6.90 (m, 2H), 5.52 (s, 2H), 3.82 (s, 3H) ppm; $^{13}C\{1H\}$ NMR (100 MHz, $CDCl_3$): δ 160.7, 159.8, 147.8, 133.3, 133.1, 129.5, 129.0 127.5, 122.9, 114.0, 113.3, 102.4, 55.4, 52.1 ppm; HRMS-ESI: (*m*/*z*) $[M + H]^+$ calcd for $C_{16}H_{14}N_3OCl$: 300.0898, found 300.0894; IR (film DCM): *v* 3126, 3102, 2944, 2842, 1616, 1560, 1497, 1445, 1444, 1249, 1222, 1174, 1105, 1095, 1074, 1026, 977, 849, 831, 818, 757, 538 cm^{-1}; m.p. 349 ºC.

(**4-phenyl-1-(2-(thiophen-2-yl)ethan-2-on-1-yl)-1*H*-1,2,3-triazole, 24)** orange crystals, 242 mg, yield 90%



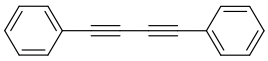
^1H NMR (400 MHz, $CDCl_3$): δ 7.96 (s, 1H), 7.89-7.82 (m, 3H), 7.78-7.76 (m, 1H), 7.46-7.38 (m, 2H), 7.37-7.30 (m, 1H), 7.20-7.18 (m, 1H), 5.78 (s, 2H) ppm; $^{13}C\{1H\}$ NMR (100 MHz, $CDCl_3$): δ

183.2, 148.3, 135.6, 133.2, 132.9, 129.2, 128.8, 128.8, 128.2, 126.2, 125.8, 121.3, 55.4 ppm. Spectroscopic data for the compound **24** was consistent with the previously reported ones.[9]

2.6 Catalytic activity of complex 7: typical procedure for Glaser type cross-coupling reaction

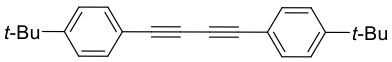
In a vial fitted with a screw cap, alkyne (1.0 mmol) and pyridine (0.1 mmol) were dissolved in solvent (1 mL). Next, copper catalyst **7** (0.01 mmol) was introduced to the reaction mixture. The reaction was performed at room temperature and was monitored by TLC plate. After completion of the reaction, 1.5 mL of Et_2O was added to the vial and phases separation was fulfilled. Organic phase was carefully sampled, dried over $MgSO_4$ and evaporated to dryness. The crude product was purified by filtration on short pad of silica gel, using cyclohexane/ethyl acetate 95:5 as eluent, to obtain corresponding substituted 1,3-diyne (79-93% yield).

(**1,4-diphenylbuta-1,3-diyne, 25**) white solid, 187 mg, yield 92%.



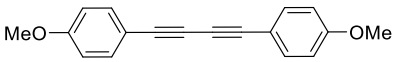
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.58-7.46 (m, 4H), 7.43-7.27 (m, 6H) ppm; ^{13}C{1H} NMR (100 MHz, $CDCl_3$): δ 132.5, 129.2, 128.4, 121.8, 81.5, 73.8 ppm. Spectroscopic data for the compound **25** were consistent with the previously reported ones.[10]

(**1,4-bis(4-*tert*-butylphenyl)buta-1,3-diyne, 26**) white solid, 288 mg, yield 91%.



^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45 (d, *J* = 8.6 Hz, 4H), 7.34 (d, *J* = 8.7 Hz, 4H), 1.30 (s, 18H) ppm; ^{13}C{1H} NMR (100 MHz, $CDCl_3$): δ 152.5, 132.2, 125.4, 118.8, 81.5, 73.4, 34.9, 31.1 ppm. Spectroscopic data for the compound **26** were consistent with the previously reported ones.[11]

(**1,4-bis(4-methoxyphenyl)buta-1,3-diyne, 27**) yellowish solid, 243 mg, yield 93%.



^{1}H NMR (400 MHz, $CDCl_3$): δ 7.45 (d, *J* = 8.9 Hz, 4H), 6.84 (d, *J* = 8.9 Hz, 4H), 3.81 (s, 3H) ppm; ^{13}C{1H} NMR (100 MHz, $CDCl_3$): δ 160.2, 134.0, 114.1, 113.9, 81.2, 72.9, 55.3 ppm. Spectroscopic data for the compound **27** were consistent with the previously reported ones.[10]

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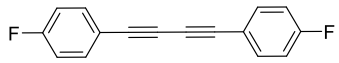
[9] D. Kumar, V. B. Reddy and R. S. Varma, *Tetrahedron Letters*, **2009**, *50*, 2065-2068.

[10] E. Merkul, D. Urselmann, T. J. J. Müller, *European Journal of Organic Chemistry*, **2011**, *2*, 238-242.

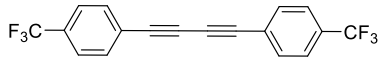
[11] De-X. Liu, Fei-L. Li, Hong-X. Li, J. Gao, Jian-P. Lang, *Tetrahedron*, **2014**, *70*, 2416-2421.

(**1,4-bis(4-fluorophenyl)buta-1,3-diyne, 28**) white solid, 188 mg, yield 79%.



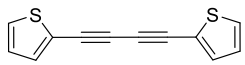
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.53-7.46 (m, 4H), 7.06-6.99 (m, 4H) ppm; ^{13}C{1H} NMR (100 MHz, $CDCl_3$): δ 163.1 (d, *J* = 272.7 Hz), 134.6 (d, *J* = 8.6 Hz), 117.8 (d, *J* = 3.4 Hz), 116.0 (d, *J* = 22.3 Hz), 80.4, 73.1 ppm; ^{19}F NMR (376 MHz, $CDCl_3$): δ –108.5 ppm. Spectroscopic data for the compound **28** were consistent with the previously reported ones.[10]

(**1,4-bis(4-trifluoromethylphenyl)buta-1,3-diyne, 29**) white solid, 300 mg, yield 89%



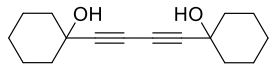
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.59-7.50 (m, 4H), 7.21-7.15 (m, 4H) ppm; ^{13}C{1H} NMR (100 MHz, $CDCl_3$): δ 149.6 (d, *J* = 1.9 Hz), 134.1, 124.1, 121.6, 120.9 (d, *J* = 0.9 Hz), 120.2, 119.0, 80.4, 74.4 ppm; ^{19}F NMR (376 MHz, $CDCl_3$): δ –57.7 ppm. Spectroscopic data for the compound **29** were consistent with the previously reported ones.[10]

(**1,4-bis(thiophen-2-yl)buta-1,3-diyne, 30**) orange solid, 192 mg, yield 90%



^{1}H NMR (400 MHz, $CDCl_3$): δ 7.58-7.57 (m, 2H), 7.28-7.27 (dd, *J* = 5.0, 3.0 Hz, 2H), 7.16-7.15 (m, 2H) ppm; ^{13}C{1H} NMR (100 MHz, $CDCl_3$): δ 131.2, 130.1, 125.6, 120.8, 79.5, 73.5 ppm. Spectroscopic data for the compound **30** were consistent with the previously reported ones.[11]

(**1,1'-(ethyne-1,2-diyl)dicyclohexan-1-ol, 31**) white solid, 218 mg, yield 86%



^{1}H NMR (400 MHz, $CDCl_3$): δ 2.05-1.80 (m, 5H), 1.79-1.39 (m, 15H), 1.15-1.32 (m, 2H) ppm; ^{13}C{1H} NMR (100 MHz, $CDCl_3$): δ 82.9, 69.2, 68.3, 39.6, 25.0, 23.1 ppm. Spectroscopic data for the compound **31** were consistent with the previously reported ones.[12]

2.7. Recyclability study

2.7.1 CuAAC reaction

The recycling process was carried out in the vial, under air atmosphere. After completion of CuAAC transformation leading to 1-benzyl-4-phenyl-1*H*-1,2,3-triazole (**11**), (performed as

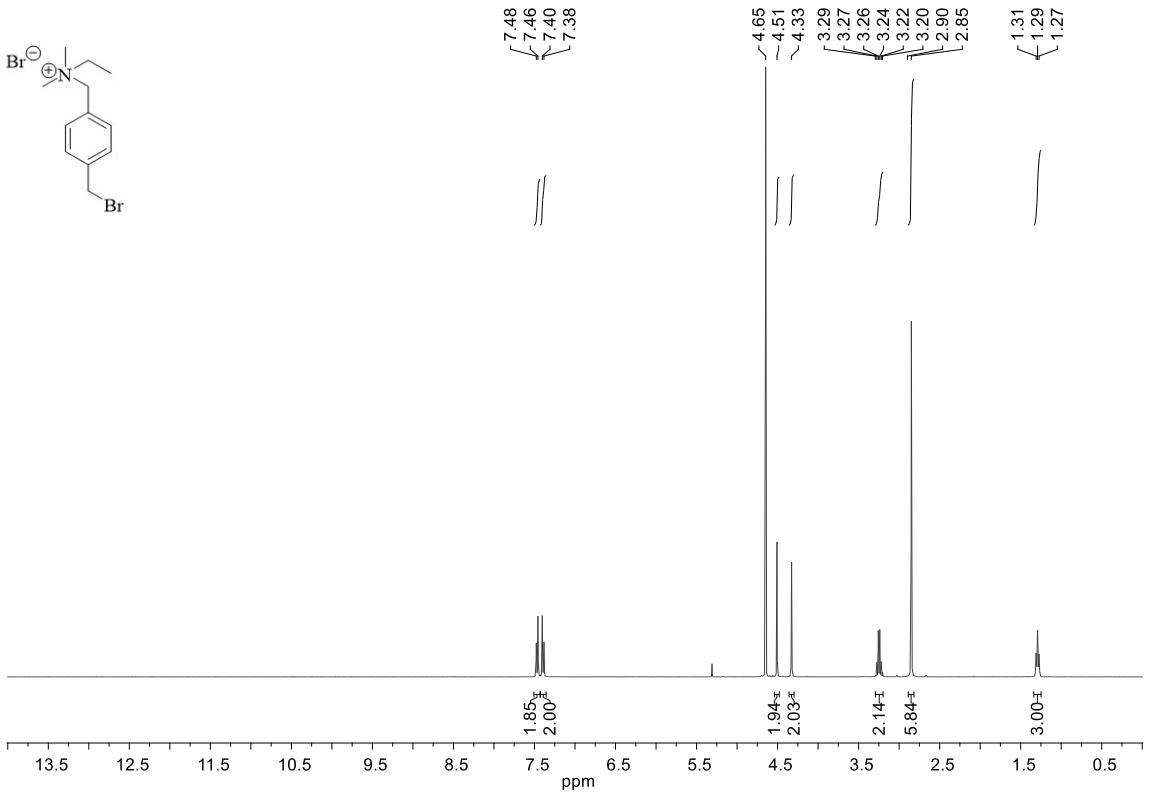
[12] A. Lei, M. Srivastava, X. Zhang, *Journal of Organic Chemistry*, **2002**, *67*, 1969-1971.

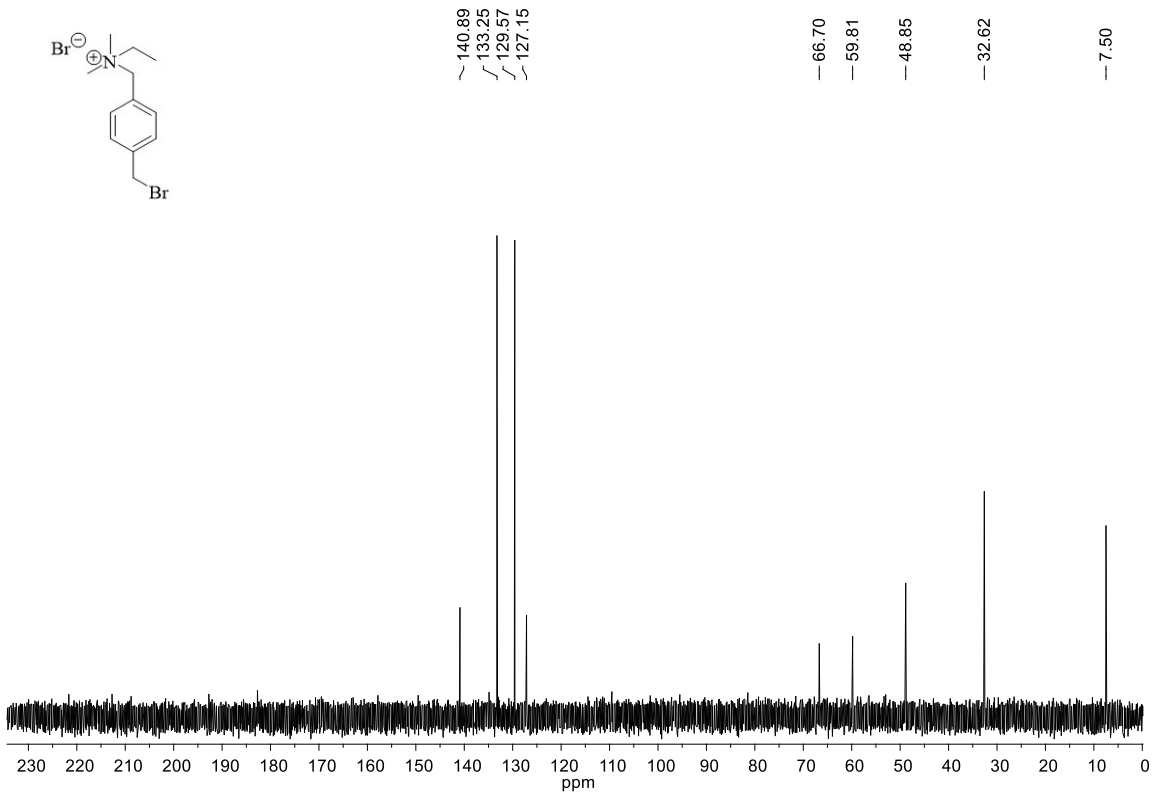
described in typical procedure in the section **2.5**), the reaction mixture was extracted with Et_2O (4 x 1.5 mL) to remove starting materials and products. Organic phases were combined and evaporated to dryness. Crude organic mixture was filtered on short pad of silica gel, using cyclohexane/ethyl acetate 10:1 as eluent to receive the pure triazole **11**. The residual aqueous phase with copper catalyst **7** was filled with fresh reactants and all manipulations were repeated. All studies on recycling copper catalyst **7** were repeated three times.

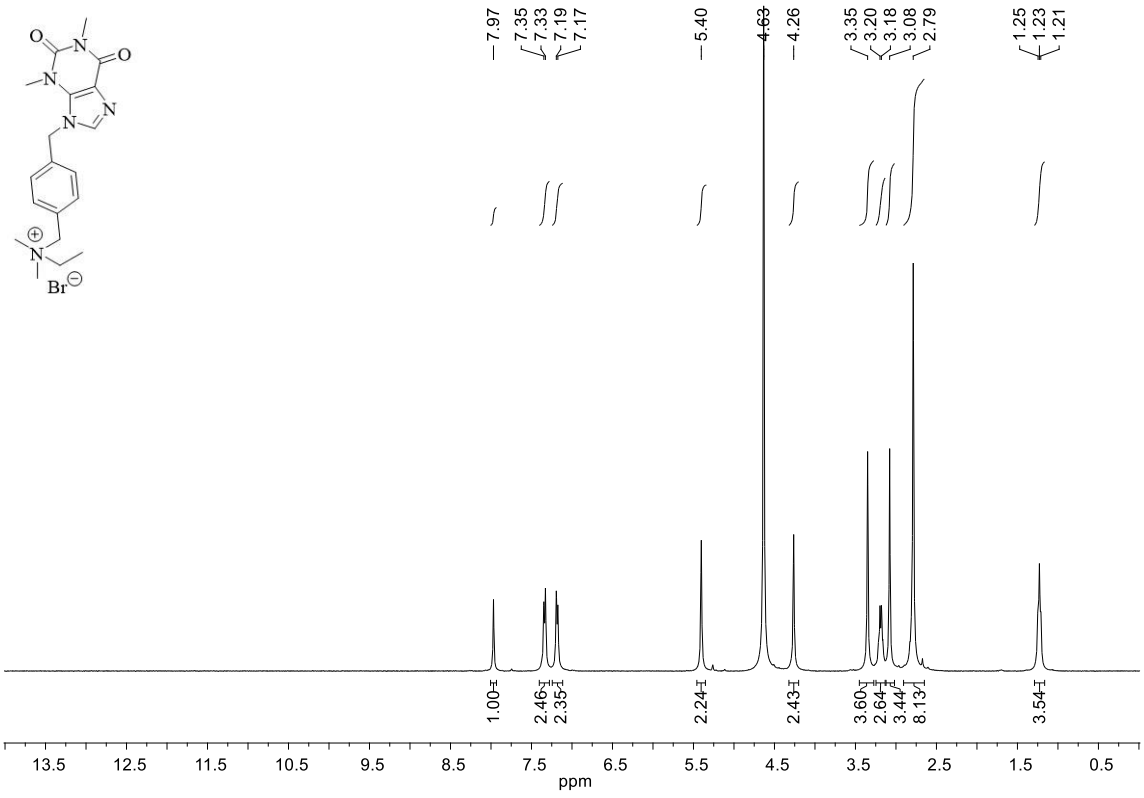
2.7.2 Glaser homo-coupling

The recycling process was carried out in the vial, under air atmosphere. After the completion of Glaser homo-coupling to 1,4-diphenylbuta-1,3-diyne (**25**), (performed as described in typical procedure in the section **2.6**), the reaction mixture was extracted with Et_2O (4 x 1.5 mL) to remove starting materials and products. Organic phases were combined and evaporated to dryness. Crude organic mixture was filtered on short pad of silica gel, using cyclohexane/ethyl acetate 95:5 as eluent to receive the product **25**. The residual aqueous phase with copper catalyst **7** was filled with fresh reactants and all manipulations were repeated. All studies on recycling copper catalyst **7** were repeated three times.

3. Representative ^{1}H NMR, ^{13}C NMR and ^{19}F NMR spectra



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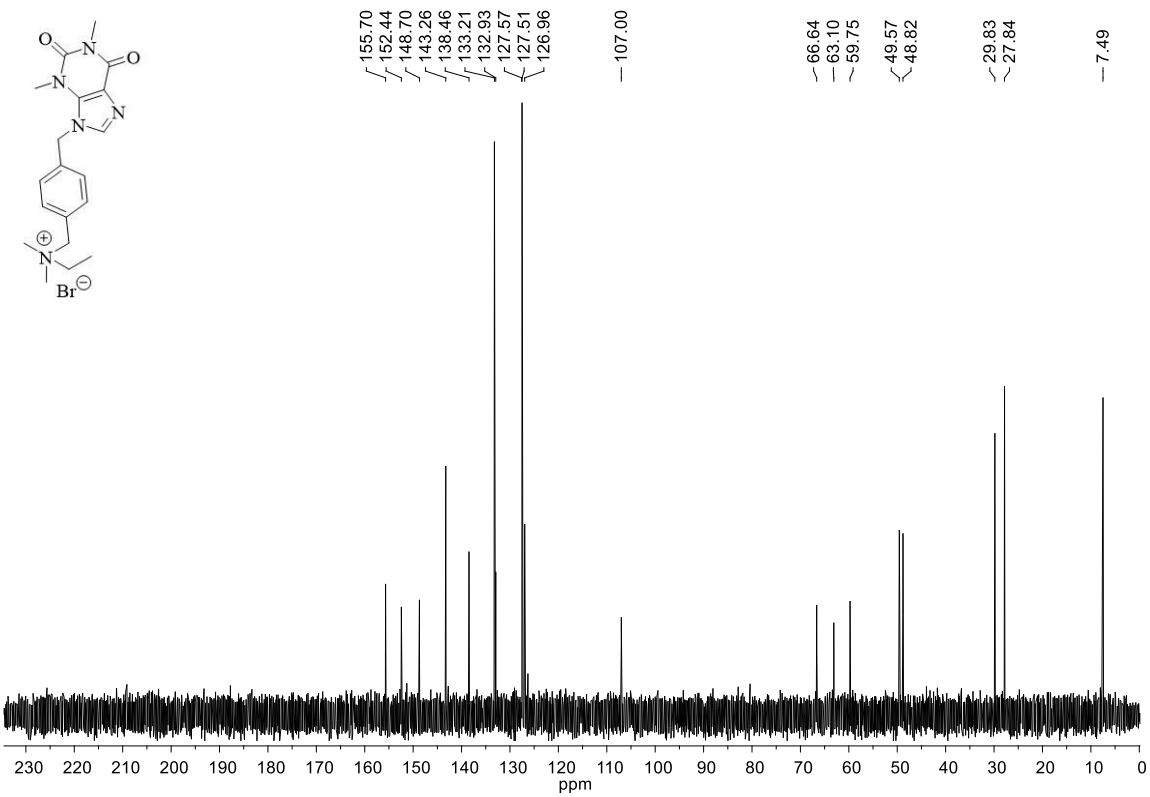
7.35
7.33
7.19
7.17
5.40
4.63
4.26
3.35
3.20
3.18
3.08
2.79
1.25
1.23
1.21
1.00
2.46
2.35
2.24
2.43
3.60
2.64
3.44
8.13
3.54
13.5 12.5 11.5 10.5 9.5 8.5 7.5 6.5 5.5 4.5 3.5 2.5 1.5 0.5
ppm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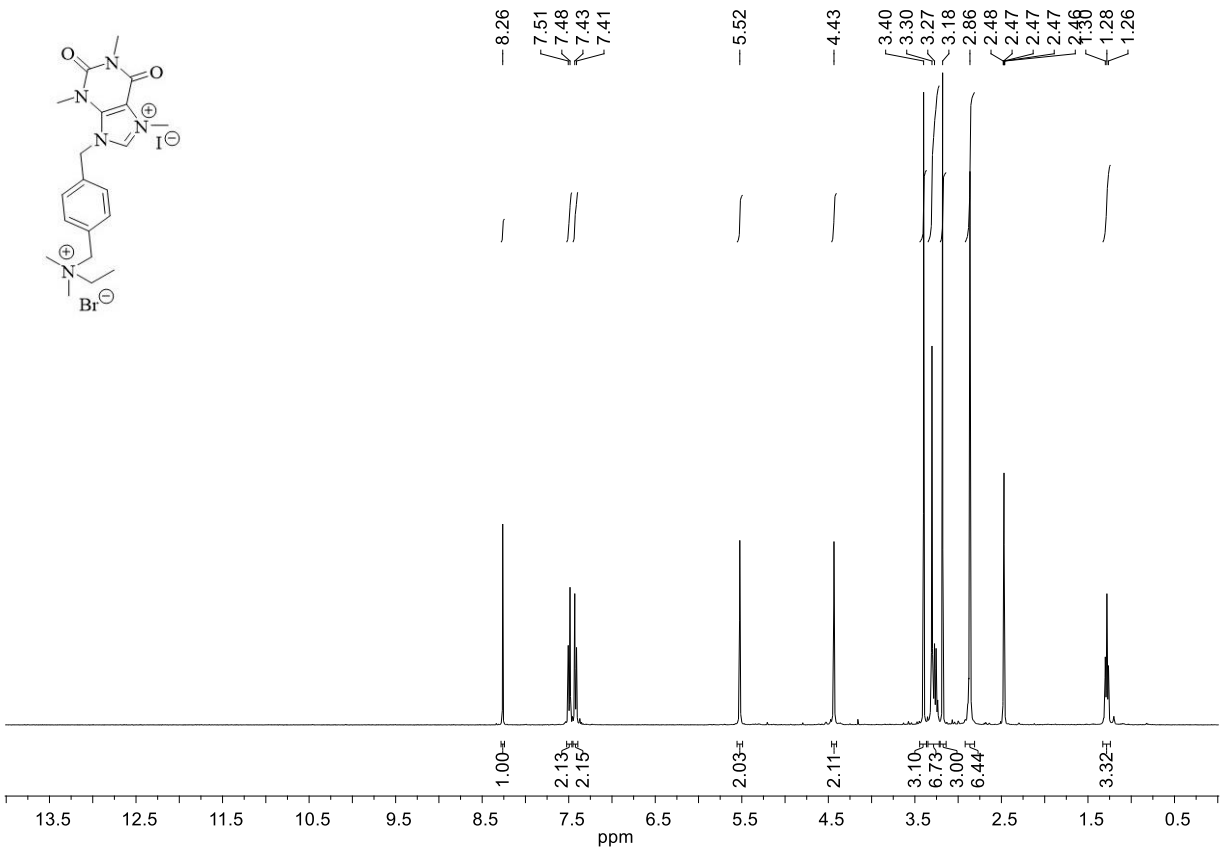
152.44
148.70
143.26
138.46
133.21
132.93
127.57
127.51
126.96
107.00
66.64
63.10
59.75
49.57
48.82
29.83
27.84
7.49
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
ppm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7.48
7.43
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5.52
4.43
3.40
3.30
3.27
3.18
2.86
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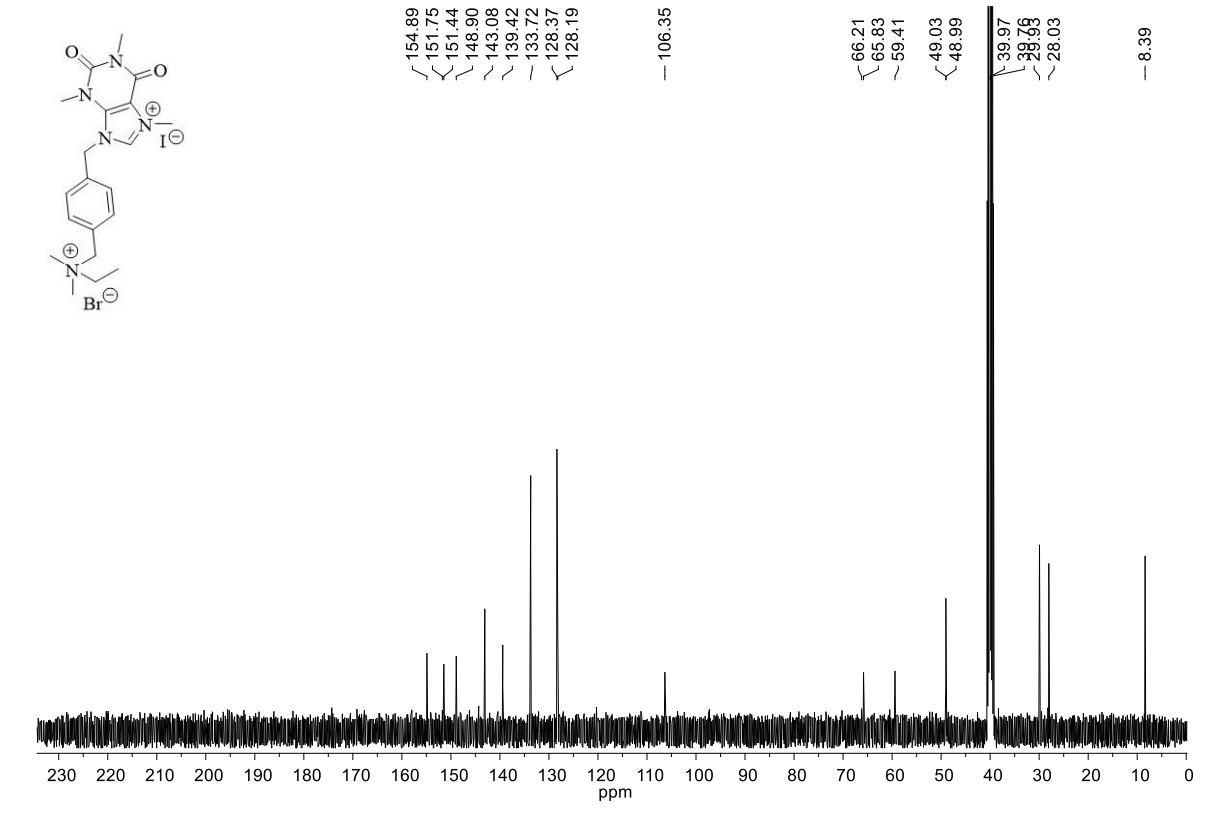
2.47
2.47
2.46
1.30
1.28
1.26
1.00
2.13
2.15
2.03
2.11
3.10
6.73
3.00
6.44
3.32
13.5
12.5
11.5
10.5
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
ppm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128.37
128.19
106.35
66.21
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59.41
49.03
48.99
39.97
28.03
8.39
230
220
210
200
190
180
170
160
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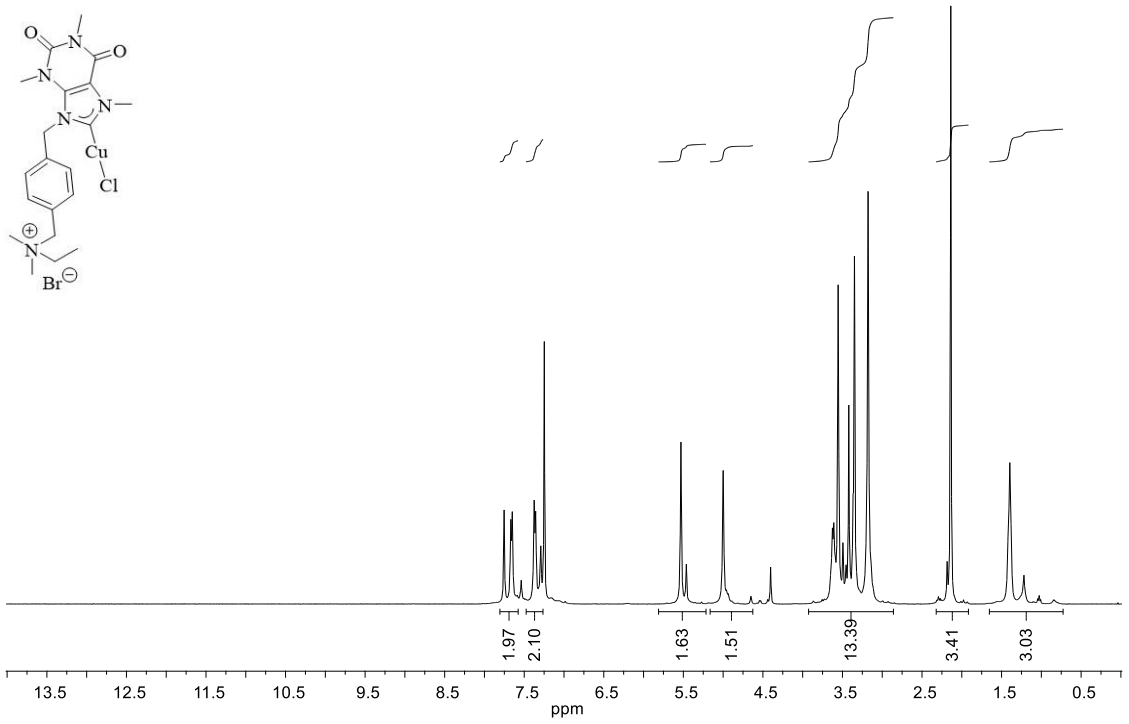
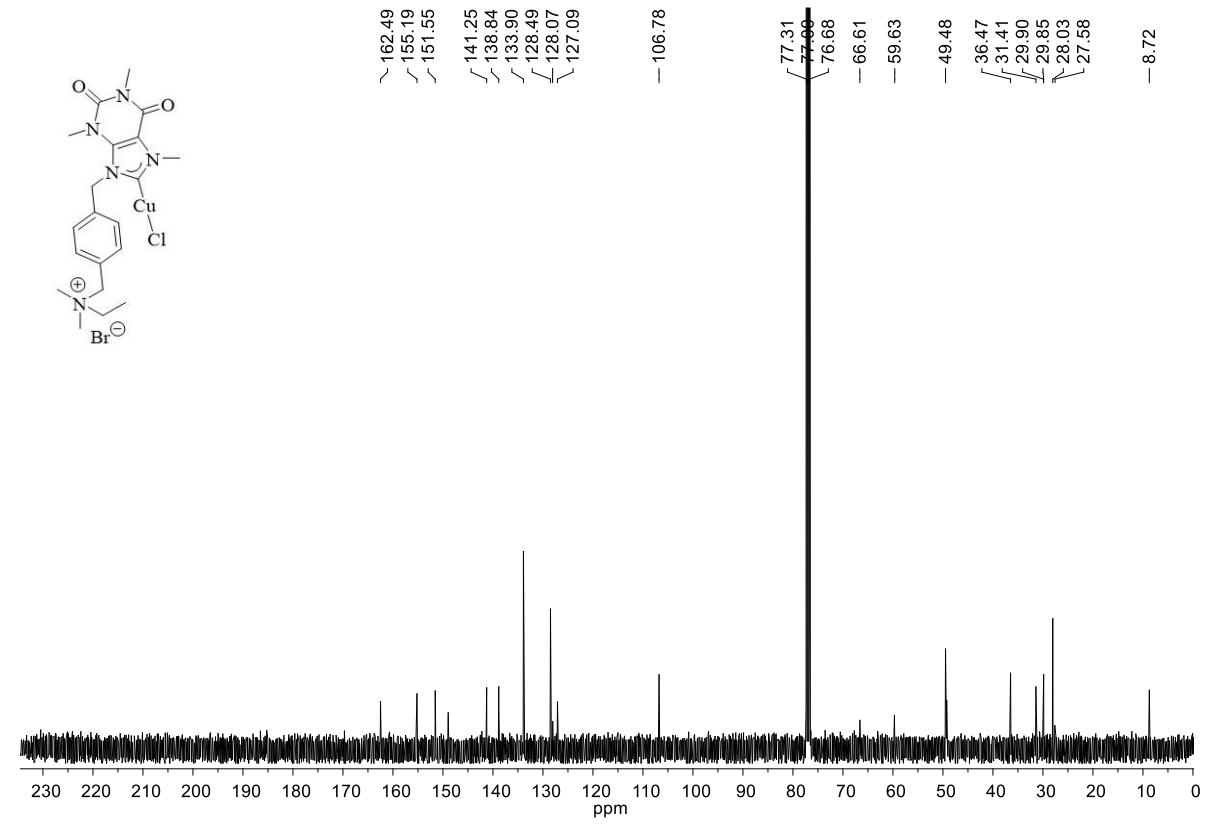
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


1.97
2.10
1.63
1.51
13.39
3.41
3.03
13.5
12.5
11.5
10.5
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
ppm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155.19
151.55
141.25
138.84
133.90
128.49
128.07
127.09
106.78
77.31
77.00
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66.61
59.63
49.48
36.47
31.41
29.90
29.85
28.03
27.58
8.72
230
220
210
200
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100
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60
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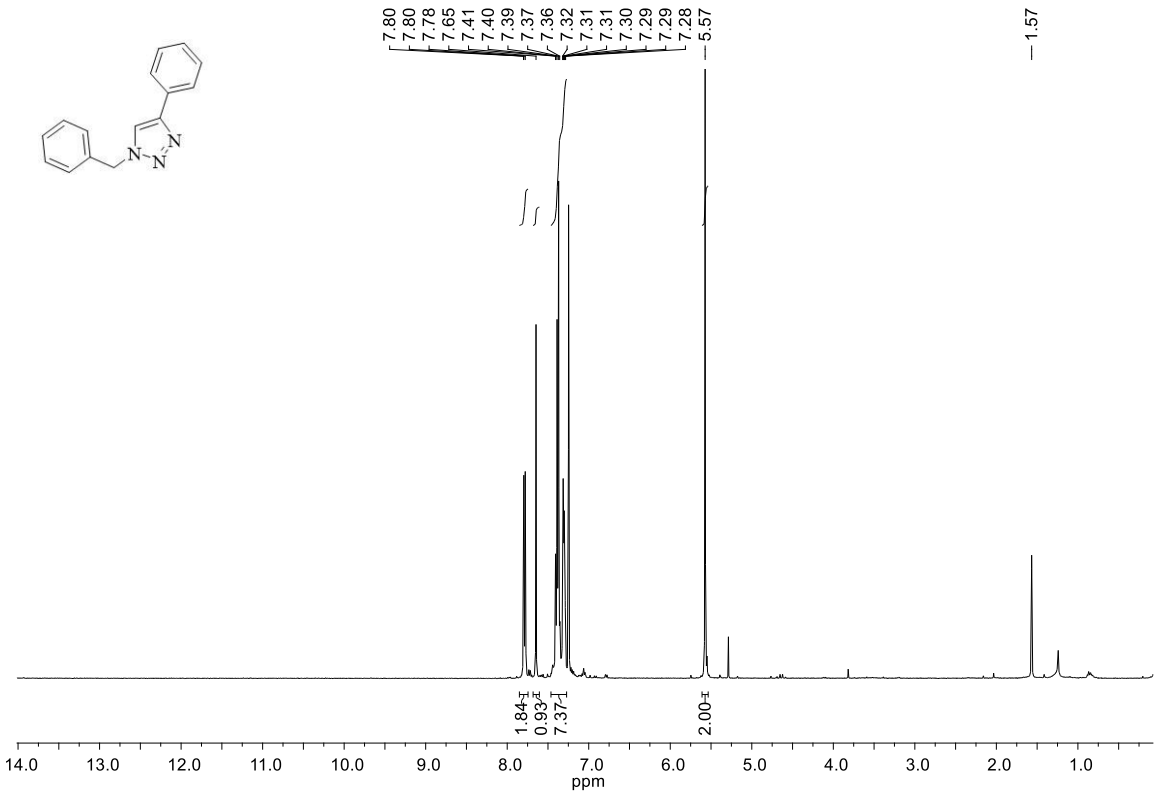
0
ppm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7.31
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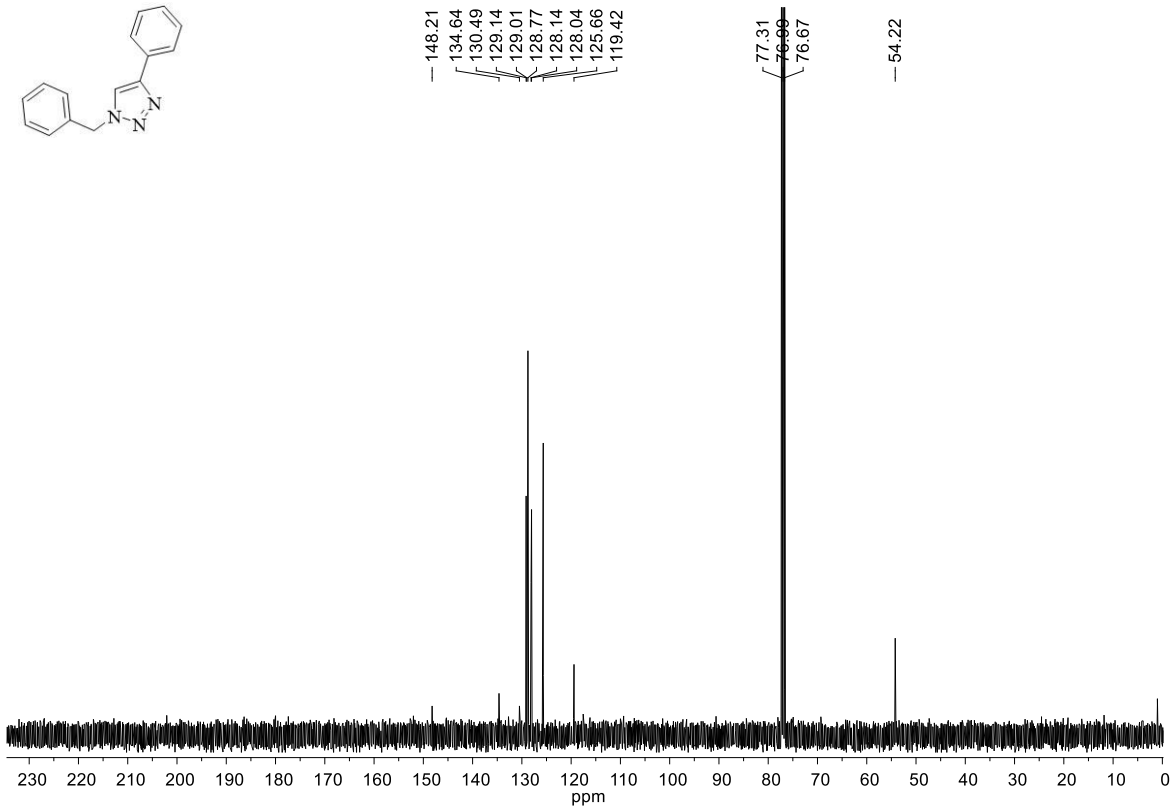
7.30
7.29
7.29
7.28
5.57
1.57
1.84
0.93
7.37
2.00
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
ppm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128.14
128.04
125.66
119.42
77.31
76.99
76.67
54.22
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
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20
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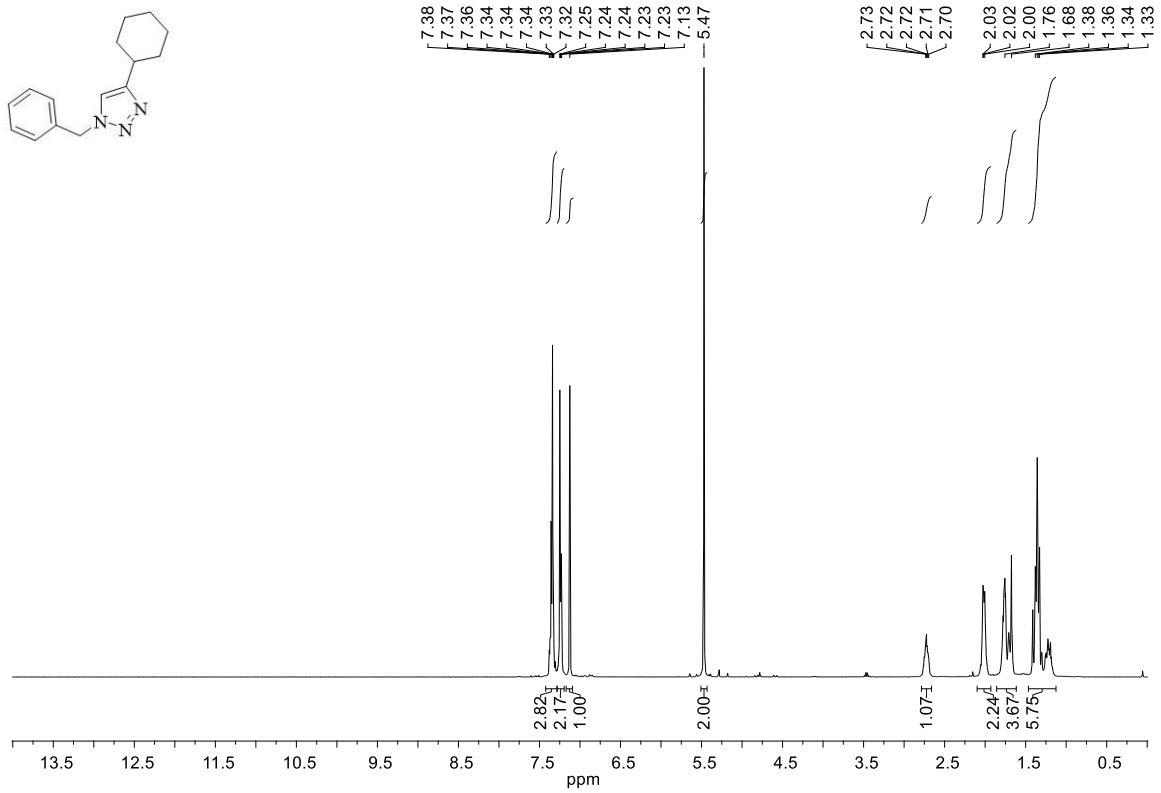
0
ppm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7.33
7.32
7.25
7.24
7.24
7.23
7.23
7.13
5.47
2.73
2.72
2.72
2.71
2.70
2.03
2.02
2.00
1.76
1.68
1.38
1.36
1.34
1.33
2.82
2.17
1.00
2.00
1.07
2.24
3.67
5.75
13.5
12.5
11.5
10.5
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8.5
7.5
6.5
5.5
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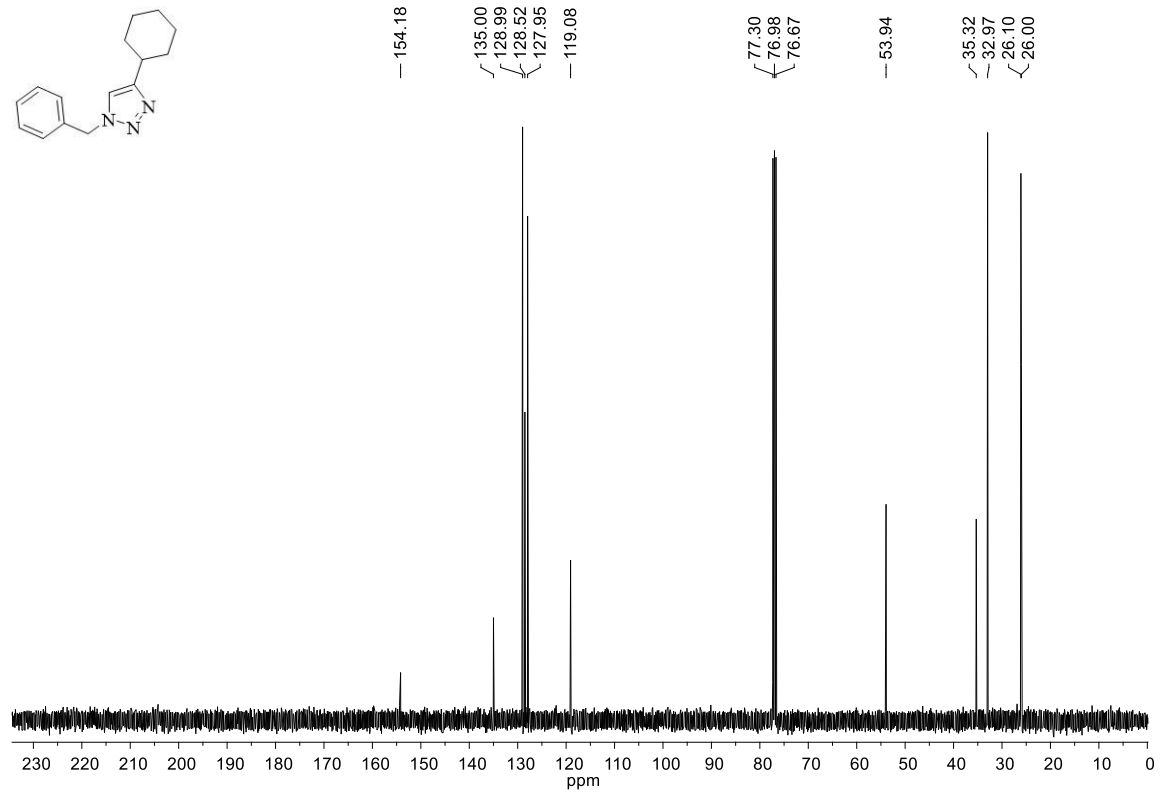
3.5
2.5
1.5
0.5
ppm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76.98
76.67
53.94
35.32
32.97
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200
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60
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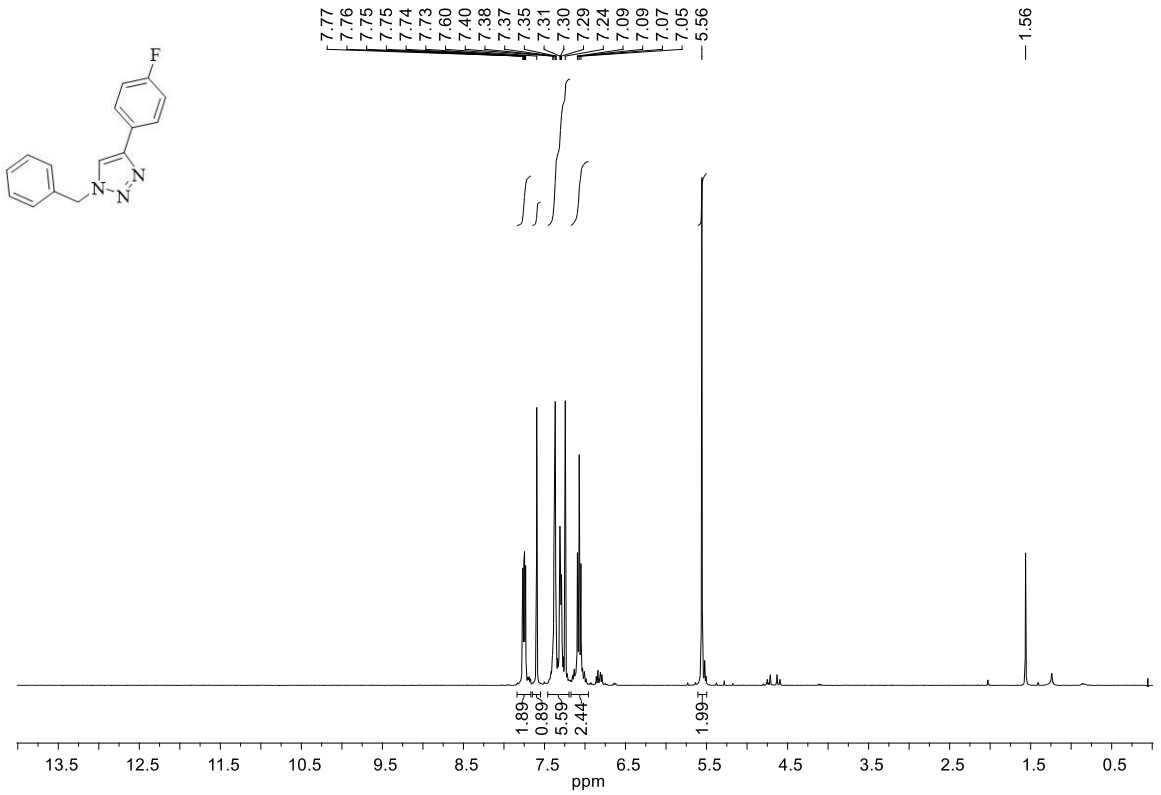
F
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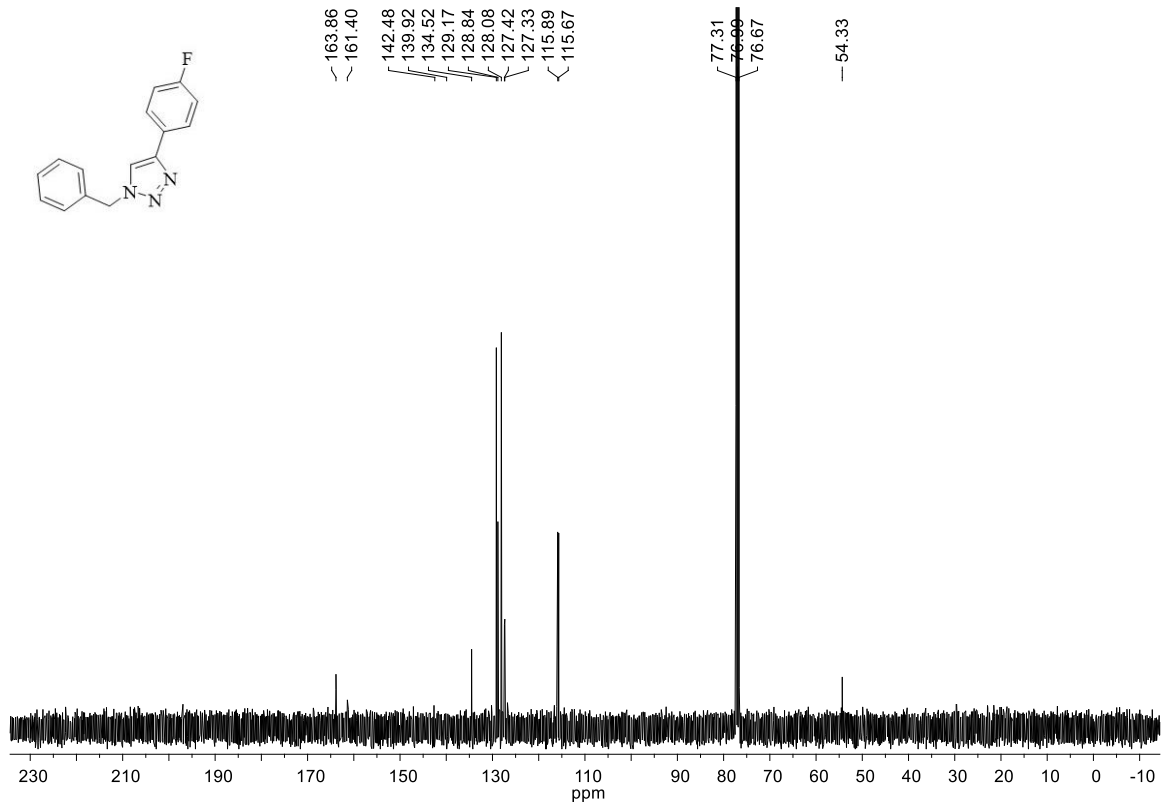
7.30
7.29
7.24
7.09
7.09
7.07
7.05
5.56
1.56
1.89
0.89
5.59
2.44
1.99
13.5
12.5
11.5
10.5
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
ppm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163.86
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142.48
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129.17
128.84
128.08
127.42
127.33
115.89
115.67
77.31
76.99
76.67
54.33
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190
170
150
130
110
90
80
70
60
50
40
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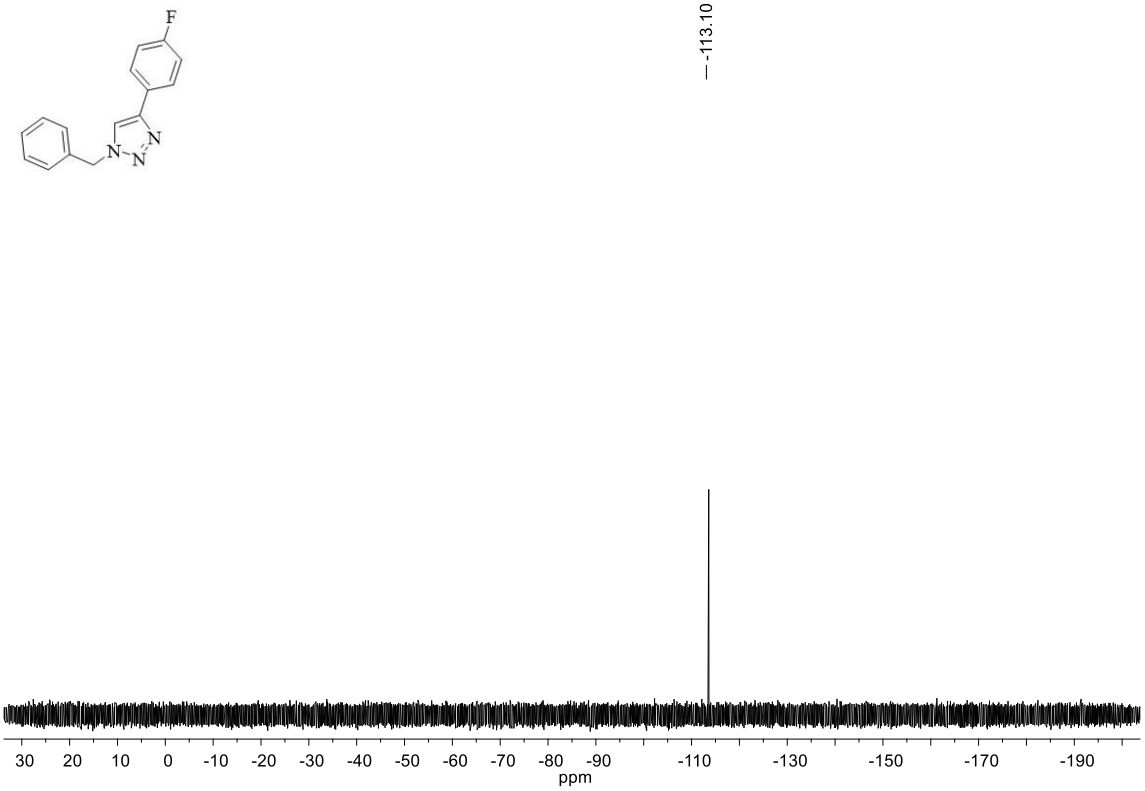
20
10
0
-10
ppm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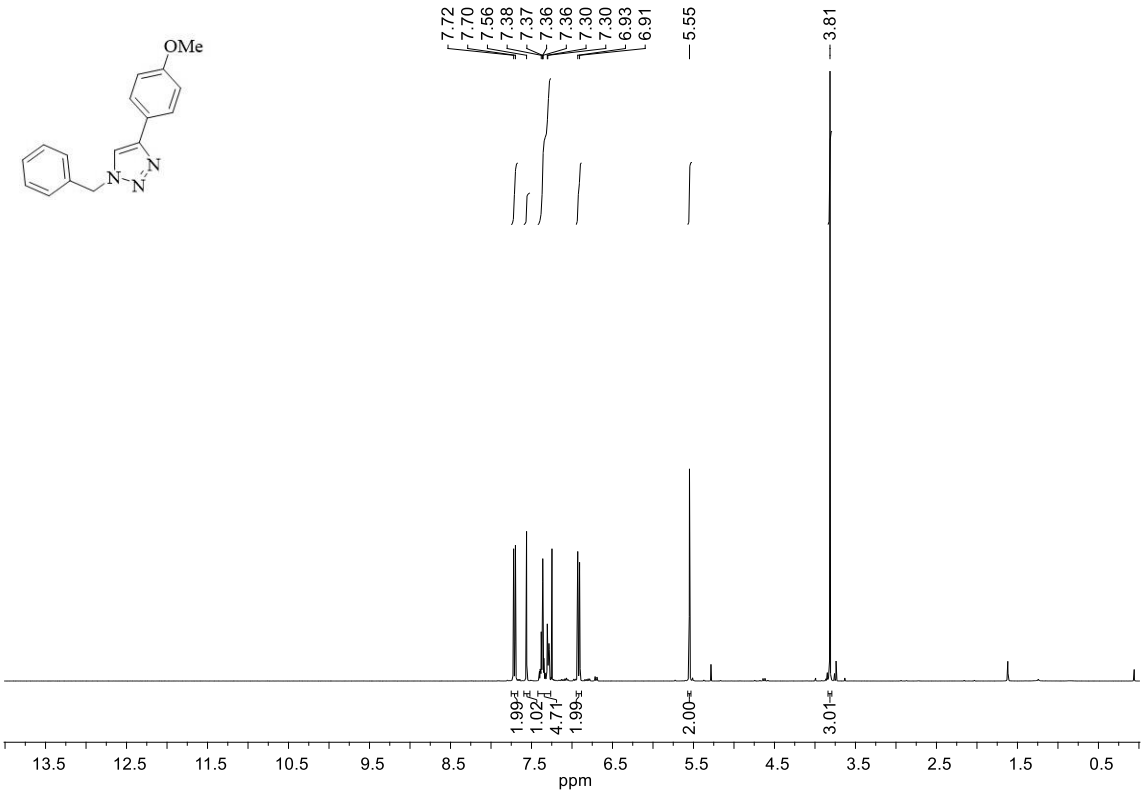
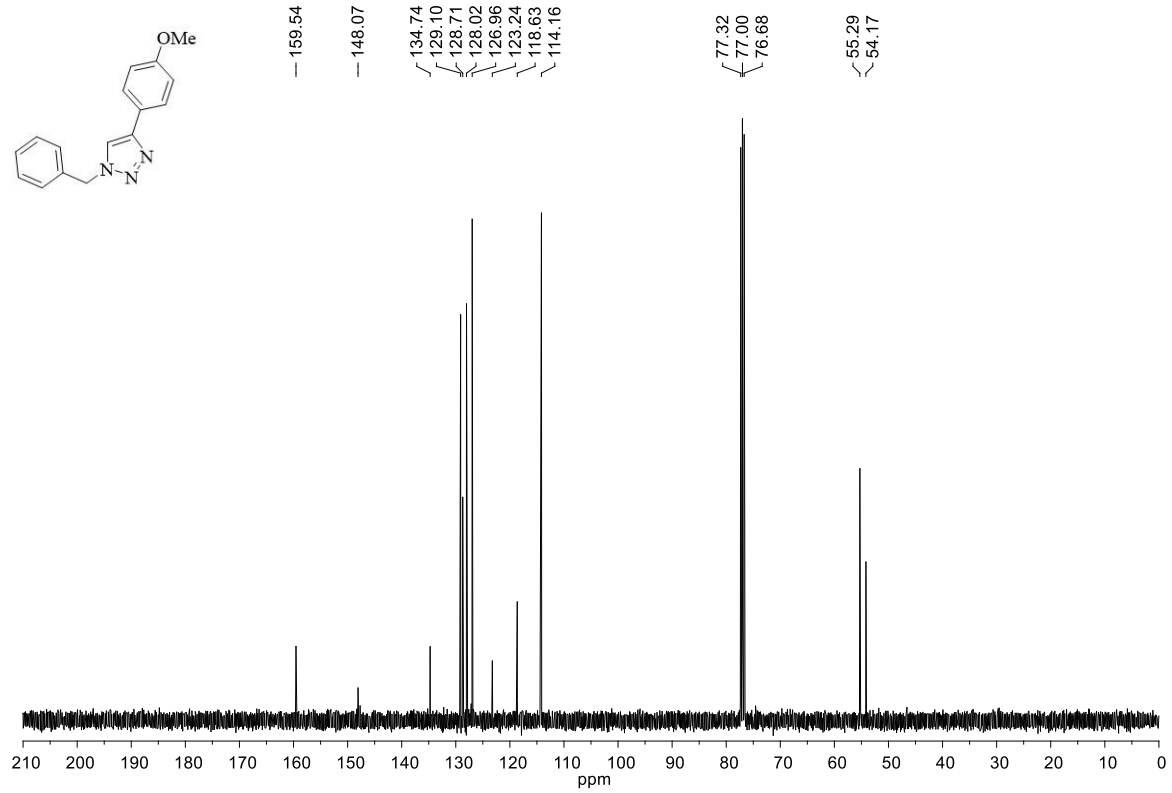
ppm


OMe
7.72
7.70
7.56
7.38
7.37
7.36
7.36
7.30
7.30
6.93
6.91
5.55
3.81
1.99
1.02
4.71
1.99
2.00
3.01
13.5 12.5 11.5 10.5 9.5 8.5 7.5 6.5 5.5 4.5 3.5 2.5 1.5 0.5
ppm


OMe
159.54
148.07
134.74
129.10
128.71
128.02
126.96
123.24
118.63
114.16
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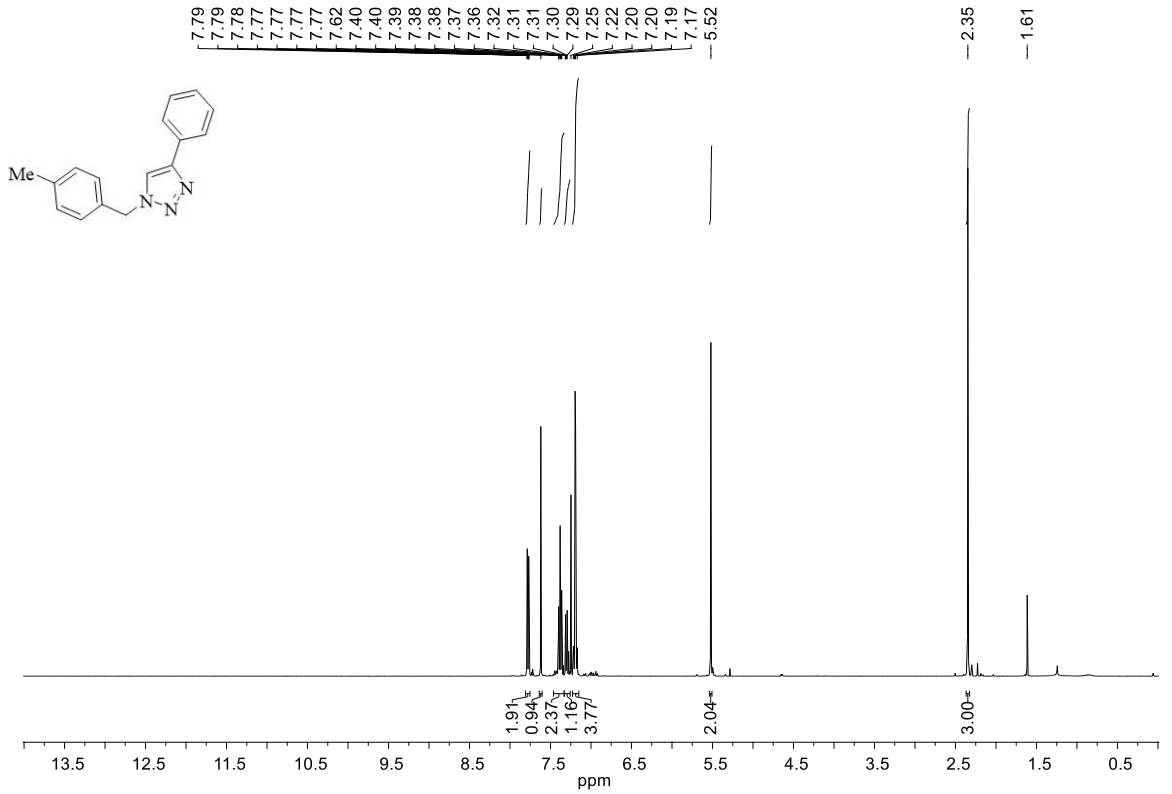
77.00
76.68
55.29
54.17
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
ppm


Me
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7.78
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7.77
7.77
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7.40
7.40
7.39
7.38
7.38
7.37
7.36
7.32
7.31
7.31
7.30
7.29
7.25
7.22
7.20
7.20
7.19
7.17
5.52
2.35
1.61
1.91
0.94
2.37
1.16
3.77
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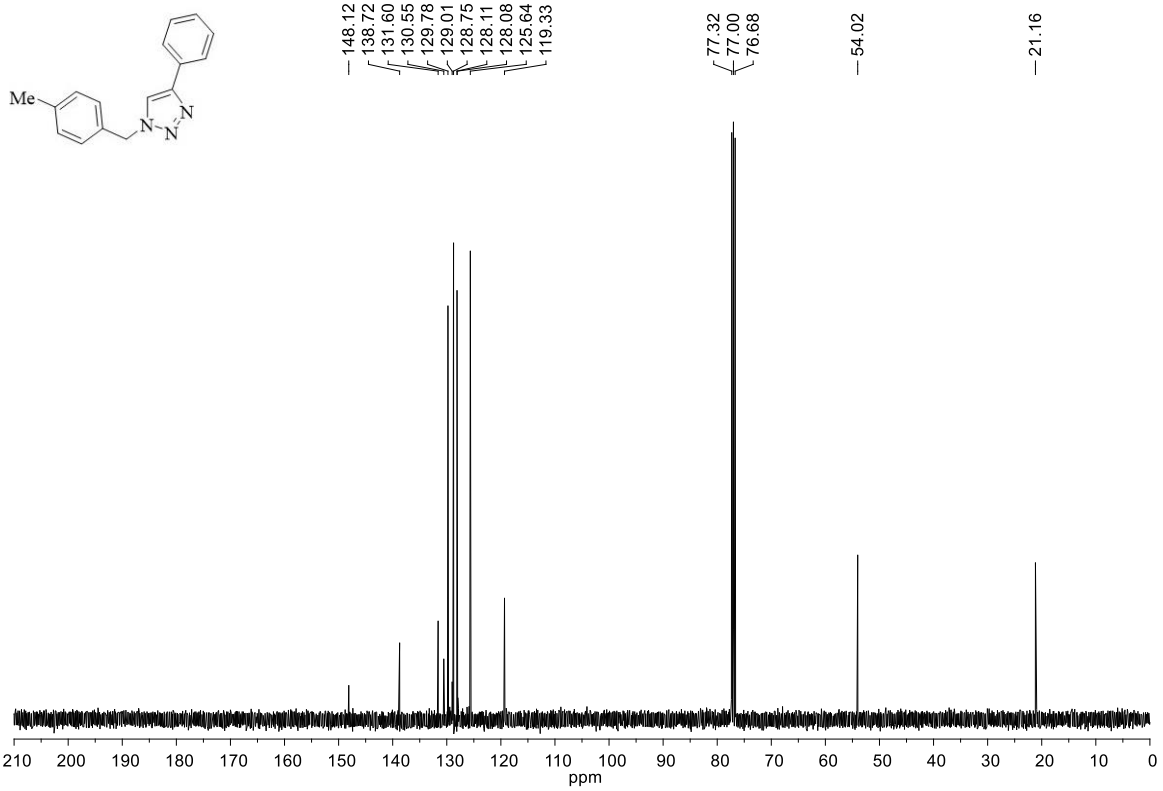
3.00
13.5 12.5 11.5 10.5 9.5 8.5 7.5 6.5 5.5 4.5 3.5 2.5 1.5 0.5
ppm


Me
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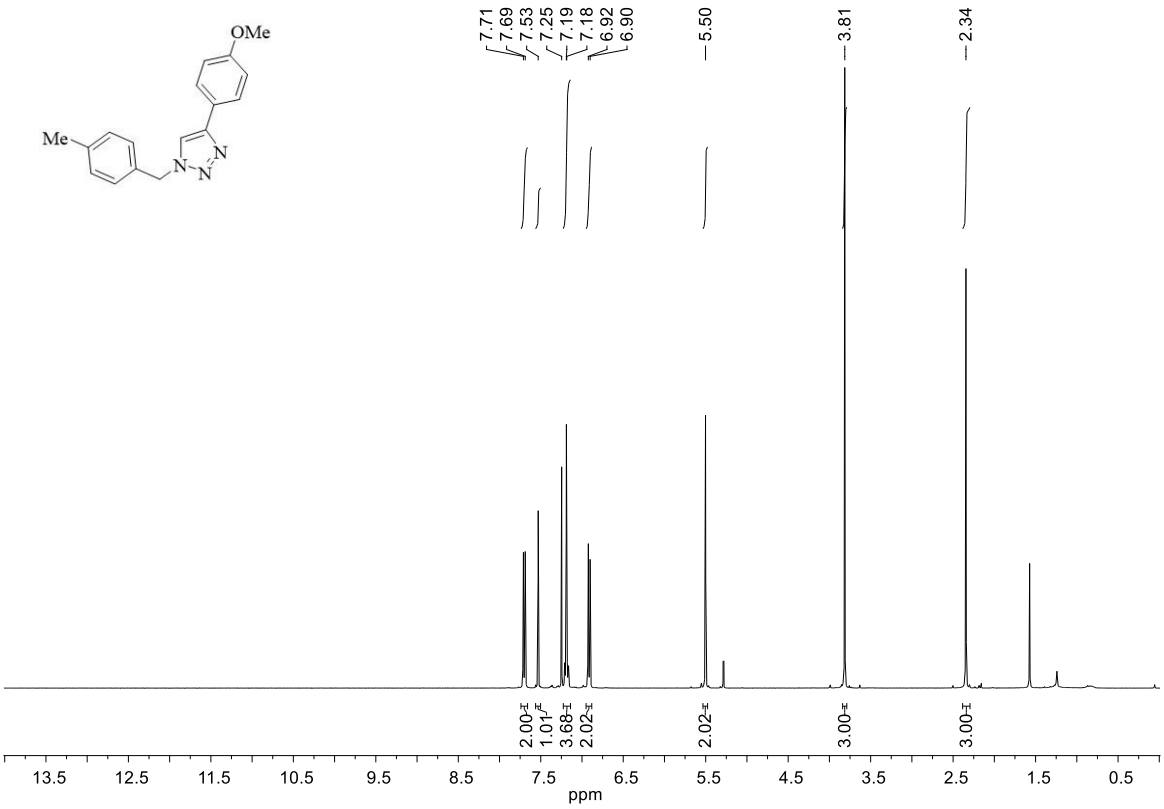
131.60
130.55
129.78
129.01
128.75
128.11
128.08
125.64
119.33
77.32
77.00
76.68
54.02
21.16
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
ppm


OMe
Me
7.71
7.69
7.53
7.25
7.19
7.18
6.92
6.90
5.50
3.81
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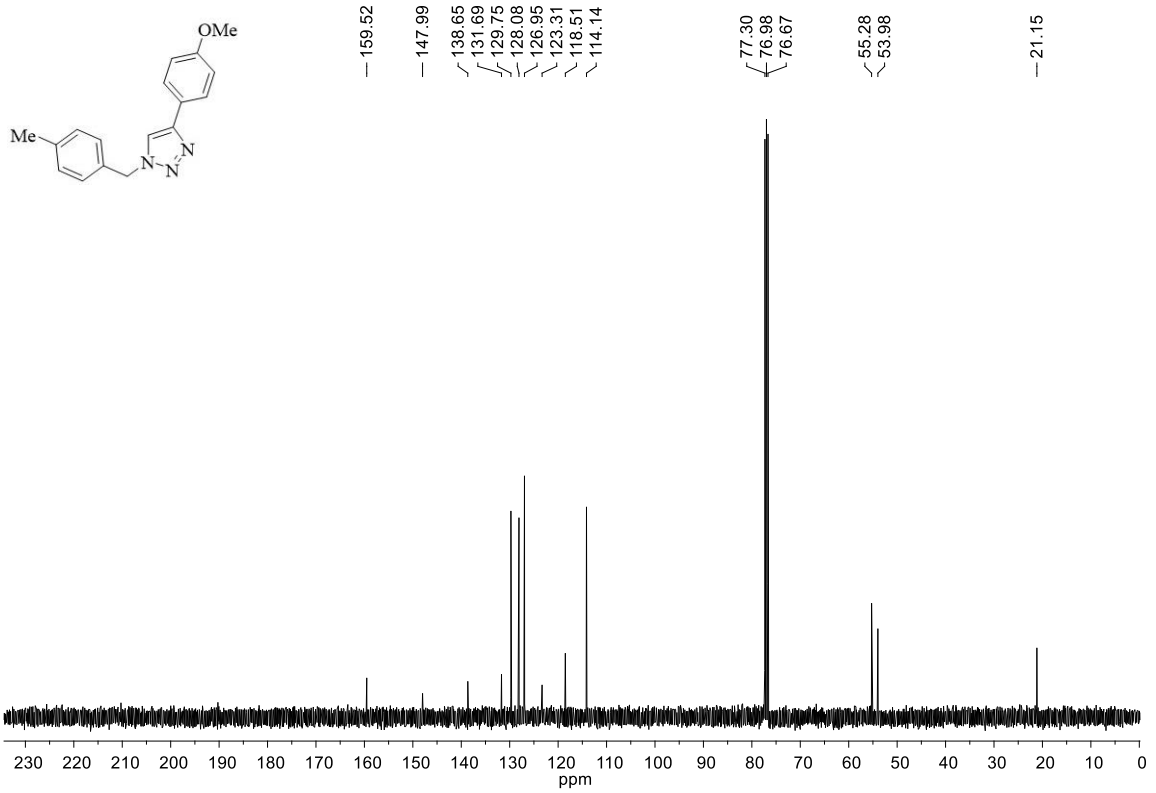
2.00
1.01
3.68
2.02
2.02
3.00
3.00
13.5 12.5 11.5 10.5 9.5 8.5 7.5 6.5 5.5 4.5 3.5 2.5 1.5 0.5
ppm


OMe
Me
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147.99
138.65
131.69
129.75
128.08
126.95
123.31
118.51
114.14
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76.67
55.28
53.98
21.15
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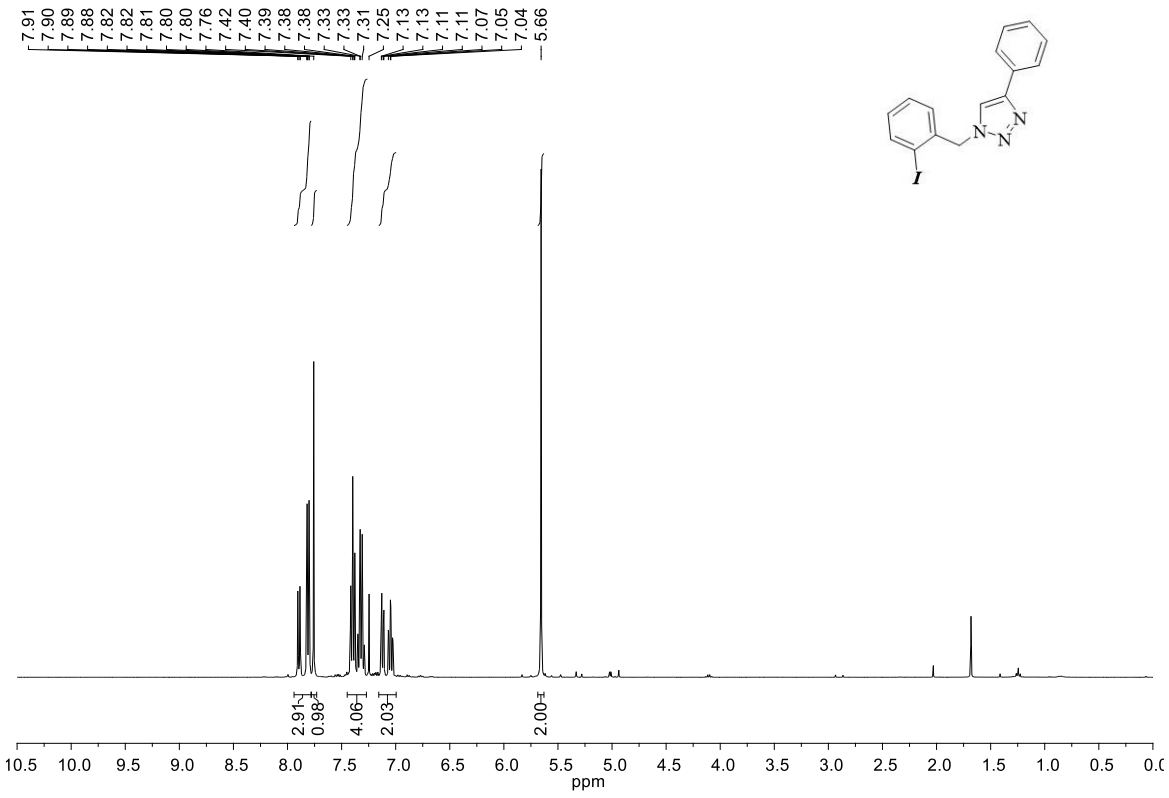
ppm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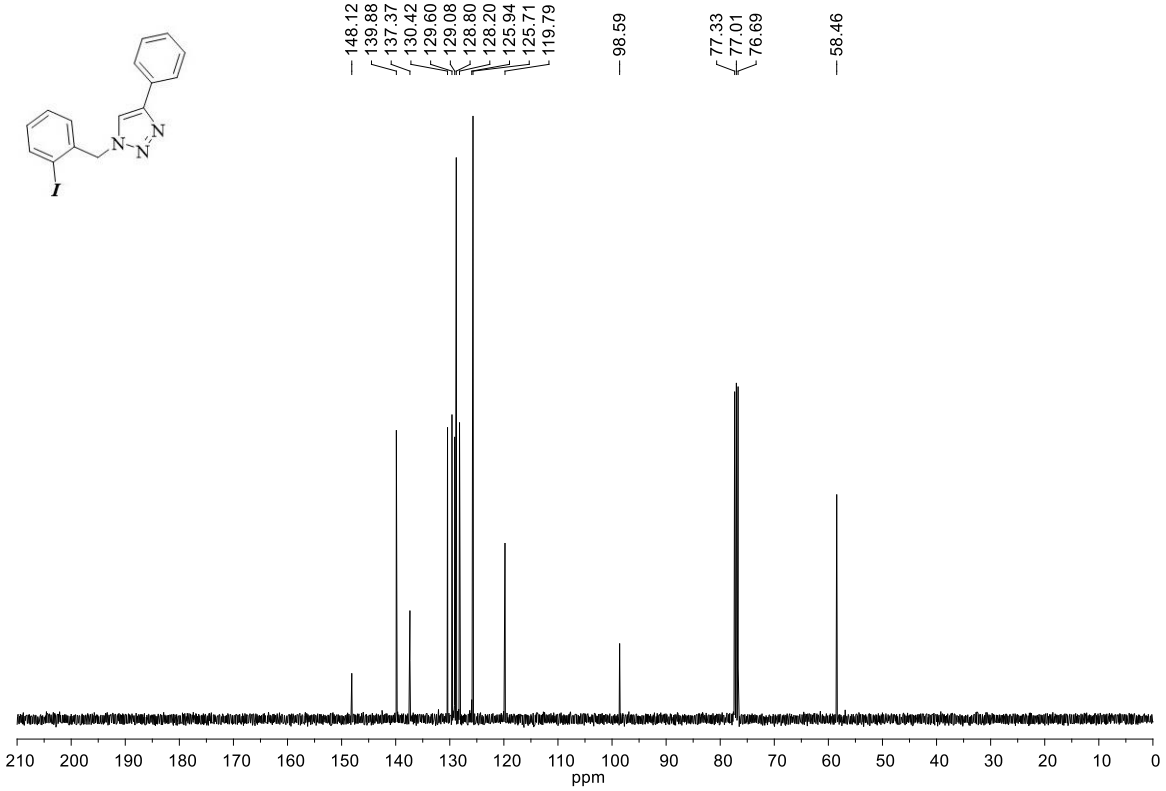
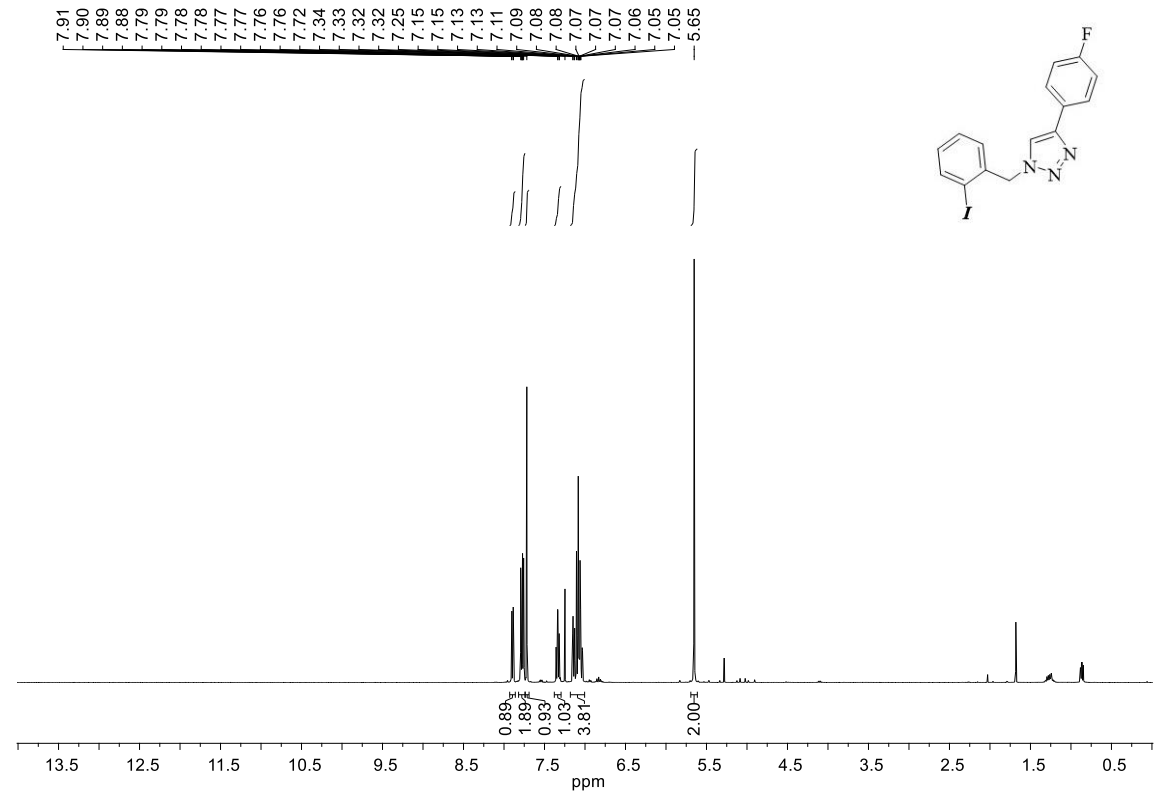
7.82
7.81
7.80
7.80
7.76
7.42
7.40
7.39
7.38
7.38
7.33
7.33
7.31
7.25
7.13
7.13
7.11
7.11
7.07
7.05
7.04
5.66
I
2.91
0.98
4.06
2.03
2.00
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
ppm


148.12
139.88
137.37
130.42
129.60
129.08
128.80
128.20
125.94
125.71
119.79
98.59
77.33
77.01
76.69
58.46
I
N
N
N
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
ppm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7.90
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7.78
7.78
7.77
7.77
7.76
7.76
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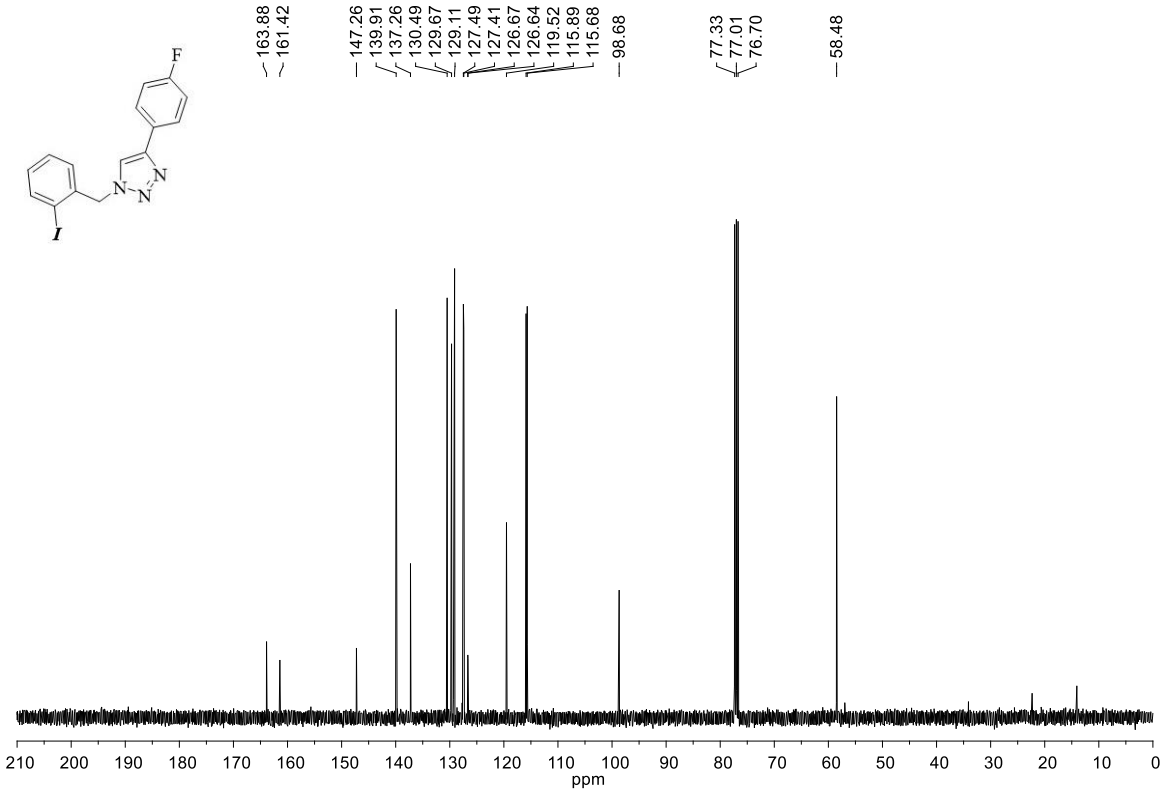
7.33
7.32
7.32
7.25
7.15
7.15
7.13
7.13
7.11
7.09
7.08
7.08
7.07
7.07
7.07
7.06
7.05
7.05
5.65
F
I
N
N
N
0.89
1.89
0.93
1.03
3.81
2.00
13.5 12.5 11.5 10.5 9.5 8.5 7.5 6.5 5.5 4.5 3.5 2.5 1.5 0.5
ppm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130.49
129.67
129.11
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127.41
126.67
126.64
119.52
115.89
115.68
98.68
77.33
77.01
76.70
58.48
F
I
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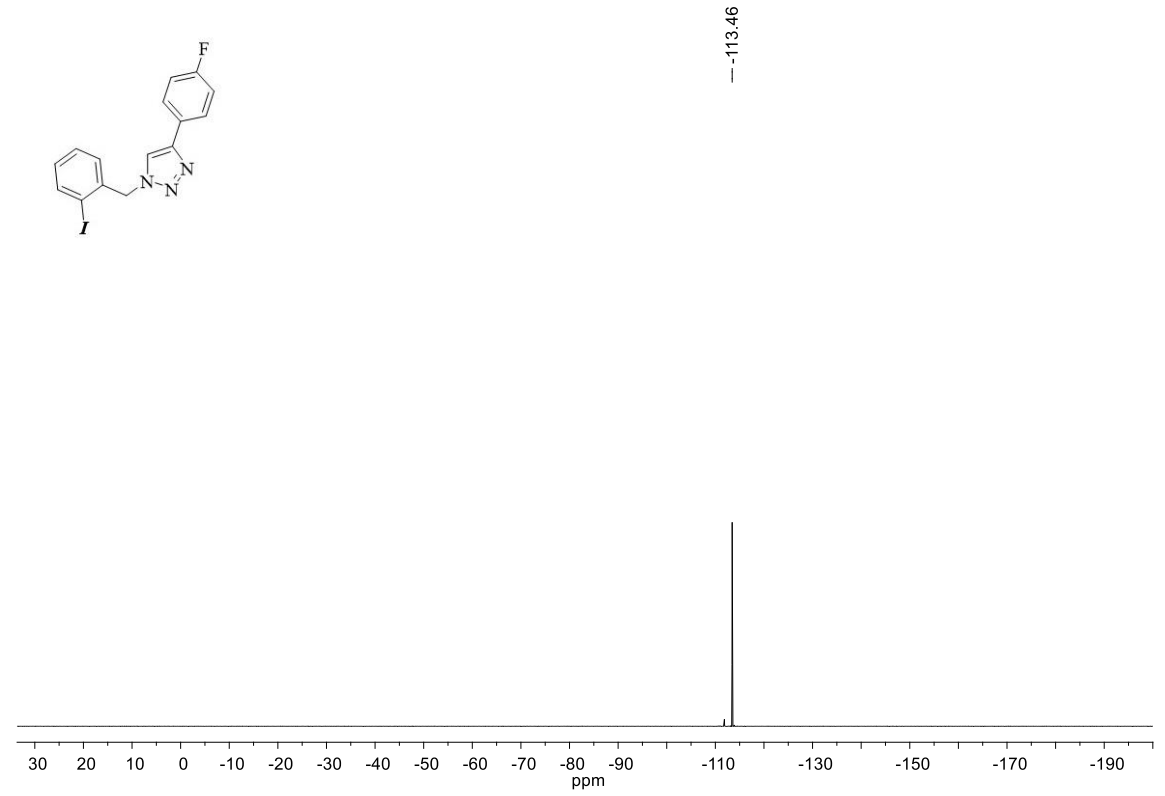
ppm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F
I
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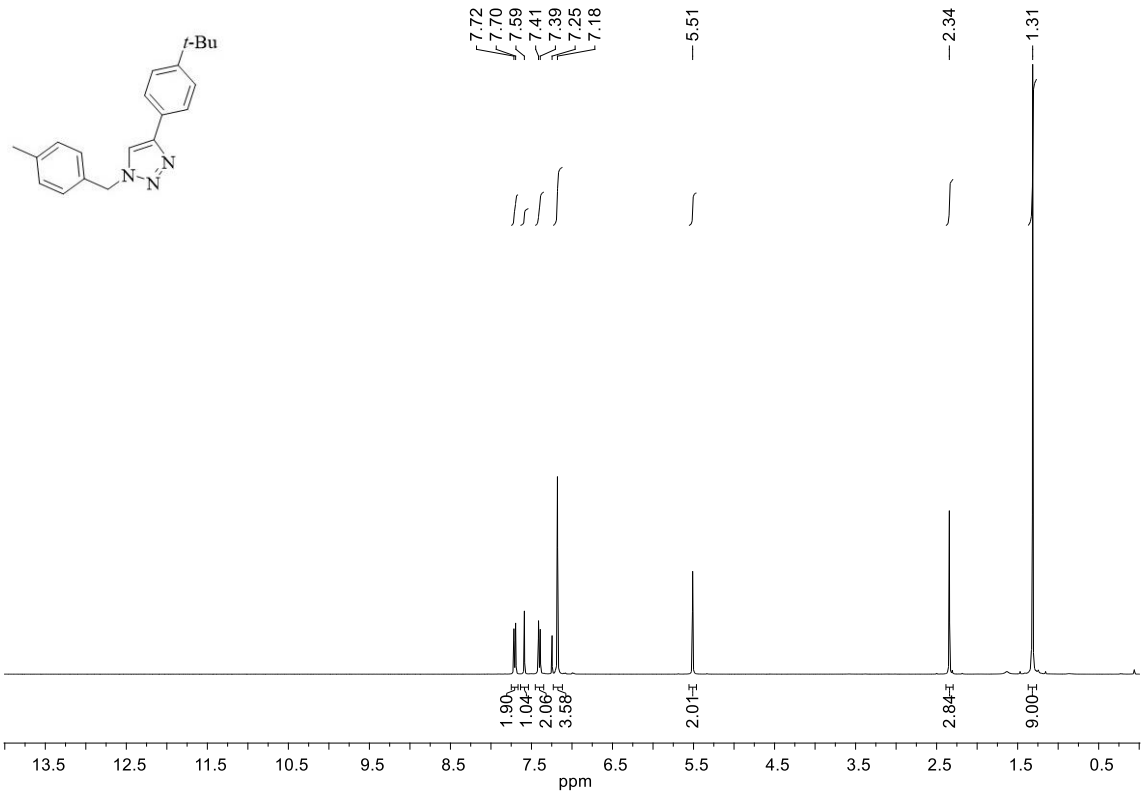
ppm


t-Bu
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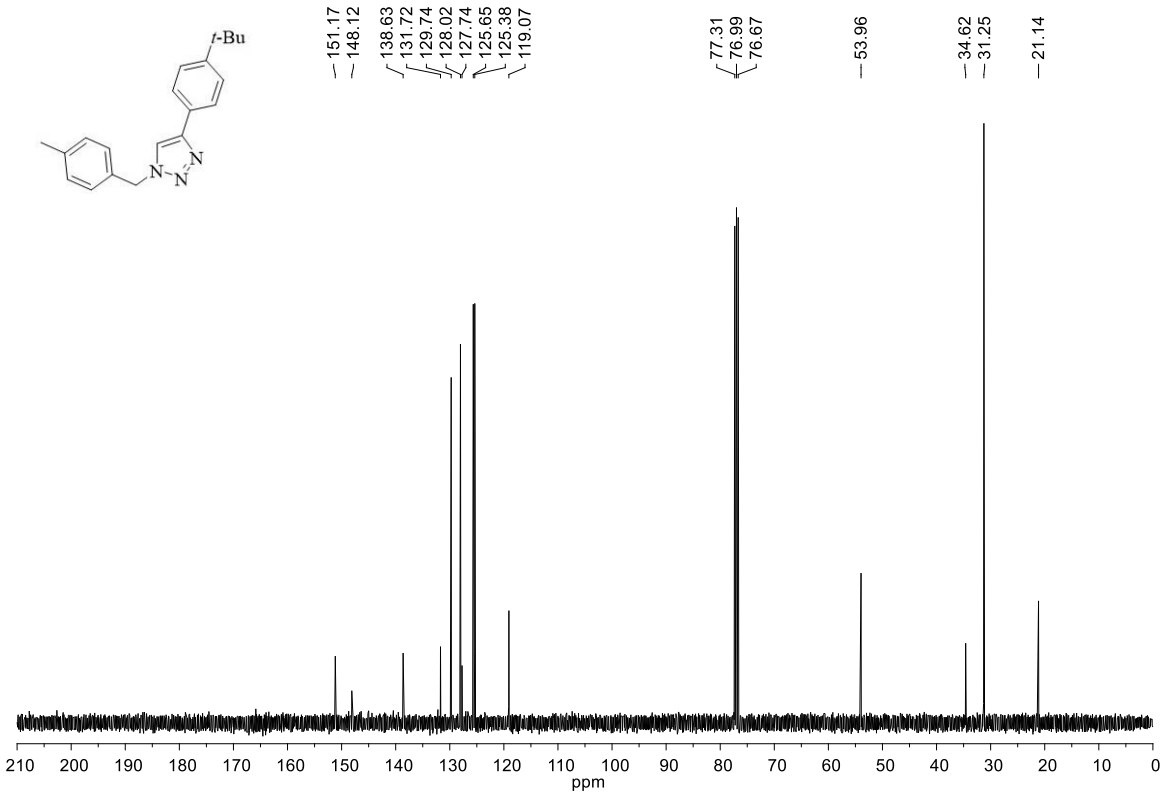
7.39
7.25
7.18
5.51
2.34
1.31
1.90
1.04
2.06
3.58
2.01
2.84
9.00
13.5
12.5
11.5
10.5
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
ppm


t-Bu
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129.74
128.02
127.74
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125.38
119.07
77.31
76.99
76.67
53.96
34.62
31.25
21.14
210
200
190
180
170
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150
140
130
120
110
100
90
80
70
60
50
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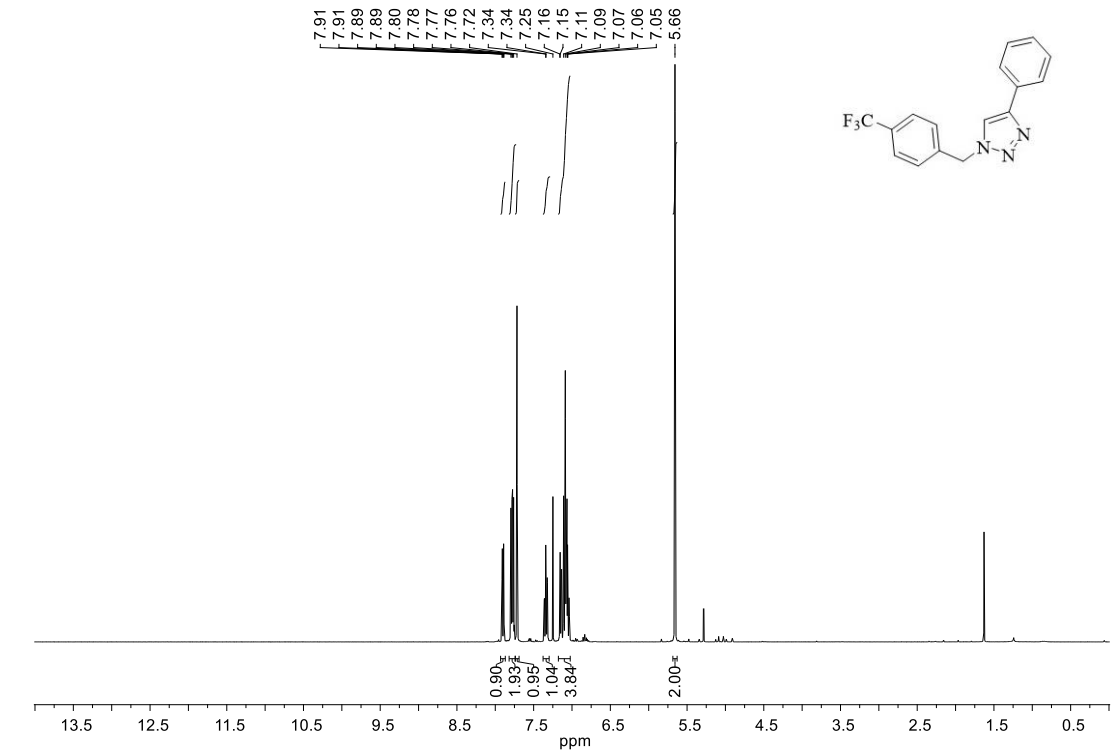
30
20
10
0
ppm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7.76
7.72
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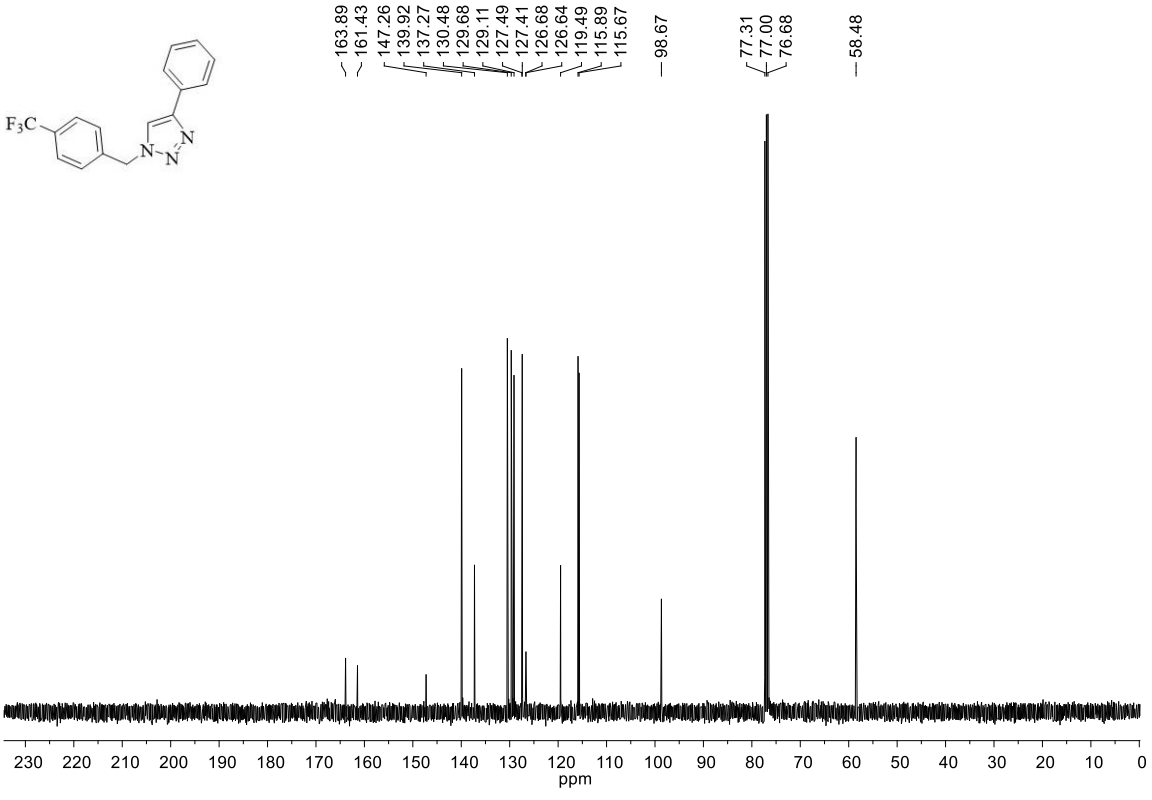
7.34
7.25
7.16
7.15
7.11
7.09
7.07
7.06
7.05
5.66
F3C
0.90
1.93
0.95
1.04
3.84
2.00
13.5 12.5 11.5 10.5 9.5 8.5 7.5 6.5 5.5 4.5 3.5 2.5 1.5 0.5
ppm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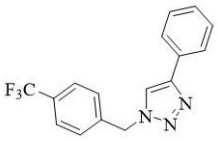
130.48
129.68
129.11
127.49
127.41
126.68
126.64
119.49
115.89
115.67
98.67
77.31
77.00
76.68
58.48
F3C
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
ppm



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-113.49
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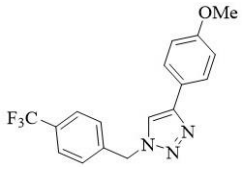
ppm



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7.63
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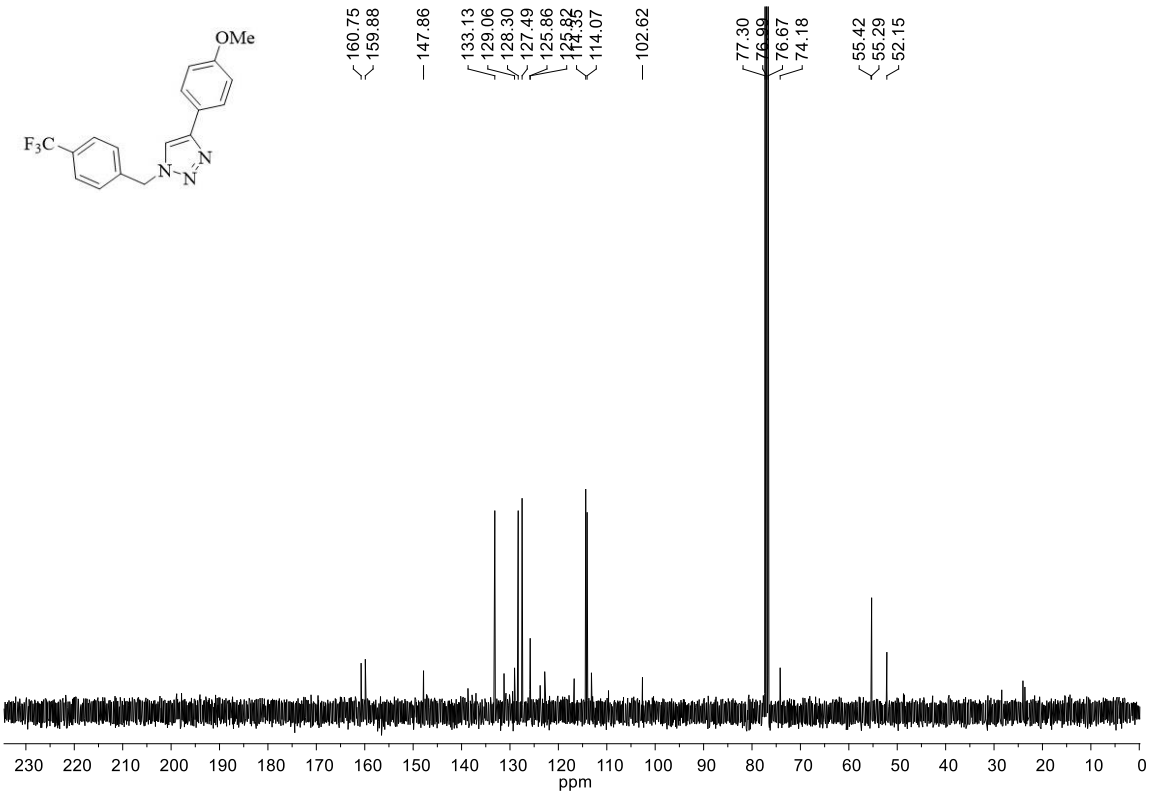
7.41
7.25
6.94
6.92
5.62
3.82
1.55
1.88
1.83
0.90
1.93
1.99
2.00
3.00
13.5 12.5 11.5 10.5 9.5 8.5 7.5 6.5 5.5 4.5 3.5 2.5 1.5 0.5
ppm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N
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129.06
128.30
127.49
125.86
114.35
114.07
102.62
77.30
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74.18
55.42
55.29
52.15
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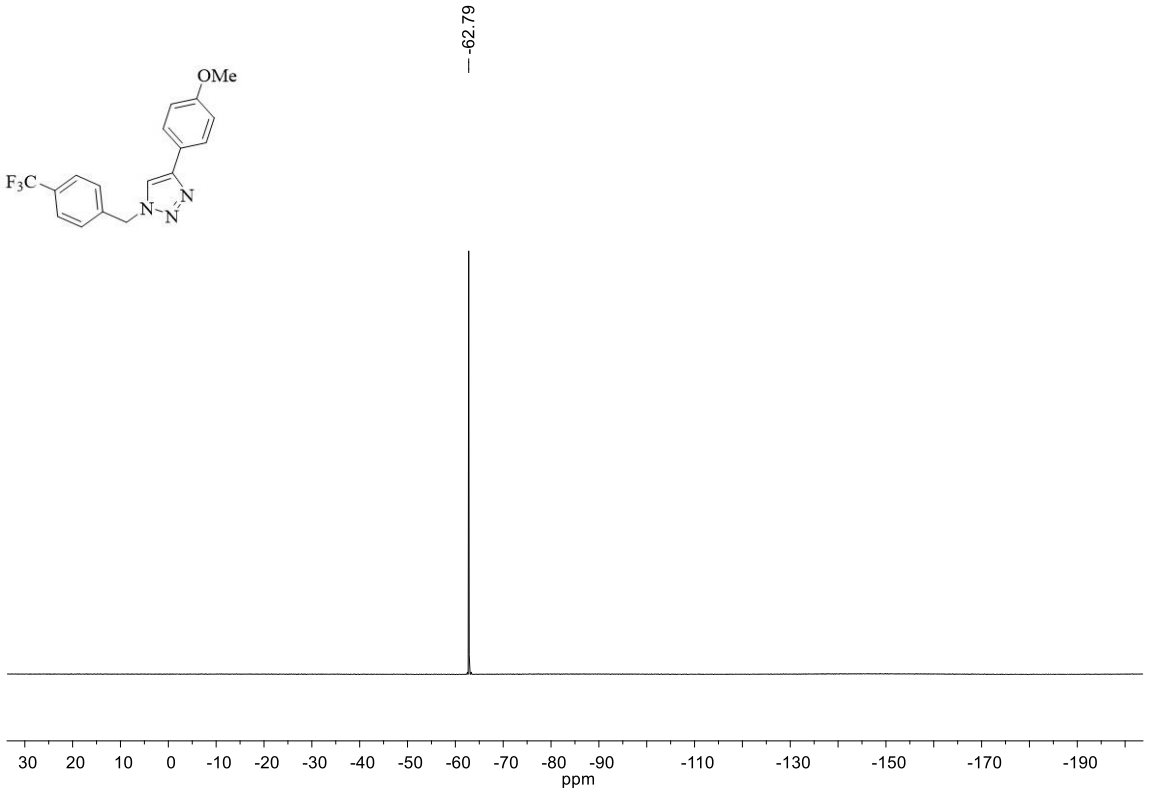
ppm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N
N
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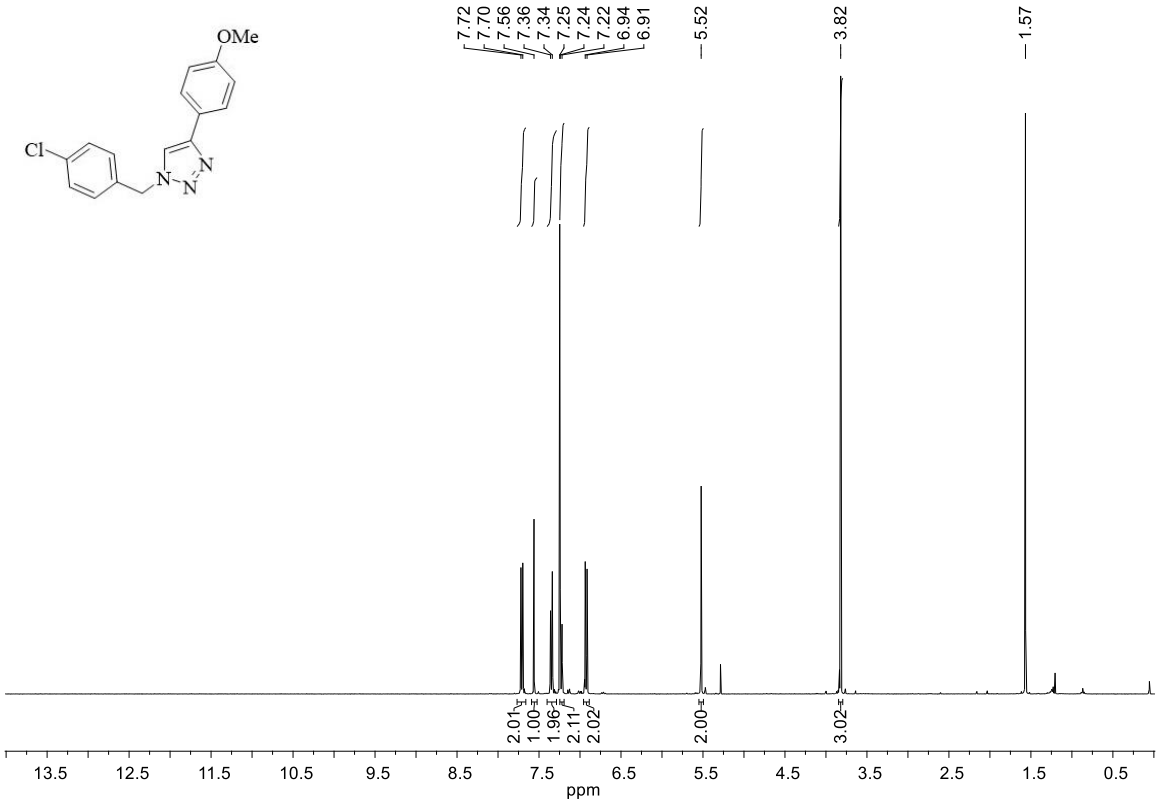
ppm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7.34
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7.24
7.22
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6.91
5.52
3.82
1.57
2.01
1.00
1.96
2.11
2.02
2.00
3.02
13.5
12.5
11.5
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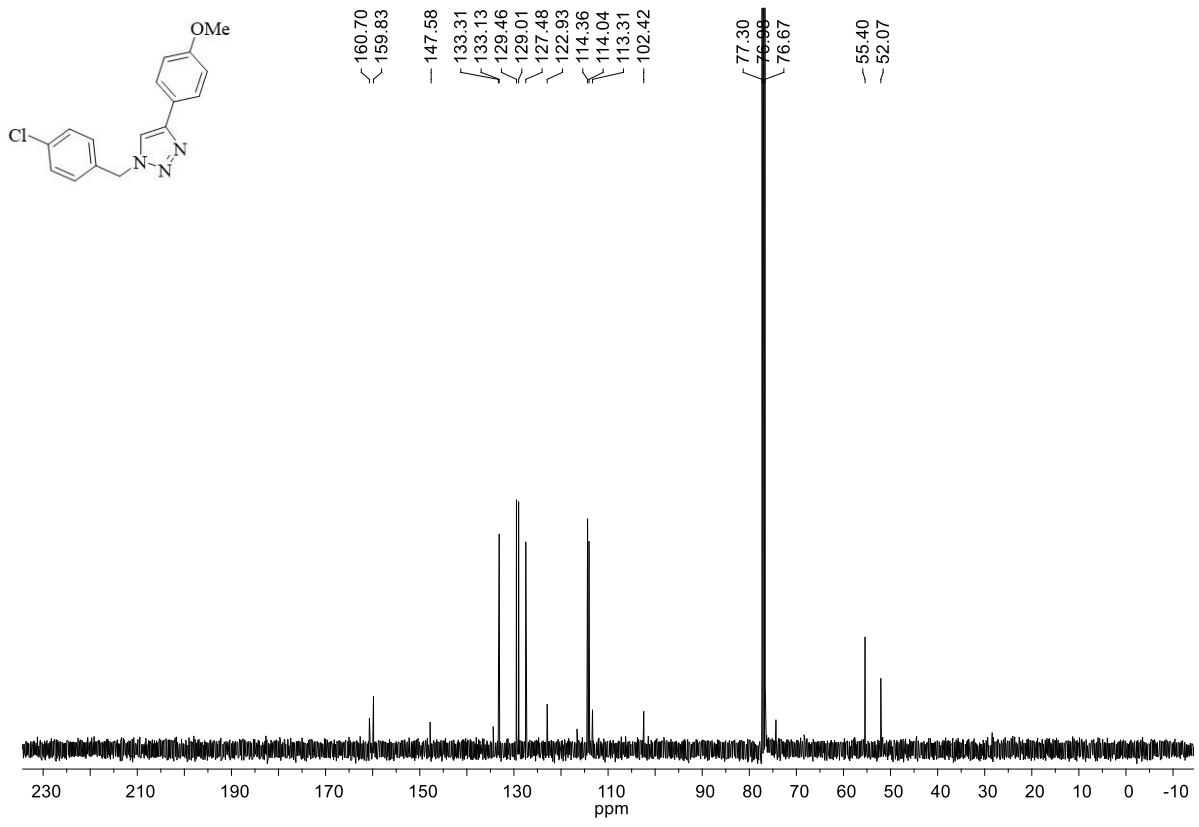
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
ppm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133.13
129.46
129.01
127.48
122.93
114.36
114.04
113.31
102.42
77.30
76.99
76.67
55.40
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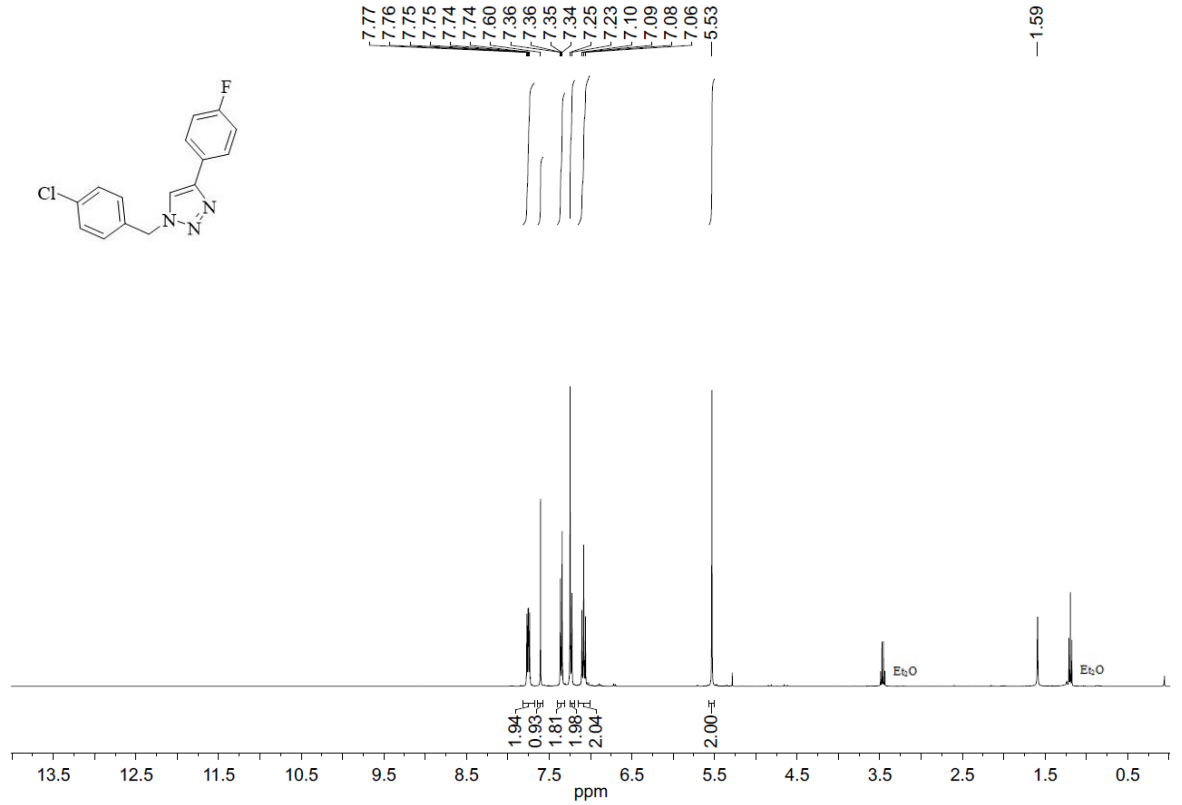
170
150
130
110
90
80
70
60
50
40
30
20
10
0
-10
ppm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7.34
7.25
7.23
7.10
7.09
7.08
7.06
5.53
1.59
F
Cl
N
N
N
Et2O
Et2O
1.94
0.93
1.81
1.98
2.04
2.00
13.5
12.5
11.5
10.5
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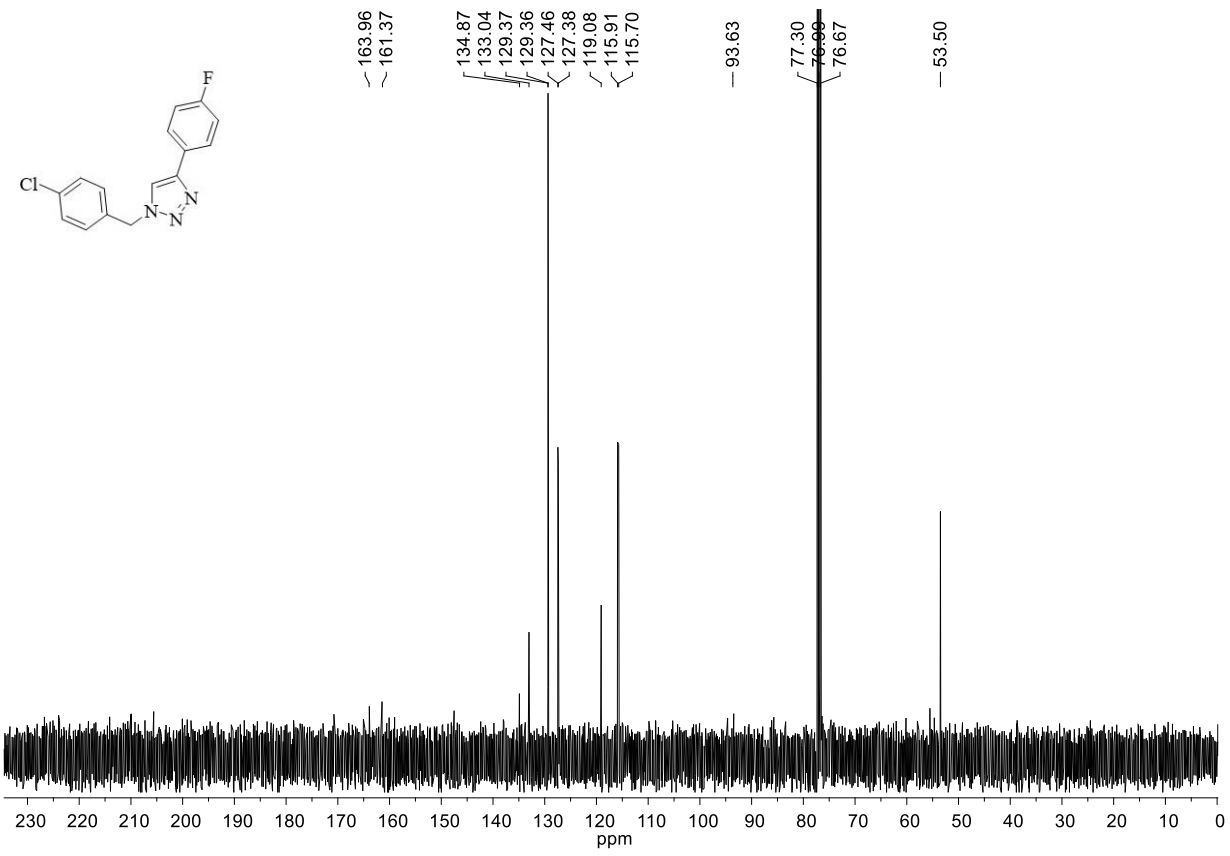
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
ppm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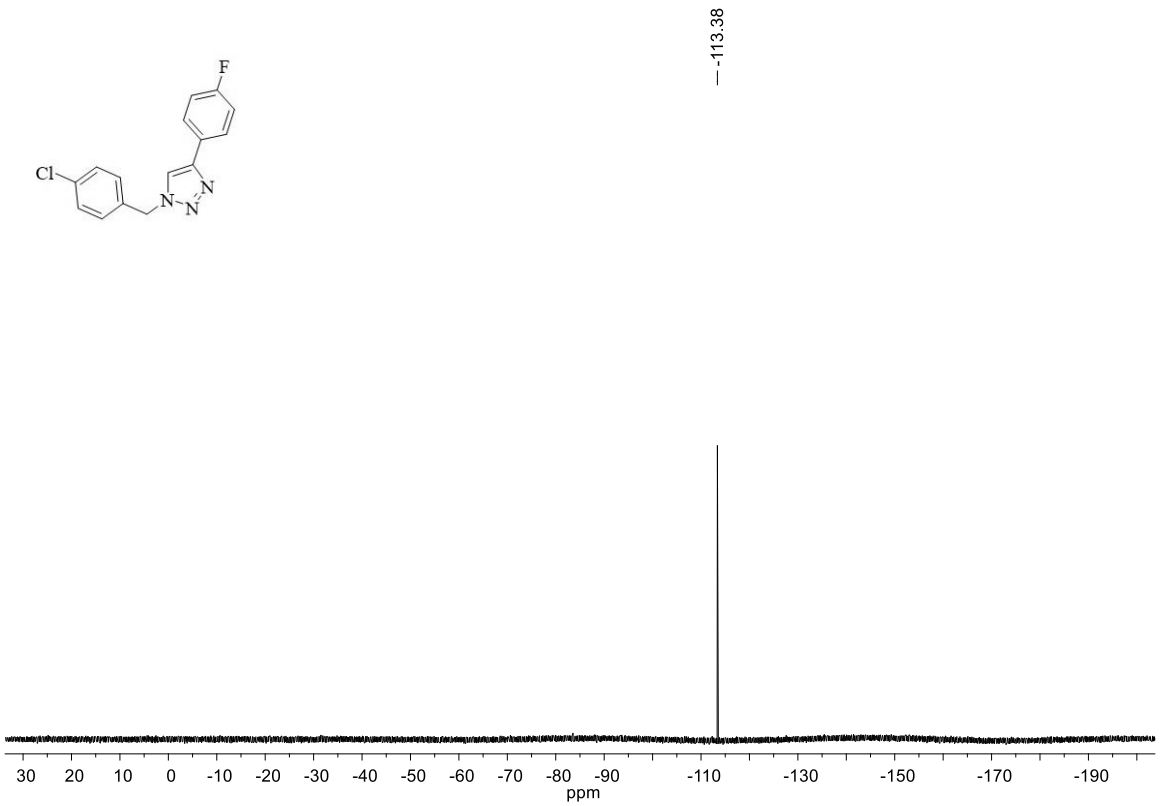
129.36
127.46
127.38
119.08
115.91
115.70
93.63
77.30
76.00
76.67
53.50
F
Cl
N
N
N
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm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Cl
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N
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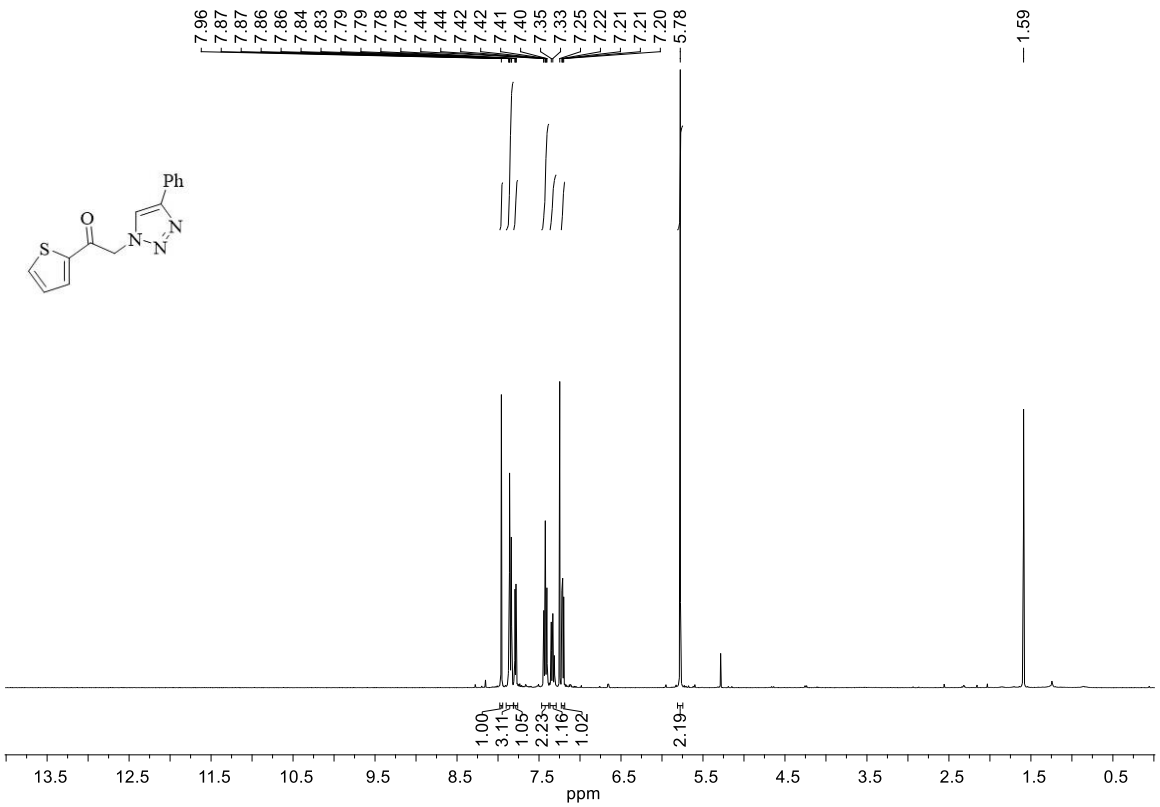
ppm


Ph
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S
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7.79
7.78
7.78
7.44
7.44
7.42
7.42
7.41
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7.35
7.33
7.25
7.22
7.21
7.21
7.20
5.78
1.59
1.00
3.11
1.05
2.23
1.16
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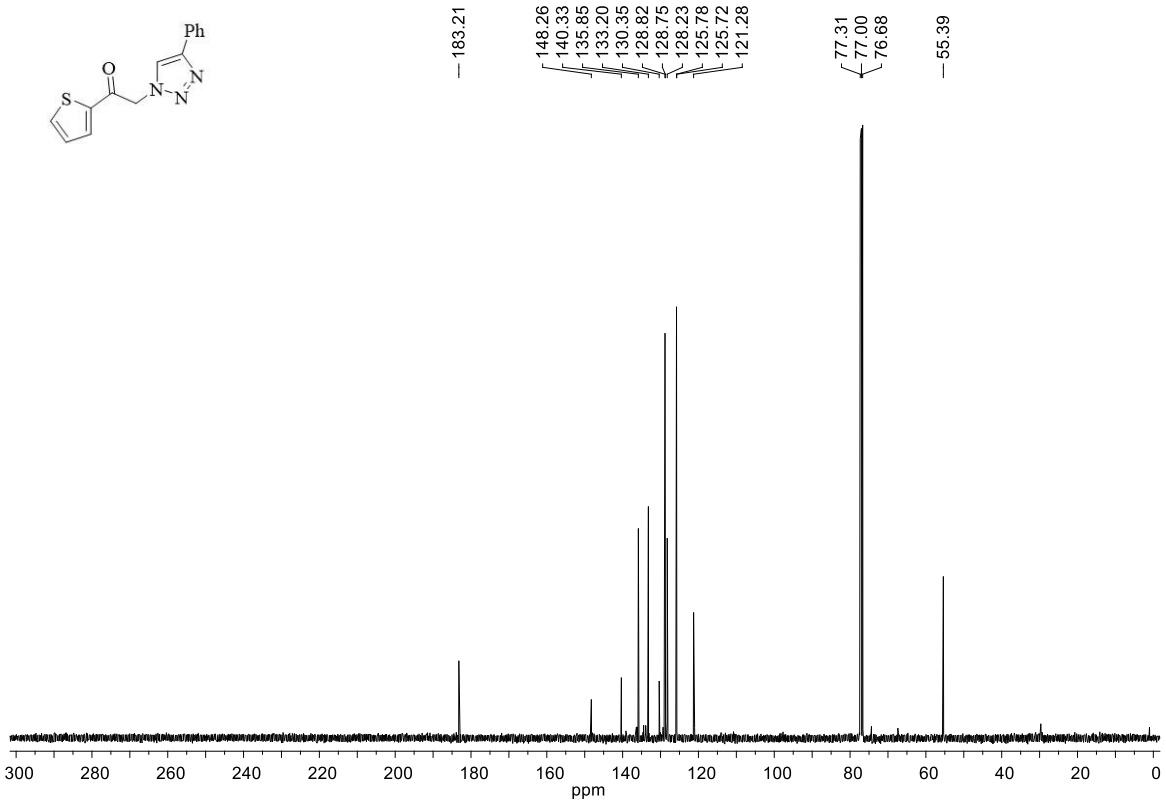
2.19
13.5 12.5 11.5 10.5 9.5 8.5 7.5 6.5 5.5 4.5 3.5 2.5 1.5 0.5
ppm


Ph
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S
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N
N
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128.82
128.75
128.23
125.78
125.72
121.28
77.31
77.00
76.68
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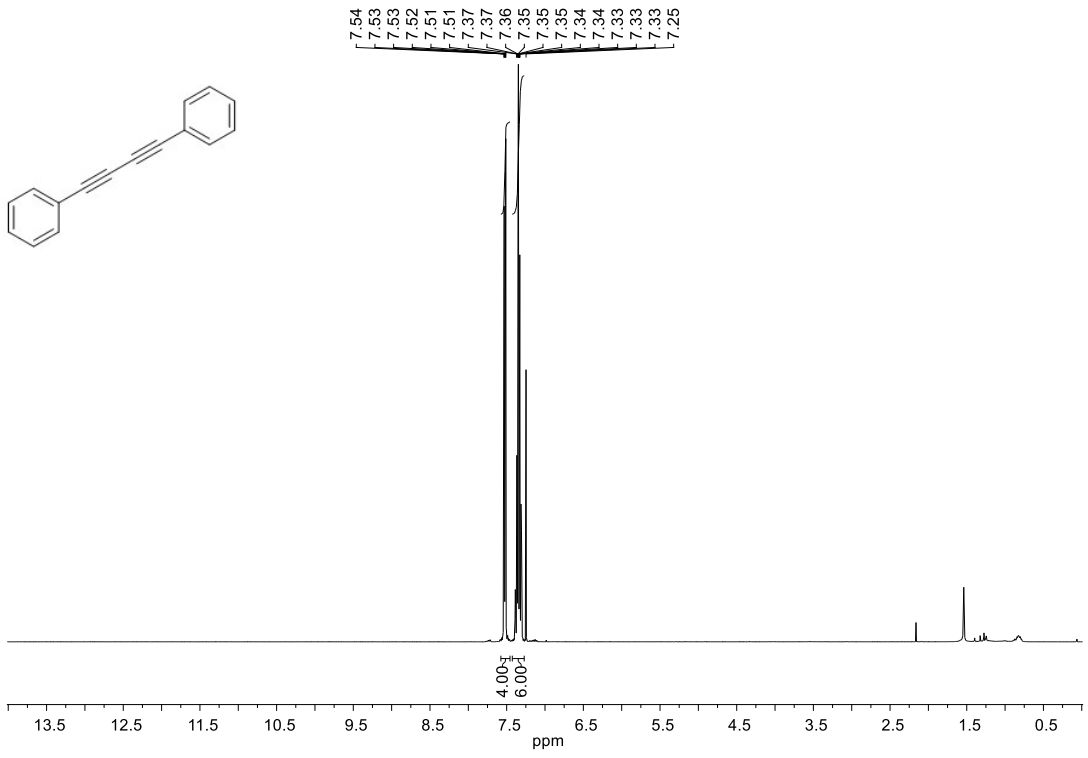
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
ppm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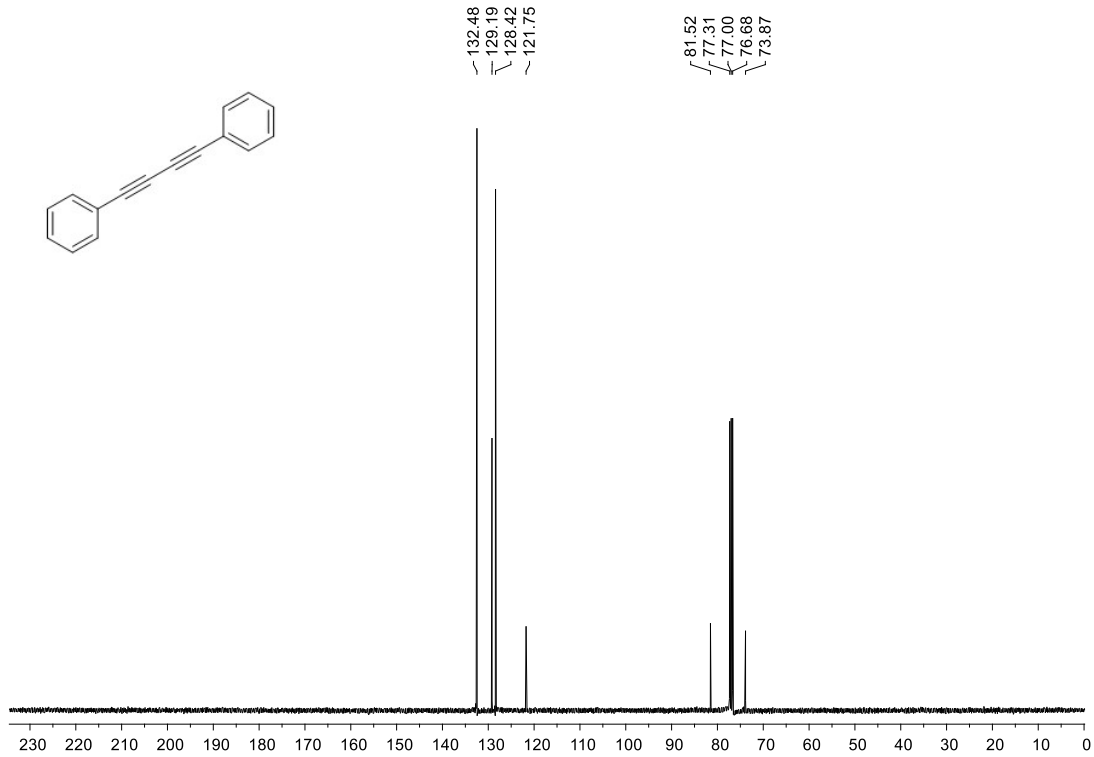
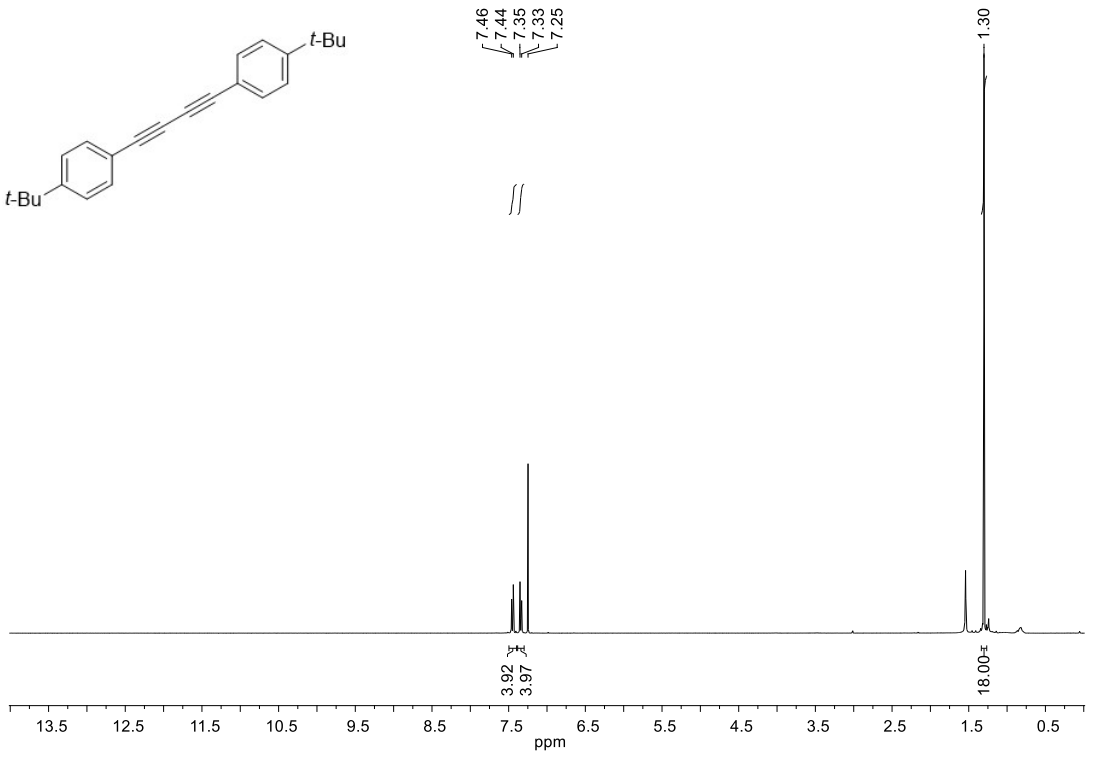
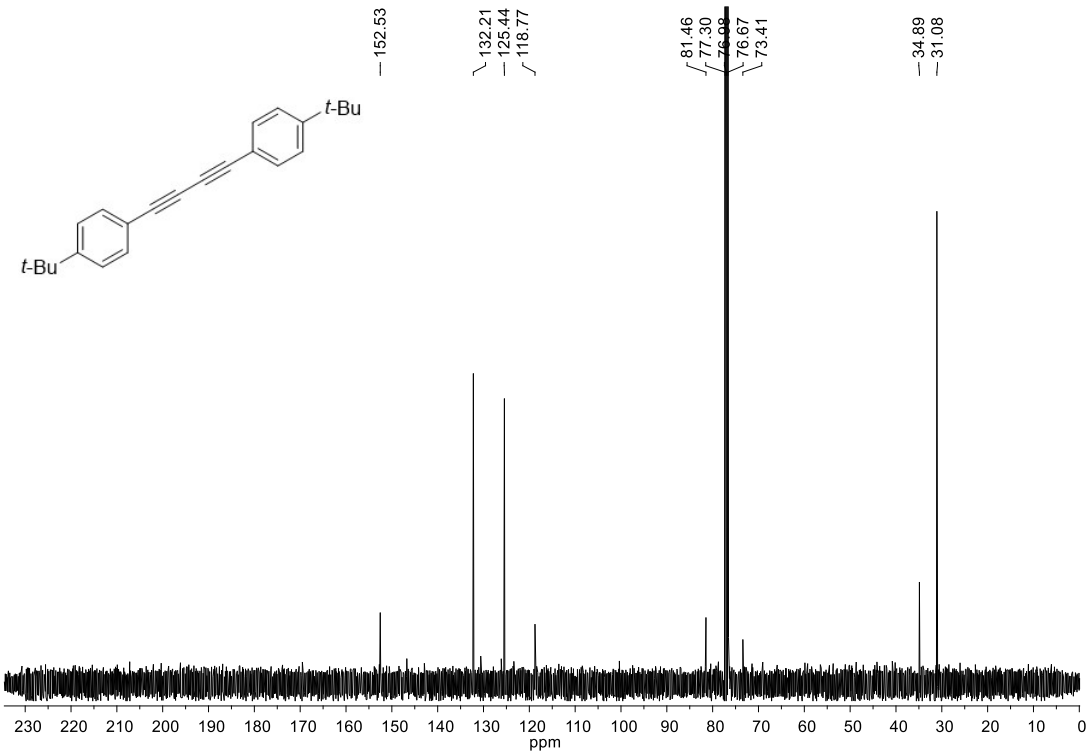
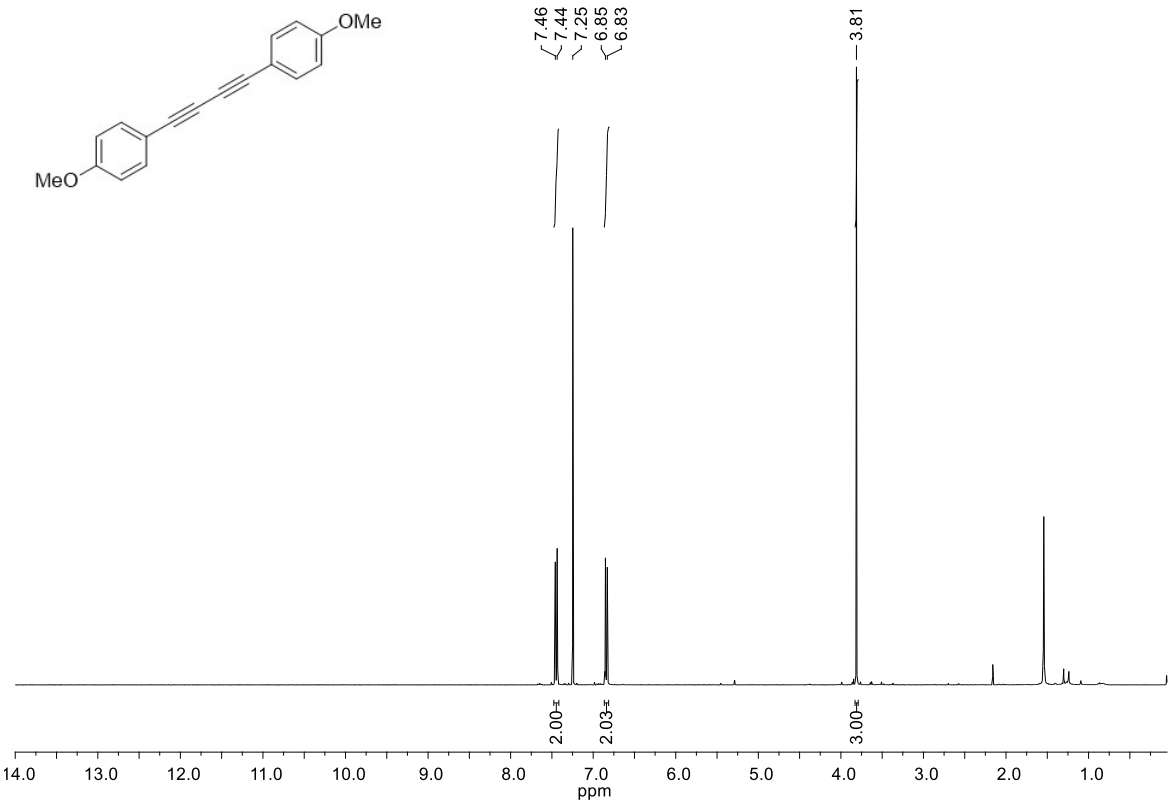
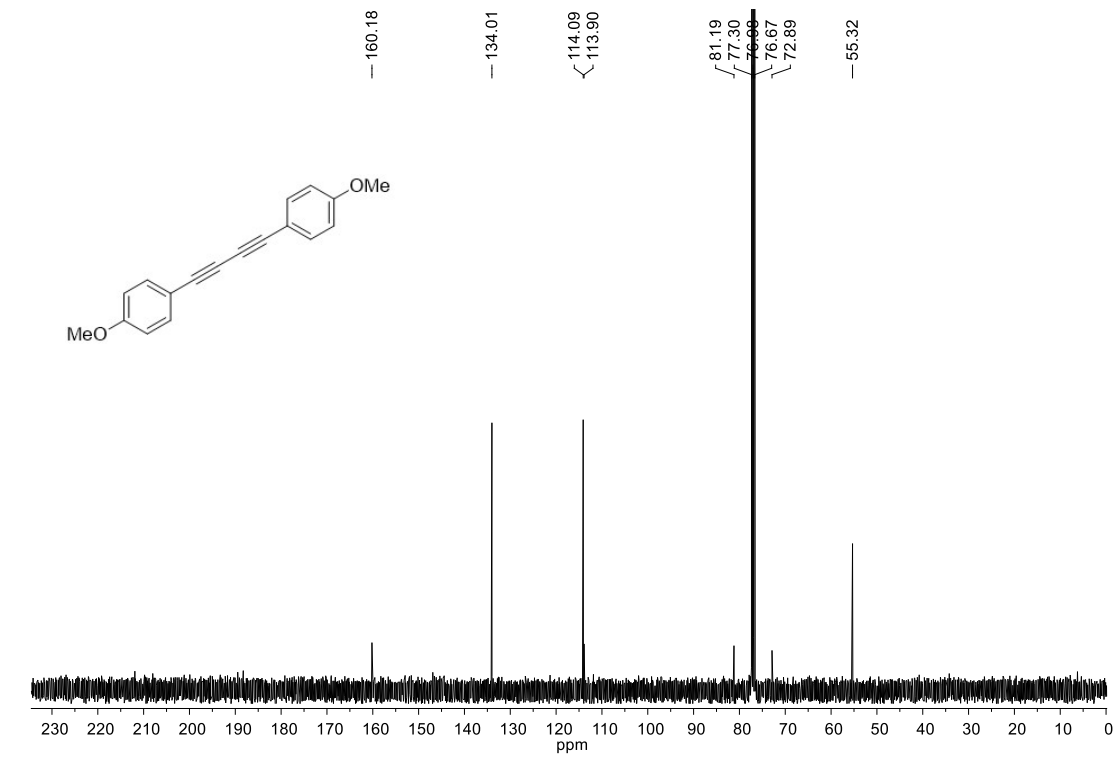
11.5
10.5
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
ppm

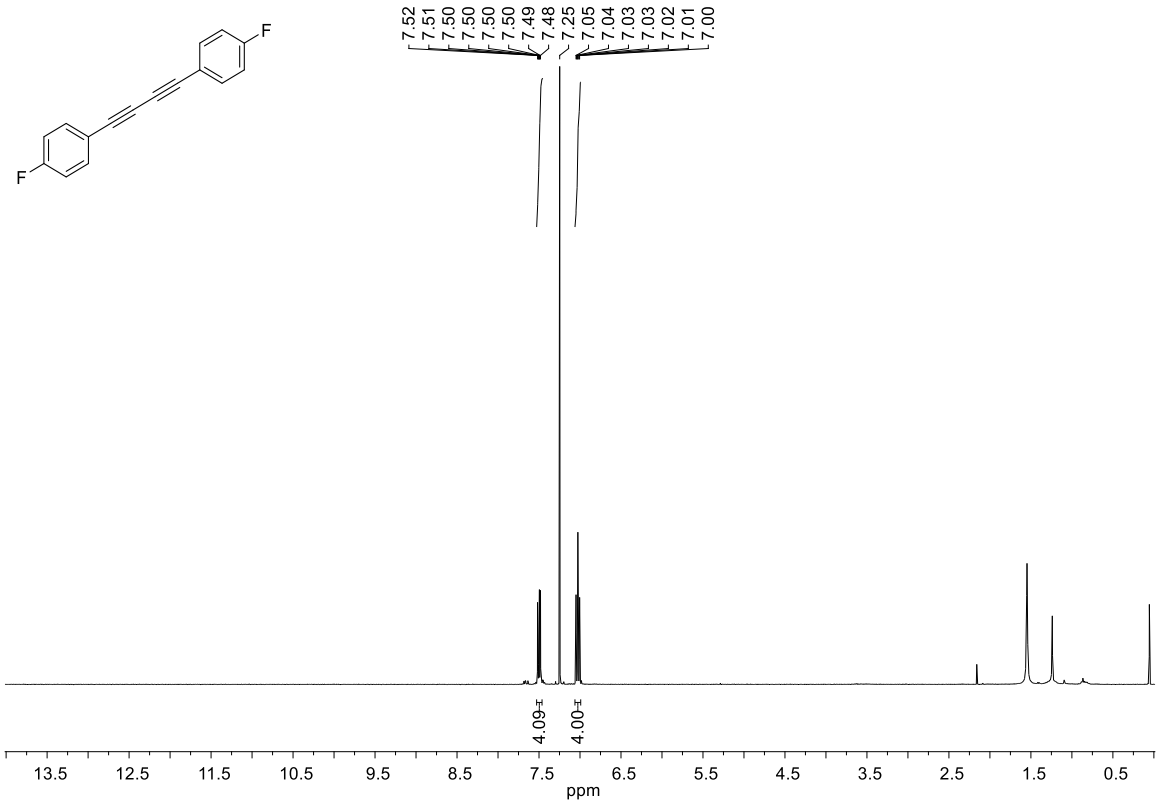

132.48
129.19
128.42
121.75
81.52
77.31
77.00
76.68
73.87
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0

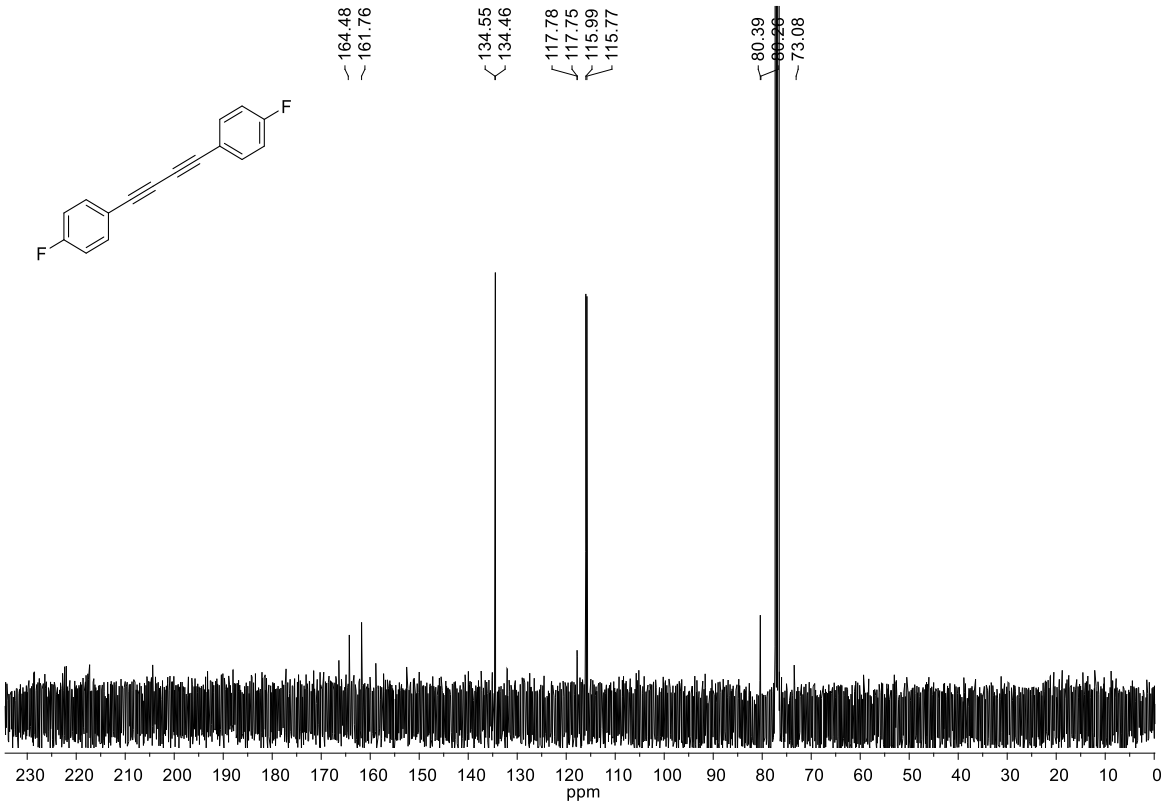

t-Bu
t-Bu
7.46
7.44
7.35
7.33
7.25
1.30
3.92
3.97
18.00
13.5 12.5 11.5 10.5 9.5 8.5 7.5 6.5 5.5 4.5 3.5 2.5 1.5 0.5
ppm

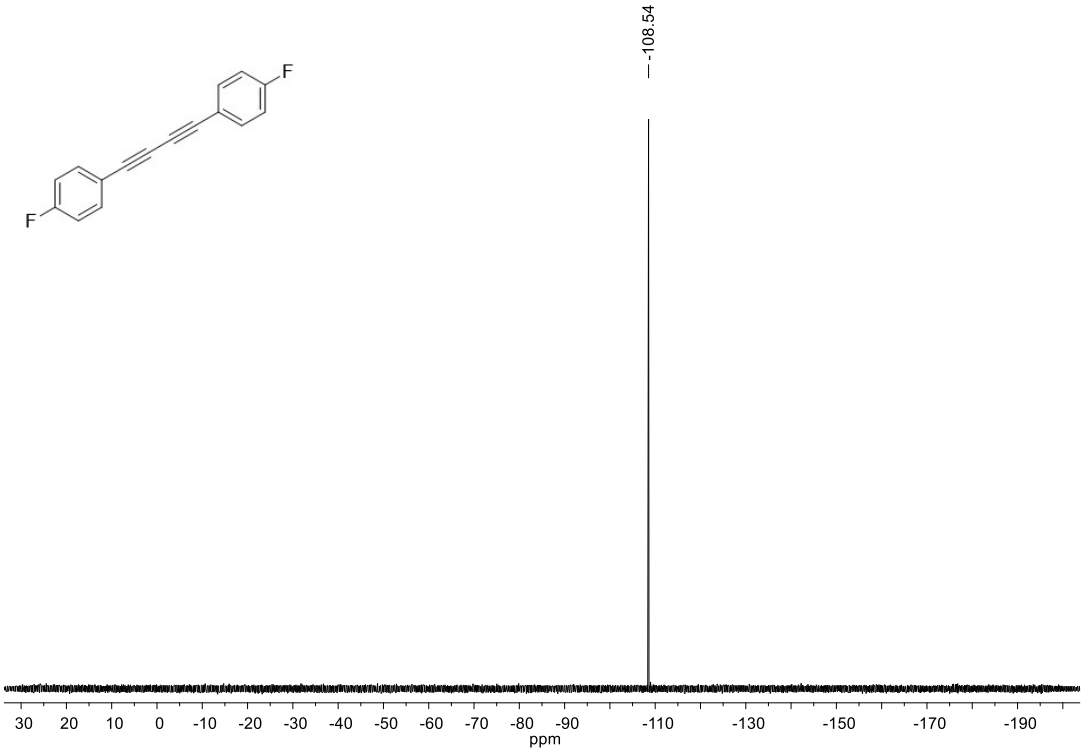

152.53
132.21
125.44
118.77
81.46
77.30
76.67
73.41
34.89
31.08
t-Bu
t-Bu
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
ppm

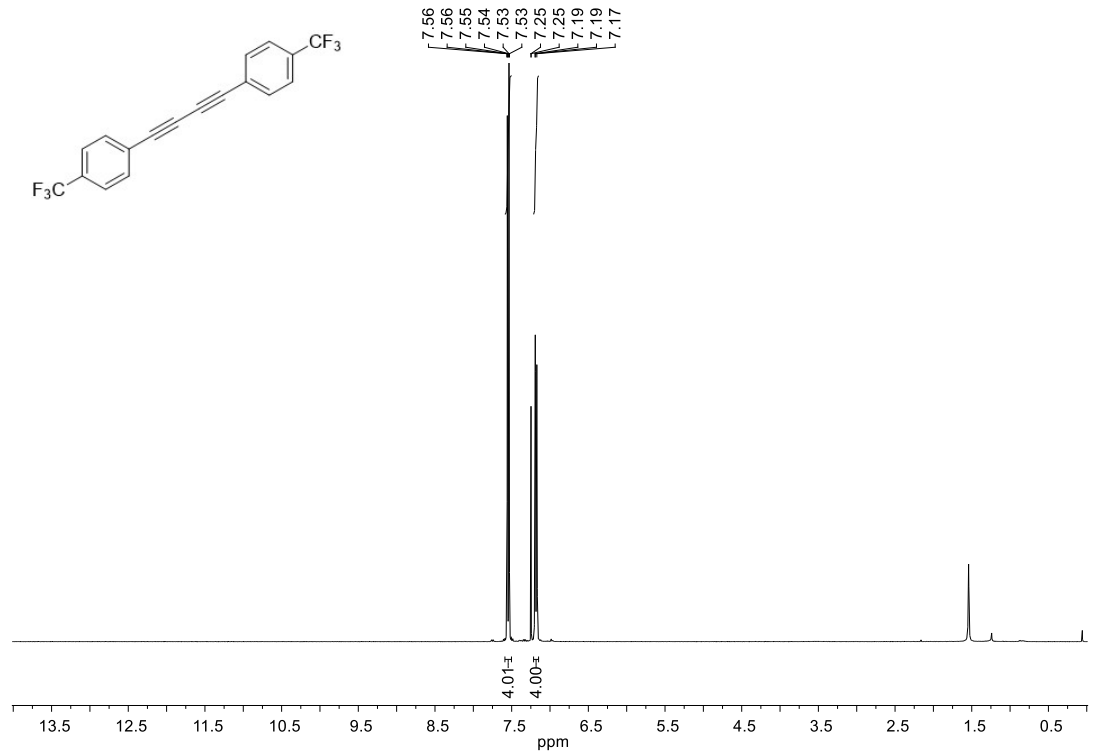

7.46
7.44
7.25
6.85
6.83
3.81
OMe
MeO
2.00
2.03
3.00
14.0 13.0 12.0 11.0 10.0 9.0 8.0 7.0 6.0 5.0 4.0 3.0 2.0 1.0
ppm

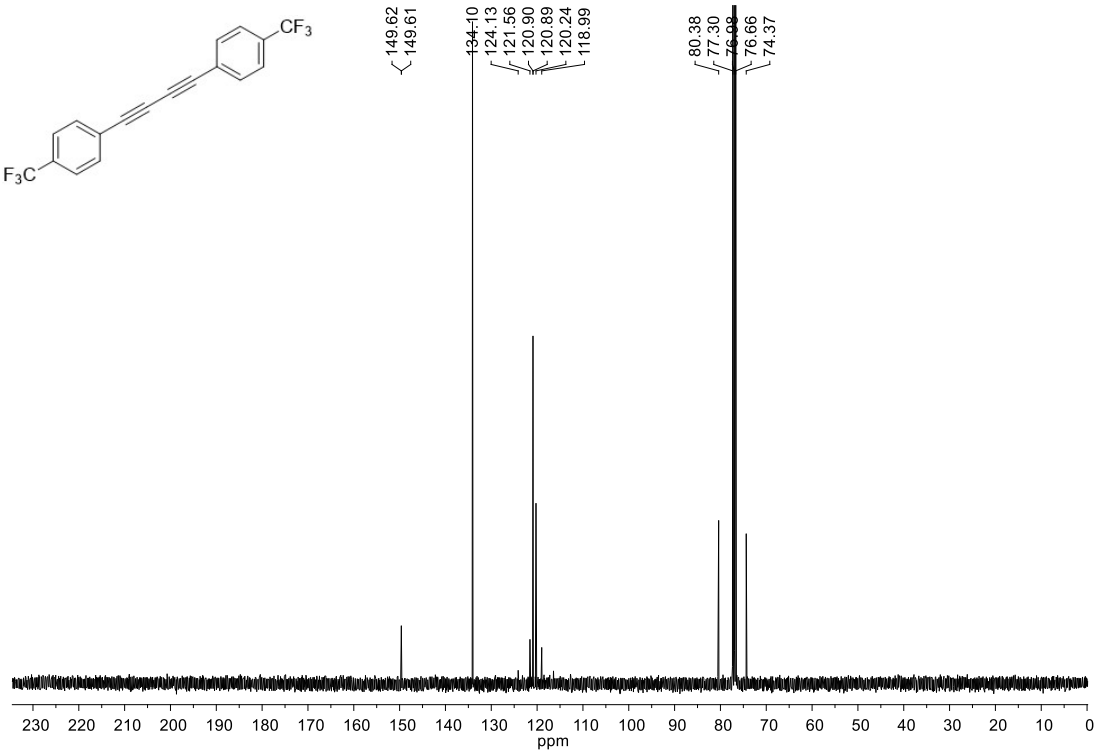

160.18
134.01
114.09
113.90
81.19
77.30
76.67
72.89
55.32
OMe
MeO
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
ppm

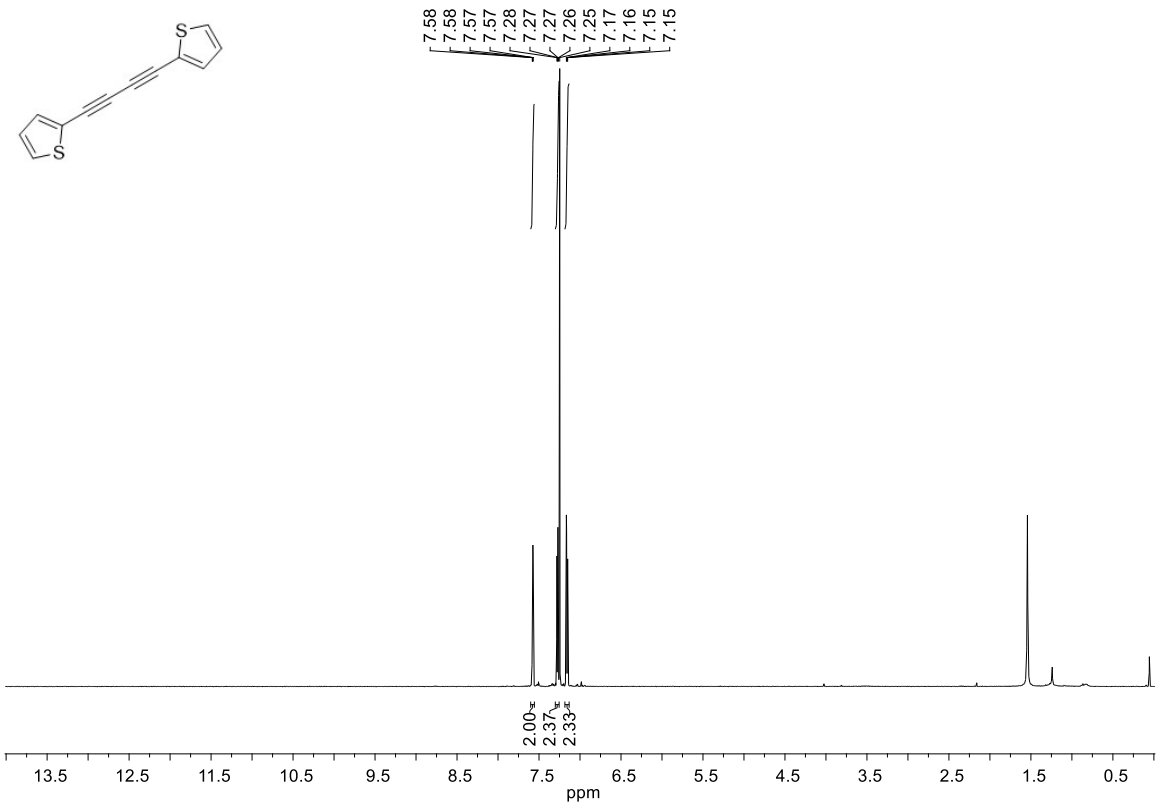

7.52
7.51
7.50
7.50
7.50
7.50
7.49
7.48
7.25
7.05
7.04
7.03
7.03
7.02
7.01
7.00
F
F
4.09
4.00
13.5 12.5 11.5 10.5 9.5 8.5 7.5 6.5 5.5 4.5 3.5 2.5 1.5 0.5
ppm

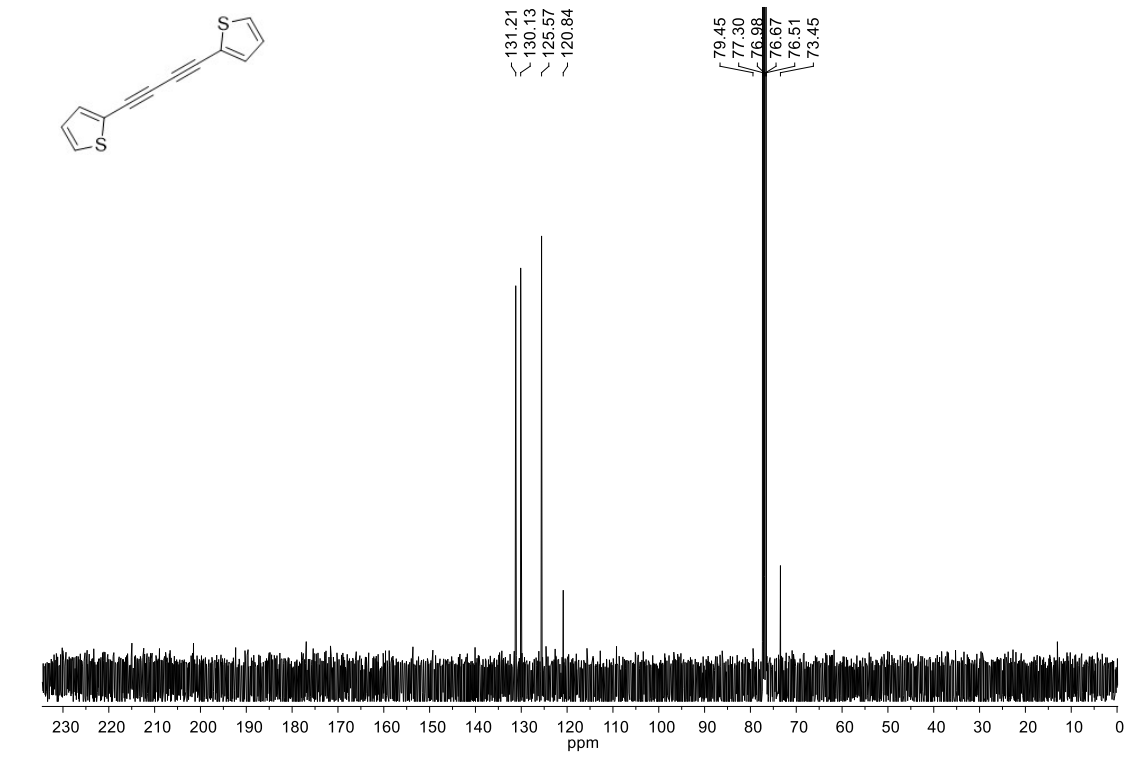

164.48
161.76
134.55
134.46
117.78
117.75
115.99
115.77
80.39
80.20
73.08
F
F
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
ppm

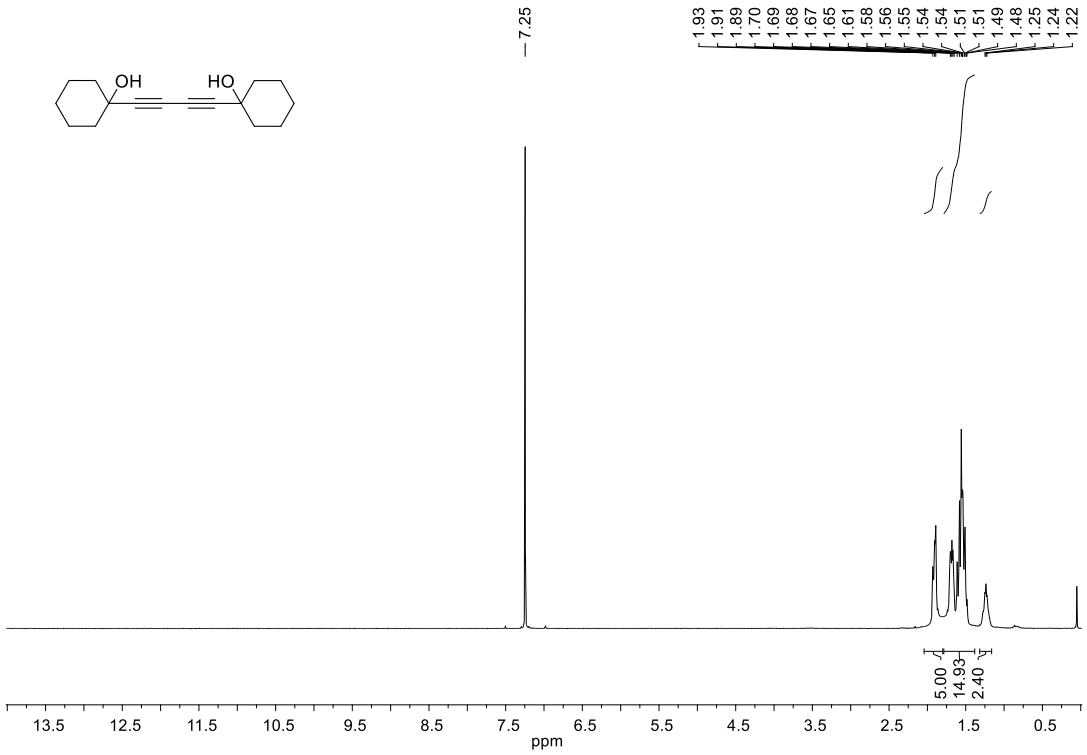

-108.54
F
F
30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -110 -130 -150 -170 -190
ppm

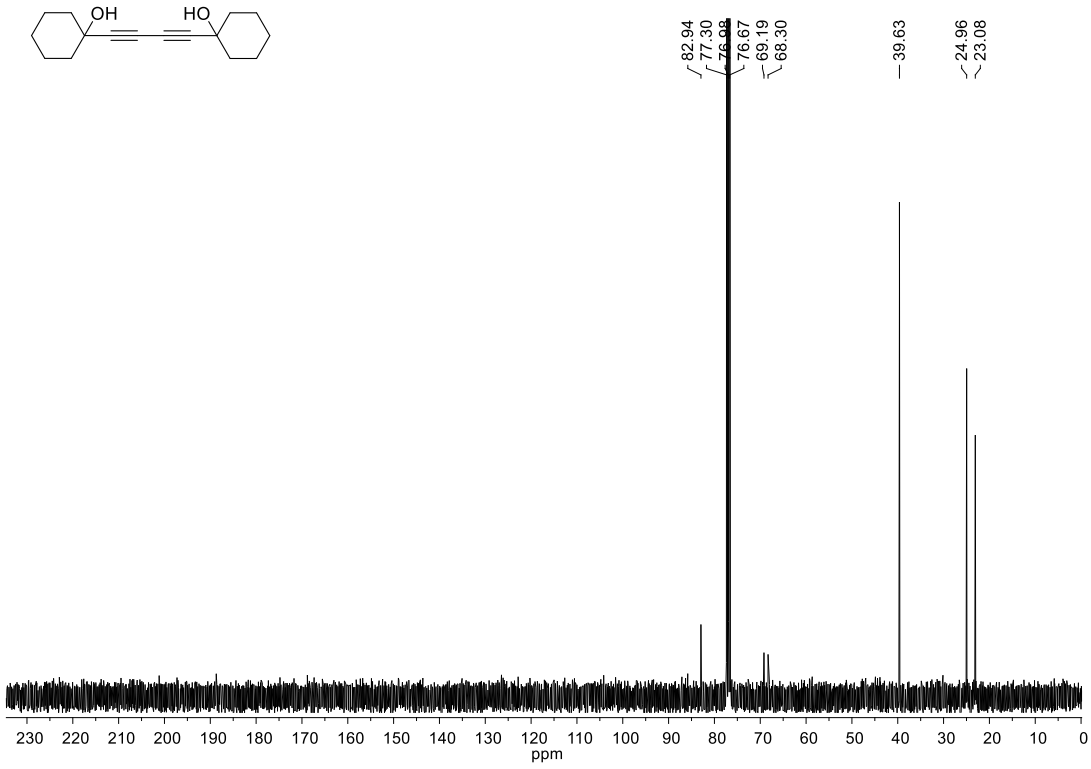

7.56
7.56
7.55
7.54
7.53
7.53
7.25
7.25
7.19
7.19
7.17
CF3
F3C
4.01
4.00
13.5
12.5
11.5
10.5
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
ppm


149.62
149.61
134.10
124.13
121.56
120.90
120.89
120.24
118.99
80.38
77.30
76.66
74.37
CF3
F3C
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


7.58
7.58
7.57
7.57
7.28
7.27
7.27
7.26
7.25
7.17
7.16
7.15
7.15
2.00
2.37
2.33
13.5
12.5
11.5
10.5
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
ppm


131.21
130.13
125.57
120.84
79.45
77.30
76.98
76.67
76.51
73.45
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


OH
HO
7.25
1.93
1.91
1.89
1.70
1.69
1.68
1.67
1.65
1.61
1.58
1.56
1.55
1.54
1.54
1.51
1.51
1.49
1.48
1.25
1.24
1.22
5.00
14.93
2.40
13.5
12.5
11.5
10.5
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
ppm


OH
HO
82.94
77.30
76.98
76.67
69.19
68.30
39.63
24.96
23.08
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm