Supporting Information

Room-Temperature Direct Alkynylation of Arenes with Copper Acetylides

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General Information.

All reactions were carried out in oven-dried glassware under an argon atmosphere employing standard techniques in handling air-sensitive materials unless otherwise stated.

All reagents and solvents were reagent grade. Acetonitrile and *N*,*N*-dimethylformamide were freshly distilled from calcium hydride under argon. All reagents were used as supplied.

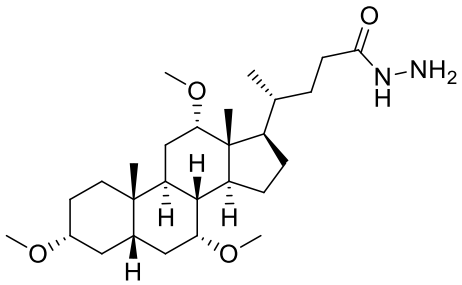
Reactions were magnetically stirred and monitored by thin layer chromatography using Merck-Kiesegel 60F_{254} plates. Flash chromatography was performed with silica gel 60 (particle size 35-70 μm) supplied by Merck. Yields refer to chromatographically and spectroscopically pure compounds.

Proton NMR spectra were recorded using an internal deuterium lock at ambient temperature on Bruker 300 and 400 MHz spectrometers. Internal reference of δ_H 7.26 was used for $CDCl_3$. Data are presented as follows: chemical shift (in ppm on the δ scale relative to δ_{TMS} = 0), multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, quint. = quintuplet, non. = nonuplet, m = multiplet, br. = broad, app. = apparent), coupling constant (*J*/Hz) and integration. Resonances that are either partially or fully obscured are denoted obscured (obs.). Carbon-13 NMR spectra were recorded at 75 MHz using $CDCl_3$ *(*δ_C 77.16) as internal reference. Fluorine-19 NMR spectra were recorded at 376 MHz using CF_3CH_2OH *(*δ_F -77.59) as internal reference.

Optical rotations were recorded on an Atago AP-100 automatic polarimeter at 589 nm and reported as follows: $[\alpha]_D^{25}$, concentration (*c* in g/100 mL), and solvent. Melting points were recorded on a Stuart Scientific Analogue SMP11. Infrared spectra were recorded on a Bruker Alpha Spectrometer (ATR). High-resolution mass-spectra were obtained on Waters Qtof Micro, Waters QTof API US or Thermo Finnigan MAT 95XP spectrometers.

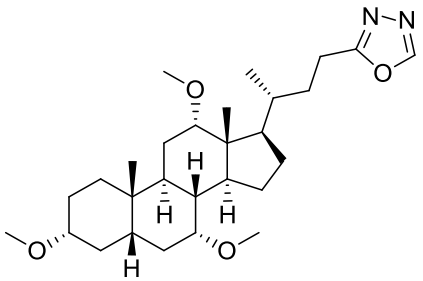
Experimental Procedures and Characterization Data:

Unreported Starting Materials

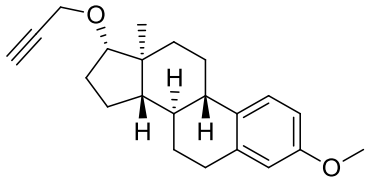


(*R*)-4-[(3*R*,5*S*,7*R*,8*R*,9*S*,10*S*,12*S*,13*R*,14*S*,17*R*)-3,7,12-Trimethoxy-10,13-dimethylhexadeca-hydro-1*H*-cyclopenta[*a*]phenanthren-17-yl]pentanehydrazide. To a solution of (*R*)-methyl-4-[(3*R*,5*S*,7*R*,8*R*,9*S*,10*S*,12*S*,13*R*,14*S*,17*R*)-3,7,12-trimethoxy-10,13-dimethylhexadecahydro-1*H*-cyclopenta[*a*]phenanthren-17-yl]pentanoate[S1] (4.8 g, 10.3 mmol) in methanol (25 mL) was added hydrazine hydrate (10 mL, 206 mmol). The resulting reaction mixture was vigorously stirred at reflux overnight, cooled back to room temperature and concentrated under vacuum. The crude residue was taken up with water (50 mL) and EtOAc (50 mL). The organic layer was separated and the aqueous layer was extracted with EtOAc. Combined organic layers were washed with brine, dried over $MgSO_4$, filtered and concentrated under vacuum to afford the desired hydrazide as a white solid (4.8 g, 10.3 mmol, quant.) which was used in the next step without further purification. Mp: 77 °C; $[\alpha]_D^{25}$ + 45 (*c* 1.0, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$): δ 6.76 (s, 1H), 3.88 (s, 2H), 3.36-3.30 (obs. m, 1H), 3.32 (s, 3H), 3.24 (s, 3H), 3.20 (s, 3H), 3.13 (app. d, *J* = 4.2 Hz, 1H), 3.05-2.92 (m, 1H), 2.28-1.58 (m, 14H), 1.58-1.11 (m, 9H), 1.09-0.94 (m, 1H), 0.91 (d, *J* = 6.3 Hz, 3H), 0.89 (s, 3H), 0.64 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 174.7, 82.1, 80.1, 77.1, 56.0, 55.8, 55.5, 46.2, 42.8, 42.1, 39.7, 35.4, 35.2, 35.0, 34.6, 31.6, 31.2, 28.1, 27.9, 27.5, 26.9, 23.3, 23.0, 22.1, 17.6, 12.6; IR (ATR): ν_{max} 3443, 2931, 2869, 1652, 1519, 1454, 1370, 1192, 1100, 753 cm^{-1}; ESIHRMS *m/z* calcd for $C_{27}H_{49}N_2O_4$ $[M+H]^+$ 465.6392, found 465.3689.

[S1] Rueda-Becerril, M.; Chatalova Sazepin, C.; Leung, J. C. T.; Okbinoglu, T.; Kennepohl, P.; Paquin, J.-F.; Sammis, G. M. *J. Am. Chem. Soc.* **2012**, *134*, 4026.



2-{(*R*)-3-[(3*R*,5*S*,7*R*,8*R*,9*S*,10*S*,12*S*,13*R*,14*S*,17*R*)-3,7,12-Trimethoxy-10,13-dimethyl-hexadecahydro-1*H*-cyclopenta[*a*]phenanthren-17-yl]butyl}-1,3,4-oxadiazole. To a solution of (*R*)-4-[(3*R*,5*S*,7*R*,8*R*,9*S*,10*S*,12*S*,13*R*,14*S*,17*R*)-3,7,12-trimethoxy-10,13-dimethylhexadecahydro-1*H*-cyclopenta[*a*]phenanthren-17-yl]pentanehydrazide (2.5 g, 5.4 mmol) in triethyl orthoformate (20 mL) was added *p*-toluenesulfonic acid monohydrate (51 mg, 0.3 mmol). The resulting reaction mixture was vigorously stirred at reflux for 24 hours, cooled back to room temperature and concentrated under vacuum. The crude residue was finally purified by flash column chromatography over silica gel (cyclohexane/EtOAc: 70/30) to afford the desired 1,3,4-oxadiazole as a white solid (2.3 g, 4.8 mmol, 88%). Mp: 152 °C; $[\alpha]_D^{25}$ + 45 (*c* 1.0, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.31 (s, 1H), 3.33 (app. d, *J* = 11.2 Hz, 1H), 3.31 (s, 3H), 3.25 (s, 3H), 3.19 (s, 3H), 3.12 (app. d, *J* = 2.5 Hz, 1H), 3.05-2.74 (m, 3H), 2.26-1.38 (m, 16H), 1.37-1.10 (m, 4H), 1.09-0.83 (obs. m, 2H), 0.97 (d, *J* = 6.4 Hz, 3H), 0.88 (s, 3H), 0.64 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 167.8, 152.9, 82.0, 80.8, 77.0, 56.0, 55.8, 55.5, 46.3, 46.2, 42.8, 42.1, 39.7, 35.4, 35.2, 35.0, 34.5, 32.6, 28.1, 27.9, 27.5, 26.9, 23.2, 23.0, 22.1 (2C), 17.4, 12.6; IR (ATR): ν_{max} 2939, 1574, 1519, 1471, 1453, 1372, 1100, 956, 643 cm^{-1}; ESIHRMS *m/z* calcd for $C_{28}H_{47}N_2O_4$ $[M+H]^+$ 475.3536, found 475.3540.



***O*$_3$-Methyl-*O*$_{17}$-propargyl-estradiol.** To a solution of *O*$_3$-methyl-estradiol (2.1 g, 7.5 mmol) in *N,N*-dimethylformamide (30 mL) was added sodium hydride (60% dispersion in mineral oil, 1.5 g, 38

mmol) portionwise over 15 min. The mixture was allowed to stir for 15 min at rt and propargyl bromide (80% solution in toluene, 4.2 mL, 38 mmol) was added dropwise at rt. The resulting reaction mixture was vigorously stirred at rt overnight, diluted with water (50 mL) and extracted with diethyl ether. Combined organic layers were washed with brine, dried over $MgSO_4$, filtered and concentrated under vacuum. The crude residue was finally purified by flash column chromatography over silica gel (cyclohexane/CH_2Cl_2: 80/20 then 60/40) to afford the desired terminal alkyne as an orange solid (958 mg, 3.0 mmol, 39%). Mp: 119 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.21 (d, *J* = 8.6 Hz, 1H), 6.72 (d, *J* = 8.5 Hz, 1H), 6.64 (s, 1H), 4.20 (s, 2H), 3.78 (s, 3H), 3.64 (t, *J* = 8.3 Hz, 1H), 2.92-2.78 (m, 2H), 2.42 (t, *J* = 1.9 Hz, 1H), 2.36-1.98 (m, 4H), 1.94-1.81 (m, 1H), 1.78-1.15 (m, 8H), 0.81 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 157.6, 138.1, 132.7, 126.4, 113.9, 111.6, 88.3, 80.7, 73.9, 57.3, 55.3, 50.3, 44.0, 43.3, 38.7, 37.8, 29.9, 27.8, 27.3, 26.5, 23.2, 11.8; IR (ATR): ν_{max} 3249, 2909, 2864, 2127, 1495, 1447, 1280, 1255, 1133, 1086, 1037, 868, 739, 692 cm^{-1}; EIHRMS *m/z* calcd for $C_{22}H_{28}O_2$ $[M]^+$ 324.2089, found 324.2088.

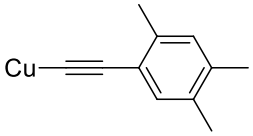
Experimental Procedures and Characterization Data:

Unreported Alkynylcopper Reagents

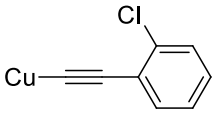
Alkynylcopper reagents were prepared according to our previously reported procedures recalled below.[S2]

- **Method A using copper iodide in aqueous ammonia and ethanol.** To a solution of copper iodide (3.8 g, 20.0 mmol) in a mixture of aqueous ammonium hydroxide (28% NH_3 solution, 50 mL) and ethanol (30 mL) was added the alkyne (10.0 mmol, neat if the alkyne is a liquid, dissolved in 5 mL of ethanol if the alkyne is a solid) dropwise. The deep blue reaction mixture was stirred overnight at room temperature under argon and the yellow precipitate was collected by filtration and successively washed with ammonium hydroxide (10% NH_3 aqueous solution, 3x50 mL), water (3x50 mL), ethanol (3x50 mL), and diethyl ether (3x50 mL). The bright yellow solid was then dried under high vacuum overnight to afford the desired polymeric alkynylcopper reagent which was used without further purification.
- **Method B using copper iodide and potassium carbonate in DMF.** To a suspension of copper iodide (762 mg, 4.0 mmol) in DMF (15 mL) was added a solution of the alkyne (4.0 mmol) in DMF (5 mL) *via* cannula and under argon. Finely powdered potassium carbonate (1.1 g, 8.0 mmol) was then added at rt and the resulting slurry was stirred under argon for 2 hours, slowly turning into a bright yellow and thick suspension of the copper acetylide which was then collected by filtration and successively washed with ammonium hydroxide (10 % NH_3 aqueous solution, 2x10 mL), water (2x10 mL), absolute ethanol (2x10 mL) and diethyl ether (2x10 mL). The bright yellow solid was then dried under high vacuum overnight to afford the desired polymeric alkynylcopper reagent.

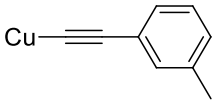
[S2] (a) Jouvin, K.; Heimburger, J.; Evano, G. *Chem. Sci.* **2012**, *3*, 756. (b) Jouvin, K.; Veillard, R.; Theunissen, C.; Alayrac, C.; Gaumont, A.-C.; Evano, G. *Org. Lett.* **2013**, *15*, 4592.



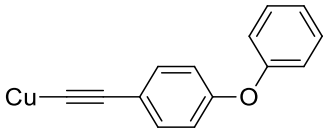
[(2,4,5-Trimethylphenyl)ethynyl]copper. This compound was obtained according to method B; Yield: 68% (1.5 g, 7.1 mmol).



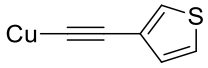
[(2-Chlorophenyl)ethynyl]copper. This compound was obtained according to method A; Yield: 75% (1.2 g, 5.9 mmol).



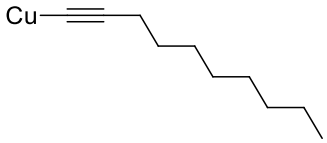
[(3-Methylphenyl)ethynyl]copper. This compound was obtained according to method A; Yield: 86% (770 mg, 4.3 mmol).



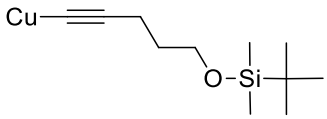
[(4-Phenoxyphenyl)ethynyl]copper. This compound was obtained according to method A; Yield: 73% (1.8 g, 7.1 mmol).



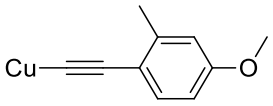
(Thiophen-3-ylethynyl)copper. This compound was obtained according to method A; Yield: 96% (718 mg, 4.2 mmol).



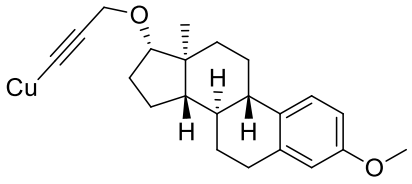
Dec-1-yn-1-ylcopper. This compound was obtained according to method A; Yield: 72% (2.9 g, 14.4 mmol).



{5-[(*tert*-Butyldimethylsilyl)oxy]pent-1-yn-1-yl}copper. This compound was obtained according to method A; Yield: 68% (1.9 g, 7.3 mmol).



[(4-Methoxy-2-methylphenyl)ethynyl]copper. This compound was obtained according to method A; Yield: 73% (1.6 g, 7.5 mmol).



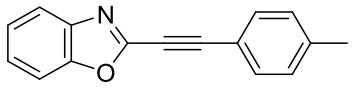
[(*O*$_3$-Methyl-estradiol-*O*$_{17}$-yl)prop-1-yn-1-yl]copper. This compound was obtained according to method B; Yield: 58% (448 mg, 1.2 mmol).

Experimental Procedure and Characterization Data:

Alkynylation of Azoles and Polyhalogenated Arenes

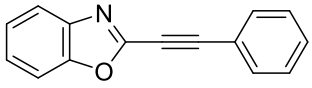
General procedure:

In a 5 mL round bottom flask, the arene (4.0 mmol) was dissolved in acetonitrile (4 mL). 1,10-Phenanthroline (901 mg, 5.0 mmol), lithium *tert*-butoxide (80 mg, 1.0 mmol) and the alkynylcopper reagent (1.0 mmol) were next successively added and the resulting brownish slurry was vigorously stirred at room temperature under an oxygen atmosphere (balloon) for 48 hours. The reaction mixture was then diluted with EtOAc, filtered over a short plug of silica gel (washed with EtOAc) and concentrated under vacuum. The crude residue was finally purified by flash column chromatography over silica gel to afford the desired alkynylated arene.



7a

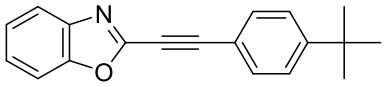
2-[(4-Methylphenyl)ethynyl]benzoxazole 7a. Yield: 54% (126 mg, 540 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 90/10; White solid. This compound has been previously reported.[S3]



7b

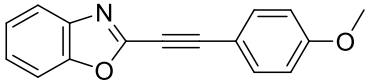
2-(Phenylethynyl)benzoxazole 7b. Yield: 43% (95 mg, 433 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 95/5; Pale yellow solid. This compound has been previously reported.[S3]

[S3] Matsuyama, N.; Hirano, K.; Satoh, T.; Miura, M. *Org. Lett.* **2009**, *11*, 4156.



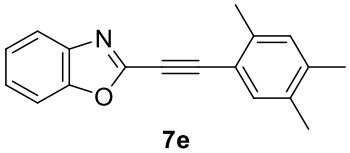
7c

2-[(4-*tert*-Butylphenyl)ethynyl]benzoxazole 7c. Yield: 50% (138 mg, 501 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 95/5; Pale yellow solid; Mp: 90 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.78-7.72 (m, 1H), 7.60 (d, *J* = 8.3 Hz, 2H), 7.54-7.48 (m, 1H), 7.42 (d, *J* = 8.3 Hz, 2H), 7.39-7.32 (m, 2H), 1.32 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 154.0, 150.4, 148.0, 141.2, 132.3, 126.2, 125.7, 125.0, 120.4, 117.2, 110.6, 93.9, 77.1, 35.1, 31.1; IR (ATR): ν_{max} 2961, 2925, 2221, 1549, 1450, 1242, 1147, 1136, 1100, 940, 834, 740 cm^{-1}; ESIHRMS *m/z* calcd for $C_{19}H_{18}NO$ $[M+H]^+$ 276.1388, found 276.1397.



7d

2-[(4-Methoxyphenyl)ethynyl]benzoxazole 7d. Yield: 46% (116 mg, 465 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 85/15; Pale yellow solid. This compound has been previously reported.[S4]

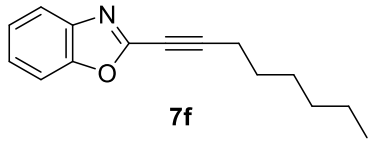


7e

2-[(2,4,5-Trimethylphenyl)ethynyl]benzoxazole 7e. Yield: 60% (125 mg, 478 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 95/5; Pale yellow solid; Mp: 112 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.78-7.71 (m, 1H), 7.55-7.48 (m, 1H), 7.42-7.32 (m, 2H), 7.37 (obs. s, 1H), 7.01 (s, 1H), 2.50 (s, 3H), 2.24 (s, 3H), 2.21 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 150.3, 148.2, 141.1, 139.7, 139.1, 134.2, 133.7, 131.2, 126.1, 124.9, 120.3, 117.2, 110.5, 93.3, 80.4, 20.1,

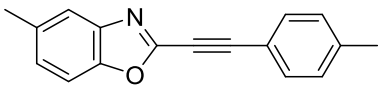
[S4] Matsuyama, N.; Kitahara, M.; Hirano, K.; Satoh, T.; Miura, M. *Org. Lett.* **2010**, *12*, 2358.

19.9, 19.1; IR (ATR): ν_{max} 2917, 2215, 1546, 1448, 1340, 1235, 1159, 1066, 934, 879, 742 cm^{-1}; ESIHRMS *m/z* calcd for $C_{18}H_{16}NO$ $[M+H]^+$ 262.1232, found 262.1228.



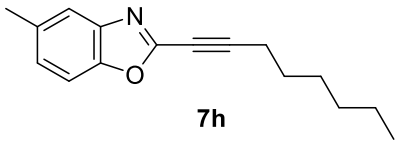
7f

2-(Oct-1-yn-1-yl)benzoxazole 7f. Yield: 40% (90 mg, 396 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 95/5; Pale yellow oil. This compound has been previously reported.[S3]



7g

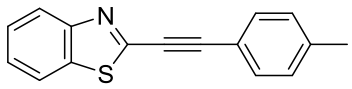
5-Methyl-2-[(4-methylphenyl)ethynyl]benzoxazole 7g. Yield: 47% (117 mg, 473 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 95/5; White solid. This compound has been previously reported.[S5]



7h

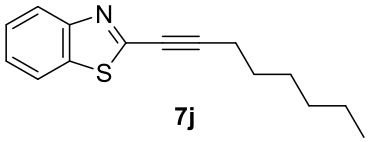
5-Methyl-2-(oct-1-yn-1-yl)benzoxazole 7h. Yield: 42% (101 mg, 418 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 95/5; Pale yellow oil. This compound has been previously reported.[S5]

[S5] Kim, S. H.; Chang, S. *Org. Lett.* **2010**, *12*, 1868.



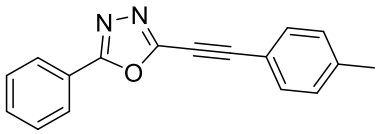
7i

2-[(4-Methylphenyl)ethynyl]benzothiazole 7i. Yield: 52% (131 mg, 525 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 95/5; Pale yellow solid. This compound has been previously reported.[S6]



7j

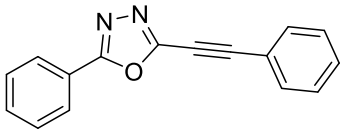
2-(Oct-1-yn-1-yl)benzothiazole 7j. Yield: 41% (90 mg, 396 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 95/5; Pale yellow oil. This compound has been previously reported.[S6]



9a

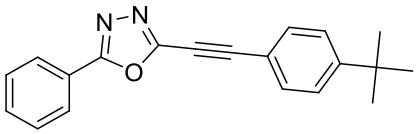
2-[(4-Methylphenyl)ethynyl]-5-phenyl-1,3,4-oxadiazole 9a. Yield: 65% (170 mg, 653 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 95/5; White solid. This compound has been previously reported.[S7]

[S6] Lu, L.; Yan, H.; Sun, P.; Zhu, Y.; Yang, H.; Liu, D.; Rong, G.; Mao, J. *Eur. J. Org. Chem.* **2013**, 1644.
[S7] Kitahara, M.; Hirano, K.; Tsurugi, H.; Satoh, T.; Miura, M. *Chem. Eur. J.* **2010**, *16*, 1772.



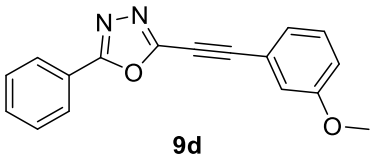
9b

2-(Phenylethynyl)-5-phenyl-1,3,4-oxadiazole 9b. Yield: 50% (122 mg, 495 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 95/5; Pale yellow solid. This compound has been previously reported.[S8]



9c

2-[(4-*tert*-Butylphenyl)ethynyl]-5-phenyl-1,3,4-oxadiazole 9c. Yield: 71% (185 mg, 711 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 95/5; Pale yellow solid; Mp: 104 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.05 (dd, *J* = 8.1 and 1.8 Hz, 2H), 7.54 (d, *J* = 8.6 Hz, 2H), 7.51-7.42 (m, 3H), 7.39 (d, *J* = 8.6 Hz, 2H), 1.29 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 164.6, 154.2, 150.7, 132.1, 132.0, 129.1, 127.0, 125.7, 123.3, 116.6, 97.6, 72.7, 35.0, 31.0; IR (ATR): ν_{max} 2959, 2225, 1540, 1482, 1450, 1362, 1269, 1171, 1091, 1012, 831, 775, 713, 688 cm^{-1}; ESIHRMS *m/z* calcd for $C_{20}H_{19}N_2O$ $[M+H]^+$ 303.1497, found 303.1496.

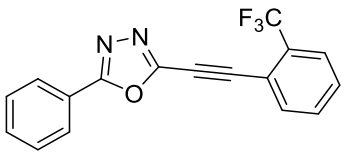


9d

2-[(3-Methoxyphenyl)ethynyl]-5-phenyl-1,3,4-oxadiazole 9d. Yield: 48% (132 mg, 478 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 90/10; Pale yellow solid; Mp: 106 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.06 (dd, *J* = 8.1 and 1.4 Hz, 2H), 7.57-7.44 (m, 3H), 7.32-

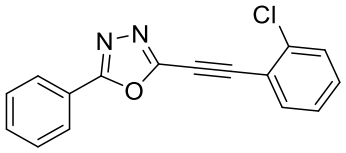
[S8] Besselièvre, F.; Piguel, S. *Angew. Chem., Int. Ed.* **2009**, *48*, 9553.

7.17 (m, 2H), 7.14-7.10 (m, 1H), 7.02-6.95 (m, 1H), 3.79 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ159.4, 132.2, 129.8, 129.2 (2C), 127.1 (2C), 124.8, 123.3, 120.7, 117.4, 116.9, 97.1, 77.9, 55.4; IR (ATR): ν_{max} 2919, 2233, 1606, 1574, 1548, 1539, 1448, 1427, 1290, 1229, 1144, 1051, 892, 789, 712, 686 cm^{-1}; ESIHRMS *m/z* calcd for $C_{17}H_{13}N_2O_2$ $[M+H]^+$ 277.0977, found 277.0981.



9e

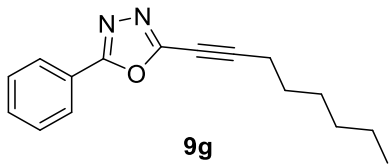
2-[(2-Trifluoromethylphenyl)ethynyl]-5-phenyl-1,3,4-oxadiazole 9e. Yield: 63% (198 mg, 630 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 95/5; Pale yellow solid; Mp: 112 °C, ^{1}H NMR (300 MHz, $CDCl_3$): δ8.01 (d, *J* = 7.5 Hz, 2H), 7.73 (d, *J* = 7.3 Hz, 1H), 7.67 (d, *J* = 7.2 Hz, 1H), 7.60-7.39 (m, 5H); ^{13}C NMR (75 MHz, $CDCl_3$): δ165.0, 150.1, 134.7, 132.2, 132.2 (q, *J* = 31.1 Hz), 131.8, 130.5, 129.1, 127.1, 126.2 (q, *J* = 4.9 Hz), 123.1 (q, *J* = 271.9 Hz), 123.0, 117.7 (q, *J* = 2.1 Hz), 92.4, 77.7; ^{19}F NMR (376 MHz, $CDCl_3$): δ62.3 (s); IR (neat): ν_{max} 2942, 2232, 1545, 1530, 1482, 1449, 1322, 1264, 1163, 1124, 1112, 1059, 1034, 770, 713, 667, 656 cm^{-1}; ESIHRMS *m/z* calcd for $C_{17}H_{10}N_2OF_3$ $[M+H]^+$ 315.0745, found 315.0753.



9f

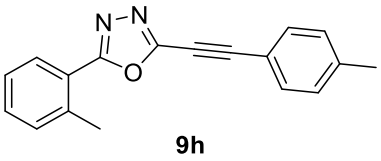
2-[(2-Chlorophenyl)ethynyl]-5-phenyl-1,3,4-oxadiazole 9f. Yield: 50% (142 mg, 506 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 95/5; Pale yellow solid; Mp: 120 °C ; ^{1}H NMR (300 MHz, $CDCl_3$): δ8.08 (dd, *J* = 7.8 and 1.4 Hz, 2H), 7.64 (dd, *J* = 7.5 and 1.4 Hz, 1H), 7.59-7.42 (m, 4H), 7.42-7.26 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ165.0, 150.4, 136.8, 134.2, 132.3, 131.7, 129.7, 129.2, 127.2, 126.8, 123.3, 120.1, 93.6, 77.5; IR (neat): ν_{max} 2920,

2851, 2221, 1529, 1481, 1463, 1450, 1093, 1064, 765, 712, 691 cm^{-1}; ESIHRMS *m/z* calcd for $C_{16}H_{10}N_2OCl$ $[M+H]^+$ 281.0482, found 281.0483.



9g

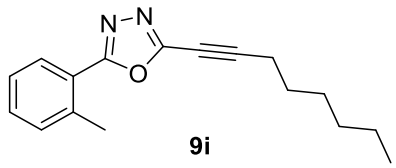
2-(Oct-1-yn-1-yl)-5-phenyl-1,3,4-oxadiazole 9g. Yield: 54% (138 mg, 543 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 95/5; White solid. This compound has been previously reported.[S9]



9h

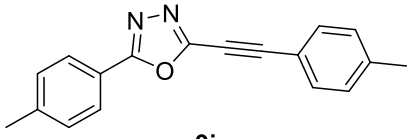
5-(2-Methylphenyl)-2-[(4-methylphenyl)ethynyl]-1,3,4-oxadiazole 9h. Yield: 52% (143 mg, 521 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 90/10; White solid; Mp: 102 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.96 (d, *J* = 7.9 Hz, 1H), 7.52 (d, *J* = 8.1 Hz, 2H), 7.45-7.37 (m, 1H), 7.35-7.27 (m, 2H), 7.19 (d, *J* = 7.9 Hz, 2H), 2.73 (s, 3H), 2.37 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 141.2, 138.7, 132.3 (2C), 131.8, 131.6, 129.5 (2C), 129.1, 126.2, 122.4, 116.8, 97.6, 72.8, 22.2, 21.7; IR (neat): ν_{max} 2925, 2226, 1538, 1488, 1455, 1387, 1170, 1065, 1015, 960, 817, 772, 725 cm^{-1}; ESIHRMS *m/z* calcd for $C_{18}H_{15}N_2O$ $[M+H]^+$ 275.1184, found 275.1185.

[S9] Kawano, T.; Matsuyama, N.; Hirano, K.; Satoh, T.; Miura, M. *J. Org. Chem.* **2010**, *75*, 1764.



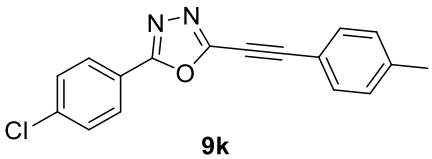
9i

5-(2-Methylphenyl)-2-(Oct-1-yn-1-yl)-1,3,4-oxadiazole 9i. Yield: 51% (137 mg, 510 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 90/10; Pale yellow oil; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.90 (d, *J* = 8.0 Hz, 1H), 7.42-7.34 (m, 1H), 7.33-7.24 (m, 2H), 2.69 (s, 3H), 2.49 (t, *J* = 7.0 Hz, 2H), 1.65 (app. quint., *J* = 6.8 Hz, 2H), 1.51-1.38 (m, 2H), 1.36-1.24 (m, 4H), 0.88 (t, *J* = 6.8 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ164.7, 150.2, 138.6, 131.8, 131.5, 129.1, 126.2, 122.5, 100.3, 65.3, 31.3, 28.6, 27.6, 22.5, 22.1, 19.5, 14.0; IR (ATR): ν_{max} 2930, 2859, 2244, 1530, 1490, 1456, 1242, 1031, 775, 730, 672 cm^{-1}; ESIHRMS *m/z* calcd for $C_{17}H_{21}N_2O$ [M+H]+ 269.1654, found 269.1651.



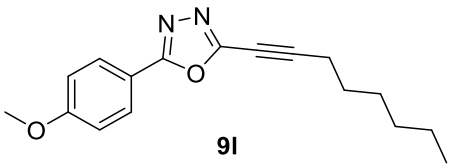
9j

5-(4-Methylphenyl)-2-[(4-methylphenyl)ethynyl]-1,3,4-oxadiazole 9j. Yield: 55% (150 mg, 547 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 95/5; White solid. This compound has been previously reported.[S7]



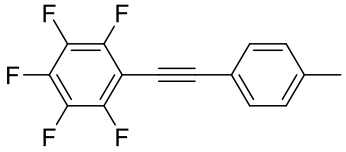
9k

5-(4-Chlorophenyl)-2-[(4-methylphenyl)ethynyl]-1,3,4-oxadiazole 9k. Yield: 49% (144 mg, 488 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 95/5; Pale yellow solid. This compound has been previously reported.[S7]



9l

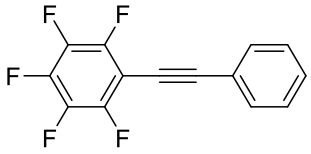
5-(4-Methoxyphenyl)-2-(Oct-1-yn-1-yl)-1,3,4-oxadiazole 9l. Yield: 48% (125 mg, 480 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 90/10; Pale yellow oil; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.95 (d, *J* = 9.0 Hz, 2H), 6.95 (d, *J* = 9.0 Hz, 2H), 3.83 (s, 3H), 2.47 (t, *J* = 7.0 Hz, 2H), 1.63 (app. quint., *J* = 6.8 Hz, 2H), 1.50-1.37 (m, 2H), 1.34-1.24 (m, 4H), 0.87 (t, *J* = 6.8 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 164.4, 162.6, 150.1, 128.8, 116.0, 114.6, 100.0, 65.4, 55.5, 31.3, 28.6, 27.6, 22.5, 19.5, 14.1; IR (ATR): ν_{max} 2930, 2244, 1613, 1532, 1496, 1426, 1307, 1256, 1174, 1094, 1026, 838, 743, 710 cm^{-1}; ESIHRMS *m/z* calcd for $C_{17}H_{21}N_2O_2$ $[M+H]^+$ 285.1603, found 285.1606.



11a

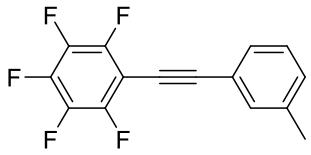
1,2,3,4,5-Pentafluoro-6-[(4-methylphenyl)ethynyl]benzene 11a. Yield: 77% (218 mg, 772 µmol), 70% (1.97 g, 7.0 mmol). Solvent system for flash column chromatography: pentane; White solid. This compound has been previously reported.[S10]

[S10] Wei, Y.; Zhao, H.; Kan, J.; Su, W.; Hong, M. *J. Am. Chem. Soc.* **2010**, *132*, 2522.



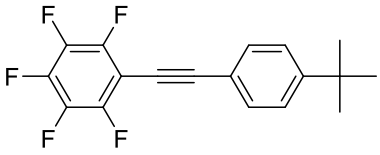
11b

1,2,3,4,5-Pentafluoro-6-(phenylethynyl)benzene 11b. Yield: 57% (152 mg, 567 µmol). Solvent system for flash column chromatography: pentane; White solid. This compound has been previously reported.[S4]



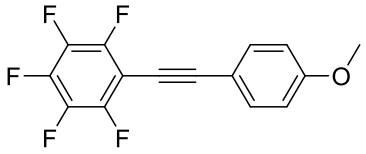
11c

1,2,3,4,5-Pentafluoro-6-[(3-methylphenyl)ethynyl]benzene 11c. Yield: 64% (182 mg, 645 µmol). Solvent system for flash column chromatography: pentane; White solid; Mp: 87 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.40 (s, 1H), 7.39 (app. d, *J* = 7.4 Hz, 1H), 7.32-7.20 (m, 2H), 2.38 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 147.3 (dm, *J* = 253.3 Hz), 141.5 (dm, *J* = 254.8 Hz), 138.5, 137.9 (dm, *J* = 253.3 Hz), 132.5, 130.7, 129.1, 128.5, 121.5, 102.0 (app. q, *J* = 3.4 Hz), 100.5 (m), 72.8 (app. q, *J* = 3.7 Hz), 21.3; ^{19}F NMR (376 MHz, $CDCl_3$): δ -136.6 (dd, *J* = 21.1 and 6.6 Hz, 2F), -153.5 (t, *J* = 20.8 Hz, 1F), -162.4 (td, *J* = 20.8 and 6.6 Hz, 2F); IR (ATR): ν_{max} 2928, 2246, 1518, 1460, 1112, 982, 789, 690 cm^{-1}; EIHRMS *m/z* calcd for $C_{15}H_7F_5$ $[M]^+$ 282.0468, found 282.0471.



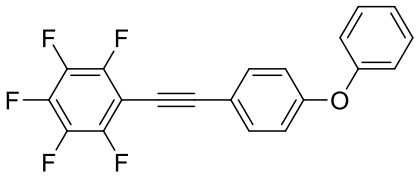
11d

1,2,3,4,5-Pentafluoro-6-[(4-*tert*-butylphenyl)ethynyl]benzene 11d. Yield: 72% (232 mg, 715 µmol). Solvent system for flash column chromatography: pentane; Beige solid. This compound has been previously reported.[S10]



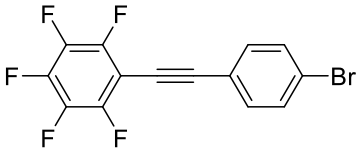
11e

1,2,3,4,5-Pentafluoro-6-[(4-methoxyphenyl)ethynyl]benzene 11e. Yield: 79% (233 mg, 781 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 95/5; Beige solid. This compound has been previously reported.[S10]



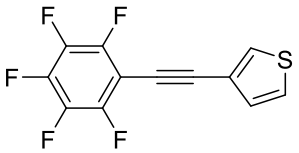
11f

1,2,3,4,5-Pentafluoro-6-[(4-phenoxyphenyl)ethynyl]benzene 11f. Yield: 68% (122 mg, 339 µmol). Solvent system for flash column chromatography: pentane; White solid; Mp: 90 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.54 (d, *J* = 6.7 Hz, 2H), 7.40 (app. t, *J* = 7.7 Hz, 2H), 7.19 (app. t, *J* = 7.3 Hz, 1H), 7.07 (d, *J* = 7.7 Hz, 2H), 7.00 (d, *J* = 8.7 Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 159.1, 156.1, 147.2 (dm, *J* = 250.0 Hz), 141.4 (dm, *J* = 254.5 Hz), 137.8 (dm, *J* = 251.3 Hz), 133.8, 130.1, 124.4, 119.9, 118.3, 115.9, 101.5 (app. q, *J* = 3.4 Hz), 100.6 (m), 72.6 (app. q, *J* = 3.7 Hz); ^{19}F NMR (376 MHz, $CDCl_3$): δ -136.7 (dd, *J* = 21.2 and 6.8 Hz, 2F), -153.6 (t, *J* = 20.7 Hz, 1F), -162.4 (td, *J* = 20.8 and 6.6 Hz, 2F); IR (ATR): ν_{max} 2227, 1587, 1522, 1496, 1446, 1249, 1166, 1111, 982, 964, 903, 873, 761, 693 cm^{-1}; EIHRMS *m/z* calcd for $C_{20}H_9OF_5$ $[M]^+$ 360.0574, found 360.0571.



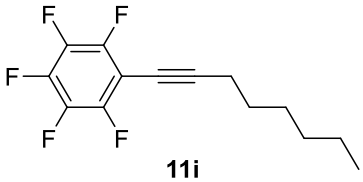
11g

1,2,3,4,5-Pentafluoro-6-[(4-bromophenyl)ethynyl]benzene 11g. Yield: 58% (75 mg, 216 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 95/5; White solid. This compound has been previously reported.[S10]



11h

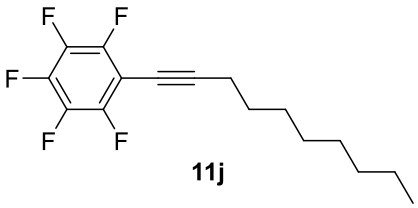
1,2,3,4,5-Pentafluoro-6-[(thiophen-3-yl)ethynyl]benzene 11h. Yield: 62% (171 mg, 623 µmol). Solvent system for flash column chromatography: pentane; White solid; Mp: 81 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.65 (dd, *J* = 2.9 and 1.1 Hz, 1H), 7.34 (dd, *J* = 5.0 and 3.0 Hz, 1H), 7.23 (dd, *J* = 5.0 and 1.1 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 147.2 (dm, *J* = 251.3 Hz), 141.5 (dm, *J* = 254.4 Hz), 137.8 (dm, *J* = 253.8 Hz), 130.9, 129.8, 126.0, 120.8, 100.4 (m), 96.9 (app. q, *J* = 3.3 Hz), 72.8 (app. q, *J* = 3.7 Hz); ^{19}F NMR (376 MHz, $CDCl_3$): δ -136.6 (dd, *J* = 21.0 and 6.2 Hz, 2F), -153.3 (t, *J* = 20.8 Hz, 1F), -162.3 (td, *J* = 20.7 and 6.6 Hz, 2F); IR (ATR): ν_{max} 2230, 1531, 1499, 984, 900, 872, 821, 782, 623 cm^{-1}; EIHRMS *m/z* calcd for $C_{12}H_3SF_5$ $[M]^+$ 273.9876, found 273.9874.



11i

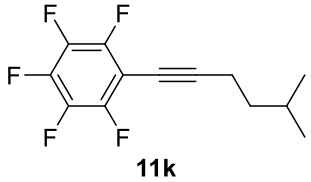
1,2,3,4,5-Pentafluoro-6-(oct-1-yn-1-yl)benzene 11i. Yield: 71% (195 mg, 706 µmol). Solvent system for flash column chromatography: pentane; Colorless oil; ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.49 (t, *J* = 7.0 Hz, 2H), 1.64 (app. quint., *J* = 7.7 Hz, 2H), 1.52-1.41 (m, 2H), 1.39-1.24 (m, 4H),

0.90 (t, *J* = 6.9 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 147.6 (dm, *J* = 250.5 Hz), 141.0 (dm, *J* = 254.7 Hz), 137.7 (dm, *J* = 252.2 Hz), 104.3 (app. q, *J* = 3.2 Hz), 100.9 (m), 64.8 (app. q, *J* = 3.5 Hz), 31.4, 28.6, 28.3, 22.7, 19.9, 14.1; ^{19}F NMR (376 MHz, $CDCl_3$): δ-137.7 (dd, *J* = 21.4 and 7.1 Hz, 2F), -154.9 (t, *J* = 20.8 Hz, 1F), -163.0 (td, *J* = 20.8 and 6.6 Hz, 2F); IR (ATR): ν_{max} 2934, 2247, 1519, 1498, 1050, 990, 841, 727 cm^{-1}; EIHRMS *m/z* calcd for $C_{14}H_{13}F_5$ $[M]^+$ 276.0937, found 276.0940.



11j

1,2,3,4,5-Pentafluoro-6-(dec-1-yn-1-yl)benzene[S11] 11j. Yield: 78% (248 mg, 777 µmol). Colorless oil; ^{1}H NMR (300 MHz, $CDCl_3$): δ2.49 (t, *J* = 7.0 Hz, 2H), 1.64 (app. quint., *J* = 7.7 Hz, 2H), 1.52-1.40 (m, 2H), 1.38-1.21 (m, 8H), 0.86 (t, *J* = 6.9 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 147.6 (dm, *J* = 251.1 Hz), 141.0 (dm, *J* = 253.9 Hz), 137.7 (dm, *J* = 251.1 Hz), 104.3 (app. q, *J* = 3.3 Hz), 100.9 (m), 64.8 (app. q, *J* = 3.7 Hz), 32.0, 29.3, 29.2, 28.9, 28.3, 22.8, 19.9, 14.2; ^{19}F NMR (376 MHz, $CDCl_3$): δ-137.6 (dd, *J* = 21.4 and 7.1 Hz, 2F), -154.9 (t, *J* = 20.8 Hz, 1F), -163.0 (td, *J* = 20.8 and 6.6 Hz, 2F); IR (ATR): ν_{max} 2929, 2858, 2247, 1519, 1498, 1048, 990, 841, 727 cm^{-1}; EIHRMS *m/z* calcd for $C_{16}H_{17}F_5$ $[M]^+$ 304.1250, found 304.1247.

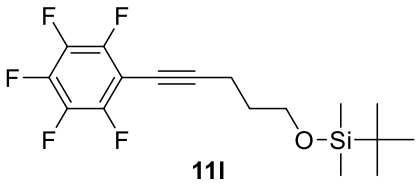


11k

1,2,3,4,5-Pentafluoro-6-(5-methylhex-1-yn-1-yl)benzene 11k. Yield: 84% (110 mg, 419 µmol). Solvent system for flash column chromatography: pentane; Colorless volatile oil; ^{1}H NMR (300 MHz, $CDCl_3$): δ2.50 (t, *J* = 7.3 Hz, 2H), 1.76 (app. non., *J* = 6.7 Hz, 1H), 1.54 (app. q, *J* = 7.2 Hz, 2H),

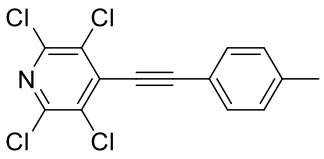
[S11] Chen, Q.-Y.; Li, Z.-T. *J. Chem. Soc., Perkin Trans. 1*, **1992**, 2931.

0.94 (d, *J* = 6.6 Hz, 6H); ^{13}C NMR (75 MHz, $CDCl_3$): δ147.6 (dm, *J* = 249.9 Hz), 141.0 (dm, *J* = 254.2 Hz), 137.8 (dm, *J* = 254.2 Hz), 104.3 (app. q, *J* = 3.2 Hz), 100.9 (m), 64.7 (app. q, *J* = 3.7 Hz), 37.2, 27.5, 22.2, 18.0; ^{19}F NMR (376 MHz, $CDCl_3$): δ-137.7 (dd, *J* = 21.5 and 7.1 Hz, 2F), -154.9 (t, *J* = 20.8 Hz, 1F), -163.0 (td, *J* = 20.8 and 6.6 Hz, 2F); IR (ATR): ν_{max} 2961, 2248, 1518, 1496, 1079, 1052, 989, 727 cm^{-1}; EIHRMS *m/z* calcd for $C_{13}H_{11}F_5$ $[M]^+$ 262.0781, found 262.0779.



11l

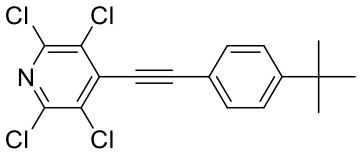
1,2,3,4,5-Pentafluoro-6-[5-(*tert*-butyldimethylsilyloxy)pent-1-yn-1-yl]benzene 11l. Yield: 71% (130 mg, 357 µmol). Solvent system for flash column chromatography: pentane; Colorless oil; ^{1}H NMR (300 MHz, $CDCl_3$): δ3.76 (t, *J* = 5.9 Hz, 2H), 2.60 (t, *J* = 6.9 Hz, 2H), 1.83 (app. quint., *J* = 6.3 Hz, 2H), 0.90 (s, 9H), 0.07 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$): δ147.6 (dm, *J* = 250.8 Hz), 141.1 (dm, *J* = 253.7 Hz), 137.8 (dm, *J* = 252.0Hz), 103.8 (app. q, *J* = 3.3 Hz), 100.8 (m), 64.9 (app. q, *J* = 3.4 Hz), 61.4, 31.3, 26.0, 18.5, 16.4, 5.3; ^{19}F NMR (376 MHz, $CDCl_3$): δ-137.5 (dd, *J* = 21.6 and 7.4 Hz, 2F), -154.6 (t, *J* = 20.7 Hz, 1F), -162.8 (td, *J* = 20.8 and 6.6 Hz, 2F); IR (ATR): ν_{max} 2955, 2859, 2248, 1519, 1499, 1473, 1255, 1106, 1048, 990, 836, 776, 715, 664 cm^{-1}; EIHRMS *m/z* calcd for $C_{17}H_{21}OF_5Si$ $[M]^+$ 364.1282, found 364.1280.



13a

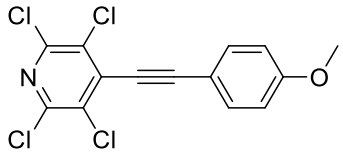
2,3,5,6-Tetrachloro-4-[(4-methylphenyl)ethynyl]pyridine 13a. Following the general procedure using (*p*-tolylacetylene)copper (90 mg, 0.5 mmol), 2,3,5,6-tetrachloropyridine (434 mg, 2.0 mmol), ^{t}BuOLi (40 mg, 0.5 mmol) and 1,10-phenanthroline (450 mg, 2.5 mmol) in DMF (4 mL); Yield: 60% (100 mg, 302 µmol). Solvent system for flash column chromatography: pentane; Pale

yellow solid; Mp: 164 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.52 (d, *J* = 8.1 Hz, 2H), 7.21 (d, *J* = 7.9 Hz, 2H), 2.41 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 146.0, 141.4, 135.4, 132.5, 130.7, 129.6, 117.9, 107.7, 82.1, 21.9; IR (ATR): ν_{max} 2918, 2217, 1534, 1315, 1266, 926, 816, 706 cm^{-1}; ESIHRMS *m/z* calcd for $C_{14}H_8NCl_4$ $[M+H]^+$ 329.9411, found 329.9417.



13b

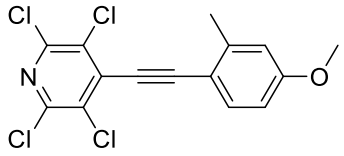
2,3,5,6-Tetrachloro-4-[(4-*tert*-butylphenyl)ethynyl]pyridine 13b. Following the general procedure using (*p*-*tert*-butylacetylene)copper (110 mg, 0.5 mmol), 2,3,5,6-tetrachloropyridine (434 mg, 2.0 mmol), ^{t}BuOLi (40 mg, 0.5 mmol) and 1,10-phenanthroline (450 mg, 2.5 mmol) in DMF (4 mL); Yield: 64% (120 mg, 322 µmol). Solvent system for flash column chromatography: cyclohexane; White solid; Mp: 197 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.57 (d, *J* = 8.3 Hz, 2H), 7.44 (d, *J* = 8.5 Hz, 2H), 1.34 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 154.5, 146.0, 135.5, 132.3, 130.8, 125.9, 118.0, 107.6, 82.1, 35.2, 31.2; IR (ATR): ν_{max} 2965, 2221, 1534, 1313, 1271, 1113, 931, 834, 706 cm^{-1}; ESIHRMS *m/z* calcd for $C_{17}H_{14}NCl_4$ $[M+H]^+$ 371.9880, found 371.9877.



13c

2,3,5,6-Tetrachloro-4-[(4-methoxyphenyl)ethynyl]pyridine 13c. Following the general procedure using (*p*-methoxyacetylene)copper (97 mg, 0.5 mmol), 2,3,5,6-tetrachloropyridine (434 mg, 2.0 mmol), ^{t}BuOLi (40 mg, 0.5 mmol) and 1,10-phenanthroline (450 mg, 2.5 mmol) in DMF (4 mL); Yield: 67% (116 mg, 334 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 95/5; Yellow solid; Mp: 145 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.55 (d, *J* = 8.9

Hz, 2H), 6.90 (d, *J* = 8.9 Hz, 2H), 3.85 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 161.6, 145.9, 135.5, 134.3, 130.4, 114.4, 112.9, 108.0, 82.0, 55.6; IR (ATR): ν_{max} 2917, 2214, 1601, 1508, 1313, 1295, 1257, 1165, 1025, 927, 833, 706 cm^{-1}; ESIHRMS *m/z* calcd for $C_{14}H_8NOCl_4$ $[M+H]^+$ 345.9360, found 345.9360.

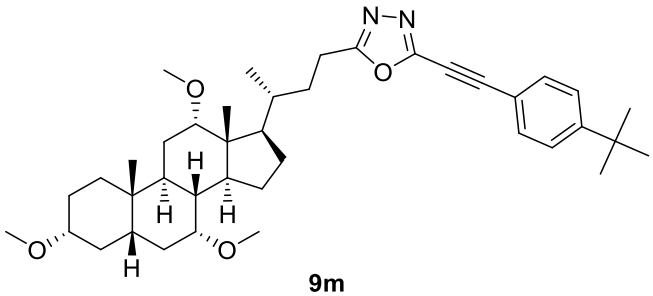


13d

2,3,5,6-Tetrachloro-4-[(4-methoxy-2-methylphenyl)ethynyl]pyridine 13d. Following the general procedure using [(4-methoxy-2-methylphenyl)ethynyl]copper (104 mg, 0.5 mmol), 2,3,5,6-tetrachloropyridine (434 mg, 2.0 mmol), ^{t}BuOLi (40 mg, 0.5 mmol) and 1,10-phenanthroline (450 mg, 2.5 mmol) in DMF (4 mL); Yield: 79% (142 mg, 393 µmol). Solvent system for flash column chromatography: cyclohexane; Pale yellow solid; Mp: 169 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.54 (d, *J* = 8.5 Hz, 1H), 6.80 (d, *J* = 2.1 Hz, 1H), 6.76 (dd, *J* = 6.2 and 2.3 Hz, 1H), 3.84 (s, 3H), 2.54 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 161.7, 146.0, 144.1, 135.7, 134.9, 130.2, 115.5, 113.1, 112.0, 107.4, 85.7, 55.5, 21.3; IR (ATR): ν_{max} 2936, 2201, 1599, 1530, 1311, 1267, 1239, 1033, 908, 850, 706 cm^{-1}; ESIHRMS *m/z* calcd for $C_{15}H_{10}NOCl_4$ $[M+H]^+$ 359.9516, found 359.9519.

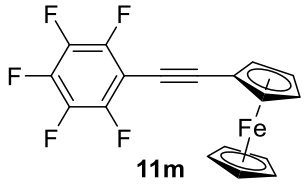
Experimental Procedure and Characterization Data:

Alkynylation of Complex Substrates and Consecutive Double Alkynylation



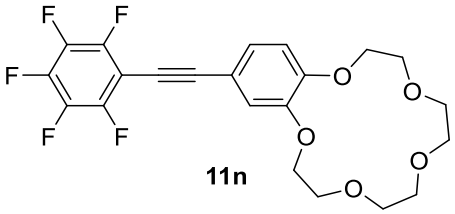
9m

2-{[4-(*tert*-Butyl)phenyl]ethynyl}-5-{(*R*)-3-[(3*R*,5*S*,7*R*,8*R*,9*S*,10*S*,12*S*,13*R*,14*S*,17*R*)-3,7,12-trimethoxy-10,13-dimethylhexadecahydro-1*H*-cyclopenta[*a*]phenanthren-17-yl]butyl}-1,3,4-oxadiazole 9m. To a solution of 2-{(*R*)-3-[(3*R*,5*S*,7*R*,8*R*,9*S*,10*S*,12*S*,13*R*,14*S*,17*R*)-3,7,12-trimethoxy-10,13-dimethyl-hexadeca-hydro-1*H*-cyclopenta[*a*]phenanthren-17-yl]butyl}-1,3,4-oxadiazole (178 mg, 375 µmol) in acetonitrile (2 mL) were successively added 1,10-phenanthroline (225 mg, 1.25 mmol), lithium *tert*-butoxide (20 mg, 250 µmol) and {[4-(*tert*-butyl)phenyl]ethynyl}copper (55 mg, 250 µmol). The resulting brownish slurry was vigorously stirred at room temperature under an oxygen atmosphere (balloon) for 3 hours. The reaction mixture was then diluted with EtOAc, filtered over a short plug of silica gel (washed with EtOAc) and concentrated under vacuum. The crude residue was finally purified by flash column chromatography over silica gel (cyclohexane/EtOAc: 70/30) to afford the desired alkynylated 1,3,4-oxadiazole as a pale yellow solid (72 mg, 114 µmol, 46%). Mp: 74 °C; $[\alpha]_D^{25}$ + 28 (*c* 1.0, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$): δ7.54 (d, *J* = 8.3 Hz, 2H), 7.41 (d, *J* = 8.3 Hz, 2H), 3.39-3.34 (m, 1H), 3.32 (s, 3H), 3.25 (s, 3H), 3.20 (s, 3H), 3.13 (app. d, *J* = 2.4 Hz, 1H), 3.05-2.72 (m, 3H), 2.31-1.39 (m, 16H), 1.37-1.12 (obs. m, 4H), 1.32 (s, 9H), 1.11-0.80 (obs. m, 2H), 0.98 (d, *J* = 6.4 Hz, 3H), 0.89 (s, 3H), 0.65 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.1, 154.2, 151.1, 132.2, 125.8, 117.0, 96.9, 82.0, 80.8, 77.0, 72.7, 56.0, 55.8, 55.5, 46.3, 46.2, 42.8, 42.0, 39.7, 35.4, 35.2 (2C), 35.0, 34.5, 32.7, 31.2, 28.1, 27.9, 27.5, 26.8, 23.2, 23.0, 22.5, 22.1, 17.5, 12.6; IR (ATR): ν_{max} 2931, 2868, 2818, 2230, 1542, 1455, 1369, 1159, 1101, 835 cm^{-1}; ESIHRMS *m/z* calcd for $C_{40}H_{59}N_2O_4$ $[M+H]^+$ 631.4475, found 631.4474.



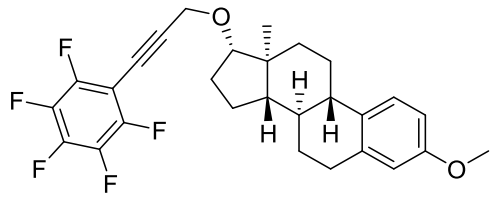
11m

1,2,3,4,5-Pentafluoro-6-(ferrocenylethynyl)benzene 11m. Yield: 78% (292 mg, 776 µmol). Solvent system for flash column chromatography: pentane; Orange solid; Mp: 137 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 4.58 (app. s, 2H), 4.32 (app. s, 2H), 4.27 (s, 5H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 147.2 (dm, *J* = 250.4 Hz), 141.0 (dm, *J* = 255.6 Hz), 137.8 (dm, *J* = 250.6 Hz), 102.0 (app. q, *J* = 3.4 Hz), 101.1 (m), 72.1, 70.4, 69.8, 69.2 (app. q, *J* = 3.7 Hz), 63.0; ^{19}F NMR (376 MHz, $CDCl_3$): δ -137.2 (dd, *J* = 21.8 and 7.2 Hz, 2F), -154.6 (t, *J* = 20.7 Hz, 1F), -162.8 (td, *J* = 20.8 and 6.4 Hz, 2F); IR (ATR): ν_{max} 2934, 2230, 1523, 1498, 1120, 983, 971, 827 cm^{-1}; EIHRMS *m/z* calcd for $C_{18}H_9F_5Fe$ $[M]^+$ 375.9974, found 375.9977.



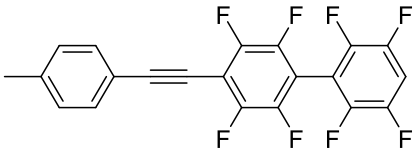
11n

1,2,3,4,5-Pentafluoro-6-[(2,3,5,6,8,9,11,12-octahydrobenzo[b][1,4,7,10,13]pentaoxacyclo-pentadecin-15-yl)ethynyl]benzene 11n. Yield: 57% (75 mg, 164 µmol). Solvent system for flash column chromatography: EtOAc; Yellow solid; Mp: 102 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.16 (dd, *J* = 8.3 and 1.8 Hz, 1H), 7.03 (d, *J* = 1.9 Hz, 1H), 6.83 (d, *J* = 8.3 Hz, 1H), 4.18-4.13 (m, 4H), 3.95-3.89 (m, 4H), 3.76 (s, 8H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 150.8, 148.8, 147.1 (dm, *J* = 251.6 Hz), 141.2 (dm, *J* = 255.2 Hz), 137.8 (dm, *J* = 251.2 Hz), 126.2, 116.9, 114.0, 113.3, 102.0 (app. q, *J* = 2.8 Hz), 100.7 (m), 72.0 (app. q, *J* = 3.3 Hz), 71.2 (2C), 70.5, 70.4, 69.5, 69.4, 69.1, 68.8; ^{19}F NMR (376 MHz, $CDCl_3$): δ -136.9 (dd, *J* = 21.0 and 6.7 Hz, 2F), -153.7 (t, *J* = 20.6 Hz, 1F), -162.5 (td, *J* = 20.7 and 6.5 Hz, 2F); IR (ATR): ν_{max} 2932, 2891, 2220, 1522, 1499, 1448, 1338, 1270, 1246, 1203, 1138, 1051, 1004, 989, 943, 849, 805 cm^{-1};



11o

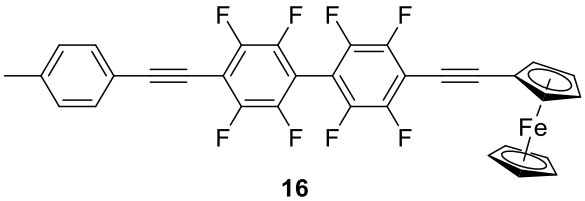
***O*$_3$-Methyl-*O*$_{17}$-[3-(pentafluorophenyl)prop-2-yn-1-yl]estradiol 11o.** Yield: 63% (77 mg, 157 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 90/10; White solid; Mp: 102 °C; $[\alpha]_D^{25}$ - 6 (*c* 1.0, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.21 (d, *J* = 8.6 Hz, 1H), 6.72 (dd, *J* = 8.6 and 2.7 Hz, 1H), 6.63 (d, *J* = 2.6 Hz, 1H), 4.51 (A of AB syst., *J* = 16.4 Hz, 1H), 4.46 (B of AB syst., *J* = 16.4 Hz, 1H), 3.79 (s, 3H), 3.71 (t, *J* = 8.4 Hz, 1H), 2.95-2.80 (m, 2H), 2.36-2.27 (m, 1H), 2.26-2.03 (m, 3H), 1.95-1.84 (m, 1H), 1.80-1.69 (m, 1H), 1.68-1.56 (m, 1H), 1.56-1.20 (m, 6H), 0.85 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 157.6, 147.6 (dm, *J* = 250.2 Hz), 141.7 (dm, *J* = 256.1 Hz), 138.0, 137.7 (dm, *J* = 248.7 Hz), 132.7, 126.4, 113.9, 111.6, 99.8 (m), 99.3 (app. q, *J* = 3.0 Hz), 88.8, 69.9 (app. q, *J* = 3.4 Hz), 58.0, 55.3, 50.3, 44.0, 43.4, 38.7, 37.7, 29.9, 27.8, 27.3, 27.0, 26.5, 11.8; ^{19}F NMR (376 MHz, $CDCl_3$): δ -136.4 (dd, *J* = 20.8 and 6.2 Hz, 2F), -152.8 (t, *J* = 20.7 Hz, 1F), -162.2 (td, *J* = 20.7 and 6.7 Hz, 2F); IR (ATR): ν_{max} 2920, 2845, 2240, 1606, 1523, 1498, 1353, 1310, 1237, 1096, 1033, 988, 861, 845, 820, 785 cm^{-1}; EIHRMS *m/z* calcd for $C_{28}H_{27}O_2F_5$ $[M]^+$ 490.1931, found 490.1924.



15

2,2',3,3',5,5',6,6'-Octafluoro-4-[(4-methylphenyl)ethynyl]-1,1'-biphenyl 15. Following the general procedure using (*p*-tolylacetylene)copper (90 mg, 0.5 mmol), 2,2',3,3',5,5',6,6'-octafluorobiphenyl (596 mg, 2.0 mmol), ^{t}BuOLi (40 mg, 0.5 mmol) and 1,10-phenanthroline (450 mg, 2.5 mmol) in acetonitrile (8 mL); Yield: 50% (103 mg, 250 µmol). Solvent system for flash column chromatography: pentane; White solid; Mp: 160 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.52 (d,

J = 8.0 Hz, 2H), 7.31-7.20 (obs. m, 1H), 7.22 (d, *J* = 7.9 Hz, 2H), 2.41 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ146.9 (dm, *J* = 250.7 Hz), 146.2 (dm, *J* = 253.0 Hz), 144.1 (dm, *J* = 253.6 Hz), 140.5, 132.1, 129.5, 118.5, 108.0 (obs. t, *J* = 22 Hz), 108.0 (m), 107.0 (m), 103.9 (app. t, *J* = 3.2 Hz), 73.7 (app. t, *J* = 3.8 Hz), 21.7; ^{19}F NMR (376 MHz, $CDCl_3$): δ-136.5 (app. q, *J* = 9.9 Hz, 2F), -138.1 (app. q, *J* = 9.7 Hz, 2F), -138.3- -138.5 (m, 2F), -139.1- -139.3 (m, 2F); IR (ATR): ν_{max} 2922, 2219, 1512, 1478, 1219, 1176, 1077, 992, 929, 817, 702 cm^{-1}; EIHRMS *m/z* calcd for $C_{21}H_8F_8$ $[M]^+$ 412.0498, found 412.0501.

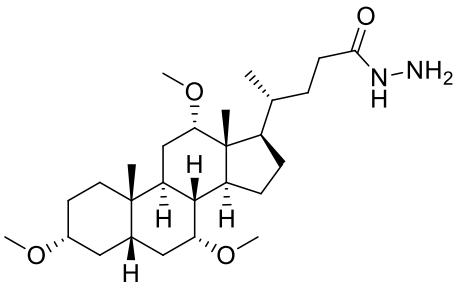


16

2,2',3,3',5,5',6,6'-Octafluoro-4-[(4-methylphenyl)ethynyl]-4'-(ferrocenylethynyl)-1,1'-biphenyl 16. Following the general procedure using (ferrocenylethynyl)copper (139 µmol), 2,2',3,3',5,5',6,6'-octafluoro-4-[(4-methylphenyl)ethynyl]-1,1'-biphenyl 18 (208 µmol), ^{t}BuOLi (139 µmol) and 1,10-phenanthroline (695 µmmol) in DMF (1 mL); Yield: 58% (50 mg, 81 µmol). Solvent system for flash column chromatography: cyclohexane/EtOAc: 80/20; Orange solid; Mp: 189 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ7.52 (d, *J* = 8.0 Hz, 2H), 7.22 (d, *J* = 7.9 Hz, 2H), 4.62 (app. t, *J* = 1.8 Hz, 2H), 4.35 (app. t, *J* = 1.8 Hz, 2H), 4.29 (s, 5H), 2.41 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 145.9 (dm, *J* = 251.4 Hz), 143.2 (dm, *J* = 252.2 Hz), 139.5, 131.1, 128.5, 117.5, 106.7 (m), 106.0 (m), 105.1 (m), 103.4 (app. t, *J* = 2.9 Hz), 103.0 (app. t, *J* = 3.2 Hz), 72.8 (app. t, *J* = 3.8 Hz), 71.2, 69.5 (2C), 69.0, 61.7, 20.8; ^{19}F NMR (376 MHz, $CDCl_3$): δ-136.5 (app. q, *J* = 10.0 Hz, 2F), -137.0 (app. q, *J* = 10.3 Hz, 2F), -139.0 (app. sext, *J* = 10.0 Hz, 2F), -139.2 (app. sext., *J* = 9.9 Hz, 2F); IR (ATR): ν_{max} 2954, 2221, 1649, 1468, 1223, 1109, 999, 968, 818, 760, 728, 704 cm^{-1}; EIHRMS *m/z* calcd for $C_{33}H_{16}F_8Fe$ $[M]^+$ 620.0474, found 620.0476.

Supporting Information

^{1}H and ^{13}C NMR spectra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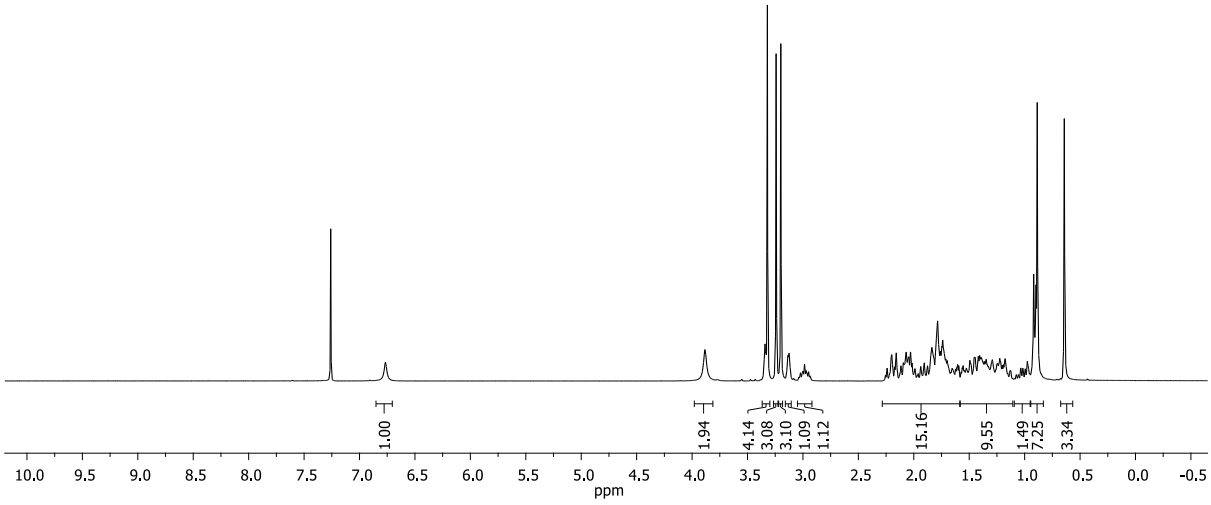
H
O
O
H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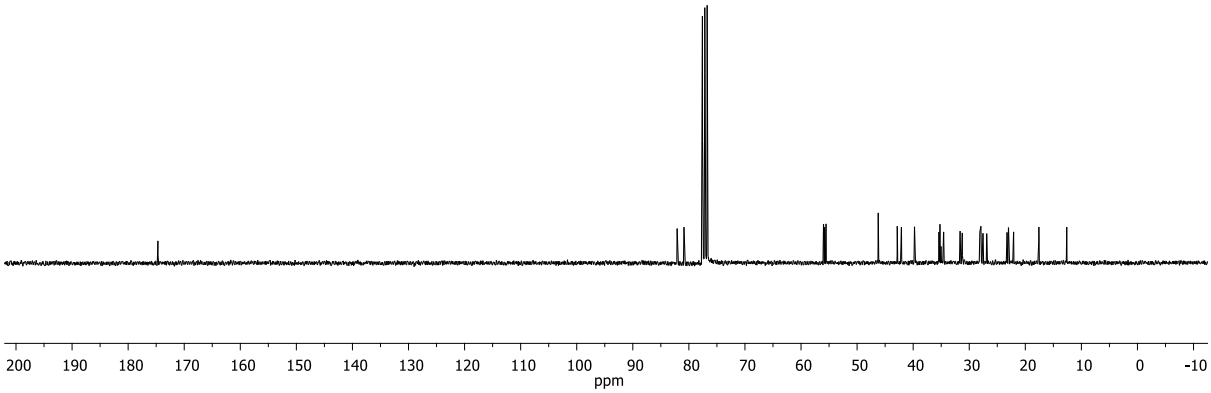
ppm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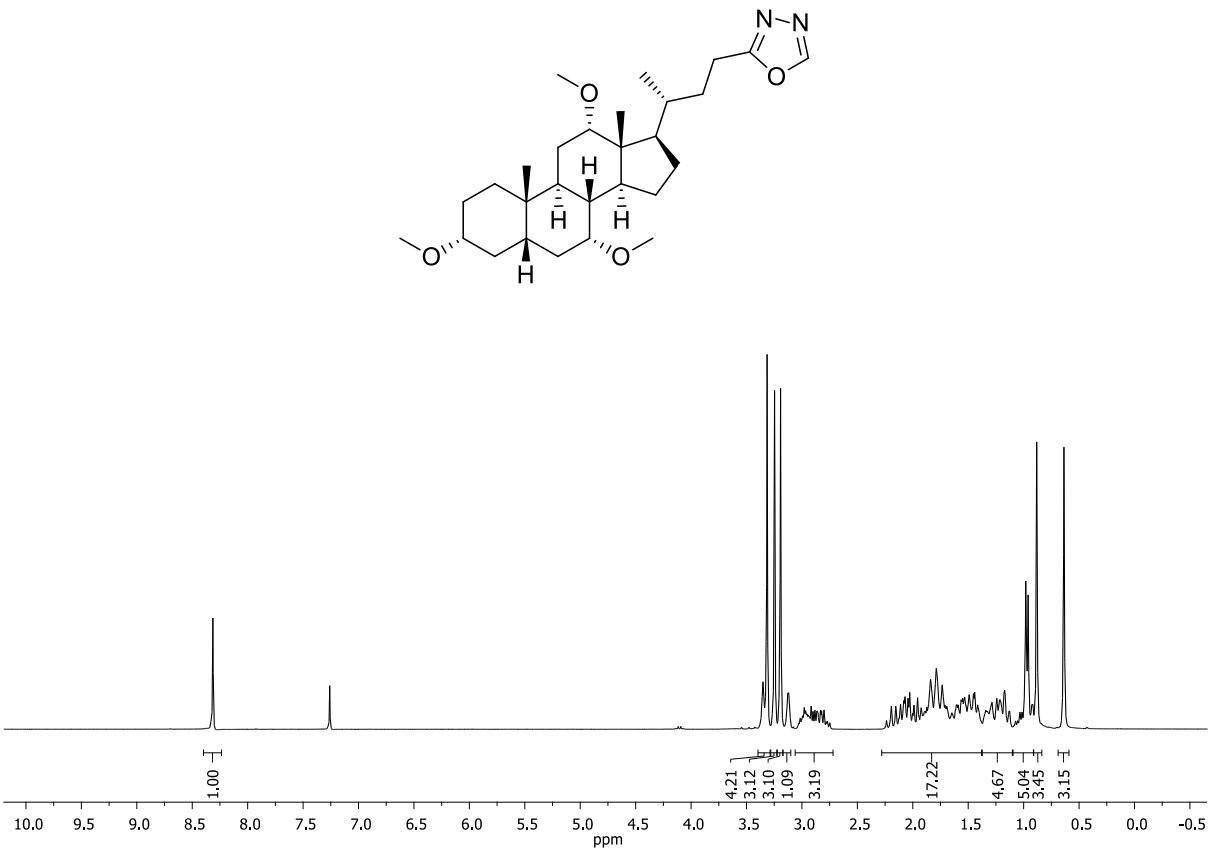
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3.45
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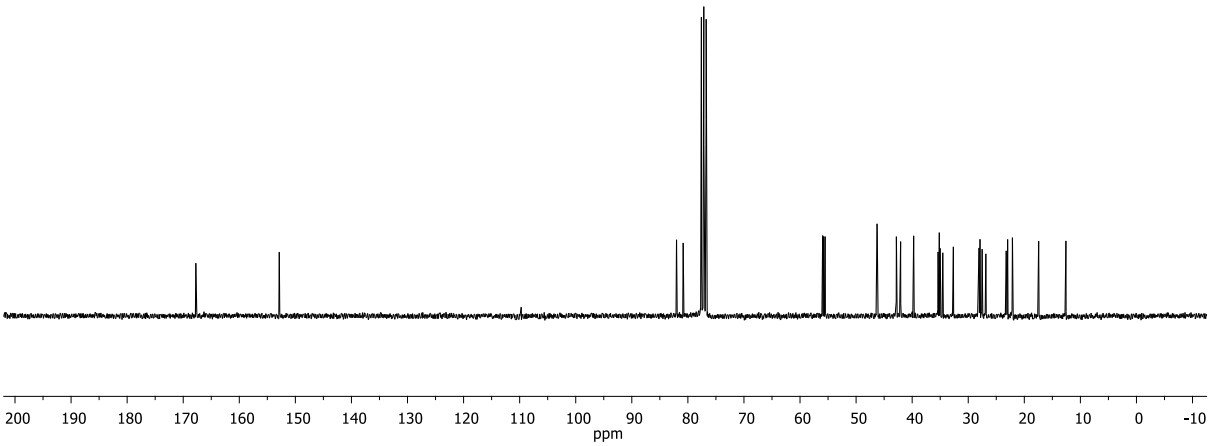
ppm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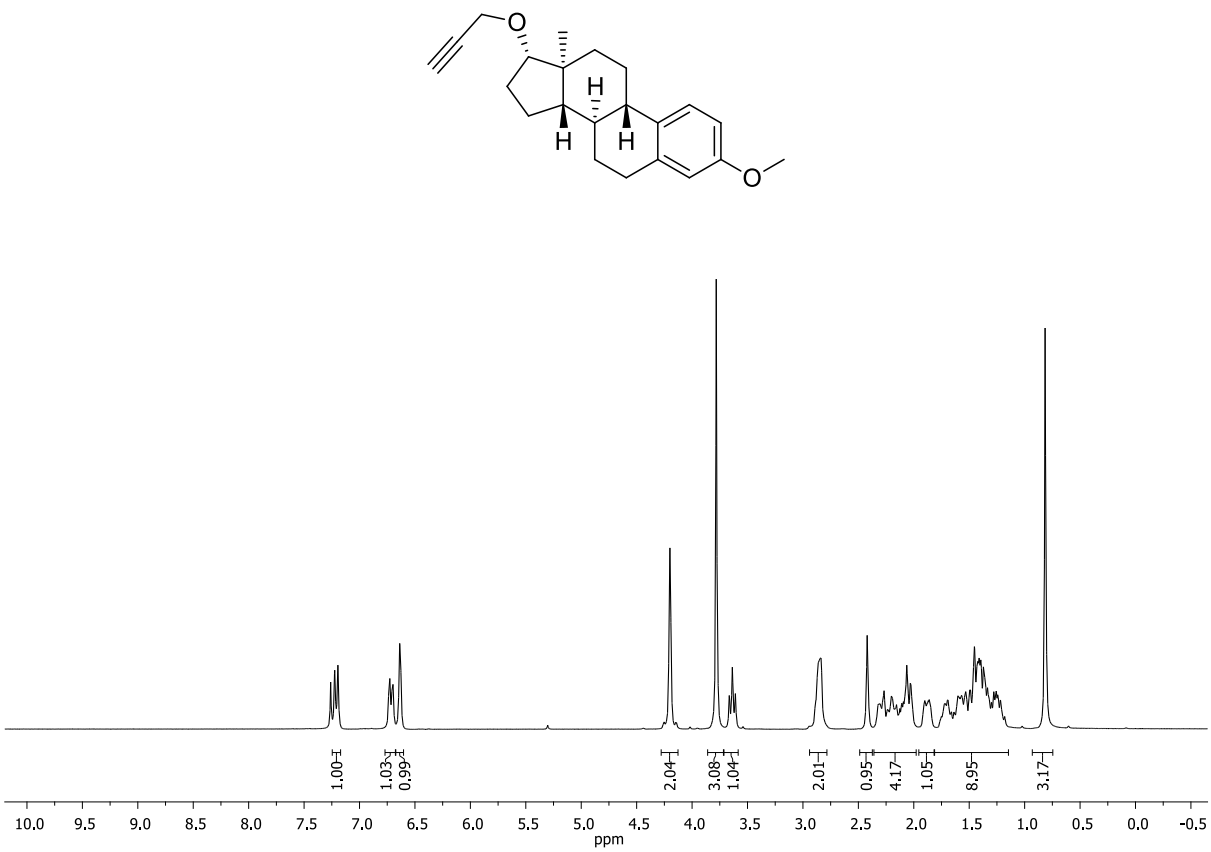
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3.17
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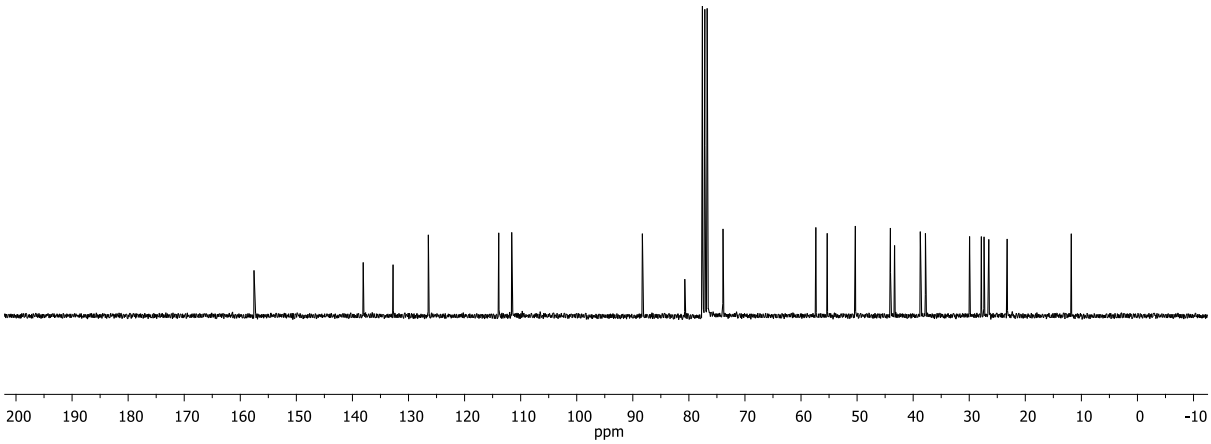
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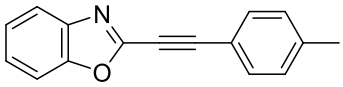

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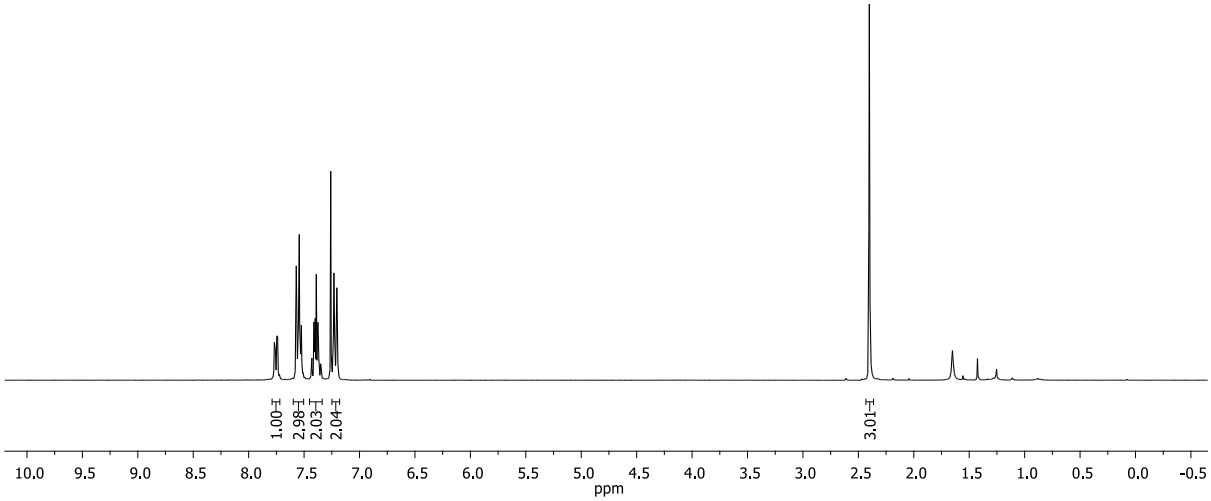
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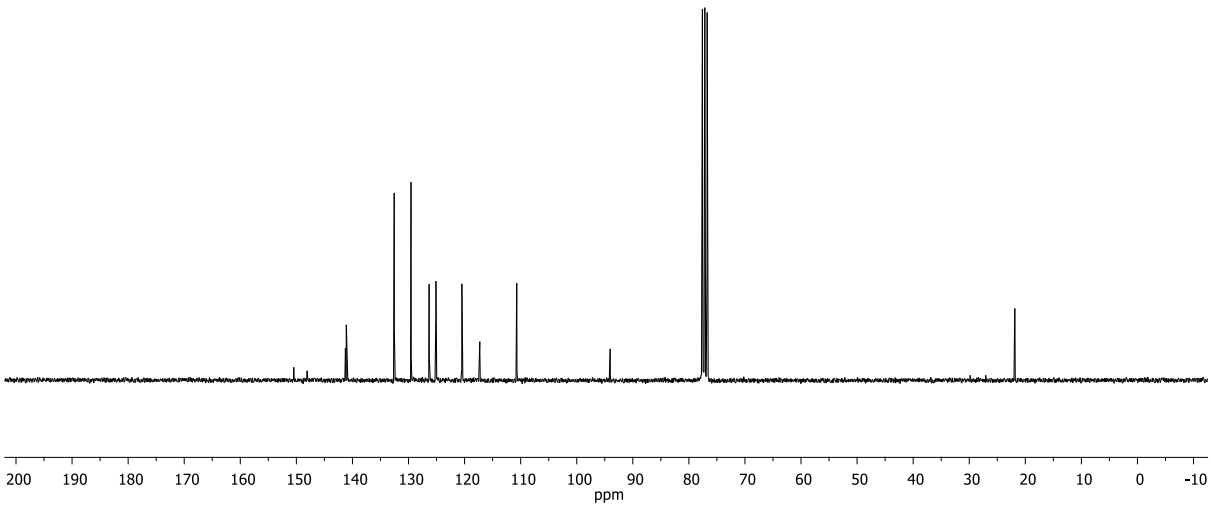
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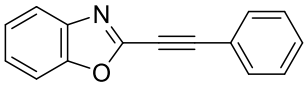
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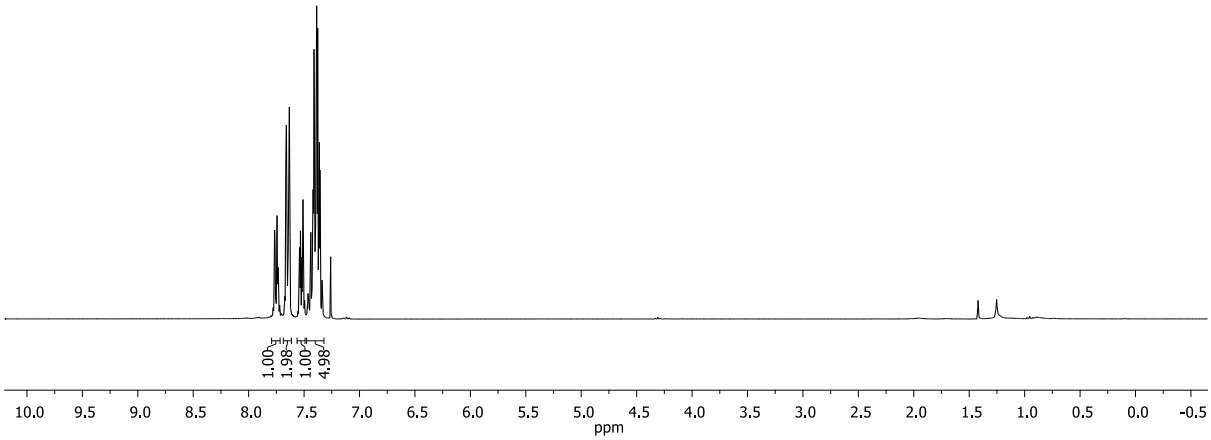
O

7b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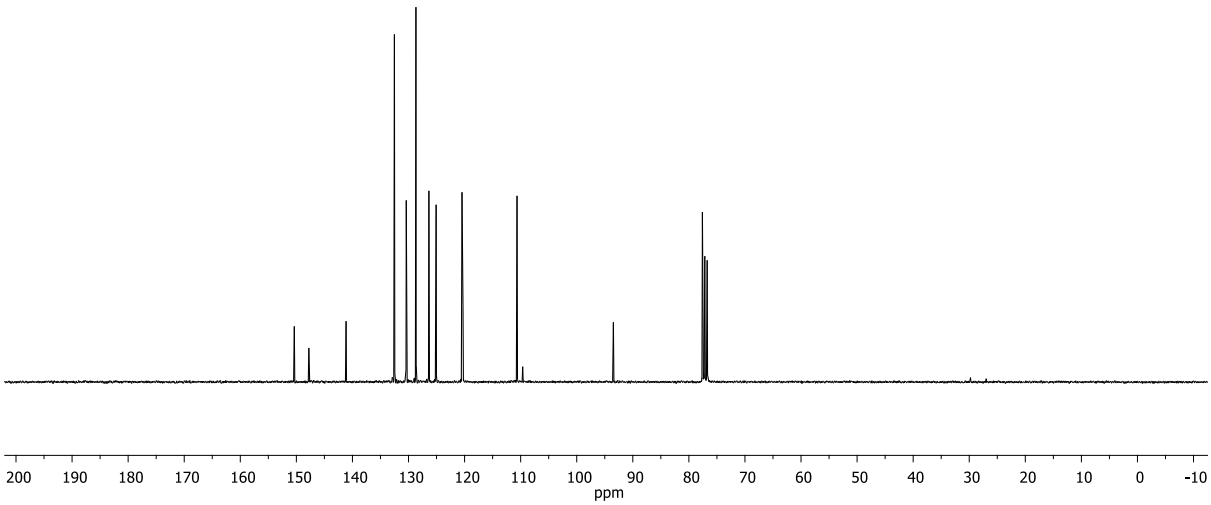
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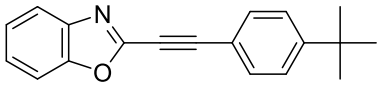

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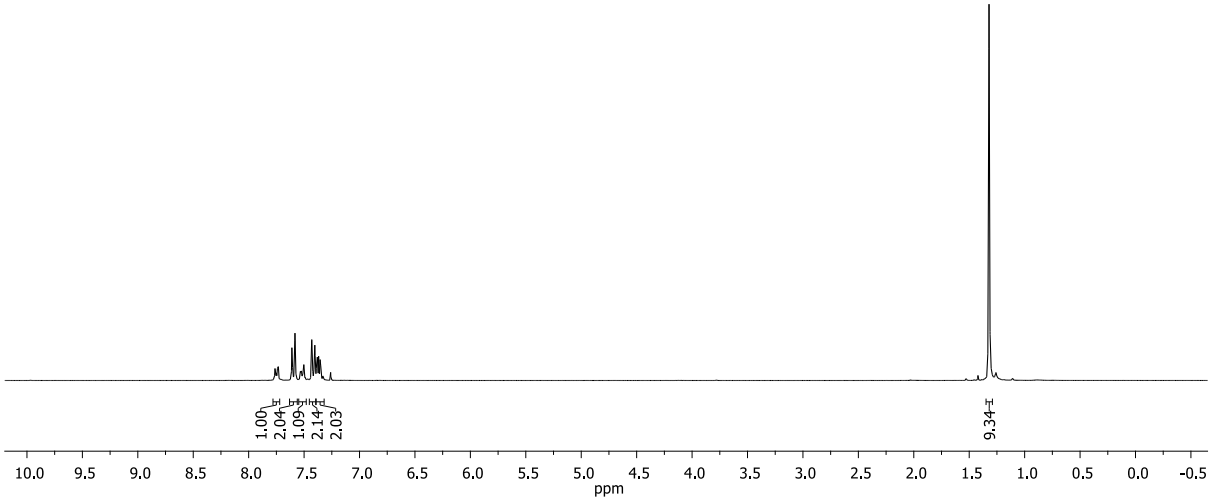
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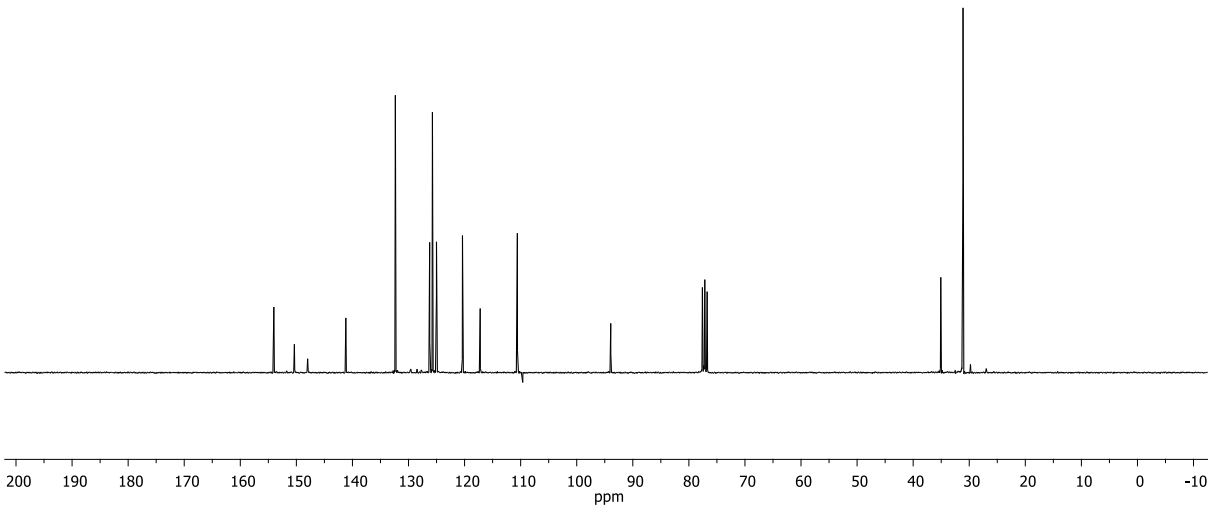
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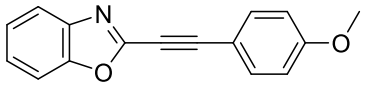

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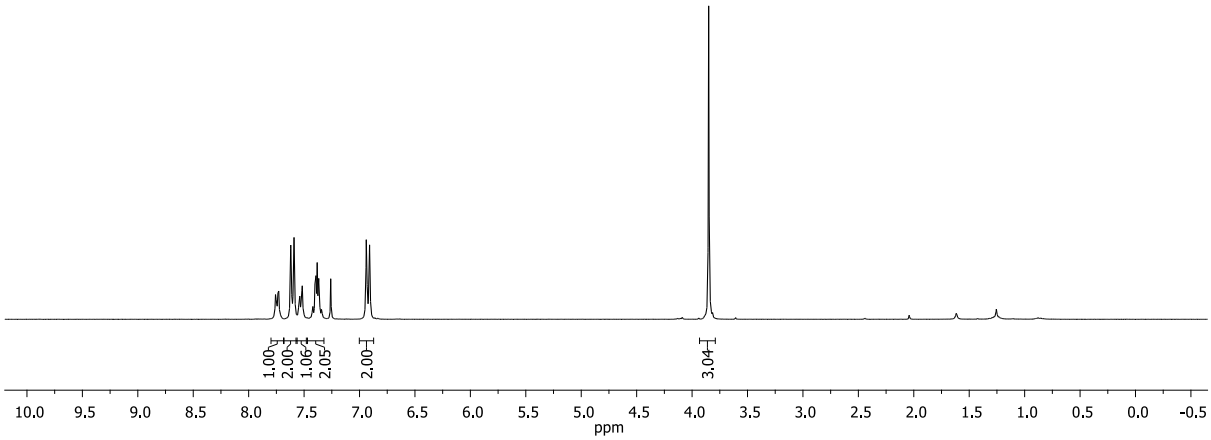
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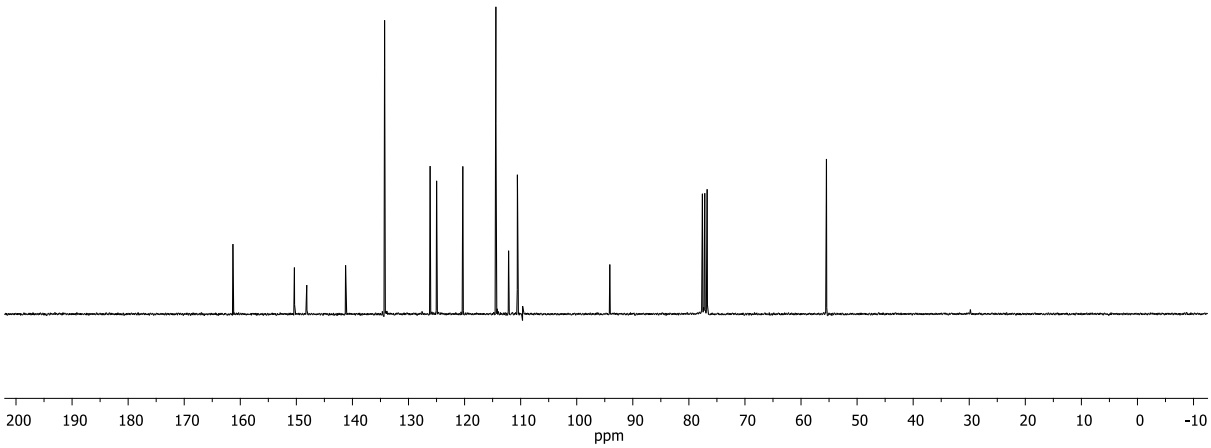
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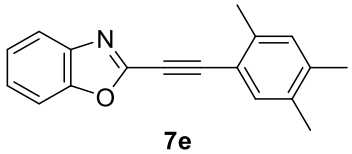

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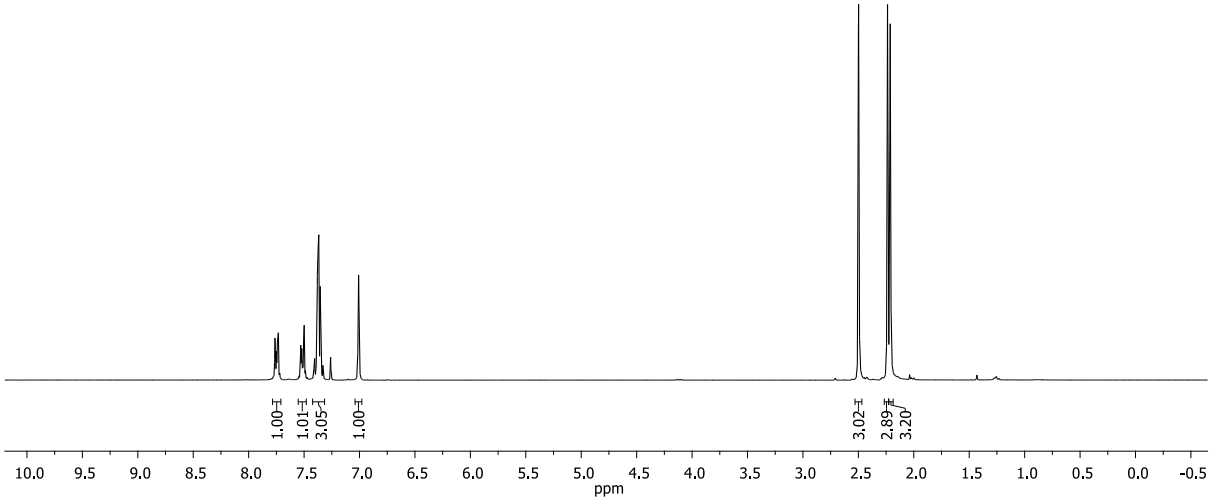
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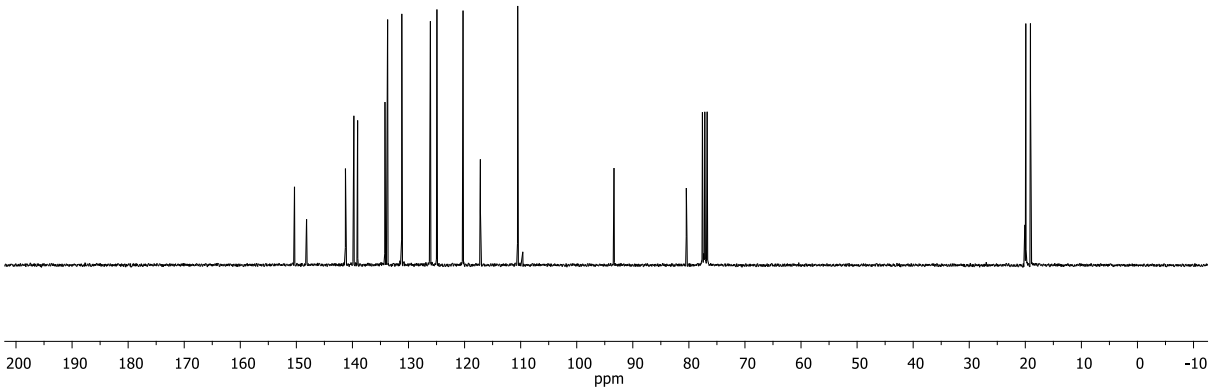
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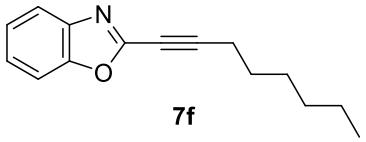

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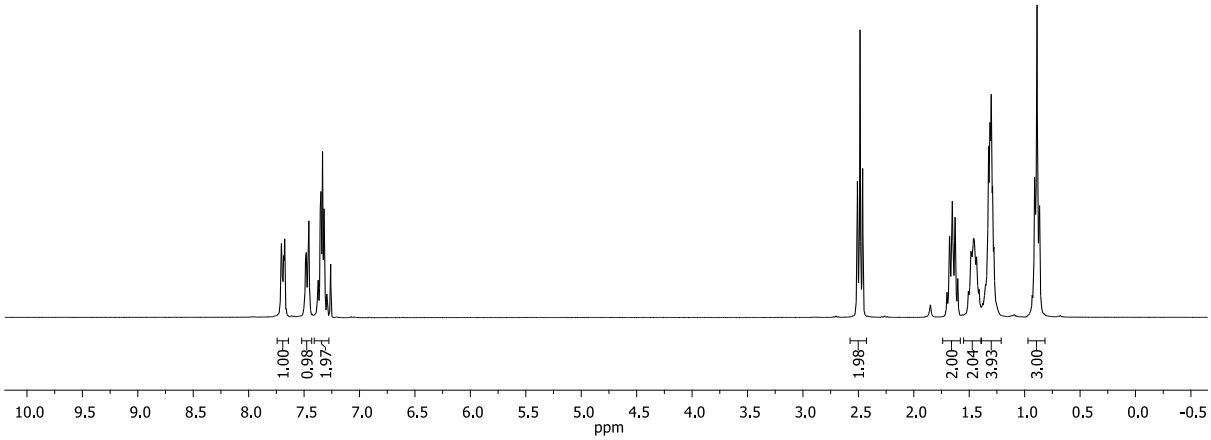
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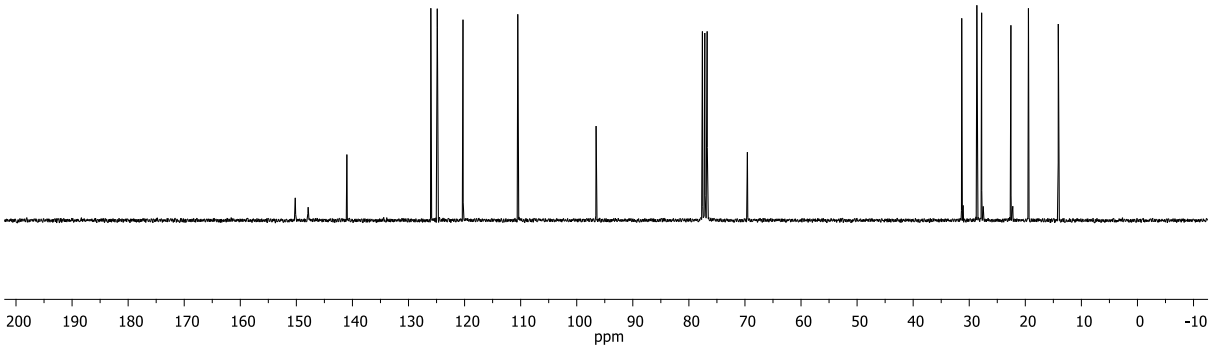
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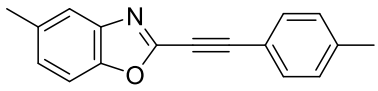

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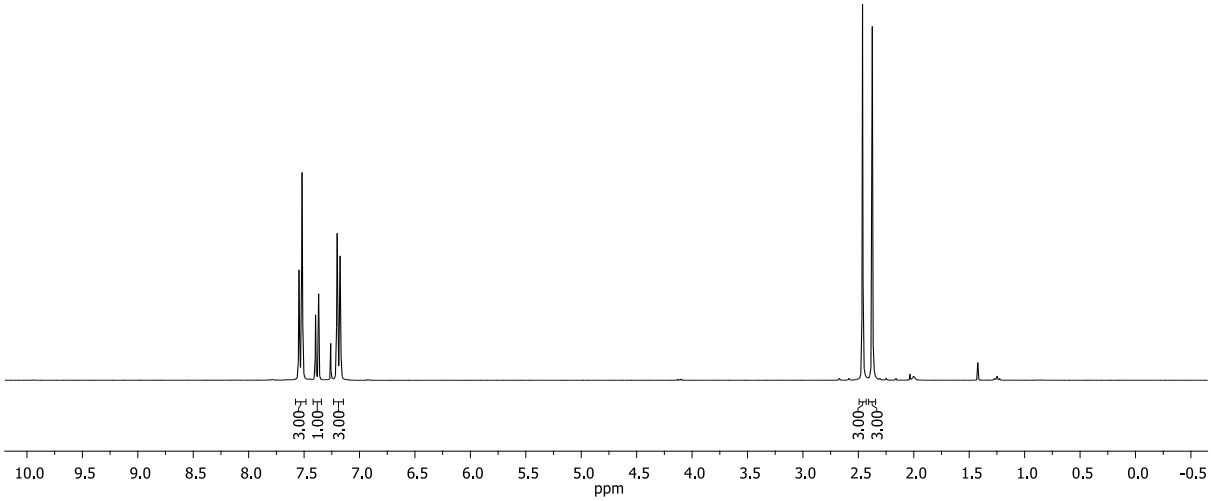
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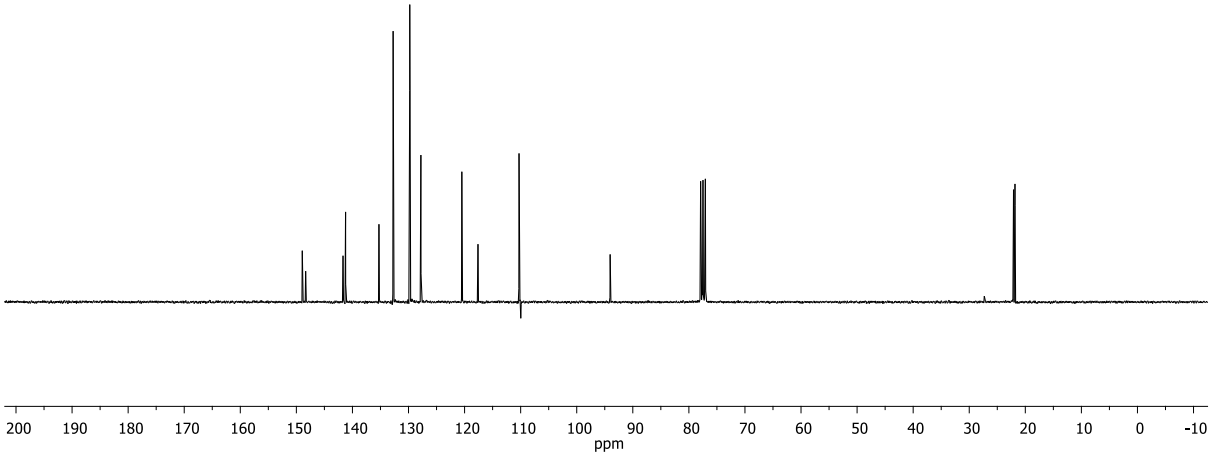
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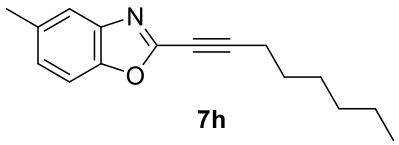

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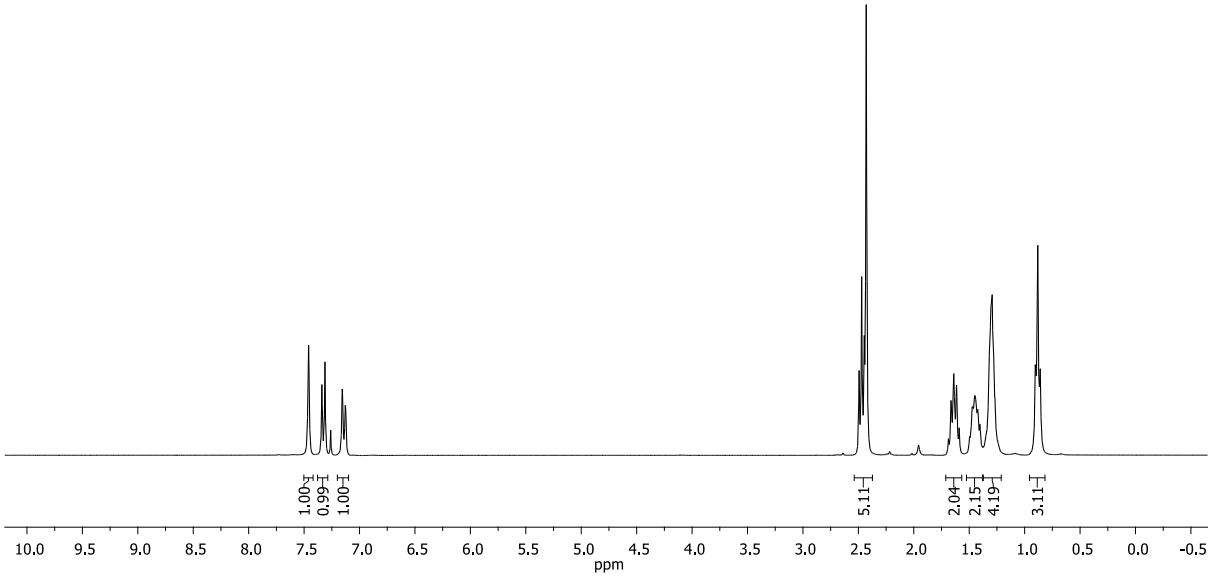
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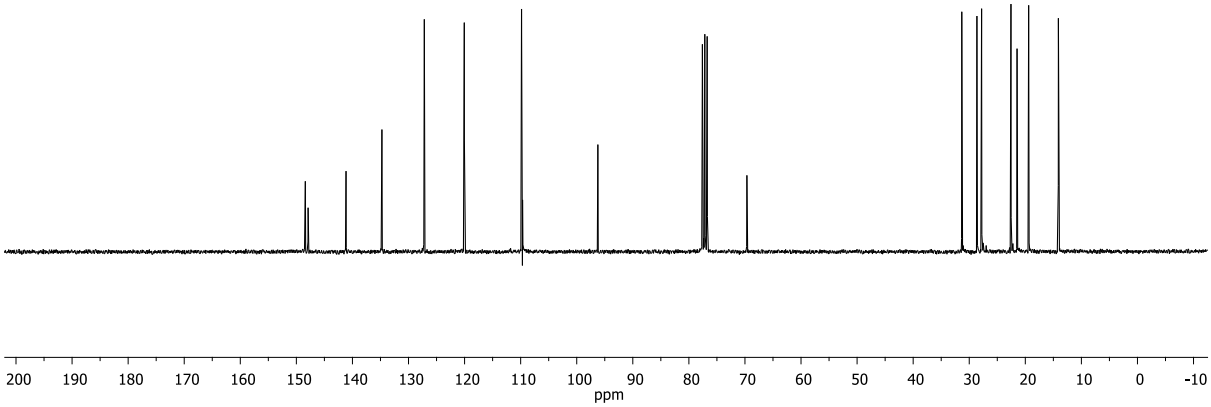
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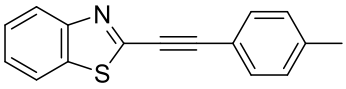

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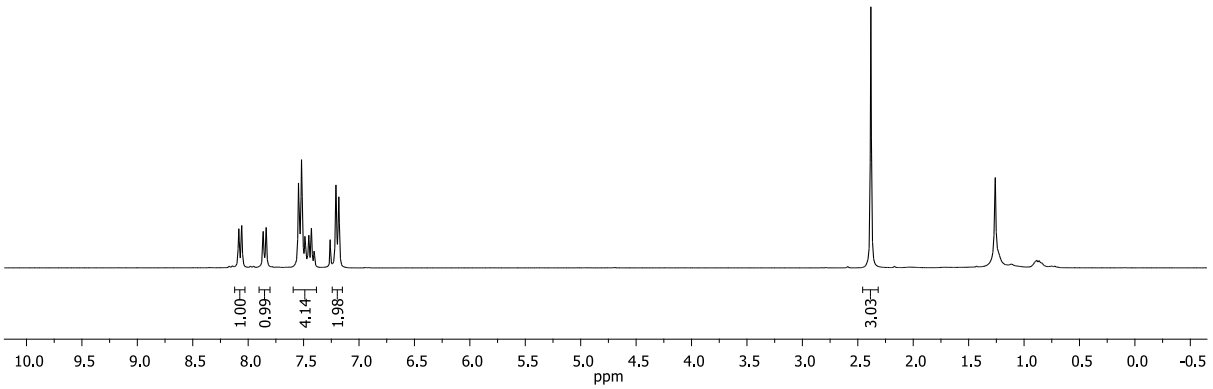
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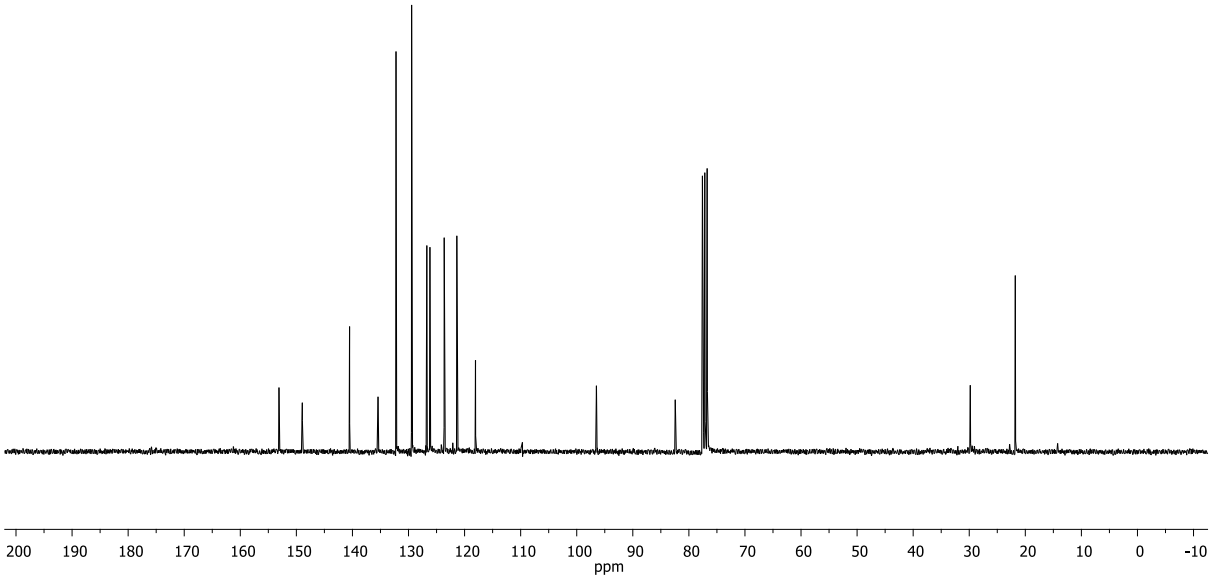
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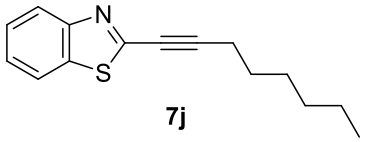
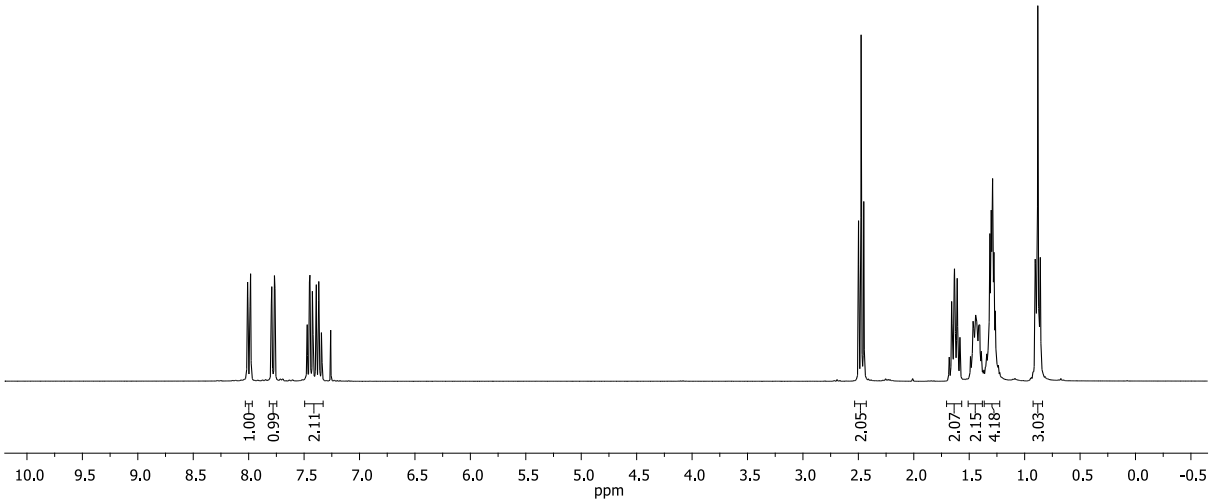


7j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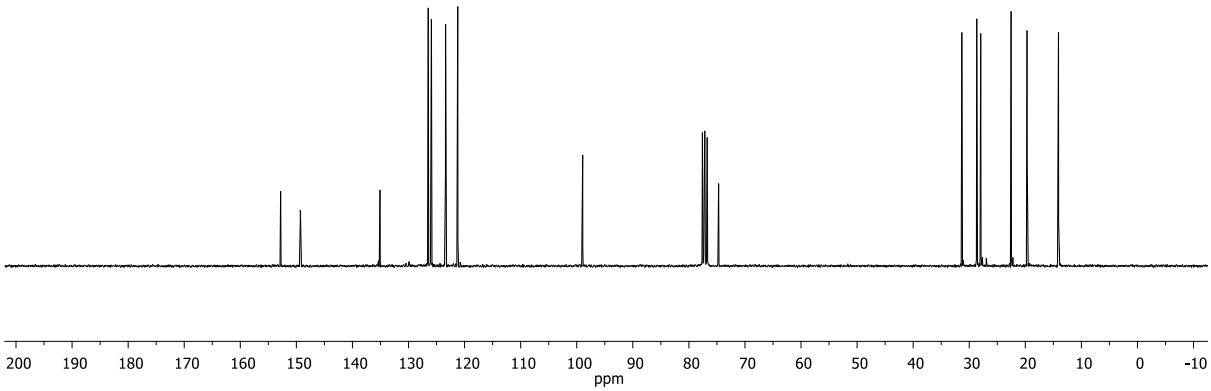
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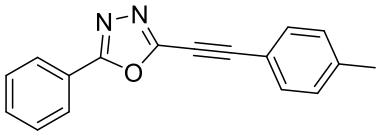

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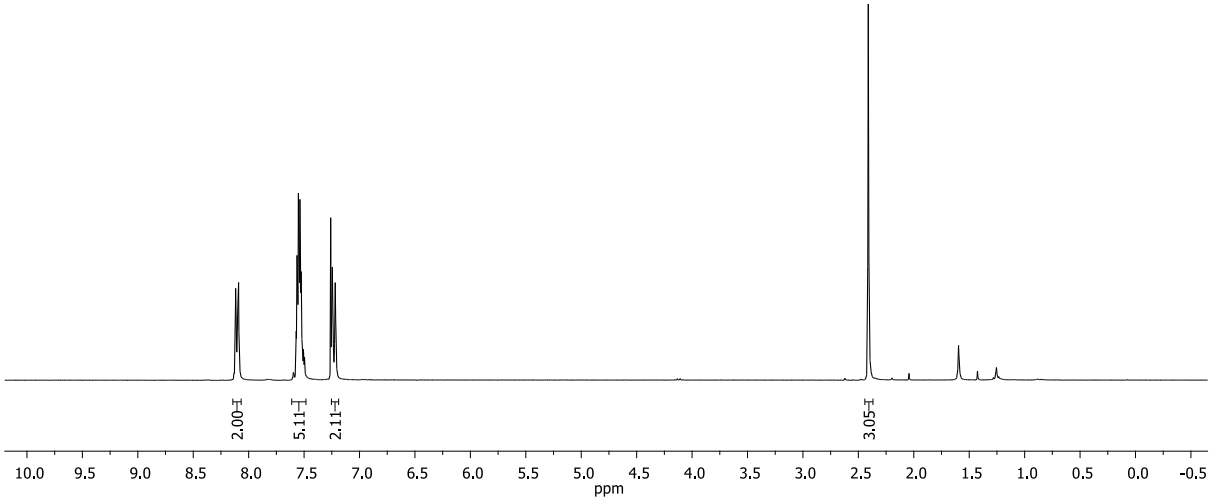
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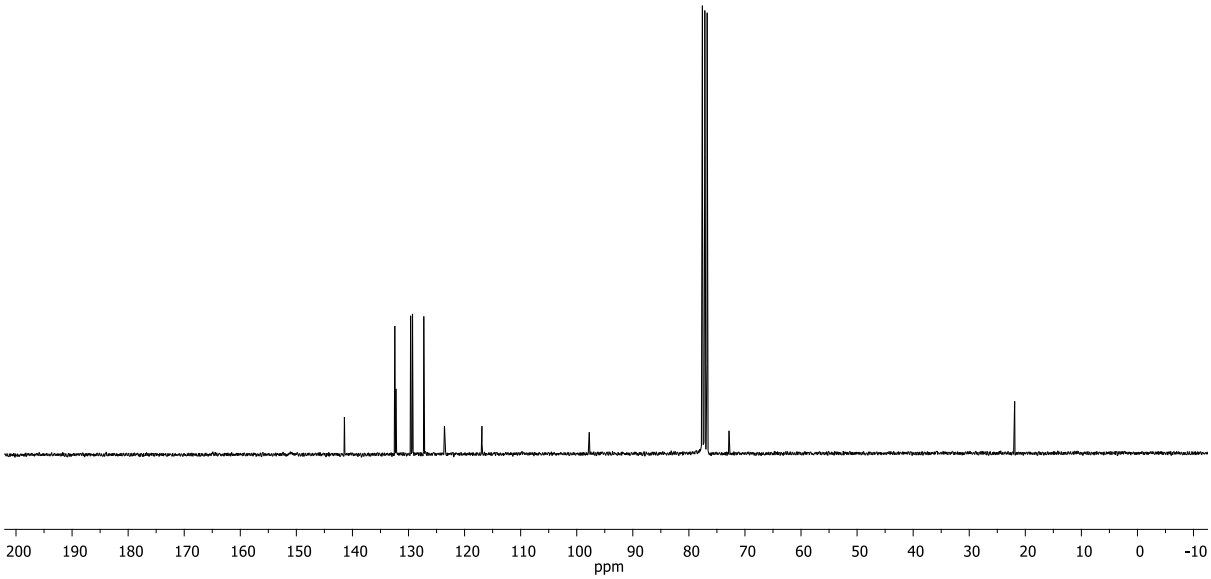
5.11
2.11
3.05
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
ppm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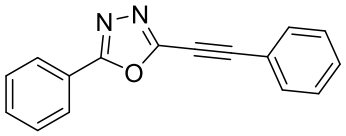

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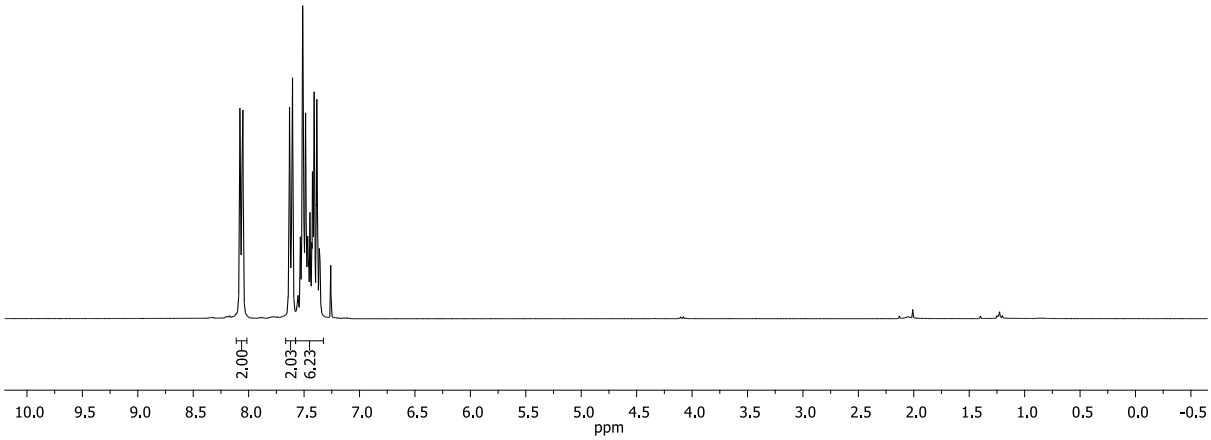
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6.23
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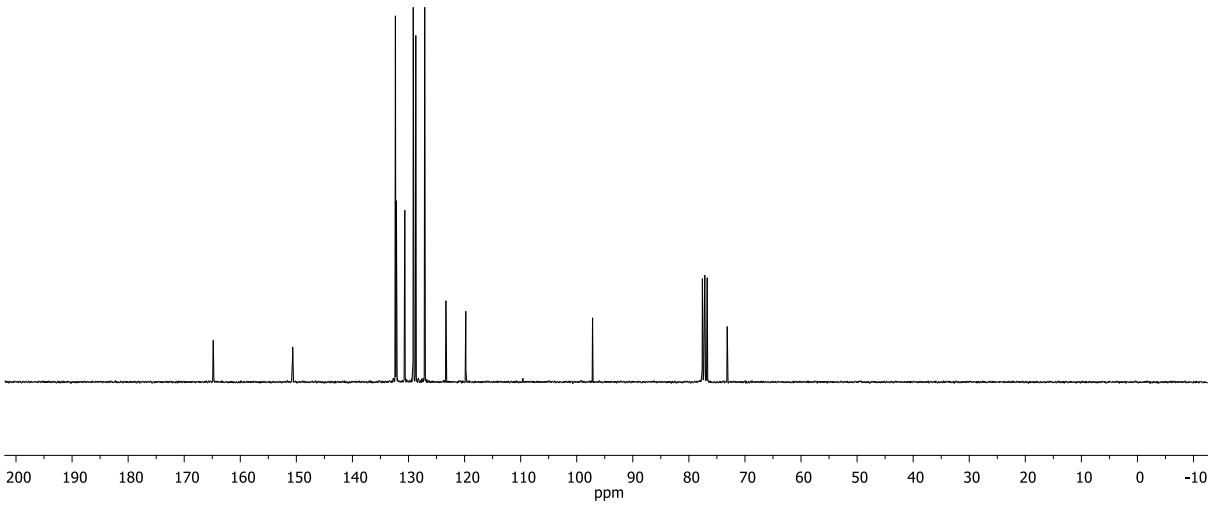
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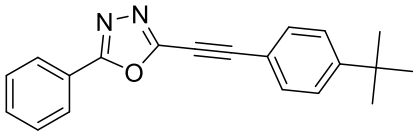

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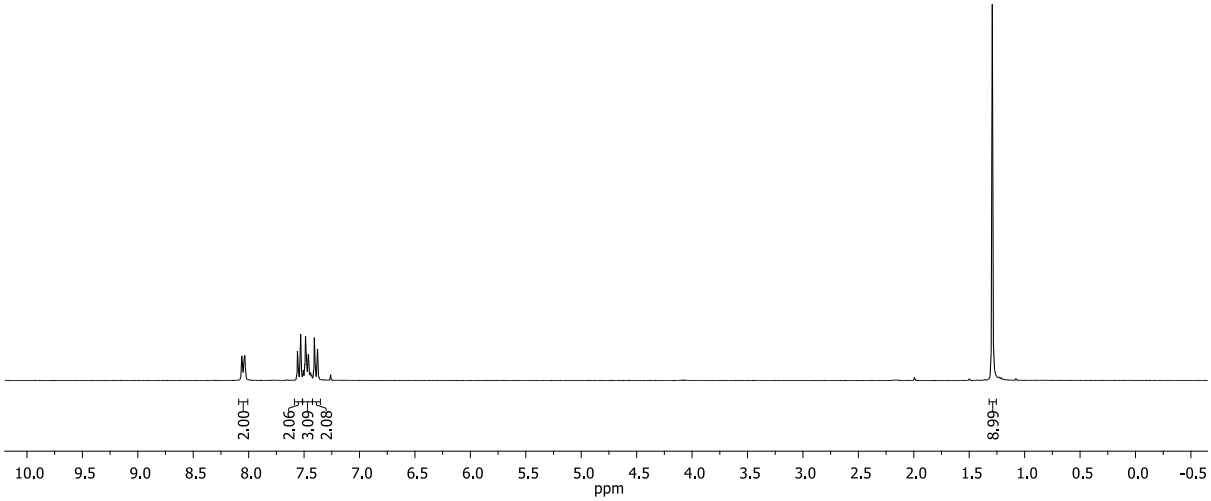
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2.08
8.99
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
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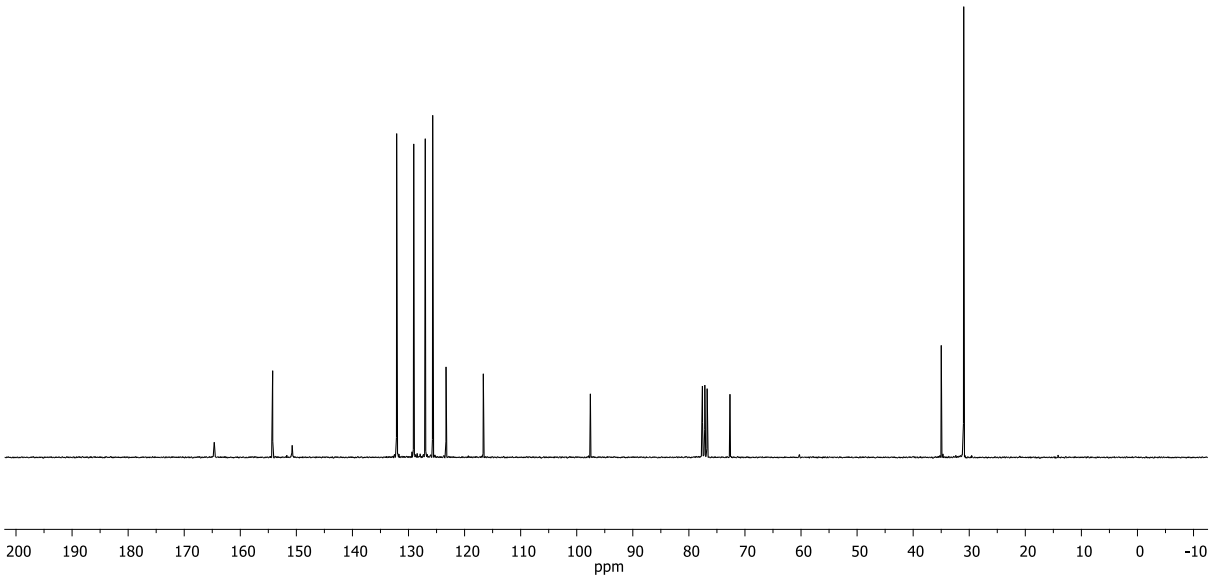
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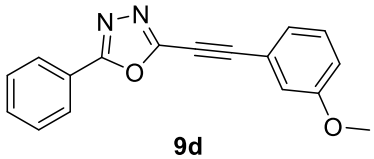

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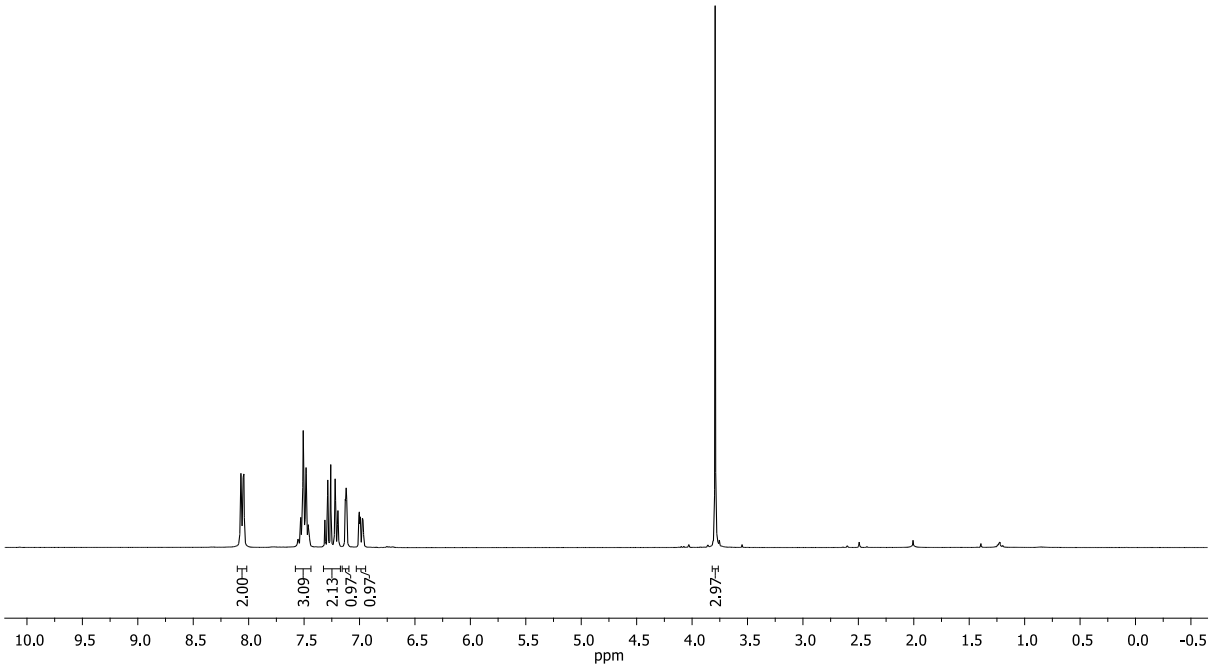
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0.97
2.97
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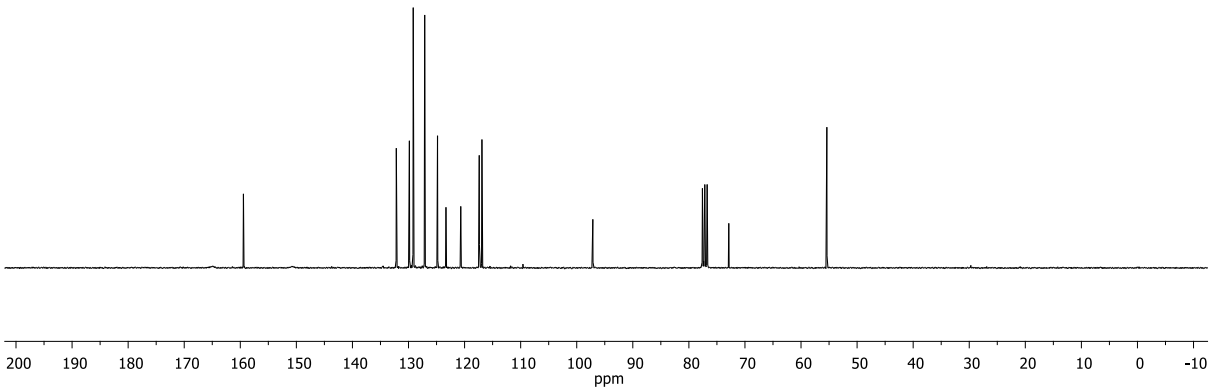
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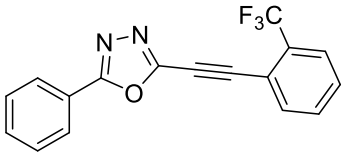
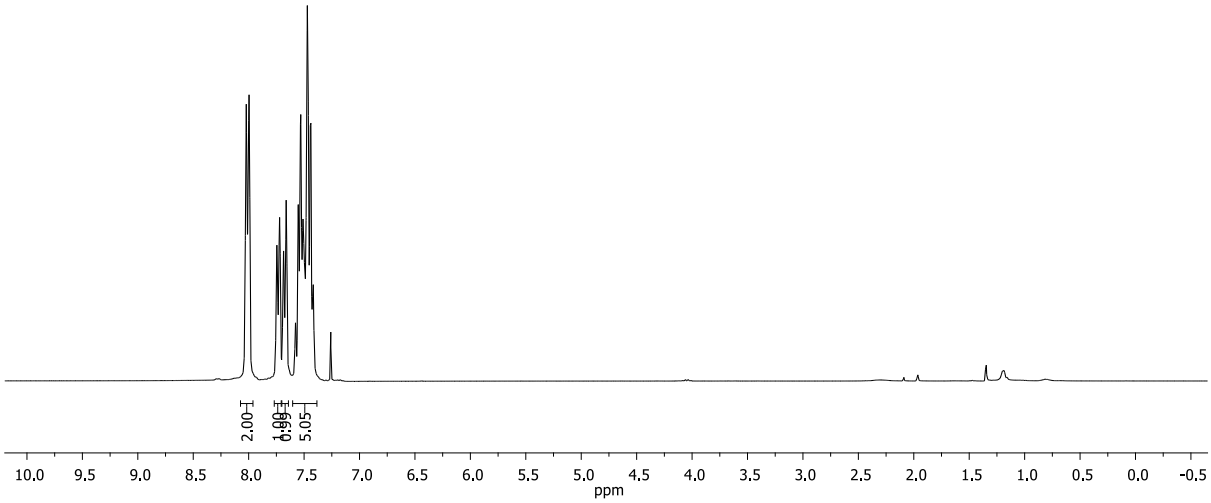
ppm


F3C
N
N
O

9e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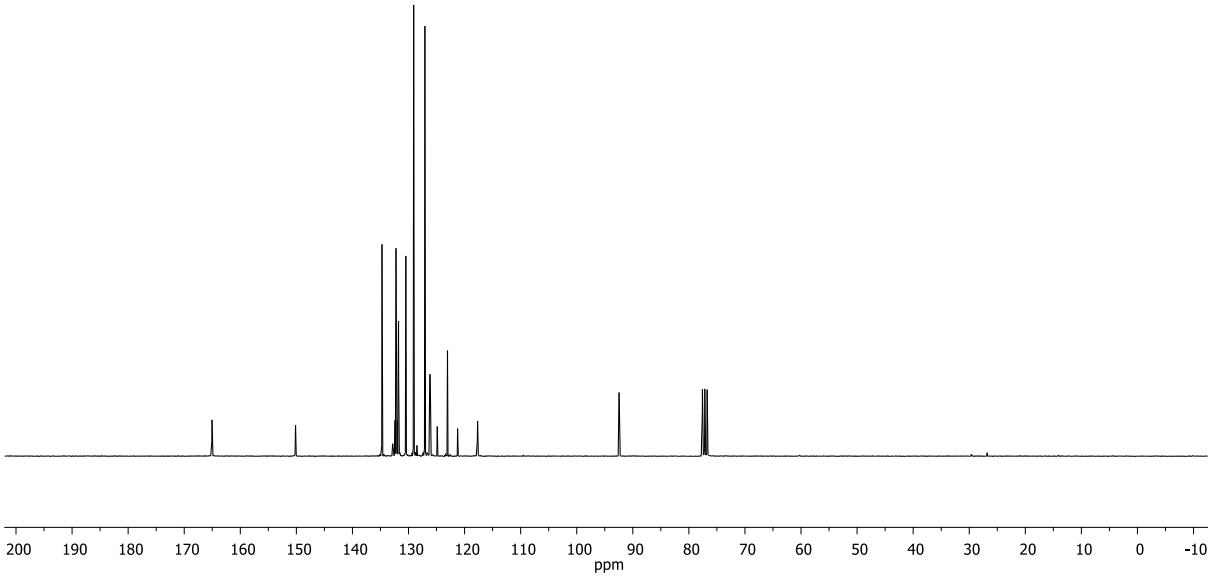
1.00
0.99
5.05
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
ppm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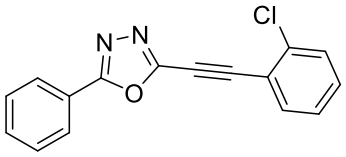
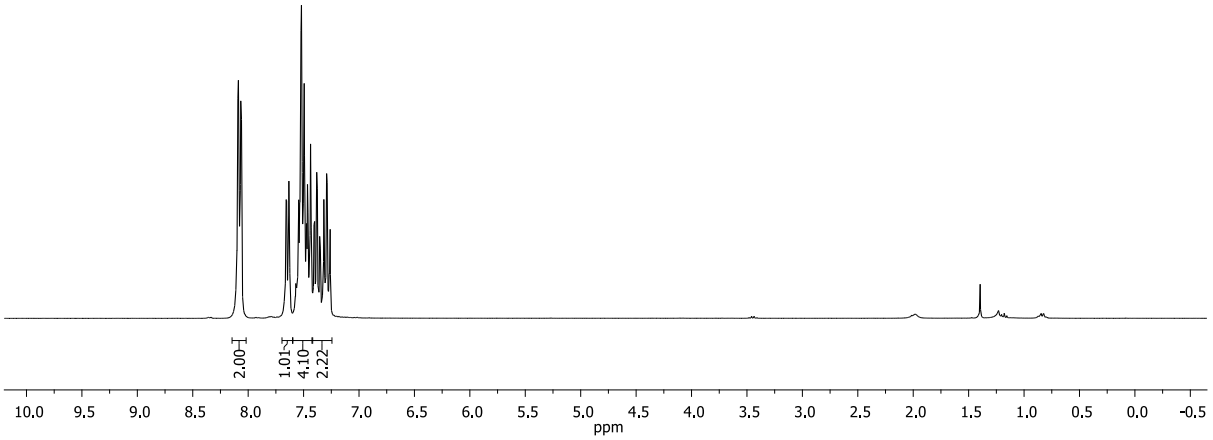
ppm


Cl
N
N
O

9f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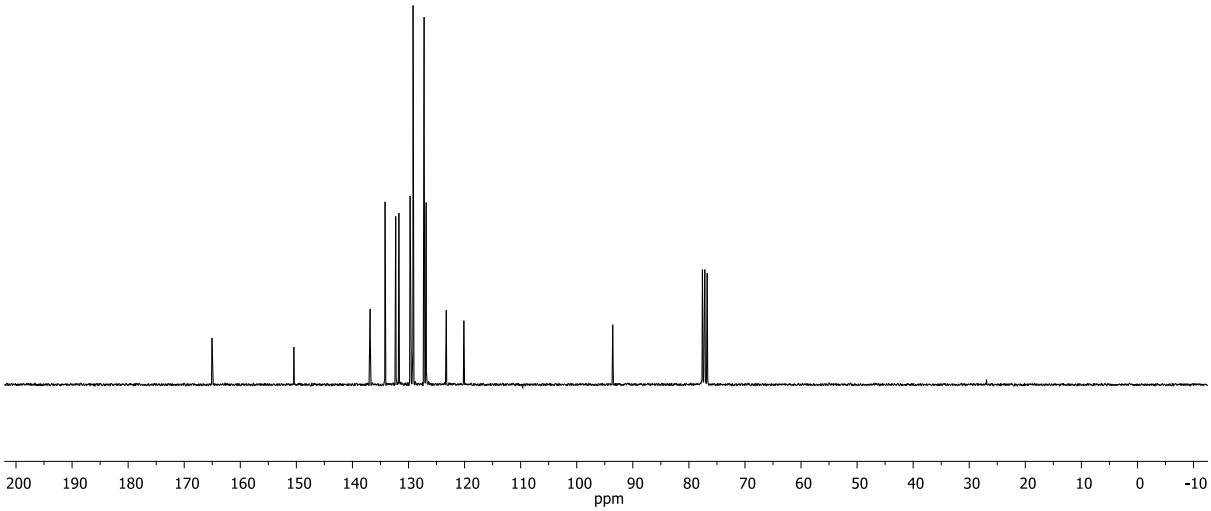
1.01
4.10
2.22
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
ppm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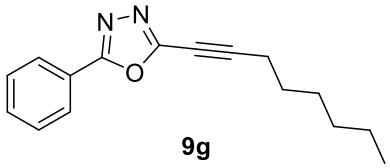
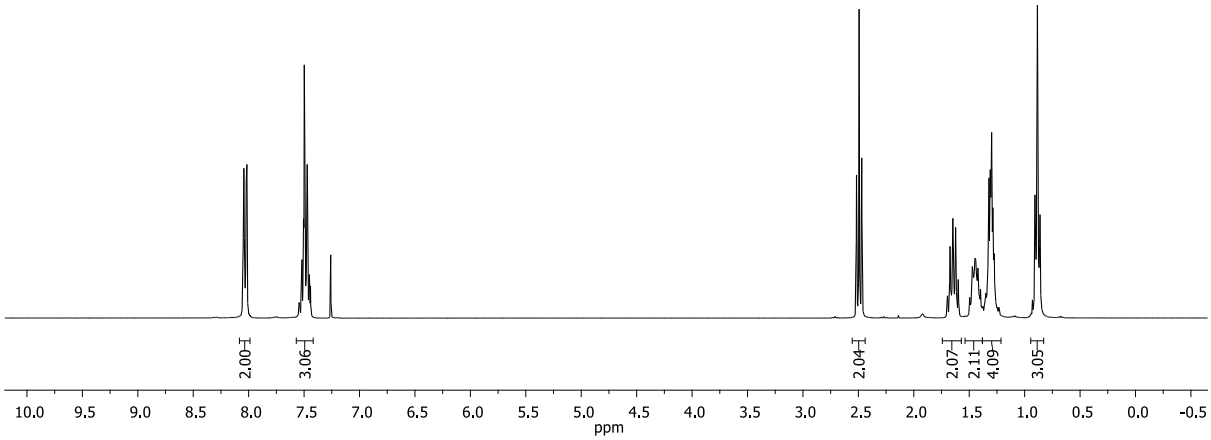


9g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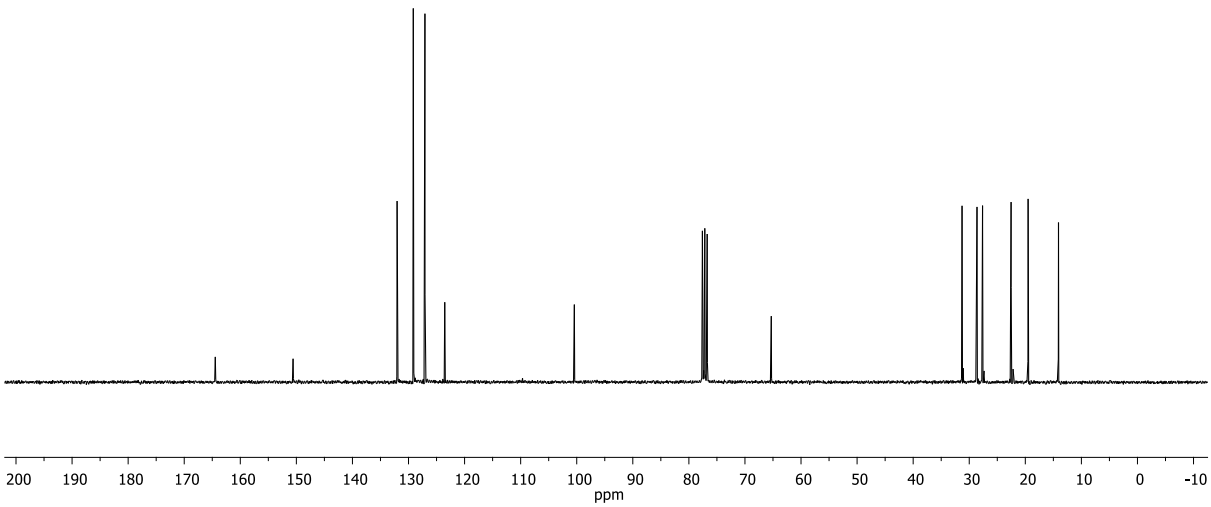
2.04
2.07
2.11
4.09
3.05
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
ppm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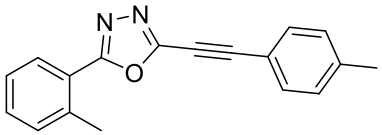
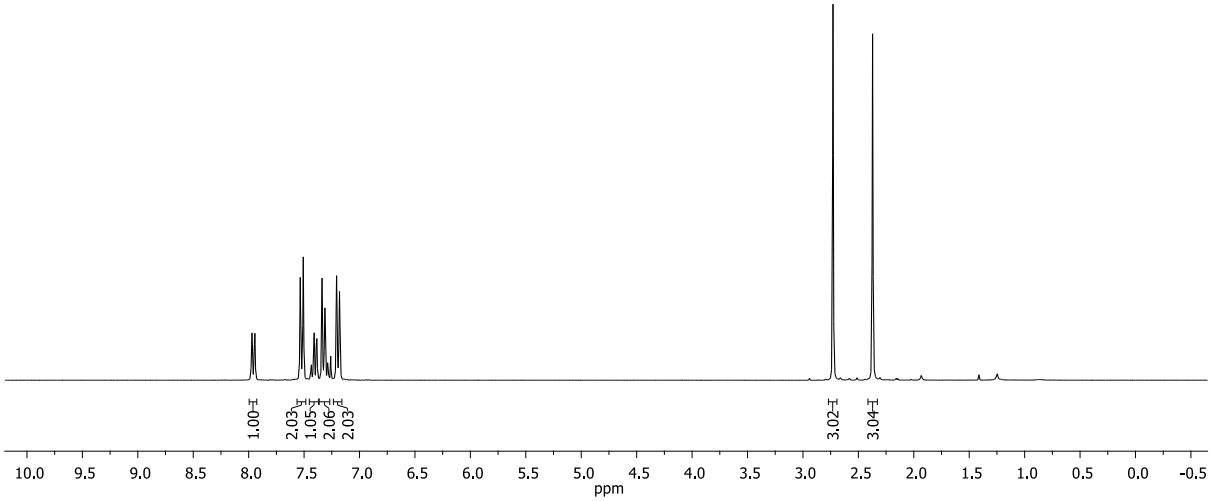
ppm



9h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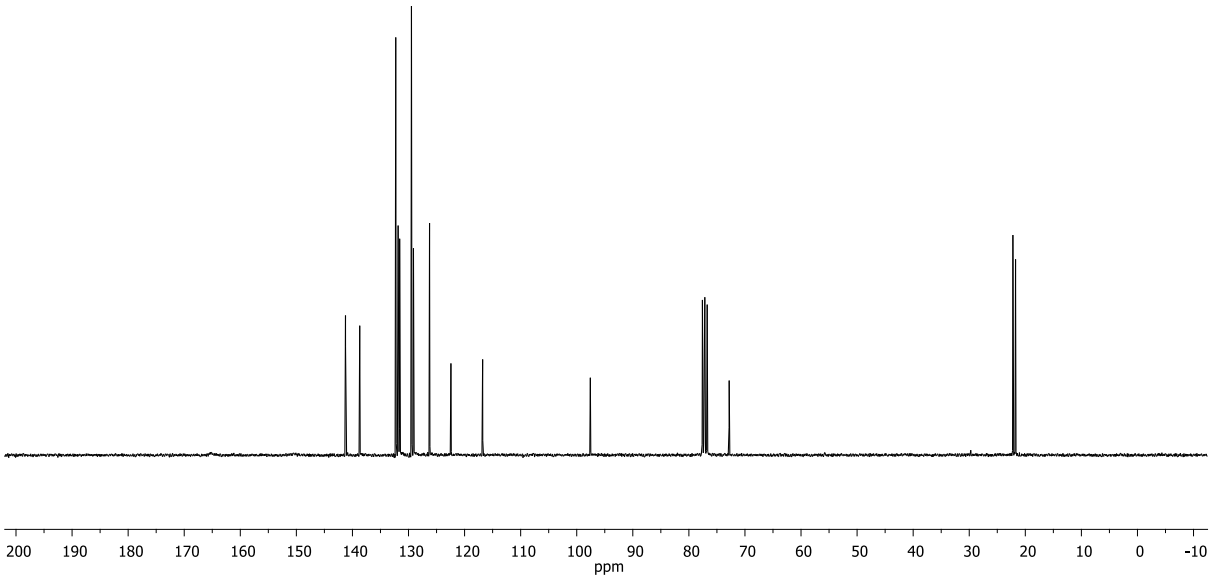
2.03
1.05
2.06
2.03
3.02
3.04
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
ppm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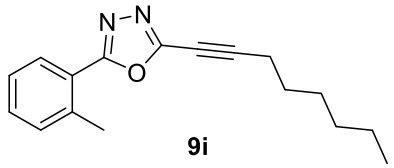
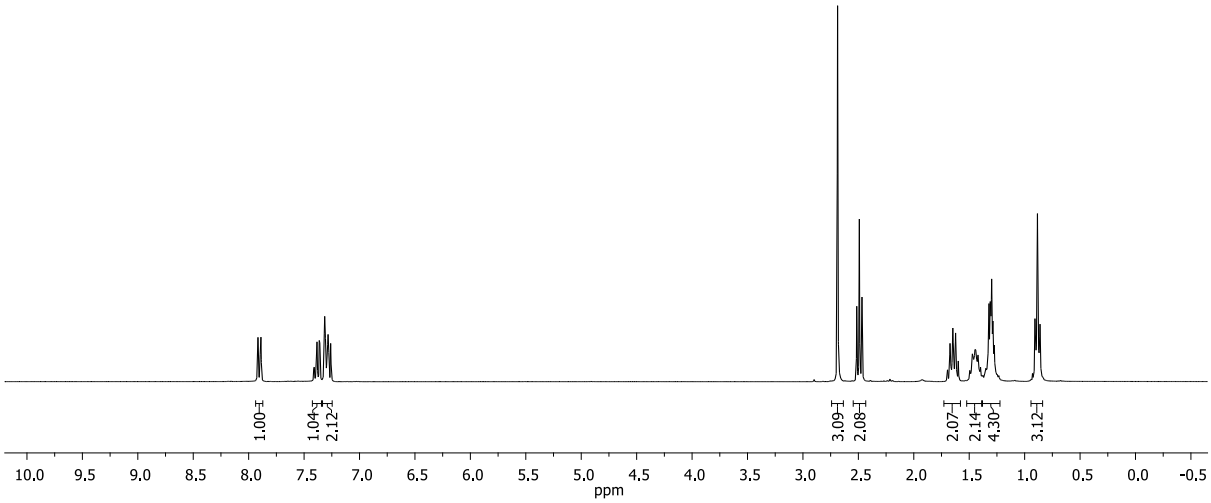


9i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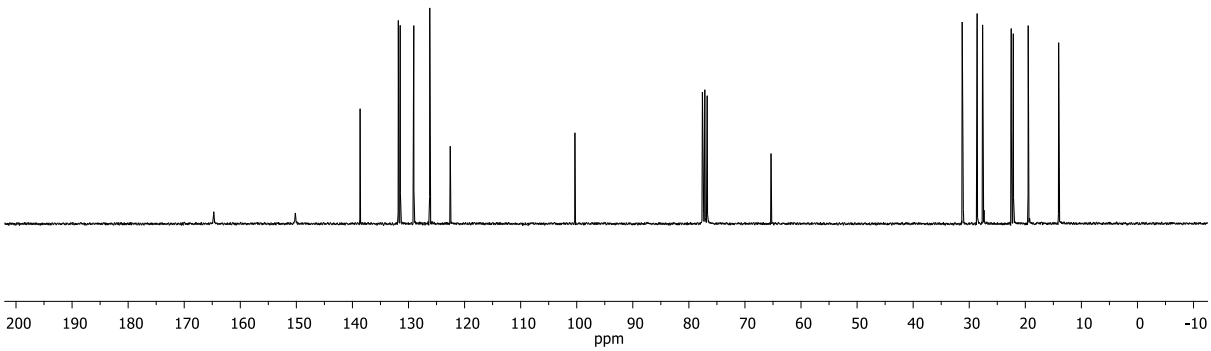
2.12
3.09
2.08
2.07
2.14
4.30
3.12
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
ppm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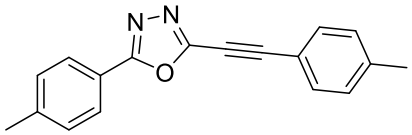
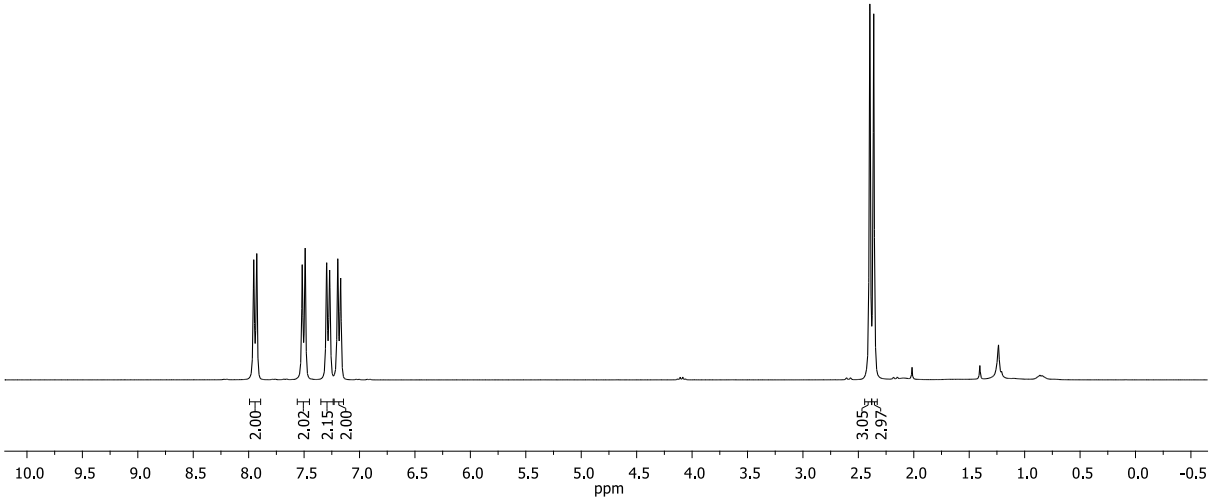
ppm



9j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2.00
3.05
2.97
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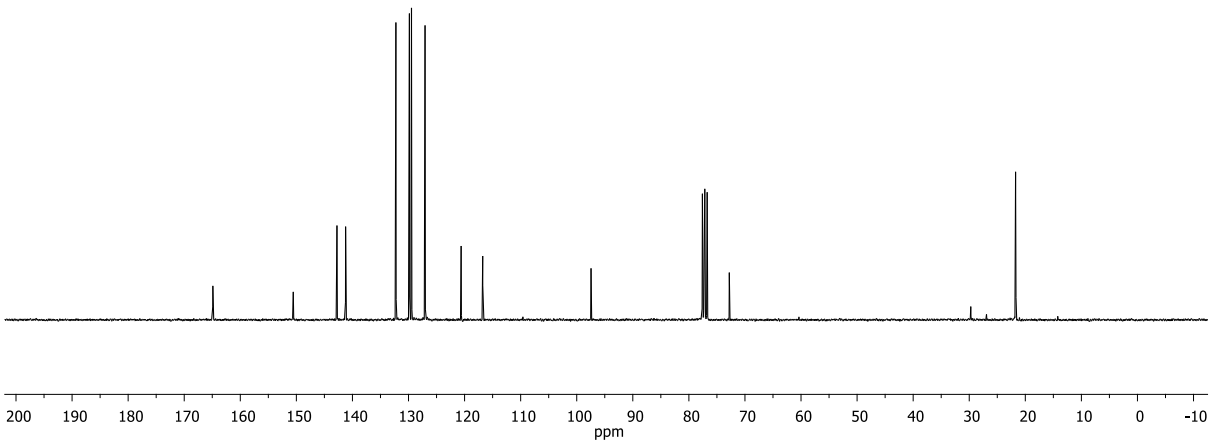
ppm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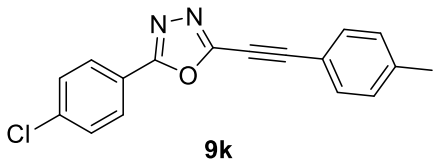
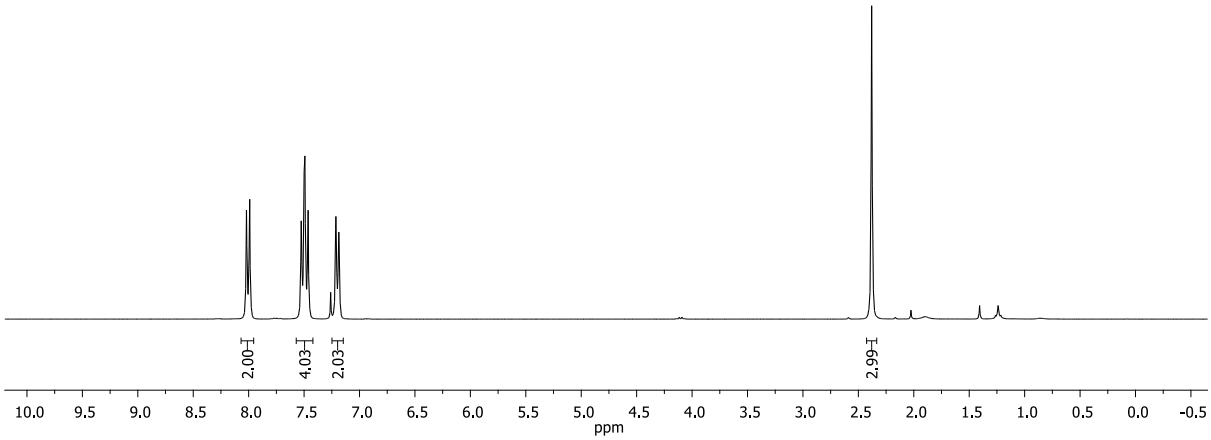
ppm


N
N
O
Cl

9k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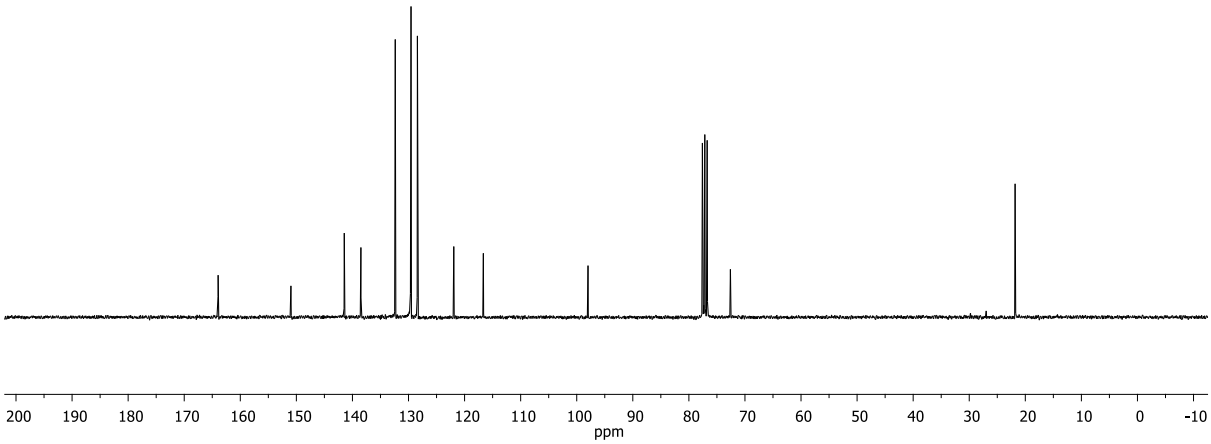
4.03
2.03
2.99
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
ppm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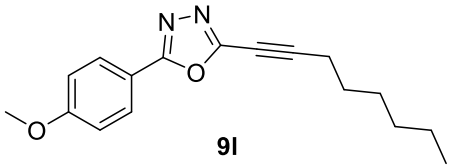
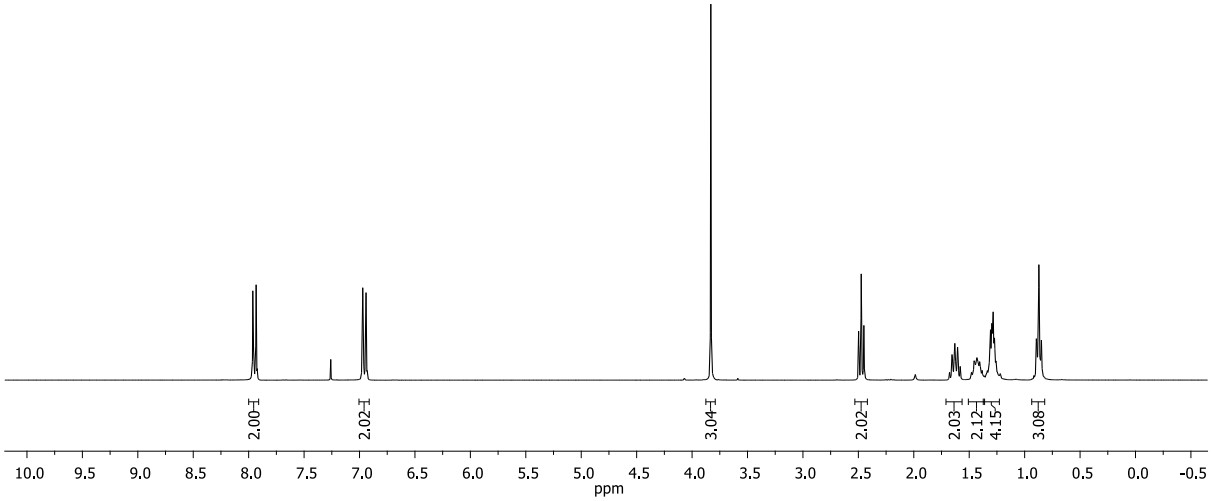
ppm



9l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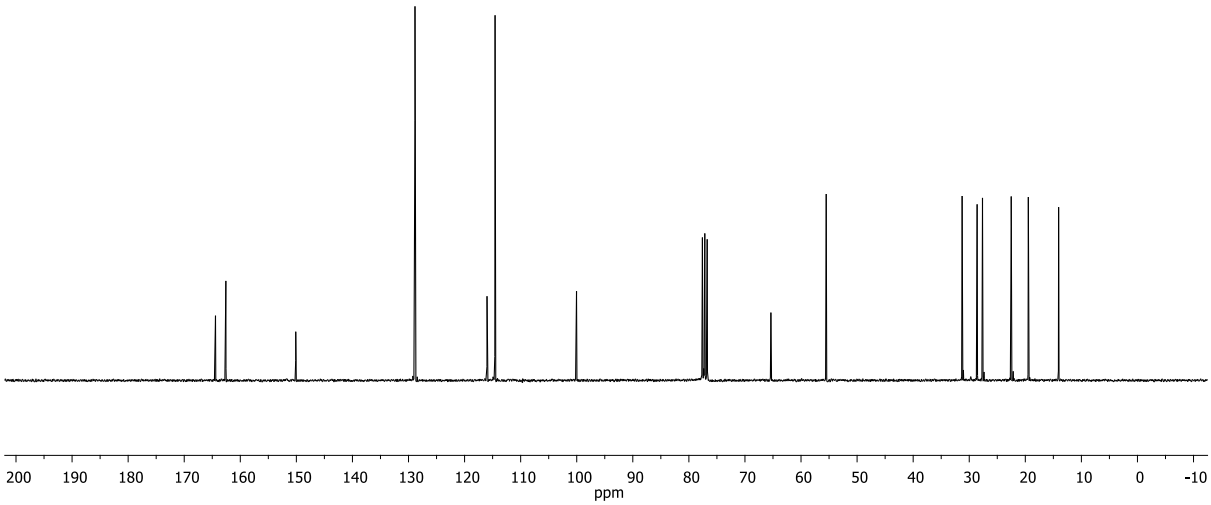
3.04
2.02
2.03
2.12
4.15
3.08
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
ppm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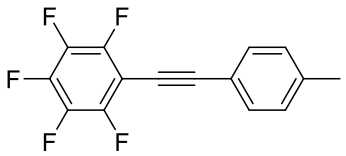
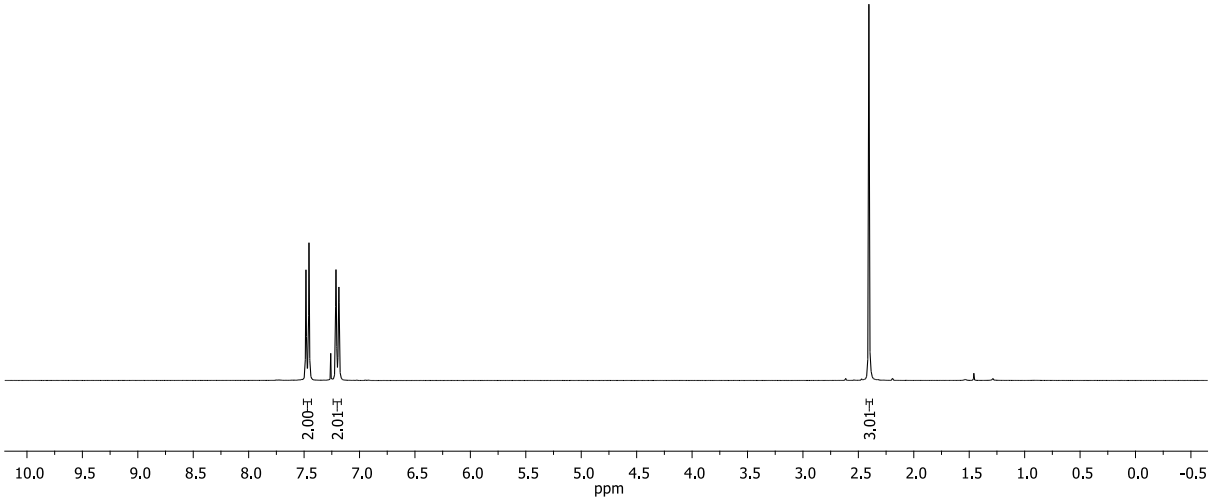
ppm



11a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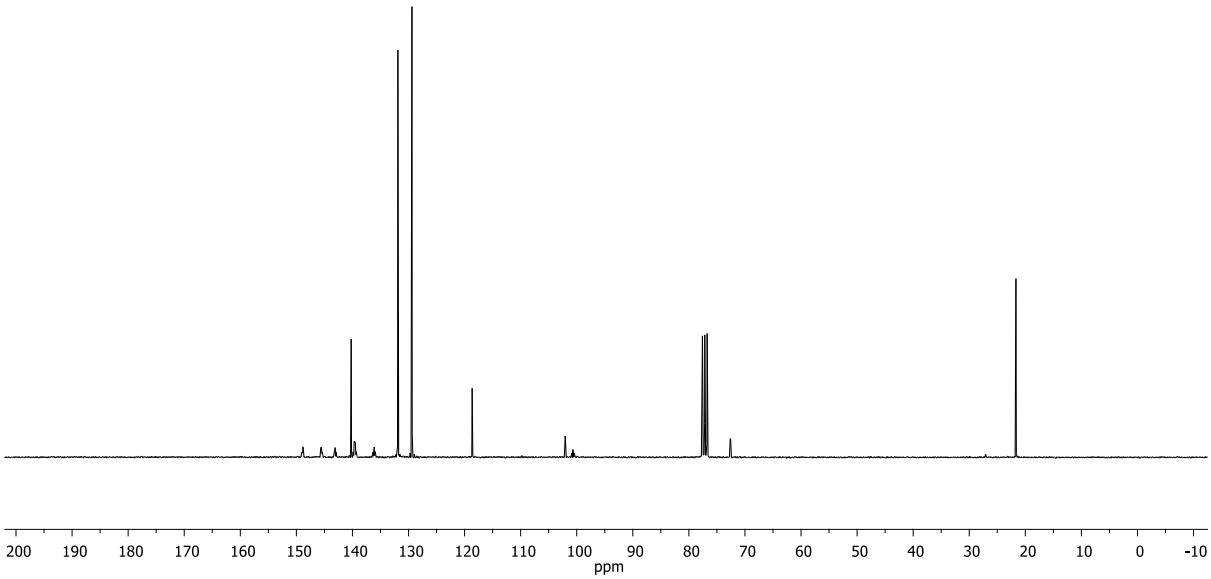
3.01
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
ppm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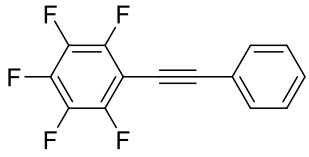
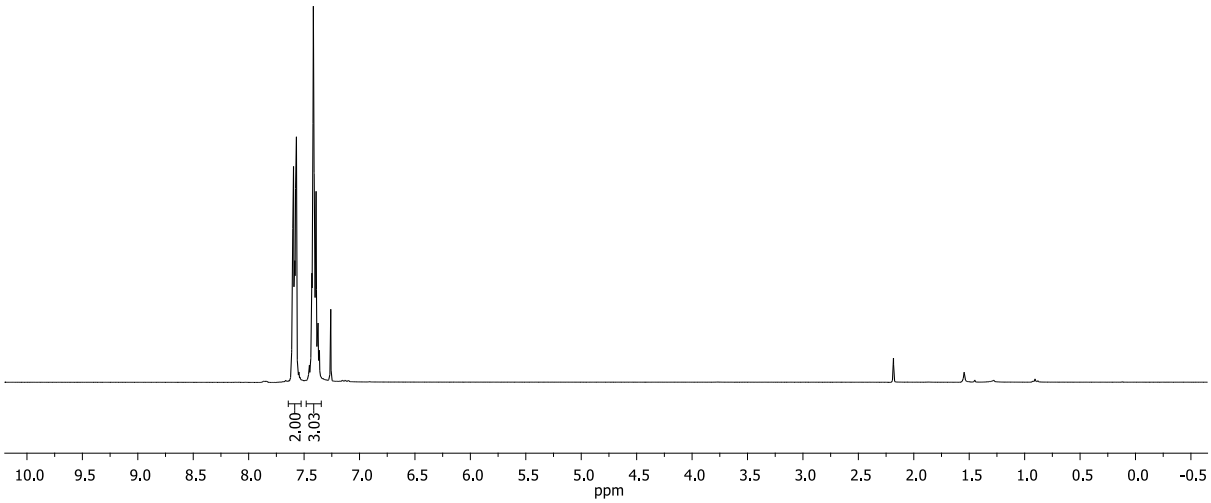
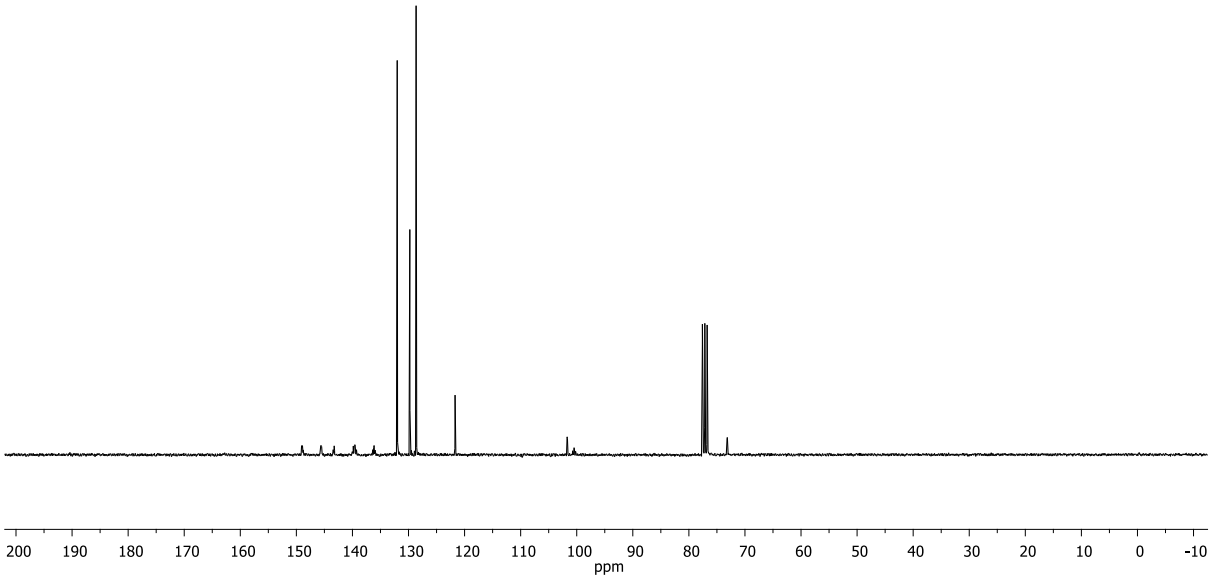
ppm



11b


2.00
3.03
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 -0.5
ppm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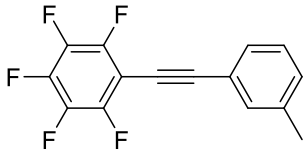
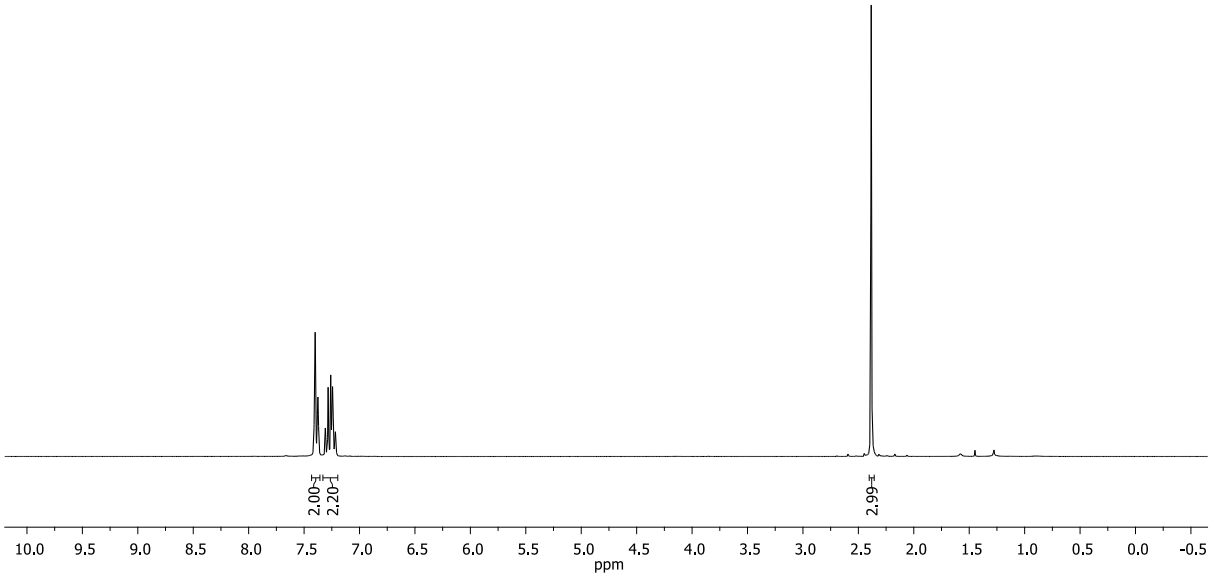
ppm


F
F
F
F
F

11c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2.20
2.99
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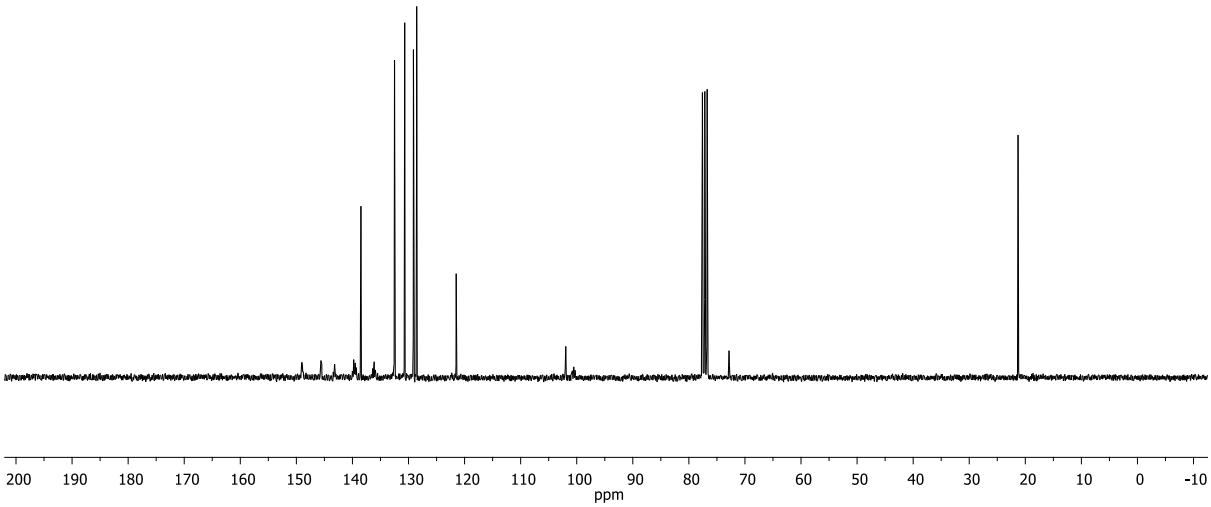
ppm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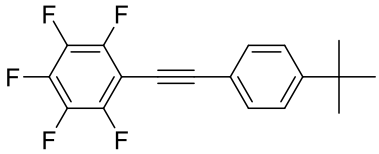
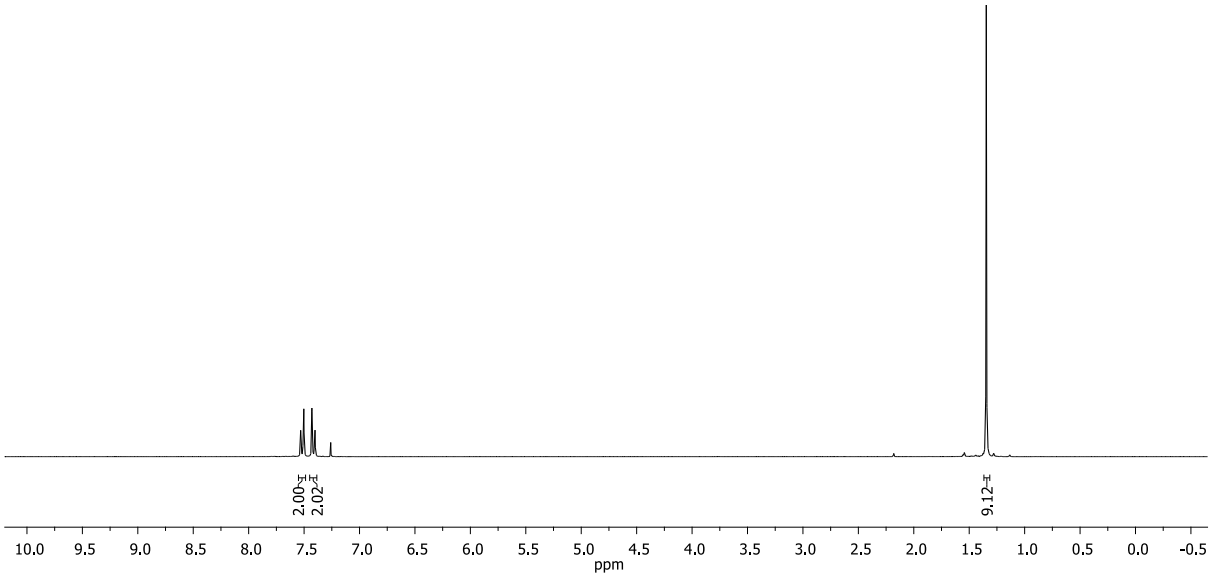


11d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2.02
9.12
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
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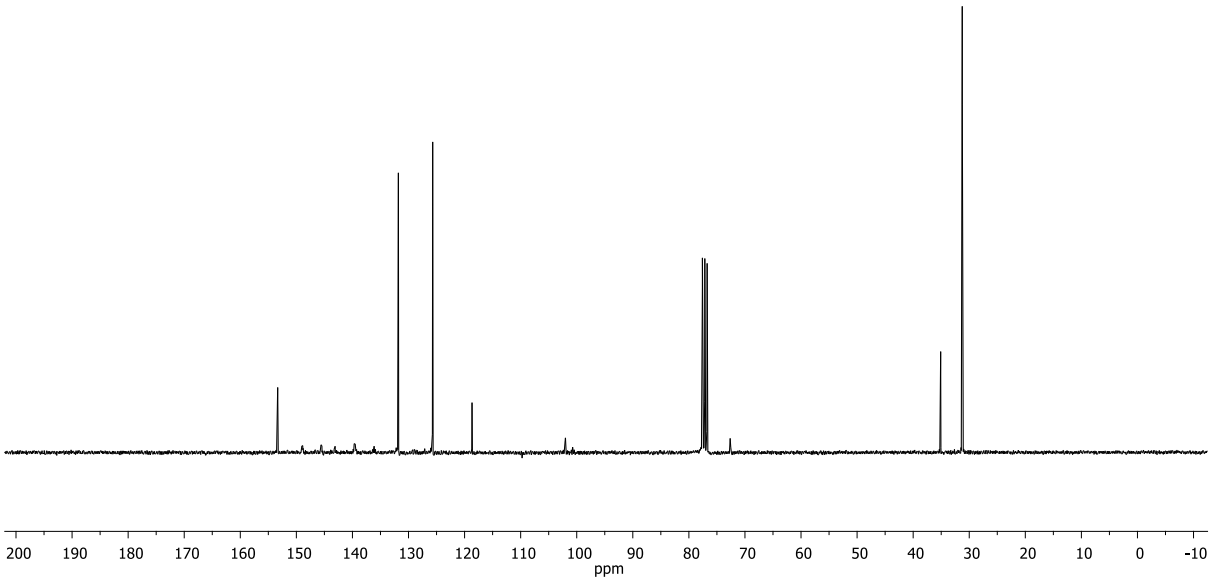
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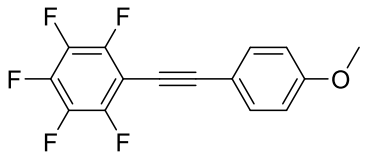
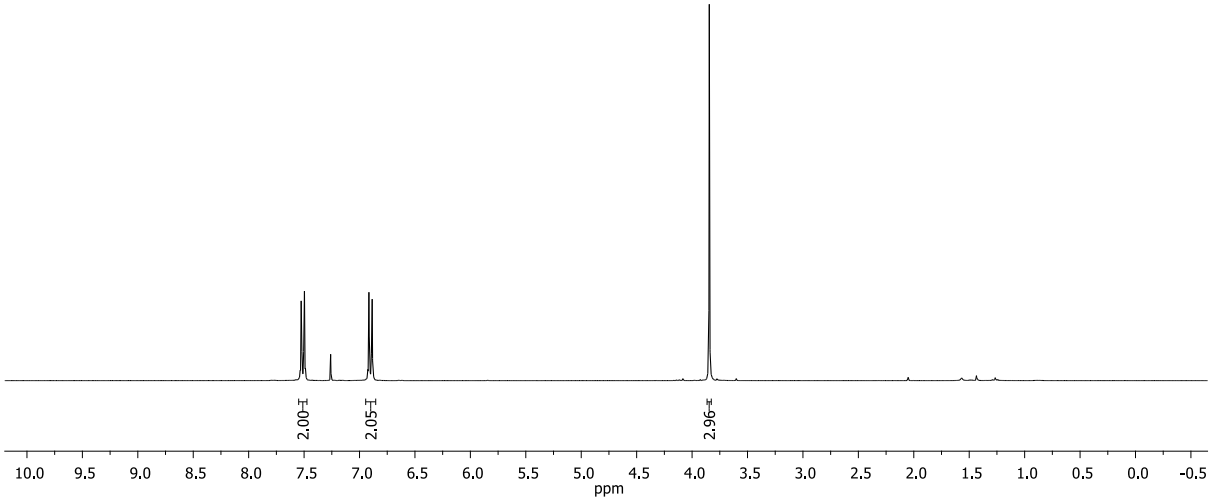


11e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2.05
2.96
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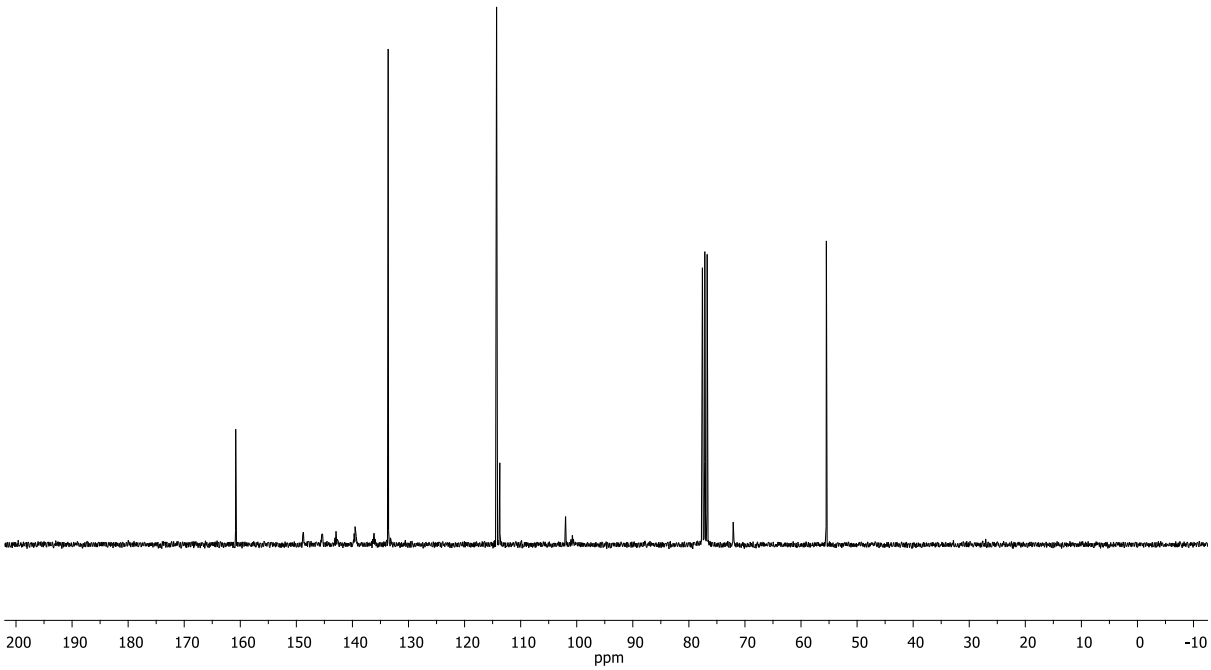
ppm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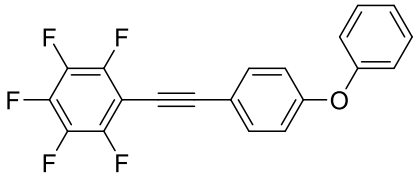
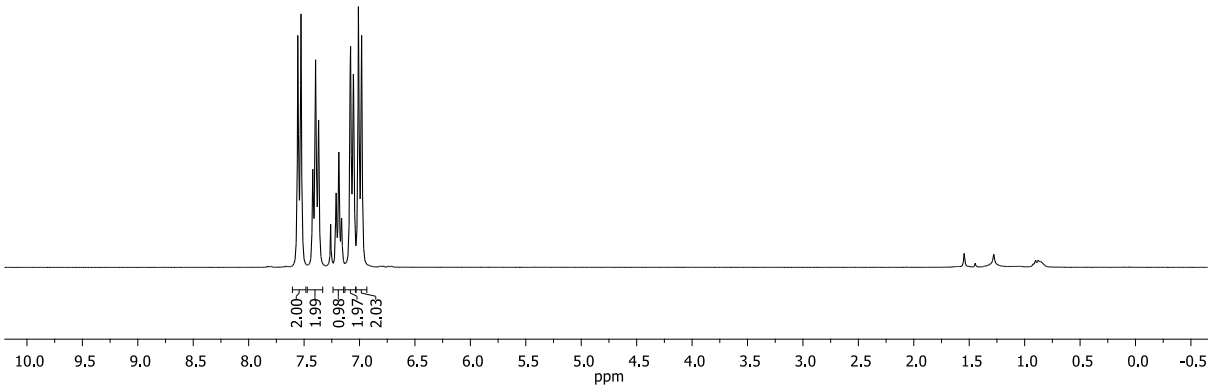
ppm


F
F
F
F
F
O

11f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1.99
0.98
1.97
2.03
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 -0.5
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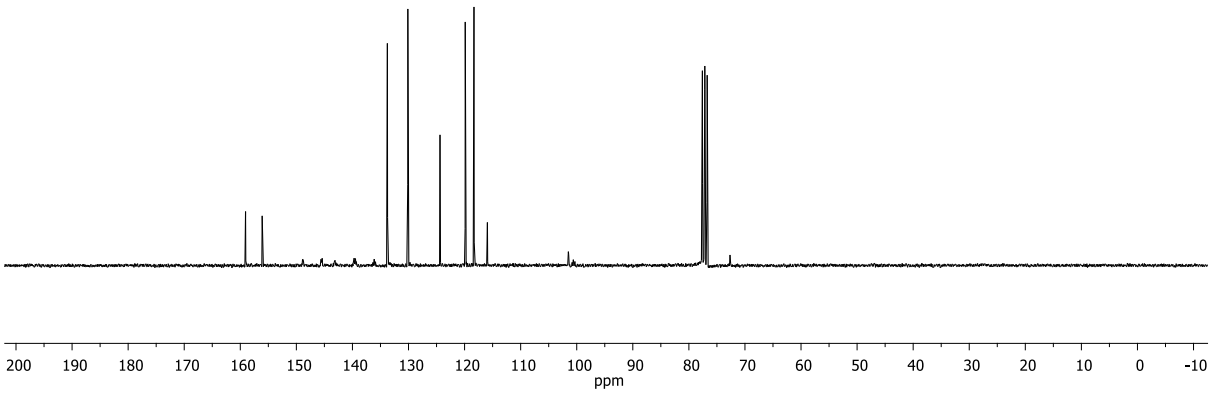
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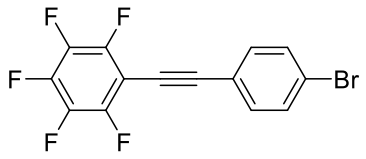
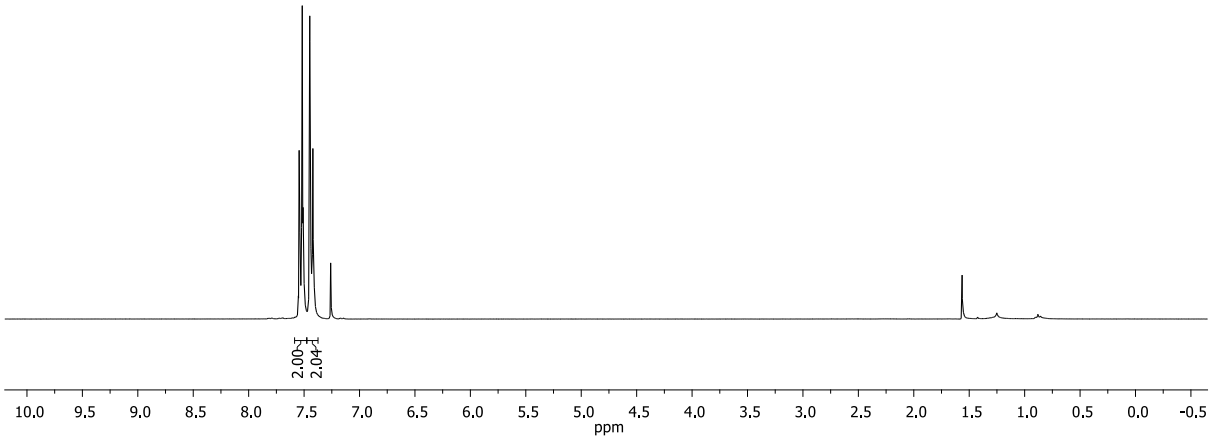
ppm


F
F
F
F
F
Br

11g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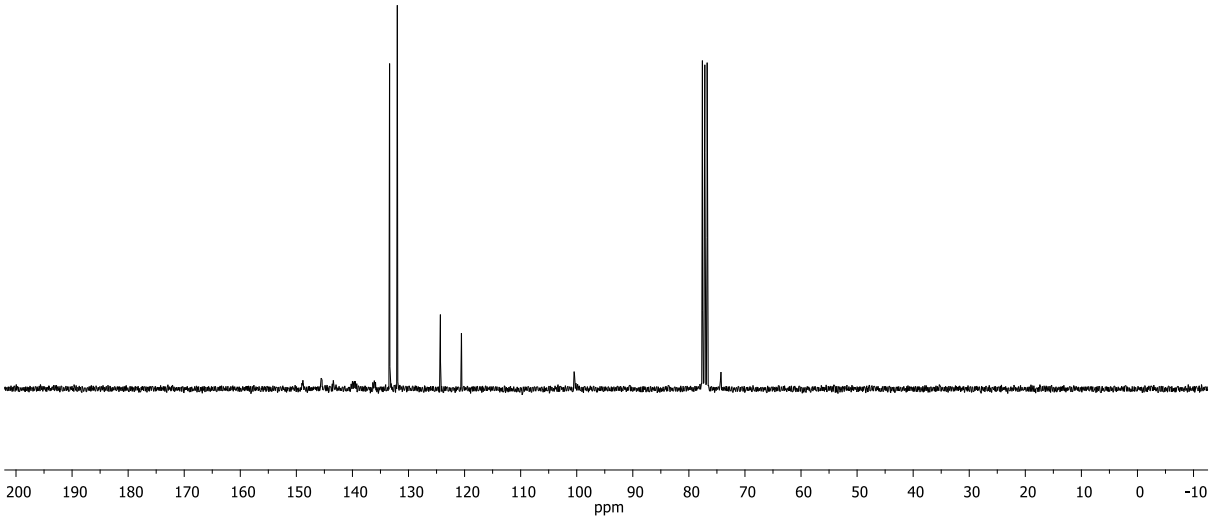
2.04
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
ppm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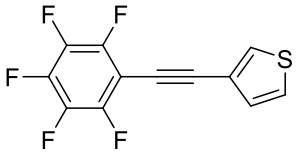
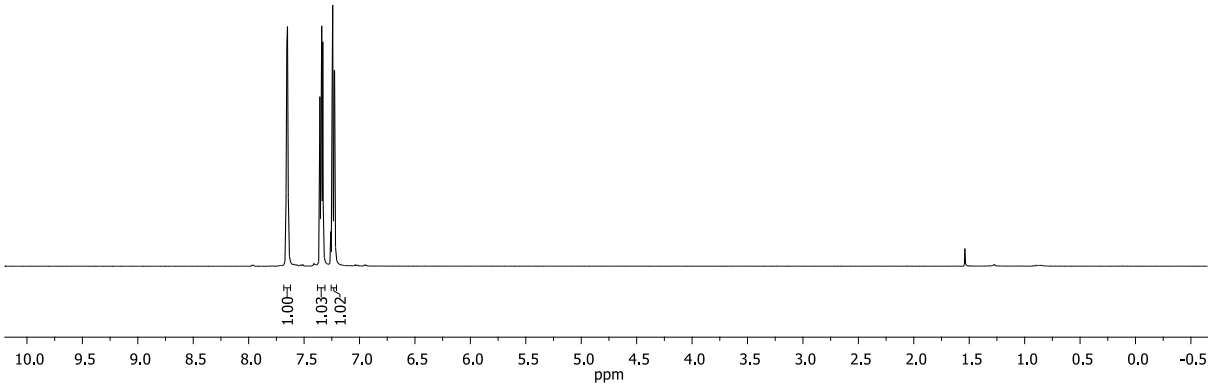
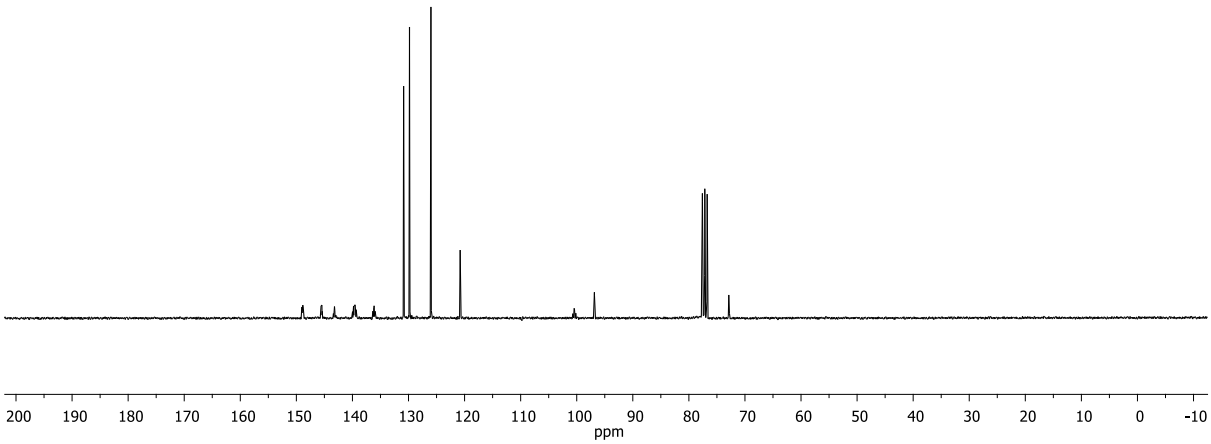
ppm


F
F
F
S
F
F

11h


1.00
1.03
1.02
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 -0.5
ppm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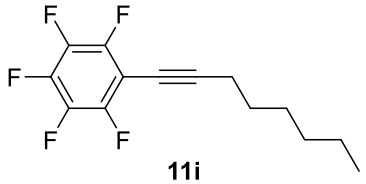
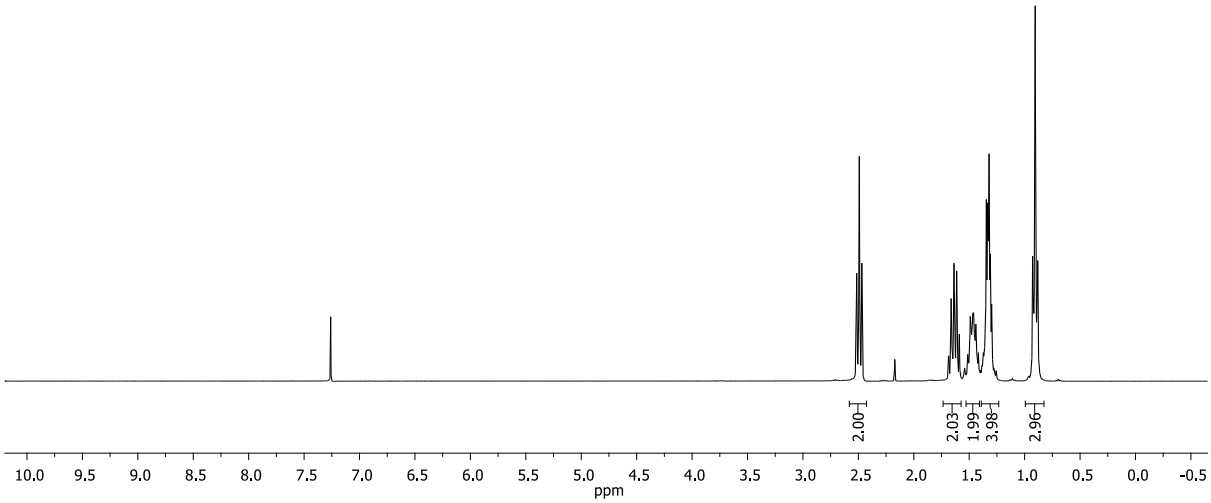
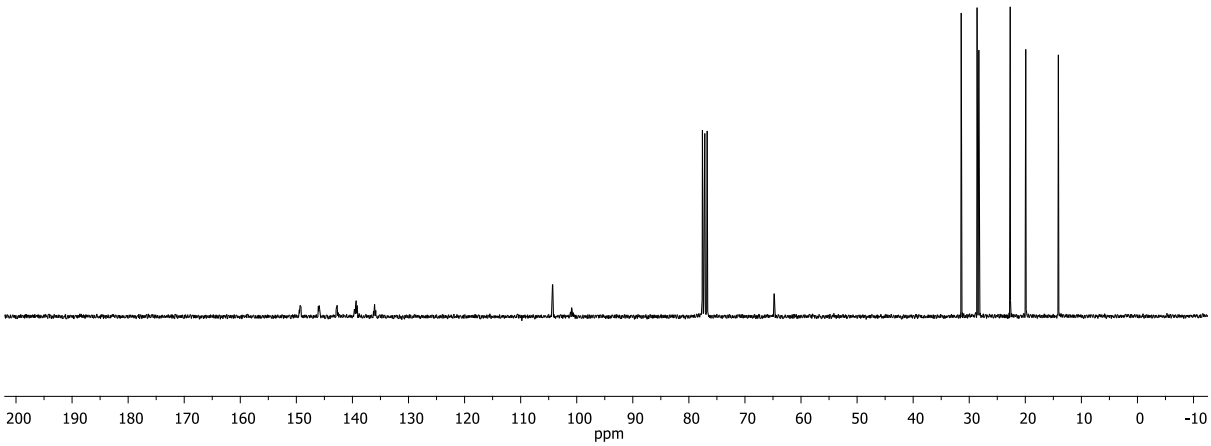
ppm



11i


2.00
2.03
1.99
3.98
2.96
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 -0.5
ppm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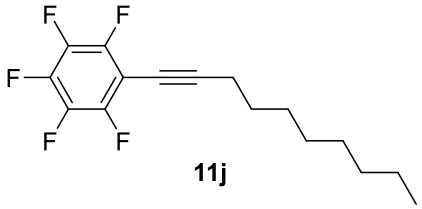
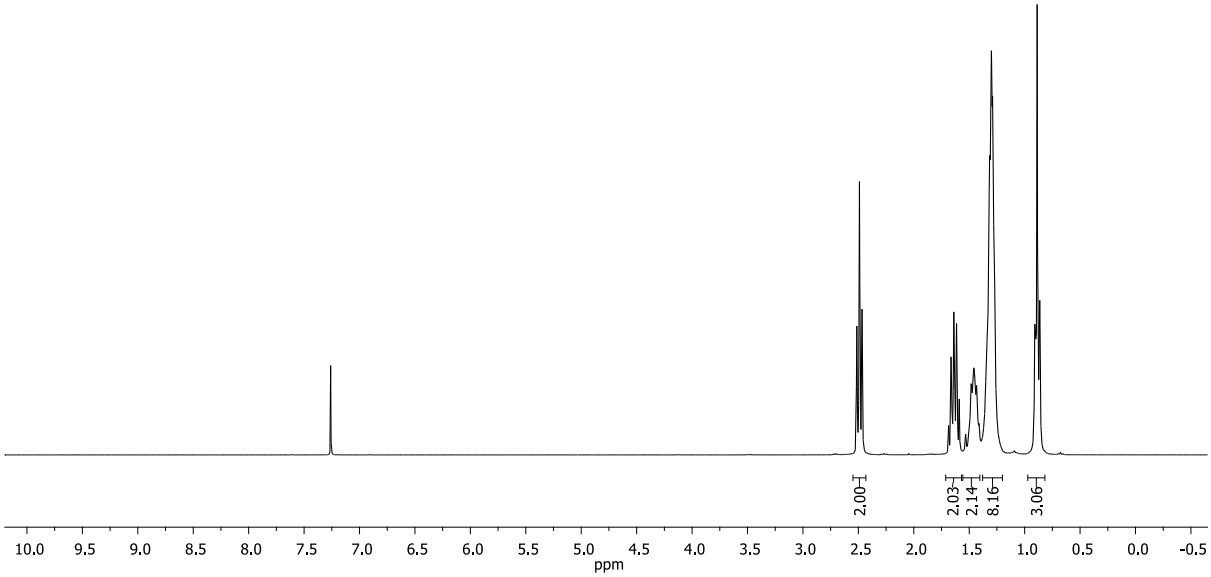
ppm


F
F
F
F
F

11j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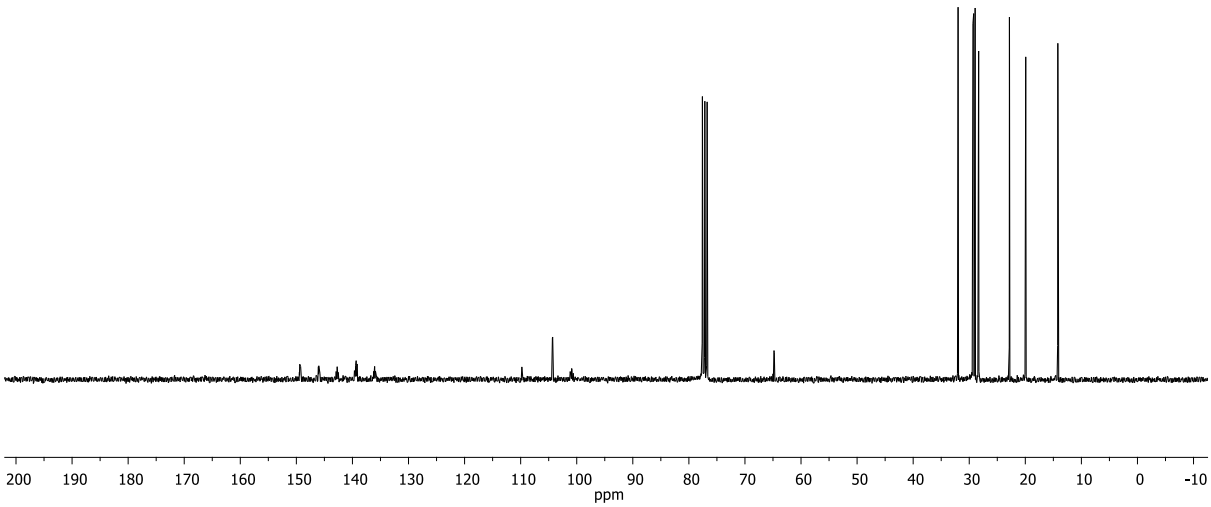
2.03
2.14
8.16
3.06
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
ppm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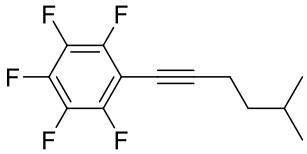
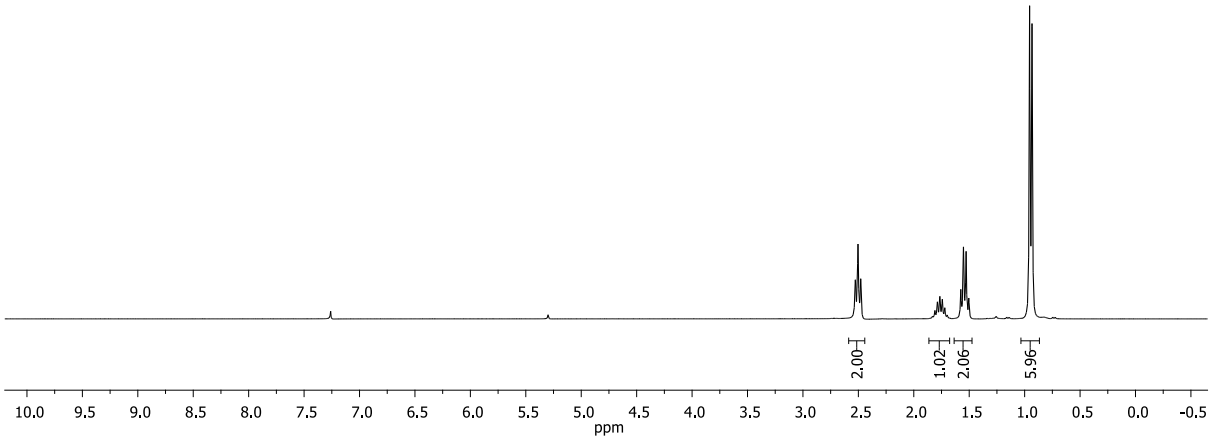
ppm


F
F
F
F
F

11k


2.00
1.02
2.06
5.96
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 -0.5
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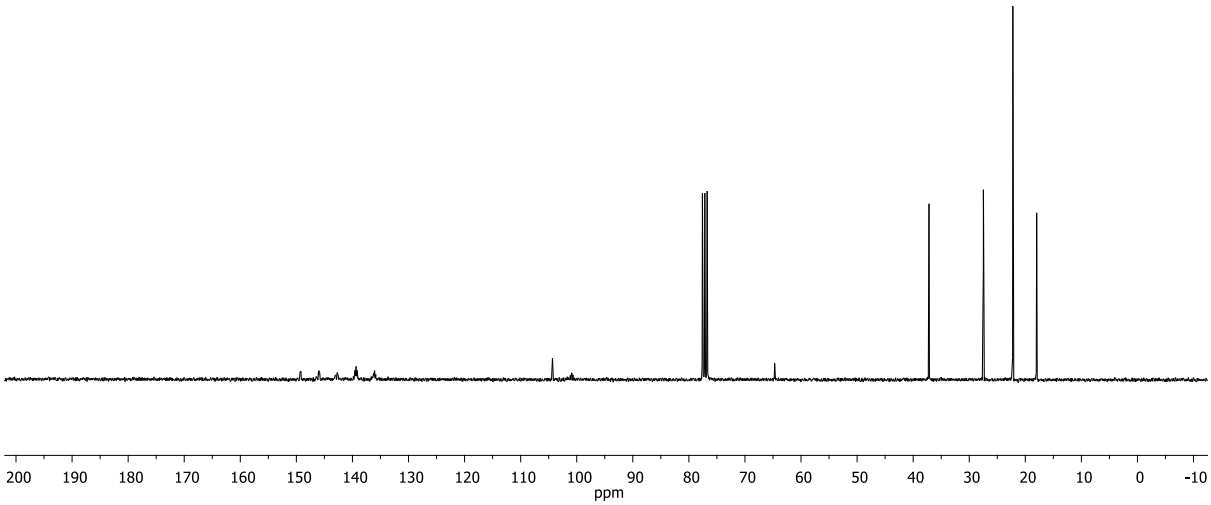
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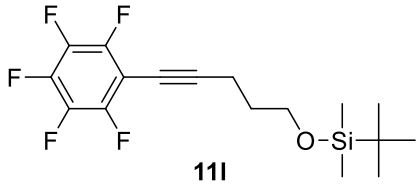
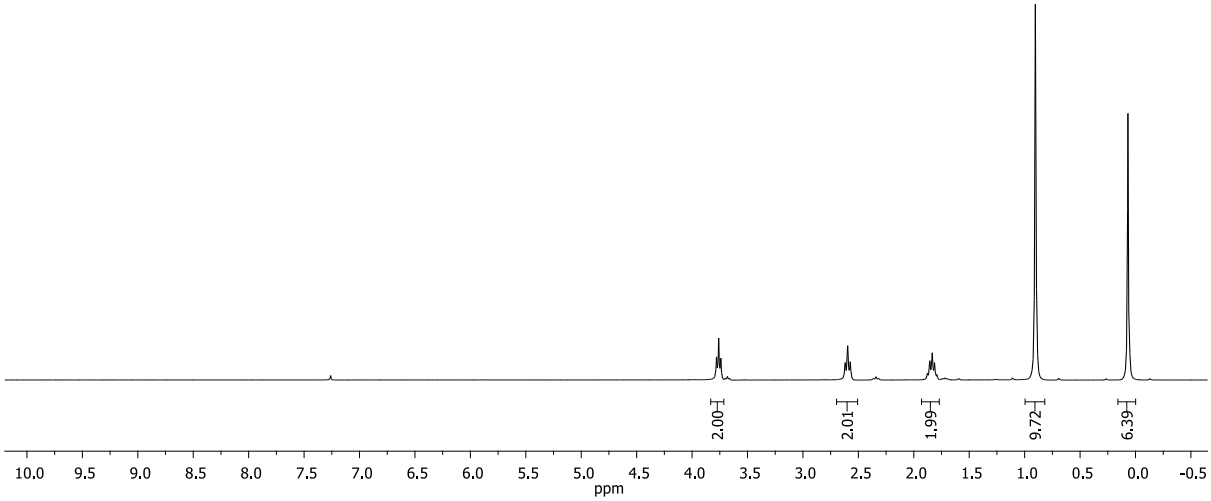
ppm


F
F
F
F
F
O
Si

11l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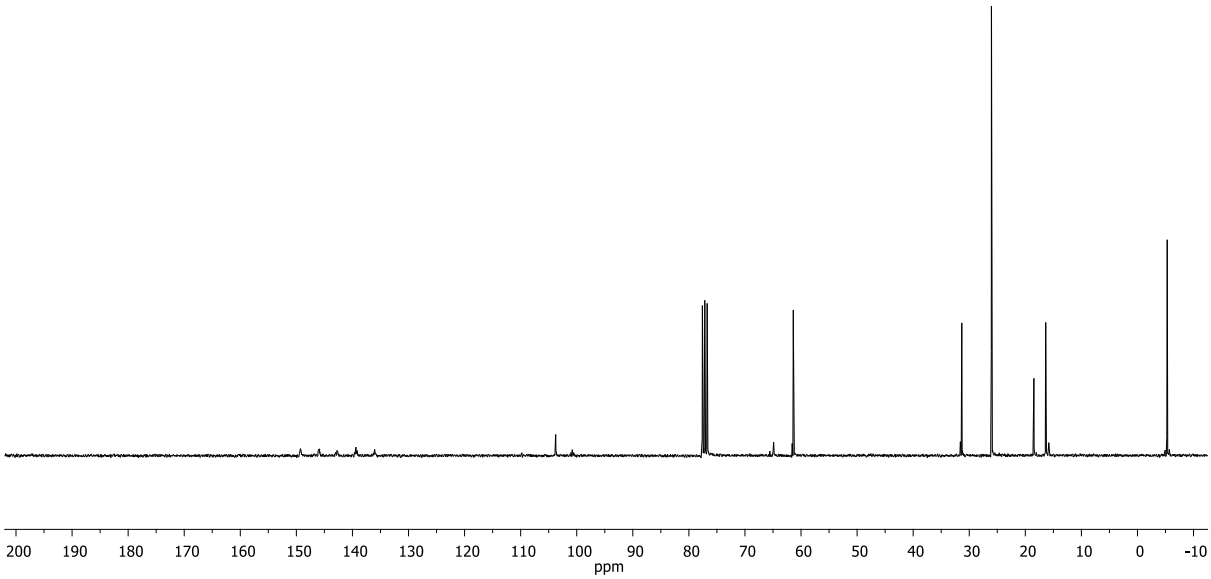
2.01
1.99
9.72
6.39
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
ppm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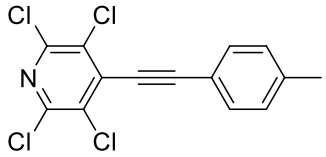
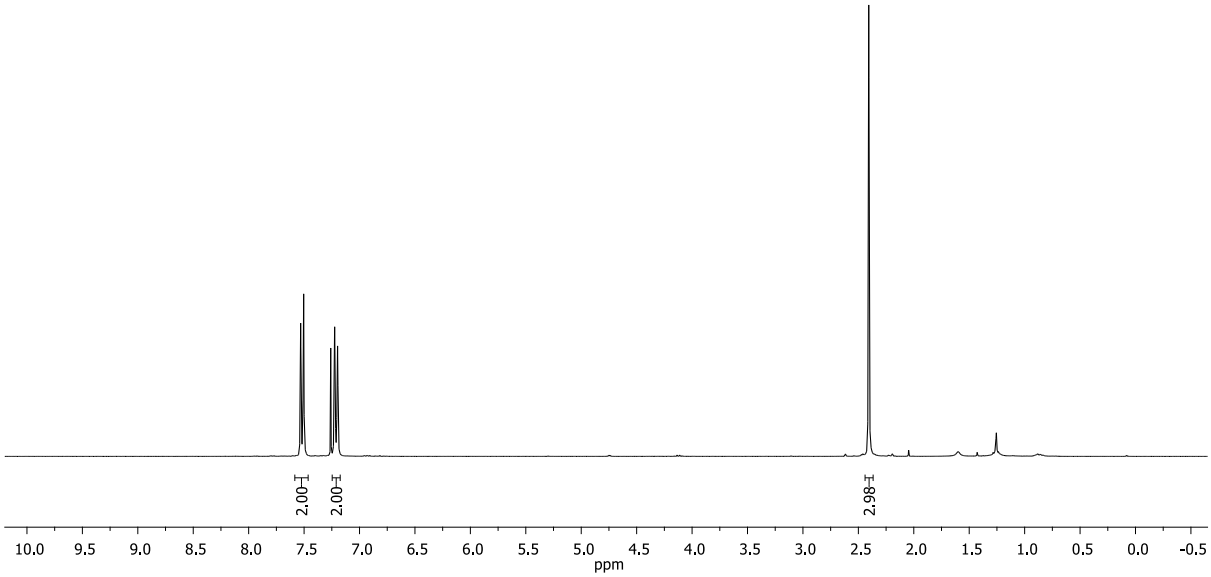
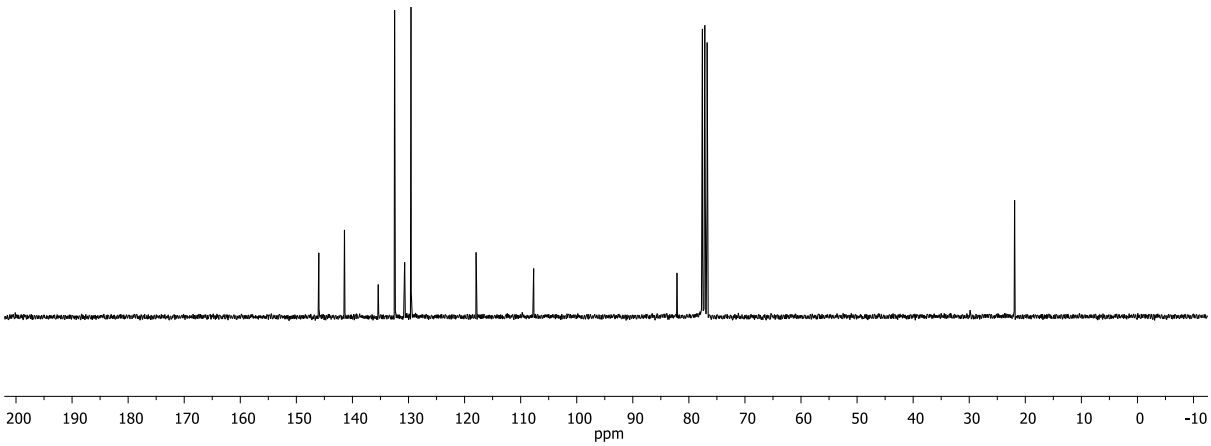
ppm


Cl
Cl
N
Cl
Cl

13a


2.00
2.00
2.98
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 -0.5
ppm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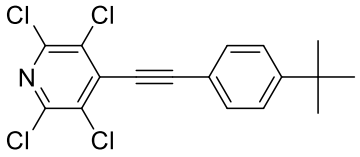
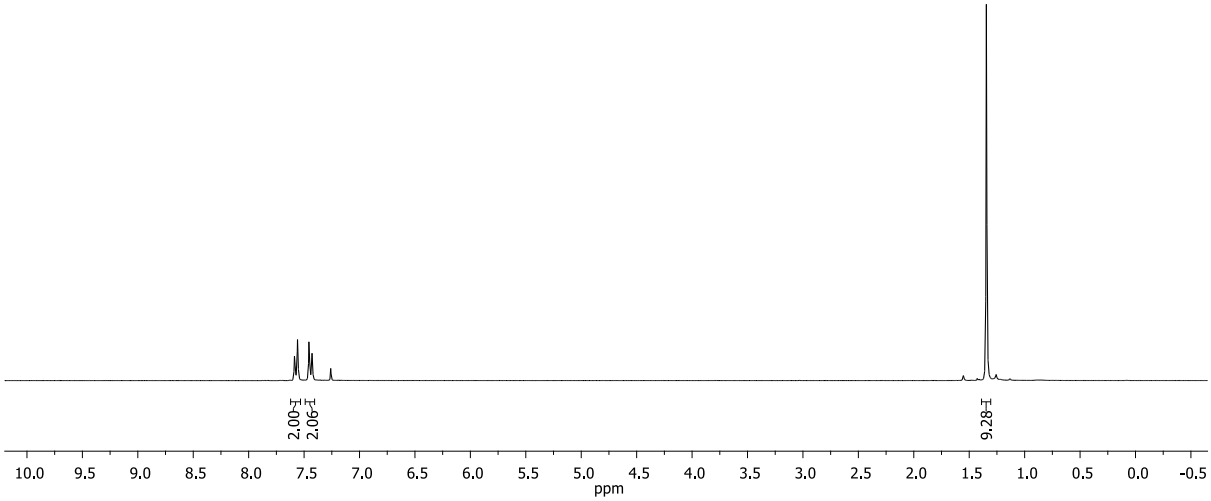
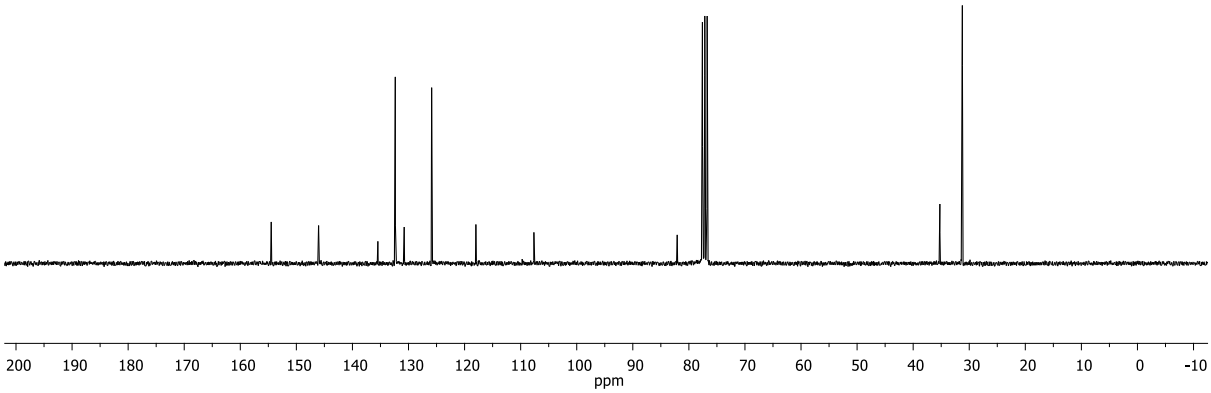
ppm


Cl
Cl
N
Cl
Cl

13b


2.00
2.06
9.28
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 -0.5
ppm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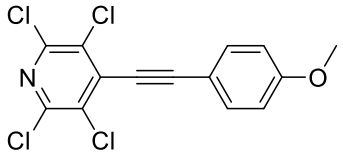
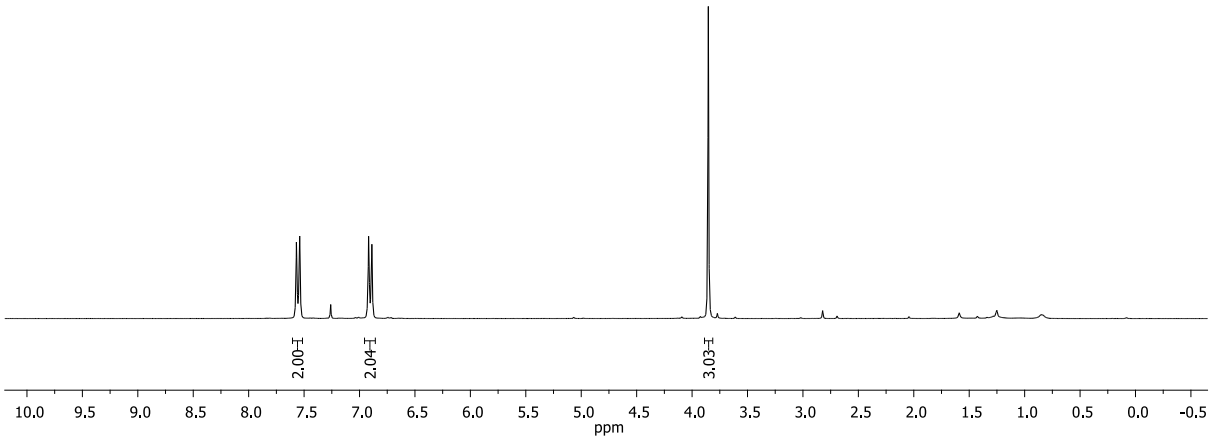
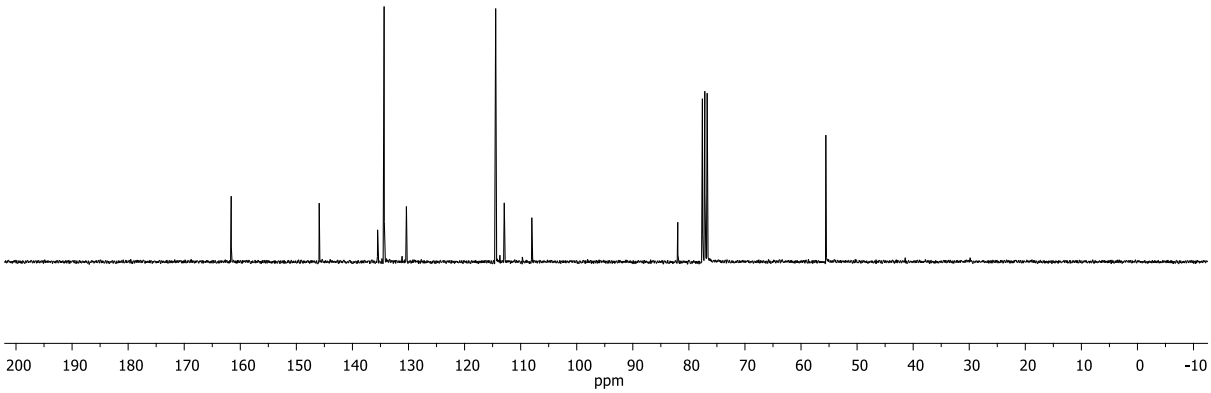
ppm


Cl
Cl
N
Cl
Cl
O

13c


2.00
2.04
3.03
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 -0.5
ppm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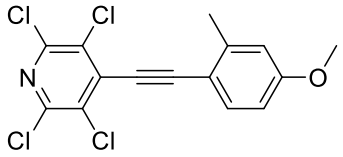
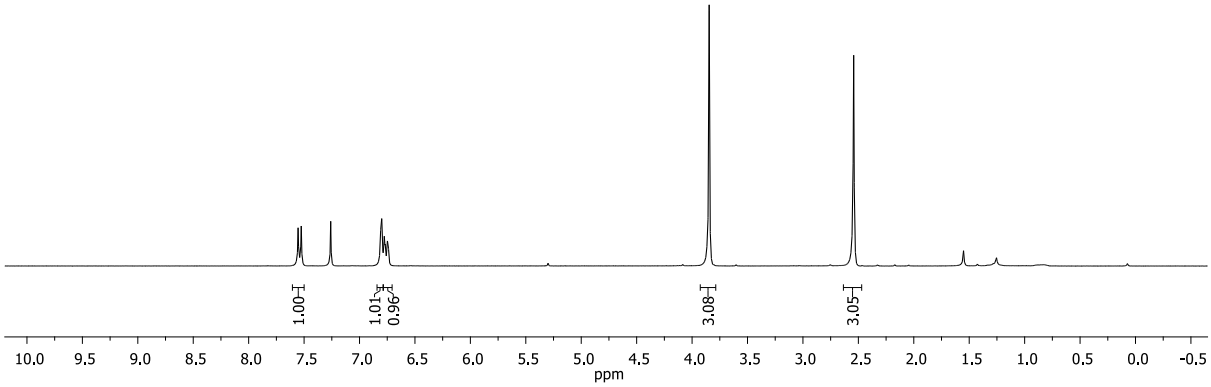
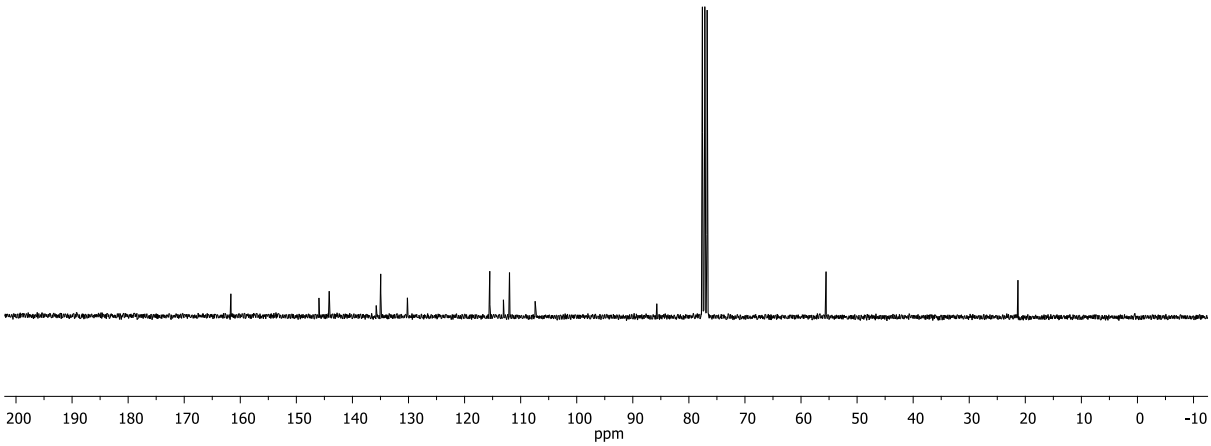
ppm


Cl
Cl
N
Cl
Cl
O

13d


1.00
1.01
0.96
3.08
3.05
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 -0.5
ppm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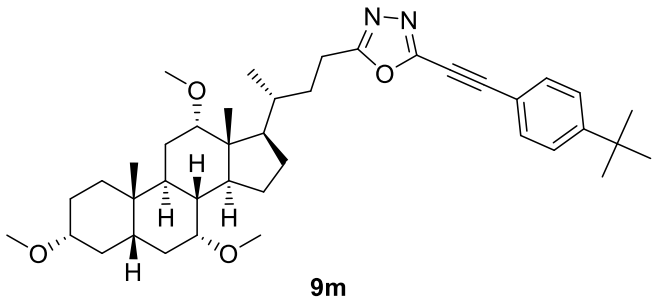
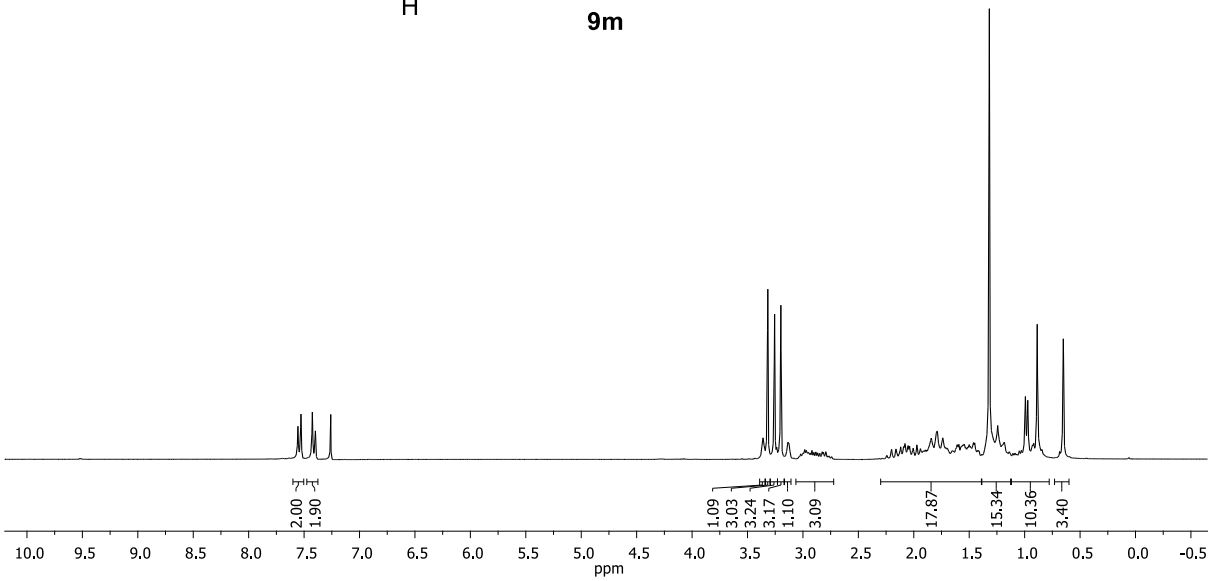
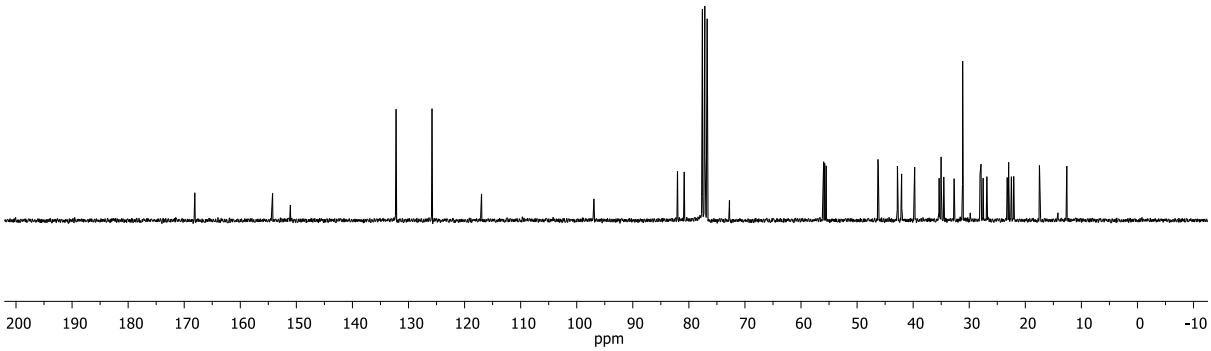
ppm


N
N
O
O
H
H
H
O
O
H

9m


2.00
1.90
1.09
3.03
3.24
3.17
1.10
3.09
17.87
15.34
10.36
3.40
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 -0.5
ppm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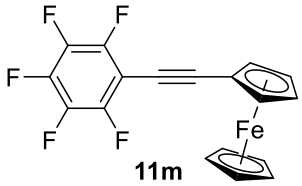
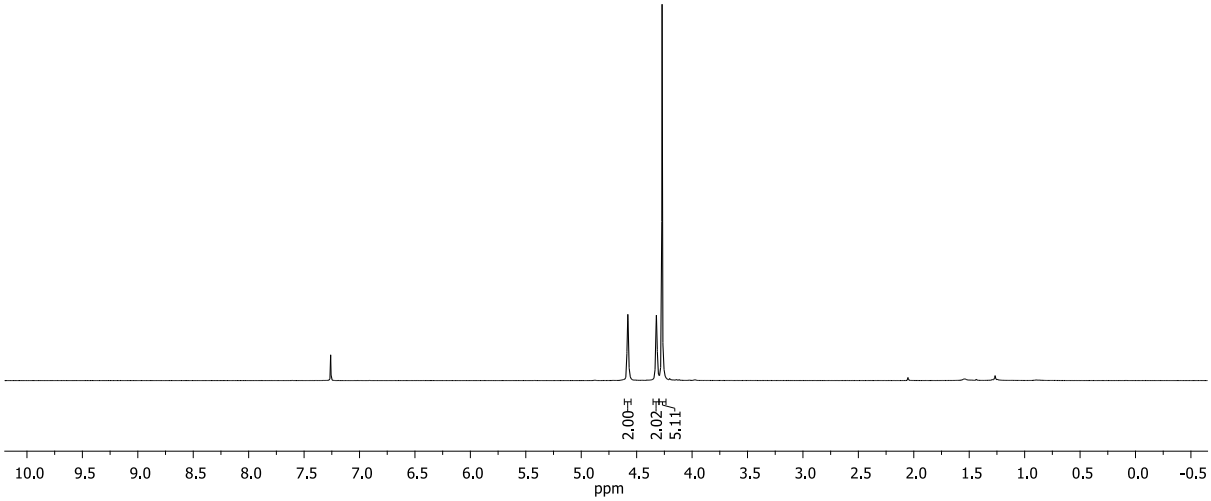
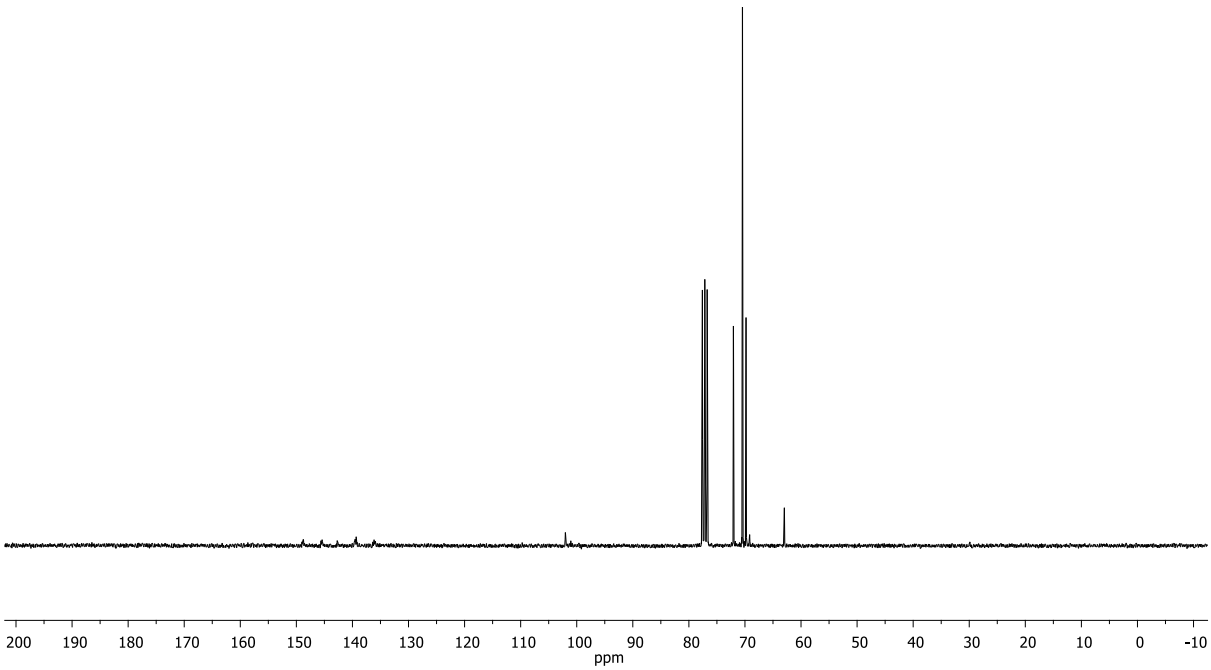
ppm


F
F
F
F
F
Fe

11m


2.00
2.02
5.11
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 -0.5
ppm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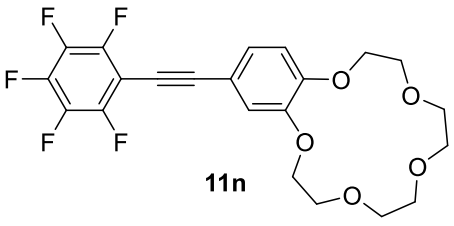
ppm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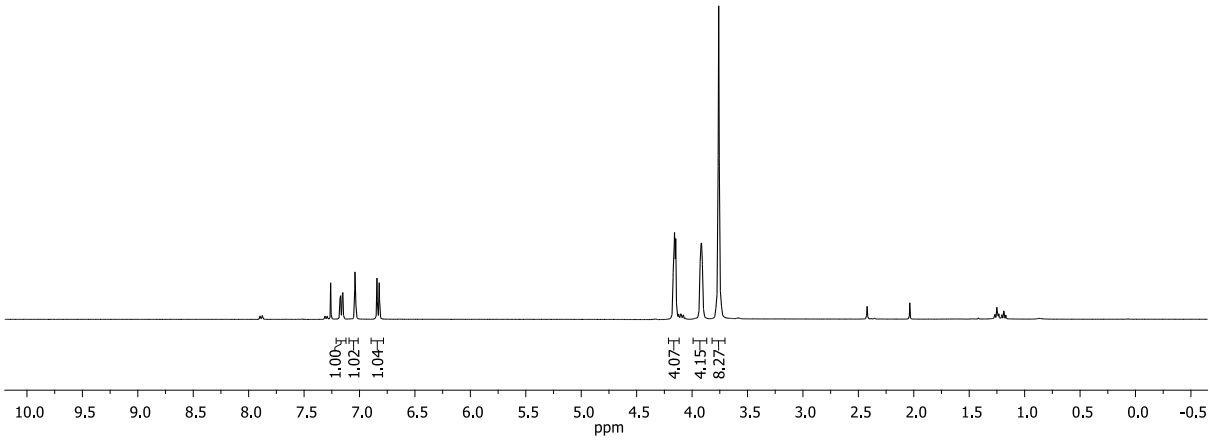
F
F
F
F
O
O
O
O
O

11n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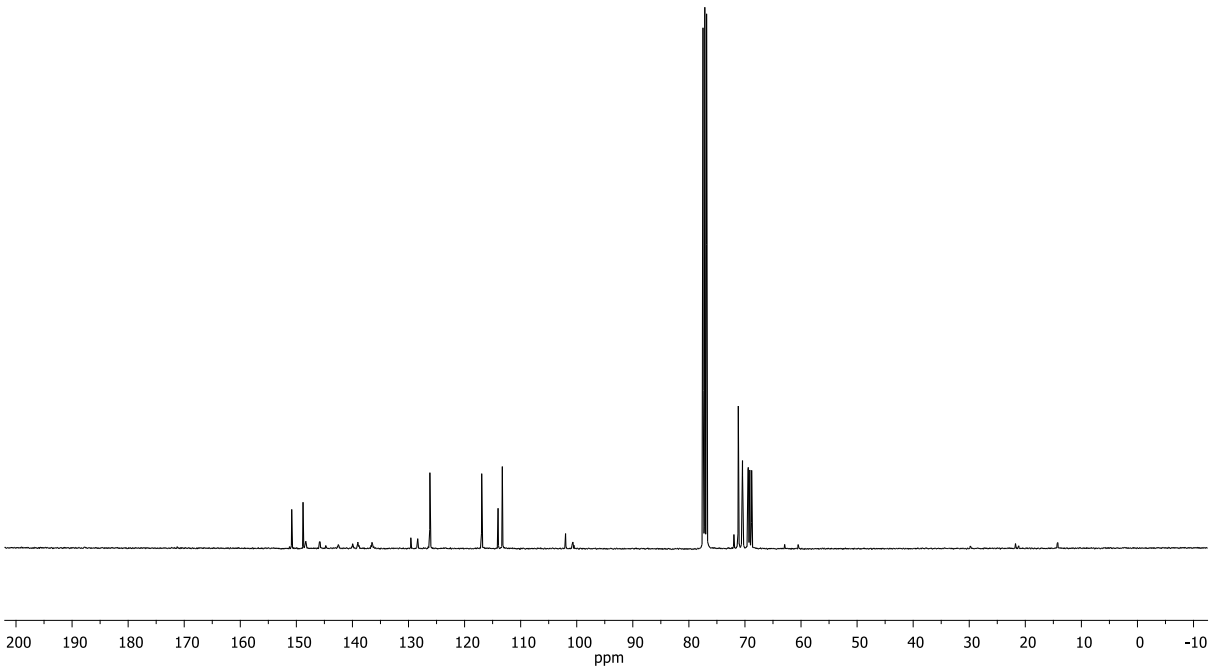
1.02
1.04
4.07
4.15
8.27
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
ppm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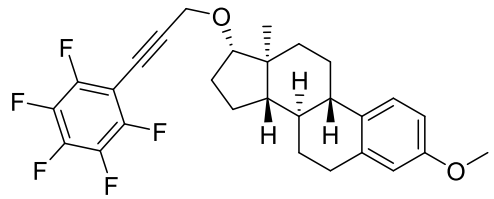
ppm


F
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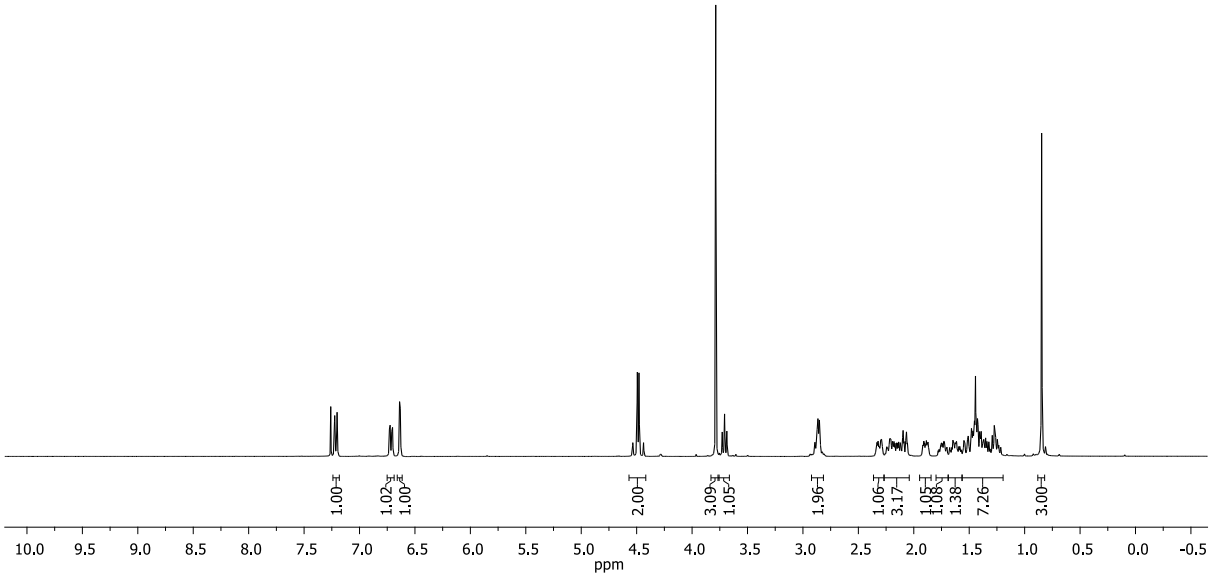
F
F
F
O
H
H
H
O

11o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2.00
3.09
1.05
1.96
1.06
3.17
1.05
1.08
1.38
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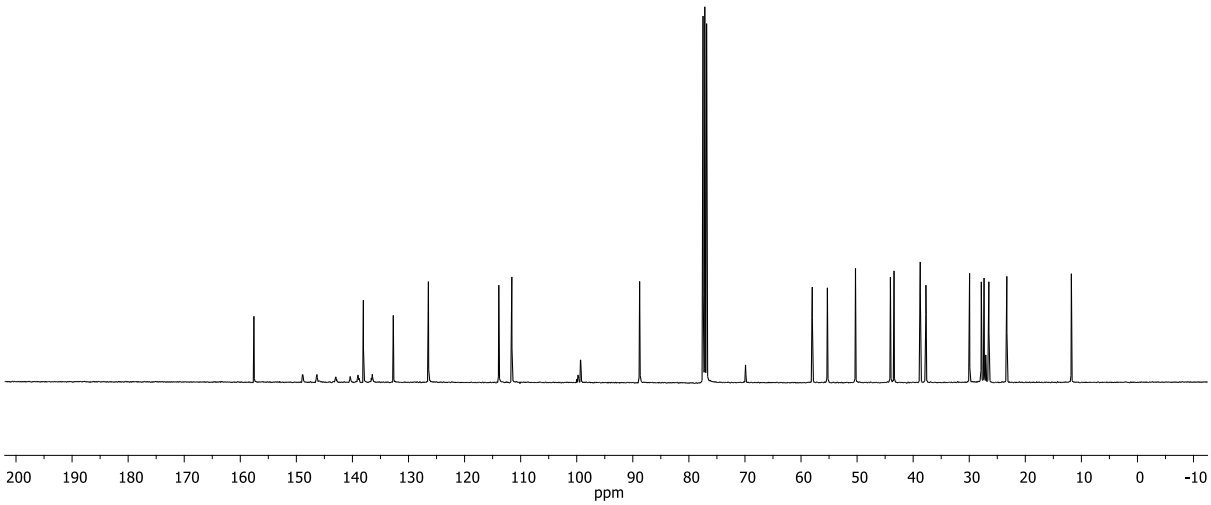
3.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
ppm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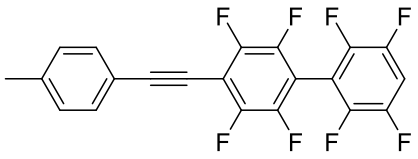
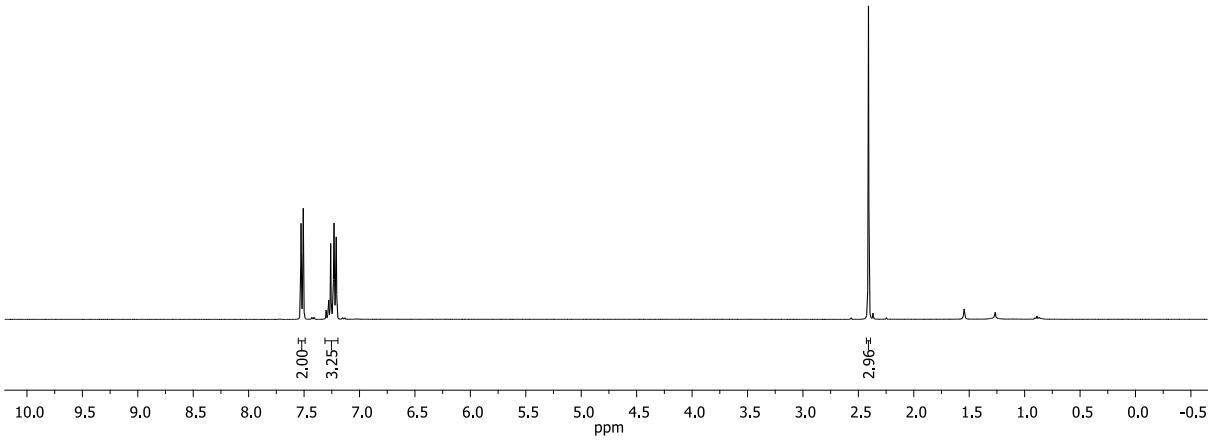
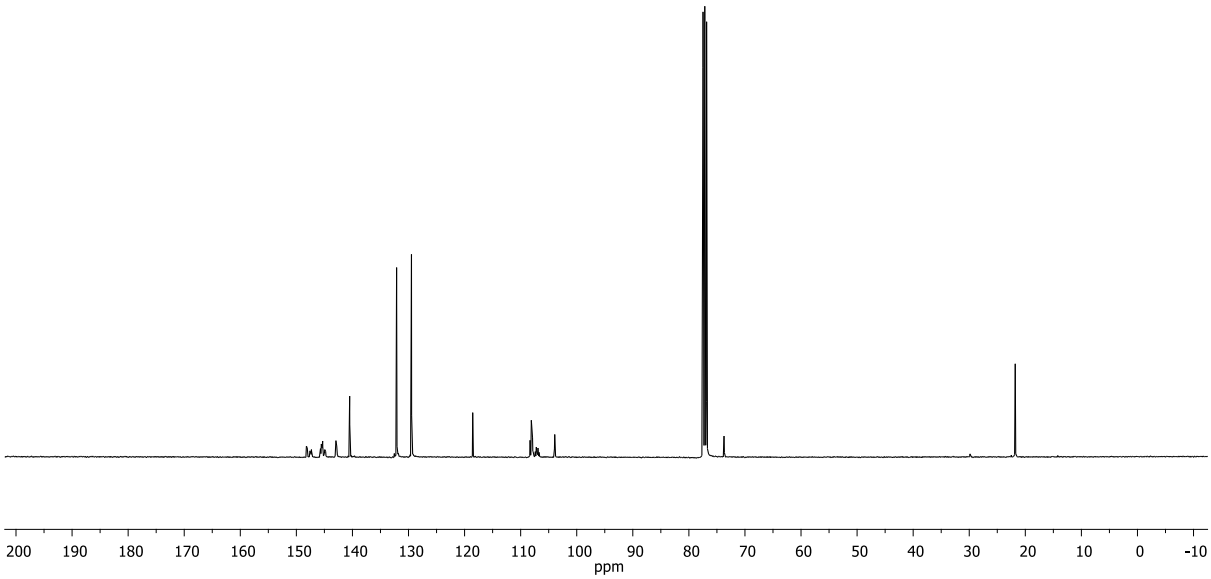
ppm



15


2.00
3.25
2.96
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 -0.5
ppm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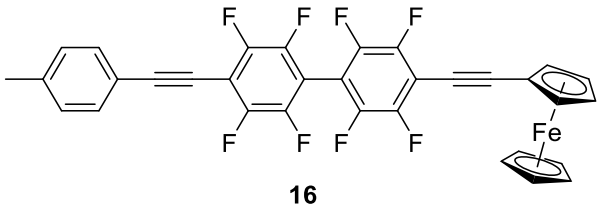
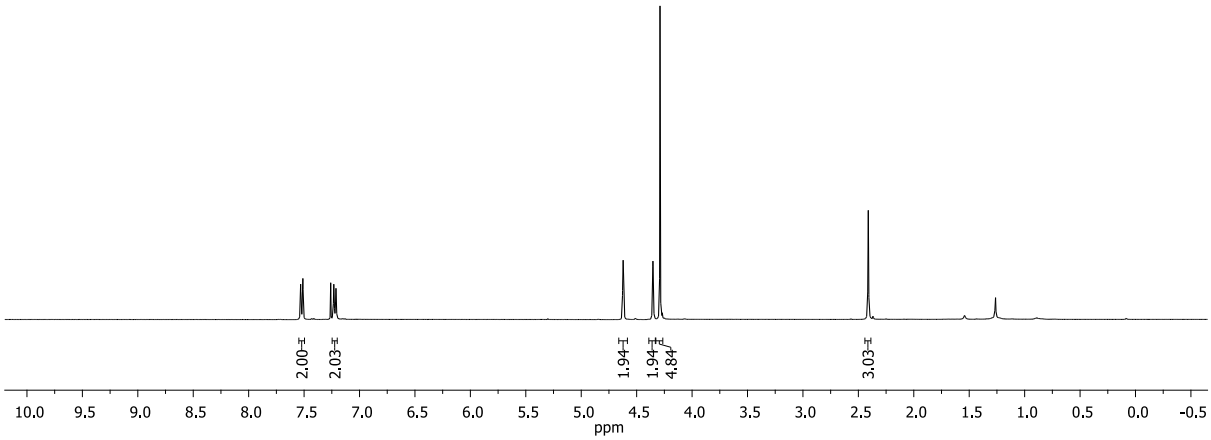
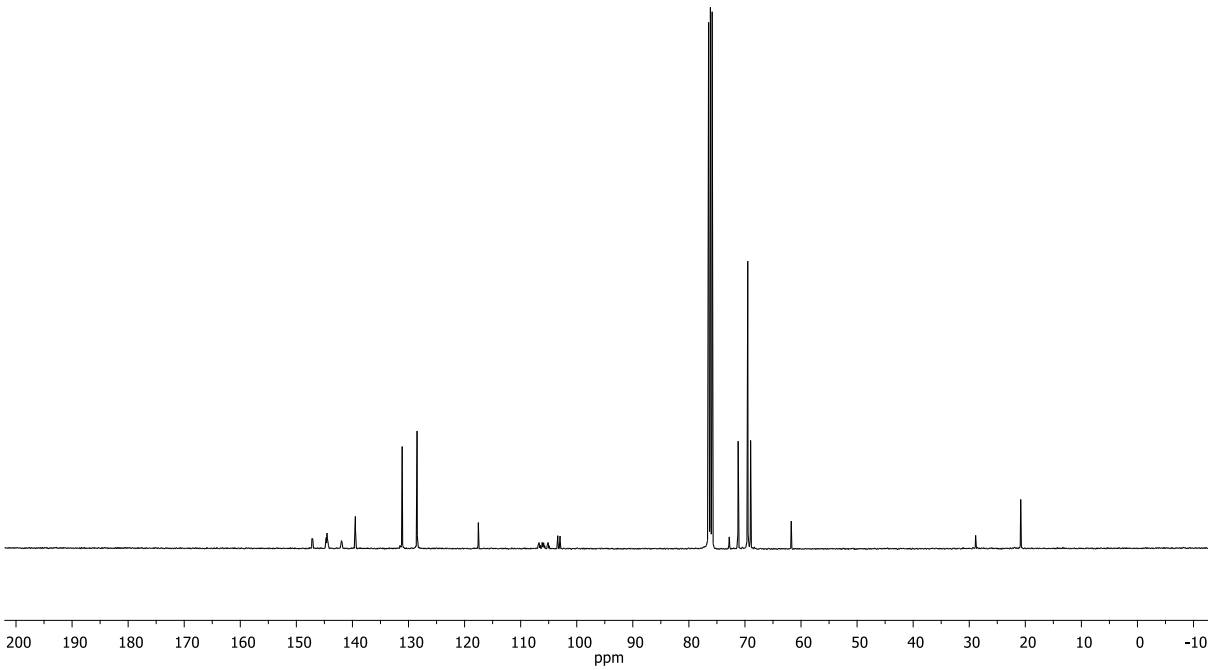
ppm


F
F
F
F
F
F
F
F
Fe

16


2.00
2.03
1.94
1.94
4.84
3.03
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 -0.5
ppm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ppm