Mild and Efficient Nickel-Catalyzed Heck Reactions with Electron-Rich Olefins

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Supporting Information

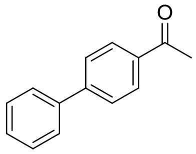
General Methods

All reactions were carried out in 7.0 mL sample vials with a teflon sealed screwcap in a glovebox under an argon atmosphere. All purchased chemicals were used as received without further purification. Solvents were dried according to standard procedures, reactions were monitored by thin-layer chromatography (TLC) analysis and flash chromatography was carried out on silica gel 60 (230-400 mesh). The chemical shifts are reported in ppm relative to solvent residual peak.[1] The ^{1}H NMR spectra were recorded at 400 MHz, ^{13}C NMR spectra were recorded at 100 MHz and ^{19}F NMR spectra were recorded at 376 MHz on a Varian Mercury 400 spectrometer. MS spectra were recorded on a LC TOF (ES) apparatus. The aryl triflates were synthesized according to known procedures.[2] The aryl sulfonates depicted in Table 3 were prepared using known procedures.[3]

General Procedure for the Ni(0)-Catalyzed Heck Reaction

Aryl sulfonate (1.0 equiv), DPPF (0.05 equiv) and Cy_2NMe (3.0 equiv) were dissolved in dioxane (3.0 mL). Vinyl ether (4.0 equiv) and $Ni(COD)_2$ (0.05 equiv) were then added and the sample vial was fitted with a Teflon sealed screwcap and removed from the glovebox. The reaction mixture was stirred at 100 °C for 20 h. Hydrolysis was performed adding 6 M HCl (3.0 mL) to the reaction mixture and stirred at room temperature for 1 h. Diethyl ether was added and the crude reaction mixture was washed twice with water and once with brine, dried over anhydrous $MgSO_4$ and filtrated. Upon concentration *in vacuo* the crude product was purified by colomn chromotography.

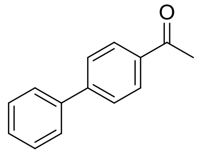
4-Acetylbiphenyl (Table 1).[4]



Flash chromatography using pentane:CH_2Cl_2 1:1 as eluent resulted in 26.4 mg (90% yield) of the title product obtained as a colorless solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.04 (d, 2H, *J* = 8.6 Hz), 7.69 (d, 2H, *J* = 8.6 Hz), 7.63 (d, 2H, *J* = 7.1 Hz), 7.48 (t, 2H, *J* = 7.1 Hz), 7.41 (t, 1H, *J* = 7.1 Hz), 2.64 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$)

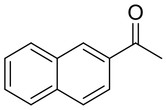
δ (ppm) 197.8, 145.9, 140.0, 136.0, 129.1, 129.0, 128.3, 127.4, 127.3, 26.8. HRMS $C_{14}H_{12}O$ [M+Na$^+$]; calculated 219.0786, found 219.0782.

4-Acetylbiphenyl (Table 4, entry 1).



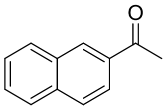
Flash chromatography using pentane:CH_2Cl_2 1:1 as eluent resulted in 89.0 mg (91% yield) of the title product obtained as a colorless solid.

2-Acetonaphthone (Table 2, entry 1).[5]



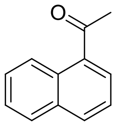
Flash chromatography using pentane:CH_2Cl_2 1:1 —> CH_2Cl_2 as eluent resulted in 77.3 mg (91% yield) of the title product obtained as a colorless solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.47 (bs, 1H), 8.04 (dd, 1H, J = 1.8, 8.6 Hz), 7.97(d, 1H, J = 8.0 Hz), 7.90-7.87 (m, 2H), 7.62-7.55 (m, 2H), 2.73 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 198.2, 135.7, 134.6, 132.6, 130.3, 129.7, 128.6, 128.5, 127.9, 126.9, 124.0, 26.8. HRMS $C_{12}H_{10}O$ [M+Na$^+$]; calculated 193.0629, found 193.0623.

2-Acetonaphthone (Table 3, entry 5).



Flash chromatography using pentane:CH_2Cl_2 1:1 —> CH_2Cl_2 as eluent resulted in 77.5 mg (91% yield) of the title product obtained as a colorless solid.

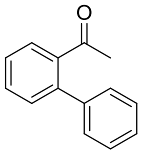
2-Acetonaphthone (Table 2, entry 2).[6]



Flash chromatography using pentane:CH_2Cl_2 1:1 —> CH_2Cl_2 as eluent resulted in 82.2 mg (97% yield) of the title product obtained as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.78 (d, 1H, J = 8.6 Hz), 7.98 (d, 1H, J = 8.2 Hz), 7.92 (d, 1H, J = 7.2 Hz), 7.87 (d, 1H, J = 8.1 Hz), 7.63-7.59 (m, 1H), 7.55-7.46 (m, 2H), 2.74 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ

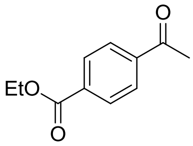
(ppm) 201.8, 135.5, 134.0, 133.1, 130.2, 128.8, 128.5, 128.1, 126.5, 126.1, 124.4, 30.0. GCMS $C_{12}H_{10}O$ [M]; calculated 170, found 170.

2-Acetylbiphenyl (Table 2, entry 3).[7]



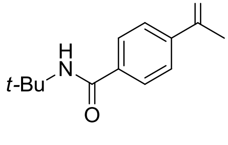
Flash chromatography using pentane:CH_2Cl_2 1:1 —> CH_2Cl_2 as eluent resulted in 86.4 mg (88% yield) of the title product obtained as a colorless oil. ^1H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.56 (dd, 1H, J = 1.2, 7.5 Hz), 7.51 (dt, 1H, J = 1.4, 7.5 Hz), 7.45-7.34 (m, 7H), 2.01 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 204.8, 140.9, 140.8, 140.5, 130.8, 130.3, 128.9, 128.7, 127.9, 127.9, 127.5, 30.5. HRMS $C_{14}H_{12}O$ [M+Na$^+$]; calculated 219.0786, found 219.0783.

Ethyl 4-acetylbenzoate (Table 2, entry 4).[8]



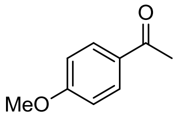
Flash chromatography using pentane:ethyl acetate 10:1 as eluent resulted in 76.5 mg (79% yield) of the title compound as a colorless solid. ^1H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.08 (dd, 2H, J = 1.6, 8.3 Hz), 7.96 (dd, 2H, J = 1.99, 8.60 Hz), 4.37 (q, 2H, J = 7.2 Hz), 2.61 (s, 3H), 1.39 (t, 3H, J = 7.2 Hz). ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 197.7, 165.9, 140.4, 134.5, 130.0, 128.4, 61.6, 27.0, 14.5. HRMS $C_{11}H_{12}O_3$ [M+Na$^+$]; calculated 215.0684, found 215.0691.

4-Acetyl-*N*-(*tert*-butyl)benzamide (Table 2, entry 5).[9]



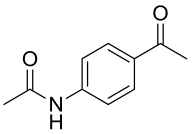
Flash chromatography using CH_2Cl_2:ether 10:1 as eluent resulted in 98.1 mg (90% yield) of the title compound as a colorless solid. ^1H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.87 (dd, 2H, J = 1.9, 8.6 Hz), 7.75 (dd, 2H, J = 1.9, 8.6 Hz), 2.52 (s, 3H), 1.42 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 197.7, 116.2, 140.0, 138.9, 128.5, 127.3, 52.1, 28.9, 26.9. HRMS $C_{13}H_{17}NO_2$ [M+Na$^+$]; calculated 242.1157, found 242.1157.

4'-Methoxyacetophenone (Table 2, entry 6).[10]



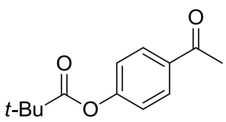
Flash chromatography using CH_2Cl_2 as eluent resulted in 69.8 mg (93% yield) as a colorless solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.94 (d, 2H, J = 9.2 Hz), 6.93 (d, 2H, J = 9.2 Hz,), 3.87 (s, 3H), 2.55 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 196.9, 163.7, 130.7, 130.5, 113.9, 55.6, 26.5. HRMS $C_9H_{10}O_2$ [M+Na$^+$]; calculated 173.0578, found 173.0577.

N-(4-Acetylphenyl)acetamide (Table 2, entry 7).[11]



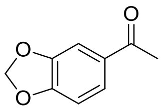
Flash chromatography using CH_2Cl_2:ethyl acetate 5:1 as eluent resulted in 46 mg (56% yield) of the title compound obtained as a colorless solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.97 (bs, 1H), 7.92 (d, 2H, J = 8.5 Hz), 7.63 (d, 2H, J = 8.5 Hz), 2.57 (s, 3H), 2.21 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 197.3, 169.1, 142.7, 130.0, 129.4, 119.1, 26.7, 24.9. HRMS $C_{10}H_{11}NO_2$ [M+Na$^+$]; calculated 200.0687, found 200.0687.

4-Acetylphenyl pivalate (Table 2, entry 8).



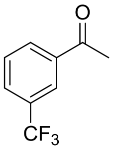
Flash chromatography using ethyl acetate:pentane 1:20 resulted in 91.3 mg (83% yield) of the title compound as a colorless solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.99 (dd, 2H, J = 2.6, 9.5 Hz,), 7.16 (dd, 2H, J = 2.6, 9.5 Hz), 2.60 (s, 3H), 1.37 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 197.1, 176.7, 155.1, 134.8, 130.1, 121.9, 39.4, 27.3, 26.8. HRMS $C_{13}H_{16}O_3$ [M+H$^+$]; calculated 221.1178, found 221.1179.

3',4'-(Methylenedioxy)acetophenone (Table 2, entry 9).[6]



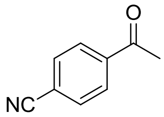
Flash chromatography using CH_2Cl_2 as eluent resulted in 62.9 mg (77% yield) of the desired product obtained as a colorless solid. ^1H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.53 (d, 1H, J = 8.1 Hz), 7.41 (s, 1H), 6.83 (d, 1H, J = 8.1 Hz), 6.02 (s, 2H), 2.52 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 196.2, 151.9, 148.3, 132.2, 124.8, 108.0, 107.9, 101.9, 26.5. HRMS $C_9H_8O_3$ [M+Na$^+$]; calculated 187.0371, found 187.0375.

3'-Trifluoromethylacetophenone (Table 2, entry 10).[12]



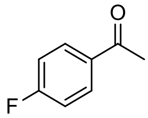
Flash chromatography using pentane:CH_2Cl_2 3:2 as eluent resulted in 75.8 mg (81% yield) of the title product obtained as a colorless oil. ^1H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.21 (s, 1H), 8.14 (d, 1H, J = 7.8 Hz), 7.49 (d, 1H, J = 7.8), 7.62 (t, 1H, J = 7.8 Hz), 2.65 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 196.7, 137.7, 131.6, 131.3, 129.7, 129.4, 125.2, 123.8 (q, J = 270.5 Hz), 26.7. ^{19}F NMR (376 MHz, $CDCl_3$) δ (ppm) -63.3. GCMS $C_9H_7F_3O$ [M]; calculated 118, found 118.

4-Acetylbenzonitrile (Table, 2, entry 11).[6]



Flash chromatography using pentane:diethyl ether 2:1 as eluent resulted in 56.7 mg (78% yield) of the title product obtained as a colorless solid. ^1H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.02 (d, 2H, J = 8.6 Hz), 7.75 (d, 2H, J = 8.6 Hz), 2.62 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 196.6, 140.0, 132.6, 128.7, 118.0, 116.4, 26.8.

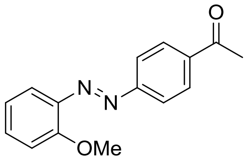
4’-Fluoroacetophenone (Table 2, entry 12).[6]



Flash chromatography using CH_2Cl_2:pentane: ethyl acetate 1:20:1 resulted in 53.8 mg (78 % yield) of the title compound as a colorless oil. ^1H NMR (400 MHz, $CDCl_3$) δ

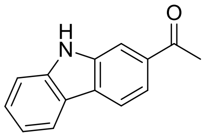
(ppm) 8.01-7.96 (m, 2H), 7.16-7.10 (m, 2H), 2.52 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 196.4, 165.7 (d, J = 254.4 Hz), 133.9 (d, J = 3.1 Hz), 130.9 (d, J = 9.1 Hz), 115.3 (d, J = 22.3 Hz), 26.5. ^{19}F NMR (376 MHz, $CDCl_3$) δ (ppm) -105.4. HRMS C_8H_7FO [M+H$^+$]; calculated 139.0559, found 139.0552.

(*E*)-1-(4-((2-Methoxyphenyl)diazenyl)phenyl)ethanone (Table 2, entry 13).



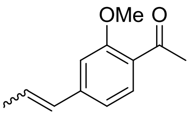
Flash chromatography using ethyl acetate:pentane 1:3 as eluent resulted in 95.4 mg (75% yield) of the title product obtained as a red solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.08 (d, 2H, J = 8.9 Hz), 7.94 (d, 2H, J = 8.1 Hz) 7.69 (dd, 1H, J = 1.8, 8.9 Hz), 7.47 (ddd, 1H, J = 1.8, 7.3, 8.9 Hz), 7.10 (dd, 1H, J = 0.5, 8. 9 Hz), 7.02 (dd, 1H, J = 0.5, 7.98 Hz), 4.02 (s, 3H), 2.63 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 197.8, 157.7, 155.8, 142.4, 138.3, 133.7, 129.6, 123.2, 121.0, 117.1, 118.1, 56.5, 27.1; HRMS $C_{15}H_{14}N_2O_2$ [M+Na$^+$]; calculated 277.0953, found 277.0955.

2-Acetylcarbazole (Table 2, entry 14).[13]



Flash chromatography using ether:CH_2Cl_2 1:100 as eluent resulted in 80 mg (76% yield) of the title compound as a colorless solid. ^{1}H NMR (400 MHz, DMSO) δ (ppm) 11.54 (bs, 1H), 8.20 (d, 1H, J = 8.1 Hz), 8.17 (d, 1H, J = 8.6 Hz), 8.09 (d, 1H, J = 1.2 Hz), 7.77 (dd, 1H, J = 1.2, 8.1 Hz), 7.55 (d, 1H, J = 8.1 Hz), 7.46 (dd, 1H, J = 7.6, 8.1 Hz), 7.19 (dd, 1H, J = 7.6, 8.6 Hz), 2.66 (s, 3H). ^{13}C NMR (100 MHz, DMSO) δ (ppm) 197.8, 141.3, 139.2, 134.1, 127.0, 126.1, 121.6, 121.1, 120.0, 119.1, 118.7, 111.4, 111.3, 26.9. HRMS $C_{14}H_{11}NO$ [M+Na$^+$]; calculated 232.0738, found 232.0735.

(E/Z)-1-(2-Methoxy-4-(prop-1-en-1-yl)phenyl)ethanone (Table 2, entry 15).



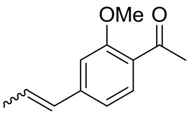
Flash chromatography using pentane:CH_2Cl_2: ether 12:3:1 as eluent resulted in 91.9 mg (97% yield) of the title compound as a colorless solid.

Major isomer (*E*): ^{1}H NMR (400 MHz, C_6D_6) δ (ppm) *inter alia* 8.02 (d, 1H, *J* = 8.0 Hz), 6.79 (d, 1H, *J* = 8.0 Hz), 6.50 (s, 1H), 6.13 (dd, 1H, *J* = 1.4, 15.8 Hz) 6.03-5.93 (m, 1H), 3.14 (s, 3H), 2.49 (s, 3H), 1.60 (dd, 3H, *J* = 1.4, 6.5 Hz).

Minor isomer (*Z*): ^{1}H NMR (400 MHz, C_6D_6) δ (ppm) *inter alia* 8.0 (d, 1H, *J* = 8.0 Hz,), 6.77 (d, 1H, *J* = 8.0 Hz), 6.50 (s, 1H), 6.26 (dd, 1H, *J* = 1.8, 11.6 Hz) 5.62 (dq, 1H, *J* = 7.1, 11.6 Hz), 3.10 (s, 3H), 2.48 (s, 3H), 1.78 (dd, 3H, *J* = 1.8, 7.1 Hz).

Both Isomers: ^{13}C NMR (100 MHz, C_6D_6) δ (ppm) 196.8, 159.5, 159.1, 143.4, 143.1, 131.2, 130.8, 129.6 (2C), 121.3, 118.2, 112.1, 109.2, 54.7, 31.8, 18.4, 14.6. HRMS $C_{12}H_{14}O_2$ [M+Na$^+$] calculated 213.0891, found 213.0889.

(E/Z)-1-(2-Methoxy-4-(prop-1-en-1-yl)phenyl)ethanone (Table 2, entry 16).



Flash chromatography using CH_2Cl_2 as eluent resulted in 87.4 mg (92% yield) of the title compound as a colorless solid.

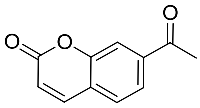
(*Z*)-Isomer: ^{1}H NMR (400 MHz, C_6D_6) δ (ppm) *inter alia* 7.99 (d, 1H, *J* = 7.5 Hz,), 6.26 (dd, 1H, *J* = 1.8, 11.6 Hz), 5.62 (dq, 1H, *J* = 7.2, 11.6 Hz), 3.11 (s, 3H), 2.48 (s, 3H), 1.62 (dd, 3H, *J* = 1.8, 7.2 Hz).

(E)-Isomer: ^{1}H NMR (400 MHz, C_6D_6) δ (ppm) *inter alia* 8.02 (d, 1H, *J* = 7.5 Hz), 6.13 (dd, 1H, *J* = 1.2, 15.7 Hz), 5.99 (dq, 1H, *J* = 6.5, 15.7 Hz), 3.16 (s, 3H), 2.48 (s, 3H), 1.60 (dd, 3H, *J* = 1.2, 6.5).

Allyl-Isomer: ^{1}H NMR (400 MHz, C_6D_6) δ (ppm) *inter alia* 7.96 (d, 1H, *J* = 7.9 Hz), 6.57 (d, 1H, *J* = 7.9), 6.39 (s, 1H), 5.80-5.69 (m, 1H), 4.50-4.90 (m, 2H), 3.13 (s, 3H), 3.06 (d, 2H, *J* = 6.6 Hz), 2.47 (s, 3H).

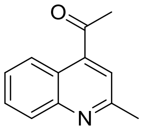
All Isomers: ^{13}C NMR (100 MHz, C_6D_6) δ (ppm) 197.0, 196.8, 159.5, 159.3, 159.1, 146.2, 143.4, 143.1, 136.6, 132.6, 131.2, 131.0, 130.9, 130.7, 129.6, 128.6, 126.9, 126.7, 121.3, 121.1, 118.2, 116.2, 112.1, 111.8, 109.2, 54.7, 40.3, 31.8, 31.7, 18.4, 14.6.

7-Acetyl-2*H*-chromen-2-one (Table 2, entry 17).



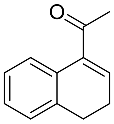
Flash chromatography using diethyl ether:pentane:CH_2Cl_2 2:2:1 as eluent resulted in 73.0 mg (78% yield) of the title product obtained as a colorless solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.82-7.79 (m, 2H), 7.73 (d, 1H, *J* = 9.5 Hz), 7.56 (d, 1H, *J* = 7.9 Hz), 6.48 (d, 1H, *J* = 9.5 Hz), 2.61 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 196.5, 160.1, 153.9, 142.5, 139.3, 128.3, 122.2, 118.9, 116.7, 26.9. HRMS $C_{11}H_{18}O_3$ [M+Na$^+$]; calculated 211.0371, found 211.0366.

4-Acetyl-2-methylquinoline (Table 2, entry 18).



Flash chromatography using diethyl ether:CH_2Cl_2 1:20 as eluent followed by recrystallization from CH_2Cl_2 and pentane at -18 °C resulted in 51.7 mg (56% yield) of the title product obtained as a colorless solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.33 (dd, 1H, *J* = 0.8, 8.5 Hz), 8.02 (dd, 1H, *J* = 0.7, 8.5 Hz), 7.70-7.66 (m, 1H), 7.54-7.50 (m, 1H), 7.44 (s, 1H), 2.76 (s, 3H), 2.68 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 201.5, 158.5, 148.9, 143.1, 129.9, 129.2, 127.4, 125.3, 122.0, 120.8, 30.1, 25.4. GCMS $C_{12}H_{11}NO$ [M]; calculated 185, found 185.

4-Acetyl-1,2-dihydronaphthalene (Table 2, Entry 19).



Flash chromatography using pentane:CH_2Cl_2 1:1 —> CH_2Cl_2 as eluent resulted in 57.9 mg (67% yield) of the title product obtained as a pale yellow oil. ^1H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.70 (d, 1H, J = 7.8 Hz), 7.25-7.15 (m, 3H), 7.01 (t, 1H, J = 4.9 Hz), 2.75 (t, 2H, J = 7.8 Hz), 2.47-2.41 (m, 5H). ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 199.5, 139.3, 139.3, 136.6, 130.9, 127.8, 127.7, 126.7, 126.6, 28.0, 27.6, 23.8. GCMS $C_{12}H_{12}O$ [M]; calculated 172, found 172.

Computational details

All DFT calculations were carried out using the Jaguar program,[14] with the B3LYP hybrid functional[15] and the LACVP* basis set.[16] Complexes were optimized *in vacuo* and subjected to vibrational analysis to validate the nature of the stationary point as ground states or transition states, respectively. Solution phase energies were obtained by single-point calculations on the gas phase structure. The singlet-triplet gap for the investigated Ni complexes was examined by continually running single point energy calculations on the optimized singlet structures. In all cases, the triplet was found to be higher in energy.

The solvent was modeled by Jaguar's Poisson-Boltzmann method[17] with parameters describing THF (ε = 7.6, probe radius = 2.52 Å) which is a competent solvent for the title reaction, and computationally more feasible than the experimentally preferred dioxane. The solution phase Gibbs free energy was estimated by adding the gas phase vibrational contribution to the single-point solution phase energy. A dispersion correction term was calculated and added to give the total energy.[18] All transition states were refined by eigenmode following and verified by the presence of only one imaginary frequence. Visual inspection backed up that the eigenvector corresponded well to the formation of the correct bond or torsional rotation and QRC calculations were used to confirm this.[19]

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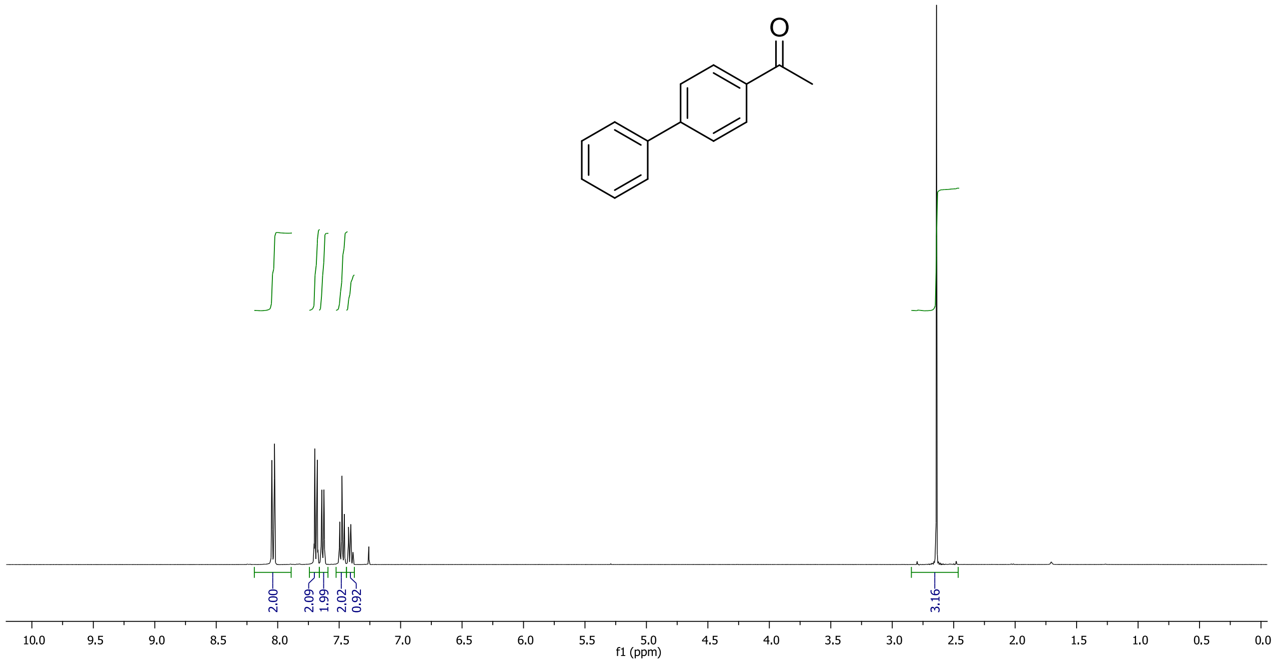
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6.5
6.0
5.5
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3.5
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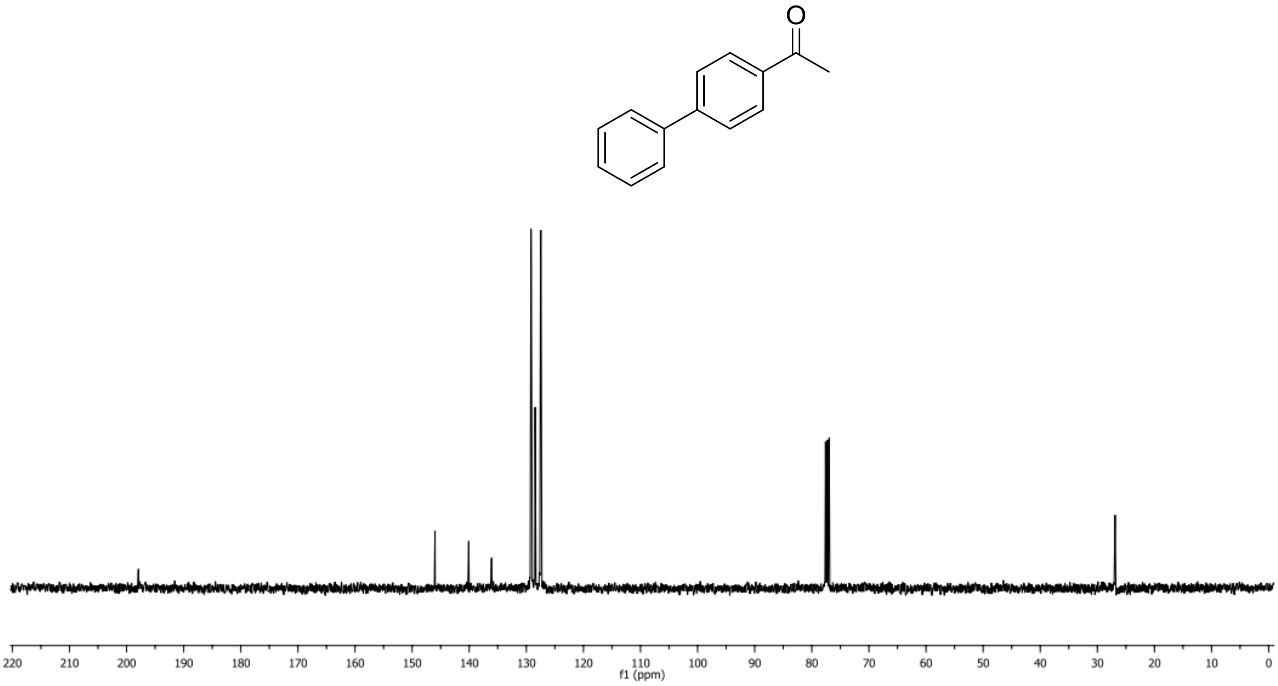
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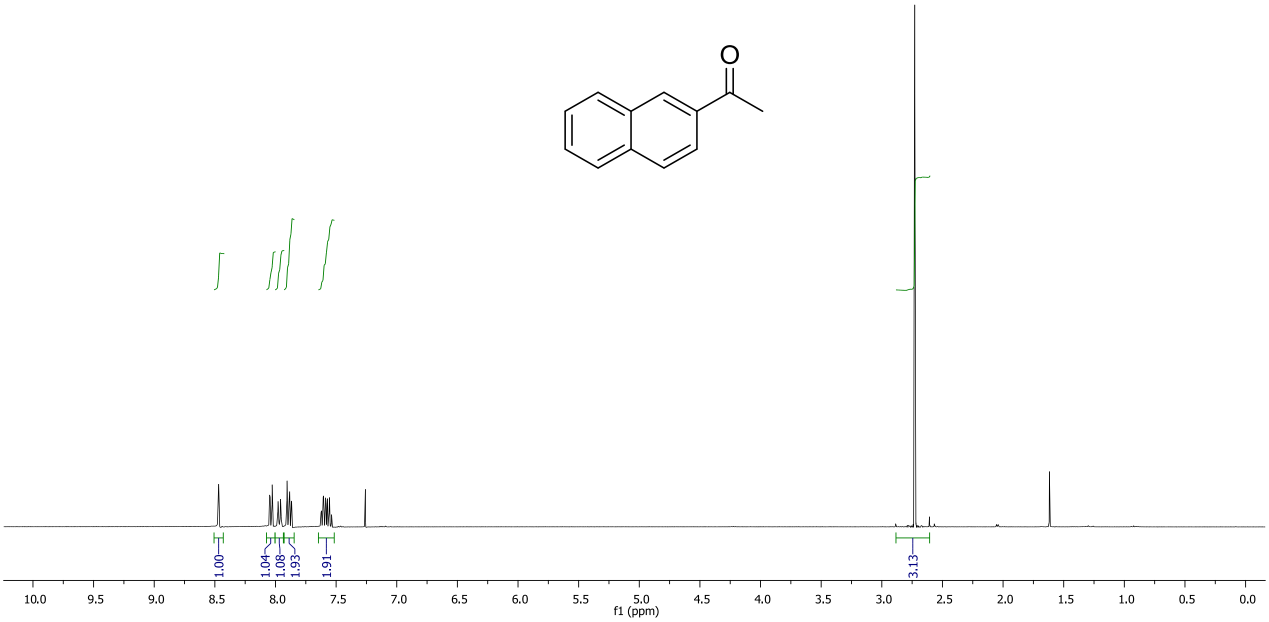
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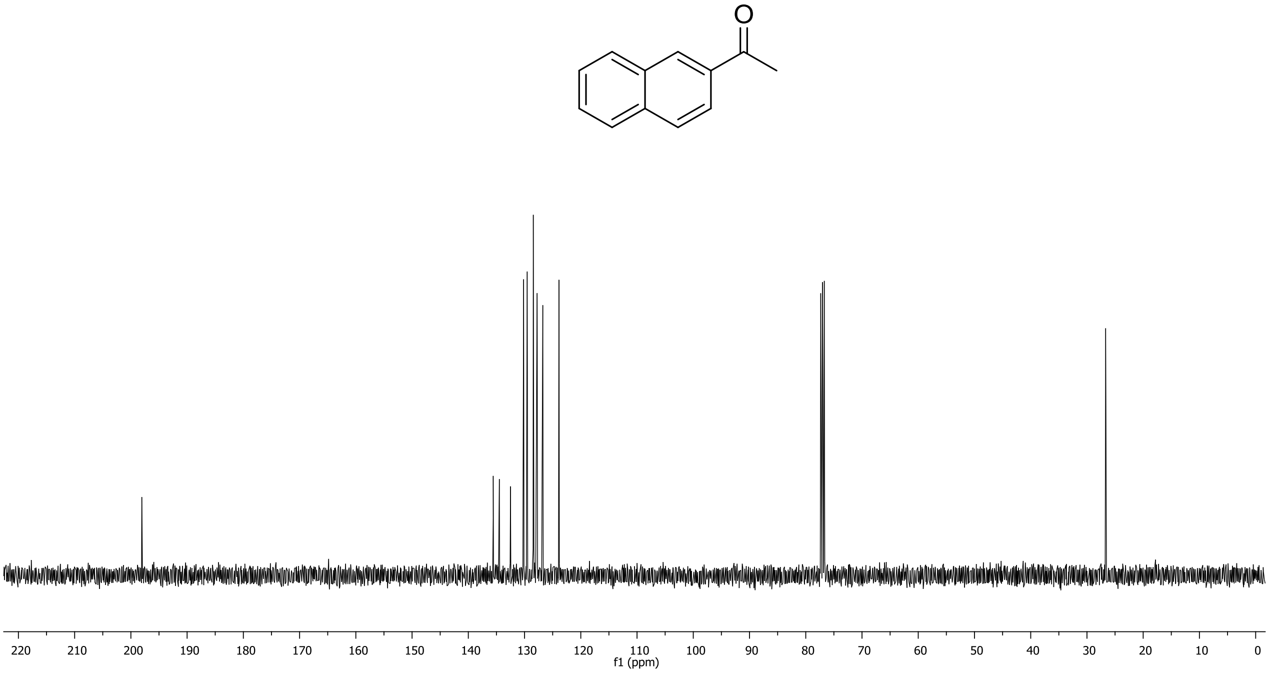
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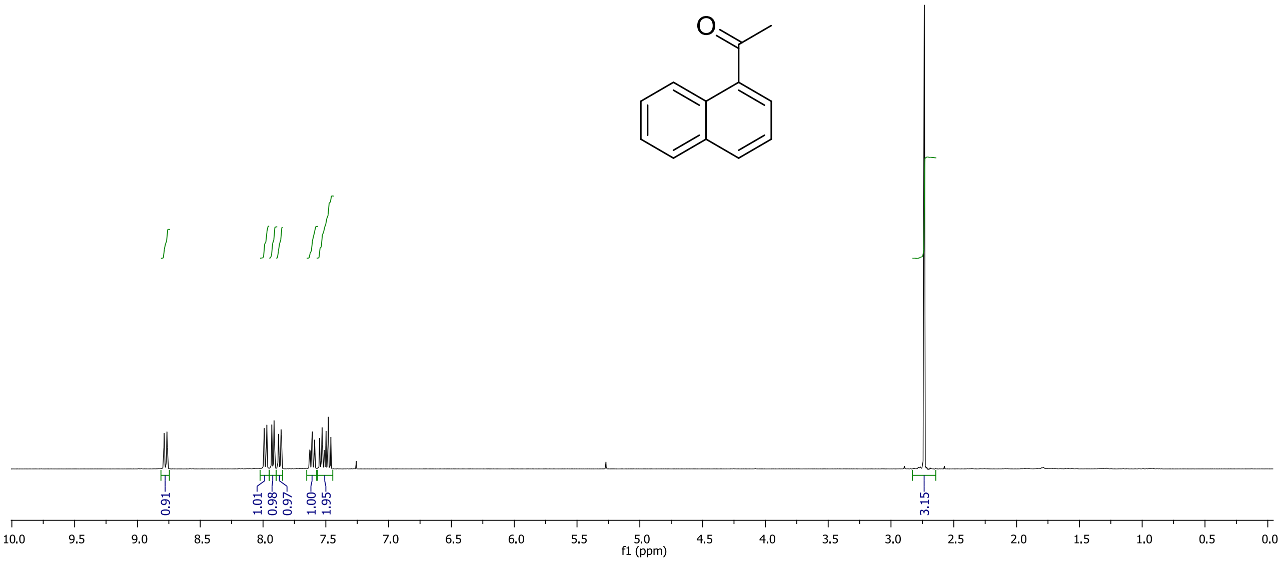
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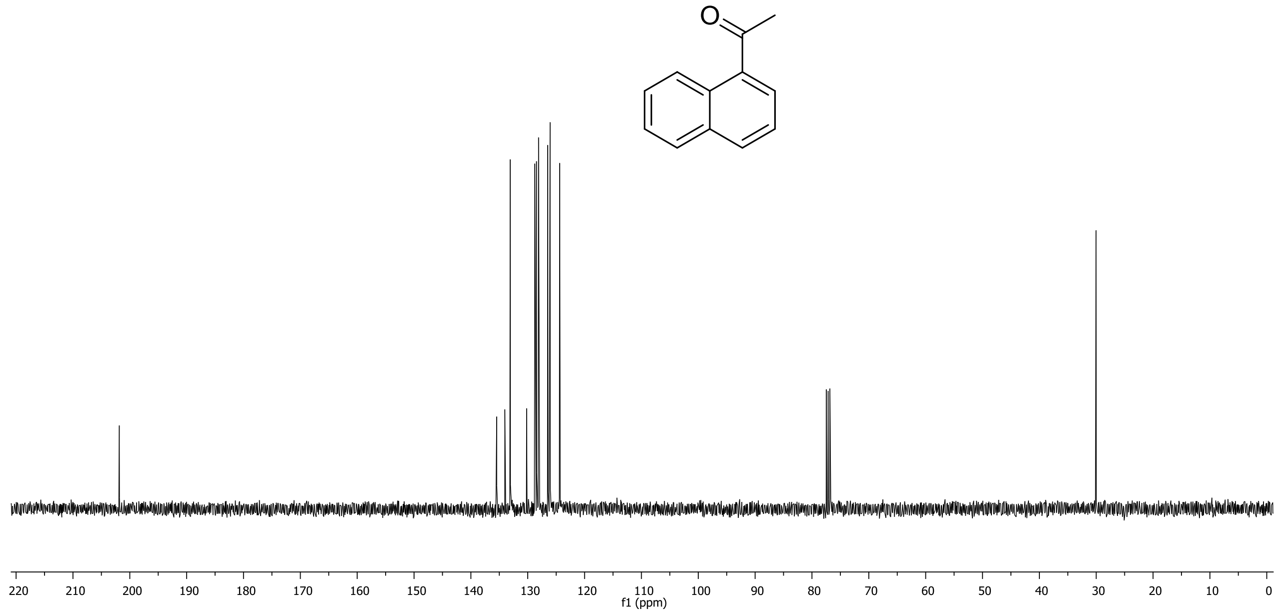
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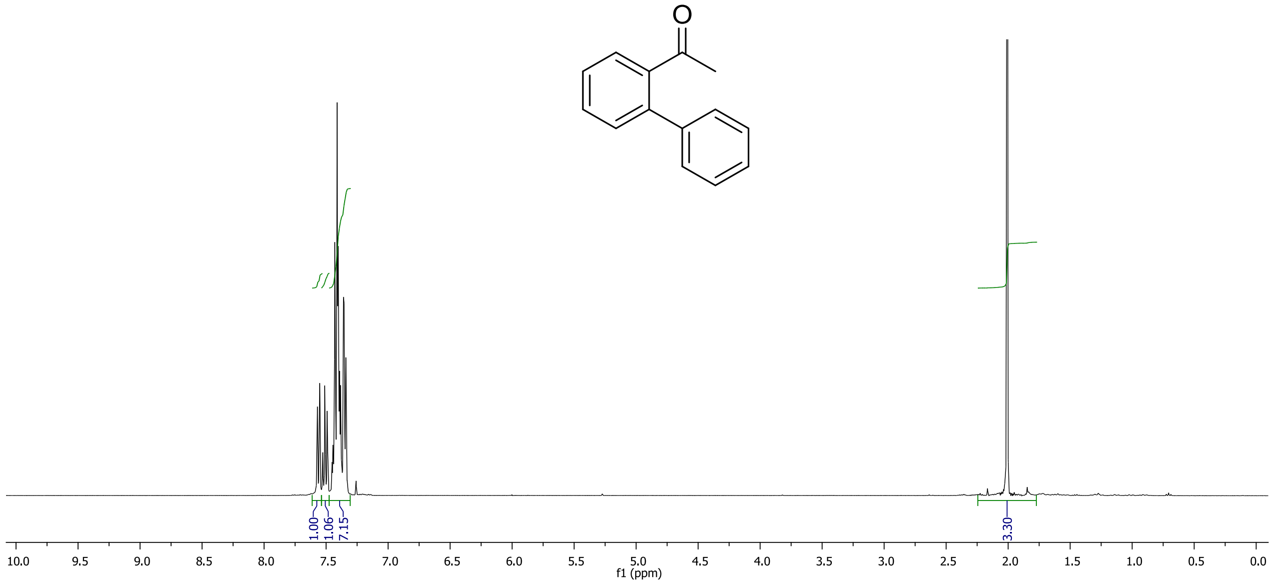
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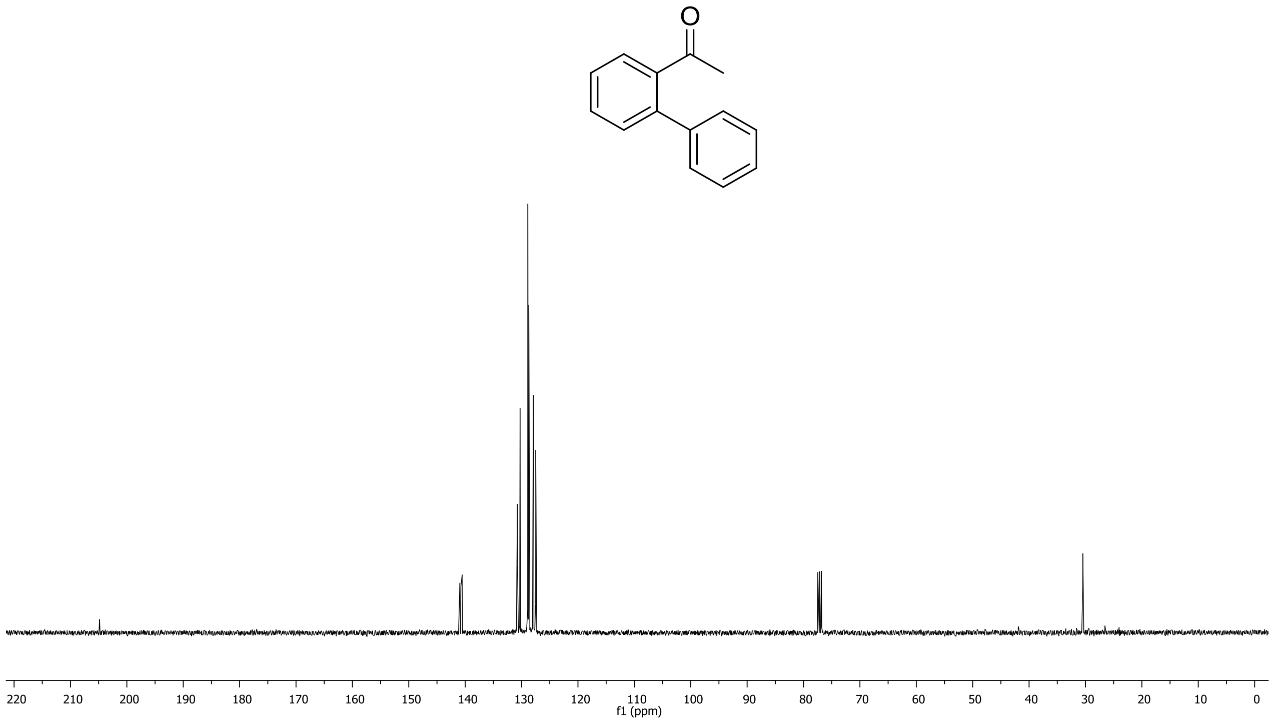
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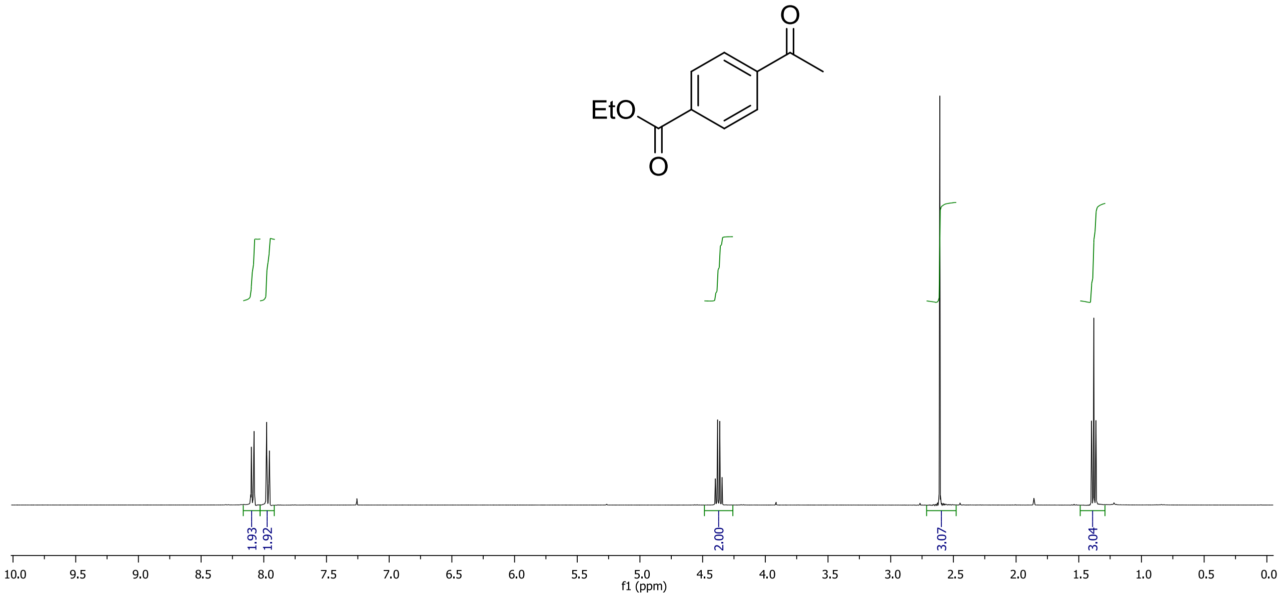
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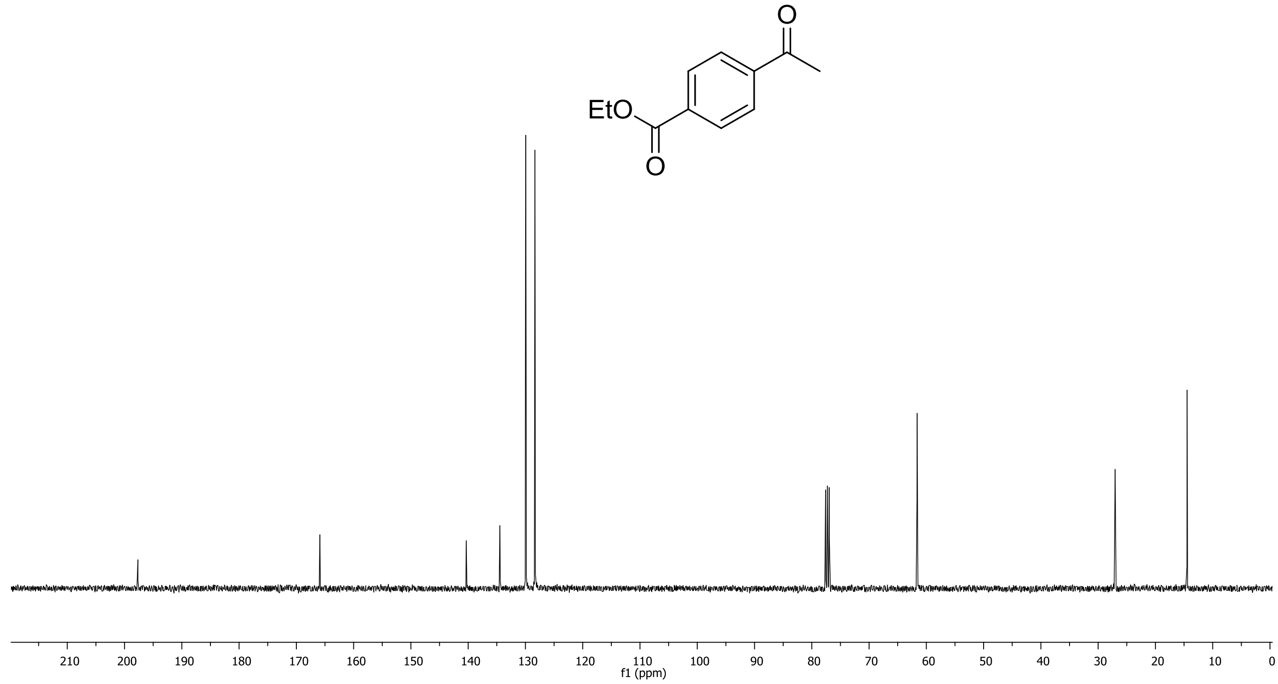
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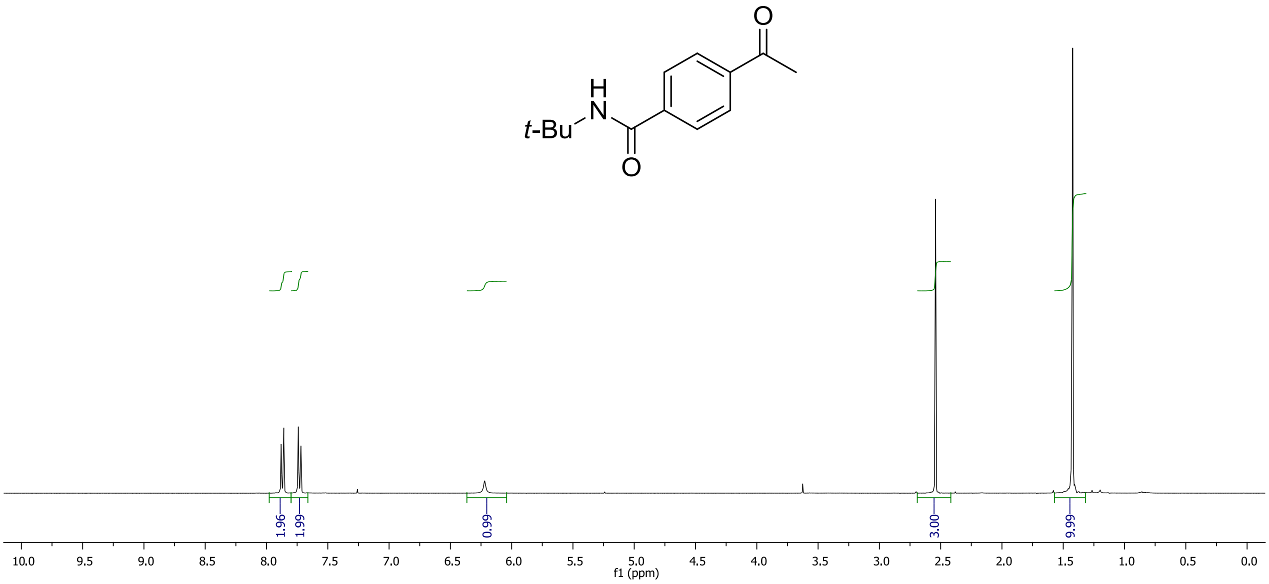
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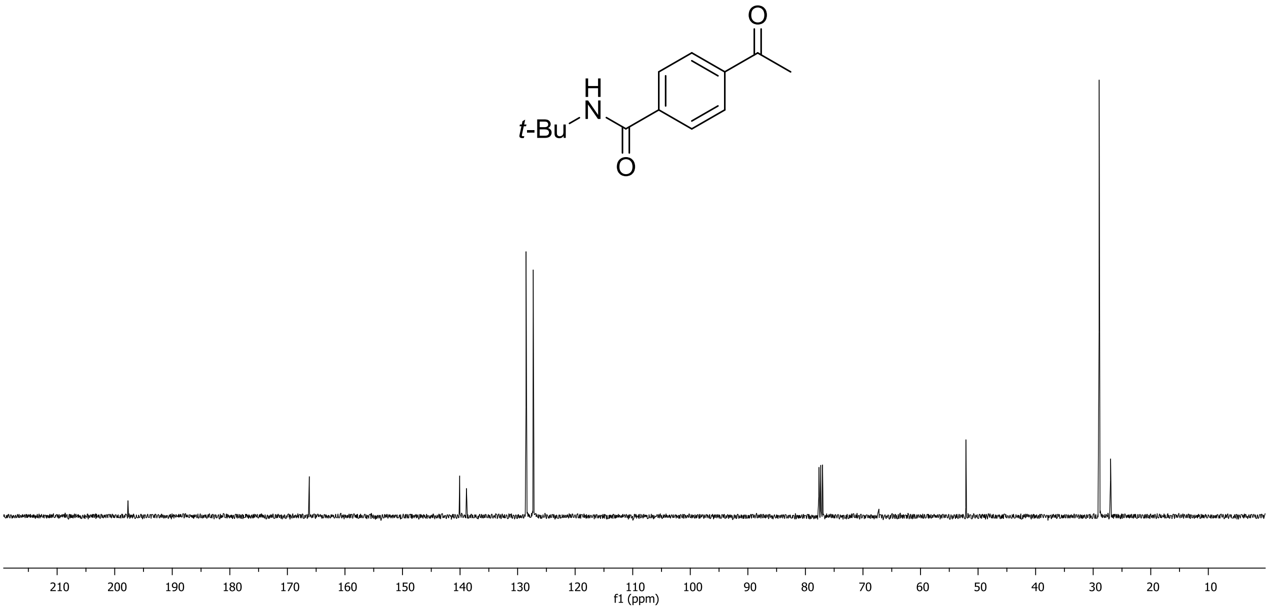
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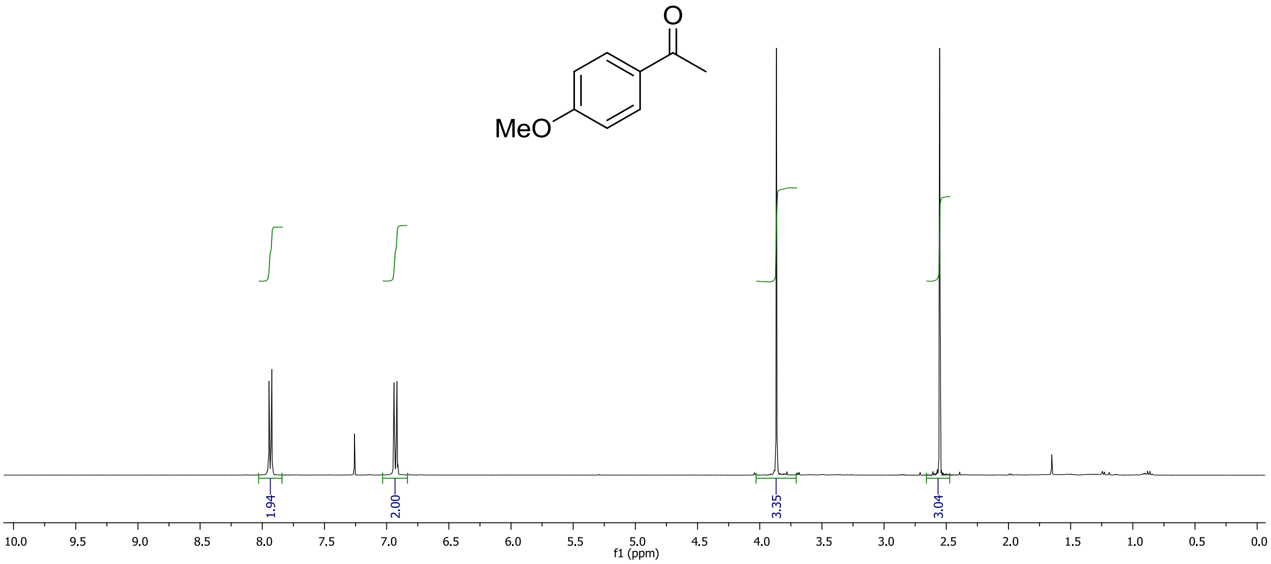
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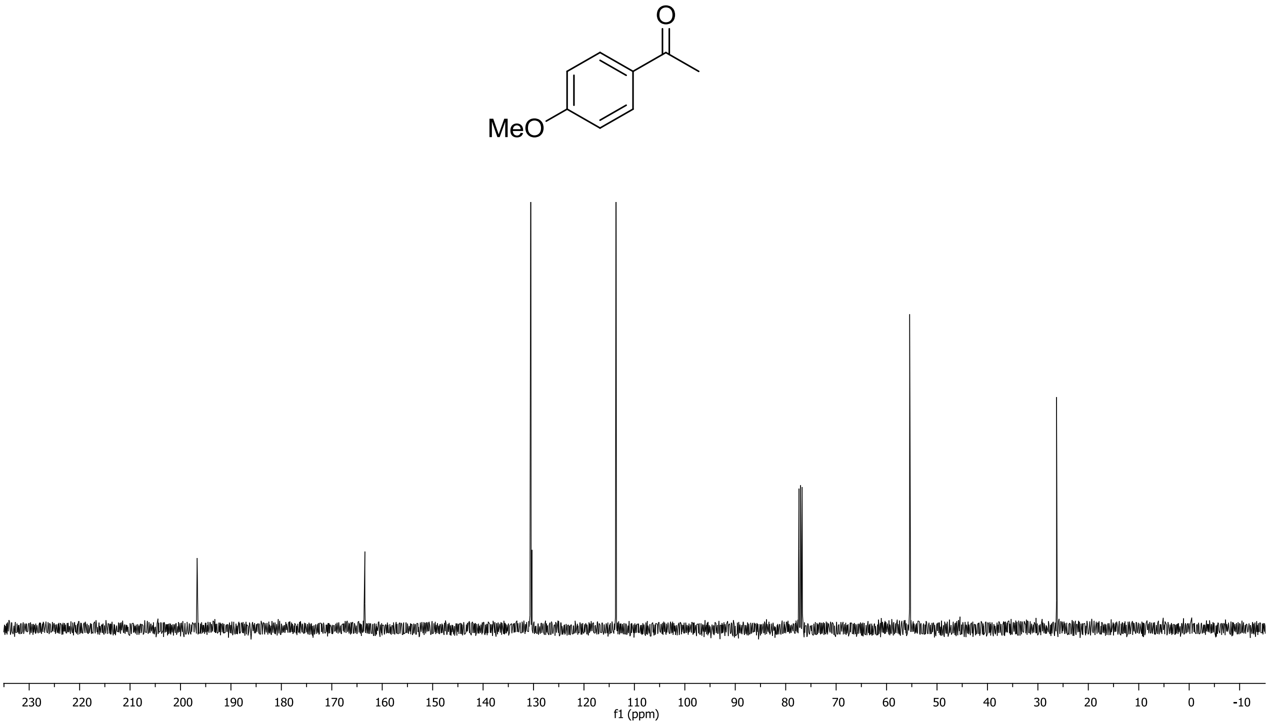
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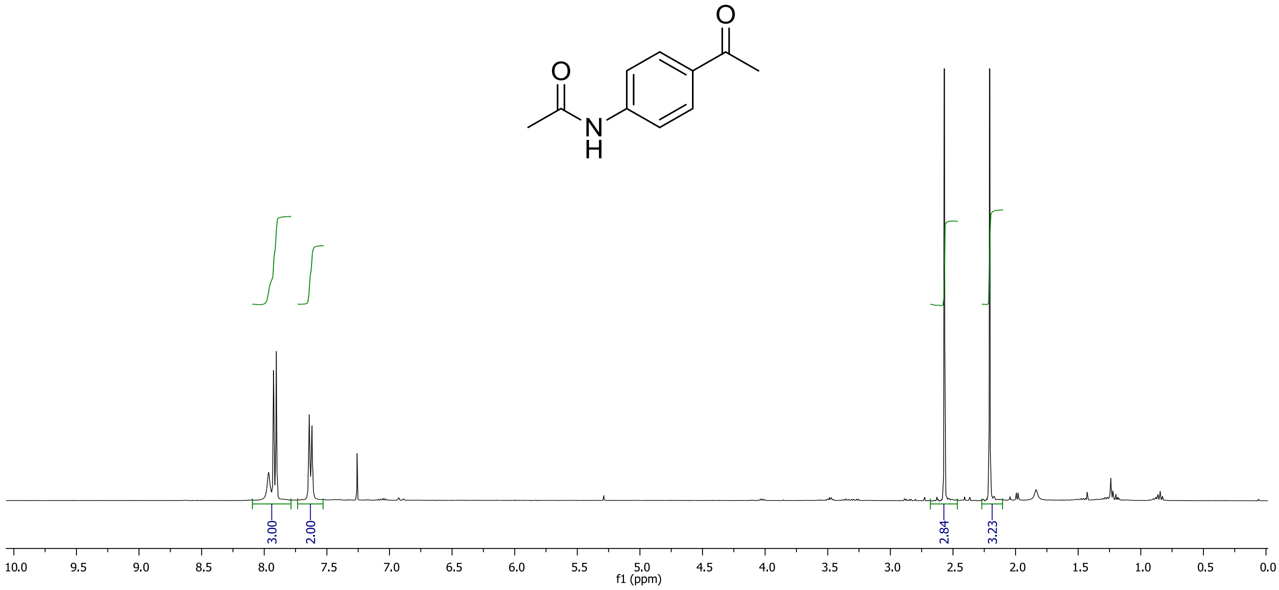
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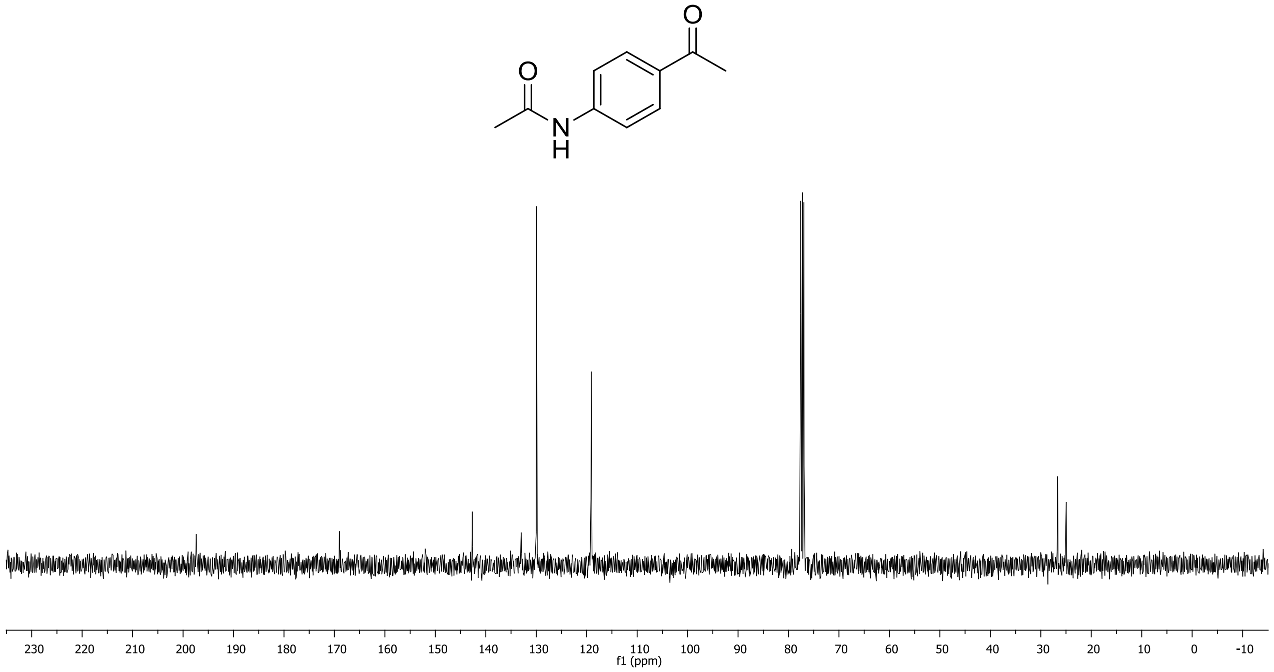
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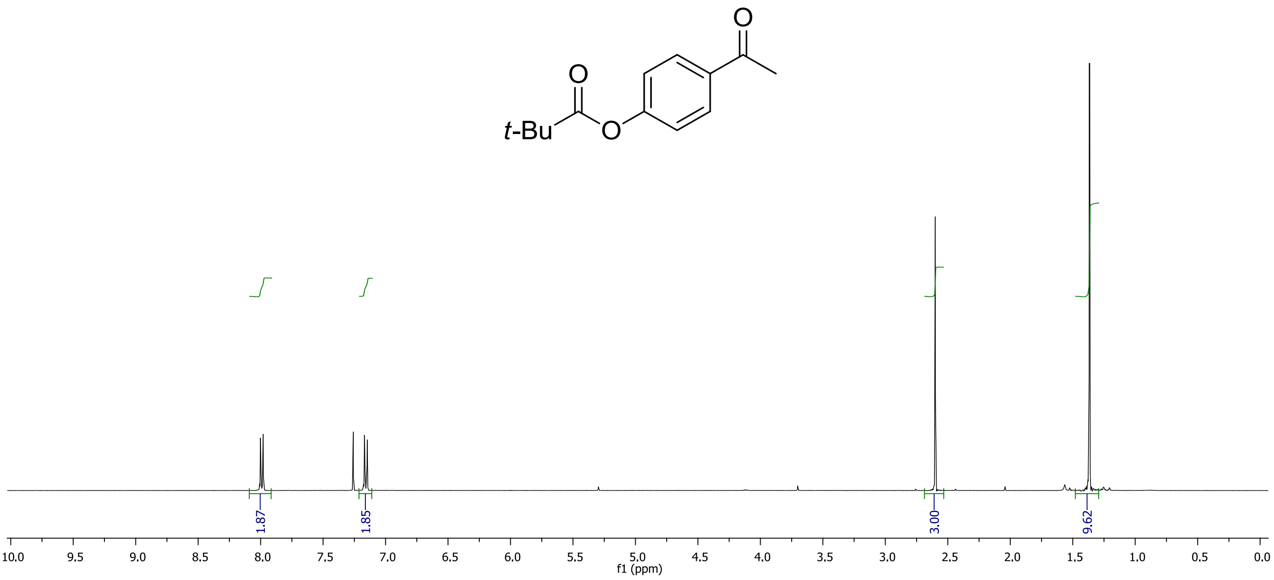
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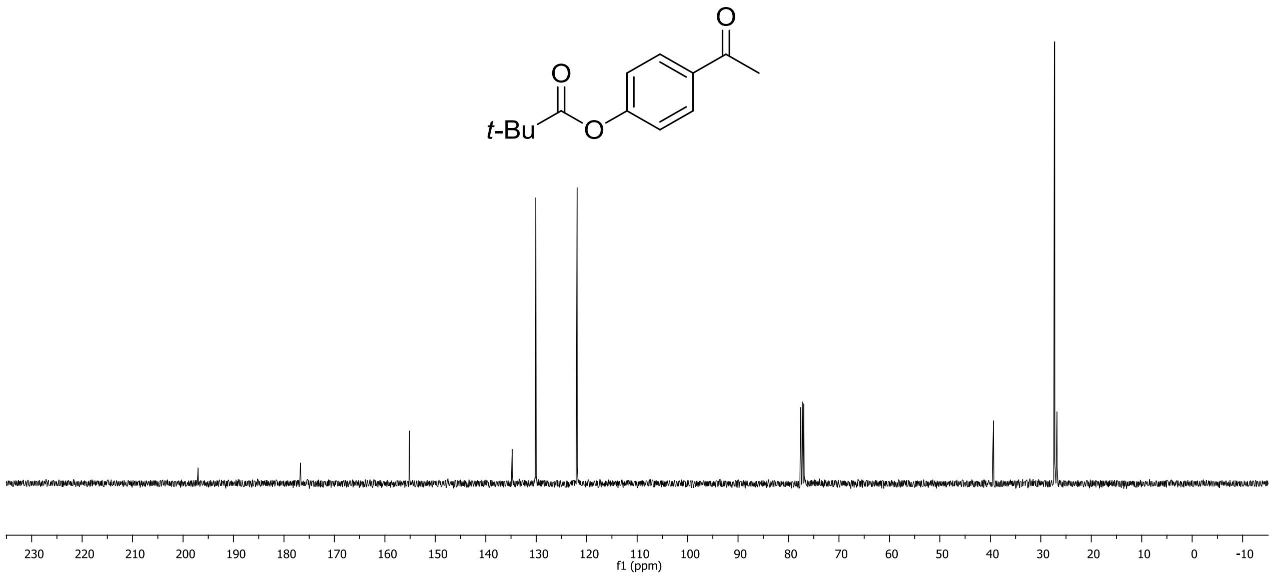
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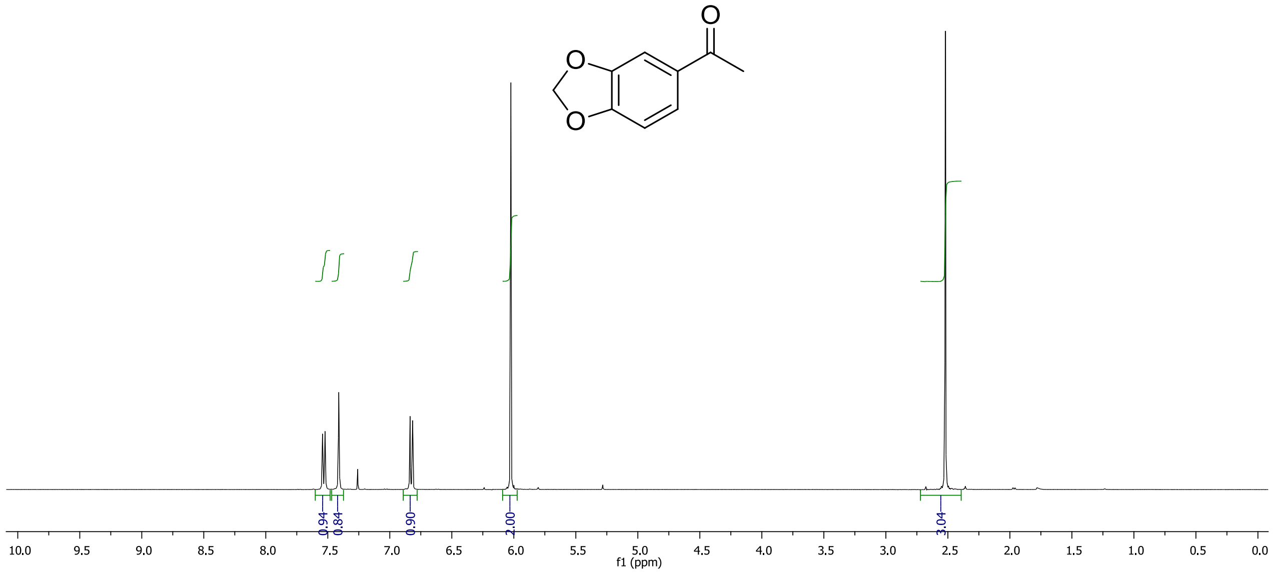
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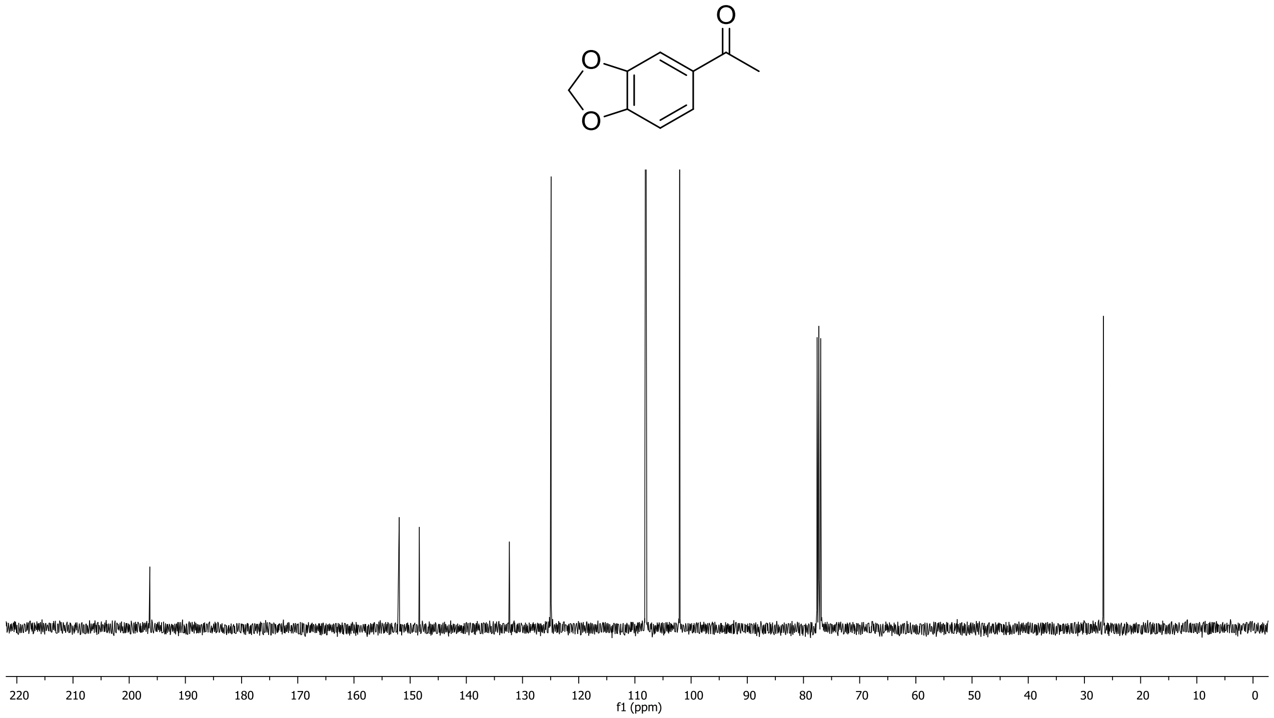
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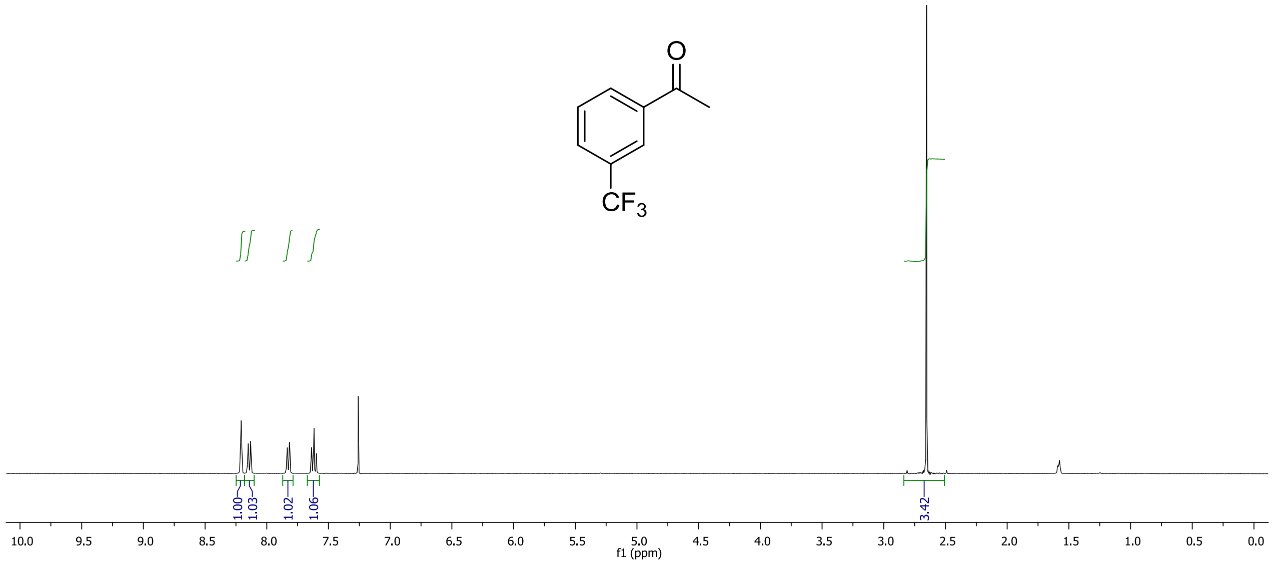
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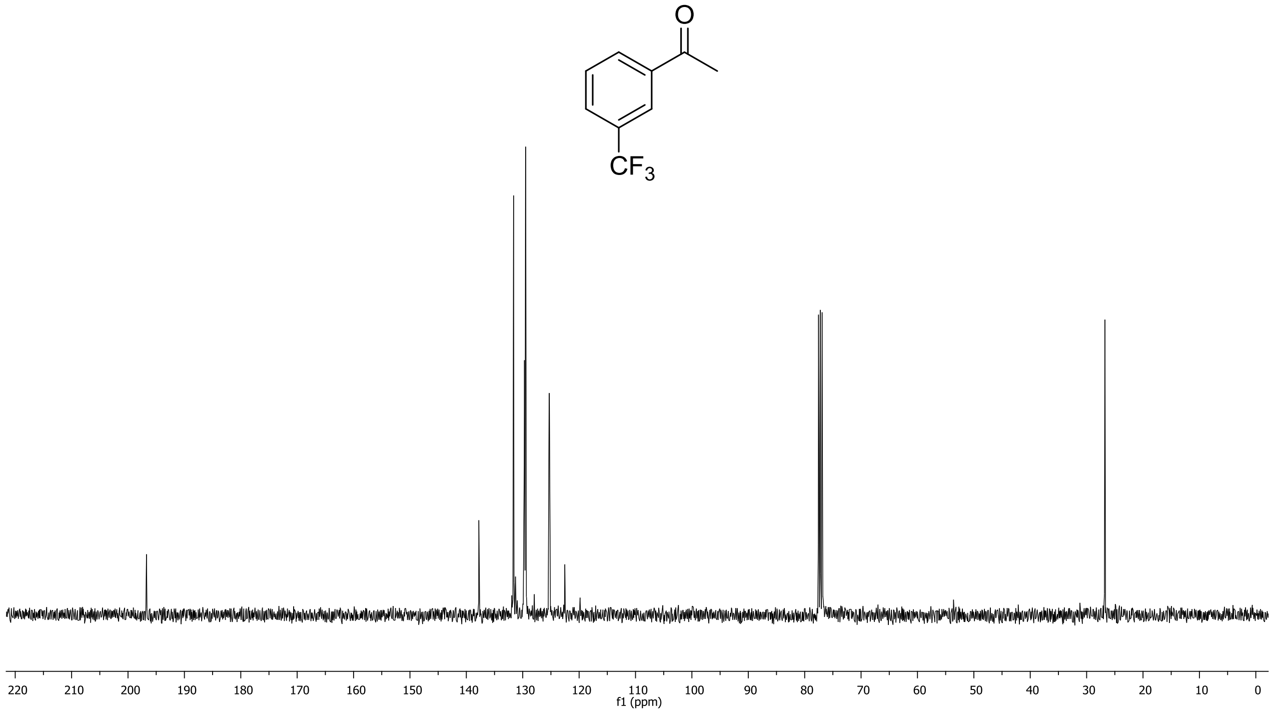
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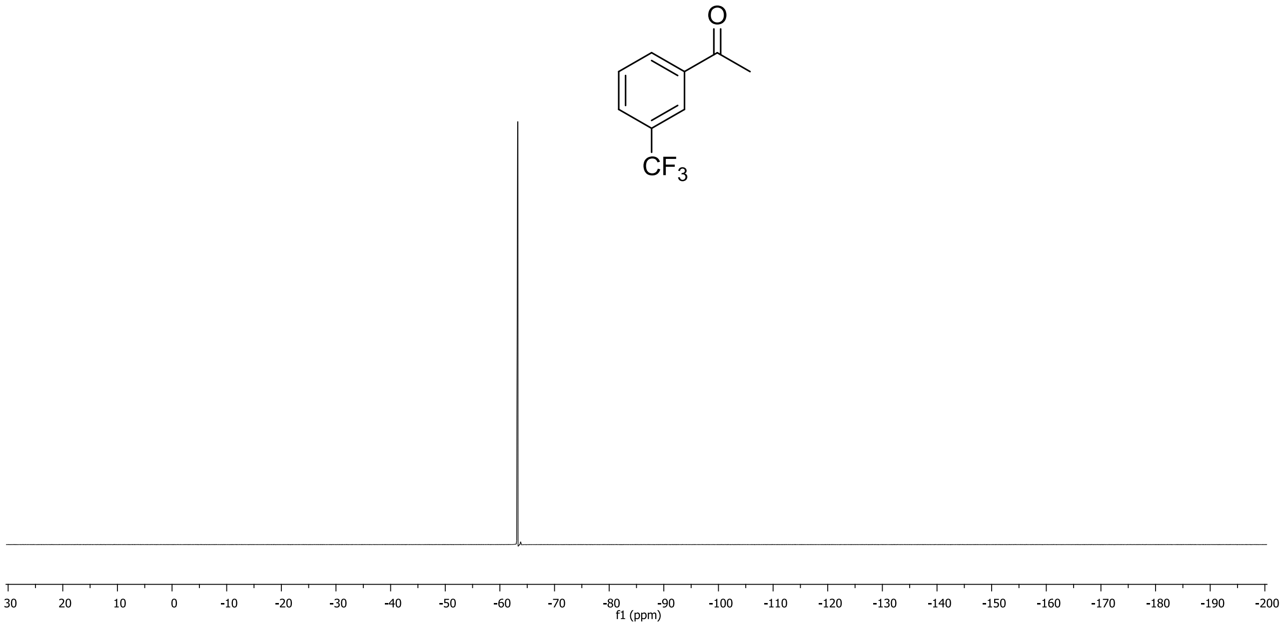
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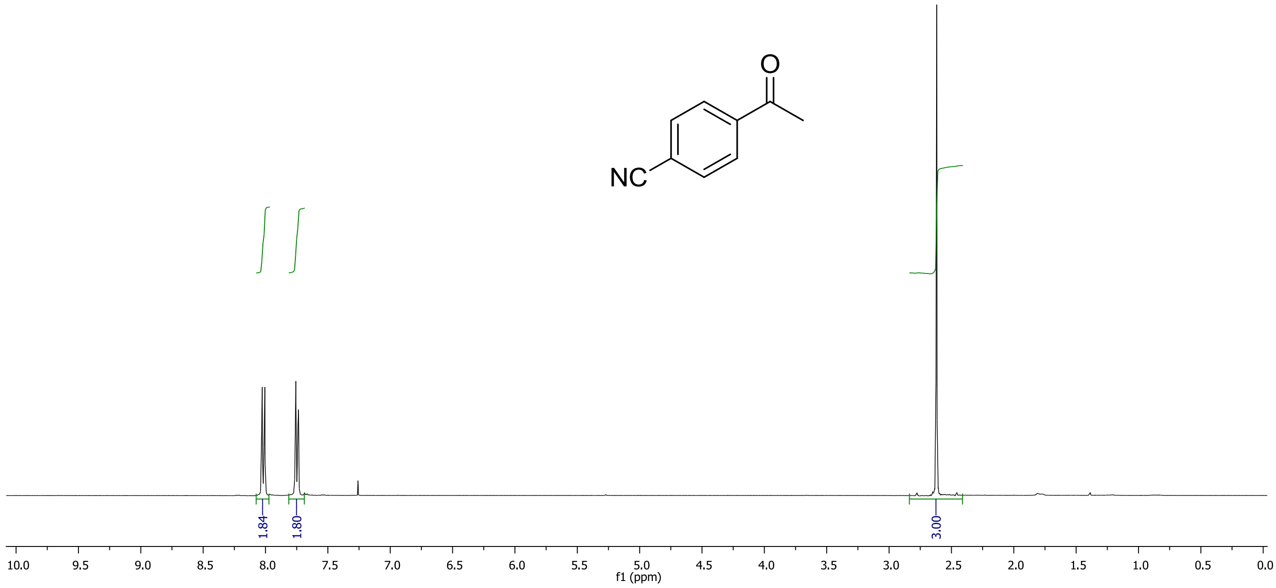
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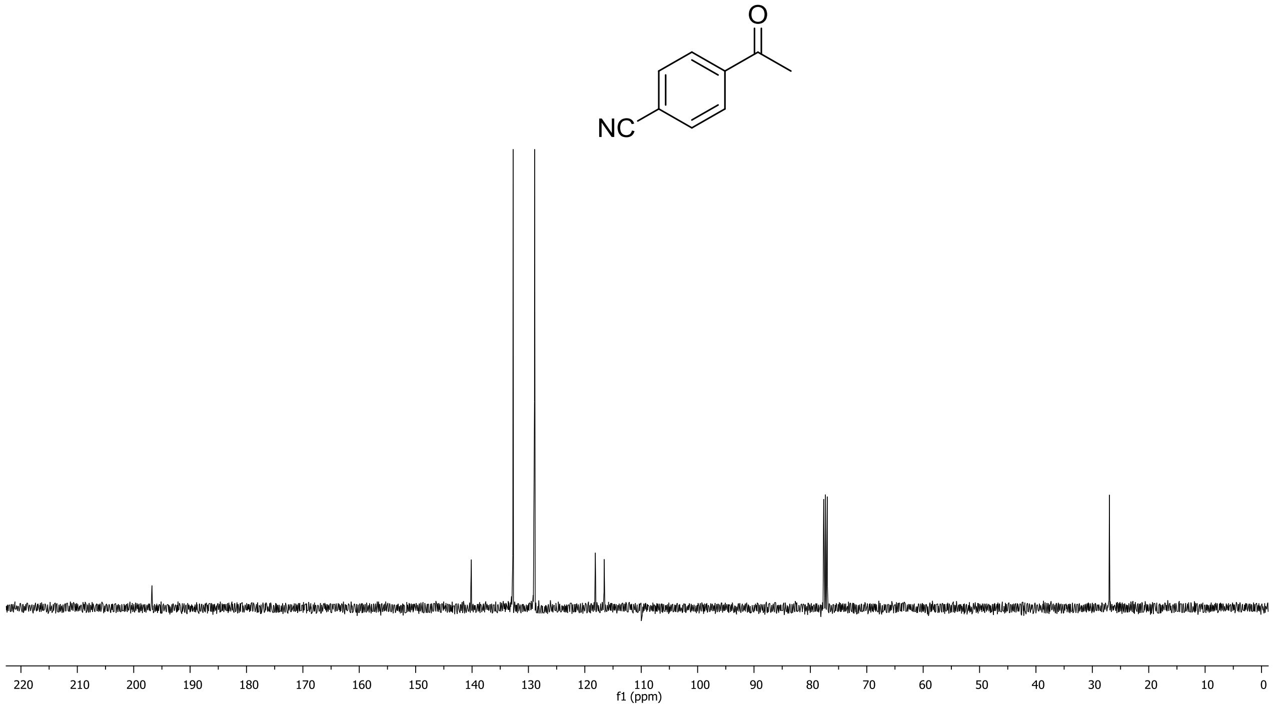
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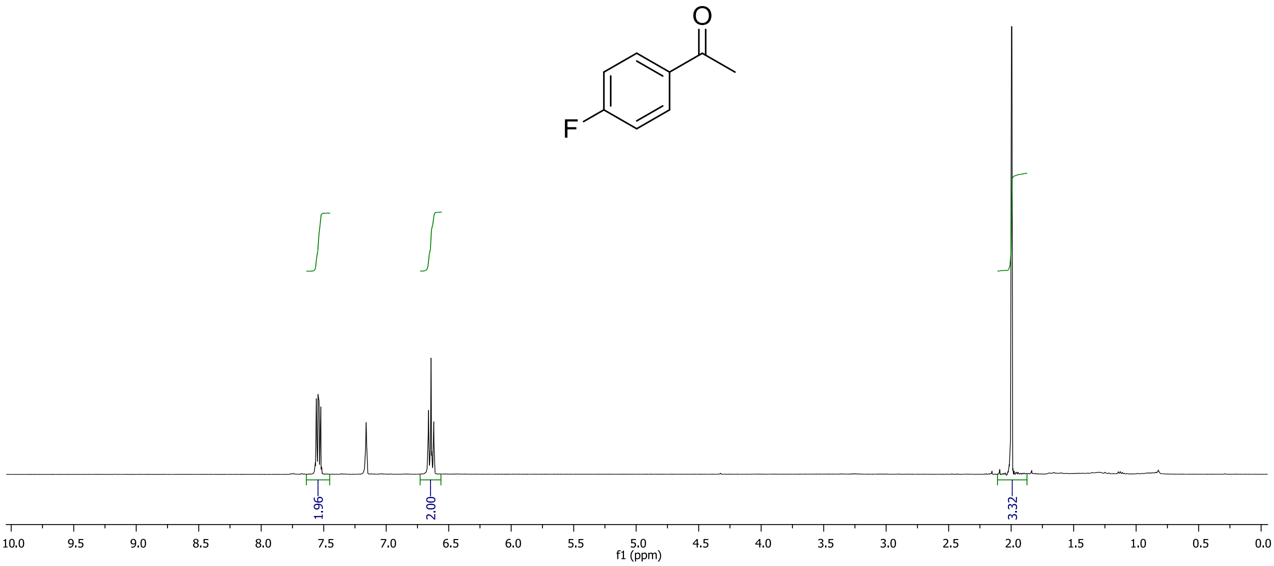
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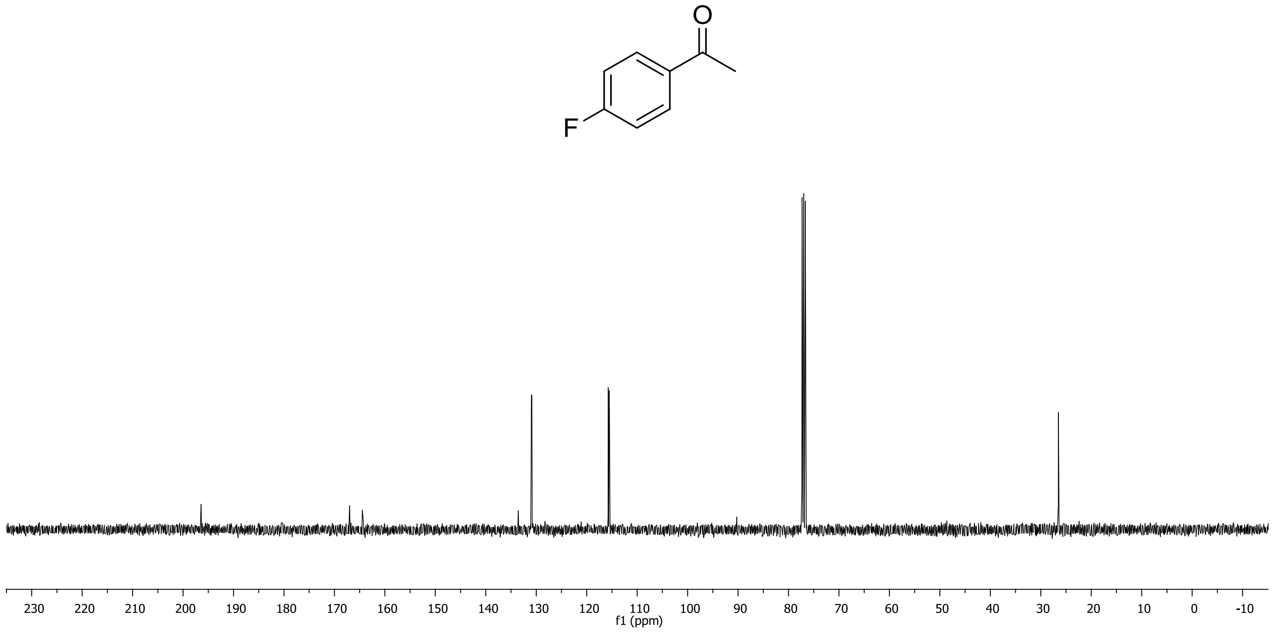
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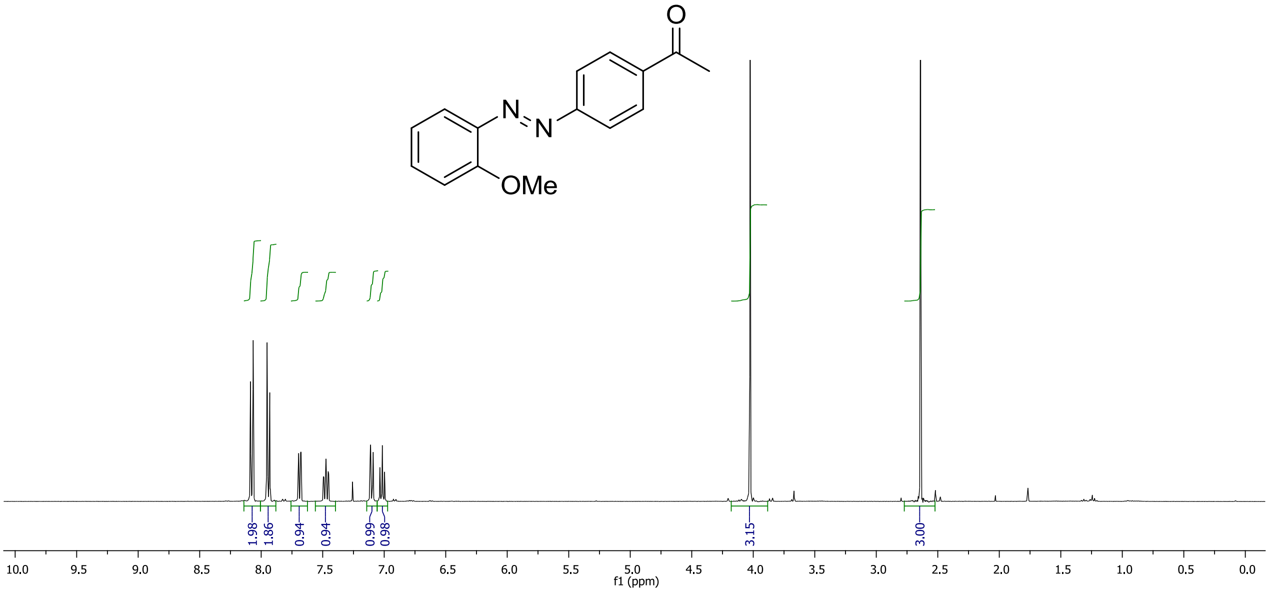
f1 (ppm)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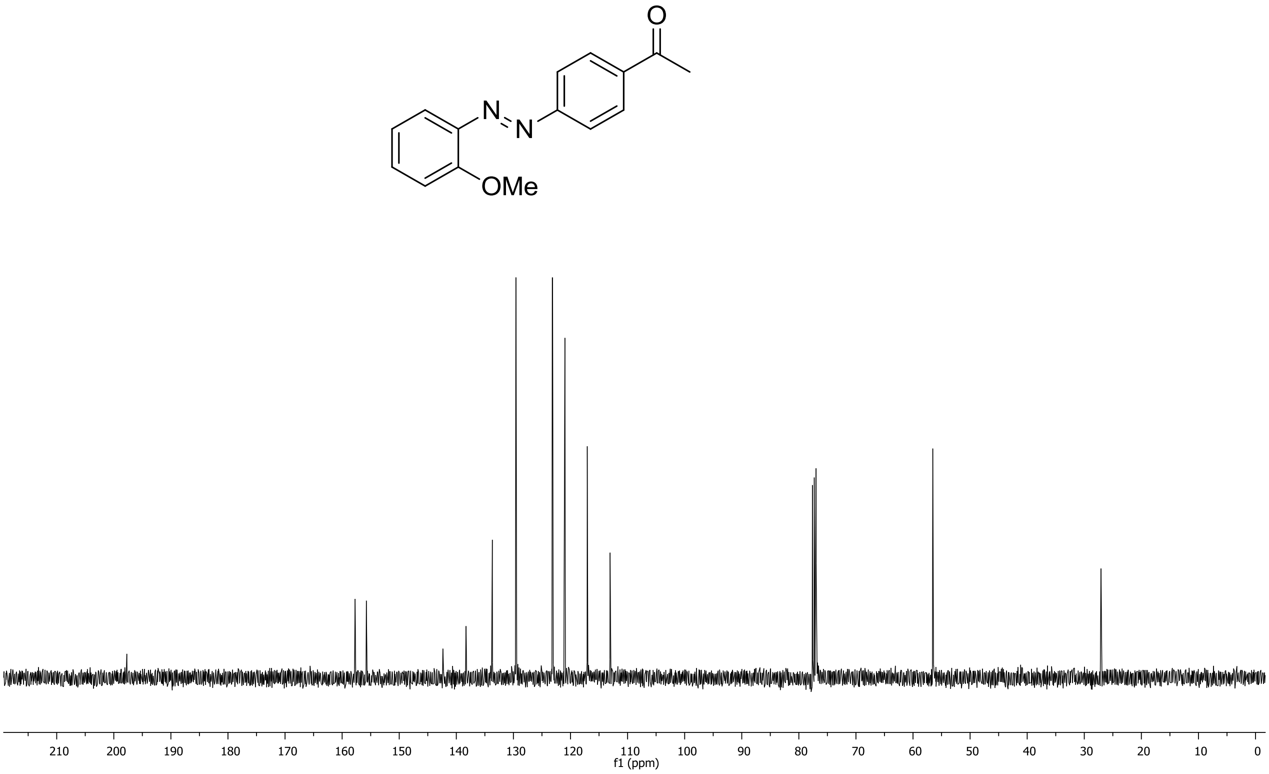
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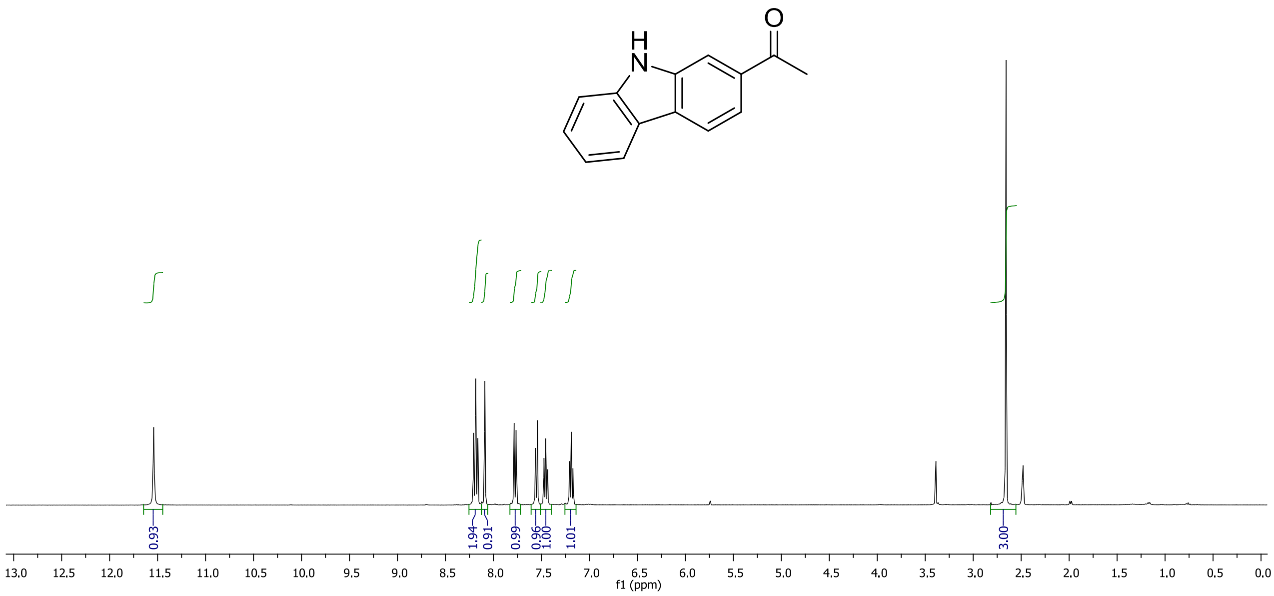
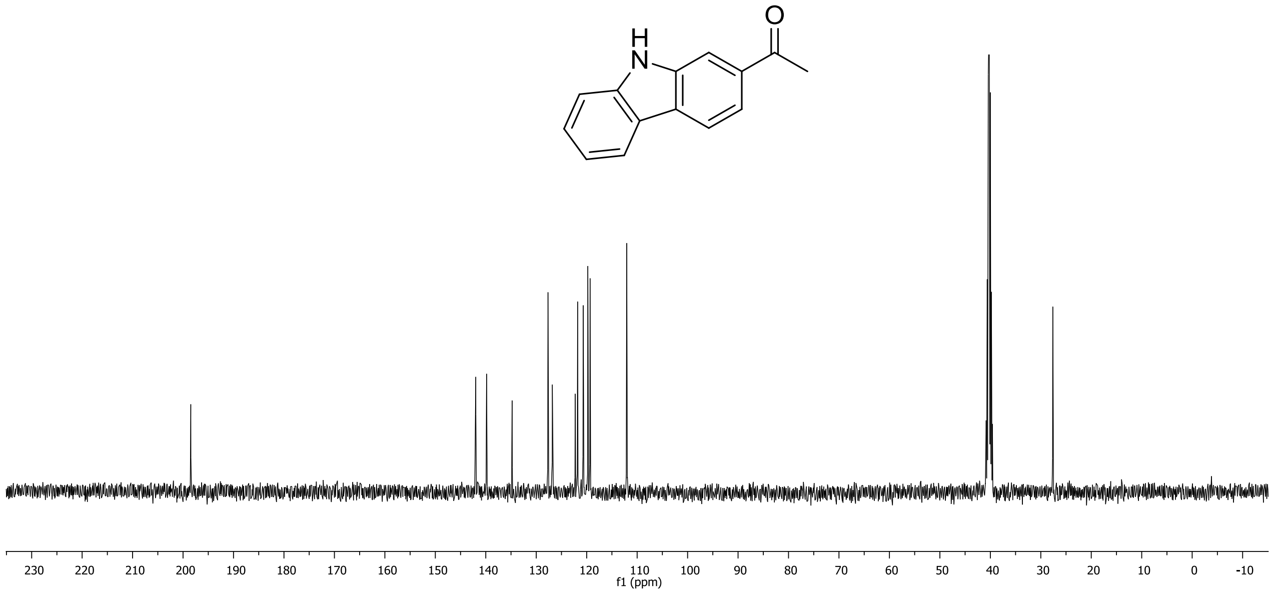
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


O
H
N
0.93
1.94
0.91
0.99
0.96
1.00
1.01
3.00
13.0
12.5
12.0
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)


O
H
N
230
220
210
200
190
180
170
160
150
140
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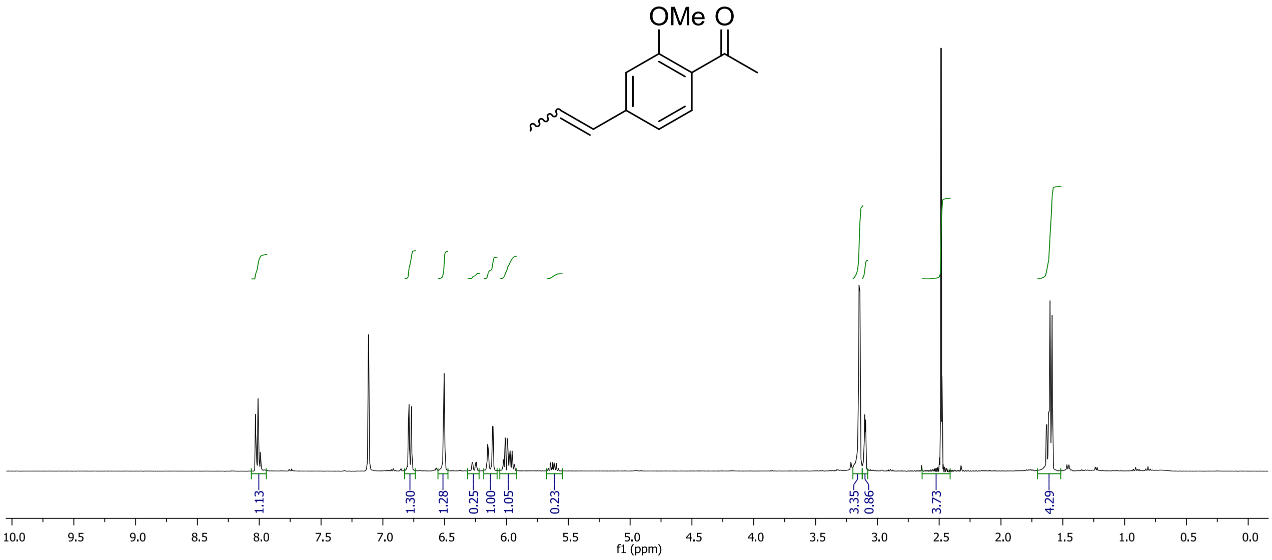
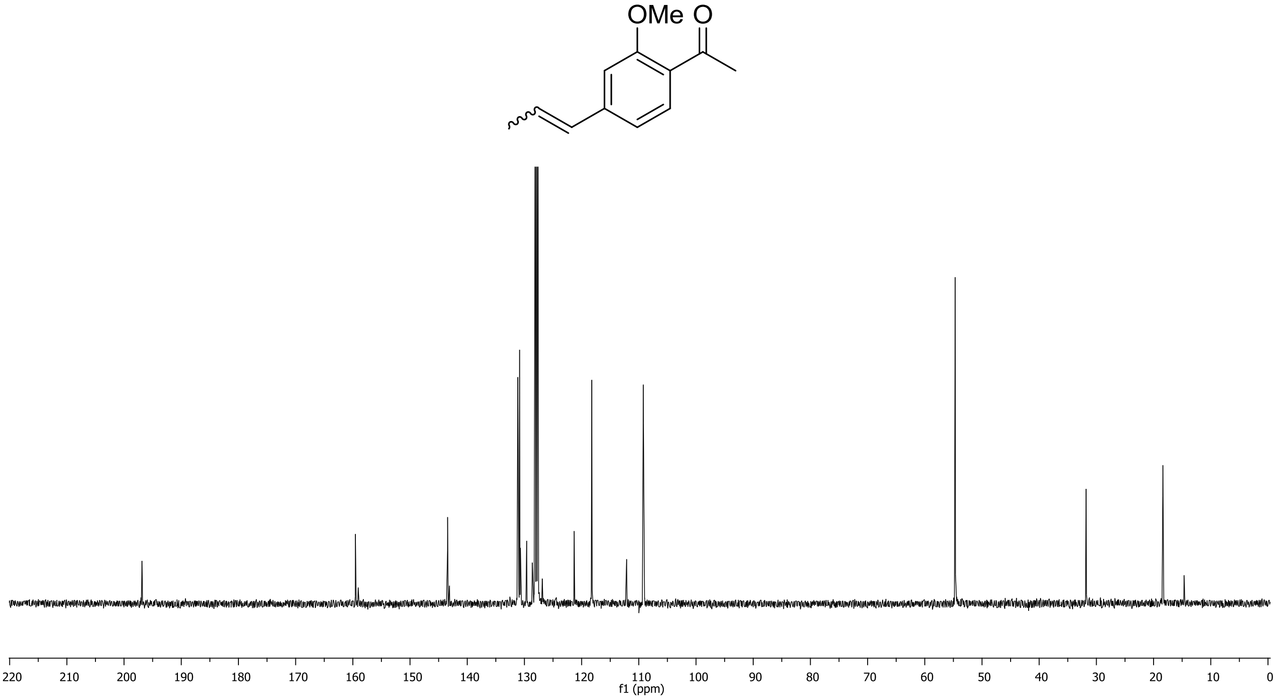
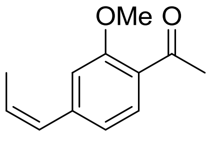
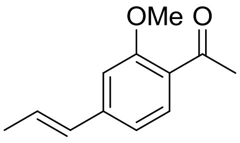
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)


OMe
O
1.13
1.30
1.28
0.25
1.00
1.05
0.23
3.35
0.86
3.73
4.29
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
f1 (ppm)

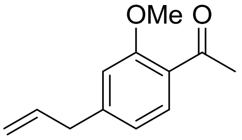

OMe
O
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


OMe
O

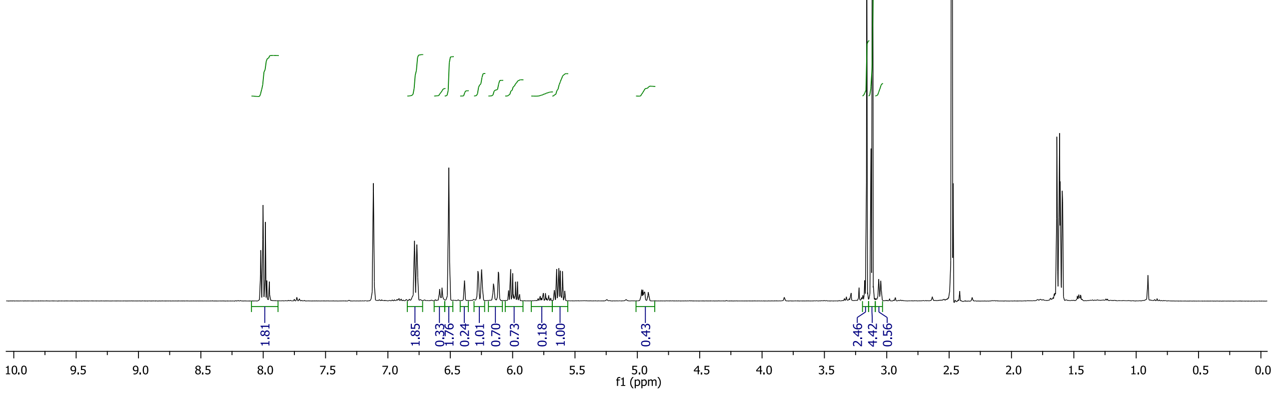
10

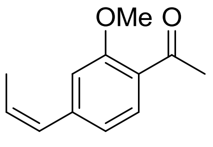

OMe
O

7

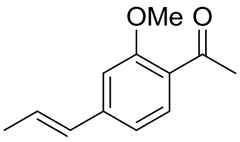

OMe
O

2

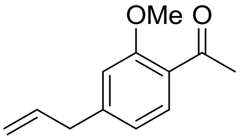

1.81
1.85
0.33
1.76
0.24
1.01
0.70
0.73
0.18
1.00
0.43
2.46
4.42
0.56
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)


OMe
O

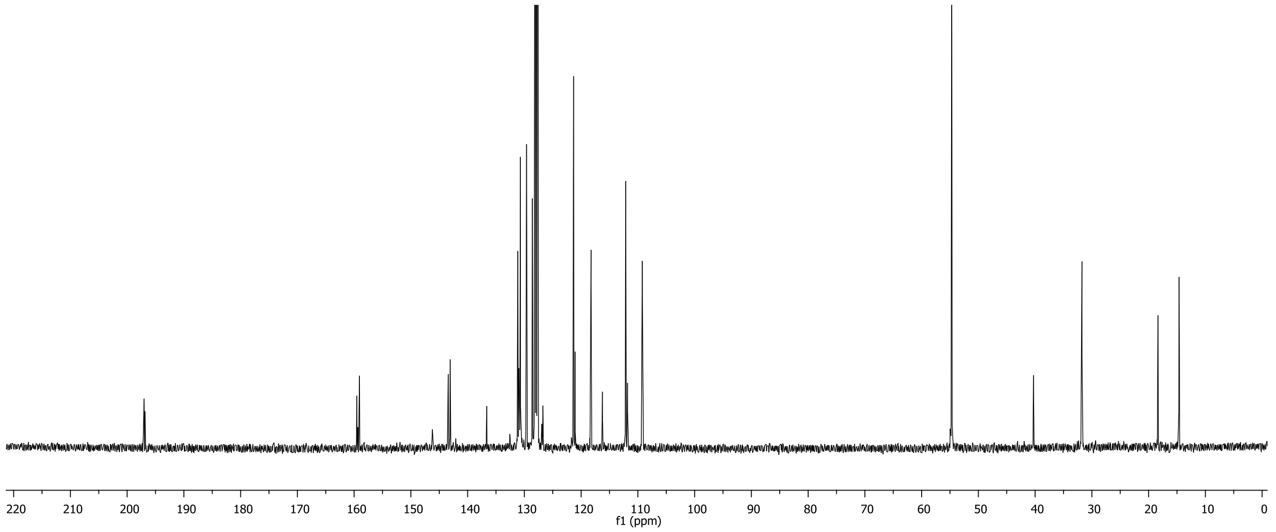
10

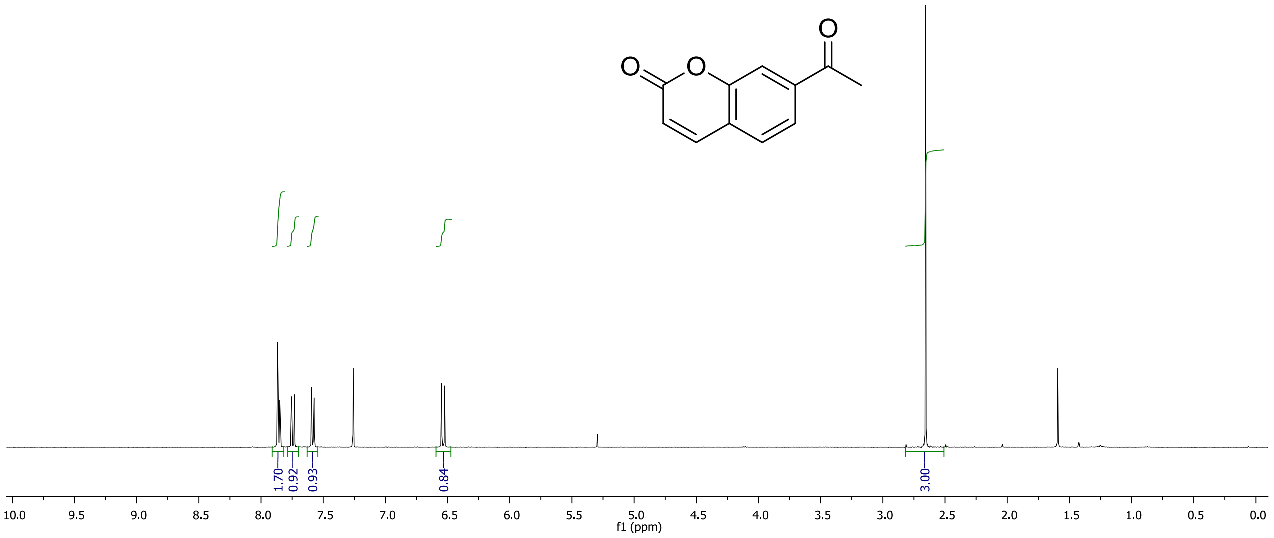

OMe
O

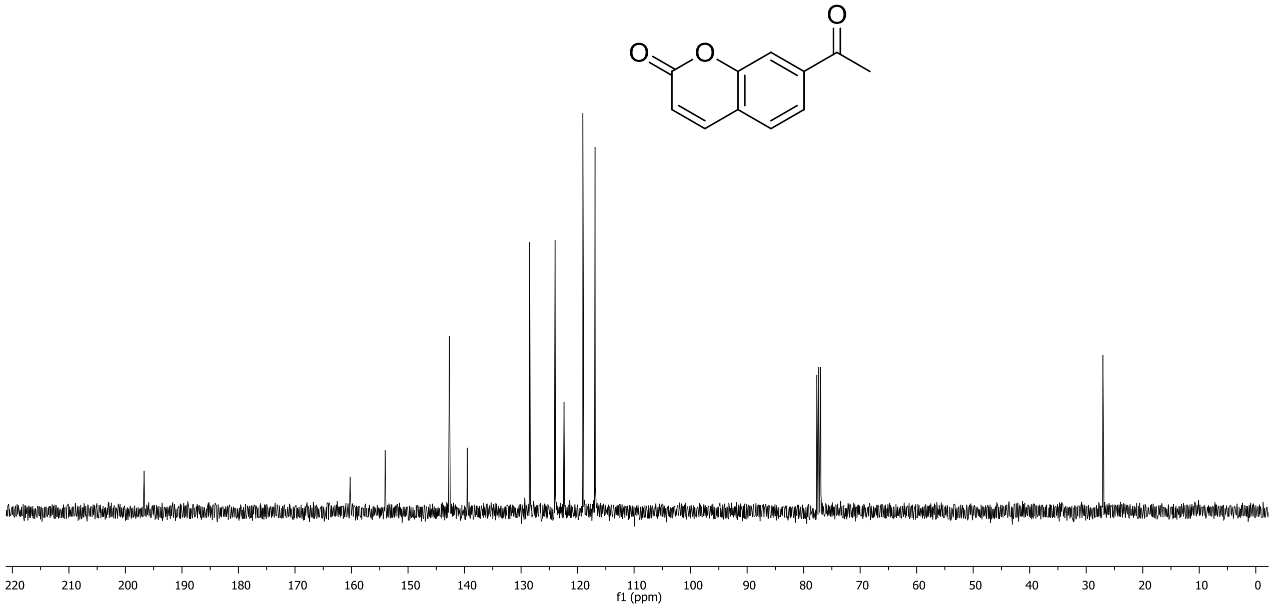
7

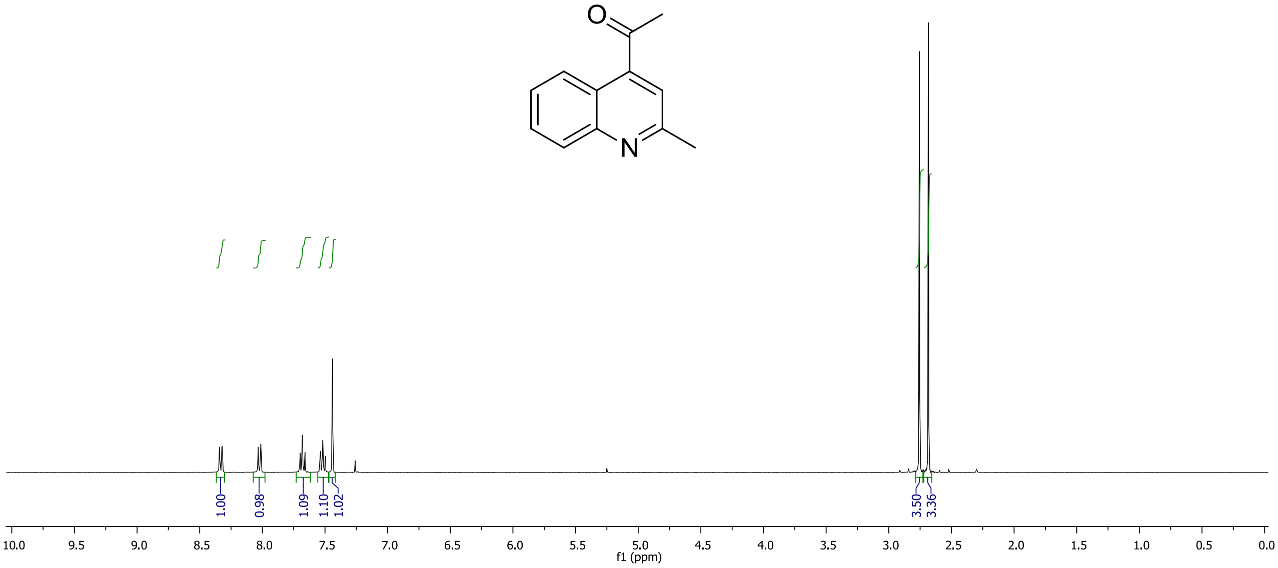

OMe
O

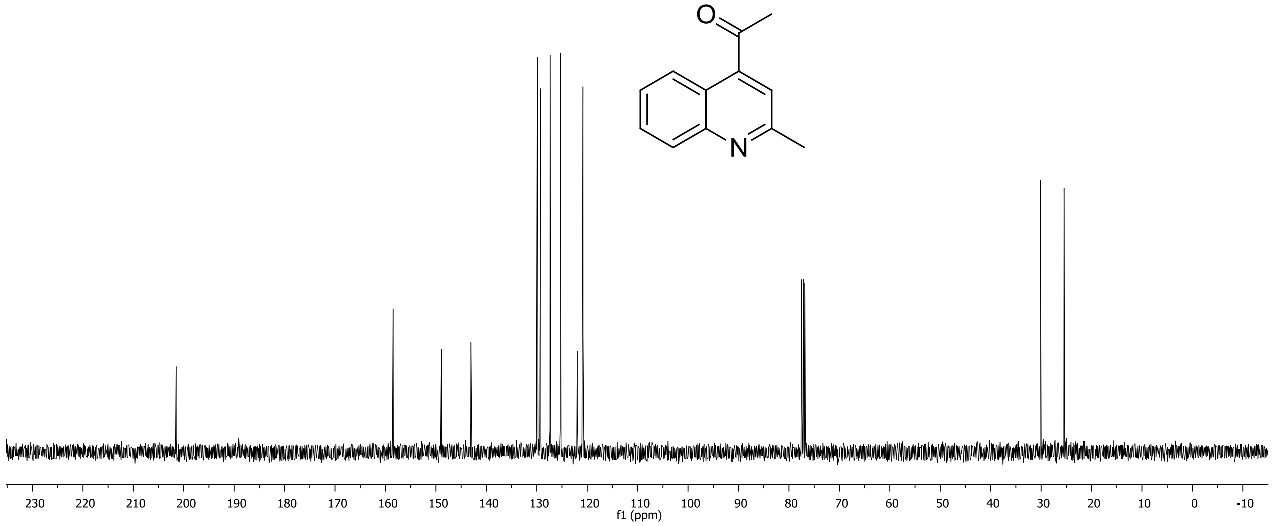
2

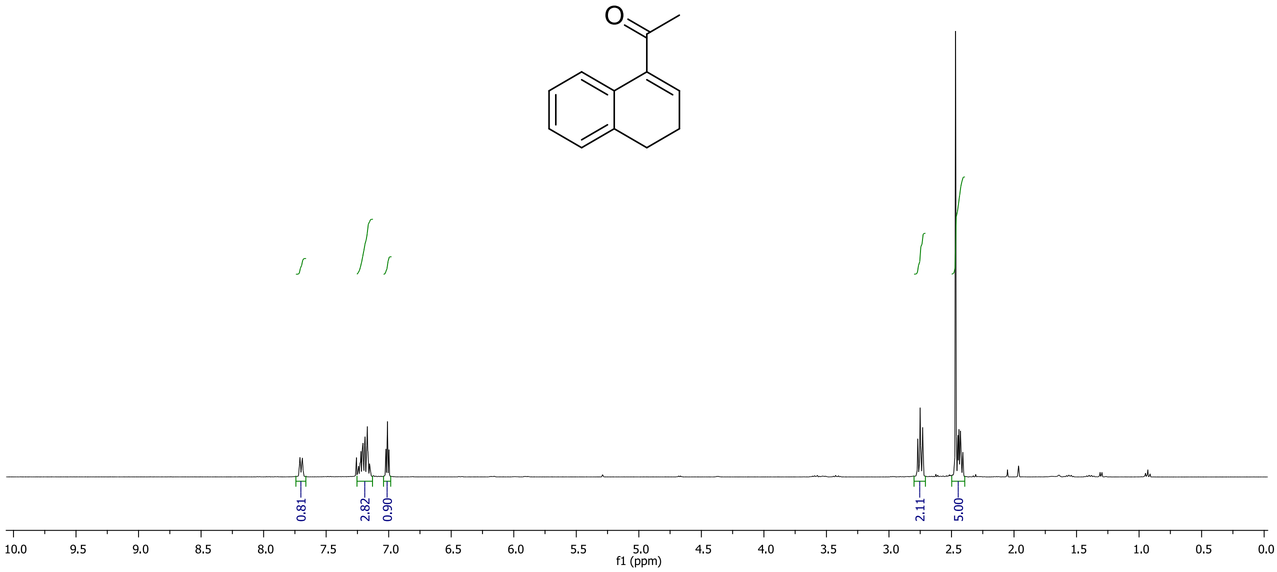

220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

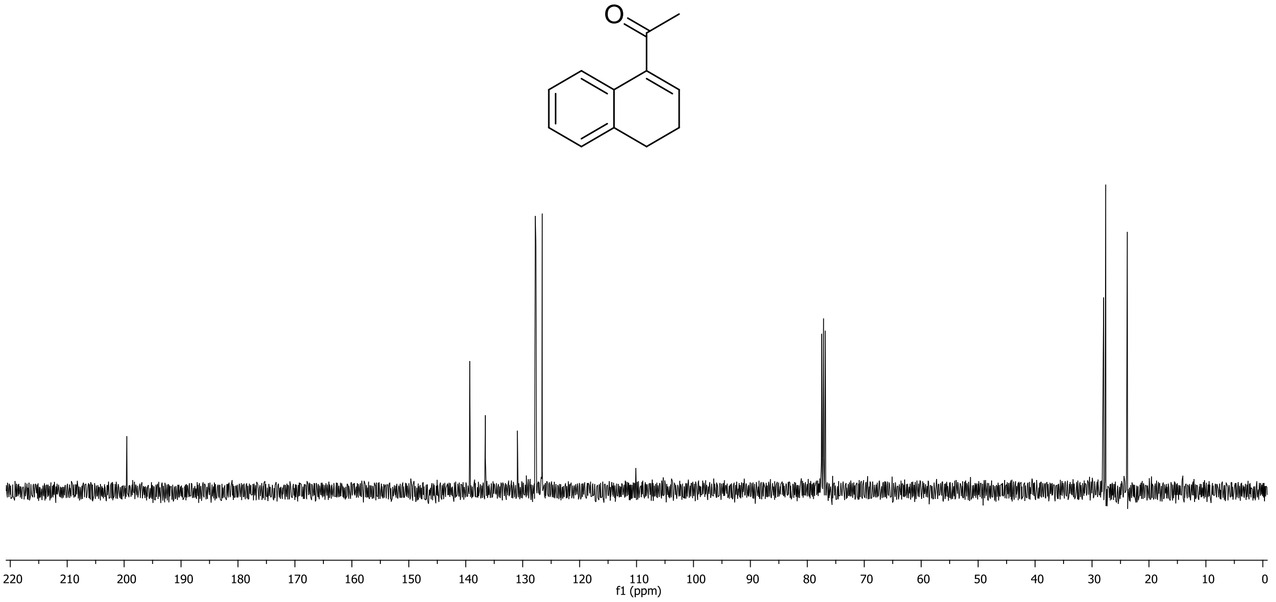

O
O
O
1.70
0.92
0.93
0.84
3.00
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)


O
O
O
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


O
N
1.00
0.98
1.09
1.10
1.02
3.50
3.36
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
f1 (ppm)


O
N
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)


O
0.81
2.82
0.90
2.11
5.00
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
f1 (ppm)


O
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)