Electronic Supplementary Material (ESI) for ChemComm.

Supporting Information

Nickel-Catalyzed C(sp^2)−C(sp^3) Coupling via Photoactive Electron Donor–Acceptor Complex

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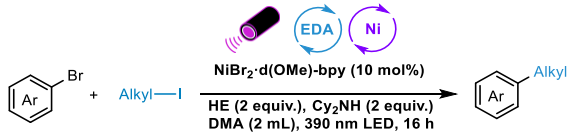
1. General Information

Unless otherwise noted, all commercially available aryl bromides and alkyl iodides were purchased from Sigma-Aldrich and used as provided without further purification. Solvents for chromatography were HPLC grade. Anhydrous and degassed DMA used in reactions was purchased from Sigma-Aldrich in Sure/Seal™ bottle (≥99%). All Analytical thin-layer chromatography (TLC) was performed on Merck silica gel aluminium plates with F-254 indicator, visualized by irradiation with UV light. Column chromatography was performed on silica gel (particle size 0.043–0.063 mm) by using Interchim PuriFlash®430 automatic purification system. ^{1}H-NMR and ^{13}C-NMR were recorded on Bruker DRX-500 and AMX-400 instruments in $CDCl_3$ and are reported relative to the solvent residual peaks. Data are reported in the following order: chemical shift (δ) in ppm; multiplicities are indicated s (singlet), bs (broad singlet), d (doublet), t (triplet), m (multiplet); coupling constants (*J*) are in Hertz (Hz). Mass spectra (EI-MS, 70 eV) were conducted on an Agilent 7890 gas chromatograph equipped with 5975C EI-MSD Triple-Axis Detector using DB5MS and HP5MS columns. HRMS analysis was performed using a Thermo LTQ Velos Orbitrap mass spectrometer (Thermo Scientific, Pittsburgh, PA, USA) equipped with an ESI source.

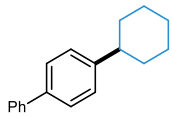
2. General Procedure for the Photoinduced C(sp^2)−C(sp^3) Coupling of Aryl Bromides and Alkyl Iodides



A dry 5 mL vial equipped with a stirring bar was charged with an aryl bromide (0.2 mmol, 1 equiv.), $NiBr_2$·d(OMe)-bpy (0.02 mmol) and HE (0.4 mmol, 2 equiv.) in glovebox. Anhydrous and degassed DMA (2 mL), Cy_2NH (2 equiv.) and alkyl iodide (0.40 mmol) were added subsequently via syringe. The reaction mixture was stirred for 16 h under the irradiation of 390 nm purpule LED with fan cooling. After the reaction is completed, the mixture was transferred to a 100 mL round bottom flask via syringe. The solution was diluted with H_2O (30 mL), extract by ethyl acetate (3×20 mL), and the combined organic layers were concentrated with a rotary evaporator. The product was purified by flash column chromatography on silica gel using hexane/EtOAc as eluent.

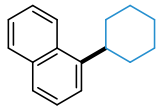
3. Spectroscopic Data of the Products

4-cyclohexyl-1,1'-biphenyl (3a)



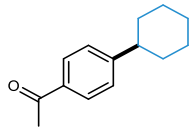
Yield: 80% (37.8 mg), white solid; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.13 (s, 4H), 2.53 – 2.43 (m, 1H), 2.34 (s, 3H), 1.85 (t, J = 9.4 Hz, 4H), 1.76 (d, J = 15.7 Hz, 1H), 1.50 – 1.32 (m, 4H), 1.28 (d, J = 2.0 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 145.2, 135.2, 129.0, 126.7, 44.2, 34.6, 27.0, 26.2, 21.0. Data in accordance with the literature[1].

1-cyclohexylnaphthalene (3b)



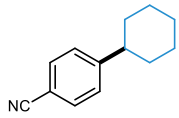
Yield: 63% (26.5 mg), colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.03 (d, J = 8.4 Hz, 1H), 7.76 (d, J = 7.4 Hz, 1H), 7.60 (d, J = 7.9 Hz, 1H), 7.45 – 7.26 (m, 4H), 3.35 – 3.13 (m, 1H), 2.07 – 1.71 (m, 5H), 1.55 – 1.39 (m, 4H), 1.32 – 1.19 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 143.9, 134.0, 131.4, 129.0, 126.3, 125.7, 125.6, 125.3, 123.3, 122.3, 39.3, 34.3, 27.3, 26.6. Data in accordance with the literature[1].

1-(4-cyclohexylphenyl) ethan-1-one (3c)



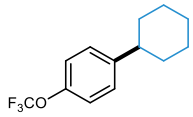
Yield: 80% (32.3 mg), colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81 (d, J = 8.4 Hz, 2H), 7.22 (d, J = 8.3 Hz, 2H), 2.50 (s, 4H), 1.88 – 1.72 (m, 4H), 1.69 (d, J = 13.9 Hz, 1H), 1.42 – 1.27 (m, 4H), 1.24 – 1.11 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 197.9, 153.8, 135.0, 128.6, 127.1, 44.7, 34.1, 26.7, 26.6, 26.0.Data in accordance with the literature[1].

4-cyclohexylbenzonitrile (3d)



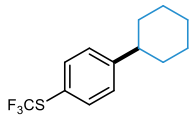
Yield:64% (23.7 mg), colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50 (d, J = 8.2 Hz, 2H), 7.23 (d, J = 8.2 Hz, 2H), 2.79 – 2.24 (m, 1H), 1.85 – 1.73 (m, 4H), 1.69 (d, J = 8.5 Hz, 1H), 1.31 (q, J = 10.9, 10.5 Hz, 4H), 1.19 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 153.5, 132.2, 127.7, 119.3, 109.6, 44.8, 34.0, 26.6, 25.9. Data in accordance with the literature[2].

1-cyclohexyl-4-(trifluoromethoxy) benzene (3e)



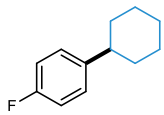
Yield:74% (36.1 mg), colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.13 (d, J = 8.7 Hz, 2H), 7.04 (d, J = 8.3 Hz, 2H), 2.50 – 2.36 (m, 1H), 1.84 – 1.72 (m, 4H), 1.68 (d, J = 12.6 Hz, 1H), 1.37 – 1.24 (m, 4H), 1.23 – 1.12 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 147.3, 147.0, 128.0, 120.9, 120.6 (q, J = 256.3 Hz), 44.0, 34.5, 26.8, 26.1. ^{19}F NMR (377 MHz, $CDCl_3$) δ -57.9. Data in accordance with the literature[1].

(4-cyclohexylphenyl) (trifluoromethyl)sulfane (3f)



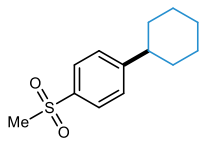
Yield:87% (45.3 mg), colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.48 (d, J = 8.0 Hz, 2H), 7.17 (d, J = 8.0 Hz, 2H), 2.55 – 2.37 (m, 1H), 1.85 – 1.72 (m, 4H), 1.68 (d, J = 11.5 Hz, 1H), 1.40 – 1.25 (m, 4H), 1.21 – 1.15 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 151.3, 136.5, 128.1, 129.75 (q, J = 308.1 Hz), 44.4, 34.2, 26.8, 26.1. ^{19}F NMR (377 MHz, $CDCl_3$) δ -43.1. Data in accordance with the literature[1].

1-cyclohexyl-4-fluorobenzene (3g)



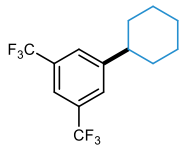
Yield:51% (18.2 mg), colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.11 – 7.03 (m, 2H), 6.94 – 6.83 (m, 2H), 2.47 – 2.33 (m, 1H), 1.83 – 1.72 (m, 4H), 1.67 (d, J = 11.4 Hz, 1H), 1.37 – 1.23 (m, 4H), 1.22 – 1.13 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 161.1 (d, J = 242.9 Hz), 143.8 (d, J = 3.1 Hz), 128.1 (d, J = 7.7 Hz), 114.9 (d, J = 20.8 Hz), 43.9, 34.7, 26.9, 26.1. ^{19}F NMR (377 MHz, $CDCl_3$) δ -117.8. Data in accordance with the literature[3].

1-cyclohexyl-4-(methylsulfonyl)benzene (3h)



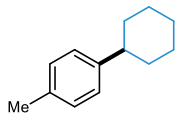
Yield:76% (36.2 mg), white solid; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78 (d, J = 8.5 Hz, 2H), 7.32 (d, J = 8.5 Hz, 2H), 2.97 (s, 3H), 2.57 – 2.48 (m, 1H), 1.86 – 1.75 (m, 4H), 1.70 (d, J = 10.6 Hz, 1H), 1.43 – 1.27 (m, 4H), 1.26 – 1.14 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 154.5, 137.9, 127.8, 127.5, 44.7, 44.6, 34.1, 26.6, 25.9. Data in accordance with the literature[1].

1-cyclohexyl-3,5-bis(trifluoromethyl)benzene (3i)



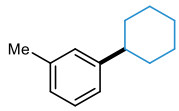
Yield:41% (24.3 mg), colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.62 (s, 1H), 7.57 (s, 2H), 2.65 – 2.49 (m, 1H), 1.88 – 1.76 (m, 4H), 1.71 (d, J = 12.1 Hz, 1H), 1.44 – 1.27 (m, 4H), 1.25 – 1.16 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 150.30, 131.5 (q, J = 32.8 Hz), 127.1, 123.6 (d, J = 272.6 Hz), 120.1 – 119.8 (m), 44.4, 34.2, 26.6, 25.9. ^{19}F NMR (377 MHz, $CDCl_3$) δ -62.8. Data in accordance with the literature[4].

1-cyclohexyl-4-methylbenzene (3j)



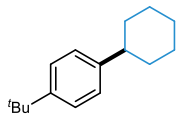
Yield:57% (19.9 mg), colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.13 (s, 4H), 2.53 – 2.43 (m, 1H), 2.34 (s, 3H), 1.85 (t, J = 9.4 Hz, 4H), 1.76 (d, J = 15.7 Hz, 1H), 1.50 – 1.32 (m, 4H), 1.28 (d, J = 2.0 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 145.2, 135.2, 129.0, 126.7, 44.2, 34.6, 27.0, 26.2, 21.0. Data in accordance with the literature[5].

1-cyclohexyl-3-methylbenzene (3k)



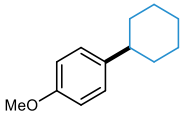
Yield:50% (17.4 mg), colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.11 (t, J = 7.5 Hz, 1H), 6.93 (t, J = 7.6 Hz, 3H), 2.38 (td, J = 11.4, 3.5 Hz, 1H), 2.26 (s, 3H), 1.79 (t, J = 6.8 Hz, 4H), 1.67 (d, J = 13.8 Hz, 1H), 1.33 (q, J = 9.9, 9.0 Hz, 4H), 1.19 – 1.21 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 148.1, 137.8, 128.2, 127.7, 126.5, 123.8, 44.6, 34.5, 27.0, 26.2, 21.5. Data in accordance with the literature[3].

1-(tert-butyl)-4-cyclohexylbenzene (3l)



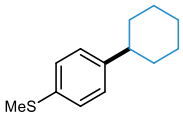
Yield:73% (31.6 mg), colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.23 (d, J = 8.3 Hz, 2H), 7.07 (d, J = 8.4 Hz, 2H), 2.39 (td, J = 11.4, 3.3 Hz, 1H), 1.78 (q, J = 7.3, 4.9 Hz, 4H), 1.66 (d, J = 12.4 Hz, 1H), 1.39 – 1.28 (m, 4H), 1.23 (s, 9H), 1.18 (d, J = 2.0 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 148.4, 145.1, 126.4, 125.1, 44.0, 34.5, 34.4, 31.5, 27.0, 26.2. Data in accordance with the literature[1].

1-cyclohexyl-4-methoxybenzene (3m)



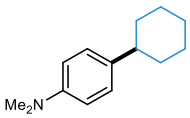
Yield:88% (33.5 mg), white solid; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.05 (d, J = 8.6 Hz, 2H), 6.76 (d, J = 8.7 Hz, 2H), 3.71 (s, 3H), 2.45 – 2.27 (m, 1H), 1.85 – 1.70 (m, 4H), 1.66 (d, J = 12.5 Hz, 1H), 1.39 – 1.22 (m, 4H), 1.22 – 1.07 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 157.7, 140.4, 127.7, 113.7, 55.3, 43.7, 34.8, 27.0, 26.2. Data in accordance with the literature[1].

(4-cyclohexylphenyl)(methyl)sulfane (3n)



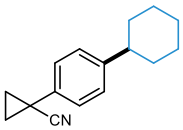
Yield:61% (25.1 mg), white solid; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.13 (d, J = 6.2 Hz, 2H), 7.06 (d, J = 8.3 Hz, 2H), 2.39 (s, 4H), 1.83 – 1.71 (m, 4H), 1.67 (d, J = 12.7 Hz, 1H), 1.38 – 1.25 (m, 4H), 1.23 – 1.11 (m, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 145.4, 135.1, 127.4, 127.2, 44.1, 34.5, 26.9, 26.2, 16.4. Data in accordance with the literature[1].

4-cyclohexyl-N, N-dimethylaniline (3o)



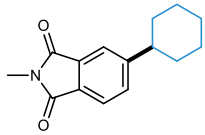
Yield:75% (30.5 mg), colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.02 (d, J = 8.4 Hz, 2H), 6.64 (d, J = 8.2 Hz, 2H), 2.83 (s, 6H), 2.38 – 2.28 (m, 1H), 1.84 – 1.71 (m, 4H), 1.65 (d, J = 13.1 Hz, 1H), 1.37 – 1.23 (m, 4H), 1.22 – 1.14 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 149.0, 136.7, 127.4, 113.1, 43.5, 41.0, 34.8, 27.1, 26.3. Data in accordance with the literature[6].

1-(4-cyclohexylphenyl) cyclopropane-1-carbonitrile (3p)



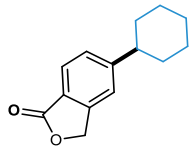
Yield:52% (23.4 mg), colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.17 – 7.07 (m, 4H), 2.49 – 2.33 (m, 1H), 1.85 – 1.71 (m, 4H), 1.67 (d, J = 15.1 Hz, 1H), 1.60 (q, J = 5.0 Hz, 2H), 1.38 – 1.24 (m, 6H), 1.22 – 1.14 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 147.7, 133.3, 127.4, 125.8, 122.8, 44.1, 34.4, 26.8, 26.1, 17.9, 13.5. Data in accordance with the literature[7].

5-cyclohexyl-2-methylisoindoline-1,3-dione (3q)



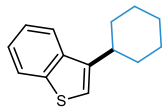
Yield:62% (30.1 mg), white solid; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.66 (d, J = 7.7 Hz, 1H), 7.62 (d, J = 1.5 Hz, 1H), 7.44 (dd, J = 7.6, 1.6 Hz, 1H), 3.08 (s, 3H), 2.62 – 2.52 (m, 1H), 1.87 – 1.75 (m, 4H), 1.70 (d, J = 14.2 Hz, 1H), 1.45 – 1.27 (m, 4H), 1.26 – 1.15 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 168.9, 168.6, 132.7, 132.6, 129.9, 123.2, 121.6, 45.0, 34.2, 26.6, 25.9, 23.9. Data in accordance with the literature[8].

5-cyclohexylisobenzofuran-1(3H)-one (3r)



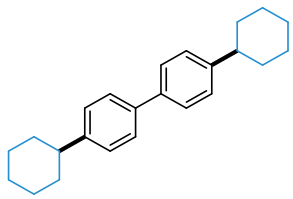
Yield:87% (37.6 mg), white solid; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.75 (d, J = 8.0 Hz, 1H), 7.30 (d, J = 8.0 Hz, 1H), 7.24 (s, 1H), 5.21 (s, 2H), 2.64 – 2.49 (m, 1H), 1.88 – 1.75 (m, 4H), 1.71 (d, J = 12.6 Hz, 1H), 1.44 – 1.27 (m, 4H), 1.26 – 1.14 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.2, 155.3, 147.1, 128.3, 125.6, 123.5, 120.1, 69.6, 45.1, 34.3, 26.7, 26.0. Data in accordance with the literature[1].

3-cyclohexylbenzo[b]thiophene (3s)



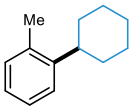
Yield:93% (40.2 mg), colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.77 (d, J = 7.3 Hz, 1H), 7.70 (d, J = 7.1 Hz, 1H), 7.31 – 7.20 (m, 2H), 6.98 (s, 1H), 2.93 – 2.73 (m, 1H), 2.01 (d, J = 8.1 Hz, 2H), 1.79 (d, J = 8.4 Hz, 2H), 1.73 (d, J = 12.6 Hz, 1H), 1.48 – 1.32 (m, 4H), 1.31 – 1.15 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 142.9, 140.6, 138.6, 124.1, 123.7, 123.0, 121.8, 119.2, 38.0, 33.6, 26.9, 26.4. Data in accordance with the literature[9].

4,4'-dicyclohexyl-1,1'-biphenyl (3t)



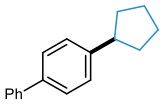
Yield:72% (45.8 mg), white solid; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.42 (d, J = 8.1 Hz, 4H), 7.18 (d, J = 8.1 Hz, 4H), 2.45 (td, J = 11.4, 5.1 Hz, 2H), 1.89 – 1.73 (m, 9H), 1.68 (d, J = 10.9 Hz, 2H), 1.43 – 1.27 (m, 9H), 1.24 – 1.12 (m, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 146.9, 138.7, 127.2, 126.9, 44.3, 34.5, 27.0, 26.2. Data in accordance with the literature[1].

1-cyclohexyl-2-methylbenzene (3u)



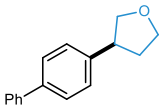
Yield:48% (16.7 mg), colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.26 (m, 1H), 7.20 (dd, *J* = 17.3, 7.6 Hz, 2H), 7.12 (t, *J* = 7.3 Hz, 1H), 2.80 – 2.68 (m, 1H), 2.37 (s, 3H), 1.87 (dd, *J* = 19.6, 7.1 Hz, 4H), 1.80 (m, 1H), 1.45 (t, *J* = 9.7 Hz, 4H), 1.37 – 1.29 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 146.4, 135.2, 131.7, 126.1, 125.5, 125.4, 40.1, 33.7, 27.2, 26.4, 19.4. Data in accordance with the literature[1].

4-cyclopentyl-1,1'-biphenyl (4a)



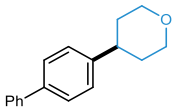
Yield:84% (37.3 mg) , white solid; ^{1}H NMR (400 MHz, $CDCl_3$) *δ* 7.49 (d, *J* = 7.3 Hz, 2H), 7.43 (d, *J* = 8.2 Hz, 2H), 7.33 (t, *J* = 7.7 Hz, 2H), 7.26 – 7.20 (m, 3H), 3.02 – 2.87 (m, 1H), 2.08 – 1.96 (m, 2H), 1.79 – 1.70 (m, 2H), 1.67 – 1.48 (m, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) *δ* 145.7, 141.2, 138.7, 128.8, 128.7, 127.6, 127.04, 126.98, 45.7, 34.7, 25.6. Data in accordance with the literature[1].

(S)-3-([1,1'-biphenyl]-4-yl)tetrahydrofuran (4b)



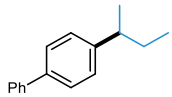
Yield:64% (28.7 mg), white solid; ^{1}H NMR (400 MHz, $CDCl_3$) *δ* 7.50 (d, *J* = 6.9 Hz, 2H), 7.47 (d, *J* = 8.3 Hz, 2H), 7.35 (t, *J* = 7.7 Hz, 2H), 7.28 – 7.25 (m, 2H), 7.25 – 7.23 (m, 1H), 4.09 (t, *J* = 8.0 Hz, 1H), 4.02 (td, *J* = 8.4, 4.5 Hz, 1H), 3.86 (q, *J* = 7.9 Hz, 1H), 3.69 (t, *J* = 8.0 Hz, 1H), 3.37 (p, *J* = 7.8 Hz, 1H), 2.39 – 2.26 (m, 1H), 2.04 – 1.91 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) *δ* 141.8, 140.9, 139.5, 128.8, 127.7, 127.3, 127.2, 127.0, 74.7, 68.6, 44.7, 34.7. Data in accordance with the literature[1].

4-([1,1'-biphenyl]-4-yl)tetrahydro-2H-pyran (4c)



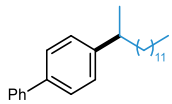
Yield:90% (42.9 mg), white solid; ^{1}H NMR (400 MHz, $CDCl_3$) *δ* 7.50 (d, *J* = 7.5 Hz, 2H), 7.47 (d, *J* = 8.2 Hz, 2H), 7.35 (t, *J* = 7.7 Hz, 2H), 7.26 (d, *J* = 7.4 Hz, 1H), 7.22 (d, *J* = 8.1 Hz, 2H), 4.02 (dd, *J* = 11.5, 2.4 Hz, 2H), 3.54 – 3.39 (m, 2H), 2.78 – 2.66 (m, 1H), 1.85 – 1.75 (m, 2H), 1.75 – 1.67 (m, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) *δ* 145.0, 141.0, 139.3, 128.8, 127.3, 127.2, 127.1, 127.0, 68.4, 41.3, 34.0. Data in accordance with the literature[10].

(S)-4-(sec-butyl)-1,1'-biphenyl (4d)



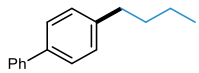
Yield:86% (36.1 mg), white solid; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.51 (d, J = 7.0 Hz, 2H), 7.44 (d, J = 8.2 Hz, 2H), 7.34 (t, J = 7.7 Hz, 2H), 7.23 (t, J = 7.3 Hz, 1H), 7.17 (d, J = 8.2 Hz, 2H), 2.62 – 2.50 (m, 1H), 1.62 – 1.49 (m, 2H), 1.19 (d, J = 7.0 Hz, 3H), 0.78 (t, J = 7.4 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 146.9, 141.2, 138.7, 128.8, 128.7, 127.5, 127.03, 126.97, 41.4, 31.2, 21.9, 12.3. Data in accordance with the literature[11].

(S)-4-(tetradecan-2-yl)-1,1'-biphenyl (4e)



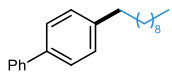
Yield:73% (51.1 mg), white solid; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50 (d, J = 7.6 Hz, 2H), 7.43 (d, J = 8.0 Hz, 2H), 7.33 (t, J = 7.6 Hz, 2H), 7.22 (t, J = 7.4 Hz, 1H), 7.16 (d, J = 8.0 Hz, 2H), 2.69 – 2.57 (m, 1H), 1.57 – 1.45 (m, 2H), 1.22 – 1.12 (m, 23H), 0.79 (t, J = 6.7 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 147.2, 141.2, 138.7, 128.8, 128.7, 127.4, 127.04, 126.96, 39.7, 38.5, 32.0, 29.8, 29.74, 29.65, 29.4, 27.8, 22.8, 22.4, 14.2. Data in accordance with the literature[1].

4-butyl-1,1'-biphenyl (4f)



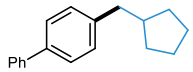
Yield:69% (29.0 mg), colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50 (d, J = 7.2 Hz, 2H), 7.43 (d, J = 6.3 Hz, 2H), 7.34 (t, J = 7.7 Hz, 2H), 7.23 (t, J = 7.4 Hz, 1H), 7.17 (d, J = 8.0 Hz, 2H), 2.57 (t, J = 7.8 Hz, 2H), 1.56 (p, J = 7.6 Hz, 2H), 1.38 – 1.24 (m, 2H), 0.87 (t, J = 7.3 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 142.1, 141.2, 138.6, 128.9, 128.8, 128.7, 127.03, 126.98, 35.3, 33.7, 22.5, 14.0. Data in accordance with the literature[12].

4-decyl-1,1'-biphenyl (4g)



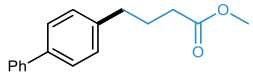
Yield:75% (44.1 mg), white solid; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50 (d, J = 7.2 Hz, 2H), 7.43 (d, J = 8.1 Hz, 2H), 7.33 (t, J = 7.6 Hz, 2H), 7.23 (t, J = 7.3 Hz, 1H), 7.17 (d, J = 7.9 Hz, 2H), 2.56 (t, J = 7.8 Hz, 2H), 1.63 – 1.51 (m, 2H), 1.30 – 1.16 (m, 14H), 0.80 (t, J = 6.7 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 142.2, 141.2, 138.6, 128.9, 128.8, 128.7, 127.02, 126.98, 35.7, 32.0, 31.6, 29.69, 29.67, 29.6, 29.44, 29.40, 22.7, 14.2. Data in accordance with the literature[13].

4-(cyclopentylmethyl)-1,1'-biphenyl (4h)



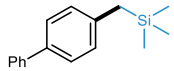
Yield:83% (39.2 mg), colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.51 (d, *J* = 7.2 Hz, 2H), 7.42 (d, *J* = 6.1 Hz, 2H), 7.34 (t, *J* = 7.7 Hz, 2H), 7.24 (t, *J* = 7.4 Hz, 1H), 7.16 (d, *J* = 8.0 Hz, 2H), 2.57 (d, *J* = 7.4 Hz, 2H), 2.11 – 1.97 (m, 1H), 1.71 – 1.61 (m, 2H), 1.61 – 1.52 (m, 2H), 1.49 – 1.41 (m, 2H), 1.19 – 1.11 (m, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 141.6, 141.2, 138.5, 129.3, 128.7, 126.97, 126.92, 126.9, 42.0, 41.8, 32.6, 25.0. Data in accordance with the literature[14].

methyl 4-([1,1'-biphenyl]-4-yl)butanoate (4i)



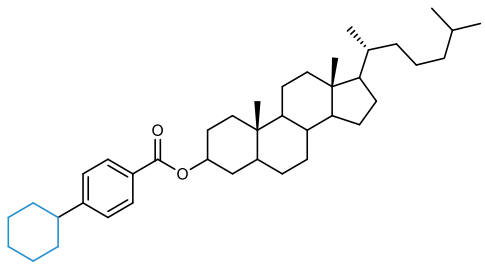
Yield:78% (39.6 mg), colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) *δ* 7.49 (d, *J* = 7.9 Hz, 2H), 7.44 (d, *J* = 8.3 Hz, 2H), 7.34 (t, *J* = 7.6 Hz, 2H), 7.24 (t, *J* = 7.3 Hz, 1H), 7.17 (d, *J* = 8.0 Hz, 2H), 3.59 (s, 3H), 2.61 (t, *J* = 7.6 Hz, 2H), 2.28 (t, *J* = 7.4 Hz, 2H), 1.91 (p, *J* = 7.5 Hz, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) *δ* 174.0, 141.1, 140.5, 139.0, 128.9, 128.7, 127.2, 127.1, 127.0, 51.6, 34.8, 33.4, 26.5. Data in accordance with the literature[15].

([1,1'-biphenyl]-4-ylmethyl)trimethylsilane (4j)



Yield:68% (32.7 mg), white solid; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.71 (d, *J* = 7.0 Hz, 2H), 7.59 (d, *J* = 8.2 Hz, 2H), 7.54 (t, *J* = 7.7 Hz, 2H), 7.42 (t, *J* = 7.3 Hz, 1H), 7.19 (d, *J* = 8.2 Hz, 2H), 2.25 (s, 2H), 0.15 (s, 9H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 141.3, 139.8, 136.8, 128.7, 128.5, 126.9, 126.8, 126.8, 26.8, -1.8. Data in accordance with the literature[16].

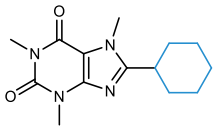
(10S,13R)-17-butyl-10,13-dimethylhexadecahydro-1H-cyclopenta[a]phenanthren-3-yl 4-cyclohexylbenzoate (5a)



Yield:60% (62.2 mg), white solid; ^{1}H NMR (400 MHz, $CDCl_3$) *δ* 7.87 (d, *J* = 8.3 Hz, 2H), 7.17 (d, *J* = 8.3 Hz, 2H), 4.98 – 4.74 (m, 1H), 2.52 – 2.41 (m, 1H), 1.81 – 0.97 (m, 41H), 0.83 (d, *J* = 6.4 Hz, 3H), 0.80 (d, *J* = 1.9 Hz, 3H), 0.78 (d, *J* = 2.3 Hz, 6H), 0.58 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) *δ* 166.2, 153.2, 129.7, 128.6, 126.8, 74.1, 56.5, 56.3, 54.3, 44.8, 44.7, 42.6, 40.0, 39.6, 36.9, 36.2, 35.9, 35.6, 34.2, 32.1, 28.7, 28.3, 28.1, 27.7, 26.8, 26.1, 24.3, 23.9, 22.9, 22.6, 21.3, 18.7, 12.3, 12.1. Data in accordance with the

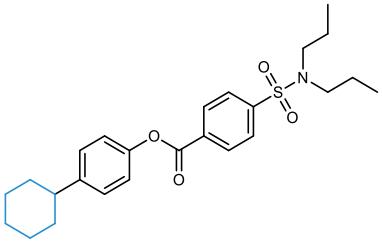
literature.[1]

8-cyclohexyl-1,3,7-trimethyl-3,7-dihydro-1H-purine-2,6-dione (5b)



Yield:33% (18.2 mg), white solid; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.86 (s, 3H), 3.50 (s, 3H), 3.32 (s, 3H), 2.69 – 2.59 (m, 1H), 1.88 – 1.75 (m, 4H), 1.73 – 1.55 (m, 4H), 1.38 – 1.32 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 158.03, 155.51, 151.83, 148.14, 107.05, 35.83, 31.42, 30.96, 29.77, 27.85, 26.02, 25.58. Data in accordance with the literature[17].

4-cyclohexylphenyl 4-(N,N-dipropylsulfamoyl)benzoate (5c)



Yield:62% (55.0 mg), white solid; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.24 (d, J = 8.5 Hz, 2H), 7.87 (d, J = 8.5 Hz, 2H), 7.20 (d, J = 8.3 Hz, 2H), 7.05 (d, J = 8.6 Hz, 2H), 3.14 – 2.96 (m, 4H), 2.57 – 2.37 (m, 1H), 1.88 – 1.73 (m, 4H), 1.68 (d, J = 10.5 Hz, 1H), 1.52 – 1.44 (m, 4H), 1.42 – 1.26 (m, 4H), 1.21 – 1.16 (m, 1H), 0.81 (t, J = 7.4 Hz, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 164.1, 148.6, 146.1, 144.8, 133.1, 130.8, 127.9, 127.2, 121.1, 50.0, 44.1, 34.6, 26.9, 26.1, 22.0, 11.2. Data in accordance with the literature[1].

4. References

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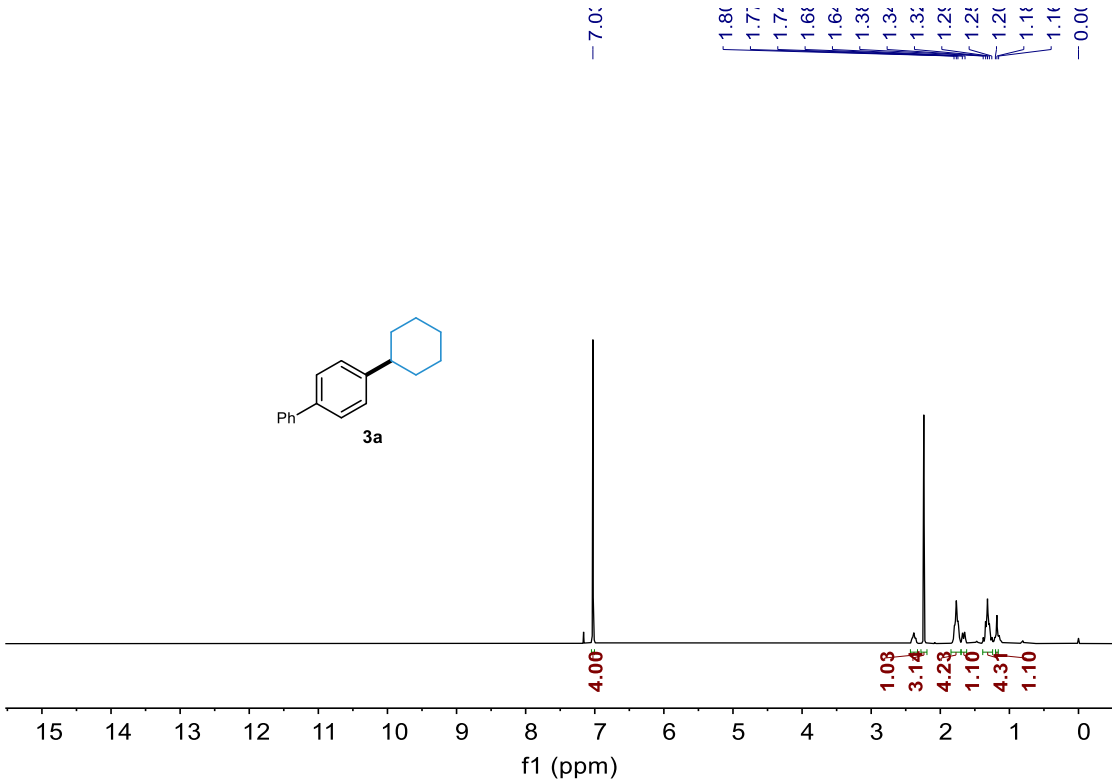
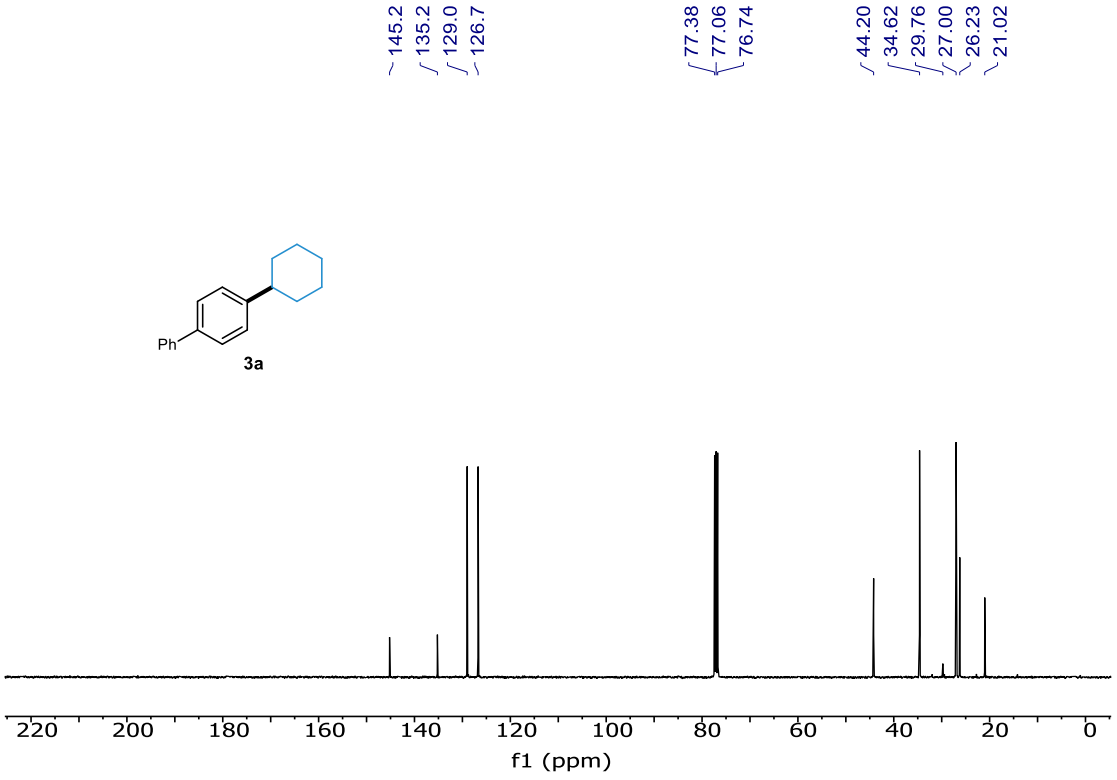
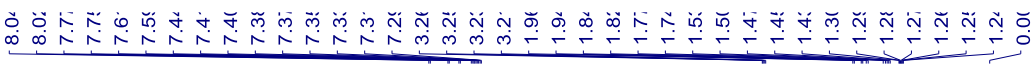
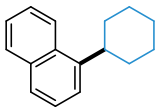
5. Copies of Products 1H NMR and 13C NMR:

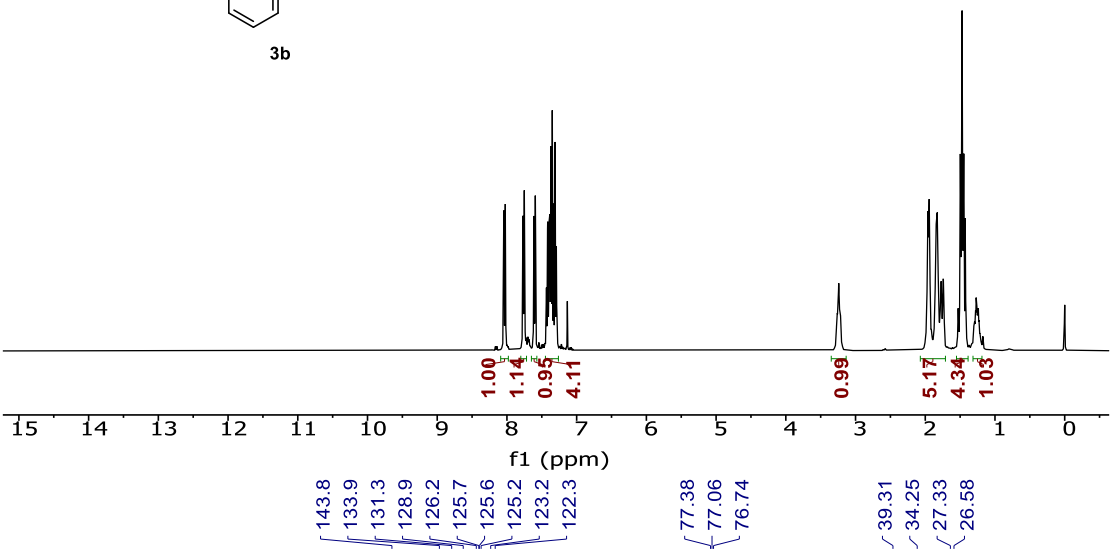




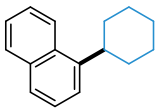




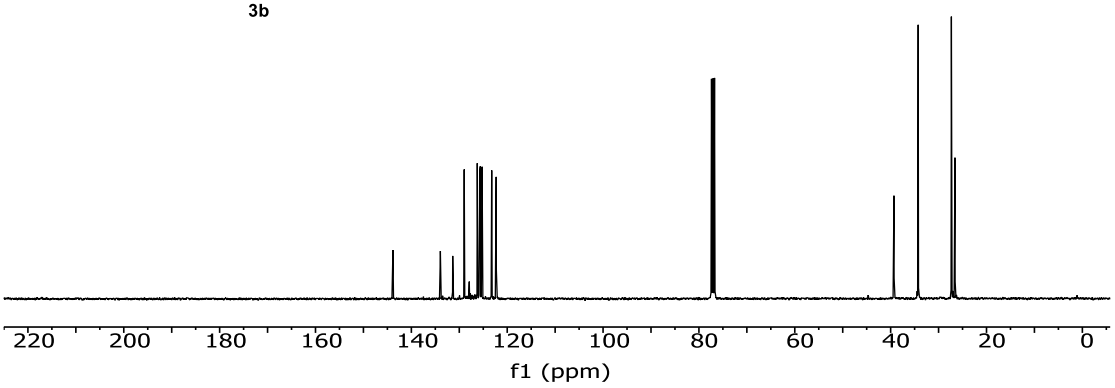
3b


1.00
1.14
0.95
4.11
0.99
5.17
4.34
1.03
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)

143.8
133.9
131.3
128.9
126.2
125.7
125.6
125.2
123.2
122.3
77.38
77.06
76.74
39.31
34.25
27.33
26.58



3b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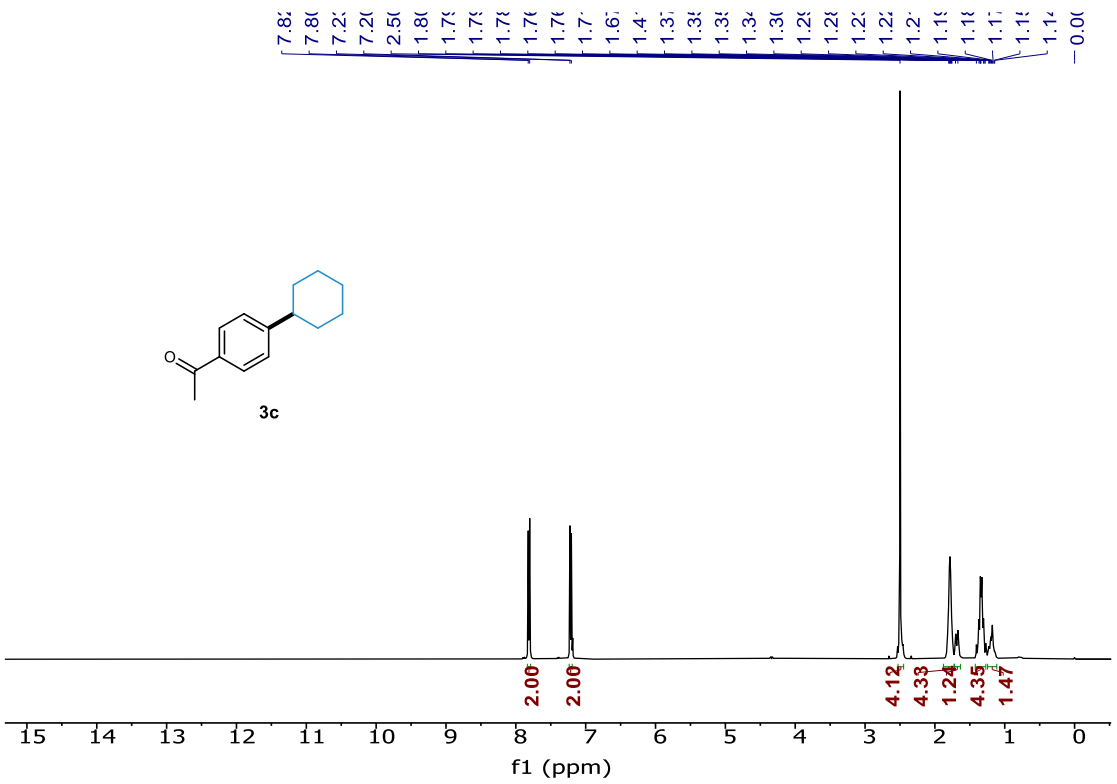
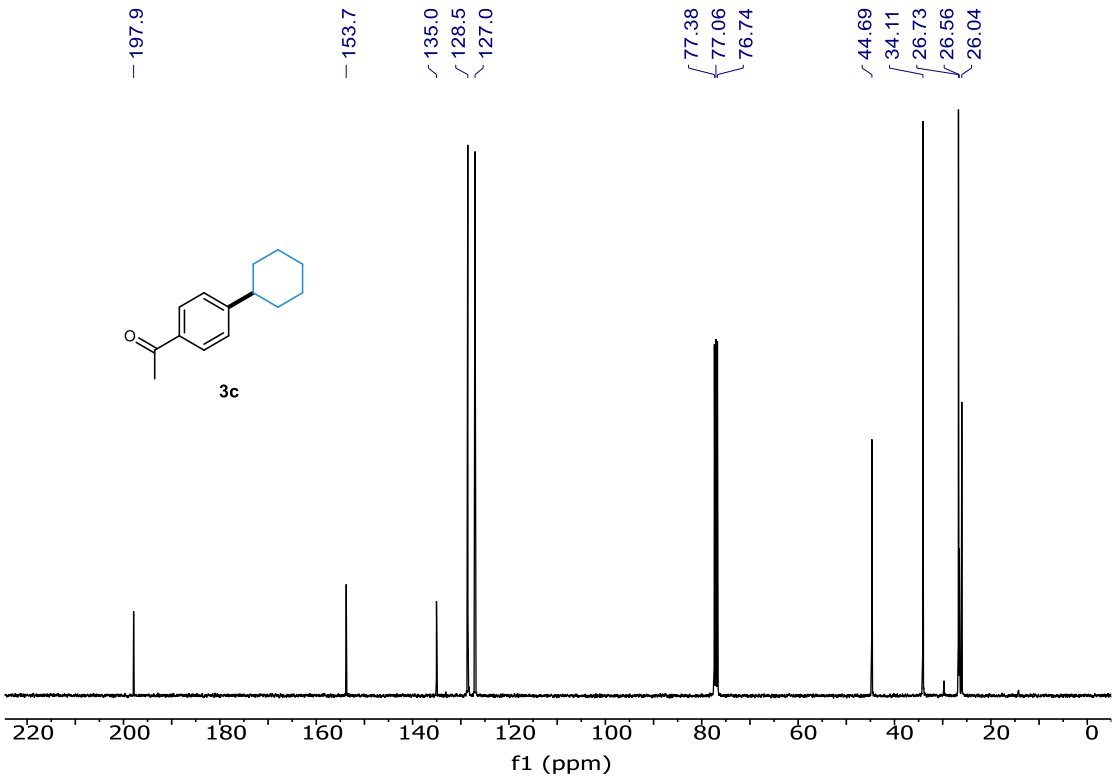
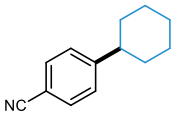
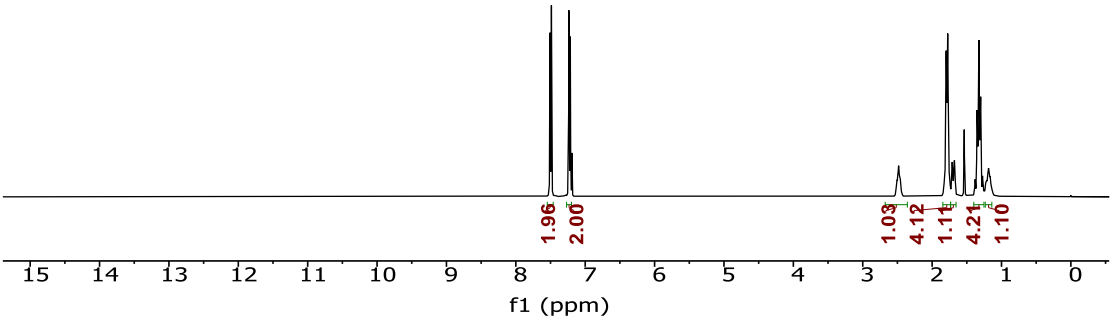
f1 (ppm)

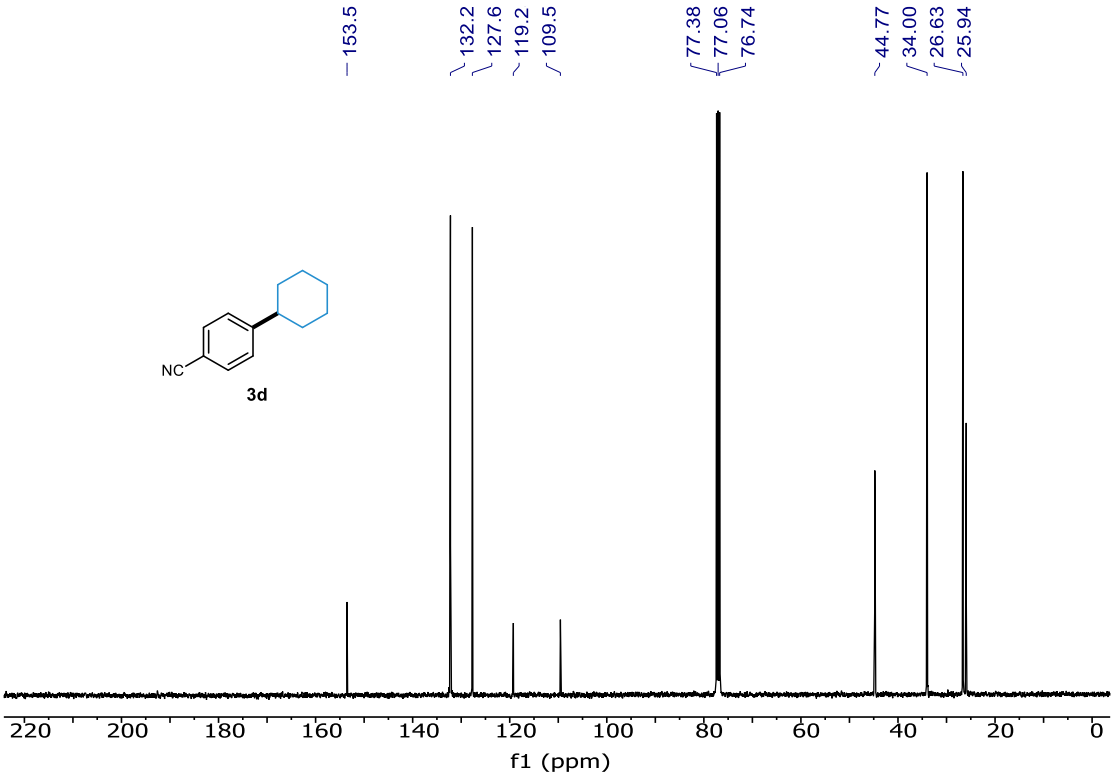

7.84
7.80
7.24
7.20
2.50
1.80
1.75
1.73
1.71
1.70
1.70
1.70
1.63
1.47
1.33
1.31
1.31
1.34
1.30
1.28
1.28
1.24
1.22
1.22
1.20
1.15
1.13
1.11
1.11
1.14
0.00
O
3c
2.00
2.00
4.12
4.33
1.24
4.35
1.47
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)


197.9
153.7
135.0
128.5
127.0
77.38
77.06
76.74
44.69
34.11
26.73
26.56
26.04
O
3c
220 200 180 160 140 120 100 80 60 40 20 0
f1 (ppm)


NC

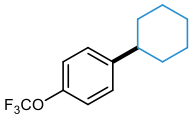
3d


1.96
2.00
1.03
4.12
1.11
4.21
1.10
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)

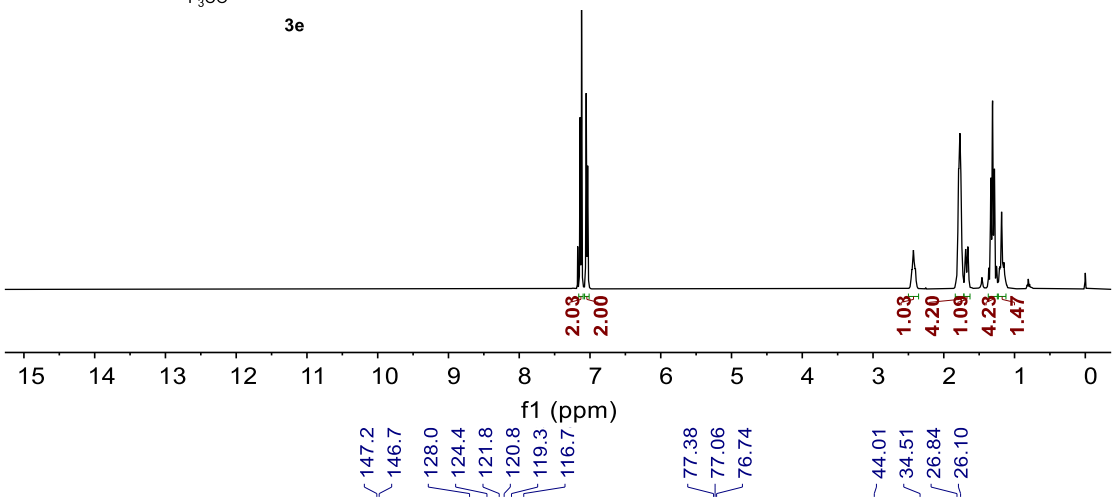

153.5
132.2
127.6
119.2
109.5
77.38
77.06
76.74
44.77
34.00
26.63
25.94
220 200 180 160 140 120 100 80 60 40 20 0
f1 (ppm)

NC

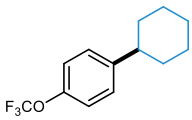
3d


F3CO

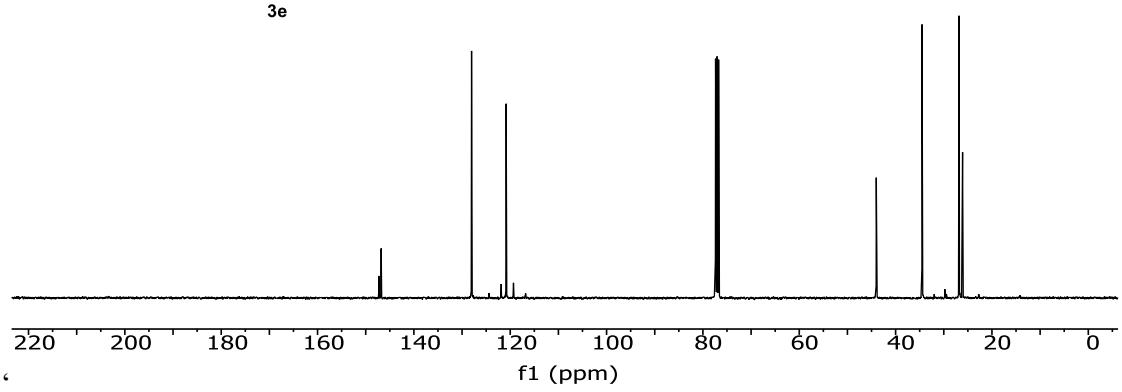
3e

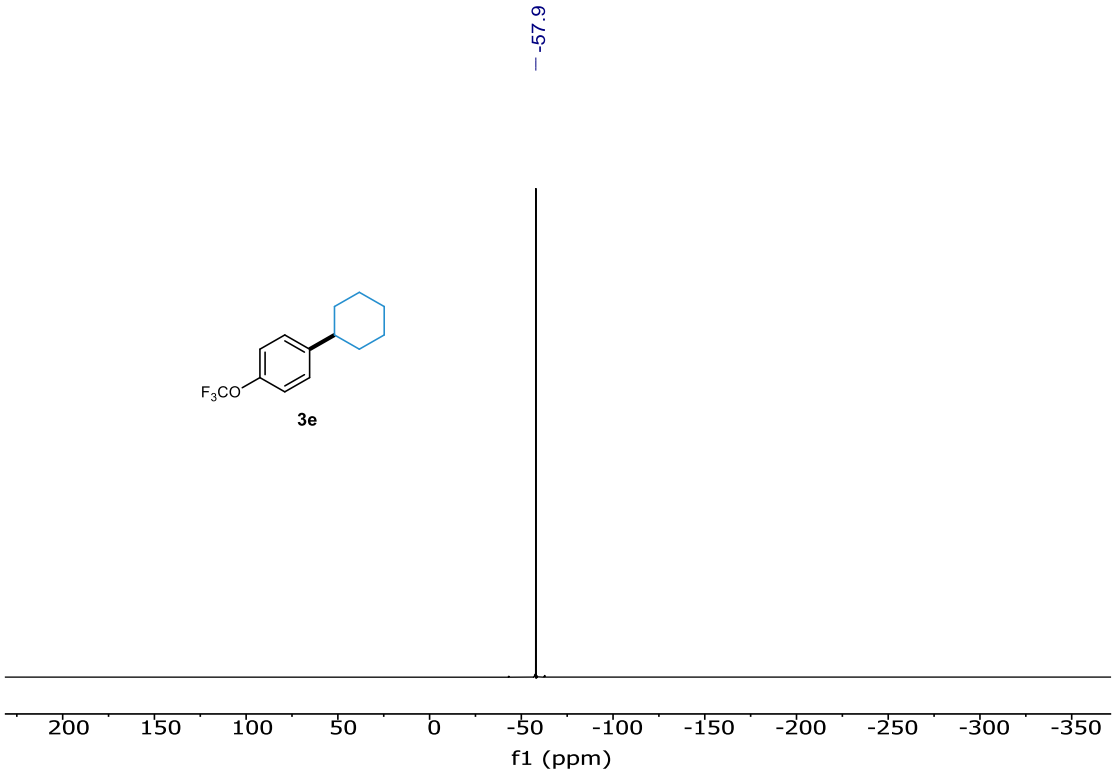

2.03
2.00
1.03
4.20
1.09
4.23
1.47
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)

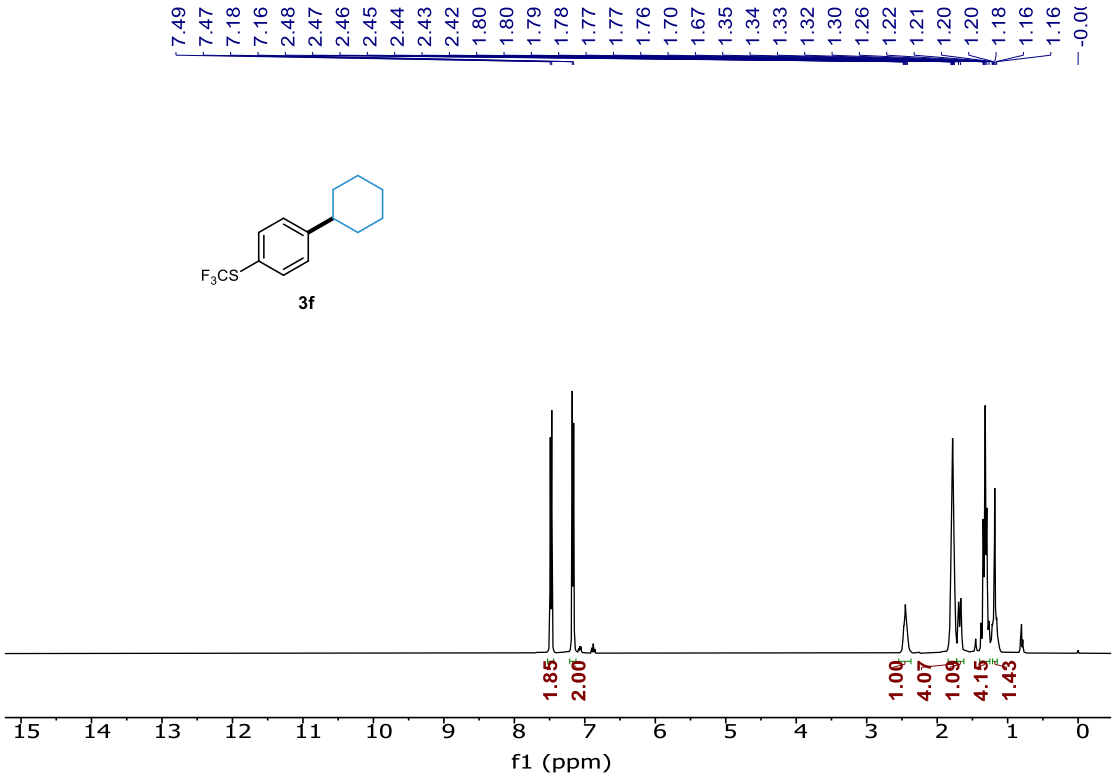
147.2
146.7
128.0
124.4
121.8
120.8
119.3
116.7
77.38
77.06
76.74
44.01
34.51
26.84
26.10

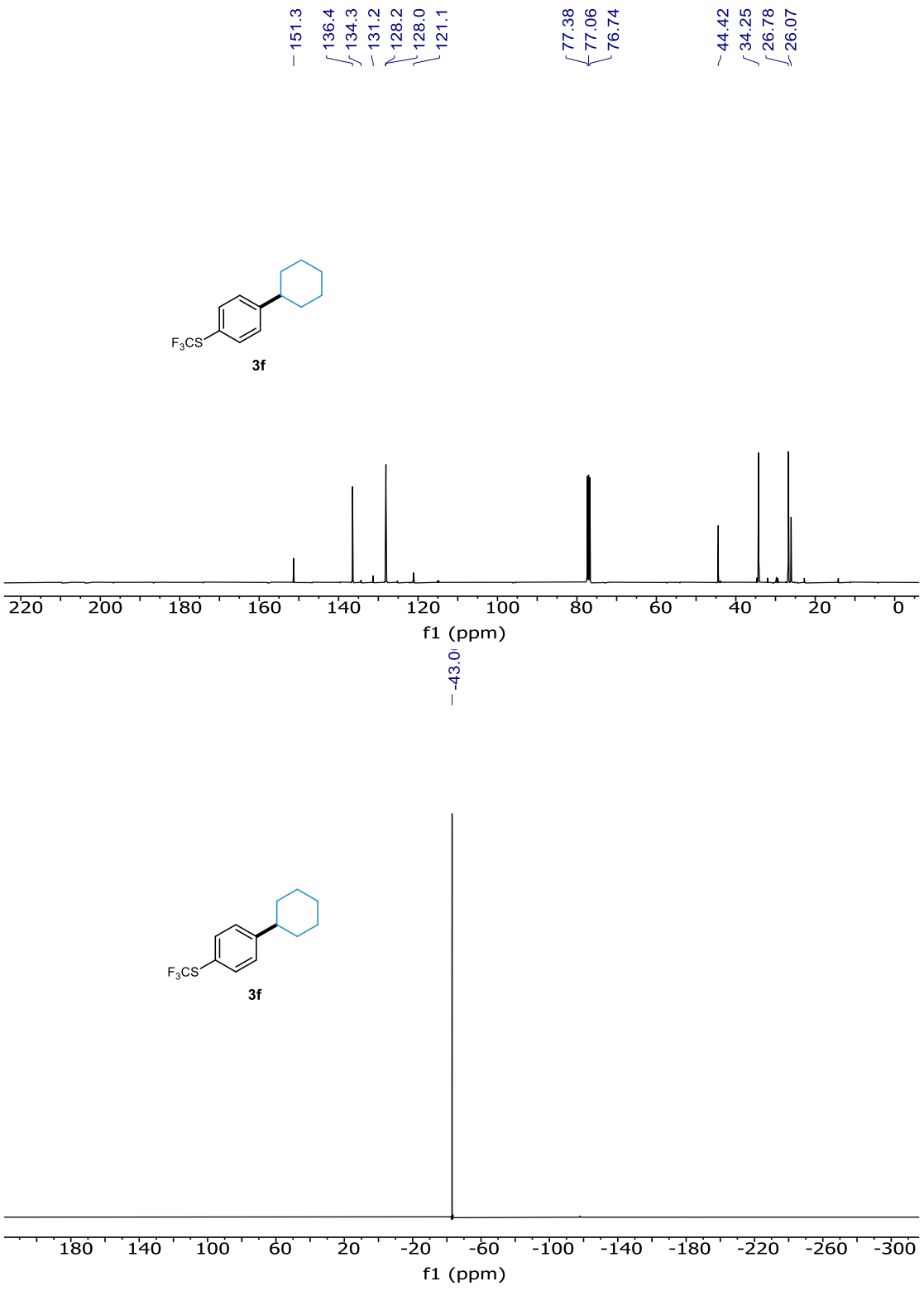

F3CO

3e

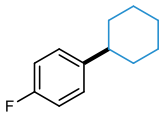

220 200 180 160 140 120 100 80 60 40 20 0
f1 (ppm)


-57.9
F3CO
3e
200
150
100
50
0
-50
-100
-150
-200
-250
-300
-350
f1 (ppm)

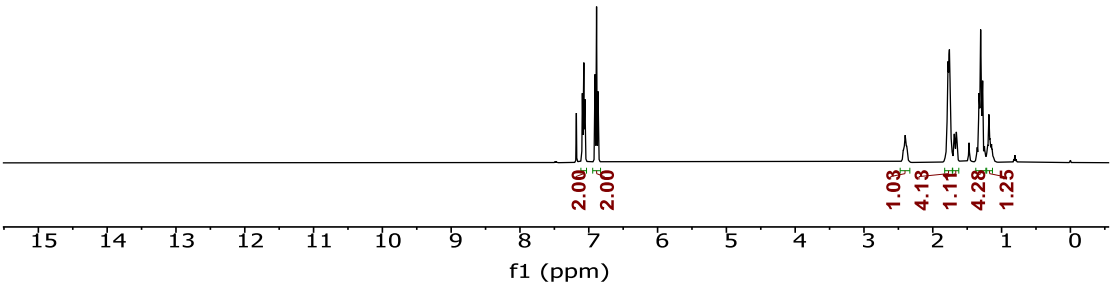

7.49
7.47
7.18
7.16
2.48
2.47
2.46
2.45
2.44
2.43
2.42
1.80
1.80
1.79
1.78
1.77
1.77
1.76
1.70
1.67
1.35
1.34
1.33
1.32
1.30
1.26
1.22
1.21
1.20
1.20
1.18
1.16
1.16
F3CS
3f
1.85
2.00
1.00
4.07
1.09
4.15
1.43
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
f1 (ppm)

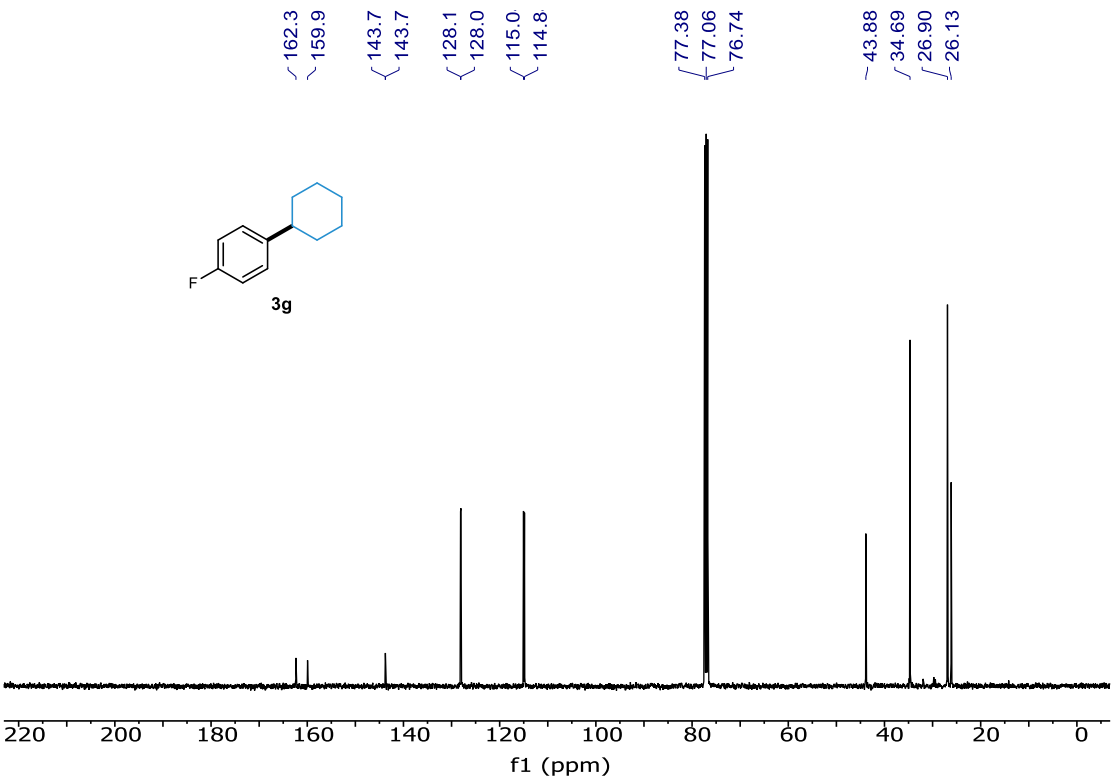

151.3
136.4
134.3
131.2
128.2
128.0
121.1
77.38
77.06
76.74
44.42
34.25
26.78
26.07
F3CS
3f
220
200
180
160
140
120
100
80
60
40
20
0
f1 (ppm)
-43.0
F3CS
3f
180
140
100
60
20
-20
-60
-100
-140
-180
-220
-260
-300
f1 (ppm)

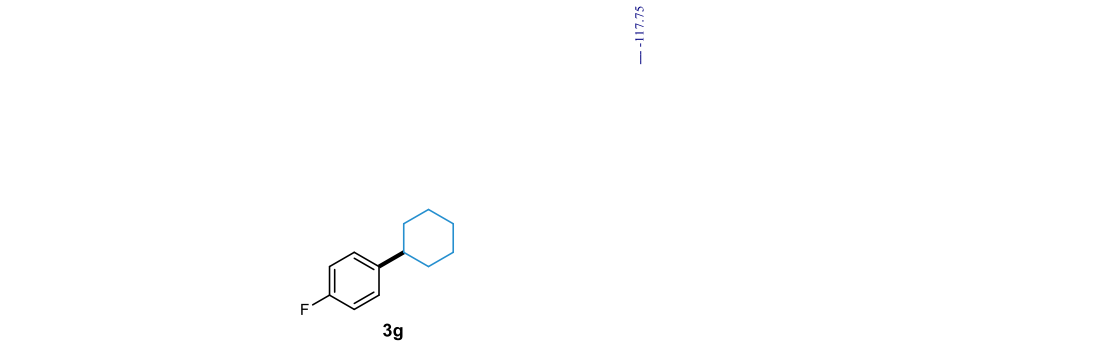

7.09
7.09
7.08
7.07
7.06
7.06
6.91
6.90
6.89
6.89
6.88
6.87
6.86
2.42
2.41
2.40
2.39
2.38
2.37
1.78
1.78
1.76
1.76
1.75
1.74
1.68
1.65
1.33
1.32
1.30
1.30
1.28
1.28
1.21
1.20
1.18
1.17
1.15
1.15
0.00

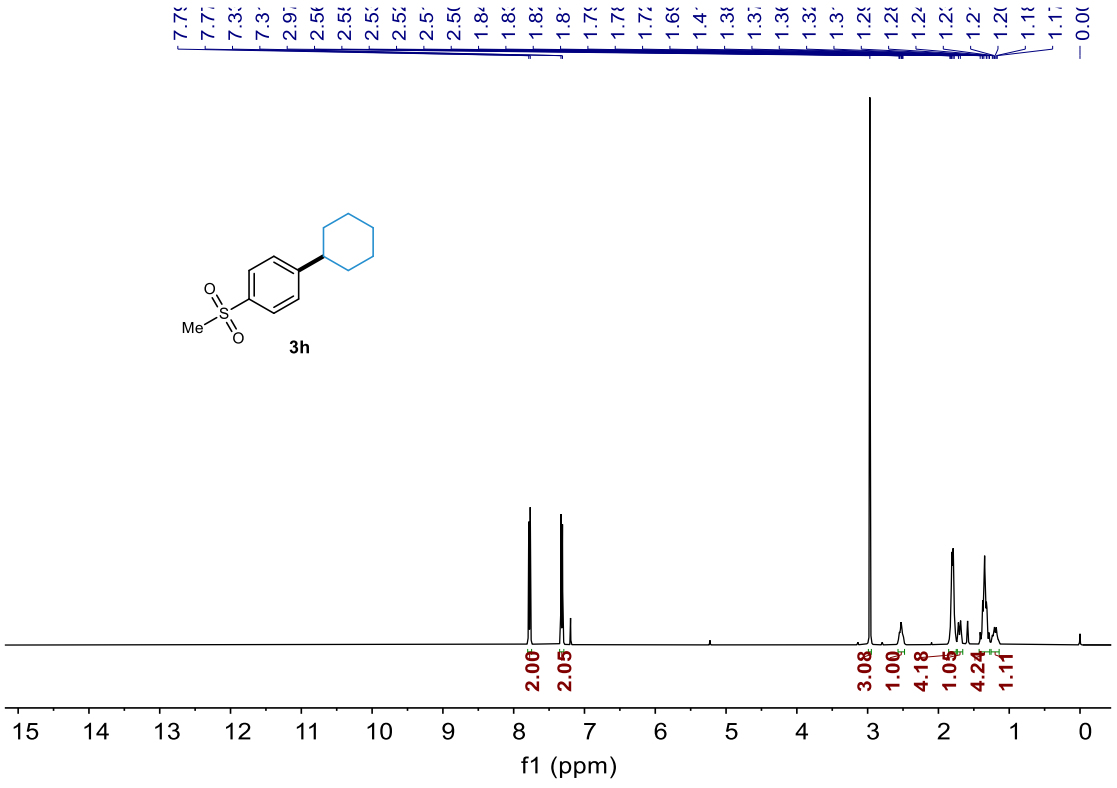

F

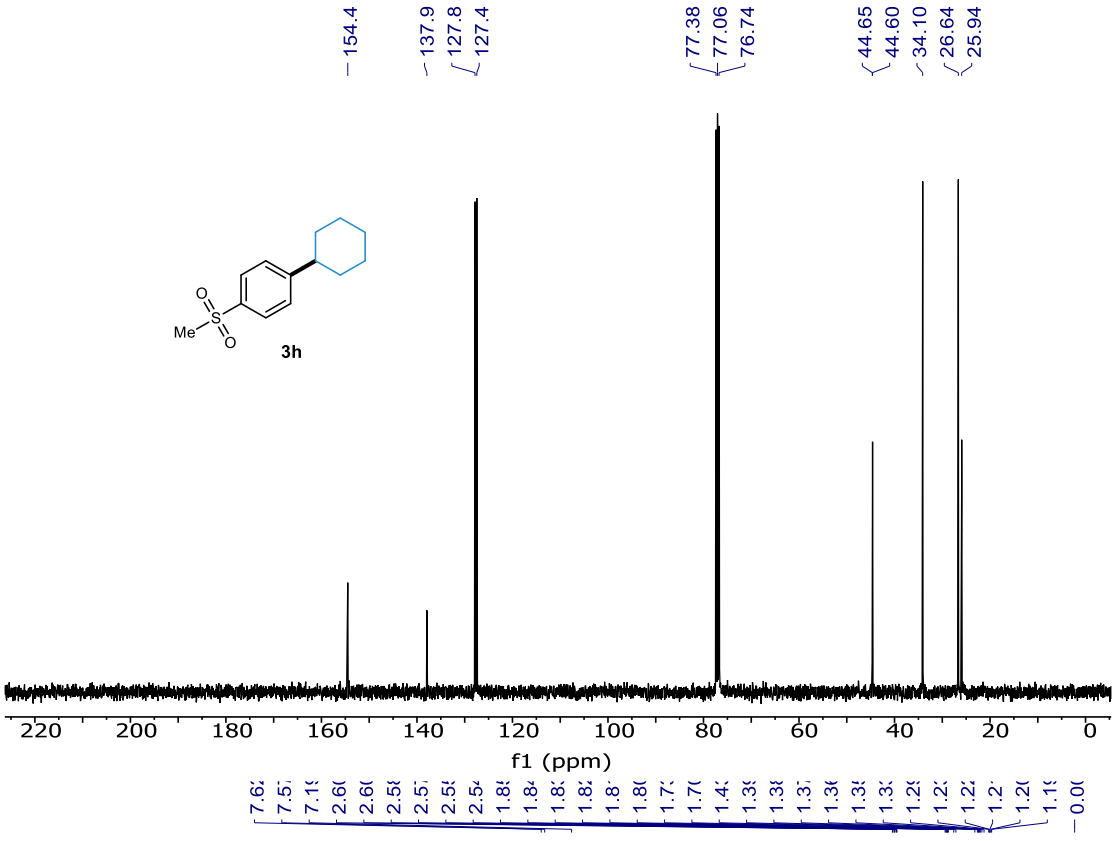
3g

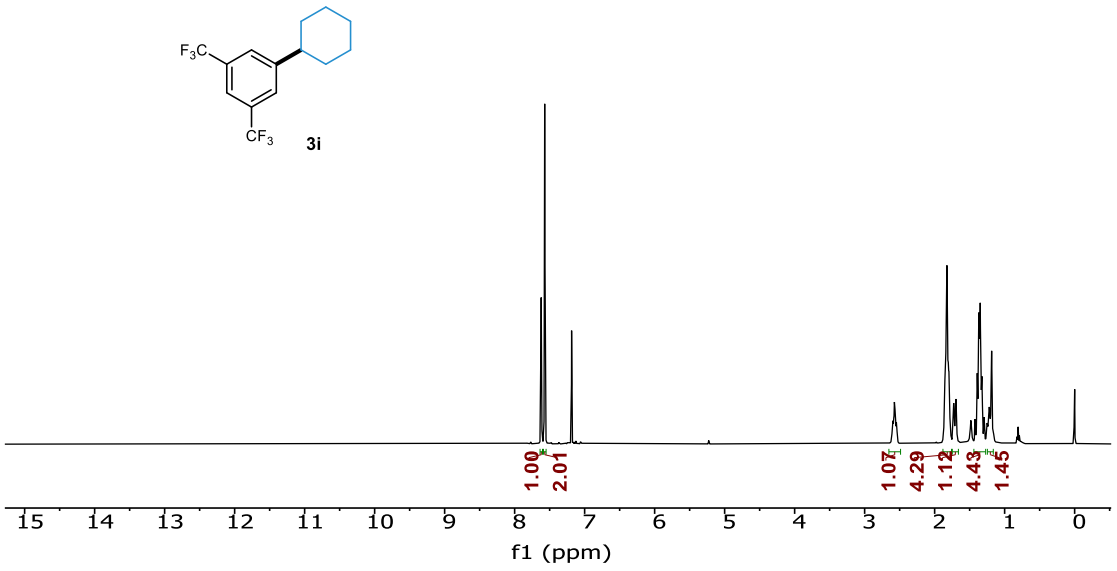

2.00
2.00
1.03
4.13
1.11
4.29
1.25
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
f1 (ppm)

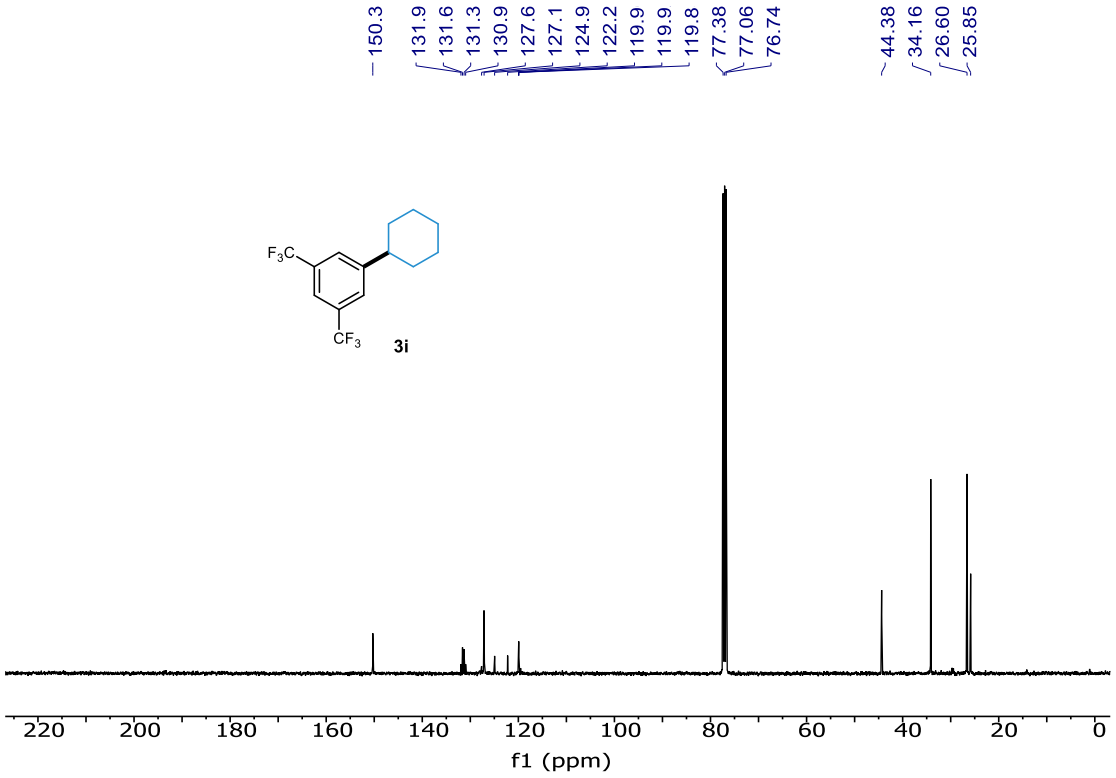

162.3
159.9
143.7
143.7
128.1
128.0
115.0
114.8
77.38
77.06
76.74
43.88
34.69
26.90
26.13
F
3g
220
200
180
160
140
120
100
80
60
40
20
0
f1 (ppm)

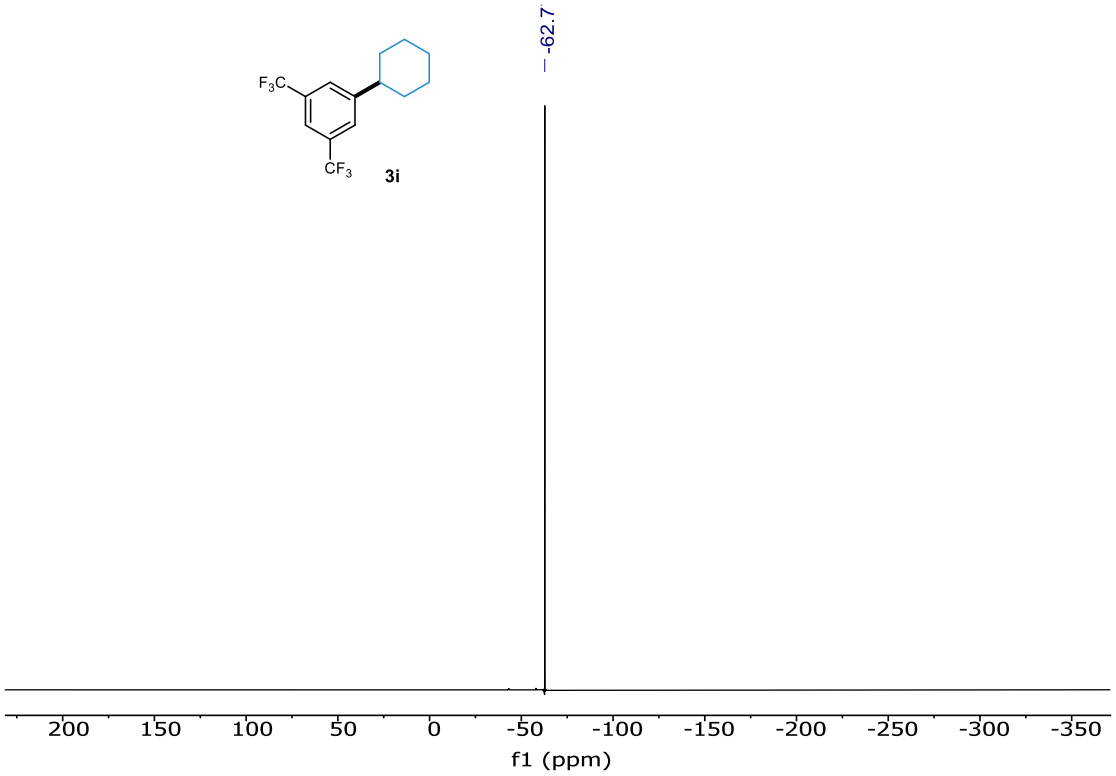

-117.75
F
3g
10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210
f1 (ppm)

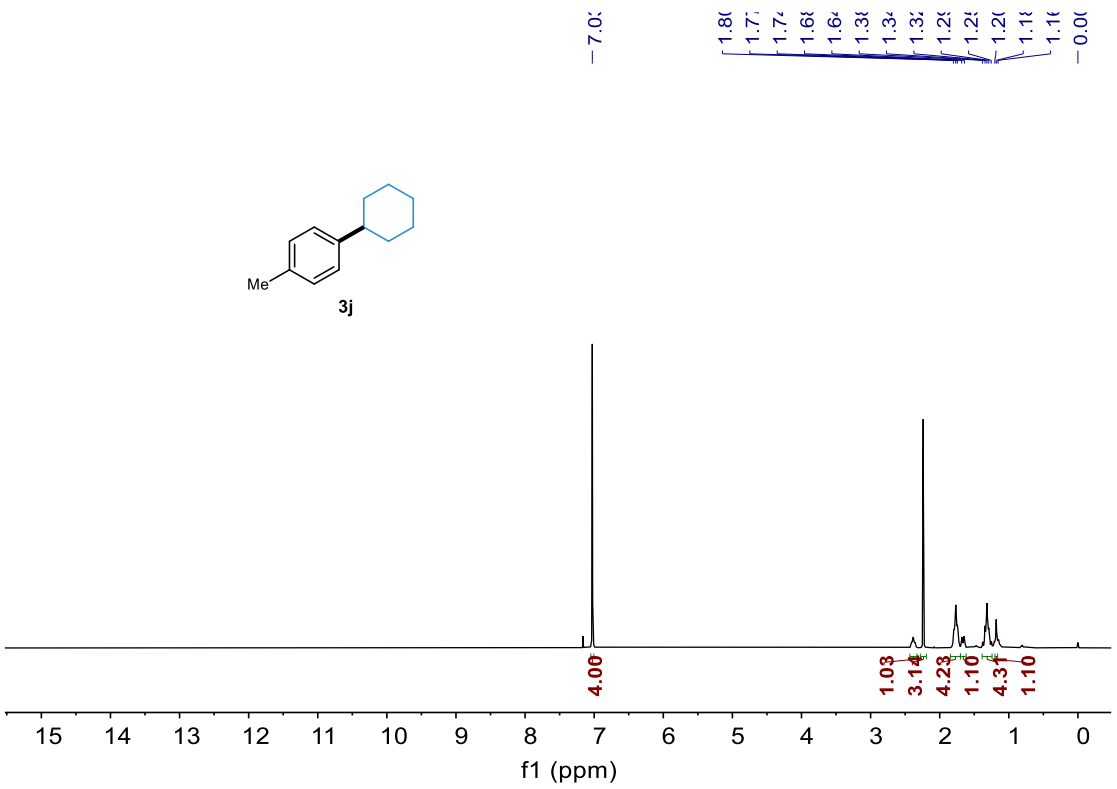

Me
O
S
O
3h
2.00
2.05
3.08
1.00
4.18
1.05
4.24
1.11
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)

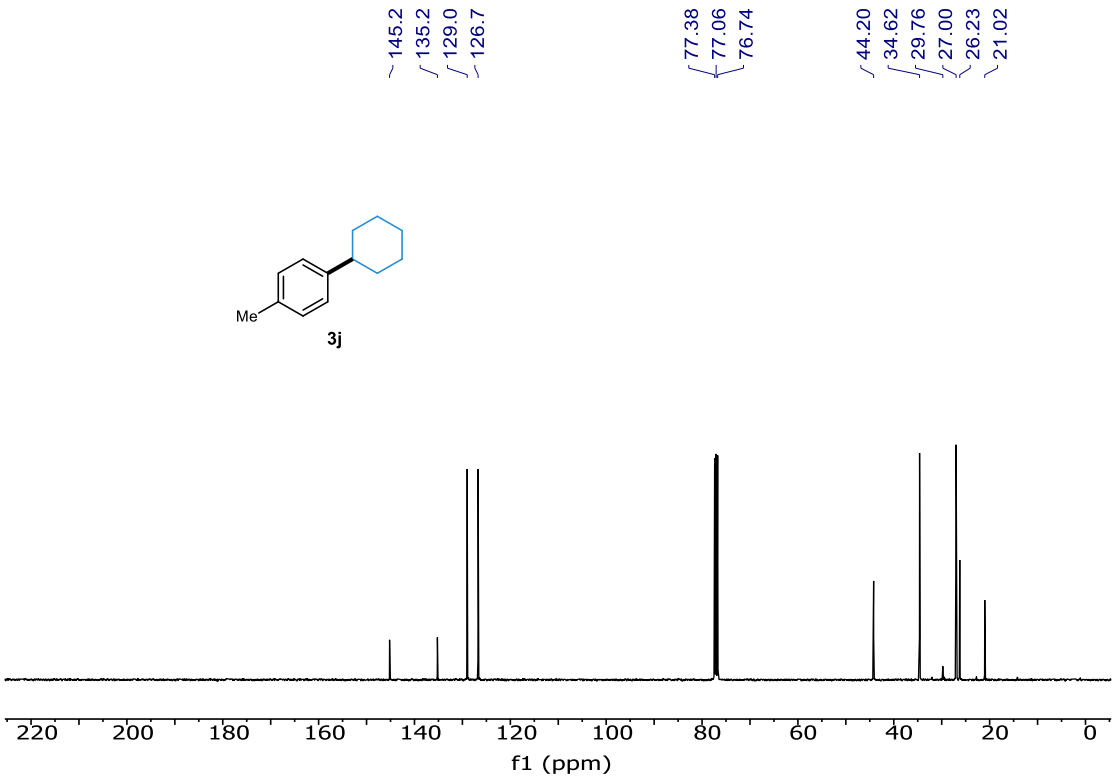

154.4
137.9
127.8
127.4
77.38
77.06
76.74
44.65
44.60
34.10
26.64
25.94
Me
S
O
O
3h
220
200
180
160
140
120
100
80
60
40
20
0
f1 (ppm)

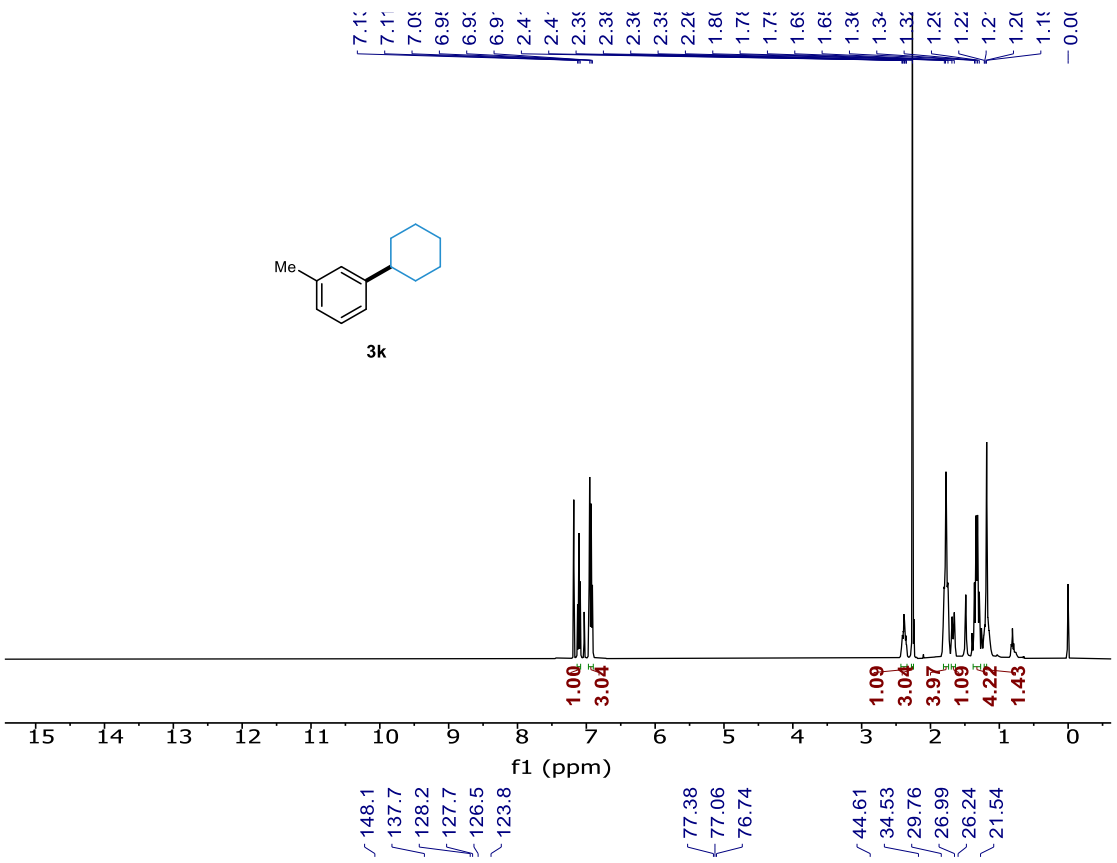

F3C
CF3
3i
1.00
2.01
1.07
4.29
1.12
4.43
1.45
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
f1 (ppm)

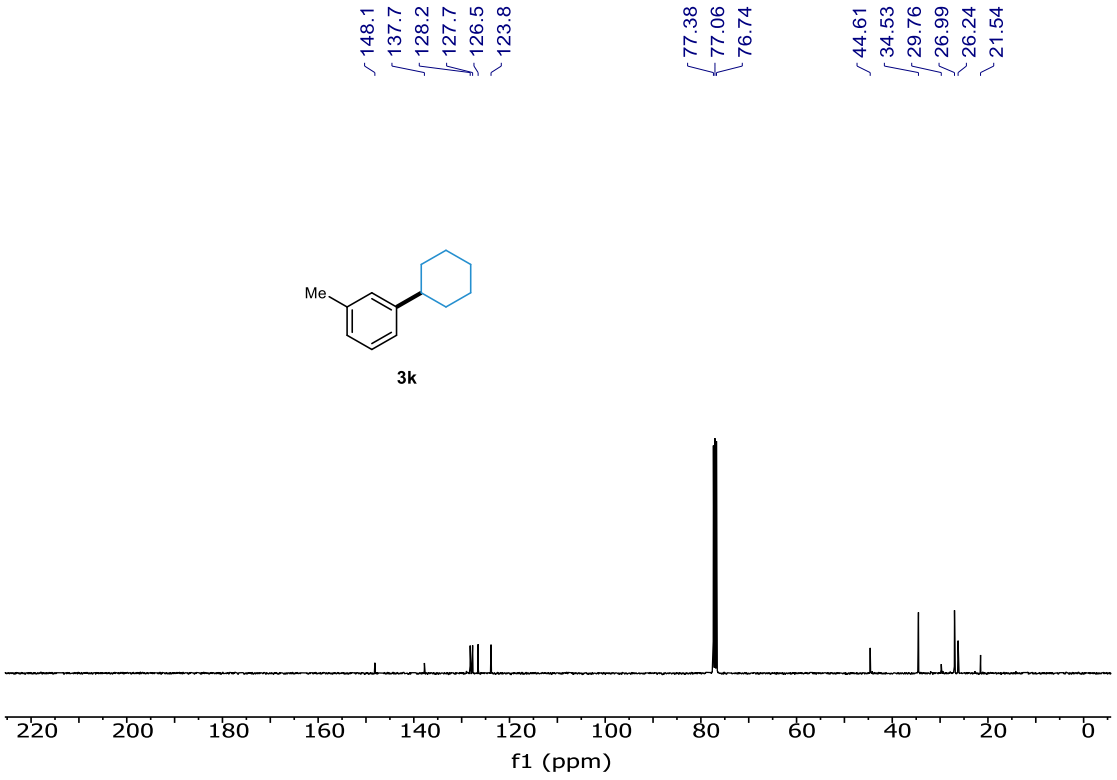

150.3
131.9
131.6
131.3
130.9
127.6
127.1
124.9
122.2
119.9
119.9
119.8
77.38
77.06
76.74
44.38
34.16
26.60
25.85
F3C
CF3
3i
220
200
180
160
140
120
100
80
60
40
20
0
f1 (ppm)

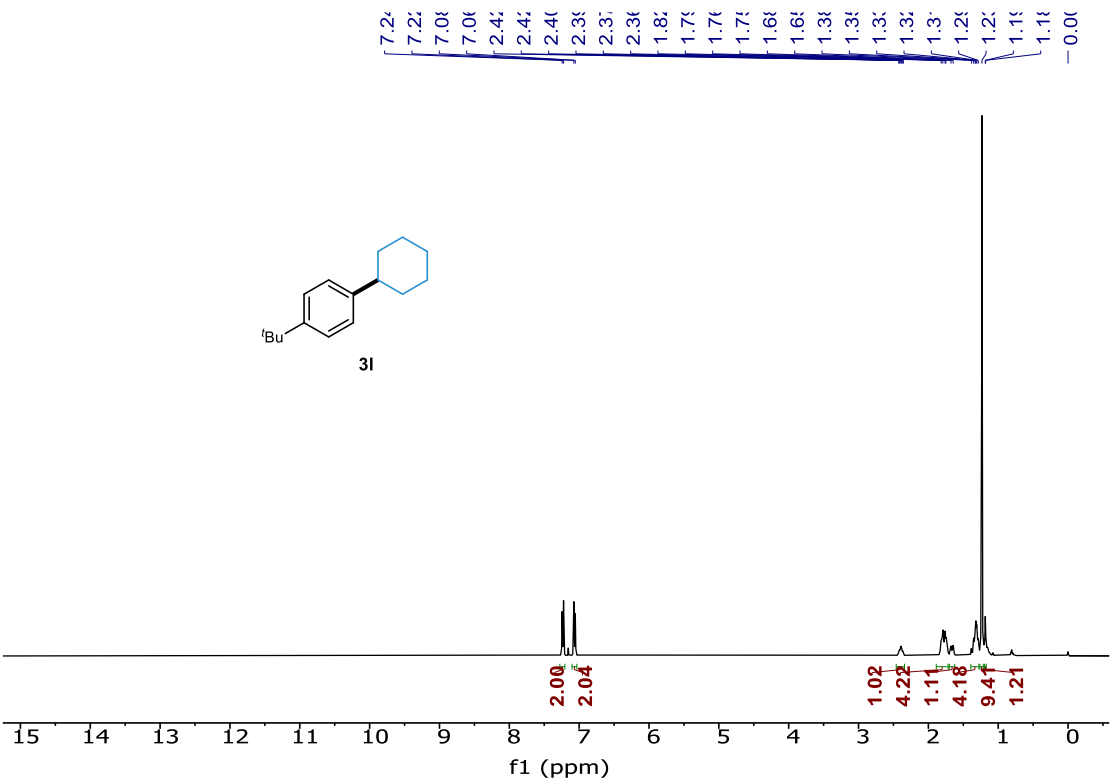

-62.7
F3C
CF3
3i
200
150
100
50
0
-50
-100
-150
-200
-250
-300
-350
f1 (ppm)

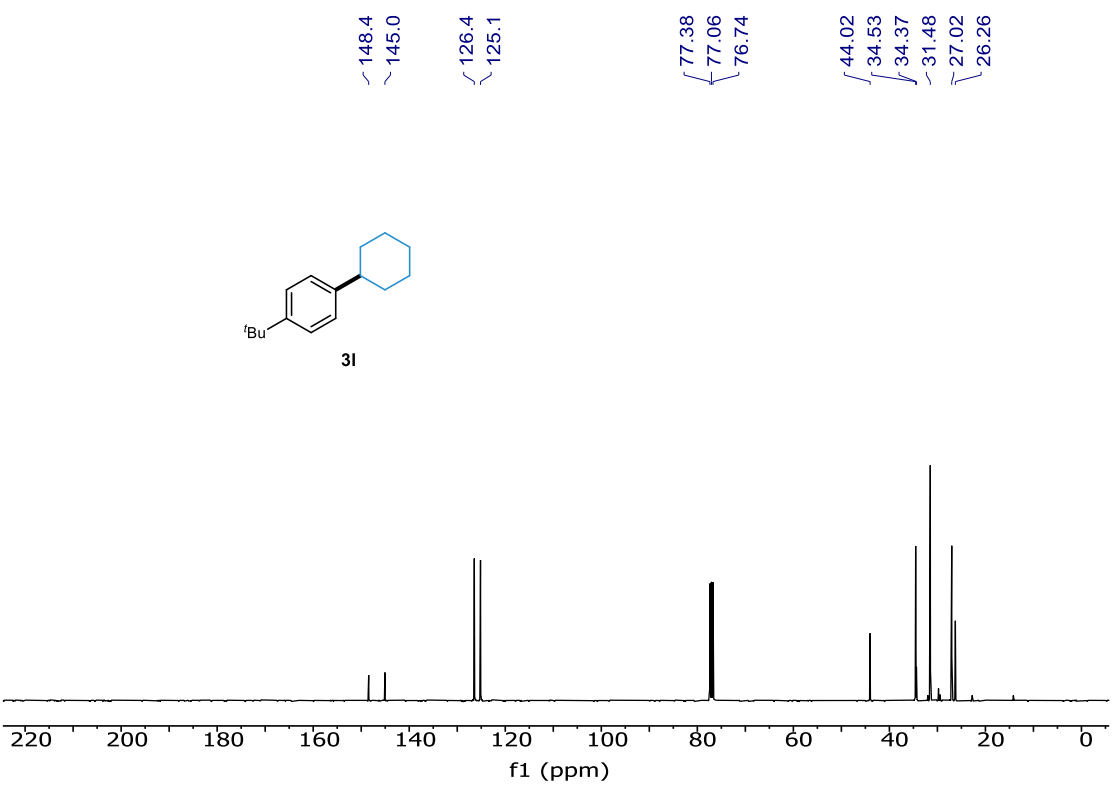

Me
3j
4.00
1.03
3.14
4.23
1.10
4.31
1.10
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)

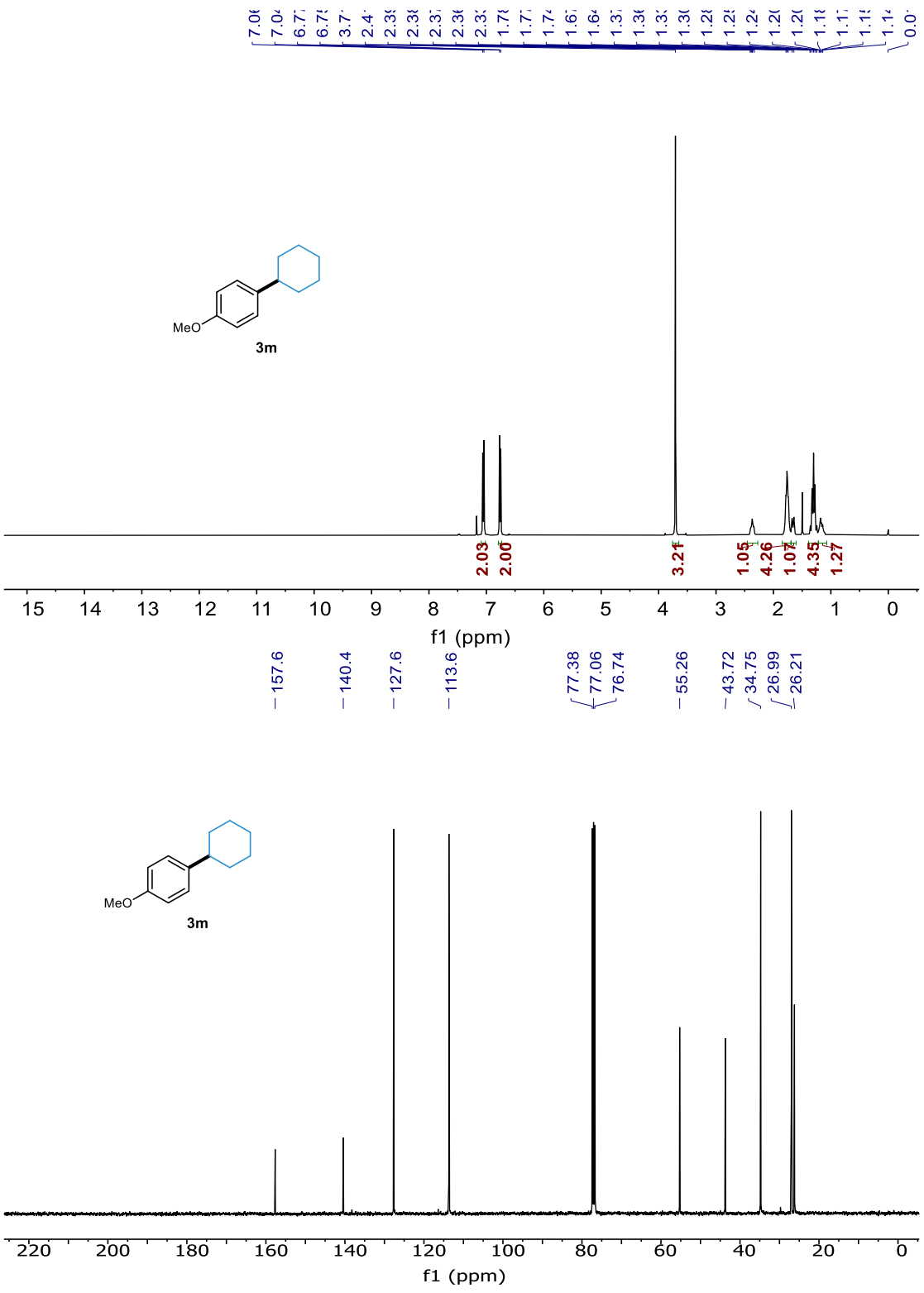

145.2
135.2
129.0
126.7
77.38
77.06
76.74
44.20
34.62
29.76
27.00
26.23
21.02
Me
3j
220 200 180 160 140 120 100 80 60 40 20 0
f1 (ppm)

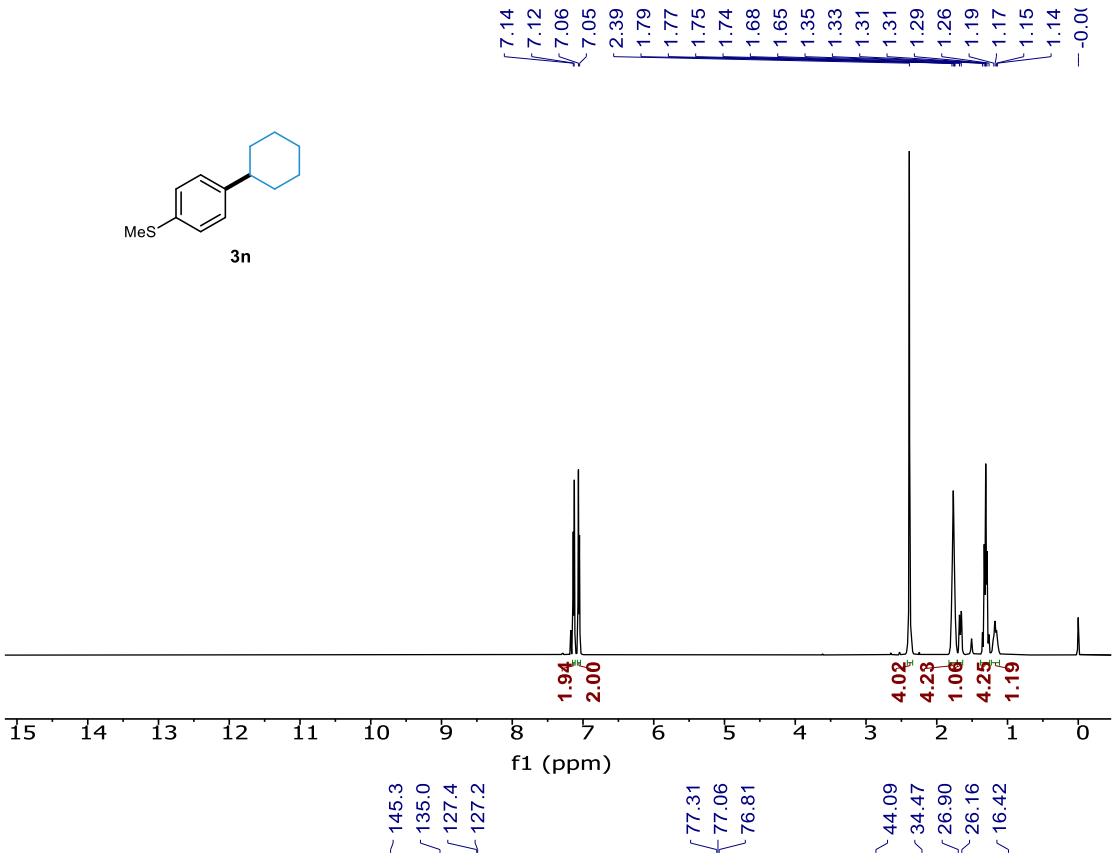

Me
3k
1.00
3.04
1.09
3.04
3.97
1.09
4.22
1.43
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)

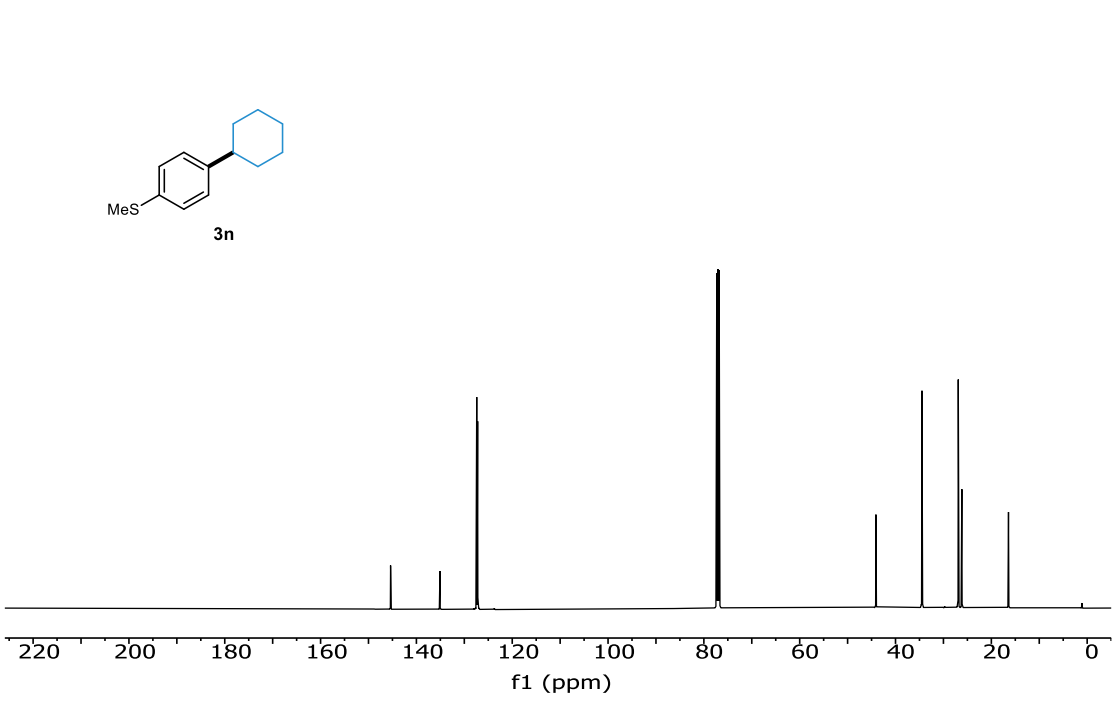

148.1
137.7
128.2
127.7
126.5
123.8
77.38
77.06
76.74
44.61
34.53
29.76
26.99
26.24
21.54
Me
3k
220 200 180 160 140 120 100 80 60 40 20 0
f1 (ppm)

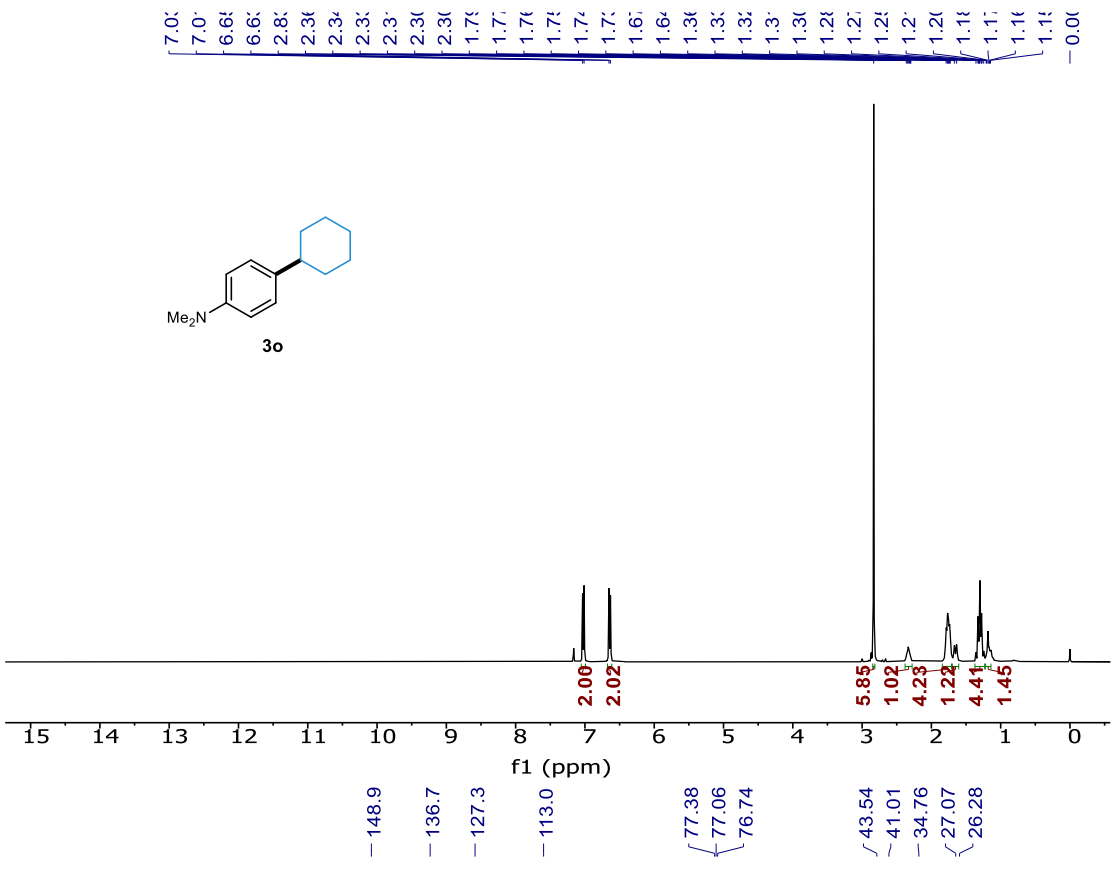

tBu
3l
2.00
2.04
1.02
4.22
1.11
4.18
9.41
1.21
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)

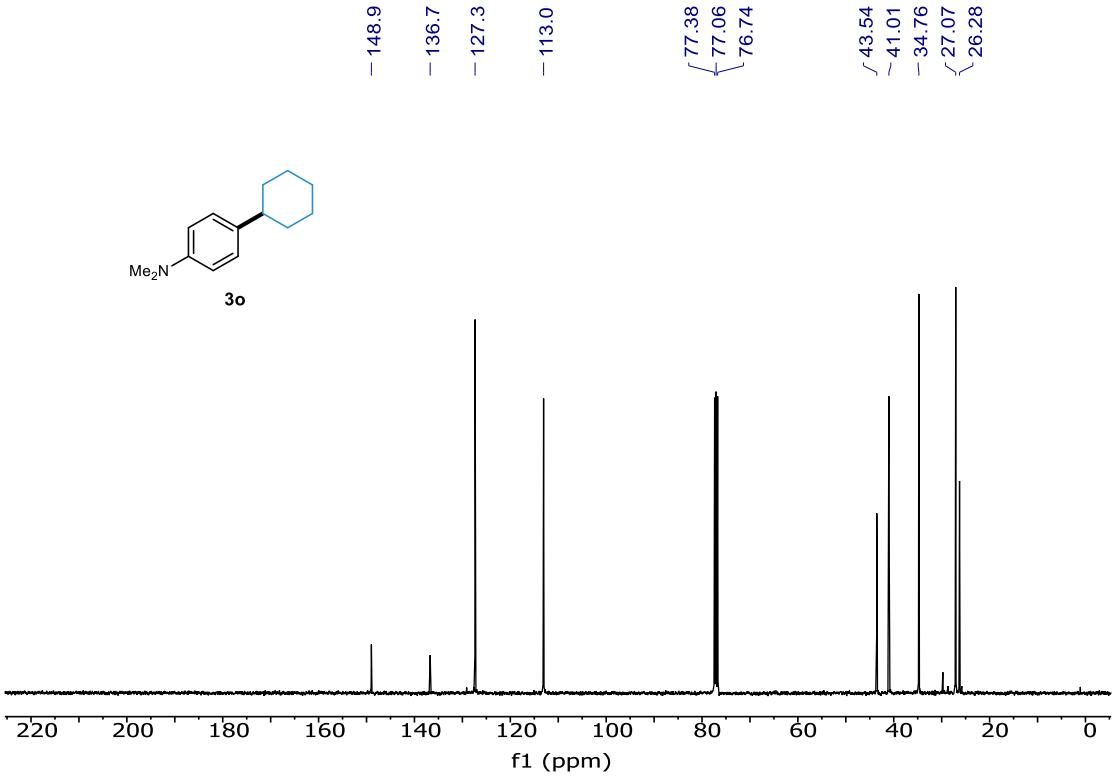

148.4
145.0
126.4
125.1
77.38
77.06
76.74
44.02
34.53
34.37
31.48
27.02
26.26
tBu
3l
220 200 180 160 140 120 100 80 60 40 20 0
f1 (ppm)

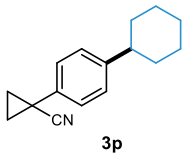

MeO
3m
2.03
2.00
3.21
1.05
4.26
1.07
4.35
1.27
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)
157.6
140.4
127.6
113.6
77.38
77.06
76.74
55.26
43.72
34.75
26.99
26.21
MeO
3m
220 200 180 160 140 120 100 80 60 40 20 0
f1 (ppm)


7.14
7.12
7.06
7.05
2.39
1.79
1.77
1.75
1.74
1.68
1.65
1.35
1.33
1.31
1.31
1.29
1.26
1.19
1.17
1.15
1.14
MeS
3n
1.94
2.00
4.02
4.23
1.08
4.25
1.19
f1 (ppm)

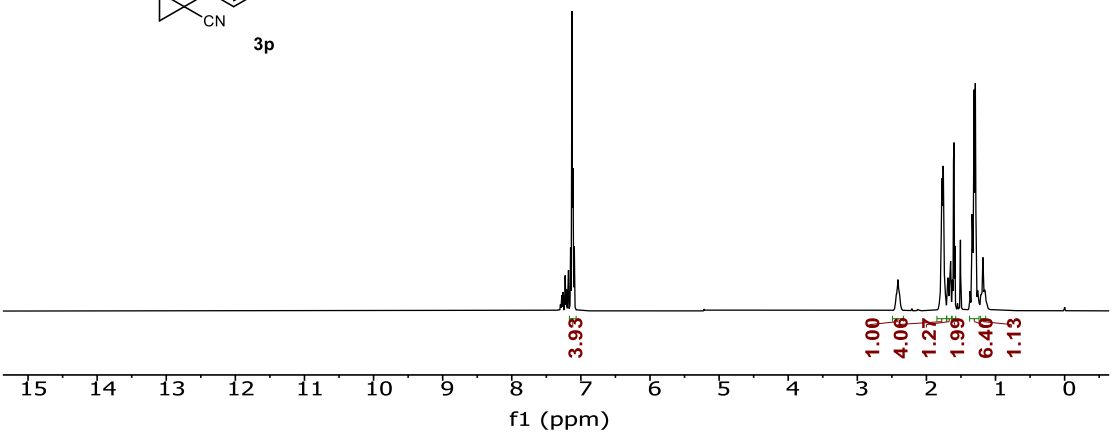

145.3
135.0
127.4
127.2
77.31
77.06
76.81
44.09
34.47
26.90
26.16
16.42
MeS
3n
f1 (ppm)


Me2N
3o
2.00
2.02
5.85
1.02
4.23
1.22
4.41
1.45
f1 (ppm)

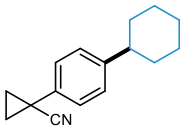

148.9
136.7
127.3
113.0
77.38
77.06
76.74
43.54
41.01
34.76
27.07
26.28
Me2N
3o
f1 (ppm)


CN

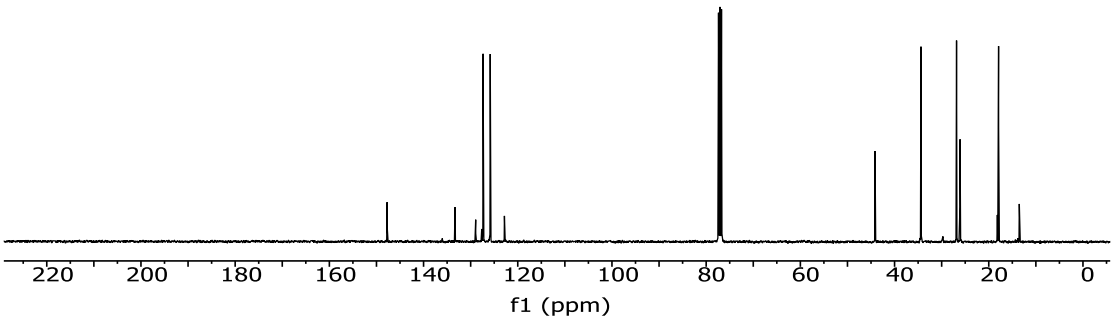
3p

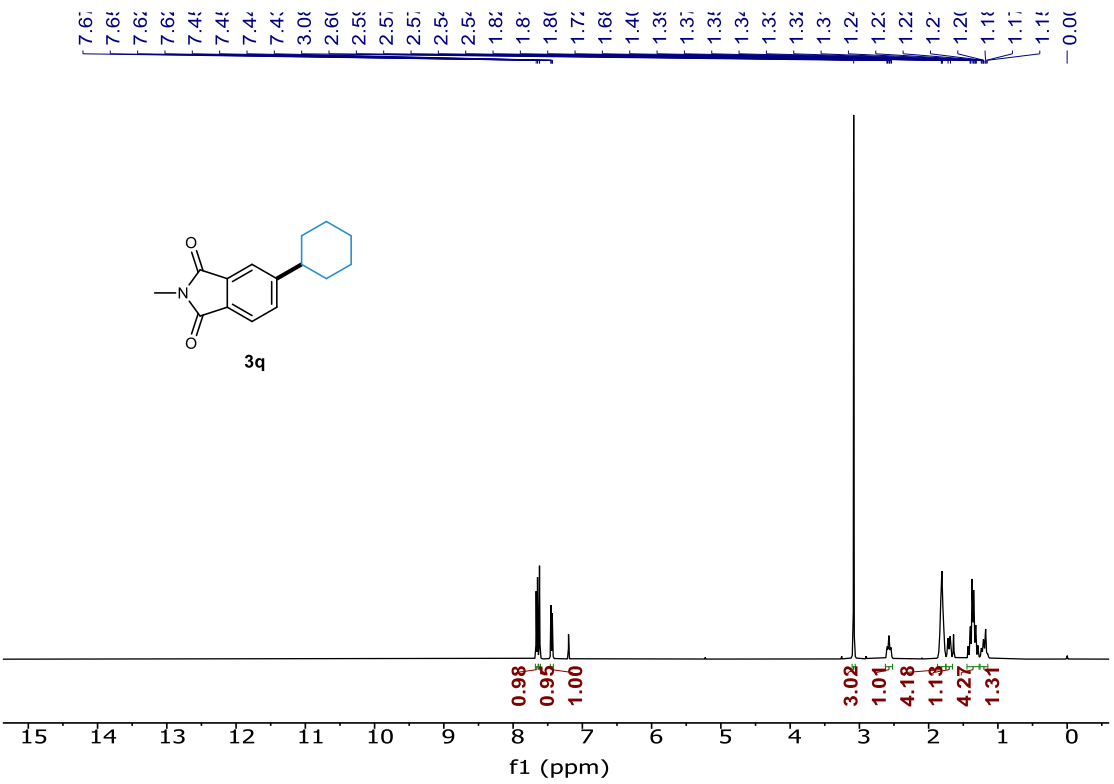

3.93
1.00
4.06
1.27
1.99
6.40
1.13
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
f1 (ppm)

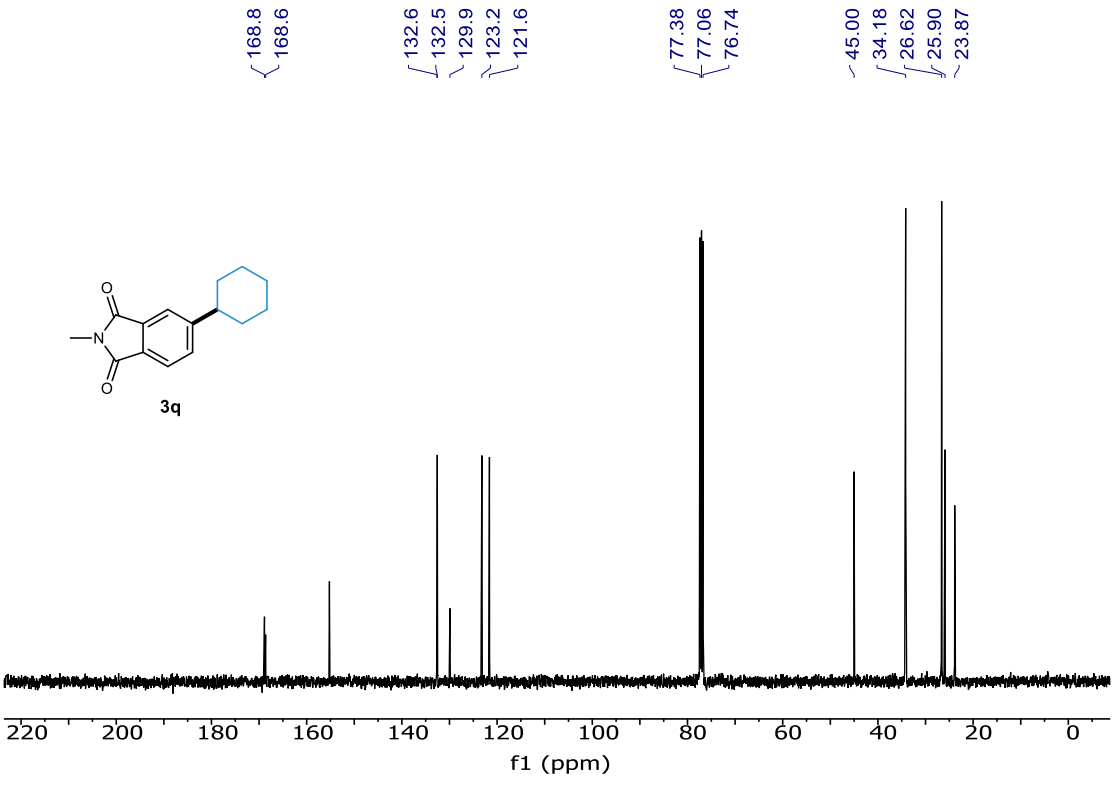

147.7
133.3
127.3
125.8
122.8
77.38
77.06
76.74
44.15
34.39
26.84
26.10
17.92
13.52

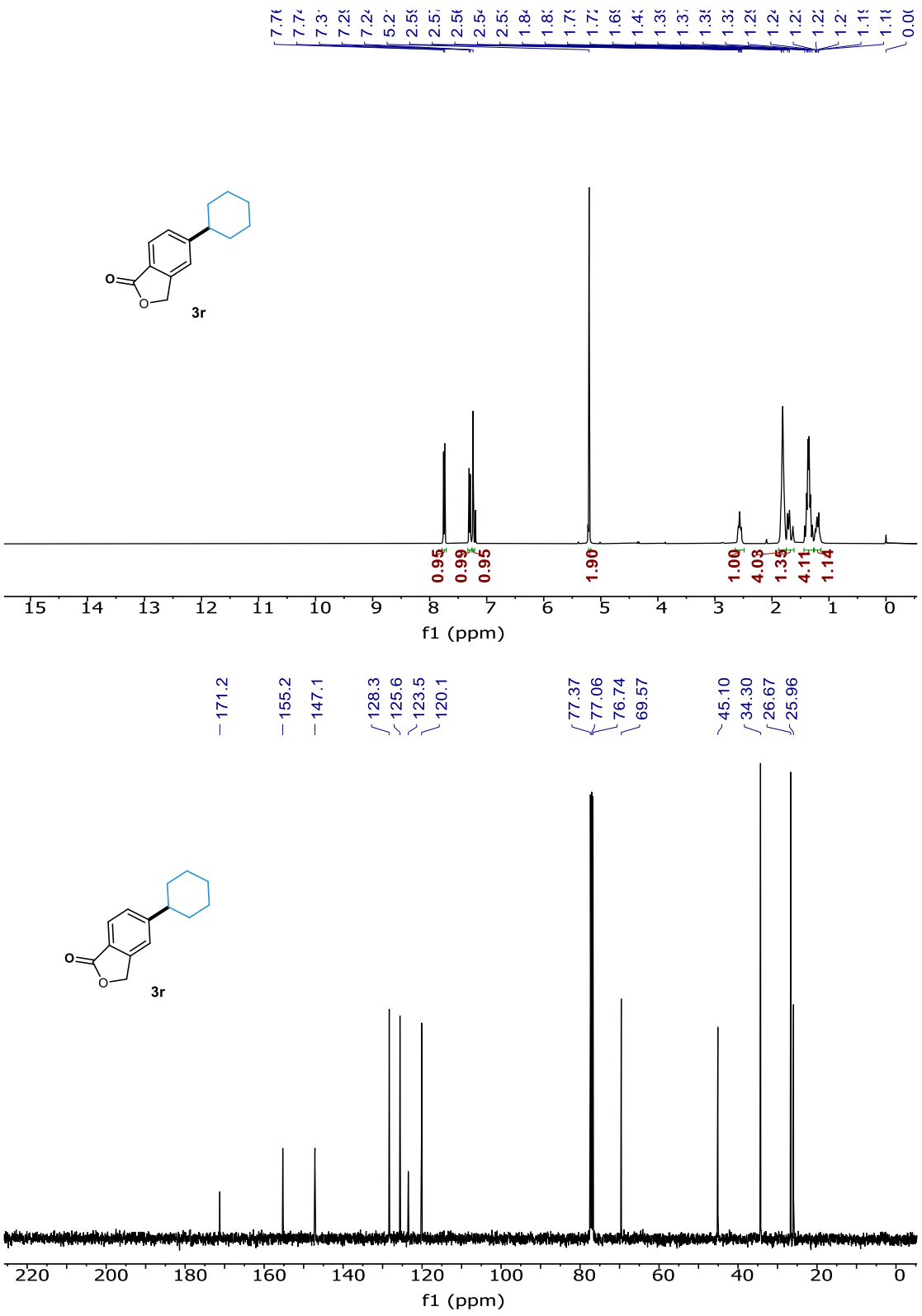

CN

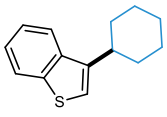
3p


220
200
180
160
140
120
100
80
60
40
20
0
f1 (ppm)

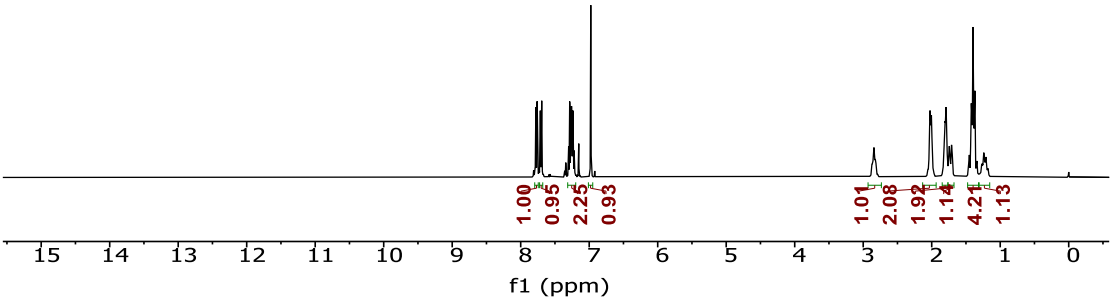

3q
0.98
0.95
1.00
3.02
1.01
4.18
1.13
4.27
1.31
f1 (ppm)


168.8
168.6
132.6
132.5
129.9
123.2
121.6
77.38
77.06
76.74
45.00
34.18
26.62
25.90
23.87
3q
f1 (ppm)

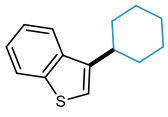

3r
0.95
0.99
0.95
1.90
1.00
4.03
1.35
4.11
1.14
f1 (ppm)
171.2
155.2
147.1
128.3
125.6
123.5
120.1
77.37
77.06
76.74
69.57
45.10
34.30
26.67
25.96
3r
f1 (ppm)



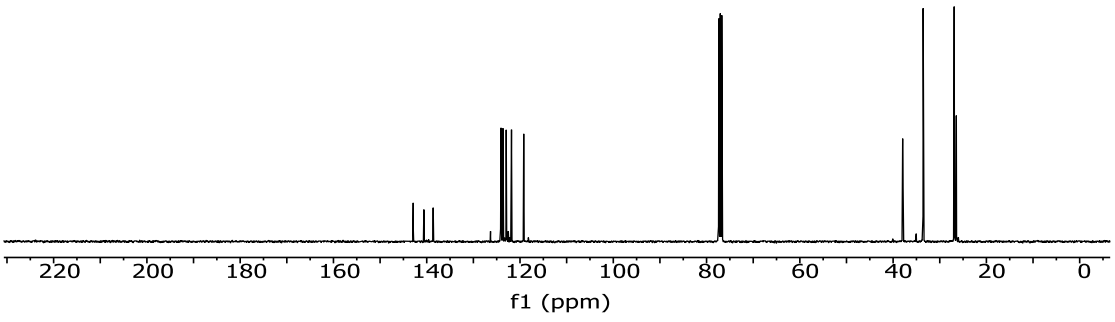
3s

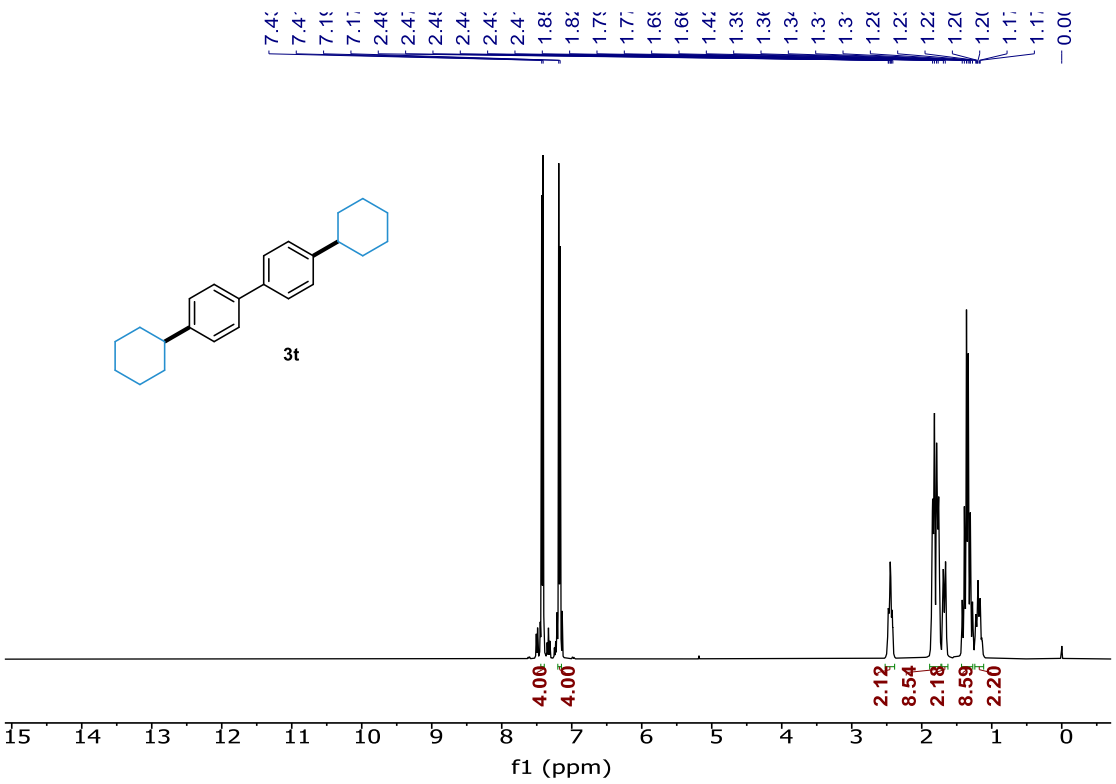

1.00
0.95
2.25
0.93
1.01
2.08
1.92
1.14
4.21
1.13
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)

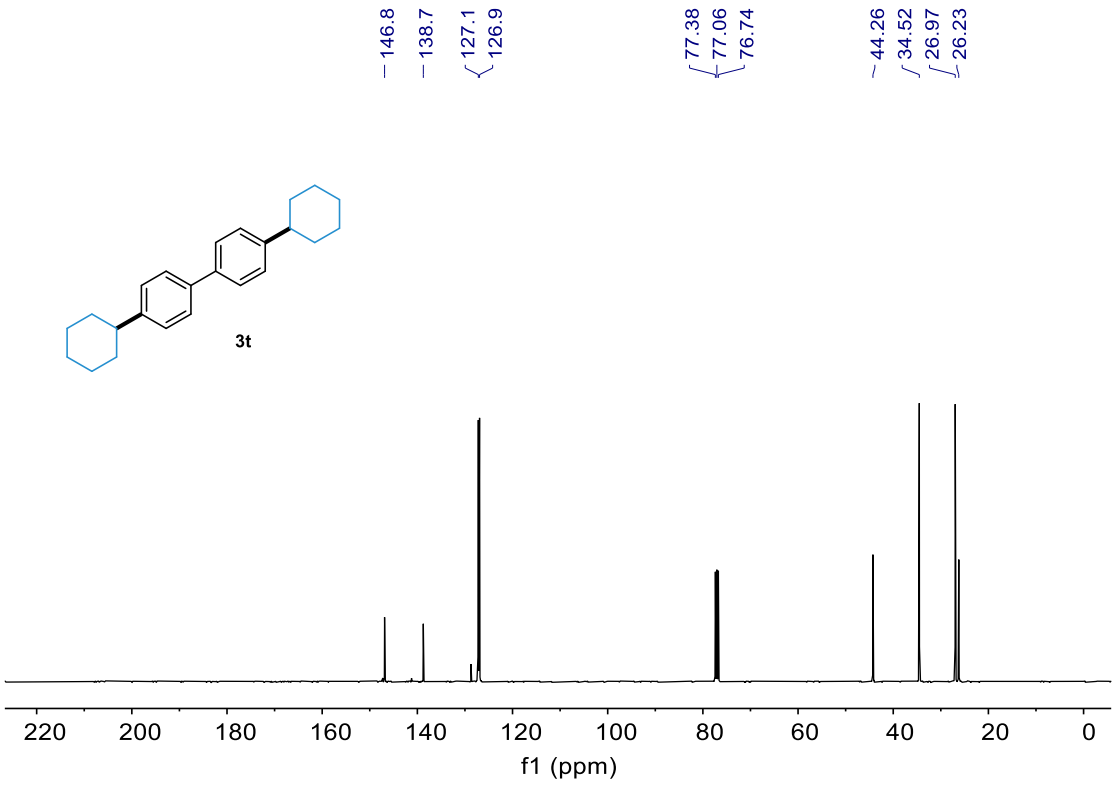

142.8
140.6
138.6
124.0
123.6
122.9
121.8
119.2
77.37
77.06
76.74
37.96
33.56
26.90
26.45

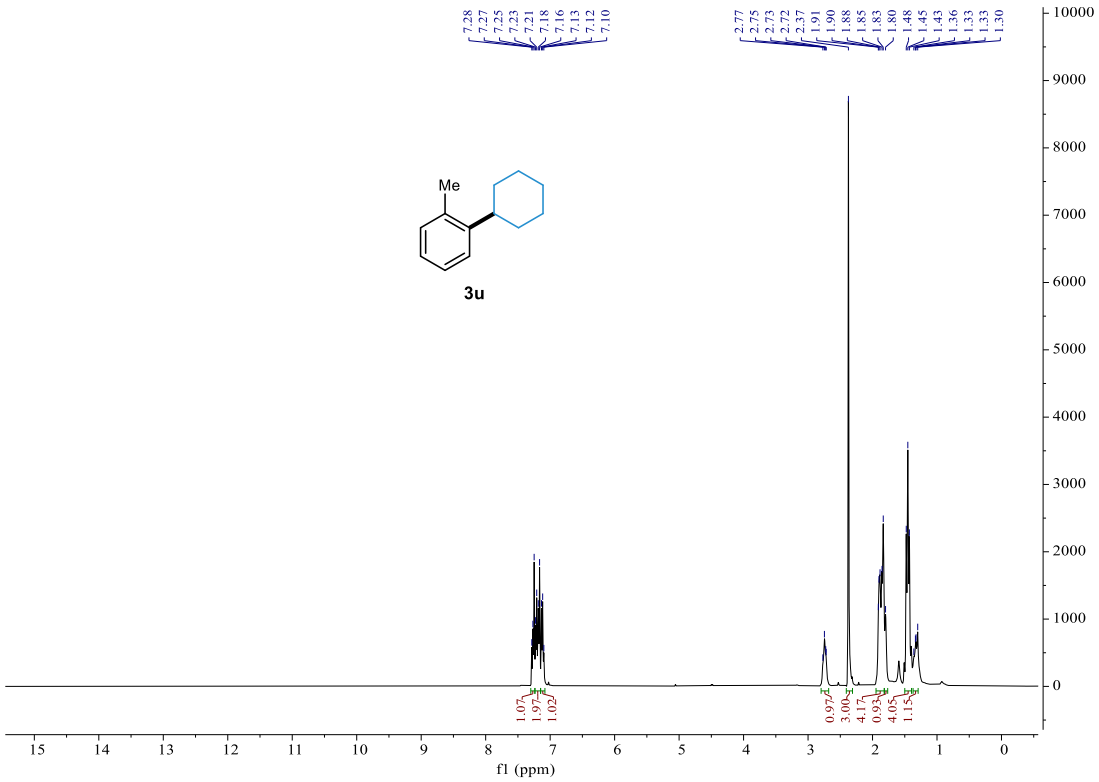


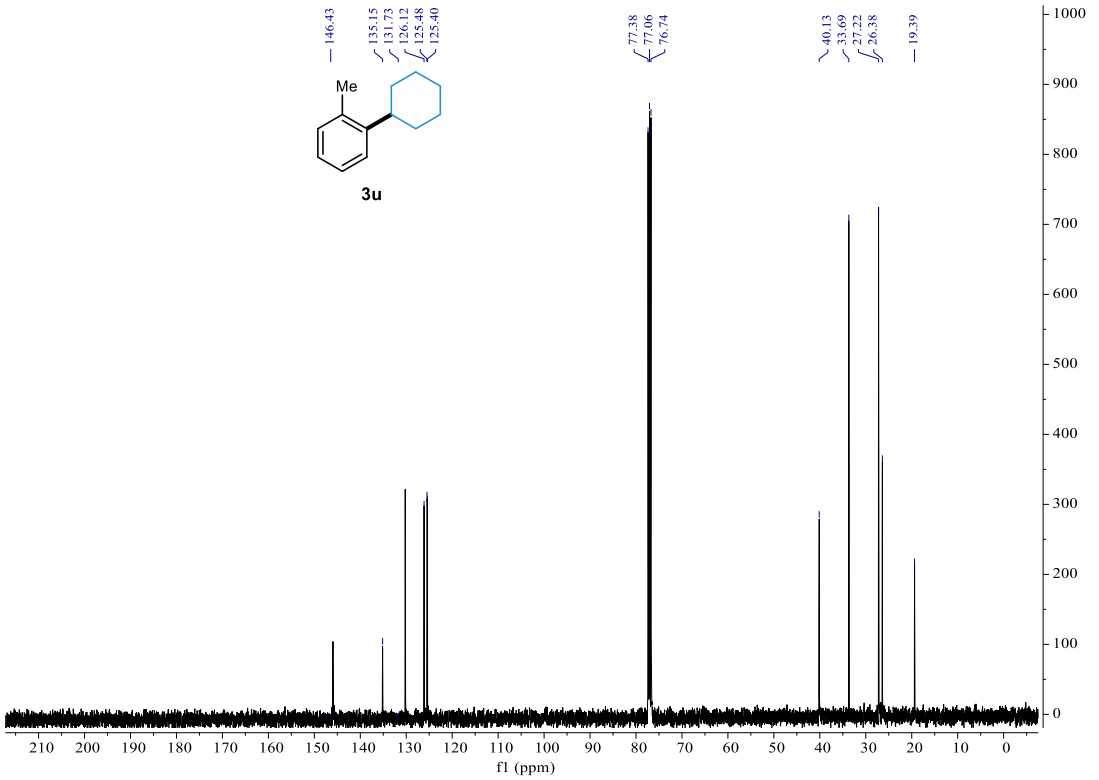
3s

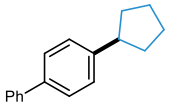

220 200 180 160 140 120 100 80 60 40 20 0
f1 (ppm)


3t
4.00
4.00
2.12
8.54
2.18
8.59
2.20
f1 (ppm)

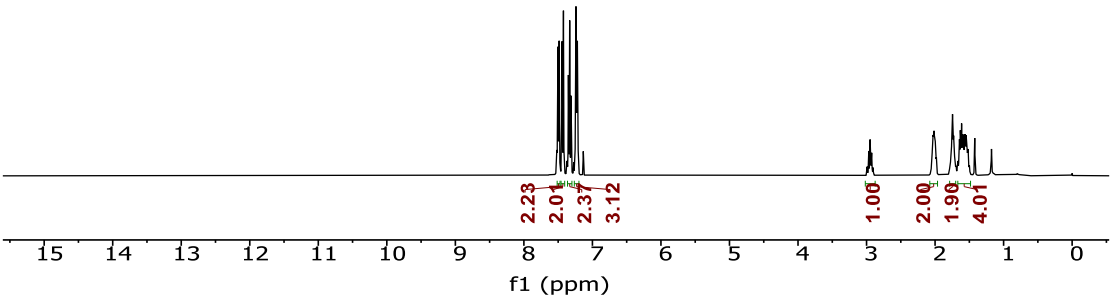

146.8
138.7
127.1
126.9
77.38
77.06
76.74
44.26
34.52
26.97
26.23
3t
f1 (ppm)


7.28
7.27
7.25
7.23
7.21
7.18
7.16
7.13
7.12
7.10
2.77
2.75
2.73
2.72
2.37
1.91
1.90
1.88
1.85
1.83
1.80
1.48
1.45
1.43
1.36
1.33
1.33
1.30
Me
3u
1.07
1.97
1.02
0.97
3.00
4.17
0.93
4.05
1.15
f1 (ppm)

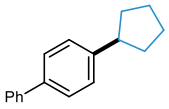

146.43
135.15
131.73
126.12
125.48
125.40
77.38
77.06
76.74
40.13
33.69
27.22
26.38
19.39
Me
3u
f1 (ppm)


Ph

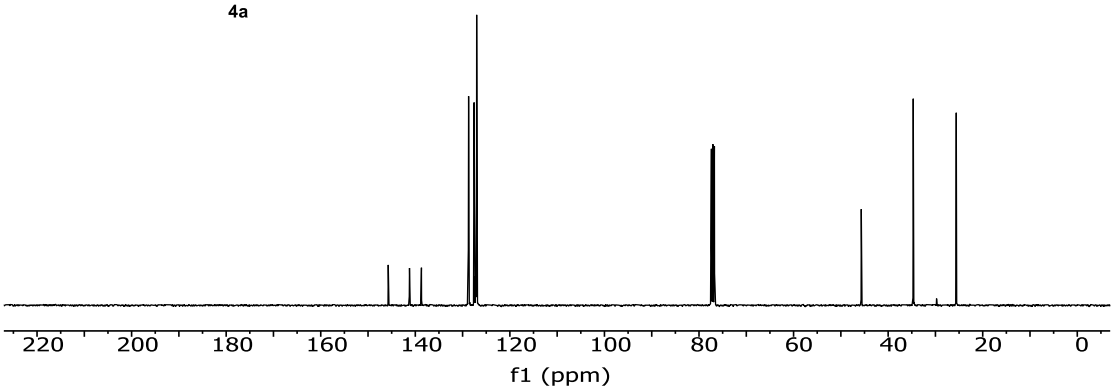
4a

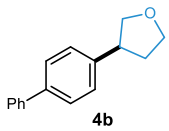

2.23
2.01
2.37
3.12
1.00
2.00
1.90
4.01
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)


145.7
141.2
138.7
128.7
128.7
127.5
127.0
126.9
77.38
77.06
76.74
45.68
34.69
25.59

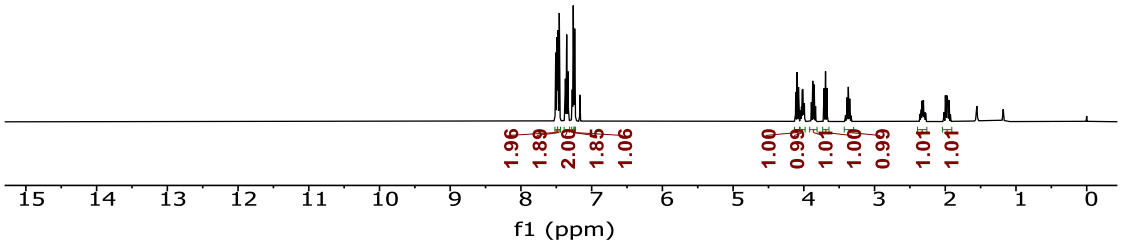

Ph

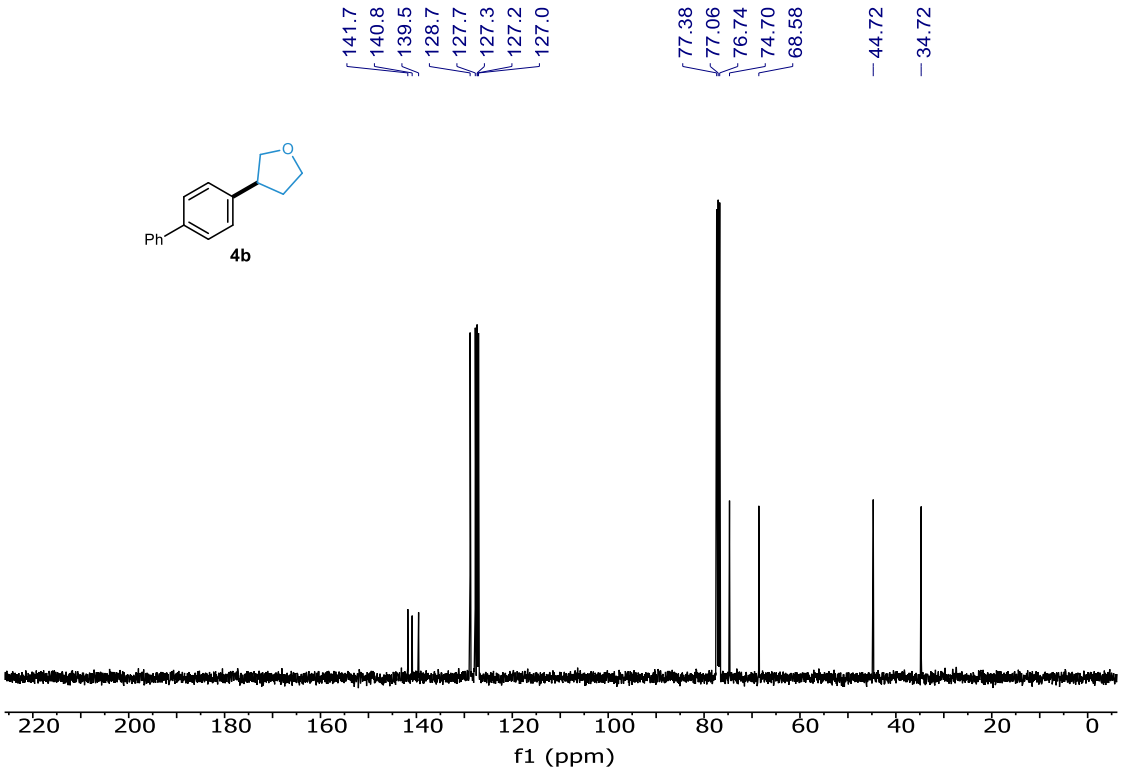
4a


220 200 180 160 140 120 100 80 60 40 20 0
f1 (ppm)

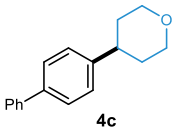

Ph
O

4b

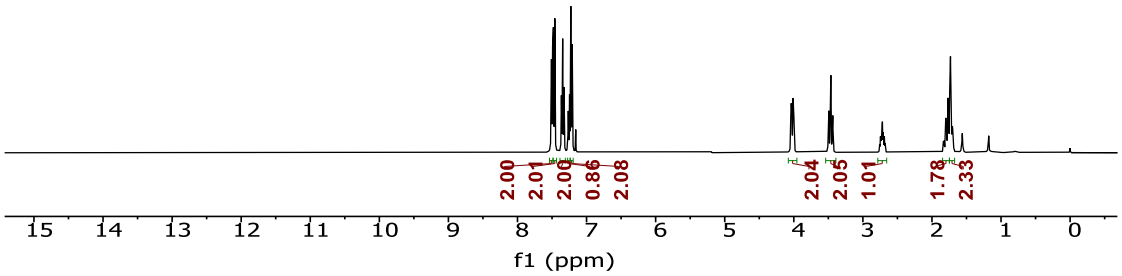

1.96
1.89
2.00
1.85
1.06
1.00
0.99
1.01
1.00
0.99
1.01
1.01
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)


141.7
140.8
139.5
128.7
127.7
127.3
127.2
127.0
77.38
77.06
76.74
74.70
68.58
44.72
34.72
Ph
O
220 200 180 160 140 120 100 80 60 40 20 0
f1 (ppm)

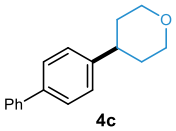
4b


O
Ph

4c

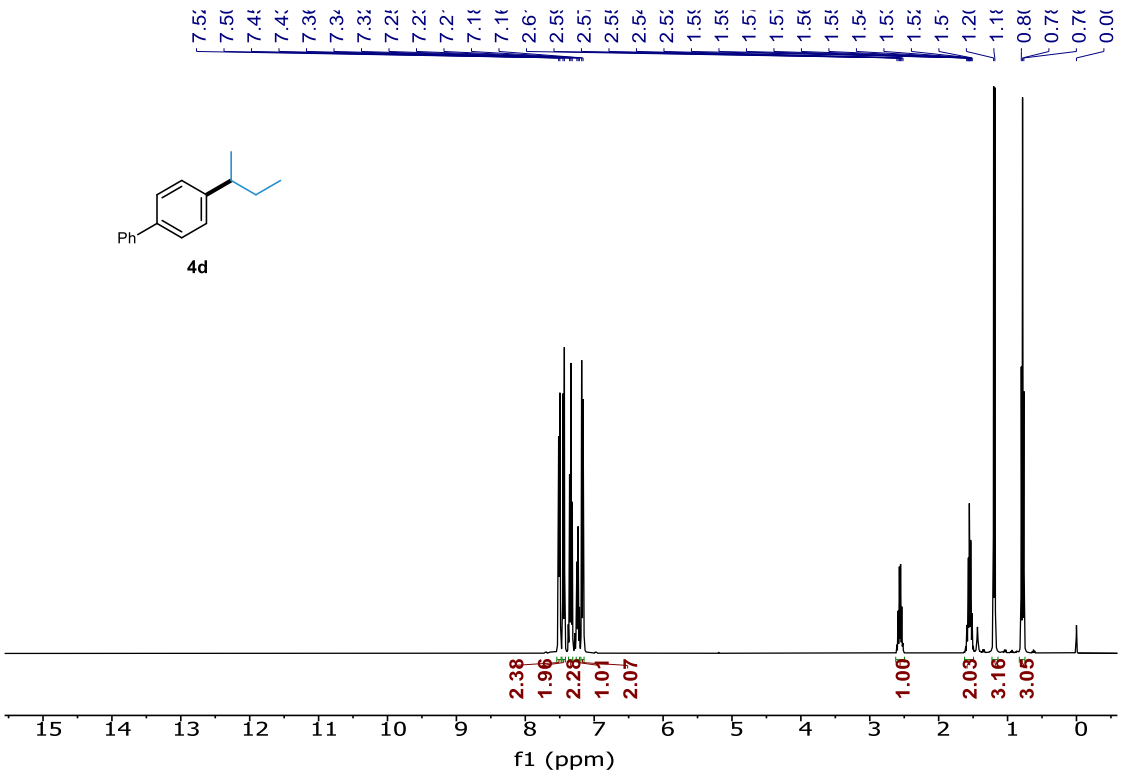

2.00
2.01
2.00
0.86
2.08
2.04
2.05
1.01
1.78
2.33
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)

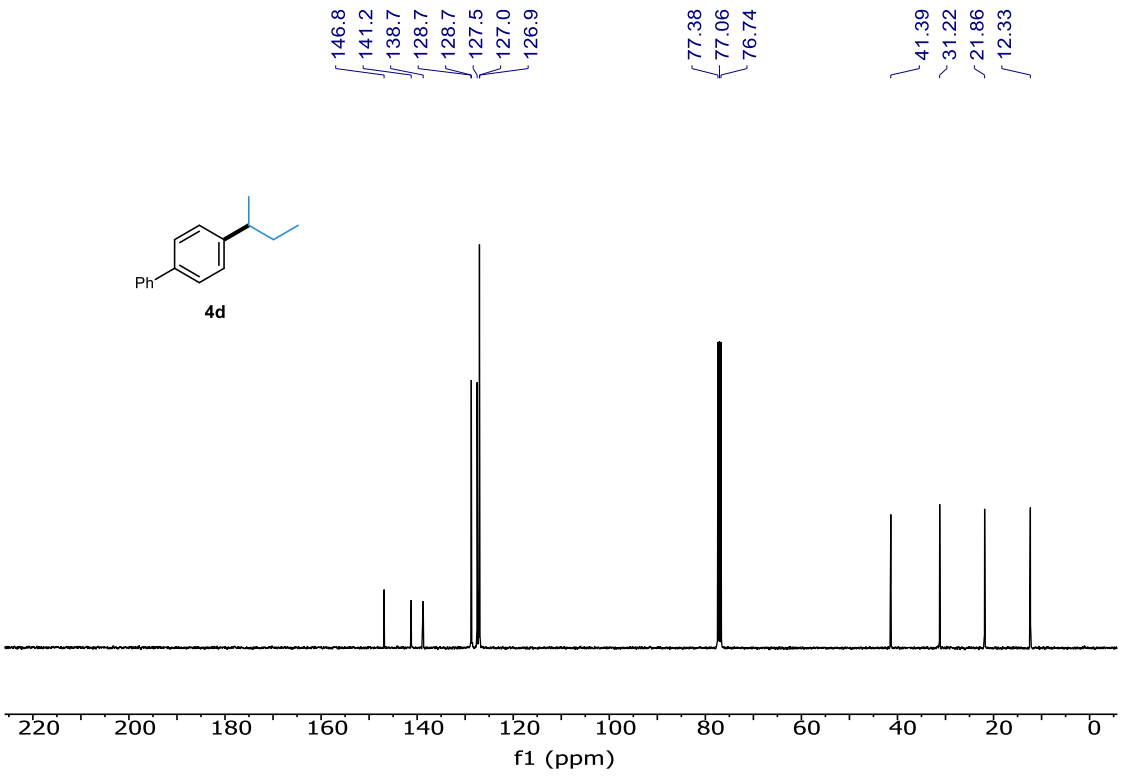

144.9
140.9
139.3
128.7
127.2
127.1
127.1
127.0
77.38
77.06
76.74
68.43
41.26
33.96

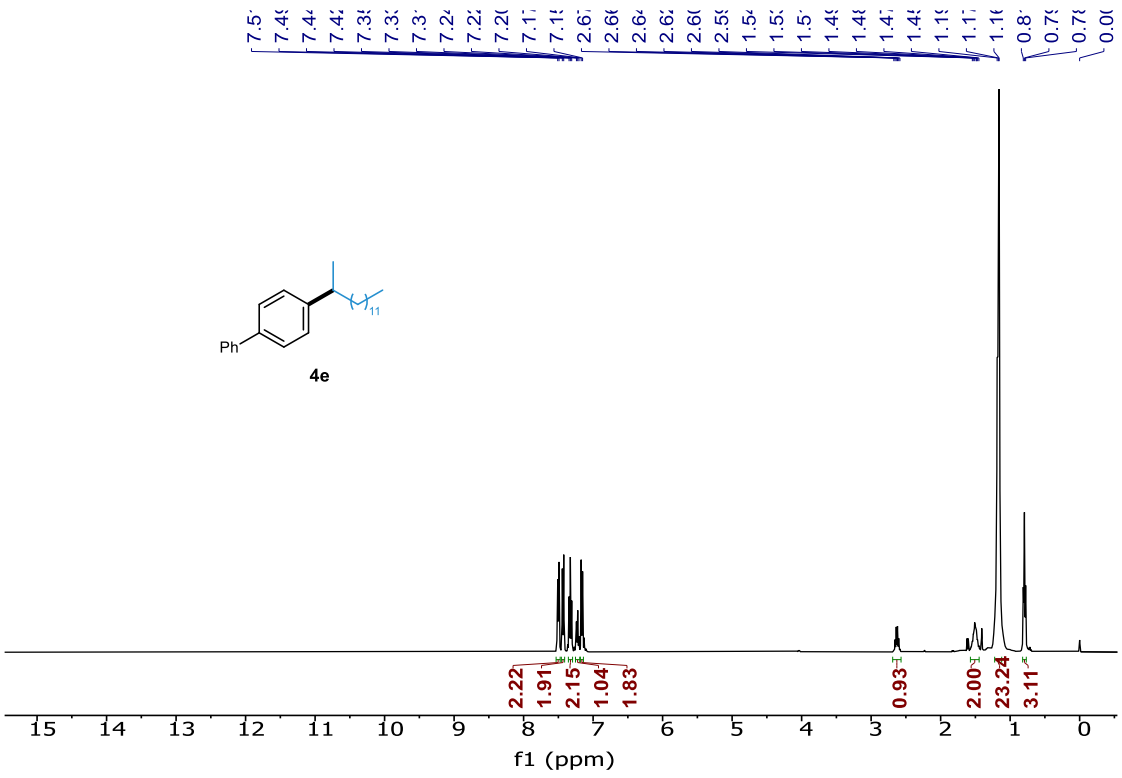

O
Ph

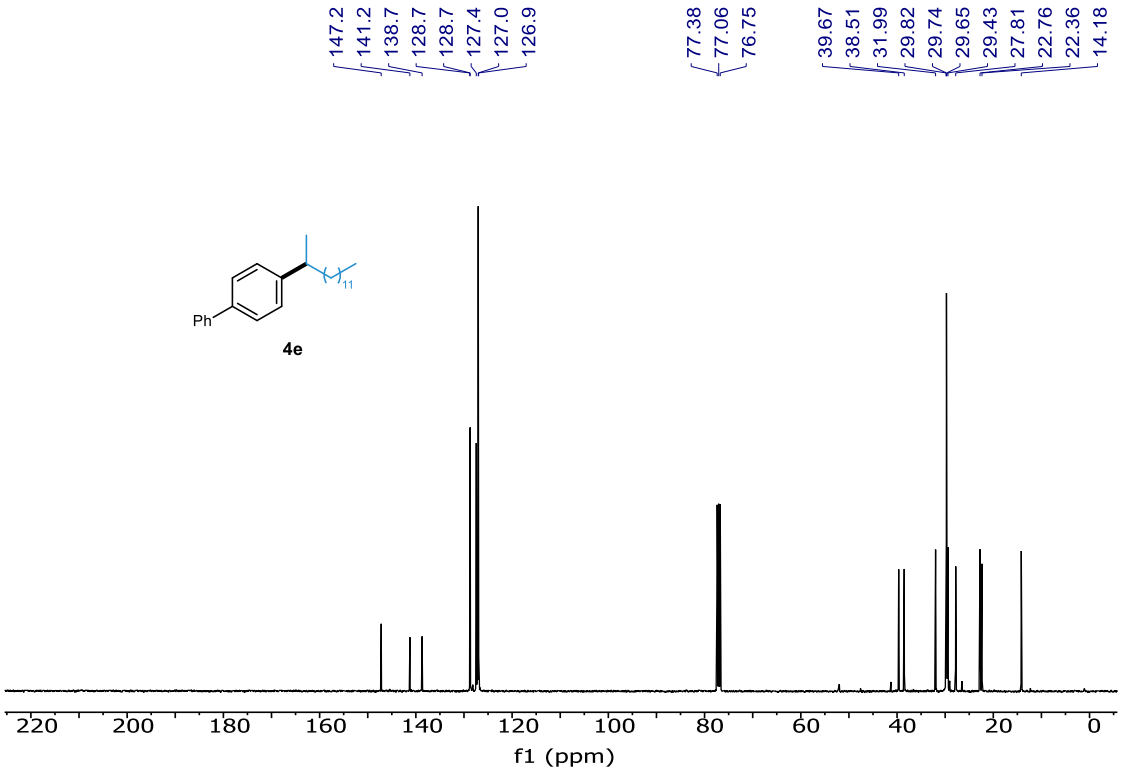
4c

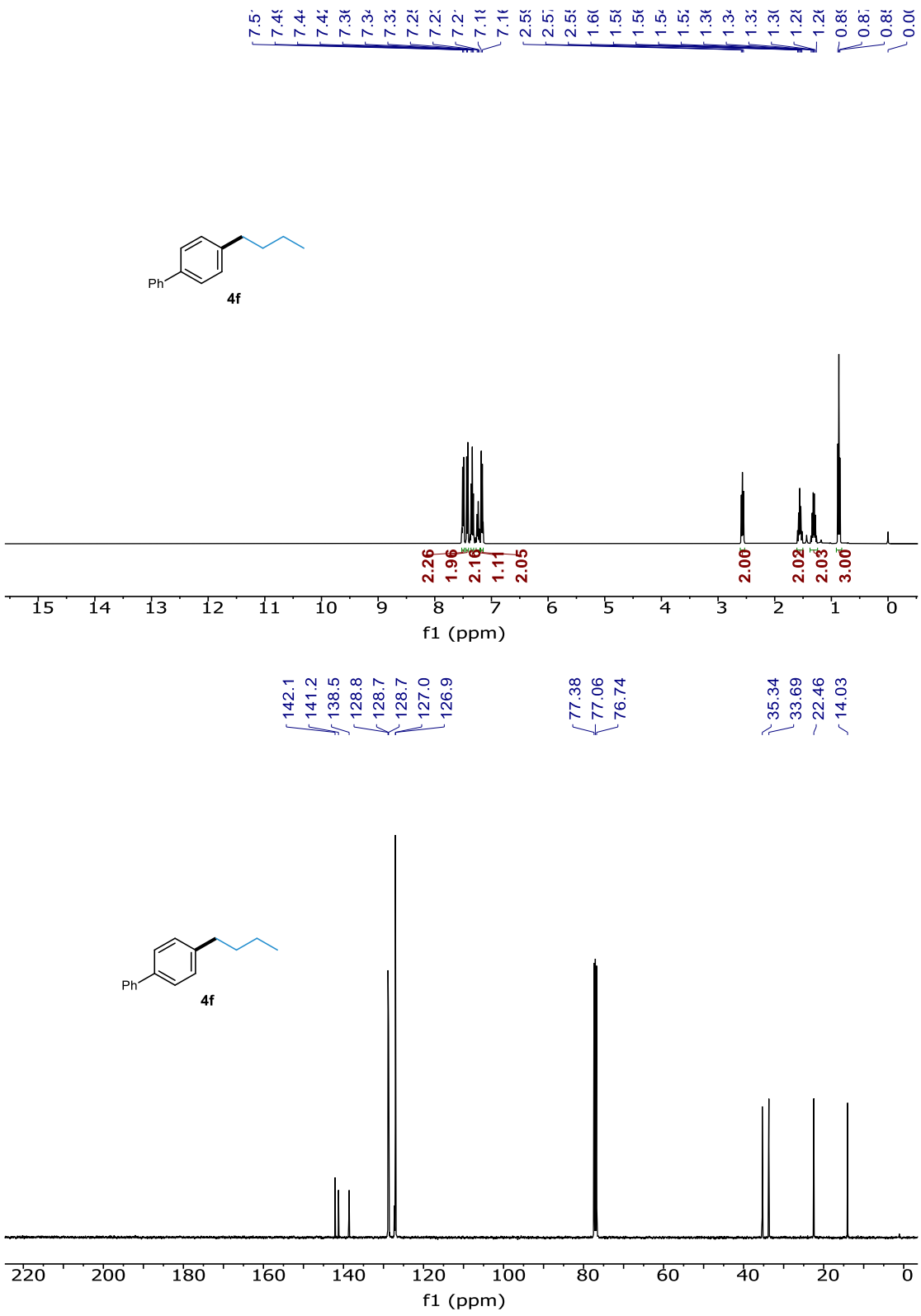
220 200 180 160 140 120 100 80 60 40 20 0
f1 (ppm)

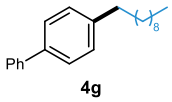

Ph
4d
2.38
1.96
2.22
1.01
2.07
1.00
2.03
3.16
3.05
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
f1 (ppm)


Ph
4d
146.8
141.2
138.7
128.7
128.7
127.5
127.0
126.9
77.38
77.06
76.74
41.39
31.22
21.86
12.33
220
200
180
160
140
120
100
80
60
40
20
0
f1 (ppm)

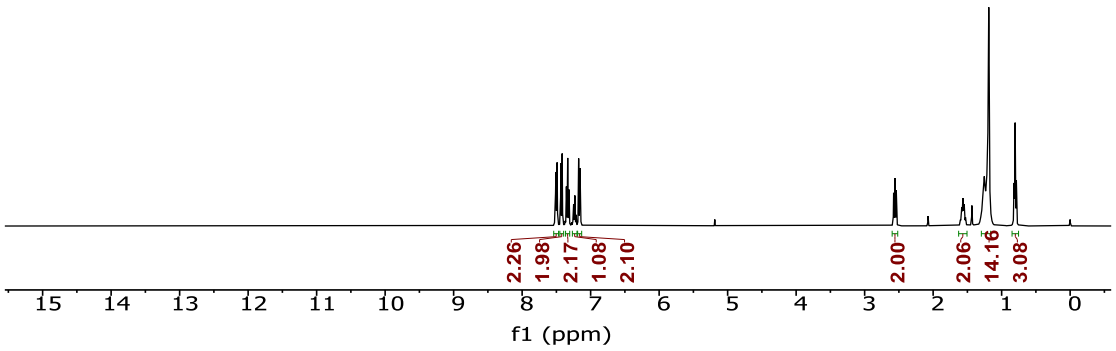

Ph
11
4e
2.22
1.91
2.15
1.04
1.83
0.93
2.00
23.24
3.11
f1 (ppm)

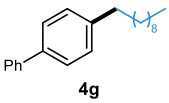

Ph
11
4e
f1 (ppm)


Ph
4f
2.26
1.96
2.10
1.11
2.05
2.00
2.02
2.03
3.00
f1 (ppm)
142.1
141.2
138.5
128.8
128.7
128.7
127.0
126.9
77.38
77.06
76.74
35.34
33.69
22.46
14.03
Ph
4f
f1 (ppm)


Ph
8

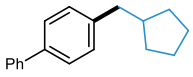
4g


2.26
1.98
2.17
1.08
2.10
2.00
2.06
14.16
3.08
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)

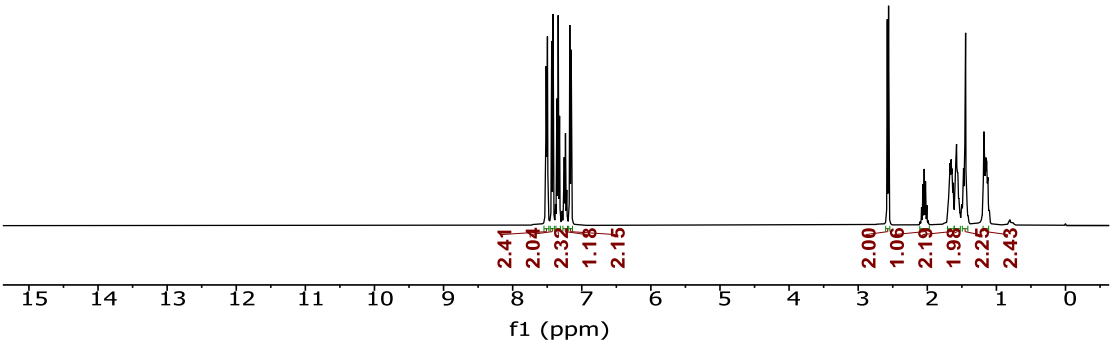

Ph
8

4g

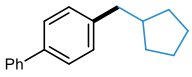
220 200 180 160 140 120 100 80 60 40 20 0
f1 (ppm)


Ph

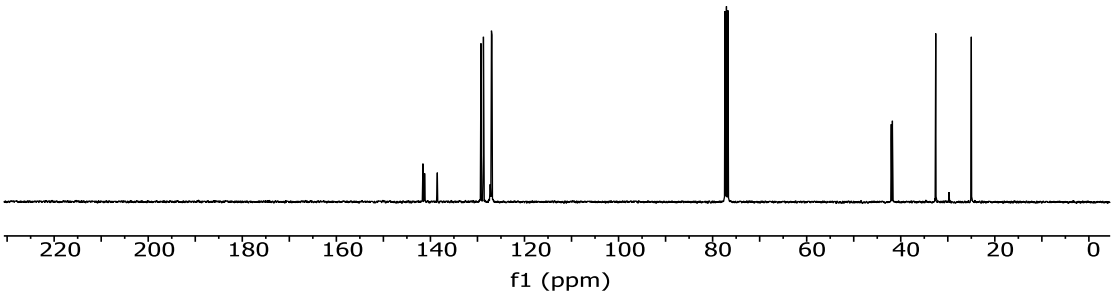
4h

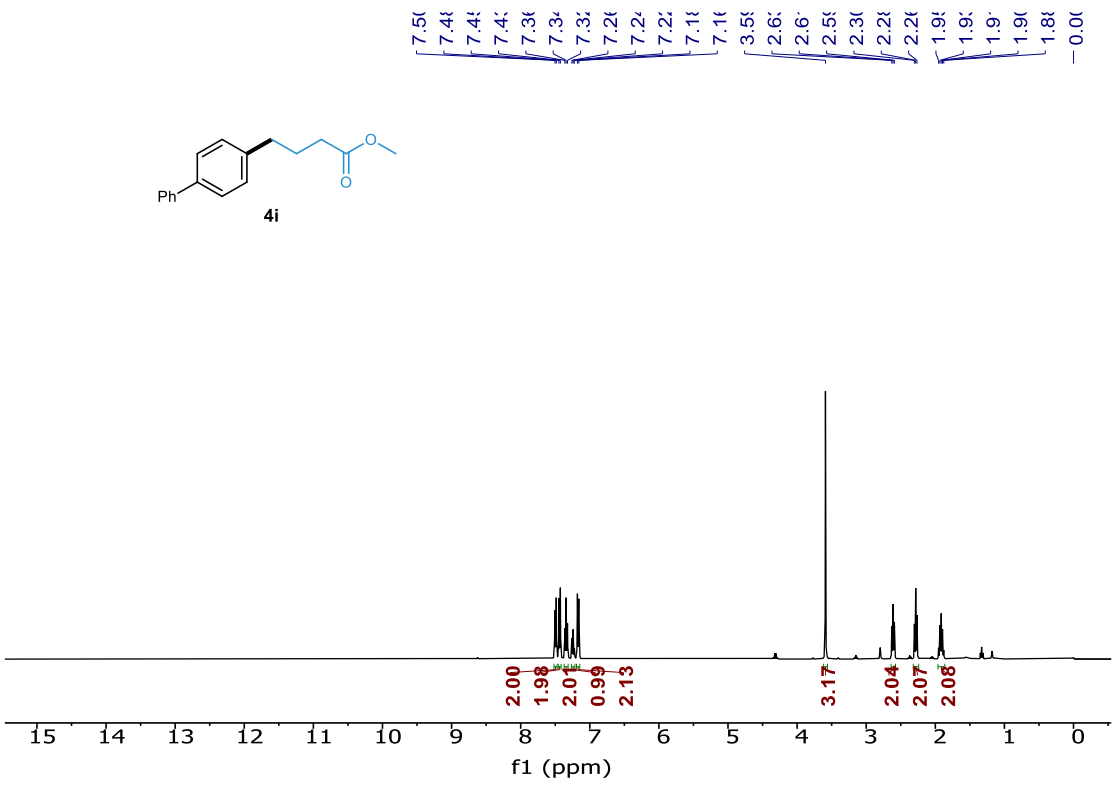

2.41
2.04
2.32
1.18
2.15
2.00
1.06
2.19
1.99
2.25
2.43
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)

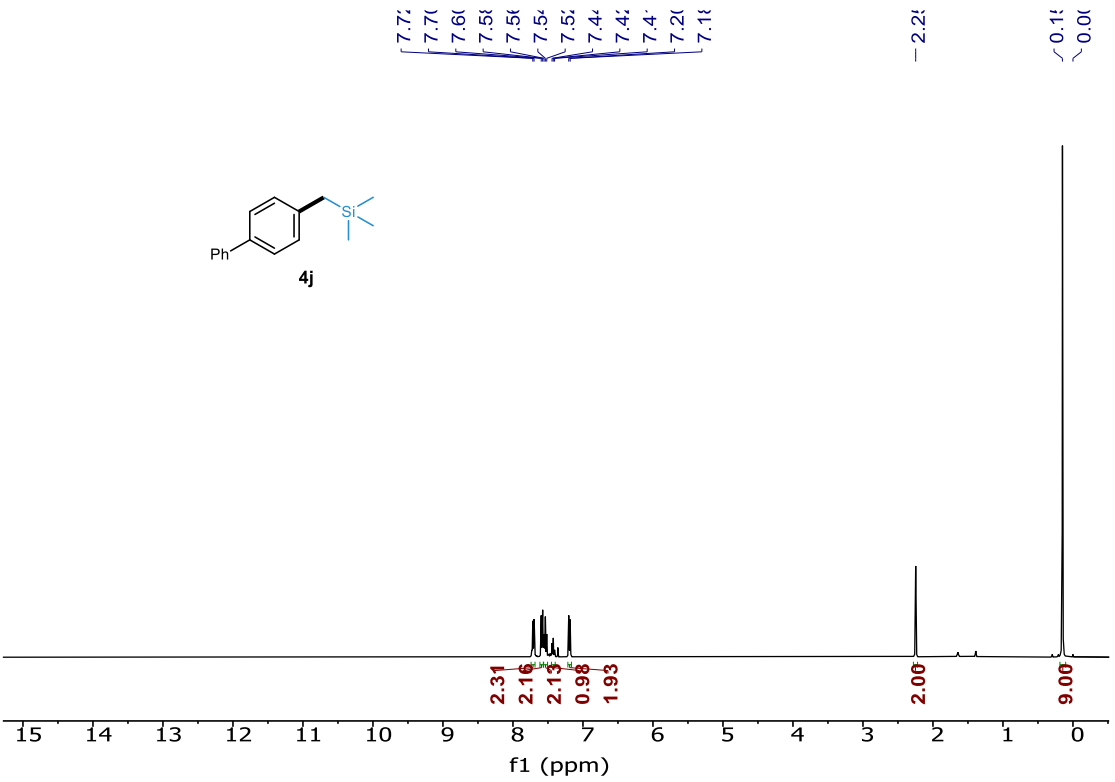

141.5
141.2
138.5
129.2
128.7
127.0
126.9
126.9
77.38
77.06
76.74
42.02
41.78
32.57
25.00

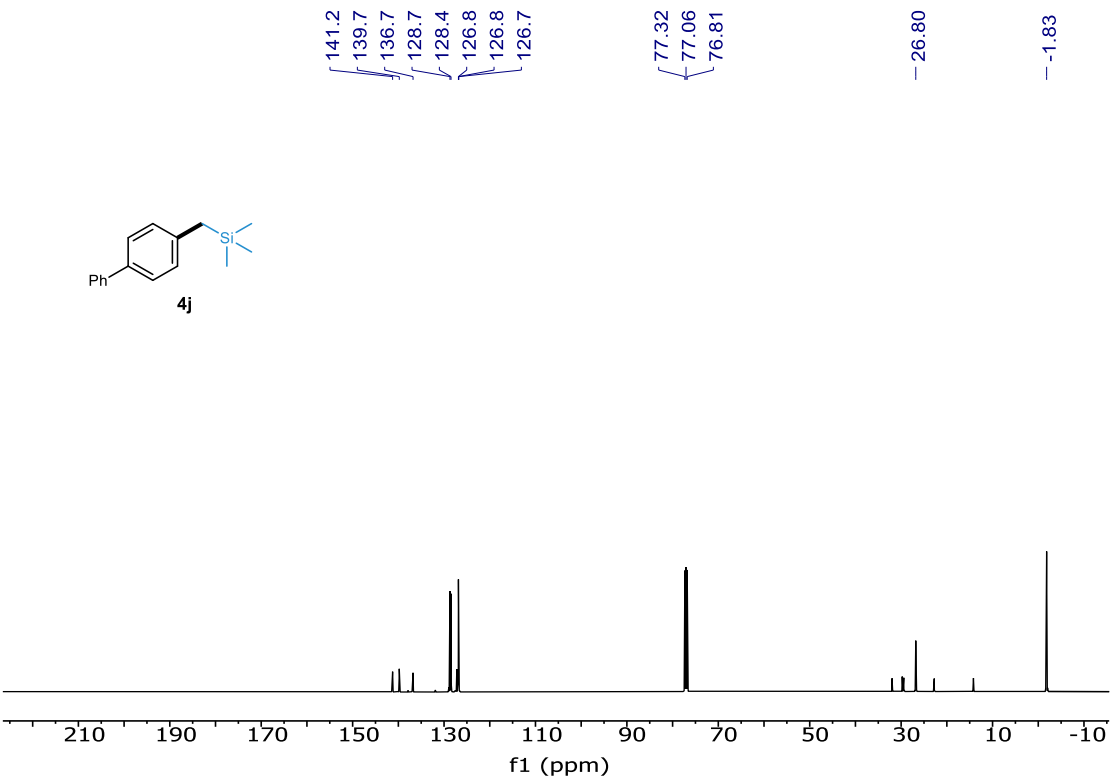

Ph

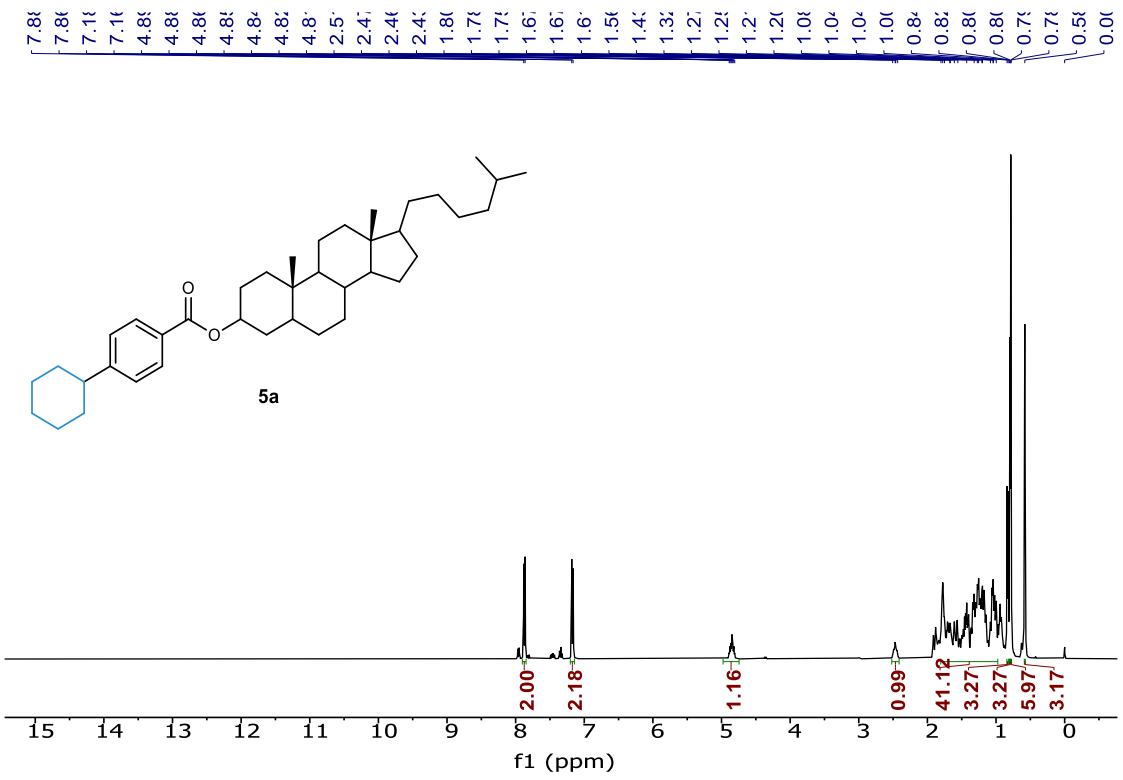
4h

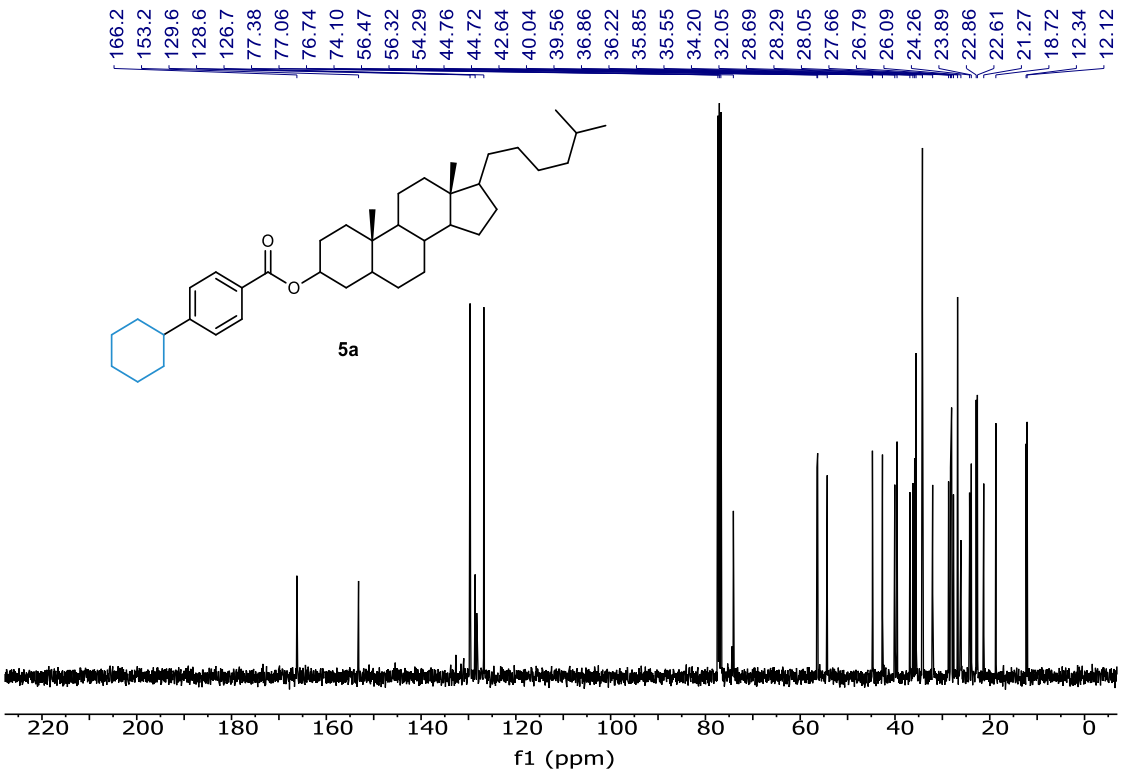

220 200 180 160 140 120 100 80 60 40 20 0
f1 (ppm)

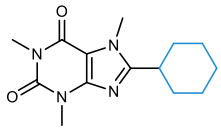

Ph
O
O
4i
2.00
1.98
2.01
0.99
2.13
3.17
2.04
2.07
2.08
f1 (ppm)
Ph
O
O
4i
f1 (ppm)


Si
Ph
4j
2.31
2.16
2.13
0.98
1.93
2.00
9.00
f1 (ppm)

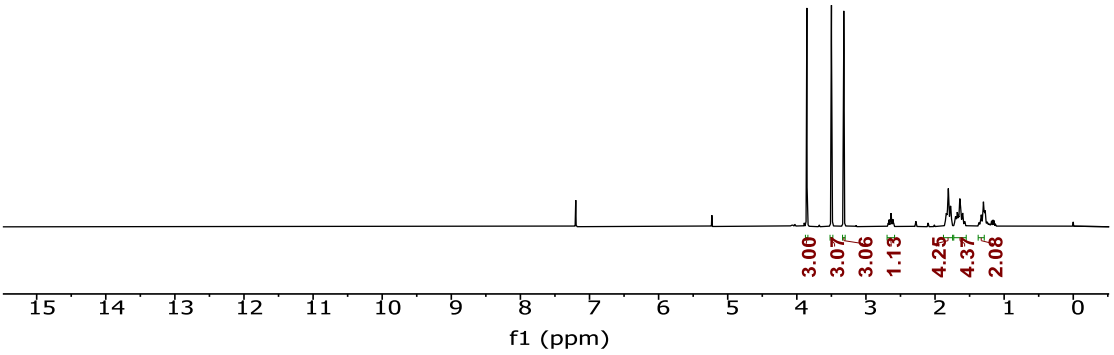

Si
Ph
4j
f1 (ppm)

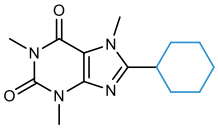

5a
2.00
2.18
1.16
0.99
41.12
3.27
3.27
5.97
3.17
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)


5a
220 200 180 160 140 120 100 80 60 40 20 0
f1 (ppm)



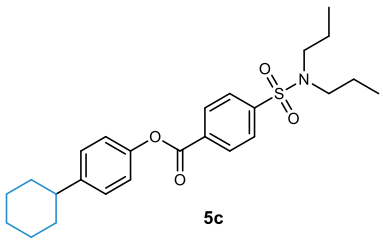
5b

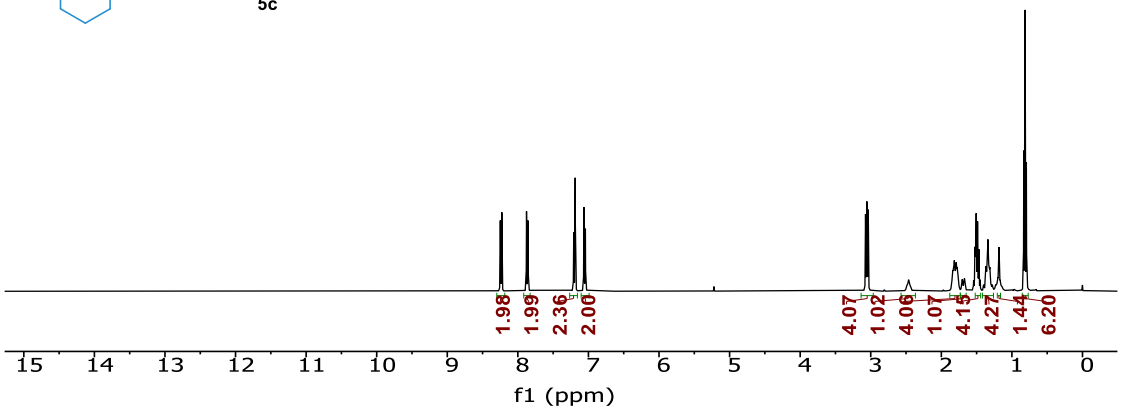

3.00
3.07
3.06
1.13
4.25
4.37
2.08
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)

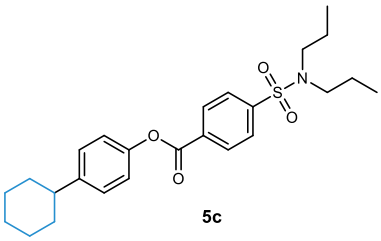


5b

158.0
155.5
151.8
148.1
107.0
77.38
77.06
76.74
35.83
31.42
30.96
29.77
27.85
26.02
25.58
220 200 180 160 140 120 100 80 60 40 20 0
f1 (ppm)


5c


1.98
1.99
2.36
2.00
4.07
1.02
4.06
1.07
4.15
4.27
1.44
6.20
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)


5c

220 200 180 160 140 120 100 80 60 40 20 0
f1 (ppm)